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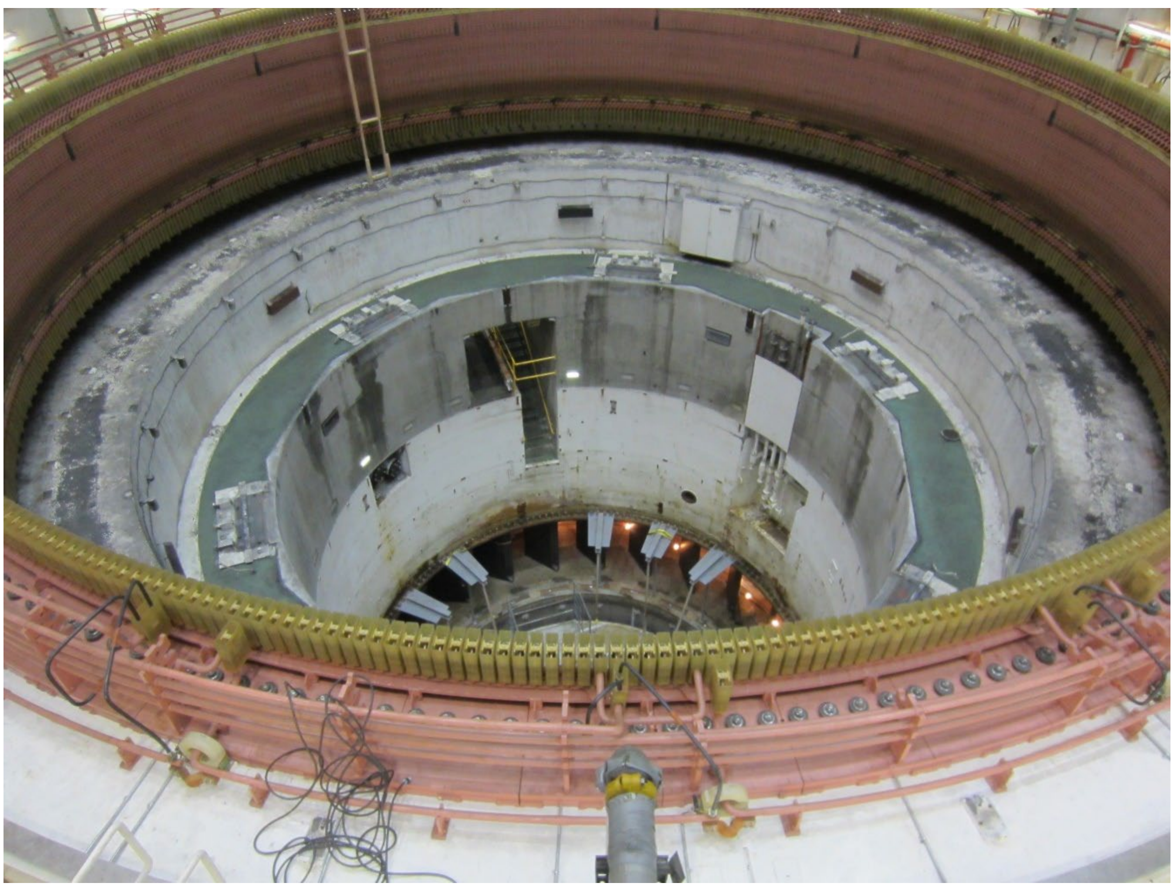
Facilities Instructions, Standards, and Techniques - Volume 4-7

Commissioning Guide for Hydroelectric Facilities



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The Bureau of Reclamation operates and maintains 53 hydroelectric powerplants and many switchyards, pumping plants, dams, canals, and associated facilities that are important to electric power and water delivery systems. This document establishes consistent guidelines and procedures for the commissioning of hydropower units.

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Commissioning Guide for Hydroelectric Facilities

Prepared by

Power Resources Office
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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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IEC 62381, "Automation Systems in the Process Industry - Factory Acceptance Test (FAT), Site Acceptance Test (SAT), and Site Integration Test (SIT)"
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IEEE Std 117, "IEEE Standard Test Procedure for Thermal Evaluation of Systems of Insulating Materials for Random-Wound AC Electric Machinery"
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IEEE Std 400, "IEEE Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems Rated 5 kV and Above"
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IEEE Std 522, "IEEE Guide for Testing Turn Insulation of Form-Wound Stator Coils for Alternating-Current Electric Machines"

IEEE Std 810, "IEEE Standard for Hydraulic Turbine and Generator Shaft Couplings and Shaft Runout Tolerances."

IEEE Std 943 (Withdrawn), "IEEE Guide for Aging Mechanisms and Diagnostic Procedures in Evaluating Electrical Insulation Systems"

IEEE Std 1010, "IEEE Guide for Control of Hydroelectric Power Plants"

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IEEE Std 1095, "IEEE Guide for the Installation of Vertical Generators and Generator/Motors for Hydroelectric applications."

IEEE Std 1106, "IEEE Recommended Practice for Installation, Maintenance, Testing and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications"

IEEE Std 1207, "IEEE Guide for the Application of Turbine Governing Systems for Hydroelectric Generating Units"

IEEE Std 1242, "IEEE Guide for Specifying and Selecting Power, Control, and Special-Purpose Cable for Petroleum and Chemical Plants"

IEEE Std. 1248-2020, "IEEE Guide for the Commissioning of Electrical Systems in Hydroelectric Power Plants"

IEEE Std 1434, "IEEE Guide for the Maintenance of Partial Discharges in AC Electric Machinery"

IEEE Std. 1827, "Guide for Electrical and Control Design of Hydroelectric Water Conveyance Facilities

IEEE Std C37.09, "IEEE Standard Test Procedure for AC High-Voltage Circuit Breakers with Rated Maximum Voltage Above 1000 V"

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IEEE Std C37.16, "IEEE Standard for Preferred Ratings, Related Requirements, and application Recommendations for Low-Voltage AC (635 V and below) and DC (3200 V and below) Power Circuit Breakers"

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IEEE/ANSI C37.20.2, "IEEE Standard for Metal-Clad Switchgear"

IEEE Std C37.20.3, "IEEE Standard for Metal-Enclosed Interrupter Switchgear"

IEEE Std C37.21, "IEEE Standard for Control Switchboards"

IEEE C37.23, "Standard for Metal-Enclosed Bus"

IEEE Std C37.102, "IEEE Guide for AC Generator Protection"

IEEE Std C37.122.3, "IEEE Guide for Sulfur Hexafluoride (SF_6) Gas Handling for High-Voltage (over 1000 Vac) Equipment"

IEEE Std C50.12, "IEEE Standard for Salient-Pole 50 Hz and 60 Hz Synchronous Generators and Generator/Motors for Hydraulic Turbine applications Rated 5 MVA and Above"

IEEE Std C57.12.00, "IEEE Standard for General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers"

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IEEE Std C57.12.90, "IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers"

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IEEE Std C57.13, “IEEE Standard Requirements for Instrument Transformers”
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IEEE Std C57.161, “IEEE Guide for Dielectric Frequency Response Test”
IEEE Std C57.166, “IEEE Guide for Acceptance and Maintenance of Insulating Liquids in Electrical Equipment.”
IEEE Std P1434, “Guide for the Measurement of Partial Discharges in AC Electric Machinery”
ISO 1217: 2009, “Displacement Compressors – Acceptance Tests”
ISO 1680, “Acoustics – Test Code for the Measurement of Airborne Noise Emitted by Rotating Electrical Machines”
ISO 2151: 2004, “Noise Test Code for Compressors and Vacuum Pumps-Engineering Method (Grade 2)”
ISO 2537, “Hydrometry-Rotating Element Current Meters”
ISO 3455, “Hydrometry: Calibration of Current-Meters in Straight Open Tanks”
ISO 4310, “Cranes – Test Code and Procedures”
ISO 5388, “1981 Stationary Air Compressors-Safety Rules and Code of Practice”
ISO 6183, “Fire Protection Equipment – Carbon Dioxide Extinguishing Systems for Use on Premises – Design and Installation”
ISO/TS 7240, “Fire Detection and Alarm Systems”
ISO 8573: 2010 thru 8573-9: 2004, “Compressed Air Quality Standards and Testing”
ISO 11011: 2013, “Compressed Air-Energy Efficiency - Assessment”
ISO 12500: 2007 thru 12500-4: 2009, “Filters for Compressed Air Testing”
ISO 14518, “Cranes – Requirements for Test Loads”
ISO 18740: 2016, “Turbo-compressors-Performance Test Code – Simplified Acceptance Test”
ISO 20816-1, “Mechanical Vibration - Measurement and Evaluation of Machine Vibration”
ISO 21940-11, “Mechanical Vibration – Rotor Balancing – Part 11: Procedures and Tolerances for Rotors with Rigid Behavior”
NEBB, “Testing, Adjusting, and Balancing of Environmental Systems”
NEMA MG 1, “Motors and Generators”

NEMA WC7/ICEA S-66-524, "Cross-Linked Thermosetting Polyethylene Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy (Withdrawn)"
NEMA WC8/ICEA S-68-516, "Ethylene-Propylene Insulated Wire and Cable for the Transmission and Distribution (Withdrawn)"
NERC Standard PRC-019, "Coordination of Generating Unit or Plant Capabilities, Voltage Regulating, Controls, and Protection"
NERC Standard VAR-501-WECC-3.1, "Power System Stabilizer"
NETA ATS, "Standard for Acceptance Testing Specifications for Electrical Power Equipment and Systems"
NETA ECS 2020, "Standard for Electrical Commissioning Specifications of Electrical Power Equipment and Systems"
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NFPA 72, "National Fire Alarm and Signaling Code"
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NFPA 2001, "Standard on Clean Agent Fire Extinguishing Systems"
SIS-CEN/TS 14816, "Fixed Firefighting Systems – Water Spray Systems – Design, Installation, and Maintenance"
SIS-CEN/TS 14972, "Fixed Firefighting Systems – Water Mist Systems – Design and Installation"
SMACNA, "HVAC Systems – Testing, Adjusting and Balancing"
Swedish Std SS0EN-50522 R1, "Earthing of Power Installations Exceeding 1 kV ac"

References

CEATI Report No. T122700-0386, "Commissioning Guide for Hydroelectric Generating Systems-Major Electrical and Mechanical Equipment"
CEATI Report No. T122700-0398, "Commissioning Guide for Hydroelectric Generating Stations – Auxiliary Systems and Equipment"
IEEE Std. 1248-2020, "IEEE Guide for the Commissioning of Electrical Systems in Hydroelectric Power Plants"

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Reclamation Standard No. 12 *Plant Testing-Chapter 1: Synchronous Generator, Rotor and Design Generator/Rotor Field Tests*

Reclamation Forms

POM Site https://teamssp.bor.doi.net/printanddup/forms/POM%20Forms/Forms/AllItems.aspx
POM-226 FIST Revision Request
POM-300 FIST Variance Form

Acronyms and Abbreviations

A	Amperes
ac	Alternating Current
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
AVR	Automatic Voltage Regulator
AWG	American Wire Gauge
BHP	Brake Horsepower
°C	Degree Celsius
C&I	Control and Instrumentation Mechanic
CEATI	Centre for Energy Advancement through Technological Innovation
cfs	Cubic Feet per Second
CO_2	Carbon Dioxide
CPU	Central Processing Unit
CT	Current Transformer
D&S	Directives and Standards
dc	Direct Current
DSC	Distributed Control System
El.	Elevation
EL-CID	Electromagnetic Core Imperfection Detection
EMC	Electromagnetic Compatibility
ESD	Emergency Shutdown
E-STOP	Emergency Stop
°F	Degree Fahrenheit
FAT	Factory Acceptance Test
FIST	Facilities Instructions, Standards, and Techniques
FRA	Frequency Response Analysis
ft	Foot
GSU	Generator Step Up (Transformer)
hipot	High Potential Test
HMI	Human Machine Interface
HPU	Hydraulic Power Unit
HVAC	Heating Ventilation and Air Conditioning
Hz	Hertz
I	Current
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
I/O	Input/Output
IR	Infrared
ISD	Immediate Shutdown
ISO	International Standards Organization
kV	kilovolt
kVA	Kilovolt Ampere
MCC	Motor Control Center

mils	One-thousandth of an inch (Unit of measure)
Mvar	Megavoltampere Reactive
MW	Megawatt
NERC	North American Electric Reliability Corporation
NETA	International Electric Testing Association
NFPA	National Fire Prevention Association
OEM	Original Equipment Manufacturer
O&M	Operations and Maintenance
P&ID	Piping and Instrumentation Diagrams
P	Pressure
PEB	Power Equipment Bulletin
PI	Polarization Index
PLC	Programmable Logic Controller
PPE	Personal Protective Equipment
PRO	Power Resources Office
PSI	Pounds Per Square Inch
PSS	Power System Stabilizer
PT	Potential Transformer
Q	Flow
QSD	Quick Shutdown
R	Resistance
Reclamation	Bureau of Reclamation
RM	Reclamation Manual
RPM	Revolutions Per Minute
RSHS	Reclamation Safety and Health Standards
RTD	Resistance Temperature Detector
RTU	Remote Terminal Unit
SAT	Site Acceptance Test
SCADA	Supervisory Control and Data Acquisition
SCR	Short Circuit Radio
SF_6	Sulphur Hexafluoride Gas
SMACNA	Sheet Metal and Air Conditioning Contractors' National Association
SNL	Speed-No-Load
SSU	Station Service Unit
TIF	Telephone Interference Factor
TSC	Technical Service Center
V	Volts
var	Voltampere Reactive (Reactive Power)
Vdc	Volts Direct Current
VFD	Variable Frequency Drive
W	Watts
WECC	Western Electricity Coordinating Council
X,Y,Z	Axis coordinates

Symbols

°	degree
Ω	ohms (resistance)
%	percent
#	number

1.0 Introduction

The Bureau of Reclamation operates and maintains hydroelectric powerplants, switchyards, pumping plants, water delivery equipment and associated facilities in the 17 western United States. These facilities house complex electrical and mechanical equipment that must be kept operational because they are critical to the electric power and water delivery systems relied on by many. FIST are technical documents that provide criteria and procedures that should be utilized by the offices involved in managing Reclamation facilities and assets.

This document establishes standard technical practices and procedures to ensure the safe, reliable, economic, and efficient commissioning of equipment and systems for hydroelectric generating units located in Federal facilities and ultimately protecting Federal investments. These technical practices provide a sufficient level of detail to ensure consistent application while providing flexibility for the use of innovative techniques and approaches. This document was developed with input from staff in Reclamation's Denver, regional, and area offices.

1.1 Purpose and Scope

This document serves as a technical guide for commissioning critical infrastructure in Reclamation hydroelectric facilities. Much of the material contained in this volume is based on Reclamation Subject Matter Experts and industry guidelines for commissioning including: Reclamation FIST documents, CEATI Report No. T122700-0386, "Commissioning Guide for Hydroelectric Generating Systems-Major Electrical and Mechanical Equipment", CEATI Report No. T122700-0398, "Commissioning Guide for Hydroelectric Generating Stations – Auxiliary Systems and Equipment", and IEEE Std. 1248-2020, "IEEE Guide for the Commissioning of Electrical Systems in Hydroelectric Power Plants".

This document is intended to promote uniformity in the manner that assets are managed, documented, and coordinated, and may be utilized by transferred facilities and other entities as appropriate. It establishes consistent procedures, minimum standards and criteria for commissioning activities associated with hydroelectric generating units, equipment and systems owned and operated by Reclamation. Other technical documents may provide additional electrical and mechanical information for the equipment or systems discussed in this document.

The purpose of this FIST document is to provide general guidelines and procedures for management, facility personnel, engineers, design engineers, operators and testing personnel involved in the commissioning of major equipment and systems for hydroelectric facilities.

Most of Reclamations generating units vary by manufacturer, design, and their related support equipment. Expectations are that facility personnel are the most familiar with the equipment in their own facilities and therefore should incorporate their own knowledge and experience when performing commissioning activities. The intent of this document is to provide an initial structure and guidance that can be used to produce unit-specific commissioning documents and procedures.

1.2 Manufacturer Recommendations

Due to the differences in equipment designs, owner's manuals and manufacturer's recommended procedures should be consulted when developing unit-specific commissioning documents and procedures. Not following the manufacturer's guidance may void the warranty of new equipment. If there is a discrepancy between the FIST and the manufacturer's recommendations, the commissioning technical documents must use the more stringent practice unless there is a reason that a less restrictive maintenance practice is warranted. Use of a less restrictive maintenance practice must be approved as outlined in RM D&S FAC 04-14 by either a deviation or a variance. A deviation maybe granted in accordance with RM D&S RCD 03-03 and POM Form 300.

1.3 FIST Revision Requests

The FIST Revision Request Form (POM-226) is used to request changes to a FIST document. The request will include a summary of the recommended changes and a basis for the revision or new FIST. These forms will be submitted to the Manager, PRO. The PRO Manager will keep a list of Revision Requests for each FIST and include these in the next scheduled revision unless the change is prioritized sooner.

1.4 Commissioning Safety

Safety is an essential part of commissioning activities. Commissioning is a dynamic time which involves abnormal and for some, never before seen activities. Since hydroelectric facilities contain systems and equipment which produce, contain, or store various sources of of hazardous energy; it is essential to properly identify the hazards involved with working on or near equipment that contains hazardous energy to create a safe working condition.. It is important that all hazards be assessed prior to the start of work. All commissioingactivities must be conducted in accordance with FIST 1-1, *Hazardous Energy Control Program*, FIST 5-14, *Electrical Safety Program*, and the Reclamation Safety and Health Standards. A job hazard analysis must be conducted as well.

2.0 Introduction to Commissioning

Commissioning is a process to plan, develop, and perform inspection and testing procedures in an orderly sequence to ensure the safe, reliable, and successful operation of all systems, components, and equipment associated with a generating unit. Commissioning is a required process which follows new installation, repair, replacement, overhaul, or modernization to bring a hydroelectric generating unit into operation, which includes verification of unit performance and reliability, and is used to ensure all equipment is ready for acceptance and transfer to the facility owner/operator for normal and reliable operation. Testing performed as part of the commissioning process assists in verifying critical items such as equipment safety, functionality, adherence to performance specification requirements, and installation/as-built documentation.

3.0 Planning for Commissioning

Hydroelectric projects for refurbishment and new facilities can span a wide range of scope and complexity, such as, unit refurbishment, facility refurbishment, addition of a new unit to an existing powerhouse, and construction of a new facility.

Planning for commissioning should begin as soon as practical but is usually dependent upon completion of most of the design activities before commissioning details can be defined. Above all, it is important to have experienced team members, clear roles and responsibilities, and adequate time to develop a commissioning plan that will ensure successful commissioning of the project.

The administrative/planning phase of the commissioning plan involves identifying and clarifying the roles of all participants involved in the commissioning program. Planning for commissioning is also dependent upon coordination with operations and the availability of the appropriate personnel and information required for commissioning. These individuals will comprise the commissioning team. Once the role of each team member has been identified, a commissioning plan for the turnover of the equipment/systems from the construction contractor to the facility owner needs to be developed which includes inspection and test plans, construction completion dates, and a commissioning schedule. The commissioning procedures should be based on the requirements of the contract technical specifications and goals.

3.1 Commissioning Team

The formation of the commissioning team should consist of members with experience in the key areas of commissioning and those with extensive knowledge who are familiar with the facility equipment and systems. Each participant organization providing commissioning resources needs to designate a representative. These representatives must have sufficient knowledge of their products and technology, as well as a defined level of authority to make decisions and/or the means to respond quickly.

It is important to identify a person with commissioning experience to be the leader of the commissioning team and to have a support team that may consist of representatives from the owner, suppliers, manufacturers, and the contractor. The commissioning manager and the commissioning team should be appointed when the design work has been substantially completed but should begin at least six months prior to the commencement of the commissioning activities. Owners should require that the commissioning manager, lead test engineer, and the commissioning leads be named, and their credentials may be provided for acceptance. A commissioning team may include but not be limited to the:

- Owner/Commissioning Manager
- Contractor
- Manufacturer/Supplier Representatives
- Project Manager
- Project Design Engineer
- Commissioning Leads
- Operations Lead

- Lead Test Engineer

3.2 Roles and Responsibilities of Commissioning Team

Owner/Commissioning Manager – The owner is usually the operator and provides the operations and maintenance personnel who participate in the commissioning program. The owner or their designated representative will be the commissioning manager. The commissioning manager has the responsibility of developing the overall commissioning plan, planning the resources and schedules, and coordinating the performance of the commissioning plan for commissioning activities to proceed smoothly. The commissioning manager should ensure all parties follow the prescribed checks, tests, and sign offs required for a timely, safe, and successful completion of the commissioning activities. The commissioning manager's responsibilities are usually:

- Develops the overall commissioning plan.
- Reviews administrative, construction, pre-commissioning and commissioning programs, and schedules.
- Recommends and maintains key staff for commissioning process.
- Coordinates with Control Center Operations
- Ensures all contractor operations involving the control of hazardous energy (lockout/tagout)at Reclamation-owned, -controlled, or occupied facilities and construction sites comply with FIST 1-1, *Hazardous Energy Control Program*, requirements.
- Witnesses testing activities, as necessary, in support of the commissioning program.
- Provides coordination with offsite operating, dispatching, or interfacing agencies, as required.
- Conditionally accepts equipment and systems for operation during the pre-commissioning testing phase.
- Collects, reviews, and develops the deficiency lists.
- Accepts equipment, systems, and facilities, subsequent to successful testing of these items, and provides final acceptance of the project.
- Operates all permanent plant equipment to support the start-up schedule.
- Refers areas of dispute to Facility and Power Operations Management for final decisions.
- Monitors control of documentation.
- Verifies that all contractual obligations are met.

Contractor – A contractor typically furnishes, installs, and tests the equipment and systems under the terms and conditions of the contract. Tests performed by the contractor may be witnessed by the owner (or their designated representative). The contractor usually:

- Performs construction and pre-commissioning testing on contractor-furnished equipment and systems in accordance with the test requirements contained within the contract.
- Performs construction testing on owner-furnished equipment in accordance with the contract.
- Records test data results during construction and pre-commissioning testing, distributes it to the engineer, and incorporates it into the system turnover package.

- Understands FIST 1-1, *Hazardous Energy Control Program*, and coordinates contractor operations involving the control of hazardous energy (lockout/tagout) with Reclamation at Reclamation-owned, -controlled, or occupied facilities and construction sites.
- Schedules completion of construction work and construction test activities to support the overall commissioning program.
- Provides the engineer with status of contractor-furnished equipment and system deficiency list items; advises the engineer when turnover for pre-commissioning testing will occur on contractor-furnished equipment and owner-furnished equipment.
- Provides craft personnel required during construction and pre-commissioning testing by the contractor, and in support of pre-commissioning and commissioning testing performed by the engineer.
- Participates in the development of schedules for all phases of the commissioning program.
- Provides system deficiency list with equipment turnover and resolves all deficiencies.
- Notifies the lead test engineer of any engineering or construction deficiencies that will not allow for proper testing and operation of any system.

Manufacturer/Supplier – In addition to factory tests to be performed on manufacturer's equipment, tests are typically performed during the installation phase in accordance with the specifications/contract. These tests are performed in support of the commissioning program and in keeping with the schedules for pre-commissioning and commissioning testing. Manufacturer/supplier representatives are involved during installation and testing to verify the equipment is properly installed and meets design and contract requirements. They may be involved in all phases of the commissioning program. The responsibilities in each phase should be clearly identified in the contract. For example, many of the manufacturer's tests listed below may also be performed by the owner's engineering and testing personnel to verify contractual requirements and these tests may be witnessed by the manufacturer or the test data provided to the manufacturer. Typical manufacturer tests may include:

- Unit alignment
- Rotational runout
- Rotor diameter measurement
- Rotor roundness measurement
- Stator bore diameter measurement
- Stator roundness and verticality measurement
- Airgap measurement
- Bearing alignment and measurements
- Verification of temperature devices
- Current transformer polarity
- Braking system
- Bearing oil lubrication system
- Stator and rotor winding insulation resistance and polarization index (PI) tests
- Stator and rotor winding insulation high-potential withstand/proof testing
- Stator and rotor winding conductor resistance (micro-Ohmmeter tests)
- Stator winding baseline high-voltage, direct-current ramp test (dc ramp)
- Stator winding ripple spring compression measurements (if equipped)
- Rotor winding turn-to-turn (pole drop) test

- Open circuit saturation test
- Short-circuit test
- Phase sequence test
- Heat run
- Overspeed tests
- Load rejection tests

Project Manager – The project manager has the lead role in planning, executing, monitoring, controlling, and closing-out projects. They are accountable for the entire project scope, the project team and resources, the project budget, and the success or failure of the entire project.

Project Design Engineer – The project design engineer typically provides the design documents to install and test the equipment. The project design engineer usually:

- Provides all engineering documents and information necessary for completion of construction and testing.
- Furnishes engineers on site to provide assistance on design and engineering problems.

Commissioning Leads – The commissioning manager may be supported by commissioning leads assigned by the manufacturers, the contractors, and the owner (for their scope of supply). The commissioning leads will have specialized skills to cover the mechanical, electrical, protection and control, and civil/structural elements of the project. The commissioning leads will perform the commissioning work under the direction of the commissioning manager, generally using procedures developed by their employer. These individuals will work concurrently to commission systems and equipment within their assigned jurisdiction, help resolve issues, and ensure compliance of documentation. Commissioning leads ensure as-built documents, setpoint lists, and deficiencies are identified and recorded and will generally support schedule compliance.

Lead Test Engineer – The lead test engineer has the overall responsibility for coordinating and ensuring that construction, pre-commissioning, and commissioning testing of owner- and /or contractor-furnished equipment, and the commissioning testing of contractor-furnished equipment are performed. The lead test engineer usually directs all activities to help ensure a smooth and effective commissioning program and is typically responsible for the overall conduct of the program for all project equipment and systems. The lead test engineer usually has responsibility for scheduling and directing the efforts of those assigned to the performance of the commissioning activities. The lead test engineer typically coordinates the interface activities of the contractor for construction and the owner’s personnel required to accomplish the commissioning program.

The lead test engineer should prepare the procedures required to implement the program and give final approval to these procedures prior to owner review and approval. These procedures should be incorporated into a commissioning manual. In addition, the lead test engineer should:

- Coordinate the presence of manufacturer/supplier representatives during the commissioning testing phase.
- Work with the engineers and manufacturers to resolve design questions encountered during the commissioning program.
- Participate in the development of schedules for construction and pre-commissioning testing of contractor-furnished equipment and systems.

- Develop, in conjunction with the owner, schedules for pre-commissioning and commissioning testing of contractor-furnished equipment and systems.
- Review and accept equipment and systems that have been tested by the contractor in accordance with construction test procedures.
- Verify pre-commissioning and commissioning testing of all equipment and systems are performed.
- Verify performance testing requirements are scheduled and performed.

Coordinating Roles - The commissioning manager, lead test engineer, and commissioning leads direct the tests, coordinate the representatives, and monitor the record keeping for as-built documentation. The commissioning manager, lead test engineer, and commissioning leads should be available after the commissioning activities are completed, to collect and consolidate the commissioning reports, to participate in post operation tests (including re-testing of corrections and modifications), and to participate in the review of as-built documents.

3.3 Development of Commissioning Plan

The commissioning team will oversee the consolidation of complete commissioning procedures for all elements of the facility with support of the various suppliers. The documents will be issued in several iterations among the owner, the suppliers, and the commissioning team until the documents are considered ready for the start of commissioning activities.

The final documents will require review by and approval from the owner and other commissioning participants. The documents should have strict version control as other documents may be added during the development of the final commissioning plan.

3.4 Commissioning Plan

A commissioning plan should be prepared that defines the roles and responsibilities of all those involved, includes the schedule for commissioning activities, identifies and outlines the various test procedures required, and thoroughly documents the commissioning results. Planning efforts for commissioning should begin as soon as possible but are usually contingent upon the design activities being completed. Therefore, creation of the commissioning plan should begin near the end of the design phase and be completed prior to the commissioning team arriving at the facility.

A commissioning plan should include and describe the requirements for the following phases/activities:

Administrative/Planning Phase – This task involves identifying and clarifying the roles of all participants involved in the commissioning program. These individuals will comprise the commissioning team. Once the role of each team member has been identified, a commissioning plan for the turnover of the equipment/systems from the construction contractor to the facility owner needs to be developed which includes inspection and test plans, construction completion dates, and a commissioning schedule. The commissioning procedures should be based on the requirements of the contract technical specifications and goals.

Commissioning Procedure Acceptance – After the commissioning documentation has been completed, all involved parties (facility owner, engineering staff, facility personnel, contractor, and equipment manufacturers) should be provided the opportunity and ample time scheduled to review the commissioning procedures and formally agree using an approval signature process on the final version prior to the start of commissioning.

Construction Testing Phase – This phase includes pre-shutdown baseline readings, factory acceptance tests, development of test procedures and a quality control plan for equipment during installation for verification of proper operation of the mechanical, electrical, and instrumentation equipment and systems. The Quality Control Plan should identify who is responsible for testing, what testing is required with reference to acceptable tolerances and acceptance criteria from the contract specification and when the testing should be performed. This will ensure corrections are made prior to major disassembly or deficiencies findings.

Pre-Commissioning Phase – This phase includes:

1) Offline (Dry) Testing – This phase is also known as pre-startup testing. These tests are performed on equipment without full system voltage or water, to determine its readiness for real operation.
2) Functional Testing – This phase is also known as pre-commissioning testing. These test procedures provide all tests and checks necessary to verify that each hydroelectric generating unit support system (especially protection and control systems) is functional before startup testing of the hydroelectric generating unit. The purpose of the functional testing is to ensure each system and its components perform in accordance with design requirements and is complete and safe to energize or operate.

Commissioning Phase – This phase is also known as online (wet) testing, startup testing, and commissioning testing. This testing is performed with the various structures and equipment pressurized and with the unit and systems powered up and placed into operation. These test procedures include mechanical and electrical runs. The mechanical runs are performed first. This begins with the first rotation (also known as initial slow roll), tests under increasing load, and ends with mechanical overspeed testing. After the mechanical overspeed test, the unit should be dewatered and fully inspected. The generator can then be excited for the first time and the non-synchronized off-line electrical tests can be performed. Synchronization tests and first connection to the grid occurs and allows the on-line electrical testing to be completed.

Trial Run – After the final on-line electrical test is completed, the trial run is performed under normal operating conditions based on available flows. The trial run is performed to ascertain if the unit is meeting the contractual requirements for unaided operation for a specific period of time with very little downtime. The equipment is typically required to operate reliably at steady state for a specified period of time before the unit or facility is considered ready for operation and handover to the owner. After the trial run is completed, the unit is usually handed over for commercial operation. The warranty period for the equipment or system often begins after the trial run in order to make a confident decision on acceptance.

Post-Commissioning – This is the step between the end of planned commissioning, and the point where all contractual obligations have been resolved. This phase also includes the performance of all remaining regulatory testing. Recommissioning and additional testing of repairs to address identified deficiencies are completed during scheduled outages. Inspections are performed during a scheduled outage as part of the contractual requirements for warranty.

Acceptance – Acceptance is a point in which the work is complete, and the owner accepts the equipment and systems and releases the contractors and suppliers from a number of contractual liabilities. The owner will need a good understanding of the unresolved issues and how to manage them.

Performance Testing – Performance test procedures are developed to verify equipment performance meets manufacturer's stated guarantees and to establish initial baseline operational performance for future reference. Unit absolute efficiency and maximum power output are typically tested. This testing is normally performed after the unit is released for commercial operation and the owner and manufacturer have agreed on the readiness of the equipment and a schedule that ensures specified operating conditions are met/optimized such as water flow and water reservoir level (head).

3.5 Schedule Development and Resource Planning

In a commissioning schedule, a number of activities follow a natural sequential progression which usually defines the critical path, but many do not. The development of the schedule is also dependent upon the availability of personnel and equipment.

The commissioning manager should develop and submit the commissioning schedule with input from the project manager for the project, the owner, lead test engineer, and other suppliers and contractors. The schedule will require a resource plan to ensure that workloads are matched with resource availability. This will be an iterative process and should result in a resource plan that identifies the list of people and test equipment or test agencies that are required to be on site for each activity, and a staged mobilization schedule for all participants. The resource plan should address staff rotation and identify backups for each role during rotations and in case of a sudden departure of key personnel, to maintain the progress of commissioning activities.

During commissioning, the schedule is very dynamic, and the availability of resources can become difficult to manage, especially if activities are delayed. Often, commissioning staff from manufacturers/suppliers have other future commitments before arriving at the site and will often have "no later than" departure dates. Controlling activities around commissioning problems and delays is a daily affair. In this timeframe, the key staff should plan to meet daily to affirm the objectives of that day and to deal with any delays in schedule. The commissioning manager should evaluate the impacts and re-organize resources as needed. The commissioning manager will normally work from the planned sequence of commissioning activities that are fairly well understood by the team, but the project manager should maintain a working schedule with sufficient detail to assess the critical path and dependencies of the activities underway.

Typically, the lead test engineer, commissioning manager, and contractors develop a schedule for the design, delivery, and installation of equipment that will ultimately be commissioned in the plant. When the design is completed and the equipment purchased, necessary information becomes available for developing test procedures used for the installation checkout and operational verification. An equipment test schedule should be developed in conjunction with the construction schedule for equipment and system installation.

3.6 Deficiency Management

The commissioning activities will identify non-conformances and failures that are usually called deficiencies or "punch list" items. Additional deficiencies will also be identified after the commissioning activities have been completed. The deficiencies will vary in quantity and severity and will have a significant impact on the progress of the commissioning activities. Therefore, there is a need to effectively manage the identification and resolution of deficiencies. The process for resolution of deficiencies should be defined and agreed upon. The process can address how deficiencies are tracked, how solutions are proposed and accepted, how severity or urgency is codified, and how timelines for resolution are established.

Any system implemented to manage deficiencies must be maintained after the planned commissioning activities are completed. The system will address the need to segregate deficiencies from warranty claims. To most people, issues identified before the in-service date are considered project deficiencies, while issues identified after everyone leaves the site are considered warranty items. The commissioning plan should provide contractual guidelines on how issues will be reviewed and classified as deficiencies or warranty claims. Some of the key parameters include the timing of when an issue is found and the severity of the impact.

The commissioning plan should define how non-conformance and deficiencies will be handled. Listed below are some recommended practices to consider:

> A system similar to capturing non-conformance is appropriate. The non-conformance must first be identified, and then reviewed by the appropriate people to decide whether it will be added to the list. If so, the responsible party is required to provide a disposition. This can be tracked in a log or database through to resolution. The deficiency database can describe each system and should include the deficiency's description, the corrective course of action, the party responsible for correction, and a timeline for correction.
>
> The commissioning manager and the commissioning leads should have a core responsibility to ensure non-conformances identified during commissioning are resolved, and to bring in necessary resources and specialists when required.
>
> Deficiencies will be found as the work progresses. Some will require immediate correction and must be noted in as-built documents, while others, usually those that do not impact safety or operation of the plant, will be recorded as deficiencies with deferred correction. The commissioning leads should generally be responsible to record the deficiencies and ensure that as-built and set point lists are kept up to date.
>
> The release procedures for each phase should be defined and documented. It may include a walk-down of the system along with the applicable contractor(s) and the owner. This walk-down is intended to identify any equipment, process, or workmanship deficiencies that remain to be corrected.

Periodic meetings should include the suppliers, contractors, and the owner. Participants should review the deficiency database and update the status of the corrections.

Finally, the need for having up-to-date deficiency information must be emphasized. Most contracts assume the owner will issue a deficiency list to the suppliers and contractors at some point. The assumption is that this will occur at or close to the completion of the planned commissioning activities. A vetted and appropriate deficiency list cannot be produced if such a process has not been implemented at the start of the commissioning activities (and maintained throughout).

Some examples of deficiency management findings that are frequently encountered include:

Damage, incomplete work, and aesthetic issues – These issues are normally straight forward to deal with but will likely involve discussion as to whether a deficiency exists. In most cases, they can be deferred to the post-commissioning stage, if they do not present any safety risk to people or assets. Different people contributing to an assessment of deficiencies will have different views on what is acceptable, and the lists can get unreasonable both in terms of quantity and severity. A balance will be required to make efficient use of available resources and to complete the project within a realistic timeframe. The owner must make a decision on where to draw the line for the benefit of closing its obligations and carrying on with the business of operating the new facility.

Failed or incorrect components or elements – This category is probably the easiest to deal with as there is rarely a dispute on whether there is a deficiency. The impact tends to be the greatest if the component was not suitable for the application and a new style of device is required. It is possible that the failure may not allow commissioning to progress; delays in selecting, procuring, and installing replacements can soon add up. Auxiliary systems are prime sources for these types of failures.

Control and communication issues – Resolving control program issues and communication issues will be a major commissioning effort and will often extend well beyond the end of the planned commissioning activities. It can be difficult to pinpoint them as well-defined deficiencies. Program bugs, instances of false alarms or alarms that were not detected, different set points for different units, and forced bits may be encountered. Pairing with offsite systems can add to the complexity. After all units are commissioned, there is usually a fair amount of cleanup work necessary to reach a point where all the units have the same code. A commissioning lead dedicated to clear communication is essential.

Long resolution cycles – Deficiencies which have an impact on manufacturing, installation, re-commissioning, or especially in the case of a re-design of a portion of a system, can take a long time to resolve. When it is clear that waiting for resolution of such issues will delay placing the unit(s) into service, it is important to negotiate an agreed-upon approach with suppliers and contractors. It is not uncommon to wait 12 to 18 months to resolve some issues. This is often the result of difficulties in finding an opportunity to implement the change once the unit(s) are in commercial operation.

Deviation from expectations – People are far better at describing what they don't want than in defining what they expect. Be prepared to see requests to replace components or systems because they are seen as "not up to the job". These findings are not necessarily non-conformances to the specifications. There is a need to vet these well before they reach suppliers or contractors; otherwise they will tie up resources in significant debates and delay completion of the project.

Concerns of long-term reliability – These are issues when systems or components performance is seen as being unstable or indicative of premature wear. The discussion revolves around whether the component or system is sufficiently robust. There is rarely a good contractual basis for these issues, and they can lead to a long period of negotiation. Technical agreement is often difficult to achieve and a commercial solution may be required, such as warranty adjustment or compensation.

Substantive concern with poor contractual basis – It is possible that some issues identified are clearly important to the owner but are not well-defined in the specifications or contract. These are difficult issues since they can affect the performance and safety of the equipment or facilities. There is often little choice but to proceed with commissioning unless there is a clear risk to the safety of personnel or the equipment, and the owner is willing to accept the cost and delay of correcting the problem.

Lack of or poor documentation – Deficiencies related to documents usually imply that they are either missing, of poor quality, or not up to date. The expected documents and their quality should be captured in contract documents and specifications. There are also expectations about the state of the documents at any given point in the project, more specifically whether interim versions are expected and when the final documents will be available. It is important to be realistic with documentation. Having up-to-date documents often depends upon the availability of the right people to finalize documentation, or because the content requires multiple changes. No document will be in its final form until the planned commissioning activities are completed. The focus should be on ensuring that the information available is sufficient for the project activities under way. These differences in expectations about the state of the documentation are usually part of the deficiency list.

The never-ending deficiency – Finding the cause of a deficiency can be problematic and sometimes is never discovered, especially if the problem is intermittent. This type of deficiency starts as one issue and the first correction may not solve the problem, so another cause is found and another solution is implemented. This, in turn, may or may not solve the problem and it carries on. On occasion, everyone will give up and let it be, hoping that the problem will define itself better during the warranty period.

Difficulty in allocating responsibility – A deficiency will not be corrected until one party accepts responsibility to correct it. If the root cause cannot be defined clearly this may require some negotiation to share responsibilities among involved parties.

3.7 Documentation

3.7.1 Record Keeping

Construction and commissioning of a hydroelectric powerplant produces a wide variety of documentation. Early in the project design phase it is necessary to develop a record-keeping system where information can be readily cataloged, stored, and updated. The record-keeping system should be capable of handling documentation ranging from data stored on electronic media to full-sized reproducible drawings.

Record keeping during construction and commissioning should be a precursor to an information management system that can maintain records after the project is declared operational. It should incorporate a distribution system for all information necessary for efficient operation.

3.7.2 Engineering and Design Documentation

Documentation typically produced by engineers during design and construction includes:

- Permits and licenses
- Equipment specifications and contract documents
- Logic and flow diagrams
- Design and construction drawings
- Progress reports

3.7.3 Factory Inspection and Test Documentation

Information that can be provided by the equipment manufacturers and the material suppliers includes:

- Name and address of equipment and sub-equipment suppliers
- Equipment manuals
- Equipment specifications and recommended settings
- Manufacturer's drawings
- Recommended operating procedures
- Recommended maintenance procedures
- Factory test reports
- Turbine model test report
- Safety data sheets
- Lubricant specifications
- Software documentation
- Spare parts list
- Recommended commissioning tests

3.7.4 Commissioning Activities Documentation

The need to have a good record of the commissioning activities is driven by stakeholders who require documented evidence to demonstrate that requirements on contracts, water management plans, environmental controls, or insurance conditions have been met. Good records are invaluable for future troubleshooting and maintenance activities.

The commissioning procedures will describe the forms and information to be gathered and the structure and format of the document packages. Normally there will be sections divided into systems in the dry commissioning phase and joined sections for wet commissioning. All of this information is usually broken down by unit. The information is gathered from the various test and commissioning engineers and may be issued sometime after the commissioning tests have been completed. It is important to get a record of preliminary results prior to collecting the final version of the test reports. It is best practice that the records required for each release point be identified and filed with the completed release form.

Documentation produced during on-site commissioning and project completion includes:

- "As-built" drawings
- Acceptance test procedures
- Installation records
- Check sheets
- Human machine interface screen shots, trends, and graphical outputs
- Photographs
- Data and analysis spreadsheets
- Walk-through inspection sheets
- Protective relay and instrument settings
- Unit commissioning reports
- Unit performance tests
- Index tests
- Maintenance procedures
- Operating procedures
- Inventory and spare parts lists
- Safety standards and procedures
- Signed copies of test reports
- Exception reports
- List of deficiencies (punch list)
- A final project report

3.7.5 Drawings

The specifications or company procedures typically define the form and standards that are required for drawings, including as-built drawings. Information in drawings that are available at the beginning of the commissioning activities may change during commissioning and will continue to change well past the end of the commissioning activities. It will be up to the commissioning manager and the commissioning leads to implement procedures (e.g. Owner's Drawing Management Plan) to maintain marked-up documents as the work progresses. The set of drawings that are to be maintained for mark-ups, is to be clearly defined and identified. A consistent method needs to be developed for applying mark-ups so they are evident, legible, and clear, and a designated person needs to be identified who will have responsibility for managing the mark-ups and the drawing process. This responsibility can be distributed to different sets of drawings.

The sets of drawings that are normally modified the most include:

Equipment and Electrical Drawings – The number of changes and mark-ups will be relatively minor on the main equipment; most tend to be on the auxiliary equipment.

Control System Drawings – A lot of changes may be required on these drawings, and this will likely continue past the end of the commissioning activities. Contracts that require the submittal of final drawings within short periods after commissioning will be difficult to comply with. It is therefore important to set realistic timeframes in the planning stage about the expected timeframes needed for contractors to update drawings for final submittals.

Piping and Instrumentation Diagrams – Similar to control drawings, there may be a large number of annotations and changes to piping and instrumentation diagrams (P&ID), and they may carry on past the end of planned commissioning activities. They are also important, as they define the numbering and tagging of piping, valves, and all instruments. It is important to coordinate tagging and to track changes or additions.

3.7.6 Software Code

It is easy to lose track of how code was modified from one unit to another, especially instances of forced bits and other default parameters. There will be a need to clean up and ensure consistency at some point; this will likely extend past the end of planned commissioning activities. Working with the supplier for this system, there should be a clear process on how this will be controlled to make sure all code is eventually made consistent across all units.

3.7.7 Setpoint Lists

This should be a simple list that states where every adjustable component was set and why the setpoint was selected. There will be settings to start the commissioning activities, and these will be modified throughout until all the values are "frozen" by the end of the planned commissioning activities. There should be designated personnel with well-defined responsibilities assigned to maintain these lists.

3.8 Operation and Maintenance (O&M) Manuals

Most owners require copies of the operation and maintenance manuals prior to the start of commissioning activities. This generally allows the owner's staff to familiarize themselves with the equipment as they witness or participate in the commissioning activities. Information on drawings, data sheets, and other documentation, may change throughout commissioning, and expectations for final versions of the operations and maintenance manuals before the end of commissioning will be difficult to meet. Final versions of manuals, drawings, and other documents are rarely completed until the commissioning staff has a chance to return to their offices and provide the acquired information to their engineering teams. This is why these manuals typically arrive months after commissioning has been completed. Requesting interim versions of the manuals to support the work at hand can be useful (with the understanding that the final documents will arrive later).

3.9 Training

The extent of training services to be provided should be well defined and documented in the contract documents and specifications to meet the needs of the owner. The responsibility of carrying out the training is linked to the planning phase of commissioning for two reasons. First, if possible, the commissioning team should conduct the training since they have the best knowledge of the plant when it is to be handed over. Second, training normally begins during commissioning.

Most service and equipment suppliers work on the concept that the scope of the training requirements is intended for owner staff with previous hydropower experience. Therefore, the intent of the training will be to convey an understanding of the equipment, systems, and operations specific to the facility being constructed. In remote sites, it is often the case that the local residents who become the operators and maintenance staff require additional training beforehand and will require a longer period of adaptation to the new facility. This should be initiated well before the commissioning activities.

The training and type of training methodology is driven by the availability of trainers and owner staff. This needs to be considered during the development of the resource plan prior to commissioning. The reality at most sites is that everyone needing the training is involved with commissioning activities and there is little time for formal training activities, which is why they are normally performed after the completion of planned commissioning activities.

Training During Commissioning – The intent of this training is to provide opportunities to understand the facility designs and obtain the knowledge required to operate the facility. This training is largely unstructured with key owner employees witnessing and participating in installation and commissioning activities. The owner must identify a small group of key individuals who will commit time at the site during these activities and can later support the training of others.

The natural sources of training material are the drawings and manuals, yet they are rarely in their final state when training is underway. It is worthwhile, when preparing contracts and commissioning plans, to require a submittal of drawings and manuals with the most up-to-date information to coincide with the planned post-commissioning training. While not in their final form and accuracy, they are normally sufficient for training purposes.

4.0 Commissioning Procedures Acceptance

After the commissioning documentation has been completed, all involved parties (facility owner, engineering staff, facility personnel, contractor, and equipment manufacturers) should be provided the opportunity and ample time to review the commissioning procedures and formally agree using an approval signature process on the final version prior to the start of commissioning.

5.0 Construction Testing Phase

The construction testing phase for the purposes of this document includes pre-shutdown/baseline readings, factory acceptance tests, and the development of test procedures for equipment during installation for verification of proper operation of the mechanical, electrical, and instrumentation equipment and systems.

5.1 Pre-Shutdown/Baseline Readings

The pre-shutdown/operational readings taken prior to shutdown for a hydro unit overhaul can prove useful for determining the condition of some of the equipment and provide a baseline for comparison when the unit is restarted. High vibration levels may indicate misalignment, unbalance, damaged bearings, or possibly just an inherent characteristic of a particular unit. Temperature plots of bearing heat runs from startup are useful not only for comparing a final operating temperature but also the rate of temperature rise after the unit overhaul is complete. Testing the bearing insulation on the thrust bearing and upper guide bearings on underhung units can save time in the long run. The insulation can deteriorate over time and the time to repair or replace it is during the overhaul. Some operational readings that should be recorded prior to the shutdown are:

- Vibration readings at each guide bearing from startup to full load.
- Temperature plots of guide bearings during a normal startup.
- Normal operating temperatures of all bearing metal and oil.
- Cooling water flow, if available.
- Thrust and upper guide bearing insulation, per FIST 3-11.

5.2 Factory Acceptance Tests

A Factory Acceptance Test is used to verify that newly produced equipment works according to its construction code and purchase order specifications. Factory testing is defined by manufacturing inspections, test plans, and test protocols. It is performed by quality managers, design engineers, operators, and maintenance personnel in the manufacturing facility before delivery to and installation at the client's site. It is recommended that the owner have a representative witness the critical tests at the factory site for verification purposes. Test data should be documented to establish a baseline reference for future use by plant personnel performing maintenance. These tests are critical in evaluating the independent functioning of components and sub-systems.

Factory acceptance tests are advantageous in that it is better to test as much of the equipment as possible in the factory as correction of errors or deficiencies are cheaper, faster, and easier to make in the factory and test conditions are often better. The most important aspect is the verification of the equipment/system performance prior to being transported to the site as a majority of these tests cannot feasibly be performed at the job site.

5.3 Installation Tests and Procedures

Installation activities should be controlled through a separate inspection and test plan for installation activities and/or other quality control measures. This phase immediately precedes the commissioning activities.

Recorded inspection and test data obtained during installation will be useful for troubleshooting during commissioning and will require formal acceptance by all parties involved with the commissioning process.

Different components and systems will transition from installation to commissioning at different timeframes and each has to be controlled separately. It is not practical to assume an entire unit or facility will transition from installation to commissioning in a single event; the commissioning procedures should address this.

The construction contractor usually performs required inspections and tests to demonstrate the completed installations are in accordance with contract requirements and the most recent engineering and design information. The results of the construction testing should be documented by the construction contractor and turned over with the release of the equipment for pre-commissioning/functional testing. Formalizing a release process for the transition from installation to commissioning should be considered for some or all of the systems and components to be commissioned.

It is not necessary for all powerhouse equipment to be installed before commencing the pre-commissioning activities; however, the piece of equipment that will be undergoing pre-commissioning testing must be complete. A prerequisite document to starting the commissioning activity is a signed-off installation checklist. The commissioning engineer should verify that the installation is complete as per the installation protocol and the signed-off installation checklist. The major equipment that will be checked for installation completion includes:

- Water passage equipment (headgate or turbine inlet valve)
- Turbine
- Generator
- Transformer
- Mechanical system auxiliaries
- Electrical protection and control equipment including turbine governor and exciter
- Electrical power equipment
- Power and control cables
- High voltage switchyard equipment

Once all the conditions specified in the installation test plan are satisfied and signed off, the commissioning process can begin on that particular piece of equipment. Construction/installation testing typically includes electrical, mechanical and instrumentation aspects.

Many of the inspections and tests required during the construction phase are also required in the pre-commissioning phase. Therefore, inspection and testing procedures performed during the construction phase for specific equipment and systems are included in Chapter 7 – Pre-Commissioning Testing Phase of this document.

6.0 Pre-Commissioning Testing Phase

For the purposes of this document, the pre-commissioning testing phase includes offline (dry) testing and functional testing, which are also known as pre-commissioning tests. These tests are performed on equipment without full system voltage or water, to determine its readiness for real operation. In this phase, subsystems are powered and integrated into the control system. Dry testing of equipment operating characteristics is performed by actuating components to verify control loops such as start and shutdown cycles.

Offline (Dry) Testing – This phase is also known as pre-startup testing. These tests are performed on equipment without full system voltage or water, to determine its readiness for real operation. Completion of the offline (dry) testing phase results in a formal release to water up the facility in preparation for the commissioning phase after walk-downs for deficiencies and inspection have been performed by the owner.

The functional testing phase is also known as pre-commissioning testing. These test procedures provide all tests and checks necessary to verify that each plant system (especially protection and control systems) is functional before startup testing of the overall integrated plant system begins. The purpose of the functional testing is to ensure each system and its components perform in accordance with design requirements and are complete and safe to energize or operate.

In general, the pre-commissioning phase involves the following major steps:

- Verification of equipment nameplate data. This is to ensure that the installed equipment to be commissioned complies with the current design.
- Visual inspection of the different components to be dry commissioned. The purpose of the visual inspection is to identify any damage or unusual conditions of the equipment prior to starting commissioning.
- Pre-commissioning checks, tests, and procedures.
- Dry (Off-Line) Testing.
- Functional Testing (see Section 7.0).

6.1 Pre-Commissioning Checks, Tests, and Procedures

The lead test engineer and staff should supervise the checkout and testing during this phase. They should ensure that tests performed during this phase are conducted in accordance with approved procedures prior to moving forward to the commissioning testing phase. While verifying the control system and control circuitry during this phase of commissioning, drawings should be marked to indicate checkout is complete.

Functional/pre-commissioning testing generally includes, but is not limited to:

- Final checkout of electric motors
- Checkout of motor-operated valves, dampers, and gates
- Checkout and verification of electrical control circuitry and software, through functional testing
- Calibration of electrical relays and meters

- Verification of operator interface, control system programming, functions, and inputs/outputs
- Checkout and trip check tests of switchgear, motor control centers, and molded case breakers
- Flushing of mechanical systems/subsystems
- Blowdown of station/instrument air lines
- Verification of proper lubrication of generator and turbine bearings
- Loop calibration of all instrument loops
- Functional loop checkout of all instrument loops (checking each loop from the field device to the control board or final control device)
- Pre-commissioning testing in accordance with approved pre-commissioning test procedures
- Vendor testing of supplied equipment and systems
- Vibration testing of driven equipment
- Visual inspection of all systems and equipment
- Verification of polarity and integrity on instrument transformer circuits
- Functional tests of auxiliary systems and equipment

6.1.1 All Equipment

6.1.1.1 Nameplate Data Verification

The identification of the nameplate data for the equipment to be commissioned is recorded and compared to the data available in the latest documents and drawings. Typical information to be recorded is:

- Manufacturer
- Type
- Serial number
- Voltage class
- Current rating
- Short-circuit rating
- Bus size
- Record current transformer (CT) data
- Other relevant information as found

6.1.1.2 Visual and Audible Inspections

This test covers all equipment in a hydroelectric facility and associated switchyards. All inspections should be conducted by knowledgeable personnel experienced with the type of equipment installed and conducted in strict compliance with proper safety procedures.

This test should be conducted both as a prestart test and during initial operation. The purpose of the test is to inspect the equipment visually and audibly and to verify there are no abnormalities in the performance of the equipment that could indicate improper functioning or incipient equipment failure. The following should be verified by visual/audible inspection:

- Equipment is clear of all debris and foreign material, especially metal pieces accumulated during the installation.
- Shipping blocks and bracing are removed.
- Equipment and components are clean inside and outside.

- Inspect, and where possible, operate devices by hand to ensure correct alignment and range of mechanism.
- All electrical and mechanical connections are tight.
- Unterminated wiring is insulated and stored out of the way.
- Fuses are of proper class and rating.
- Look for missing or broken parts and insulation or bushing cracks or tracking.
- Check wiring for insulation cracks, bushings for cracks or tracking.
- All cables are tagged in accordance with the cable schedule.
- Permanent grounding connections are in place to design requirements.
- All bus joints are tight.
- All circuit breakers are installed correctly.
- All insulating and/or fire barriers are correctly installed.
- Evidence of moisture on insulating and conducting parts.
- Leakage in water, oil, gas, or air systems.
- Integrity of mechanical interlocks and padlocking mechanisms.
- Safe access to equipment.
- Abnormal temperatures after the equipment is energized.
- Abnormal noises when equipment is in operation.
- Installation is complete and properly installed according to installation and manufacturer's drawings and instructions.
- Equipment nameplate ratings are in agreement with schematic diagrams.

Additional equipment is not usually required other than that used for calibration. The necessary indicators or readouts are furnished with the equipment system.

The duration of visual inspections is variable depending on the size and complexity of the equipment or system. It can vary from minutes for a single piece of equipment to days for large systems. The work effort reflects the same variance for the same reason.

Key Reference Documents

- O&M Manuals
- Schematic Drawings of Installation

6.1.1.3 Functional Checks

This test covers all equipment in a hydroelectric facility and associated switchyards. All inspections should be conducted by knowledgeable personnel experienced with the type of equipment installed and conducted in strict compliance with proper safety procedures.
This test is conducted after all calibration, continuity, and circuit checkout is completed, but prior to initial operation. It verifies equipment properly opens, closes, starts, stops, rotates, tilts, etc., when commanded.

Tests should not only verify proper control functions under normal conditions but should also include testing to verify the correct functionality as intended under abnormal conditions and failure scenarios.

Additional equipment is not usually required other than that required for calibration. The necessary indicators or readouts are furnished with the equipment or system.

The duration of functional checks is variable depending on the size and complexity of the equipment or system. It can vary from minutes for a single piece of equipment to days for large systems. The work effort reflects the same variance for the same reason.

Key Reference Documents

- O&M manuals for equipment
- Schematic drawings of installation
- IEEE Std. 1827 for spillways and other water conveyance equipment

6.1.2 Air Handling and HVAC Systems

6.1.2.1 Air Balance Tests

The objective of system air balancing is to direct the specified air flows, in the quantities as shown in the plans, to each of the spaces and zones detailed in the plans. The supply system should be set to provide proper quantities and the return system should be adjusted proportionately to achieve an overall balance of supply, return, and outside air. To achieve this, balancing dampers should be provided on supply air branches as well as the return and outdoor air connections at the unit. Supply, return, and exhaust airflows shall be balanced to within +10% to -5% of values noted on plans. Maintaining pressure relationships as designed shall have priority over tolerances specified above. Prior to performing air balance testing, observe the integrity of space boundaries including verification that windows and doors are closed, and all applicable gaskets, sealants and safings are installed.

One important factor in relating overall flow distribution is duct leakage. Ductwork leakage class is specified by ductwork application and location during project design using ASHRAE duct leakage classes. Ductwork leakage should be tested using SMACNA's HVAC Air Duct Leakage Test Manual and should be considered when setting up branch flow to provide design flow at all outlets. Duct leakage should be verified against specified duct leakage tolerances and any deficiencies corrected prior to completing air balance testing.

Velocity within a duct is determined by traversing the duct with an anemometer or pitot tube. Velocity traverses are quite accurate in the velocity range of 800 fpm and higher. Below 800 fpm, a micro-manometer should be employed.

Balancing the air conditioning system requires adjusting the prime air movers. Best practice for air side system balancing is to vary total system air quantities by adjusting the fan speed. Branch air quantities should be adjusted by damper regulation. The fan should be operating at or near the design system condition of revolutions per minute (RPM), brake horsepower (BHP), and static pressure before beginning duct balance. A 10% increase in fan volume requires a 10% increase in fan speed. To get 10% increase in volume, the fan must generate 21% higher static pressure and the motor must put out 34% more horsepower. Since this is not always possible, try to lessen existing duct losses before increasing fan speed.

Static pressure measurements should be performed at the primary air movers. Pressure measurements should include filter and coil pressure drops, and total pressure across the supply fan (and if applicable, return fan). Temperature measurements should be conducted across the outside air and exhaust dampers to check for leakage across these components.

The equipment required for this test includes:

- A volt-amp meter
- A tachometer
- A pitot tube
- An inclined manometer, u-tube, or dry type gauge
- Thermometer
- Air velocity meter
- Rotating vane anemometers
- Hot wire anemometers

The duration of testing varies with size and type of air conditioning system. Small systems can be completed in 8 to 24 hours. Some systems may require several days.

Key Reference Documents

- FIST 2-6, *Maintenance of Auxiliary Mechanical Equipment*
- AABC, National Standards for Total System Balance
- ASHRAE Transactions and Advanced Energy Design Guides
- ASHRAE 111, Testing, Adjusting and Balancing of Heating Ventilation, Air-Conditioning and Refrigeration Systems
- SMACNA, HVAC Systems – Testing, Adjusting and Balancing
- NEBB, Testing Adjusting and Balancing of Environmental Systems

6.1.3 Alternating Current (AC) Power (Uninterruptible)

6.1.3.1 Frequency Stability Test

Electrical leads that require uninterruptible power are also, typically, the loads most affected by amplitude and frequency fluctuations in the supply voltage waveform. It is no accident that manufacturers of modern uninterruptible power supplies have developed highly stable inverter circuitry to meet the demands of critical plant equipment. Most systems employ phase-locking to ensure that the inverter output remains matched in both frequency and phase to the auxiliary source under all specified loading conditions.

Many systems built today require no routine field adjustments to the oscillator or gate driving circuitry. The manufacturer's instruction manual should be reviewed to determine the need for all adjustments in specific installations.

This test requires a frequency meter or an oscilloscope.

Reference the manufacturer's instruction manual if testing or adjustments are required.

Key Reference Documents

- Original Equipment Manufacturer (OEM) O&M manual

6.1.4 Auxiliary Power Systems

6.1.4.1 Energized Auxiliary Power Tests

Energizing the auxiliary power supply should take place after the station service switchgear tests are complete. This test does not include tests of the prime mover. This section covers the standby generator and the automatic transfer system or automatic transfer switch.

Standby generator (prime mover is not addressed in this guide)
Before performing any tests on the standby generator, the installation must be complete for the following systems:

- Fuel oil system
- Exhaust system
- Cooling system
- Starting batteries
- Battery charger
- Vibration isolators
- Interconnecting wiring
- Ventilation system and related damper controls for the generator room
- Insulation on the exhaust system
- Remote radiator, related piping, and electric fan with controls
- Door to the generator room must be in place, complete with hardware
- Sealing of the generator from any other room in the building

After the above conditions have been satisfied, the following tests should be performed on the standby generator:

- Visual inspection
- Insulation resistance test on generator winding
- Testing of the protective relay devices, in accordance with the applicable guide
- Phase relationships
- Vibration testing
- Functional checks including verification of the following signals:
    - Low lube oil pressure warning
    - Low lube oil pressure shutdown
    - High coolant temperature warning
    - High coolant temperature shutdown
    - Overspeed shutdown
    - High lube oil temperature warning
    - High lube oil temperature shutdown
- Testing of the generator set at 100% load using the load bank
- Testing of all the safety shutdowns
- Cycle crank test
- With the portable receiver load bank at 100% rated load of the generator, operate the set for at least hours, taking readings at 15-minute intervals, and record:
    - Time of reading
    - Running time
    - Ambient temperature
    - Lube oil pressure

- Lube oil temperature
- Engine coolant temperature
- Exhaust stack temperature
- Alternator voltage, phase A, B, C, A-N, B-N, C-N
- Alternator current phase A, B, and C
- Power
- Frequency
- Power factor
- Battery charger current
- Battery voltage
- Alternator stator temperature
- Fuel supply level (comparing remote level gauge and level detected on the Programmable Logic Controller [PLC])
- Make note of Human-Machine Interface (HMI) signals on the SCADA system throughout the test.
- Make note of the indicating lights on generator control panel and vacuum contactor.

– Vibration base-line test. Plot amplitude versus frequency for each main bearing cap.
– Load bank test performed in accordance with the following schedule:
    - 25% rated for 30 minutes
    - 50% rated for 30 minutes
    - 75% rated for 30 minutes
    - 100% rated for 3 hours

Photograph 1 - Engine generator set and fuel supply tank

Automatic transfer systems and switches

<u>Automatic Transfer Systems</u>

In this section, the testing procedure for a PLC based automatic transfer switch is discussed. Typically, a PLC based automatic transfer controller is used to transfer power between two independent station service systems using a tie breaker.

Before performing any functional tests on the automatic transfer system, the tests that are required on any associated equipment, such as the switchgear and PLC systems, should be complete.

Typically, the following tests are performed on a PLC based automatic transfer system for the transfer of power between source (A) and source (B):

- Hardwired interlock test
- Check the failure of any power source and the subsequent restoration of the power using the automatic transfer system.
- Check the remote operation of the automatic transfer.
- Additional remote terminal unit (RTU) signal interface verification checks.

Automatic Transfer Switches

Testing of automatic transfer switches is described in the section below.

Prior to the commissioning of an automatic transfer switch, it must be installed in its final location and the upstream breakers on both of the incoming power sources must be kept open. After this precondition is met, the following visual inspections should be performed:

- Inspection to verify the mechanical integrity and completeness of the wiring.
- Check for any signs of external or physical damage.
- Check for loose components and confirm that no foreign material is visible.
- Confirm the cleanliness of the automatic transfer switch.
- Check that all anchor bolts are tight.
- Confirm all equipment and devices are installed and properly identified.
- Before the electrical test, confirm that all breakers are in the OFF position.
- Compare nameplate information and connections to drawings and specifications.
- Check tightness of all control and power connections.
- Perform manual transfer operation.
- Confirm proper lubrication.
- Check switch to verify positive mechanical interlock between normal and alternate sources.
- Verify manual transfer warnings are attached and viable.
- Check that all covers, barriers, and doors are secure.

After the visual and mechanical inspections, the next step is to perform an electrical test. This test should be performed in accordance with the manufacturer's procedure. This typically includes the following tests:

- Contact resistance of the normal supply breaker.
- Contact resistance of the emergency supply breaker.
- Function test of both circuit breakers.
- Function test of the changeover logic.
- Insulation-resistance tests phase-to-phase and phase-to-ground with switch in both source positions.
- Verify settings and operation of control devices in accordance with design criteria and drawings.
- Calibrate and test all relays and timers including voltage and frequency-sensing relays, in-phase monitor (synchronism check), engine start and cool-down timers, transfer, and retransfer times, etc.
- Automatic transfer tests.
- Simulate loss of normal power.

- Return to normal power.
- Simulate loss of emergency power.
- Simulate all forms of single-phase conditions.

Once prerequisite tests are completed, a hand-held multimeter is usually the only test equipment required to diagnose malfunction.

Approximately two days will be required to energize auxiliary power and complete the prerequisite tests.

Key Reference Documents

- Acceptance testing specifications
- Design criteria documents
- Equipment drawings
- IEEE Std 43, IEEE Recommended Practice for Testing Insulation Resistance of Electric Machinery

6.1.5 Battery

6.1.5.1 Specific Gravity Test

This test applies to flooded cell lead acid batteries.

Specific gravity readings are recommended to be recorded once a lead-acid battery is placed in service. These readings indicate not only the state of charge, but also the general condition of the battery when evaluated over time. Specific gravity readings are not recommended for nickel-cadmium batteries since the electrolyte is passive in the chemical reaction and, therefore, provides no useful information as to the state of charge or battery condition.

Recommended procedures for reading specific gravity may vary among battery manufacturers, so the instruction manual should be followed in developing site-specific procedures. Generally, specific gravity measurements are meaningful only after the battery has been allowed to float for some period of time following addition of water to the cells. Lead-calcium cells may require several weeks on float charge for the electrolyte to become thoroughly mixed. Lead-antimony cells, on the other hand, should be mixed in just a few days because of the higher float current typical for this type of battery.

Most batteries come with an O&M manual that includes instructions for reading specific gravity using an electronic digital hydrometer. During the commissioning phase, it is highly recommended that the initial specific gravity readings be taken and recorded by the personnel responsible for periodic surveillance of the battery once it is placed in service. The reason for this is consistency of readings – changes in gravity readings over a period of time are more meaningful in the evaluation of battery condition than the absolute readings at a particular time, so it is important to achieve consistency right away. Furthermore, the format for recording battery data should be developed during this phase to ensure that the data are recorded in a consistent manner from the outset.

Equipment required would include an electronic digital hydrometer and safety equipment as recommended by the manufacturer and as required by the facility owner.

An experienced battery technician may read the specific gravity of as many as 60 cells in an hour with a recording digital hydrometer. Similar efficiency may be achieved with a non-recording hydrometer if an assistant is available to record the readings. It is best to schedule the time for these readings based on the experience level of those taking the measurements.

Key Reference Documents

- IEEE Std 450, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications
- O&M manual

Photograph 2 - Lead acid battery bank

6.1.5.2 Discharge/Capacity Tests

A capacity test, usually referred to as an acceptance or performance test, should be performed to demonstrate that the battery meets its performance specification and also to establish a baseline for comparison of the results of future periodic tests. The battery needs to be on float for a minimum amount of time before the battery will reach is published performance specification. Consult the manufacturer's literature. The purpose of the test is twofold:

- To ascertain that the battery was not damaged during packaging, shipping, handling, storage, and installation, and
- To cycle, or exercise, the battery before placing it in long-term final service, as will be the case in many hydroelectric plant applications.

The performance test is designed to verify that the battery meets the manufacturer's published (or quoted) discharge characteristics with the defined initial and final conditions. It is very important to record all test parameters, both measured and calculated, and to include them in the test documentation. These parameters should include initial electrolyte specific gravity (for lead-acid types) and open circuit cell voltages, average temperature and temperature correction factor, calculated discharge current, test duration, and acceptance criteria.

Setup and test time will vary dependent on the number of battery cells and battery capacity. An average battery usually takes one day to test for an experienced technician and one assistant.

6.1.5.3 Equalizing Charge Test

An equalizing charge, sometimes called a freshening charge in the case of a newly installed battery, should be included in preparation for placing a battery in service. Implementation schedules will often require a battery to be stored for some time before installation and connection to the charger. Most battery manufacturers allow a limited storage period without any charging and a somewhat longer period if a trickle charger is connected. In either case, it is likely that some energy has been lost from the battery through self-discharge. It is therefore very important to follow the manufacturer's instructions carefully in determining storage requirements as well as the need for an equalizing charge.

When scheduling an equalizing charge, be sure to consider the float charge duration required as a prerequisite in most performance test procedures. After an equalizing charge, batteries are usually required to float for three to seven days before the start of any performance or acceptance test.

The equipment required for this test includes a battery charger (permanent or temporary), and a digital voltmeter.

Setup time is minimal if the permanent charger is installed and calibrated. Switch the charger to equalize mode and set the equalize timer (if provided) to return the charger to float mode after a predetermined duration. If a temporary charger is to be used, the connections should be made, and the charger float and equalize voltage levels should be calibrated using a digital voltmeter. In addition, some installations require special ventilation to prevent accumulation of hydrogen during an equalizing charge.

Key Reference Documents

- IEEE Std 450, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications
- IEEE Std 1106, IEEE Recommended Practice for Installation, Maintenance, Testing and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications
- OEM O&M manual

6.1.5.4 Float Charge System Test

All batteries, especially the lead-acid types, will benefit if placed on float charge as soon after delivery as possible. Implementation schedules will often require a battery to be stored for some time before installation and connection to the charger. Most battery manufacturers allow a limited storage period for wet cells without any charging and a somewhat longer period if a trickle charger is connected. It is important not to exceed the manufacturer's recommendations on duration of storage before placing the battery on float charge.

It is also necessary to schedule the float charge duration required as a prerequisite in most battery performance test procedures. After an equalizing charge, batteries are usually required to float for three to seven days before the start of any performance or acceptance test.

This test requires the use of a battery charger (permanent or temporary), and a digital voltmeter. Float voltage should be adjusted given the ambient temperature of the battery. Consult manufacturer's literature for correct float value and temperature correction factors.

Setup time is minimal if the permanent charger is installed and calibrated. Verify that the charger is set to float mode. If a temporary charger is to be used, the connections should be made and the charger float and equalize voltage levels should be calibrated using a digital voltmeter.

Key Reference Documents

- IEEE Std 450, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Lead-Acid Batteries for Stationary Applications
- IEEE Std 1106, IEEE Recommended Practice for Installation, Maintenance, Testing and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications
- OEM O&M manual

6.1.5.5 Standard Temperature Test

Electrolyte temperature readings are recommended to be recorded on a periodic basis once a battery is placed in service. These readings are used in evaluating the battery state of charge as well as the general condition of the battery over a period of time. Initial measurements need to be taken for all cells within a few weeks after the battery has been placed on float charge. In addition to establishing a baseline for future comparison, these readings should be used to verify the installation design with respect to ventilation and heating. Some battery manufacturers recommend a maximum temperature differential among connected cells of 3 degrees Celsius (°C). If greater differentials are measured among the cells of a battery, corrective action is necessary.

Equipment for this test includes:

- An electronic digital type resistance temperature detector (RTD). Digital specific gravity meters incorporate a temperature monitor.
- Safety equipment as recommended by the manufacturer and as required by the facility owner.

Key Reference Documents

- IEEE Std 450, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Lead-Acid Batteries for Stationary Applications
- IEEE Std 1106, IEEE Recommended Practice for Installation, Maintenance, Testing and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications
- OEM O&M manual

6.1.5.6 Voltage Level Test

Overall battery voltage should be recorded on a periodic basis once a battery is placed in service. The charger output voltmeter may be used for daily or weekly readings, provided it is checked on a regular basis for calibration. A better method would be to use a calibrated digital voltmeter to take these measurements. The measurement should be taken across the battery terminals. In addition to total voltage, the individual cell voltages should be recorded periodically, though not as often. The readings are used in evaluating the general condition of the battery over a period of time. The owner should be looking for differences in individual cell voltages among all the connected cells of a battery. The manufacturers provide details on how to evaluate voltage differentials when detected under float charge conditions as well as the proper corrective actions when they occur.

The baseline data for future comparison is normally collected during commissioning. Once a battery has been on float charge for a period long enough to ensure stability, usually not more than three weeks, the baseline voltage readings may be taken. The manufacturer's recommendations should be followed to record the measurements to verify that all accompanying readings required for meaningful evaluation are included.

Equipment for this test includes:

- A digital voltmeter
- Battery tester
- Safety equipment as recommended by the manufacturer and as required by the facility owner.

The readings should only take 1 hour for a typical 60 cell battery if an assistant is available to record the cell voltage readings or if a recording voltmeter with sufficient storage capacity is used.

Key Reference Documents

- IEC 60896, Stationary Lead-Acid Batteries
- IEEE Std 450, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Lead-Acid Batteries for Stationary Applications
- IEEE Std 1106, IEEE Recommended Practice for Installation, Maintenance, Testing and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications
- OEM O&M manual

6.1.6 Bearing and Lubrication System

6.1.6.1 Bearing and Lubricating/Hydraulic Oil Checks

The bearing lubrication system is one of the most important auxiliaries for the successful operation of the generator. The commissioning of this system is crucial for the safety of the generator bearings. In this section, a general guide is provided to ensure that the oil lubrication system functions properly and has been installed as per the specification. No special equipment is required.

The following turbine/generator components require either turbine lubricating oil or hydraulic oil for proper operation. The testing of these systems verifies that the proper flow rate of oil exists in each of the following components:

- Turbine oil head for Kaplan turbines (with adjustable blades).
- Guide and thrust bearings.
- Turbine shaft seal or packing box.
- Gate and blade servomotors.
- Typically, a lubrication system for a hydro application contains two ac pumps and one dc pump. Prior to the commissioning of this particular system, the following prerequisites must be completed:

- Turbine and generator installation is complete.
- Oil piping installation is completed, flushed, leak tested, and pressure tested.
- Phase rotation has been checked on the incoming leads of the motors.

A visual inspection should be performed of the overall lubrication system prior to testing. The visual inspection includes:

- Ensure all the valves and couplings are properly tightened.
- Ensure all the drain valves are closed.
- Confirm there is no damage to any of the components of the overall lubrication system.
- Check that all the instrumentation is properly installed and identified in accordance with the P&ID.
- Check that all the valves in the lubrication system are properly identified and are in accordance with the P&ID.

Once the visual inspection of the lubrication system is performed, the system will be ready for pre-commissioning testing. In general, the following tests will be carried out in order to finalize the commissioning of this system:

- A bump test is performed to check that the pump discharge, pressure, and direction of rotation are all within the required limits.
- Open all the valves in the lubrication circuit to create a flow path through the bearings.
- Verify the motor starting current and the running current, and confirm that the pump operating parameters are within the allowable range.
- Proper checkout of the pump electric motor lead/lag controls is also required.
- The preliminary settings of all the instruments are typically done at the factory and should be checked at this stage. The instrumentation within the lubrication system –consisting mainly of pressure, flow, temperature, and level sensors – should be checked out and it should be confirmed that the main control annunciation operates correctly.
- Confirm that the flow in the visible flow indicator is as per the design requirement.
- At this stage, the pump pressure relief valves should be adjusted in order to set the desired pressure and flow in the oil lubrication system. It is important to verify the pressure rise or the motor current during this activity. In the event that there is an unusual rise in pressure above the acceptable limit or if the motor current is higher than the acceptable limit, stop the test immediately and check for any unusual conditions.
- Follow the same procedure for the second ac pump and the dc pump, as applicable for the design of the equipment.

The time to perform the static tests mentioned above, with the unit stationary, will take approximately 2 hours. However, 3-4 hours will be needed when the bearing tests are being conducted and as the unit is first rotated. One person is stationed at each device and an operator is at the unit controls. Additional personnel should be located at the pump control panel to energize/deenergize the pump motors as required.

Key Reference Documents

- FIST 2-4, *Lubrication of Powerplant Equipment*
- OEM instruction manual

Photograph 3 - Spring loaded thrust shoe bearing

6.1.7 Brakes

6.1.7.1 Braking System Tests

The brake system in a hydro generating or pumping unit is typically operated by a pneumatic or hydraulic system that acts to decelerate the rotating unit and to reduce torque produced by turbine wicket gate leakage. The brake system for large vertical hydro units is generally pneumatically operated. The air for the brakes is supplied by the station service air system at nominally 100 psi. The brake assembly on vertical units consists of vertically mounted brake cylinders and piston assemblies mounted on the lower bearing bracket of the machine and inter-connected with piping or tubing and necessary valves. Each piston has a brake pad (shoe) that bears on the brake ring, which is mounted on the bottom side of the rotor frame. The brakes are applied at approximately 25% of the unit rotating speed during shutdown, although this varies with generator design. Horizontal-shaft machines usually use a design with a rotor-caliper and disc type of brake. Certain types of pumps or pump-generators with a separate starting winding also may use dynamic braking to slow the machine prior to initiation of the brakes.

Most vertical hydro units have an automatic/manual air brake valve assembly that controls the application of the generator brake by directing air pressure to the generator brake cylinders to apply the brakes. The circuit to the valve controller or solenoid usually includes a series of interlocks which require that the wicket gates be closed, the unit be decelerated to the desired brake speed, and the unit be disconnected from the line before the brake valve can initiate the brakes. The electrical input and output signals between the brake air valve assembly and the speed sensor, the permanent magnet generator, and speed switch assembly or programmable logic controller (PLC) system will have been checked prior to performing this test.

The mechanical installation of the brake system should be completed, and the tightness of all the associated bolts and fasteners must be properly checked. All the necessary precautions for the pneumatic and hydraulic systems should be completed before energizing this section of the circuit.

As a prerequisite to the brake system pre-commissioning testing, the brake air system should be tested and inspected. Air filters should be clean, and regulators set to deliver an air pressure with minimum pressure variation through the complete stop cycle.

In order to test the brakes, prior to watering up the unit, operate the system and confirm that the nominal brake pressure is reached. Energize the appropriate directional control valve and verify that the brakes are engaged. After this is complete, de-energize the directional valve and confirm that the brakes are disengaged and all shoes drop.

After this pre-commissioning test, further commissioning of the brake system will be performed during the commissioning testing stage.

Proper operation of the unit braking system should be reverified during commissioning. Commissioning for the brakes involves both standstill tests and simulated start sequences during functional testing by initiating the air valve solenoid. Check the travel of each piston (to ensure that each pad contacts the brake ring at the same time) and check the piping system for leaks. When operating the unit for the first time, check the generator shaft rotational speed at which the brakes are applied.

Once the unit is initially mechanically operated, both the automatic and manual brake activation controls should be checked during the first couple of stops. The test consists of activating the brakes and observing that they have an appropriate effect on rotational speed. The speed of the unit when the brakes engage, and the time required to fully stop the unit should be recorded. Once the unit is stopped, the capability of the brakes to hold the unit against gate leakage flow torque should also be checked by ensuring that the unit is not rotating and that the creep indication relay system is working properly. Pneumatic or hydraulic pressure may need to be adjusted on units that exhibit excessive brake wear or excessive time to stop the unit occurs.

No special equipment is required, although some sites may wish to record unit deceleration curves of speed versus time for record purposes. Older machines that are being recommissioned may at one time have used brake pad material containing asbestos. Proper PPE and testing for asbestos are recommended when working in an asbestos contaminated environment.

No extra time is needed to perform these tests since they are done as part of the stop sequence during the initial mechanical tests.

Key Reference Documents

- FIST 2-7, *Mechanical Overhaul Procedures for Hydroelectric Units*
- FIST 2-12, *Mechanical Maintenance of Hydroelectric and Large Pump Units*
- OEM assembly and O&M instructions for the brake system
- Schematic drawing of the hydraulic power unit (HPU)
- HPU input and output list

Photograph 4 - Brake shoe assembly

6.1.8 Cables and Electrical Equipment

6.1.8.1 Insulation Resistance and Polarization Index (PI) Testing

These tests typically apply to all electrically insulated equipment in a hydroelectric facility and associated switchyards. Testing is often performed on insulation systems such as control wiring (600V class) to high-voltage systems such as, but not limited to, stator and rotor windings, power cables, stand-off insulators for low-and-high-voltage bus work, or transmission line insulators. All tests shall be performed by knowledgeable personnel experienced with the type of equipment installed and in strict compliance with proper safety procedures. Upon completion of these tests, the test specimen should be grounded properly for sufficient duration to dissipate any residual charge accumulated due to dielectric absorption effects. All non-tested phases and other insulation systems in the vicinity of the test specimen must be grounded prior to commencing testing.

Insulation resistance and PI testing applies a high, direct-voltage to the test specimen and measures the corresponding current through the insulation system of interest. These tests must be successfully completed prior to performing a high-potential withstand (proof) test, also known as a 'hipot' test. If the test specimen yields poor insulation resistance or unacceptable polarization index results, the problem must be identified and corrected, and the specimen must pass a repeat testing prior to performing final high-potential withstand test.

The testing is designed to detect insulation contamination, surface or internal moisture ingress, or serious mechanical damage. Insulation resistance and PI testing may also detect cracks or fissures in an insulation system if the applied test voltage is sufficiently high. The prescribed test voltage usually depends on the normal operating voltage of the test specimen and the applicable guide or standard from the governing body (IEEE, IEC, NEMA, ANSI, etc.). Typical applied voltages range from 500 to 10,000 Vdc and sometimes up to 15,000 Vdc.

Insulation resistance and PI testing typically are performed and discussed together. Insulation resistance tests are often generally referred to as "Megger® tests." To perform a test, a specified high, direct voltage is applied to the test specimen and held for 10 minutes. At the 1- and 10-minute intervals, the insulation resistance and/or current are recorded.

The insulation resistance is the value recorded at the 1-minute interval. Often the value will be corrected to a normalized temperature of 40 °C. The polarization index is simply the ratio of the 1- to 10-minute resistance (or current) values.

The basic equations to calculate insulation resistance and PI are as follows:

$$IR = R_{1\,min}$$

$$PI = R_{10\,min}/R_{1\,min} \quad or \quad PI = I_{1\,min}/I_{10\,min}$$

Where:

IR = Insulation Resistance

PI = Polarization Index

$R_{10\,min}$= insulation resistance at 10 minutes (Ω)

$R_{1\,min}$= insulation resistance at 1 minute (Ω)

$I_{1\,min}$= measured current at 1 minute (A)

$I_{10\,min}$= measured current at 10 minutes (A)

Insulation resistance and PI test methods for determining the condition of electrical insulation has been widely used for many years and, at low test voltages, is considered by most maintenance engineers as a general nondestructive test.

Insulation resistance and PI testing measure the capacitive charging, dielectric absorption, conduction, and leakage currents of the insulation system. Testing is often performed by applying the voltage with respect to earth ground but may sometimes be applied between phases of certain insulation systems. The test specimen must be isolated from ground and all other equipment for testing. The high-voltage lead is connected to the conductor of the test specimen and the other lead of the test set is connected to earth ground. All other phases and nearby insulation systems are also grounded for safety.

Due to the dielectric absorption characteristics of high-voltage insulation systems, the resistance appears to increase from the time voltage is applied until the test is concluded.

Insulation resistance is highly dependent upon the type of insulation and the test conditions. Resistance is inversely proportional to the temperature of the specimen and may be directly proportional to the relative humidity. Unless the tests are repeated under similar conditions, trending the data may be ambiguous. Trending can be more reliable if temperature differences are compensated for by correcting the data to an approximate value at a specific temperature, usually 40 °C.

Testing requires equipment that can provide test voltages of 500–10,000 Vdc. Because the dielectric characteristics of high-voltage insulation is dependent upon the applied voltage, it is important that the dc voltage supply be regulated for a constant output; otherwise, the quality of the test results will be negatively affected by the drift in the applied voltages.

Time required to prepare for the test is dependent upon the equipment to be tested. It may take as little as a few minutes or possibly several hours to prepare the specimen if disassembly and other isolation is required. The test itself requires only a few minutes; however, after a test is completed, the specimen should be discharged through a suitable resistor (sized to limit the current to 1 ampere) until the measured voltage and current is negligible. This function is often integrated into the test equipment. This must be verified before testing. The specimen then should remain grounded for a duration of four times the length of the test or 2 hours, whichever is greater.

Key Reference Documents

- IEEE Std 4, IEEE Standard for High-Voltage Testing Techniques
- IEEE Std 43, IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery
- IEEE Std 56, IEEE Guide for Insulation Maintenance of Electric Machines
- IEEE Std C57.152, IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus-Part 1: Oil Filled Power Transformers, Regulators, and Reactors
- IEEE Std 95, IEEE Recommended Practice for Insulation Testing of AC Electric Machinery (2300 V and Above) with High Direct Voltage
- FIST 3-1, *Testing Solid State Insulation of Electrical Equipment*

6.1.8.2 High Potential Withstand Testing

High potential (hipot) testing refers to the application of alternating, or direct, high-voltage to a test specimen for a duration of one-minute. The insulation system either passes or fails the test and is therefore categorized as a 'proof' test and does not usually provide diagnostic information. High potential withstand testing will not damage or significantly degrade an insulation system that is free of serious damage or defects. If a serious defect, damage, or severe contamination exists prior to testing, the insulation may be damaged and would fail the test. This would require repairs to correct. The objective of the test is to reveal pre-existing serious defects that would otherwise lead to short-term in-service failure.

There are many test variations that include using voltages that are dc, stepped dc, ac normal frequency, ac very low frequency, etc. Testing of certain apparatus, such as rotating machine stator windings, may not exactly duplicate the electrical voltage stress distribution on the insulation with the equipment in normal service. Theoretically, weakened insulation will puncture when subjected to the test voltage. It is presumed if the insulation does fail during the test, it would have soon failed in service if not at initial energization. For at least some voltage and insulation types, high potential testing may be considered to degrade the insulation or decrease remaining life; however, the actual loss of life is often negligible and not considered significant enough to preclude testing at regular intervals. Test voltages that do not significantly exceed equivalent normal operating voltages are considered by most experts to be impractical because they are not significantly different than normal operation stresses.

Equipment required would include a high potential test set (with sufficient voltage output capability and type required – ac, dc, very low frequency, etc.). For extra high voltage, compressed gas insulated switchgear, special gas handling, and resonant type testing equipment is often required.

The test averages 2 hours per piece of equipment including setup time but may vary significantly depending on equipment type and setup time. It normally requires two electricians or electrical test specialists.

A common question regarding high-voltage/high-potential testing is: "Will the test damage or age the insulation?" Based on Reclamation's 40+ years of experience and industry experience, high-voltage/high-potential testing does not damage or significantly age insulation in good/acceptable or serviceable condition. In Reclamation's history, testing-induced insulation failure is very rare, and all known testing-induced failures are directly attributable to defective, severely deteriorated, or physically damaged insulation. If the insulation system is physically damaged, severely deteriorated, or otherwise significantly compromised, it may fail under a high-potential test; however, detection of compromised insulation is the sole purpose of the high-potential test. If the insulation system is not physically damaged or severely deteriorated, it will not fail during testing. Detection or failure of compromised insulation during testing avoids costly in-service failures and forced outages. In-service failures may cause collateral damage that typically extends the duration of a forced outage and complicates the repair process. In some cases, direct and collateral damage from an in-service failure may be severe enough to preclude emergency repair and prevent temporary return to service. Performing insulation tests to voltage levels below the recommended values compromises the effectiveness, quality, and accuracy of information gained by the high-voltage and/or diagnostic test(s). Performing maintenance tests to lower-than-recommended values is essentially a run-to-failure policy.

Notes

- Switchgear – The operating dielectric (oil, air, SF_6, etc.) should be checked for moisture, contamination, etc., before high potential test.
- Outdoor large oil filled transformers – On-site commissioning high potential test is not recommended.
- Generators – Separate phases should be tested individually if possible.
- Cables – Usually test after delivered and again after installation. Test according to manufacturer's recommendation for special insulations.
- Motors – Test should be performed from switchgear.

Key Reference Documents

- IEEE Std C50.12, IEEE Standard for Salient-Pole 50 Hz and 60 Hz Synchronous Generators and Generator/Motors for Hydraulic Turbine applications Rated 5 MVA and Above
- NEMA WC7/ICEA S-66-524, Cross-Linked Thermosetting Polyethylene Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy – Withdrawn
- NEMA WC8/ICEA S-68-516, Ethylene-Propylene Insulated Wire and Cable for the Transmission and Distribution – Withdrawn
- IEEE Std 4, IEEE Standard for High-Voltage Testing Techniques
- IEEE Std C57.152, IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus-Part 1: Oil Filled Power Transformers, Regulators, and Reactors

- IEEE Std 95, IEEE Recommended Practice for Insulation Testing of AC Electric Machinery (2300 V and Above) with High Direct Voltage
- IEEE Std 112, IEEE Standard Test Procedure for Polyphase Induction Motors and Generators
- IEEE Std 114, IEEE Standard Test Procedure for Single-Phase Induction Motors
- IEEE Std 115, IEEE Guide for Test Procedures for Synchronous Machines Part 1 – Acceptance and Performance Testing Part II – Test Procedures and Parameter Determination for Dynamic Analysis
- IEEE Std 117, IEEE Standard Test Procedure for Thermal Evaluation of Systems of Insulating Materials for Random-Wound AC Electric Machinery
- IEEE Std 400, IEEE Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems Rated 5 kV and Above
- IEEE Std 433, IEEE Recommended Practice for Insulation Testing of AC Electric Machinery with High Voltage at Very Low Frequency
- IEEE Std 434, IEEE Guide for Functional Evaluation of Insulation Systems for AC Electric Machines Rated 2300 V and Above
- IEEE Std 1242, IEEE Guide for Specifying and Selecting Power, Control, and Special-Purpose Cable for Petroleum and Chemical Plants
- IEEE Std C37.09, IEEE Standard Test Procedure for AC High-Voltage Circuit Breakers with Rated Maximum Voltage Above 1000 V
- IEEE Std C37.010, IEEE Application Guide for AC High-Voltage Circuit Breakers > 1000 Vac Rated on a Symmetrical Current Basis
- IEEE Std C37.16, IEEE Standard for Preferred Ratings, Related Requirements, and application Recommendations for Low-Voltage AC (635 V and below) and DC (3200 V and below) Power Circuit Breakers
- IEC/IEEE 62271-37-013, IEC/IEEE International Standard for High-Voltage Switchgear and Control Gear – Part 37-013: Alternating-Current Generator Circuit-Breaker
- IEEE Std C37.20.1, IEEE Standard for Metal-Enclosed Low Voltage (1000 Vac and below, 3200 Vdc and below) Power Circuit Breaker Switchgear
- IEEE/ANSI C37.20.2, IEEE Standard for Metal-Clad Switchgear
- IEEE Std C37.21, IEEE Standard for Control Switchboards
- IEEE Std C57.12.00, IEEE Standard for General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers
- NEMA MG 1, Motors and Generators
- FIST 3-1, *Testing Solid State Insulation of Electrical Equipment*
- FIST 3-16, *Maintenance of Power Circuit Breakers*

6.1.9 Cathodic Protection

6.1.9.1 Current Measurement Test

For the purposes of commissioning, current requirements for cathodic protection systems have been previously determined during the design phase. The commissioning test verifies that the design current can be achieved and maintained by the installed system, as well as adequate corrosion mitigation as determined from the structure polarization.

Equipment required: If the system is an impressed current type, the electrical equipment contains the appropriate meters and shunts from which to read the current output of the rectifier. If the system is a galvanic current type, it may not be necessary to measure the current for the purposes of design verification. Specific test points should be selected using a voltmeter and appropriately sized shunt (resistor of known size).

For an impressed current system, the effort is minimal and consists of reading a meter, verifying the meter using a voltmeter and shunt, and checking the reading against the design requirement. A galvanic system should take approximately two people one day to locate the test points and use a voltmeter to take the required number of readings.

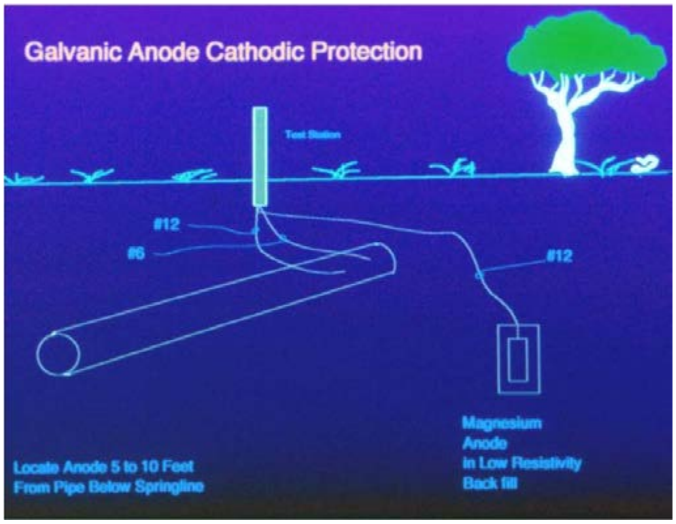


Figure 1 - Typical galvanic anode cathodic protection system installation

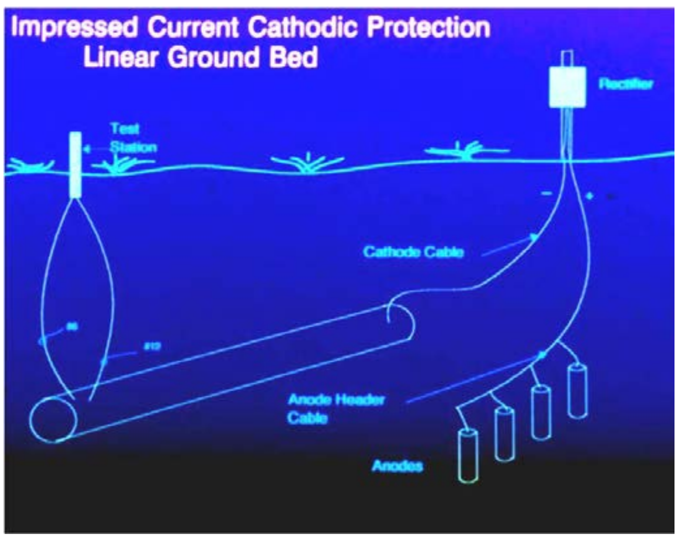


Figure 2 - Typical impressed current cathodic protection system installation

Key Reference Documents

- FIST 4-5, *Corrosion and Cathodic Protection*
- The current requirements, both galvanic and impressed, are covered in the design documents for the cathodic protection system.

6.1.9.2 Voltage Measurement Test

Prior to energizing a cathodic protection system, several structure-to-electrolyte potential readings should be taken at different points. The existing potential between the structure to be protected and the reference source should be noted (native potential). The potential difference between the structure to be protected and the reference source should then be brought into design specifications by energizing the cathodic protection system and adjusting its output. The cathodic protection system is energized using the impressed current rectifier or by electrically connecting the galvanic anodes to the structure to be protected.

A reference electrode, such as a copper-copper sulfate electrode, and a high-resistance digital voltmeter will be required.

The duration depends on the size of the cathodic protection system. Time can vary between one to seven days for the complete checkout of the system. The voltage measurements would typically take two people one to three days to perform.

Key Reference Documents

- FIST 4-5, *Corrosion and Cathodic Protection*
- The installation professional should refer to the design criteria for the specific cathodic protection system. Since these systems are unique and project specific, generic instructions do not exist.

6.1.10 Circuit Breakers

6.1.10.1 Contact Resistance Test

Contact resistance tests for circuit breakers of all voltage classes and current ratings will verify that contacts are firmly seated and that the breaker has not been damaged in shipping or handling.

Contact resistance tests should be conducted prior to energizing and placing breakers in service.

CAUTION: Circuit breaker damage will occur if the primary operating mechanism is used without the proper amount of insulating medium present in each interrupter.

Circuit breakers filled with an insulating medium, like SF_6 or mineral oil, should not be operated using the primary operating mechanism if the circuit breaker is not filled with the proper amount of insulating medium. Manual operation using the provided manual operation tool by the breaker manufacturer is the only acceptable method of moving interrupter contacts in an interrupter that has not been filled with its insulating medium. See breaker manual for instructions on manually moving interrupter contacts. Some disassembly may be required.

When draw-out type circuit breakers are provided, contact resistance measurements should be conducted with the breaker removed from its cubicle fully isolated from energized circuits ideally placed on a sturdy work bench or cart. The breaker should be cycled open and closed a few times to verify the repeatability of contact resistance and to work lubricants in the operating mechanism. Note that contact grease should not be applied to arcing contacts, otherwise arcing contact resistance may increase over time. Refer to breaker manual for proper application of contact grease and mechanism lubricant.

Prerequisite tests include visual inspection, mechanical operation, and trip and close coil continuity.

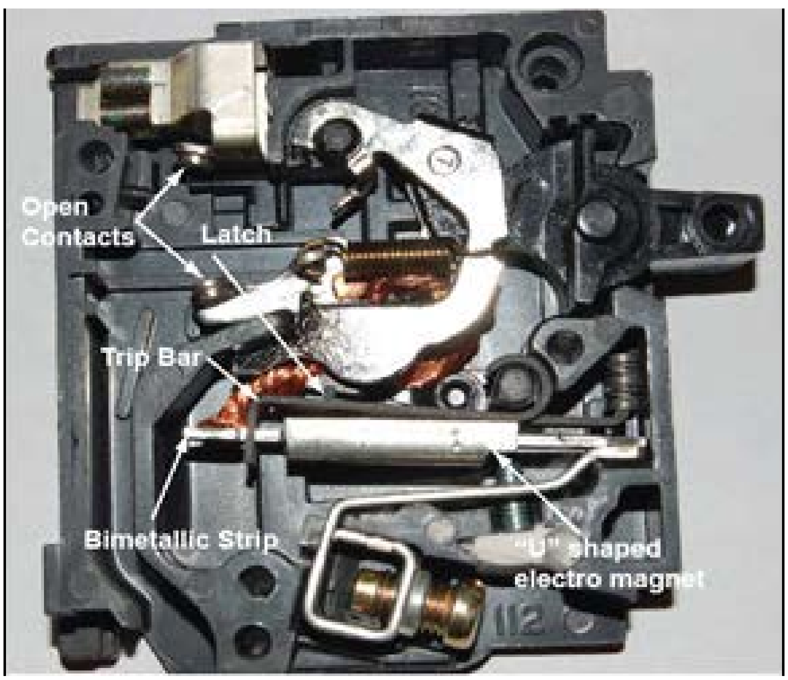
Equipment required: Instrumentation should be suitable for the level of precision required. A high-current breaker should have contact resistance in the order of micro-ohms or less. Check breaker manual for nominal contact resistance values for the specific model of circuit breaker. See IEEE Std 118 for various test methods.

A large power breaker requiring precision instruments will require approximately 4 hours for each breaker.

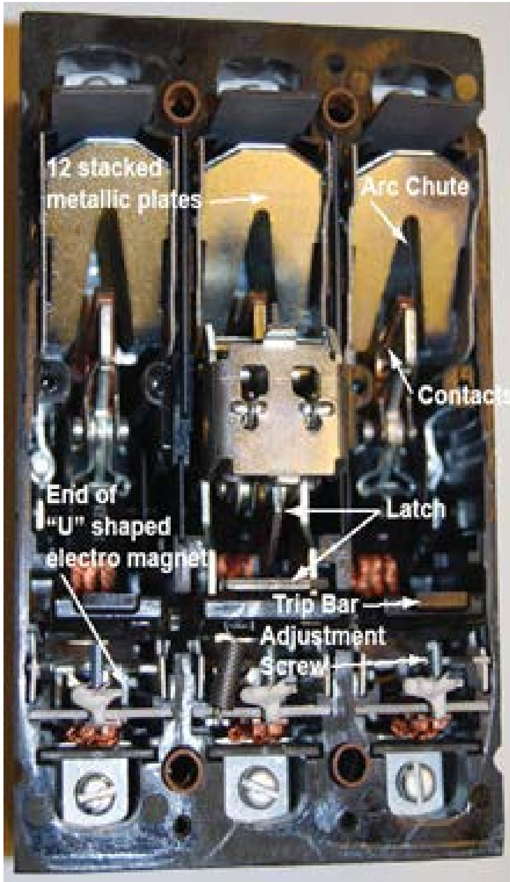
Contact resistance measurements for smaller circuit breakers with no adjustable contacts, like molded case circuit breakers, can be conducted in a few minutes for each breaker. Refer to breaker manual for contact resistance test methods.

Key Reference Documents

- IEEE Std 118 (Withdrawn), IEEE Standard Test Code for Resistance Measurements
- Manufacturer's O&M Manuals



Photograph 5 - Single pole breaker with major parts labeled



Photograph 6 - Three pole breaker with major parts labeled in the trip position

Photograph 7 - Vacuum circuit breakers

Photograph 8 - Oil circuit breaker

6.1.10.2 Insulation Test

Standard Insulation Testing

Standard insulation testing of circuit breakers uses high-voltage dc test equipment to test the insulation between each interrupter, the circuit breaker frame, and the contacts in the open position. This testing is suitable for most circuit breakers to verify that the insulation system of a circuit breaker is functional before bringing it into service. Insulation power factor testing is required for high voltage circuit breakers or for breakers that specify it in the manual.

Insulation Power Factor Testing

Insulation power factor and dissipation factor are the cosine and tangent respectively of the applied test voltage and the resulting current through the insulation, these factors fall in the 0-0.1 (or 0-10%) range. In this range, the two factors are often used interchangeably since they differ by less than 0.0005 (0.5%).

Power factor tests should be performed on each phase with the breaker in both the open and the closed position. Power factor tests should be performed on each bushing of oil-filled breakers. Use conductive straps and the hot collar procedure if bushings are not equipped with a power factor tap. The power factor of an insulation should remain constant with increasing test voltage if no discharges are present.

Insulation power factor tests are optional for medium voltage breakers with non-hygroscopic insulation.

Insulation power factor tests should be the final test prior to energization after all other tests are completed and the switchgear has been thoroughly cleaned to remove all construction dust and debris. Use only fluids or solvents specifically approved by the manufacturer.

Prerequisite tests include visual inspection, mechanical operation, trip and close coil continuity, and phase relationship.

Equipment required: Adjustable voltage source at power frequency and a precision bridge for volt, amps, and watts measurement.

Insulation power factor tests will require about 4 hours for each breaker.

Key Reference Documents

- IEEE Std C57.152, IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus – Part 1: Oil Filled Power Transformers, Regulators, and Reactors
- Manufacturer's O&M manuals
- FIST 3-16, *Maintenance of Power Circuit Breakers*

6.1.10.3 Operating Coil Continuity Test

The purpose of this test is to verify that a complete unbroken circuit exists for the closing and trip coils of electrically operated circuit breakers and switches. Depending on the equipment available, this test can be used to capture the current waveforms of each operating coil to establish a baseline performance "fingerprint" of each coil prior to commissioning. This data can be used to identify issues with operating coils in the future, or if mechanical issues arise where the operating coil cannot move the plunger properly due to an obstruction or sticky linkage.

Prerequisite tests are to check operating coil nameplate voltage against trip and close voltages actually used.

Each coil test can be expected to require about 15 minutes depending on accessibility.

Key Reference Documents

- Manufacturer's O&M data

6.1.10.4 Timing Test

Circuit breaker timing tests should be included in planning for placing a circuit breaker in service. Verification of breaker timing compared to design requirements and manufacturer's specifications is important in order to verify that the operating mechanism is configured correctly to meet the intended design specifications needed to perform open and close operations with anticipated contact wear life and safe interruption of fault currents.

Timing tests are made to determine the time required for circuit breakers or components to operate during open, close, and close-open operations, and to compare circuit breaker travel and velocity values to manufacturer's acceptable limits.

All three contacts of three-phase equipment should operate at the same time within the design criteria and the manufacturer's tolerances. Uniformity between phases is especially important for circuit breakers that isolate interconnected sources such as tie breakers and generator breakers.

Circuit breaker timing tests should be conducted prior to energization. Timing trip tests, and trip coil continuity tests for non-draw-out equipment should be conducted after permanent installation. Draw-out breaker elements may be tested in place or in test fixtures.

CAUTION: Circuit breaker damage will occur if the primary operating mechanism is used without the proper amount of insulating medium present in each interrupter.

Circuit breakers filled with an insulating medium, like SF_6 or mineral oil, should not be operated using the primary operating mechanism if the circuit breaker is not filled with the proper amount of insulating medium. Manual operation using the provided manual operation tool by the breaker manufacturer is the only acceptable method of moving interrupter contacts in an interrupter that has not been filled with its insulating medium. See breaker manual for instructions on manually moving interrupter contacts. Some disassembly may be required.

Prerequisite tests include trip tests, trip and close coil continuity, and mechanical operation.

Timing tests should be performed using equipment specifically designed to test circuit breakers. Equipment may be rented, purchased, or borrowed for testing and should have up-to-date calibration. Using equipment not specifically designed for circuit breaker testing may cause damage to circuit breakers and can produce data that may not be useful as a reference in scheduled breaker testing per maintenance procedures.

High-voltage breakers and generator breakers typically require two technicians 4 hours to set up and record timing data for all three phases. Medium to low voltage breakers typically only need one technician who can test multiple breakers in a day.

Key Reference Documents

- IEC/IEEE 62271-37-013, IEC/IEEE International Standard for High-Voltage Switchgear and Control Gear – Part 37-013: Alternating-Current Generator Circuit Breakers
- O&M manuals
- Plant design criteria documents
- FIST 3-16, *Maintenance of Power Circuit Breakers*

6.1.10.5 Circuit Breaker Trip Circuit Tests

Circuit-breaker trip tests are required prior to energizing and placing the circuit breaker in service. The purpose of this test is to verify the breaker will trip upon closure of control switch or relay contacts. When draw-out type circuit breakers are provided, preliminary tests should be conducted with the breaker in the "test position".

Prerequisite tests include:

- Visual inspection
- Mechanical operation
- Phase relationship
- Trip coil continuity
- Circuitry tests

Circuit breakers with integral trip devices require a breaker test set with the ability to perform secondary injection tests at a minimum. Breakers with over-current and other protective relays require the trip contacts be mechanically pushed closed or the trip output contacts shorted together and control switches be operated. Certain types of circuit breaker overcurrent features may require primary injection testing to verify functionality of the breaker.

Duration of trip test for any given breaker depends entirely on the complexity and number of trip sources. Approximately 15 minutes will be required for each trip source unless there are problems to be traced.

Key Reference Documents

- Manufacturer's O&M manual control sequence schematic drawings.
- FIST 3-16, *Maintenance of Power Circuit Breakers*

6.1.11 Compressed Air Systems

Compressed air systems in hydroelectric generating stations are required to operate the following equipment:

- Circuit breakers
- Generator brakes
- Draft tube water level depression for synchronous condenser operation
- Instrument air
- Service air for tools
- Additional smaller items, such as air admission control systems, cooling water flow regulation systems, fire protection systems, etc.

Equipment associated with compressed air systems include:

- Compressors
- Motors
- Dryers
- Pressure vessels
- Piping and valves
- Relief valves
- Electrical supply
- Protection and controls
- Cooling system
- Noise abatement

The commissioning of compressed air systems works most efficiently when scheduled during or prior to the installation of the downstream equipment. In order to verify that the equipment reliant upon compressed air for operation is installed correctly and according to the contract specifications/standards, the compressed air system must be fully operational. Waiting to do all commissioning at once (after installation of all of the equipment) can lead to delays due to upstream equipment not functioning correctly. Any unexpected corrective work will typically lead to significant delays and extend the duration of commissioning activities.

Photograph 9 - Rotary screw-type compressor

Pre-Commissioning

Prior to any system testing or commissioning activities, the following should be performed to ensure the compressed air system is ready for commissioning and any potential problems are resolved prior to testing:

- Installation – Confirm that installation has been completed with few or no remaining deficiencies or major problems.
- Controls Point-to-Point Checks – Point-to-point checks confirm the correct wiring and installation of all control-points. This should involve ensuring that sensors have been calibrated, field devices operate correctly, and wiring is correctly installed and terminated. It should also involve observing device responses and ensuring that they match control system display outputs.
  - For compressed air systems, controls point-to-point checks should be performed as part of the installation checks and balanced by the contractor responsible for installing the system. The commissioning team should witness the point-to-point checks and independently verify the results.
- Flushing and Cleaning – After the installation of the compressed air system, it is recommended that the system be flushed and cleaned. Any remaining debris in the piping has the potential to damage other equipment downstream, so it is important to closely inspect the piping after flushing and cleaning activities. Installation of temporary strainers and/or filters may be required during flushing.
- Document reviews – Reviews should include, but not be limited to:
  - Reviewing approved manuals and shop drawings, including electrical and mechanical schematics
  - Reviewing factory acceptance tests
  - Reviewing installation checks and balances

- General Verification and Visual Inspection – The general verification and final inspection should include, but not be limited to:
  - Nameplate verification to the drawing/specifications/contracts/standards for motors, compressors, pressure vessels, relief valves, pipes, power supplies, etc.
  - General tests and checks, including checking conductor insulation, checking for correct wiring, confirming correct alignment and rotation, ensuring equipment is grounded and control systems are operational, etc.
  - Visual installation checks to verify equipment is properly installed, all bolts are tight, equipment is adequately secured to the floor or wall, cables are tagged, connections are tight, fire systems are installed correctly, couplings or sheaves are aligned correctly, mechanical components are properly lubricated, etc.

After all inspections have been performed, the results should be documented and approval granted in the form of a certificate to energize, ready for rotation certificate, or equivalent. This document should be signed by the prime contractor and owner and be provided to confirm that the system is ready to start. These reports and certificates will form part of the commissioning records for the project and should be shared with project staff for contract management. Once the approval certificate has been obtained, the team may move into the commissioning phase.

Off-Line Commissioning

The commissioning team should confirm that:

- Piping has been flushed and cleaned
- Construction power or a permanent source of power is available for equipment start-up
- If applicable, any existing control systems have been modified and tested to work with the new equipment
- If applicable, rental compressors should be available to supply the facility during commissioning
- The system has been isolated for isolated testing
- All previously identified deficiencies have been properly addressed
- A seismic conformance letter has been issued by a seismic engineer for the installation (if required)
- The owner's representatives have been invited to witness all commissioning activities

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Note: No equipment should be started until the appropriate commissioning documentation has been completed and the start-up time and date has been scheduled and approved by all parties.

In addition, the commissioning team should confirm that all electrical service (ac or dc), low voltage alarms, and controllers are interfacing with other auxiliary systems (Privileged Access Management, fire alarm, etc.), and that all systems are ready to start.

In order for the commissioning to begin, the following items should be in place:

- An inspection test plan for commissioning needs to be developed and approved.
- A safety plan, required to identify all the risks and outline the appropriate safety procedures in the event of a failure, needs to be developed and approved.

- All required instrumentation, along with calibration records, should be available and ready for testing.
- Record documents for testing need to be prepared, approved, and ready for use.
- Qualified personnel or a manufacturer's representative should be available and present to perform testing and any necessary repairs required during testing.
- Any additional documents needed for testing need to be available as required (including reference manuals, documents, standards, contract specifications, drawings, pre-commission checklists, test procedures, etc.).

These items should be on site, either physically (if possible) or electronically, prior to commissioning. The safety plan should align with existing organization safety plans, if applicable. Safety and coordination meetings for all personnel involved with the commissioning should be held and documented prior to testing. In addition, barricades should be erected for areas identified as having potential for electrical or mechanical hazards. Advance notice should also be provided to personnel working in the vicinity of the compressed air system.

Off-Line Testing

Compressed air system off-line testing should include:

- Pneumatically pressure test all piping
- Blow out (flush) all piping
- Perform insulation resistance tests on all electrical equipment
- Final check all valve positions (for operation), gauges, and instrumentation settings

Functional Testing

Compressed air system functional testing should include:

- Bump air compressor motor to verify rotation and appropriate rise in discharge pressure
- Bump all fans and pumps, as applicable, and verify correct rotation
- Test and record before and after pressure for all pressure-reducing valves
- Record all compressor and dryer settings if programmed by hand; otherwise, save a copy as a backup
- Initiate all control systems and remote monitoring (if applicable)
- Log hours of operation "as found" and "as left"

Key Reference Documents

- CEATI Commissioning Guide for Hydroelectric Generating Stations – Auxiliary Systems and Equipment
- ASME BPVC-VIII-1: 2017 Rules for Construction of Pressure Vessels
- ASME B31.8: 2014 Gas Transmission and Distribution Piping Systems
- ASME EA-4: 2010 Energy Assessment for Compressed Air Systems
- ASME HPS: 2003 High Pressure Systems
- ASME PTC-9: 1970 Displacement Compressors, Vacuum Pumps and Blowers
- ASME PTC-10: 1997 Performance Test Code on Compressors and Exhausters
- IEEE 43-2013 Recommended Practice for Testing Insulation Resistance of Electric Machinery
- IEEE 112-2017 Standard Test Procedure for Polyphase Induction Motors and Generators
- ISO 1217: 2009 Displacement Compressors – Acceptance Tests
- ISO 2151: 2004 Noise Test Code for Compressors and Vacuum Pumps-Engineering Method (Grade 2)

- ISO 5388: 1981 Stationary Air Compressors-Safety Rules and Code of Practice
- ISO 8573: 2010 thru 8573-9: 2004 Compressed Air Quality Standards and Testing
- ISO 11011: 2013 Compressed Air-Energy Efficiency- Assessment
- ISO 12500: 2007 thru 12500-4: 2009 Filters for Compressed Air Testing
- ISO 18740: 2016 Turbo-compressors-Performance Test Code – Simplified acceptance Test

6.1.12 Control and SCADA Systems

This section provides pre-commissioning guidance for the plant control and SCADA system. The main objective of this pre-commissioning activity is to test and verify that all internal wiring is correct and also to ensure that the functionality of the overall control system is satisfactory. Typically, the main components will include the following systems:

- Unit and common plant control system
- Remote Terminal Units or Programmable Logic Controllers
- Communication system (Ethernet, serial, fiber-optic, radio, etc.)
- SCADA system nodes (master station and remote view nodes)

In order to start the pre-commissioning activity, it is important that all of the latest documents are available:

- Single line diagram
- Control system architecture showing the complete communication system(s)
- A complete input and output list of the overall system including plant device connections, cabinet connections, RTU/PLC connections, RTU/PLC point addresses, RTU/PLC to HMI communication channels, HMI tag names, and analog scaling.
- Schematic diagrams
- Wiring diagrams
- Factory test records
- Cable schedule
- Test plan
- Documentation/evidence showing SCADA system and associated components meet Reclamation cyber security requirements.

Verification or checking of the interconnection wiring should be done at this stage of the project. Tasks related to the verification of the interconnection wiring include:

- Verification of the completeness of the installation
- Point to point test
- Megger test

A thorough pre-commissioning test plan should be created in advance of any testing. No actual plant operations will be performed as part of this test plan. Operations should be simulated. Portions of this test plan can be performed as part of the Factory Acceptance Test (FAT) prior to pre-commissioning if needed, provided that the FAT test results are documented. The test plan should include:

- Validate all digital inputs from the source devices into the SCADA system.
- Validate all digital outputs from the SCADA system to the destination devices.
- Validate all analog input from the source devices into the SCADA system.
- Validate all analog outputs from the SCADA system to the destination devices.

- Document how analog input and output signals will be fully tested across the entire range of the analog signal to validate scaling.
- Validate all HMI screen animations work as anticipated (screen item movement, color change, text change, etc.).
- Validate all SCADA digital alarms occur as anticipated.
- Validate all SCADA analog alarms occur at the anticipated analog thresholds.
- Validate any SCADA safeties or interlocks that are designed to prevent unintended/accidental operation function as intended and prevent device operation for all anticipated circumstances.
- Validate automatic device operations within the RTU/PLC (e.g., automatic setpoint controls, etc.) function properly for all logical combinations of data that can affect that automatic control.
- Validate an analog input signal loss, under-range, or over-range condition does not cause any unintended SCADA or device operations.
- Document any special plant conditions that are required for testing and validation purposes.
- Validate start/stop sequences.
- Validate shutdown sequences.
- Validate manual/local control mode SCADA indication, and that SCADA operation of a device is not possible if that device is in manual/local mode.

Pre-commissioning activities for the control and SCADA system are outlined below.

The first step of the pre-commissioning activity is to ensure that the following prerequisites have been completed:

- The control panels, including the line-up, are properly installed and anchored.
- The control cables are properly terminated as per the drawings, as well as properly tagged and verified within the cable schedule.
- The internal wiring of the control cables is checked with the latest updated drawings.
- Insulation tests on the cables are complete and recorded.
- Before beginning this procedure, the fuses and the breakers mounted in the panel should be kept open for safety reasons.
- SCADA components such as RTUs, PLCs, and nodes are properly installed, and electronically secured, and physically secured if necessary.
- All communication cables must be installed between the control panel as well as the rest of the system, in accordance with the network communication diagram.
- Determine how to perform the pre-commissioning test of the SCADA system without causing actual plant operations. This might include shutdown or lockout of specific devices, or the disconnection of control wiring.

After completing all the necessary prerequisites, the next step of the pre-commissioning activity will be to confirm that the associated control panels are safe to energize. As a precaution, the following activities should be completed:

- All circuit breakers or disconnects should be open to segregate the internal circuits. This will allow for each power source, control, and/or signaling circuit to be checked methodically.
- Any circuits, cables, or wiring that are not connected with the process or field devices must be removed, to ensure there are no issues before transferring power to the panels.
- For safety reasons, each field device must be analyzed to ensure that no process equipment starts unexpectedly.

After all necessary preparations have been completed, the system is ready to begin the pre-commissioning process. The following activities should be completed as part of the pre-commissioning of the system:

- All circuit breakers or disconnects should be open to segregate the internal circuits. This will allow each power source, control, and/or signaling circuit to be inspected.
- Any circuits, cables, or wiring not connected with the process or field devices must be removed, to ensure there are no issues before transferring power to the panels.
- Insulation resistance tests must be completed for all the cables.
- After the insulation checks are completed, verify that all the wiring is in accordance with the drawings. This can be achieved by performing continuity checks.
- At this stage, close the breaker and fuses.
- After insulation checks are complete, energize the auxiliary power circuit within the cabinets.
- In order to make the RTU/PLC ready for any further checks, download the latest control program(s) to the RTU/PLC if necessary and ensure the RTU/PLC(s) are in 'Run' mode.
- Before performing any further checks, it is also important to verify that the operator interface is functional and that all the latest SCADA HMI graphics are configured during the testing process.
- Verify that all the inputs and outputs are wired properly with the control system and in accordance with the I/O list and wiring diagrams.
- Verify that communication between all the RTUs/PLCs SCADA nodes, and other devices connected to the communication system is occurring reliably.
- Perform the Test Plan to validate SCADA operation. (A typical unit control system has Local Manual, Local Auto, and Supervisory control functions. Each mode is tested separately using simulation to verify correct operation.)
- Perform the same tests above to validate SCADA operation of remote sites/plants.

Once all pre-commissioning tests and prerequisites have been completed, and all identified issues have been resolved, then the SCADA system can be configured for control and further testing of actual plant equipment. Another thorough test plan should be created prior to this testing that covers all aspects of SCADA operation that were not tested during the pre-commissioning phase.

Key Reference Documents

- NETA ECS 2020, Standard for Electrical Commissioning Specifications of Electrical Power Equipment and Systems
- FIST 3-33, *Industrial Control Systems (ICS) Including Supervisory Control and Data Acquisition (SCADA) Systems Operation and Maintenance*

6.1.13 Control Circuits

6.1.13.1 Circuitry Checkout

This is more of a process than strictly a test procedure. It involves working directly from a schematic diagram of the full circuit being checked. The checkout confirms that the circuit is in accordance with the schematic diagram. Each element in the schematic is verified to be in place and properly wired. Visual inspection is used to verify equipment nameplates, location, and quality of the wiring. Continuity testing is employed to verify proper wiring. Calibration and timing of the individual circuit elements is completed during this phase of the project. The circuitry checkout is a complete verification of the circuit, as designed, up to the commissioning test of the equipment including verification of power and/or control for each device and proper communication with the control unit. These tests should not only include testing to demonstrate operation as designed but also include testing to verify that they cannot be inadvertently defeated (e.g., a sneak circuit).

Equipment required: Any equipment required for supportive tasks such as continuity checks and calibration.

Duration is dependent upon size and complexity of circuit being checked out. Full start-stop circuitry of large hydro units can take up to two weeks for two people. Simpler circuits, such as governor pump circuits, can be completed in one day by one individual.

Key Reference Documents

- Schematic diagram of the circuit being checked out.
- Wiring diagram of the circuit being checked out.

6.1.14 Control and Protection Devices

6.1.14.1 Threshold Setting Test

Threshold setting testing consists of establishing operating levels for settable control and protective devices. The testing involves testing settable devices for present settings, adjusting the settings to the desired level, and then verifying the setting.

Calibration equipment is needed for setting mechanical devices. Relay test sets are needed for setting protective relays.

Initial settings on mechanical devices should be made and verified using "bench" testing, simulation, or actual mechanical conditions where possible. Settings may have to be adjusted later when the devices are actually operating in the plant. Settings of electrical devices can usually be made "in-situ", although protective relays are usually disconnected from normal circuitry via test switches.

Threshold settings should be carefully documented for later reference.

Key Reference Documents

- Calculated settings
- Device instruction books

6.1.15 Control Wiring

6.1.15.1 Continuity Checks

This test consists of verifying conductor integrity and proper identification. All individual conductors in a circuit shown on a schematic are verified before circuitry checkout is initiated. The continuity test is usually combined with a visual inspection. A test instrument is used to measure or verify the proper conductor path for the circuit shown on the schematic. Both ends of the conductor are unterminated and one end is grounded. The other end is tested with the instrument for a path to ground, indicating full continuity from one end of the conductor to the other. An alternate method of continuity checking is to energize the circuit and see if it works, but this can lead to precipitous failure in equipment and conductors. For fiber optic cable, Optical Time Domain Reflectometer and optical power loss tests are performed to verify the integrity of the optical fiber.

Equipment required: A volt-ohm meter, sound powered headphones, or a "continuity checker" in the form of a battery-driven buzzer or light can be used. It is cautioned that this testing is done with all circuitry de-energized.

The duration of the tests depends upon the experience of the individuals testing the conductors and the complexity and size of the circuitry being checked. For example, it would take two individuals about one week to complete all necessary continuity checks on the control system and control circuitry of a medium-sized hydro generator.

Key Reference Documents

- General electrician manuals and aids are available to aid in performing the continuity test.
- Manuals or documents explaining the procedure may exist in the project owner's records.
- Schematic diagram of the circuit being checked out.
- Wiring diagram of the circuit being checked out.

6.1.16 Cooling Water System

6.1.16.1 Cooling Water System Tests and Checks

The cooling water system is generally used to supply various equipment, such as oil lubrication system, generator heat exchangers, and other equipment.

Photograph 10 - Unit cooling water pump assembly

As a prerequisite, the following needs to be confirmed before starting commissioning:

- The cooling system skid must be installed in the final location and be properly anchored.
- All the necessary piping associated with the cooling system is completed, properly tightened, and inspected.
- All the instrumentation and monitoring devices are properly installed.

Even though the cooling water system is not in a high-pressure loop, it can still cause an electrical hazard if any leaks occur in the system. As a result, it should be properly monitored during the initial filling and pressurization.

The first step of the pre-commissioning testing activity will be to perform a visual inspection on the overall skid and the complete cooling circuit. This includes:

- Verify that all the components within the cooling water system are in accordance with the system schematic and P&ID.
- Verify that all the valves are properly installed and tightened.
- Verify that all instrumentation is properly installed.
- Confirm there is no visual damage to any of the components.

After the visual inspection, the next step is to place the equipment in service. The following activities must be completed in order to put the cooling water system into service:

- Perform an electrical check on the pump motors. Perform a Meggar test, then record and verify that the motors can be energized.
- Fill the circuits with the required coolant.
- Check the instrumentation settings and adjust them as required. Record any adjustments in the set point list.
- Check the functionality of the level switches and temperature switches in the cooling water system.
- After all the instrumentation set points are verified, start the pumps and perform the system verification.
- Start the cooling water pump and verify that the recommended system pressure has developed. Check the overall circuit to identify if there are any leaks.
- Perform the same verification with the second pump (if there is a second pump).
- Using the pressure switch, simulate pump failure and check the automatic starting of the standby/back-up pump.
- Using either of the pumps, circulate the water for 2-3 hours and verify the condition of the filters. Replace the filters if required.
- After 2-3 hours, if the cleaning is satisfactory, empty the circuit and fill it with the appropriate coolant.

Key Reference Documents

- FIST 2-6, *Maintenance of Auxiliary Mechanical Systems*
- Operation and maintenance manuals
- Schematic diagram of the cooling water system
- P&ID of the cooling water system
- Arrangement drawings of the cooling water system
- Heat exchanger drawings
- Instrumentation setting list

6.1.17 Cranes

6.1.17.1 Operation Tests

Prior to initial use, all new, reinstalled, altered, and extensively repaired or modified cranes should be tested by a qualified person to ensure compliance with referenced standards and to verify proper operation. Specific functions to be tested include:

- Hoist lift. In an unloaded condition, the hook should be raised and lowered through a full range of travel and operating speeds. Micro drive controls, if applicable, should be tested to both upper and lower limits of travel. The limit switches at the upper and lower limits of travel will be activated at each travel cycle.
- Braking system. The braking system, including trolleys, trucks, and hoist/hook components, should be tested in an unloaded condition. The tested components are subjected to various travel speeds with the brakes subsequently applied, and stopping distance and performance observed.
- Bridge and trolley traverse. The bridge and the trolley should be individually and concurrently operated over the entire travel distance.
- Travel limits. During the bridge and trolley traverse test, the limit switches at each end of travel should be engaged to stop the travel of the pretested component.

There are no specific equipment requirements for the non-load tests. Setup time is minimal and actual test time is based on the size of the crane and travel distance. Tests are usually performed concurrently. A minimum of three complete test cycles are recommended for each test referenced above.

Key Reference Documents

- ANSI/ASME B30.2, Overhead and Gantry Cranes (Top Running Bridge, Single or Multiple Girder, Top Running Trolley Hoist)
- OSHA, 29 Code of Federal Regulations (CFR) 1910.179, Overhead and Gantry Cranes
- ISO 4310, Cranes – Test Code and Procedures
- ISO 14518, Cranes – Requirements for Test Loads
- Local requirements

6.1.17.2 Load Test Performance

Prior to initial use, all new, reinstalled, altered, extensively repaired, or modified cranes should be tested by a qualified person to ensure compliance with applicable standards and to verify proper operation. Specific functions to be tested are explained in the following paragraphs.

The crane and appurtenant components should be tested in a loaded configuration. The test should be supervised by a designated or authorized person and a written report provided by the supervising person. The report should confirm the load rating of the crane and be placed in a file that is readily accessible to designated personnel.

The load rating should not be more than 80% of the maximum load (125% of rated load) suspended during the test. Also, test loads are not more than 125% of the rated load, unless the manufacturer recommends otherwise.

The following operations are part of the rated load test:

- Hoist the test load a distance to verify that the load is supported by the crane and held by the hoist brake(s).
- Transport the test load by means of the trolley for the full length of the bridge.
- Transport the test load by means of the bridge for the full length of the runway, in one direction with the trolley as close to the extreme right-hand end of the crane as practical, and in the other direction with the trolley as close to the extreme left-hand end of the crane as practical.
- Lower the test load and hold the load with the brake(s).

Equipment required for the load test are calibrated weights with identification showing weight and/or calibrated dynamometer. These weights could be concrete, billet steel, or water bags.

Setup time is minimal and actual test time is based on the size of crane and travel distance. A minimum of three complete test cycles are recommended for all tests referenced above, except the load test. The 125% load test is generally performed only once.

Key Reference Documents

- ANSI/ASME B30.2, Overhead and Gantry Cranes (Top Running Bridge, Single or Multiple Girder, Top Running Trolley Hoist
- RSHS Section 19A, *Permanently Installed (Fixed) Cranes*
- Load requirements

Photograph 11 - Bridge crane

6.1.18 Digital Controls

6.1.18.1 Control System Tests

This section covers pre-commissioning tests for simple digitally controlled systems. Examples include hydraulic pumping units, water quality systems, and outlet gate controls that use a single digital control platform with local inputs and outputs. Complex digital control systems, such as digital governors, excitation systems, unit/plant controls, and SCADA systems, are covered in their respective sections.

This test consists of verifying all inputs and outputs for the control system along with the associated logic and operator interfaces. Each input/output is tested and the associated logic sequence from each test verified, including failure modes of the input and the system. Proper display is confirmed for each signal. This can often be done as part of the control circuitry checkout for auxiliary systems, governor, and excitation systems.

In order to start the pre-commissioning activity, it is important that all of the latest documents are available:

- Control system architecture showing the complete communication system(s)
- A complete input and output list of the overall system including plant device connections, power supply connections and connections to external systems such as plant controls and SCADA.
- Schematic diagrams
- Wiring diagrams
- Factory test records
- Cable schedule
- Test plan
- Documentation/evidence showing system and associated components meet Reclamation cyber security requirements as required.

Verification of the internal wiring connections between field terminal blocks and the control devices should be performed at this stage unless it was performed previously at a Factory Acceptance Test. Verification of connection to field devices include:

- Verification of equipment grounding.
- Continuity tests (Point to point).
- Insulation resistance tests for cables (Megger).
- Proper grounding of shields for control and instrumentation cables.
- Documentation Check:
  - Compare the as-shipped drawings to the installed equipment.
  - Verify the number of devices and location match the equipment layout drawings.
  - Check nameplates are correct and match drawings.

Depending upon the complexity of the system, there may or may not be an energization checklist of tasks to be performed prior to applying power to the system. At a minimum the following shall be checked:

- Verify ratings of internal circuit breakers and fuses match the drawings.
- Test switches are in the open position and ready for energization.
- Control switches are in the Off or Local position and ready for energization.
- Isolation valves are in the correct state for energization.
- Filters and strainers are in place and drains are closed.
- All the necessary piping associated with the system is completed, properly tightened, and inspected.
- All the instrumentation and monitoring devices are properly installed.

A pre-commissioning test plan should be created in advance of any testing. Operations should be simulated to the furthest extent possible. Portions of this test plan may be performed as part of the FAT prior to pre-commissioning, provided that the FAT test results are documented. The pre-commissioning test plan should include the following as applicable:

- Check operation of control switches, indicating lights, and test switches.
- Check operation of mechanical switches, such as pressure, temperature, level, and flow.
- Check rotation of 3-phase motors.
- Verify power supply outputs are within expected range.
- Review and confirm digital control setpoints are properly set for operation.
- Validate all digital inputs from the source devices if possible or from the field terminal blocks at a minimum.
- Validate all digital outputs from the control system to the destination devices or to the field terminal blocks at a minimum.
- Validate all analog input from the source devices into the SCADA system. Simulate signals such as 4-20 mA transducer signals, RTDs, and thermocouples using a Process Simulation Meter, if available.
- Validate all analog outputs from the SCADA system to the destination devices or to the field terminal blocks at a minimum.
- Validate that all HMI screen animations work as anticipated (screen item movement, color change, text change, etc.).
- Verify if a control signal has failed, it is depicted as failed on the HMI and cannot be confused with a working signal.
- Test any historical trends or stored data such as alarm logs.
- Validate all control system digital alarms occur as anticipated.
- Validate all control system analog alarms occur at the anticipated analog thresholds.
- Validate that an analog input signal loss, under-range, or over-range condition does not cause any unintended device operations.
- Validate any control system safeties or interlocks that are designed to prevent unintended/accidental operation function as intended and prevent device operation for all anticipated circumstances.
- Validate automatic device operations to the furthest extent possible with system simulation or actual control of field devices that are available in this pre-commissioning test phase.
- Validation of start/stop sequences.
- Validation of shutdown sequences.
- Validation of manual (local) and automatic (Supervisory) control modes.
- If the system is connected to a plant control system or SCADA it is convenient to test the data displays on this system simultaneously.

System checkout also includes functional verification of inter-device communication and time synchronization. Firmware should be verified to be the correct version and any cyber security systems to be functional.

Control system programming software and associated interface computer is required.

The duration of testing depends upon the experience of the organization and individuals testing and the complexity and size of the control system being checked. If it is performed as part of the system checkout, it can take weeks as each system is checked. If it is done after the system checkout, it typically takes about one week to test a digital control system.

Key Reference Documents

- IEC 62381, Automation Systems in the Process Industry - Factory Acceptance Test (FAT), Site Acceptance Test (SAT), and Site Integration Test (SIT)
- IEC 62382, Control Systems in the Process Industry – Electrical and Instrumentation Loop Check
- Control system design basis documentation, logic diagrams, Input/Output lists, program descriptions, and operations and maintenance manuals

6.1.19 Direct Current (DC) Equipment and Cables

6.1.19.1 Polarity (DC) Test

The purpose of this test is to field verify the polarity designation of dc equipment and cables.

DC equipment is usually polarity sensitive, so it is imperative that all dc cables and devices be tested for verification of correct polarity prior to energizing. This is done by measuring the potential using a dc voltmeter with the positive terminal of the voltmeter connected to the positive terminal of the device.

Readings between the positive and negative lead of a battery system or power supply should yield the full rated voltage, for example 24 Vdc or 125 Vdc. However, as most Reclamation dc power sources are floating, a reading of the positive or negative lead to ground can produce varying results. See Section 6.1.20.1 and FIST 3-6 for more information.

Equipment required: A dc voltmeter/ammeter and a dc supply.

The duration of testing is dependent upon the experience of the individuals testing and how much work is required in isolating the device for testing.

Key Reference Documents

- Manufacturer's O&M manuals
- Distribution single-line diagram and electrical schematics.

6.1.20 Direct Current (DC) System

6.1.20.1 Ground Isolation Test

With the increasing complexity of control and backup systems in modern hydroelectric plants, the supporting station dc systems are growing in total numbers of circuits. As a result, the occurrences of ground faults are seen to increase in proportion to the number of connected devices. To increase the reliability of the dc circuits (for voltages greater than 50 V) these systems are typically ungrounded. For ungrounded dc systems, two ground faults are required (one on the positive bus and one on the negative bus) to short out the dc system voltage. It is therefore imperative that the dc power system is cleared of all ground faults before any of the supported system loads are connected. For a balanced dc system, the magnitude of the voltage of the positive bus to ground and negative bus to ground should be approximately equal.

The manufacturer's instruction manual for the battery charger should contain startup procedures, including measurement of output voltage balance with respect to ground. Depending on charger design, this test is done either before or after connection to the battery. The battery manufacturer's instructions should be followed for installation of intercell connection hardware, cleaning, and preparing the battery for service. The dc distribution centers, and main power cables should be tested for insulation resistance before connection of the battery and charger. Once all of the main power interconnections are made, the complete system should be checked for voltage balance with respect to ground. This verifies that the dc power system is properly isolated from ground before the branch circuits are energized.

Most plant dc systems employ some method of ground detection and annunciation. Depending upon system design, it is often helpful if circuits feeding these systems are among the first to be energized. The annunciator can then be used in the identification of grounded circuits as the connections are made to the dc distribution centers.

Equipment required includes a digital voltmeter, a ground detection relay, and an annunciator (if available).

The amount of work involved in isolating grounds will vary in proportion to the total number of circuits. Checkout of the battery, charger, and distribution center should take no more than a couple of days. Ground isolation testing for the supported systems should be spread throughout the plant pre-commissioning testing phase as the individual systems are energized.

Key Reference Documents

- OEM O&M manuals for battery and charger.

6.1.20.2 DC System Tests and Checks

The dc system in a powerhouse includes the following devices and equipment:

- DC battery charger
- DC battery
- DC switchgear
- DC distribution panel

DC Battery Charger and Battery Bank

The battery charger and the battery banks must be installed prior to performing any subsequent testing. Perform a visual inspection of the charger, check all wiring and associated connections, and verify the type and ratings of all dc breakers and also the ac breaker that feed the chargers. Check that the battery connections are tight and confirm that the charger's dc circuit breaker is in the OFF position.

In order to place the equipment in service, perform the following activities:

- Check that the charger ac and dc circuit breakers are in the OFF position.
- Check that the dc protection charger and battery breakers are in the OFF position.
- Check that all dc panel breaker are in the OFF position.
- Confirm that there are no obstructions preventing fee air flow through the charger.
- Verify the operation of the voltmeter and the ammeter.
- Verify the battery voltage polarity at the dc panel battery breaker. If correct close the battery breaker.

- Verify the dc voltage polarity at the dc panel charger breaker(s). If correct close the charger(s) breaker.
- Verify the dc voltage polarity at the charger output breaker connection is correct.
- Turn on the ac branch breaker and the ac input circuit breaker at the charger.
- Check charger for proper function and if an alarm has been triggered.
- Check the following functions and adjustment:
  - Floating voltage
  - Equalizing voltage
  - Low voltage alarm
  - High voltage alarm
- Adjust charger output voltage to the recommended float voltage of the battery. If correct, close charger dc output breaker. Confirm charger voltage and current are correct.
- Check the following functions and adjustments:
  - Ground fault alarm
  - Current output
  - For parallel charger- balance charger output currents.

DC Switchgear

Generally, the dc system in a hydro plant is either 220 Vdc or 125 Vdc. Drawings and documents required for commissioning of this system include:

- Powerhouse dc station service – single line diagram
- dc switchgear schematic
- Cable list
- Battery monitor documentation/drawings
- NETA Acceptance Testing Specification

Before beginning the test, the following prerequisites are required:

- Both battery banks are commissioned.
- Power and control wiring has been completed.
- Battery chargers are commissioned, energized, and connected to battery.

As a precautionary measure when working in the dc panel, the dc output breakers of all chargers must be locked open, the dc battery breaker opened, and all cables must be disconnected from their batteries.

The test includes a visual inspection and an electrical test. The following activities should be performed during the visual inspection:

- Check the external appearance of the panel for signs of damage.
- Ensure there are no foreign materials in the panel.
- Verify the panel is clean.
- Check all mounting bolts are tight.
- Verify the panel and the door are properly connected to the station grounding system.
- Verify all power and control wiring has been properly terminated and secured inside the panel.
- Verify all power cable connections to the panel are in accordance with the cable list and that the polarity is correct in each case. Typically, black is considered as (+) and white is considered as (-).

- Verify the circuit breaker ratings correspond to the single line diagram and have a means for padlocking.

Perform the following electrical test before energization of the dc switchgear panels:

- Close and trip all circuit breakers manually and verify that the operation is smooth. If the breaker is equipped with a visibreak, check each of the windows for the correct indication of the breaker status.
- Verify that the auxiliary contacts are correctly connected to the terminal blocks (as shown on the dc switchgear schematic).

Prepare the dc switchgear for insulation resistance tests of the dc switchgear panel and the associated power cables as follows:

- In the panel, open dc breakers to isolate any solid state components.
- Verify the dc output breakers of both chargers are locked open.
- Verify the cables have been disconnected from both battery banks.
- Open all feeder breakers in the downstream dc distribution panels, as necessary.
- When all circuit breakers in the dc switchgear panel are closed, perform insulation resistance tests on the circuit breakers and wiring.
- For the control wiring, check the resistance to ground with an ohmmeter.
- Open all circuit breakers in the panel.
- Verify the 4-20 mA output of the dc current transducers, where applicable.

For energization, close the dc output breakers of both battery chargers. In the dc switchgear panel, close the necessary breakers to connect the charger to the battery banks. Leave the other feeder breakers open until power is required for commissioning of the downstream loads.

6.1.21 Electrical Bus Systems

Electrical bus systems include nonsegregated-phase, segregated-phase, isolated-phase, and cable. Design parameters, ratings, temperature limitations, and performance requirements for these systems are determined by the type of electrical bus system and the environment in which it is being installed.

Ratings include maximum voltage and insulation levels, power frequency, and current; these values determine the testing parameters experienced at the factory and field prior to energization. These electrical bus systems are unique in application and a technical specialist should be consulted for all reviews. Prior to any testing or other pre-commissioning activities, the drawings and factory acceptance tests should be reviewed and approved. These documents help define a baseline for testing results during commissioning.

Factory tests include design and production tests. Design tests are made only on a representative piece of bus and are not applied to each piece; however, the design test results must be provided for qualifying tests. Production tests are performed on each bus piece prior to leaving the manufacturer's facility. The following are tests experienced:

Table 1 - Electrical Bus Systems-Factory Tests

Design Tests
Dielectric
Continuous Current
Momentary Withstand or Short Circuit Withstand Current
Short Time Withstand Current
Weather Resistance
Insulating Materials
Flame Resistance
Coatings Qualification

Production Tests
Power Frequency Withstand Voltage
Mechanical Operations
Grounding of Instrument Transformer Case
Electrical Operation and Control Wiring

After assembly and prior to energization, the electrical bus system has field tests performed. The field test includes resistance measurements for bolted connections, insulation resistance, dielectric, weather resistance, and forced-air-cooled (when applicable).

The bolted connections for the bus system must be checked with a low-resistance ohmmeter. Values should not deviate by more than 50 percent when compared to similar connections.

Prior to performing the dielectric test, the insulation system should be checked between phases and between phase and ground to ensure no faults. Measure the insulation resistance for one minute.

Dielectric tests are performed to confirm no damage has been sustained to the system. It is important to understand that the bus system must be isolated prior to performing the dielectric test. The high voltage used in dielectric strength testing is dangerous and the utmost care should be taken in conducting such tests. Safety guidelines for energized testing during an outage must be followed, but in general, at least the following should be considered to ensure a reasonable degree of safety:

- Test areas should be fenced in or surrounded by partitions or barriers.
- Only trained and authorized personnel should be permitted in test areas. It is recommended that the test of the isolated phase bus be performed under the guidance of the equipment supplier.
- Several prominent signs should be placed around the test area, warning against the danger of high voltage and prohibiting admittance of unauthorized personnel into the test area.
- Refer to the safety precautions given in the manufacturer's instruction manual for the testing apparatus.

Once dielectric testing is completed successfully, the bus system can be connected to the applicable equipment and resistance measurements performed to ensure low resistance. Torque values should be checked with manufacturer's documentation and marked.

Weather resistance tests are performed not only for outdoor bus, but all bus to check for adequacy of the field welds and assembly to prevent contamination throughout the system.

Forced-air-cooled tests include checks on the fan motor, rotation, and speed, heat exchange ability of the system, and indicating devices that control activation and alarm.

Final assembly must include a bolt torque check and resistance measurements to ensure adequate connections.

Key Reference Documents

- IEEE C37.23-2015, Standard for Metal-Enclosed Bus
- NETA ATS-2017, Standard for Acceptance Testing Specifications for Electrical Power Equipment and Systems

6.1.22 Electric Circuits

6.1.22.1 Ground Testing

Ground testing consists of verifying the absence or presence of grounds in electrical circuits. This test involves systematically searching for unintentional grounds in “ungrounded” circuits and verifying the presence of the appropriate number and locations of intentional grounds in “grounded” circuits.

A volt-ohm meter is required for this test.

A simple test to determine there are no unintentional grounds takes less than an hour.

Troubleshooting to locate and remove unintentional grounds can take from a few minutes to several days. Ground detection test equipment is available to help locate grounds. These circuits inject a small signal between the circuit under test and ground. A small probe is used to trace path to ground location.

Key Reference Documents

- IEEE Std C57.13.3, IEEE Guide for the Grounding of Instrument Transformer Secondary Circuits and Cases

6.1.23 Electrical Insulating Fluids

Electrical insulating fluids tests are commonly broken down into four property categories: physical, electrical, chemical, and other. Testing performed during different stages of commissioning serves as a tool for maintenance, and is typically performed on fluid-filled transformers and circuit breakers.

These tests are a measure of the insulating fluid quality and are performed in a laboratory or using field applicable devices. A sample of fluid is drawn under a prescribed procedure into either shipping container(s) or test apparatuses. Samples can be taken from the equipment in approximately 1 hour and shipped to an offsite lab or tested on site. Lab results are typically received in 1 week but can be expedited for 1-day return during critical times.

Results from the fluid tests should be reviewed by a technical specialist. Many results have an analysis of pass or fail; however, different types of tests may require trending to determine the final analysis.

Key Reference Documents

- IEEE Std C57.166, IEEE Guide for Acceptance and Maintenance of Insulating Liquids in Electrical Equipment
- FIST 3-30, *Transformer Maintenance*
- FIST 3-31, *Transformer Diagnostics*

6.1.24 Energy Dissipation (Pressure Relief) Valves

In certain cases, energy dissipation (pressure relief) valves are used for dissipation of the energy of the water supply in a hydro generating station following a shutdown. Typically, the energy dissipation system consists of hydraulically operated valves that are controlled from a central PLC-based control system. The opening or closing of the valves must be precise so they are operated in unison with the trip of any unit.

Dry commissioning of the energy dissipation system involves:

- Loop testing of all individual instrumentation and components.
- Verification of the instrument calibration of the dissipation valves.
- Testing of the hydraulic power unit.
- Setting the opening and closing times for the valves through adjustment of the orifices in the hydraulic system.
- Power failure testing of the valves to verify that the accumulators are properly sized to operate the valves, during a power outage condition.
- Flow transfer testing to check the transfer of the turbine flow to the energy dissipation system following shutdown or tripping of any unit.
- Turbine start up testing – this is performed to test the transition of the flow from the dissipation system to the turbine during a turbine start up.
- Test to simulate the loss of all control function or the loss of PLC and to check the behavior of the energy dissipation valves.

Key Reference Documents

- FIST 2-13, *Gates and Valves*

6.1.25 Excitation System and Excitation Transformer

This section provides guidance for the commissioning of the excitation system and the excitation transformer. Prior to commissioning of the excitation system at the site, it is important to ensure that all the shop testing on the system has been properly performed. The commissioning of the excitation system is divided into several stages which include:

- A pre-commissioning test, which is done on a machine at standstill.
- A no load test which is performed with the machine at rated speed.
- Performing tuning while the machine is synchronized.
- Final work.

This section focuses primarily on the pre-commissioning of the excitation system and all the tests and procedures that are necessary to energize the excitation transformer. Typically, the generation voltage is 13.8 kV for medium to large hydro generating stations; therefore, the excitation transformer will be energized at the 13.8 kV level for this pre-commissioning process.

6.1.25.1 Excitation Transformer

Prior to the pre-commissioning of the excitation transformer, the following prerequisites must be met:

- Installation of the transformer is complete.
- Field circuit breaker must be open.
- Equipment must be isolated per lockout tagout requirements.

The excitation transformer test will be based on the visual and mechanical inspections and the required electrical test. Visual inspection of the excitation transformer will include:

- A complete visual inspection of the overall condition of the excitation transformer. The objective of this inspection is to identify any abnormality or any visible damage.
- Verification of the transformer electrical characteristics, especially checking that the nameplate data matches the actual design.
- Confirm there are adequate grounding connections to both the transformer and the transformer enclosure.
- Inspection of the anchors and alignment, and verifying the tightness of all connection bolts. A calibrated torque-wrench should be used to thoroughly examine the tightness of the connection bolts.
- Inspection of any CTs on the high and low side windings, verifying no signs of physical damage.
- Inspect secondary CT circuits to ensure no open circuits exist in these circuits to prevent catastrophic damage to the CTs upon energization. Also, inspect CT circuits ensuring all CT shorting screws have been removed once the CT circuits look correct.
- Verify correct phasing and polarity from the high side to the low side windings to ensure proper phase rotation at the excitation bridge.
- Confirm that the unit is fully cleaned before performing any electrical tests.

Once the visual inspection is complete and no unusual conditions have been identified, the transformer will be ready for the following electrical test. The main electrical test to be performed is the insulation resistance test with phase-to-phase and phase-to-ground.

During this electrical test, a general verification should be performed on the transformer core and winding temperature elements. Ensure that the temperature elements are providing correct temperature measurements in the control system.

After successful completion of these tests, the transformer will be ready for energization.

Key Reference Documents

- Outline of the excitation transformer
- Station single line diagram
- Excitation system schematic drawings
- NETA Acceptance Testing Specifications

6.1.25.2 Excitation System

This portion of the pre-commissioning test is performed while the machine or unit is in standstill condition. The purpose of this pre-commissioning test is to prepare the excitation system for the no-load and load test while the machine is operating at its rated speed, and also to perform the final tuning of the excitation system during the synchronization process.

Before performing the pre-commissioning test of the excitation system, the exciter must be installed in its final location and the pre-commissioning of the excitation transformer must be completed and ready for energization. In addition, the necessary medium voltage power supply should be available.

At this pre-commissioning stage, a variety of exciter inspections and tests must be performed, including a visual inspection, field resistance measurement, insulation test, and verification of the control circuits and protection devices. A brief guide to these tests is outlined below:

- A complete and thorough visual inspection should be performed on the excitation system which includes:
  - Verification of the mounting of the cubicles and identification of any signs of damage.
  - A visual inspection of all the major components within the exciter cubicles which includes the field circuit breakers, field-flashing and de-excitation circuits, crowbar, external wiring, and bus bar connections.
- Perform an insulation resistance measurement of the main circuit with a vendor representative present. Record the field resistance.
- Confirm the necessary power supplies are available and record the voltage measurements of:
  - AC supply as required for the various circuits which includes the converter, panel auxiliaries, and internal supply transformer.
  - DC supply as required for the various circuits which include the electronic circuits and field flashing circuits, etc.
- Check all the following in order to verify the control circuits:
  - Digital inputs and outputs
  - Analog inputs and outputs
  - Alarm and trip circuits
  - Field-flashing circuits
  - Field breaker controls
  - Fan control circuits
- Confirm that the current version of the software containing the correct parameters specific to the project is downloaded to the exciter.
- The ground protection relaying will need to be set properly and any other temperature supervision protection will also need to be verified.

After completion of these dry tests, the exciter will be ready for no load tests and for on-line function tests during synchronization.

Key Reference Documents

- Single line diagram
- Exciter schematic drawings
- Any related operation and maintenance manual
- Site acceptance test reports

6.1.26 Fasteners

6.1.26.1 Bolted Joint Torque Test

Fasteners do not lend themselves well to testing after they are torqued or elongated during the assembly of equipment. The quality and magnitude of the preloading is best determined by the method of preloading, preloading equipment, and procedures used during the act of preloading rather that attempts to test the fasteners after preloading.

The magnitude of fastener preloading should be determined by the original equipment manufacturer (OEM). If this is not available, the fasteners should be preloaded to 66% of the material yield strength, unless engineering calculations demonstrate otherwise. Torque or elongating readings of all major bolted connections should be measured and recorded during the equipment assembly.

This test requires various fastener preloading equipment, such as manual torque wrenches, hydraulic torque wrenches, hydraulic tensioners, and other power and manual tools used for torquing or elongating fasteners during the assembly of equipment.

Key Reference Documents

- FIST 2-7, *Mechanical Overhaul Procedures for Hydroelectric Units*
- AISI, Manual of Steel Construction. Industrial Fastener Institute standards. OEM, assembly, or maintenance manual

Photograph 12 - Headcover with bolted connectors

6.1.27 Fire Protection Systems

6.1.27.1 Fire Detection and Notification System Test

The purpose of this test is to perform a National Fire Protection Agency (NFPA) code or equivalent acceptance test of the fire detection and notification system related to the generator fire protection. The procedures for the acceptance test are provided by the NFPA standard and manufacturer's instructions. The acceptance test includes a visual and physical verification of all equipment and devices to the approved design documents including mounting heights and locations, candela settings, end of line resistor locations, and device labeling. The acceptance testing will provide a systematic means of verifying the proper operation of all elements comprising the fire detection system and notification system. These elements include smoke and fire detection, signaling devices in the zone, the signaling and control wiring associated with these devices, and those elements supervising or controlling the detection and signaling devices.

The test sequence requires testing and verifying that:

- Stray voltages capable of causing erroneous operation do not exist in the zone's wiring system.
- All conductors in the zone's wiring system are isolated from ground (other than those intentionally grounded).
- All conductors of the system have been tested for conductor-to-conductor isolation.

In addition, conductor loop resistances are measured to verify that values do not exceed the manufacturer's specified limits. Other elements of the test sequence involve:

- Verifying that each initiating device and associated signaling line circuit is properly monitored in regard to circuit integrity.
- Verifying proper alarm sequencing by initiating separate supervisory and alarm elements together.
- Verifying that the voltage drop on each notification circuit does not exceed 4 volts.
- Verifying audibility meets or exceeds design expectations.
- Verifying signal transmission and quality to monitoring and dispatch locations.

All apparatus should be restored to normal as soon as possible after each test or alarm and kept in normal condition for operation. This includes requiring, resetting, or replacement of equipment as necessary.

A complete record of the tests and verification of each successful zone test should be kept and be available for examination by the authorized representative(s).

A volt-ohm meter or "continuity checker" in the form of a battery-driven buzzer or light can be used. It is cautioned that this testing is done with all circuits de-energized.

The duration of a fire zone test is dependent upon the number of initiating or signaling devices within the protected zone and the complexity of the wiring comprising the signaling and control circuits in the zone. As a conservative estimate, a test for a single zone should be able to be completed in less than an hour. The duration of tests on all zones comprising a complete fire detection system is in turn dependent upon the number of zones in the system.

Key Reference Documents

- FIST 2-6, *Maintenance of Auxiliary Mechanical Equipment*
- Manufacturer's O&M manual for the fire detection system
- ISO/TS 7240, Fire Detection and Alarm Systems
- NFPA 3, Recommended Practice on Commissioning of Fire Protection and Life Safety Systems
- NFPA 4, Standard for Integrated Testing of Fire Protection and Life Safety Systems
- NFPA 72, National Fire Alarm and Signaling Code

6.1.27.2 Fire Suppression System Test

6.1.27.2.1 CO2 and Other Gas-Based Systems - Fire Code Test The purpose of this test is to perform a NFPA code or equivalent acceptance test on CO2 or gas-based fire protection systems. The manufacturer of the system in conjunction with the system designer supplies a recommended acceptance test procedure for the system. Regardless of the system design, the acceptance test requires a visual and a physical check of the installed system including piping, nozzles, and extinguishing agent containers to determine proper installation of system components.

Functional testing includes:

- Supervision of electric and pneumatic circuits.
- Integration to system control panel.
- Operation of electrical and pneumatic systems, alarm systems, valves.
- Equipment shutdown features.
- Full discharge test.

For a total flooding application, the full discharge test should measure the system discharge time, verify achievement of the specified duration of soaking concentration, and confirm that the protected area's ventilation system is properly interlocked to shut down upon detection of fire.

For a normal maintenance function test, the system should be "puff tested" and put back into service as soon as the inspection is complete. A puff test requires flowing just enough gas to demonstrate discharge from all nozzles then closing the supply valves so as not to exhaust the remaining supply.

The following equipment is required for the discharge test:

- An accurate concentration meter capable of providing both direct readout and printout. Multiple recorders may be required for large installations.
- A stopwatch.
- Portable exhaust fan, if needed for post-test ventilation.

The duration of the code test varies with the size and type of fire protection system. A small system test can be completed in 8-24 hours. Larger systems may require several days.

Key Reference Documents

- FIST 2-6, *Maintenance of Auxiliary Mechanical Equipment*
- EN 12094 Fixed Firefighting Systems – Components for Gas-Extinguishing Systems
- NFPA 3, Recommended Practice on Commissioning of Fire Protection and Life Safety Systems
- NFPA 4, Standard for Integrated Testing of Fire Protection and Life Safety Systems

- NFPA 12, Standard on Carbon Dioxide Extinguishing Systems
- NFPA 12A, Standard on Halon 1301 Fire Extinguishing Systems
- NFPA 2001, Standard on Clean Agent Fire Extinguishing Systems
- ISO 6183, Fire Protection Equipment – Carbon Dioxide Extinguishing Systems for Use on Premises – Design and Installation
- Manufacturer's Operation and Maintenance Manual for the fire detection system.

Photograph 13 - Low pressure CO_2 tank

Photograph 14 - High pressure CO_2 storage tanks

6.1.27.2.2 Volumetric Test This test is performed on CO2-based fire protection systems and is part of NFPA code acceptance tests used with these type of protection systems. The purpose of the test is to verify that the calculated design volumes of CO2, required for a particular system effectively cover the fire hazard for the full period of time required by the design specifications and that all pressure-operated devices function as intended. The test requires discharge of the design quantity of CO2 for volumetric verification.

The following equipment is required for the volumetric test:

- An accurate concentration meter capable of providing both direct readout and printout. Multiple recorders may be required for large installations.
- Equipment for measuring weights of CO_2 cylinders.
- A stopwatch.
- Portable exhaust fan, if needed for post-test ventilation.

The duration of the volumetric test varies with the size and type of fire protection system. A test on a small system can be completed in several hours. Larger systems require more mobilization and demobilization time.

Key Reference Documents

- FIST 2-6, *Maintenance of Auxiliary Mechanical Equipment*
- Manufacturer's O&M manual for the fire detection system.
- NFPA 12, Standard on Carbon Dioxide Extinguishing Systems

6.1.27.2.3 Water-Based Systems - Fire Code Test The purpose of this test is to perform a NFPA code or equivalent acceptance test on a water-based fire protection system following installation or refurbishment of the system. Water-based fire suppression systems are categorized by the water delivery, the droplet size, and agent additions. The most common categories found in Reclamation are:

- Sprinkler systems (Automatic, Dry, and Preaction)
- Water spray fixed systems (Deluge)
- Standpipe and hose systems
- Foam-water sprinkler systems
- Water mist and hybrid-water mist

Applicable testing requirements for each water-based protection system are listed in specific NFPA documents that relate to each system type.

In general, the NFPA code acceptance test, regardless of system type, requires a visual and physical verification of component types and locations to the design documents. All sprinkler systems require a piping flushing test and a piping (and pump) hydrostatic test. All water-based systems will require a timed flow test.

Functional testing of water-based systems will include:

- Operating all control valves (manually and/or remotely).
- Recording and measuring water levels, water discharge rate, foam concentrations, and agent concentrations.
- Activating alarm and detection devices integrated with the suppression system.
- Verifying operation of integrated system components, such as solenoids, relays, and alarms.

The water supply for the water-based suppression system must be inspected and commissioned as part of the water-based system. This may include a fire pump, water storage tank, or gas pressure system. The water supply must be sufficient for all testing to be performed. Additionally, the water supply must be restored to pretesting conditions at the completion of all testing. Pumps (if employed in the system) require tests verifying flow rates, system operating pressures, measurements of operating voltages, and currents and operational checks of any associated pump controllers and their accompanying control devices.

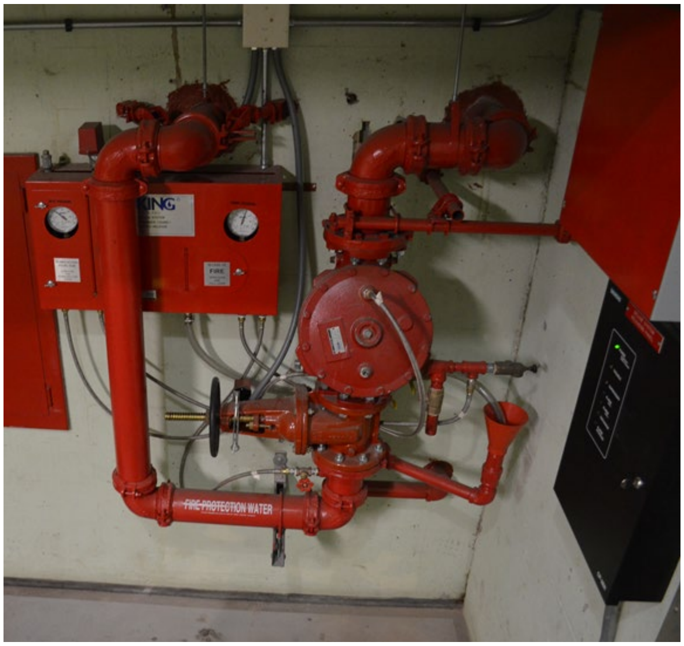
Depending upon the type of system, some or all of the following testing equipment may be required:

- Pressure gauges
- Flowmeters
- Voltmeter
- Ammeter
- Timing device

The duration of testing will vary with the size and type of the fire protection system. A small system can be completed in 8-24 hours. Larger systems can take several days.

Key Reference Documents

- FIST 2-6, *Maintenance of Auxiliary Mechanical Equipment*
- EN 12259, Fixed Firefighting Systems – Components for Sprinkler and Water Spray Systems
- EN 12845, Fixed Firefighting Systems – Automatic Sprinkler Systems – Design, Installation, and Maintenance
- SIS-CEN/TS 14816 – Fixed Firefighting Systems – Water Spray Systems – Design, Installation, and Maintenance
- SIS-CEN/TS 14972, Fixed Firefighting Systems – Water Mist Systems – Design and Installation
- NFPA 3, Recommended Practice on Commissioning and Integrated Testing of Fire Protection and Life Safety Systems
- NFPA 13, Standard for the Installation of Sprinkler Systems
- NFPA 14, Standard for the Installation of Standpipe and Hose Systems
- NFPA 15, Standard for Water Spray Fixed Systems for Fire Protection
- NFPA 16, Standard for the Installation of Foam-Water Sprinkler and Foam-Water Spray Systems
- NFPA 20, Standard for the Installation of Stationary Pumps for Fire Protection
- NFPA 22, Standard for Water Tanks for Private Fire Protection
- NFPA 25, Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems



Photograph 15 - Electrically-actuated deluge valve assembly including release panel

Photograph 16 - Wet pipe type fire suppression sprinkler system piping and fusible link

6.1.28 Generator and Large Motor Windings

This section provides guidelines for the pre-commissioning testing of the generator or large motors windings after common rehabilitation activities such as a stator rewind and field winding insulation (rotor winding) refurbishment. Specifically, this section covers necessary pre-commissioning of the stator winding, stator core, and refurbished insulation of the field poles. Because most major refurbishments often include varying levels of mechanical disassembly, this section will also cover commissioning testing of the thrust and guide bearing insulation systems. Testing of the generator or motors performance (efficiency, temperature rise, noise, vibration, etc.) during operation is covered under the "Electrical Run", Section 8.4.

Successfully refurbishing the electrical components of the machine requires many different tests and inspections at manufacturing, installation, and commissioning stages. These tests are typically required by the contractor, Reclamation specifications, and industry guidance standards to ensure the components are successfully installed. Many tests and inspections along the way are not considered in the categories of commissioning and/or pre-commissioning. These tests and checks are outside the scope of this document; however, a general categorizing and listing of inspections and tests is provided below.

General Overview

A variety of visual inspections, checks, and tests are completed during the rewind by the installing contractor. These tests, check, and inspections are not typically part of the commissioning process and occur prior to pre-commissioning and operational testing. In general, pre-commissioning testing is necessary to ensure the refurbished or replaced generator is prepared for offline excited and online operating modes. Pre-commissioning testing includes visual inspections and offline electrical testing of the rotor and stator. Several of these tests are performed using high voltage to test the integrity of the various insulation systems. It is very important to ensure that all safety considerations have been met before performing high-voltage testing. Typically, the contractor installing the field poles and stator windings will perform a suite of testing during the construction process. These tests are not considered pre-commissioning testing because they are utilized to identify and correct problems during erection of the unit. Many additional tests are performed at production factories for stator and rotor coils and stator or pole laminations which are outside the scope of this document. A general list of erection (construction in-progress) tests and inspections is included below for reference only:

- Dimensional checks of frame, keybars, and core clamping studs.
- Rated-flux core loop test (for re-used and new cores).
- Dimensional checks of core roundness, concentricity, and verticality.
- Coil-to-core contact resistance.
- RTDs - high-potential, element resistance, and wiring conductivity.
- Direct-current high-potential tests at various stages of stator coil (or bar) installation.
- Impulse (surge) tests prior to and after wedging of multi-turn stator coils.
- Stator wedge ripple spring compression measurements.

After stator or rotor (field) winding installation is complete, the following acceptance tests are typically performed:

- Stator and field winding conductor resistance.
- Insulation Resistance and Polarization Index (PI).
  Please Note: stator and field windings must pass a PI test prior to AC high-potential testing.
- AC high-potential withstand of stator and field windings.
- Reclamation performs dc ramp of stator winding with contractor to witness.
- Field winding voltage drop (pole drop).
- Field winding interconnection resistance.
- Field winding insulation resistance and PI.

Additional tests and mechanical checks may be necessary during construction depending on stator and rotor design and scope of work. Prior to final acceptance testing, the following prerequisites must be met:

- Ensure all sources of energy are properly isolated or mitigated before starting the testing.
- Stator and field winding installation is complete with adequate time allotted for curing of epoxies, paints, and other adhesives used during construction. Typically, paints and epoxies require a minimum of 24 - 48 hours at room, or sometimes elevated, temperature.
- Check that all bolted and/or brazed electrical connections are properly completed.
- Ensure the test object is free from tools and foreign objects that may compromise test results or otherwise cause damage.
- The field and stator windings are properly isolated from all bus work or other connections and ready for electrical testing. Any bus, capacitors, surge arresters, or other apparatus connected to the windings under test will skew the test results and could damage these other components.

The pre-commissioning testing for the generator is composed of two stages. The first stage is the visual inspections, and the second stage is offline operational testing. Compliance with the following installation conditions is required prior to starting the visual inspection:

- Frame and soleplate installation is complete. Grouting and radial dowels (if equipped) are set and final.
- Stator winding assembly installation is complete, including any stator winding, and core RTDs are operable.
- Stator-rotor airgap has been measured and verified acceptable for operation.
- All field poles have been properly installed and inter-connected.
- Drive wedges securing the rotor poles to the rim have been driven to 'rejection' so as to rigidly mount the poles to the rim.
- The rotor pole stand and drive wedges securing the poles to the rotor rim dovetail (or T-slot) have 100% engagement along the entire length of the rotor pole iron.
- Thrust and guide bearings and associated piping are completely installed, oiled, and ready for operation.
- Thrust and guide bearing insulation resistance has been checked and is within proper range.
- Rotor shaft grounding brush is installed (if equipped).
- Field winding assembly and associated bus work is completed.
- A **thorough** crawl-through inspection has been performed looking for presence of any tools or foreign objects.
- Slip ring assembly and bushes are in place and prepared for operation.
- Rotor alignment is verified and acceptable.
- Brake assembly is complete and pads are present.
- Generator line and neutral terminals are complete; all bolted electrical connections are properly made and all fasteners are torqued.
- Air baffles and deck plates are secured and checked for loose fasteners.
- Generator line and/or neutral CTs are installed and all CT secondary wiring has been checked for proper polarity.
- Neutral grounding cable, transformer, and resistor are installed and ready for operation.
- Control cabinet wiring is completed.
- All thermal sensors are operational and are reporting actual values.

After all pre-operational visual inspections are satisfied, perform the following offline operational tests on the generator:

CAUTION: Ensure all terminals are disconnected and the generator frame is grounded prior to this test to prevent equipment damage.

- Perform the offline electrical tests on the generator as specified in IEEE 115. The generator and auxiliary systems must be ready for normal operation. The following tests should have already been performed:
  - Insulation Resistance and Polarization Index of the field and stator windings.
  - Conductor resistance of the field and stator windings.
  - High-potential acceptance testing of the field and stator winding.
- Confirm RTDs are properly terminated within the generator auxiliary terminal box and verify valid measurements within the control systems.
- A complete inspection should be conducted on the generator mechanical systems which include verification of the inlet and exhaust ducts, checking of the bearing oil level indicators to ensure that the bearings are properly filled, and confirmation that the cooling system is functioning properly.

Once the major electrical tests and the mechanical inspections are completed, check the auxiliary systems by verifying:

- The generator air housing heaters are operational, and record the current drawn by the heating elements.
- The stator core and winding temperature sensors are functional, and the winding temperature alarm and trip levels are properly set in the control system.
- The grounding carbon brush is connected and operational (if equipped).
- The brake release switches are functional.
- All bearing temperature instrumentation, such as radial bearing pad and thrust pad temperature sensors, are properly installed and their temperature settings are properly configured in the control system.
- The speed sensors have been tested. If the speed sensors are missing pulses, they may need to be replaced and new sensors should be installed.

Additionally, the following verifications should be completed:

- Verify that it is possible to lift the generator rotor using the thrust pump; this indicates that the high-pressure lift oil system is functional.
- Verify all high-voltage connections on the phases and on the neutral ends are installed in accordance with the design drawings and verify that the tightness of the connection bolts meets the recommended torque requirement.
- Confirm that generator junction boxes are installed and completed.

Guide and Thrust Bearing Insulation Systems

Often, bearing insulation systems are not replaced and are re-used. Regardless, if the insulation is new, reused or replaced, testing is necessary prior to operation to avoid the possibility of bearing damage at startup. The thrust and upper-guide bearings of large vertical generators are insulated from the frame to prevent circulating current from passing through the bearing surfaces which might damage them. Test terminals are provided for periodic ohmmeter checks across the thrust bearing insulation. Some generators have three terminals (A, B, and G) that permit checking the insulation on both sides of the insulated metal plate separately, as well as measuring the thrust bearing oil film resistance. Other generators have only terminal A, which only permits checking the thrust-bearing insulation to ground.

Stator Core

Physical Inspection

The stator core should be examined for looseness. Core looseness should be checked with the knife test and by visual inspection for iron fretting (rust-colored dust production). Stator through bolt torque may also be checked. Pressing plates and fingers should be inspected for any broken welds or gaps between the fingers and the core iron. Any broken core laminations, laminations that protrude into the air gap, bent or loose core air duct separators, core clamping bolt troubles (anti-rotation mechanism compromised, frame attachments broken, etc.), waviness or chevroning of the laminations, or other evidence of core stress or damage should be checked. If inspection panels are present on the stator frame wrapper, they should be removed to allow inspection of the back iron and stator frame. Removal of air coolers will also allow limited back iron and frame inspection.

Electromagnetic Core Imperfection Detection (EL-CID) Test

In the EL-CID measurement, only very low magnetic flux densities are applied. As a result, this is a very simple test and easier to comply with safety requirements. The fault current during testing can be detected by a Chattock coil. The Chattock coil is an electrical device for measuring alternating current or high-speed current pulses. This coil is routed along the slot of the stator core. The output signal is proportional to the magnetic potential difference between the two contact points on the stator core surface. The EL-CID test may not detect core issues that develop in-service caused by vibrations or thermal expansion forces. It is highly recommended to use the EL-CID before and after any existing core repair is performed as a quality check.

Rated-Flux Loop Test

The loop test is performed by inducing rated operating flux density in the stator core yoke. An excitation loop requiring substantial power is required. If achieving rated flux is not practical due to power or other constraints, it is recommended the induced flux-density be at least 95% of calculated nominal value. Inducing rated flux is done with many turns of a high-voltage insulated, flexible cable that is wound through the bore and around the opposite side of the stator. This induced flux will produce a voltage between insulated core laminations. If shorted or damaged (smeared) laminations are present, this will result in circulating currents that produce localized heating. The core is scanned with an IR camera and instrumented with contact-type temperature measurement devices to monitor temperatures throughout the test durations which is typically one to two hours. If localized hot spots are identified, they are compared to industry standard temperature rise allowances to determine if the core requires repair. The main objective is to ensure the core laminations are isolated from each other to avoid circulating currents in operation that would produce excessive heating and possibly jeopardize or degrade the insulation of the installed stator coils. For newly installed stator cores the test is also mandatory to vibrate (shake-down) the core to aid in compaction of the many layers of laminations. After a new core has passed the rated-flux loop test, the core clamping bolts are re-torqued to restore any loss of compression after core settling during the test. This is usually sufficient to serve as a reliable compacting method that should last for the life of the core. For detailed information on the loop test, see Section 6.1.28.2.

Stator Winding

Physical Inspection

Several types of stator winding problems can be detected during physical inspections. For newly rewound stators this includes incomplete cure of epoxies, paints, and potting compounds; improper installation of radial pressure wedges (slot wedges); physical damages from poor installation or reassembly practices; insulation cracks; core damage; improperly applied bracing, ties, and blocking; and improper spacing between coils, ring bus, and other high voltage components. Qualified personnel familiar with stator winding installation practices should be utilized. The following areas should be inspected:

- Stator end windings (coils) or end-arms (bars), consistent spacing and proper blocking and bracing of end windings (arms).
- Stator winding end cap potting (bar type windings), insulation of multi-turn coil series and group jumpers.
- Radial pressure wedges (slot wedges).
- Surge ring: surge ring-to-frame mounting supports and surge ring-to-coil connections, proper single-point bonding of surge ring to ground.
- Circuit ring and main terminals: bus supporting structure, proper spacing and layout, insulation of all circuit taps.
- Main and neutral leads: proper insulation applied, cured, and airgap spacing between terminals and CTs or grounded components. Proper bolted connections, neutral shorting bar installed and torqued properly.
- Core laminations, core splits and support fingers checked for signs of movement or warping to the extent they may impact the winding.

Winding Conductor Resistance Measurements

The objective is to check the assembled windings for proper low-resistance of the copper conductors from end-to-end. Hundreds of individually brazed connections are made in the stator winding assembly process. Conductor resistance measurements are made by applying a direct voltage to each phase of the stator winding and measuring the resultant current then calculating the conductor resistance. For stator windings the measurement is performed by connecting the specialized low-resistance measurement test equipment leads between line-to-neutral or by installing the neutral shorting bar and making connections between the line ends of the generator terminals. Winding (copper) temperature impacts the calculated resistance value, so it is important to record the RTD temperature of the stator windings and then normalize the results to a standard temperature. This allows for comparison to manufacturer's design values and for comparison to future maintenance testing. Issues detected with this test often are due to improperly brazed connections between stator coils or bars, or improperly made bolted electrical connections at the generator terminals. Results from all phases are compared and the results should not vary by more than 0.5% as calculated from the average of all three phases.

Insulation Resistance

Insulation resistance is defined as the ratio of the applied direct voltage over the measured current. For typical stator winding insulation, an applied step-voltage will result in a measured current that decays exponentially with time. Because of this time dependency, insulation resistance is normally calculated and recorded one minute after the test voltage is applied. Insulation resistance tests are sensitive to specimen temperature and are often normalized to a standard temperature (typically 40 °C) for analysis. IEEE 43 is the reference for standard insulation resistance and polarization index testing.

Polarization Index (PI)

A polarization index test is similar to the insulation resistance test except that current (or resistance) readings are taken at two intervals, normally one and ten minutes after application of the voltage step. The ratio of these two current readings ($I_{1min}/I_{10\ min}$) or, if using resistance, ($R_{10min}/R_{1\ min}$) is termed the polarization index. Evaluation of the data is given in IEEE 43 where it states the calculated index should be 2.0 or greater to pass the test. A PI value less than 2.0 is cause for questioning the integrity of the insulation system. A stator winding may fail the PI test if it has absorbed significant moisture, has substantial surface contamination, or major physical damage. Prior to performing ac or dc high-potential acceptance testing, the winding must pass the PI test. If a winding fails the PI test, the cause of the problem must be identified and corrected before proceeding to ac or dc high-potential acceptance testing.

Ramped Voltage Test

The ramped voltage test technique uses a programmable dc, high-voltage test set that automatically ramps the voltage applied to the winding at a preselected ramp rate, usually and preferably at 1 kV per minute (16.67 volts per second [V/s]). The test record is in the form of a plot of insulation current versus applied voltage. The ramped voltage method linearly increases the applied direct voltage from zero up to some maximum prescribed value at a constant ramp rate. The current response versus applied voltage is measured and plotted, and the results are used to evaluate the condition of the insulation by noting deviations from the normal shape of the test curve. Any departure from a smooth curve could be an indication of insulation problems. Because the maximum test voltage is above the normal operating stress, the ramped voltage test is mainly a diagnostic but also may serve as a quasi, high-potential withstand test. IEEE 95 is the reference standard for ramp testing and contains reference curves for comparison.

High-Potential Withstand (Proof) Test

High-potential withstand (proof) tests are typically performed to provide assurance that the winding insulation has a minimum level of electrical strength. Because the inherent withstand capability of sound stator winding insulation is well above the prescribed proof test value, failure during a test given the appropriate test voltage indicates the insulation is severely damaged, contaminated, or compromised and is unsuitable for service. Withstand tests are intended to search for flaws in the material, for manufacturing defects, physical damages, and to demonstrate in a practical manner that the insulation has a minimum level of electrical integrity. Testing is performed with either alternating or direct voltage and current. Test duration for a withstand test is always 1-minute unless a non-standard or special investigation is deemed necessary. IEEE C50.12, NEMA MG-1, and IEEE 95 are the reference standards for ac and dc high-potential withstand testing.

Dissipation and Power Factor Measurements

The dissipation factor, or tan δ, represents the losses in an insulation tested under sinusoidal voltage conditions. Alternately, power factor can also be used to measure insulation losses. Increased losses may indicate deteriorated or compromised insulation. Absolute values of tan δ, as well as changes with respect to voltage (tip-up), are used to assess insulation quality and condition. IEEE 286, 492, and 1434 contain details about dissipation and power factor testing.

Blackout (Lights-Out) Test

This test is usually an acceptance test but can also be performed as a maintenance-oriented diagnostic. The objective is to visually identify surface corona discharges that appear on various components of a stator winding while under application of high voltage. The stator winding is energized at rated voltage, or slightly above, while observers positioned at safe locations inside the unit to look for visual evidence of corona discharges. For the test to be successful the stator winding area is required to be in pitch-black visual conditions as the light emitted by corona discharges is often very low luminance. The necessary conditions for testing are inherently hazardous which requires rigid safety protocols and extra measures to be implemented. Areas of observed corona are noted with respect to slot number and/or location in the end windings. This test is designed to allow personnel to visually observe discharge events occurring on the surface of the stator winding or slot discharges that are visible in the stator air vents, specifically:

- At the coil-to-core exit.
- Along the surface of the voltage grading treatment.
- At the voltage grading-to-conductive slot treatment boundary/overlap.
- At the end of the voltage grading treatment.
- Between end windings of different phases.
- Between end windings of the same phase (if voltage grading is compromised).
- Between coils in the same slot at the core exit.
- Between ring-buses (circuit rings).
- At the penetrations of the main terminal leads.
- Within the stator core slot (slot discharges viewed through air vents).

For new winding acceptance testing, there should be zero visible activity at each of the locations described above.

An ultra-violet (corona) camera may also be used under normal lighting conditions to achieve the same objective, reducing hazards for test personnel.

Radial Pressure (Slot) Wedge Tightness Measurements

The wedge evaluation procedure requires careful visual inspection of the wedging system, including wedges and slot packing materials. For non-ripple spring (non-compression spring) designs the wedge system may be further examined by tapping the wedges with a blunt metallic instrument, which rings or vibrates when hit against a solidly wedged slot. Loose wedges produce a dull sound when tapped. Commercial wedge tightness measuring tools are also available.

Almost all new installations will utilize ripple springs to apply radial pressure to the coils in the slots. These wedge systems utilizing under-wedge ripple springs may be evaluated using a depth gauge to measure the ripple spring compression. Typically, when a new winding is installed the ripple spring is compressed to 80% flatness under the retaining wedge.

Partial Discharge Testing

The partial discharge phenomenon is a symptom of voids, delamination, and other internal and external abnormal conditions that occur in stator winding (and other) high-voltage insulation systems. Partial discharges are basically tiny sparks that occur inside the layers of insulation of motors and generators. They occur within voids and on the surface of the stator winding insulation between phases. The test determines the number of partial discharges in the machine and though advanced diagnostics may be able to identify what component is experiencing these symptoms. The partial discharge measurement can be performed on-line and off-line if a proper excitation source is provided to energize the winding. A detailed description of the partial discharge test procedure is found in IEEE P1434-2014. For detailed information on partial discharge testing, see Section 6.1.5.2.

Field Winding

Physical Inspection

Several rotor and field winding issues can be detected during the course of physical inspections, such as loose components, physical damage, or improper assembly. Qualified personnel familiar with field winding installation should be utilized. The following areas should be inspected:

- Field poles, and pole faces.
- Field windings and interpole connections.
- Field winding leads.
- Amortisseur (damper) windings and damper winding interconnections (if equipped).
- Pole-to-rim wedging.
- Mid-span supportive blocking located between field coils of adjacent poles (if equipped).

Insulation Resistance

Insulation resistance is defined as the ratio of the applied direct voltage over the measured current. For typical field pole insulation, an applied step-voltage will result in a measured current that decays exponentially with time. Because of this time dependency, insulation resistance is normally calculated and recorded one minute after the test voltage is applied. Insulation resistance tests are sensitive to specimen temperature and are often normalized to a standard temperature (typically 40 °C) for analysis. IEEE 43 is the reference for standard insulation resistance and polarization index testing and is the primary metric to determine serviceability. Prior to performing ac or dc high-potential acceptance testing the winding must meet the minimum insulation resistance value given in IEEE 43. If a winding fails the PI test, the cause of the problem must be identified and corrected before proceeding to ac or dc high-potential acceptance testing.

Polarization Index (PI)

A polarization index test is similar to the insulation resistance test except that current (or resistance) readings are taken at two intervals, normally one and ten minutes after application of the voltage step. The ratio of these two current readings ($I_{1min}/I_{10\ min}$) or, if using resistance, ($R_{10min}/R_{1\ min}$) is termed the polarization index. Evaluation of the data is given in IEEE 43. Field windings often do not achieve the same polarization index values as stator windings because they utilize different insulation components, often with lower polarizability. Thus, the same metrics applied to stator windings may not always apply to field winding insulation systems. In general, the calculated index should be 1.5 or greater but it is often not a hard requirement to pass. This is because it depends on the insulation types used in the rewind of the poles. As with stator windings, the PI may provide information indicating the field coil insulation has absorbed significant moisture, has substantial surface contamination, or major physical damage.

Voltage (Pole) Drop Test

The voltage drop test, commonly called a 'pole-drop' is designed to detect shorted turns between the copper conductors of salient-pole field coils. The loops of copper that wrap around the pole body are insulated from each other with a small amount of thin insulation. In normal service, the voltage stress applied across these layers is very small (a few volts). The standard pole drop test is useful to detect poles that have shorted turns and only detects turns that are physically touching due to damage to insulation or physical damage that has smeared copper between turns. The test is performed by applying an alternating voltage to the entire field winding then measuring the resultant voltage drop across each pole. The evaluation is performed by taking the applied voltage across the entire winding and dividing it by the number or poles to calculate the expected per-pole voltage. A pole with a shorted turn will exhibit a voltage below expected. Typically, if the measured voltage of an individual pole is below the expected per-pole voltage by 10% the pole is suspected to have a shorted turn. Further investigation is necessary to confirm the condition.

High-Potential Withstand

High-potential withstand tests are typically performed to provide assurance that the field winding pole body and main lead insulation have a minimum level of electrical strength and proper clearances to grounded rotor surfaces. Because the inherent withstand capability of sound insulation is well above the usual proof test value, failure during a test at an appropriate voltage indicates the insulation is unsuitable for service. Withstand tests are intended to search for flaws in the material, gross physical damages, manufacturing defects, and to demonstrate in a practical manner that the insulation has a minimum level of electrical integrity. Field windings are typically given ac high-potential tests before they are put into service.

Key Reference Documents

- IEEE Std 43, IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery.
- IEEE Std 95, IEEE Recommended Practice for Insulation Testing of AC Electric Machinery (2300V and Above) With High Direct Voltage.
- IEEE Std 115-1995, Test Procedure for Synchronous Machines
- IEEE Std 286, "IEEE Recommended Practice for Measurement of Power Factor Tip-Up of Electric Machinery Stator Coil Insulation"
- IEEE Std 492, "IEEE Guide for Operation and Maintenance of Hydro-Generators"
- IEEE Std 1434, "IEEE Guide for the Maintenance of Partial Discharges in AC Electric Machinery"
- IEEE Std C.50.12, IEEE Standard for Salient-Pole 50 Hz and 60 Hz Synchronous Generators and Generator/Motors for Hydraulic Turbine applications Rated 5 MVA and Above
- IEEE Std P1434-2014, IEEE Guide for the Measurement of Partial Discharges in AC Electric Machinery
- FIST 3-1, *Testing Solid Insulation of Electrical Equipment*
- National Electrical Manufacturers Association (NEMA) MG-1. NEMA Motors and Generators

6.1.28.1 Air Gap Measurement Test

The test consists of measurements at a number of different locations around the periphery of the rotor. This may be done manually using parallel or feeler gauges or with automatic systems. During a slow rotation type test, the air gap is measured by hand at two locations. One location is a fixed position on the stator that measures rotor shape and the other is a fixed position on the rotor that measures stator shape. When using dedicated air gap measurement instrumentation, the unit is rotated, and the measurement system is activated to automatically take the appropriate number of readings.

This test is intended to verify that the rotor-stator air gap is uniform and concentric. It is performed during construction to verify proper shaft and stator alignment. The test can be performed again during initial operation if online instrumentation systems are installed. Some units have permanent online air gap sensor instrumentation installed that can be used to trend changes in air gap shape or position.

This test applies to the main generator unit and can also be applied to any large rotating electrical machine. The machine under consideration should be substantially assembled and be able to initially be rotated slowly for hand or instrumented measurements.

For the slow rotation check, only a pair of measurement tapered blocks are required at each measurement location. For the test to be performed by dedicated instruments, the full instrumentation system is required to be installed, calibrated, and operational. Portable temporary systems and permanent installed systems may be used.

Two people are required as note takers along with sufficient personnel to rotate the rotor for the slow rotation check. For the automatic process, an operator is needed to rotate the unit at a consistent speed (usually using the prime mover or a separate driving device) and a trained person is needed to activate the measurement system. These systems take some skill and training to properly interpret the data.

The slow test generally takes about 2 hours due to the number of times that the rotor should be turned, positioned, and stopped. The instrument test takes only a few minutes to test but may take several hours to set up and to interpret the results.

Key Reference Documents

- CEATI Hydroelectric Turbine-Generator Unit Guide for Erection Tolerances and Shaft System Alignment

6.1.28.2 Rated-Flux Loop Test (Core Magnetization Test)

The loop test generally has two purposes:

1) It may be used to energize the stator core, at rated-flux density, to induce vibrations from magneto-striction which allows settling of newly stacked core laminations.
2) It is used for detection of core insulation problems by observation of hot spots caused by circulating current resulting from insulation defects or physical damage(s).

The test is applicable to any laminated core typically found in hydro generators and large motors but also applies to smaller equipment. The laminated core structure should be fully stacked (piled), pressed, and each core stud torqued to the final value prescribed by the contractor. For new cores the test is performed prior to populating it with stator coils or stator bars. For aged, or in-service cores, this test may be performed with windings in-situ. For service-aged cores that are being re-wound, the core must be empty of coils, slots fully cleaned, and painted and prepared for insertion of new coils.

Suitable barriers and noise warnings should be posted to prevent hearing damage prior to testing.

The test consists of winding an excitation coil in a toroidal fashion around the core then energizing it with single-phase power-frequency ac source to establish an alternating flux in the core yoke. The core clamping structure is retightened afterward. If used for detection of core imperfections, the core may be energized at rated-flux levels and the core overall average temperature should rise about 15-20 °C. Older cores may show hot spots of up to about 10 °C, while new cores would normally not have spot temperatures in excess of 5 °C when the hot spot is compared to another similar area not experiencing a distinct temperature rise.

A suitably sized single-phase power supply with appropriate voltage and current capability to induce rated-flux is required. Also, cables suitable for the loop voltage and current capacity cable are required. A smaller single-turn, coil of wire is wound independently on the core to measure the flux voltage directly, commonly known as the search coil. Voltage produced by the search coil determines when the core yoke has reached rated flux based on calculations made by the contractor. Hearing protection is required for all people in the test area. A means of measuring core local temperatures is also needed.

A large core may require about four to six people to wind and make the appropriate connections. Once underway, the test needs to be monitored by at least two people. One of these should watch the core temperature while the second monitors the power supply and flux voltage measurement.

The setup time for such a test may take a day. The test itself may take from 4-6 hours if low flux levels are used, but an hour is typical for rated-flux conditions and new cores. Disassembly may also take another day.

Key Reference Documents

- IEEE Std 393, IEEE Standard for Test Procedures for Magnetic Cores
- IEEE Std 56, IEEE Guide for Insulation Maintenance of Electric Machines

6.1.28.3 Phase Rotation Tests

The purpose of this test is to help verify proper voltage relationship between the electrical equipment and the power system.

The test applies to any large rotating electrical machine.

The unit should be ready in all respects for rotation and should also be ready to be energized.

The test consists of bringing the unit to rated speed and energizing the field until rated voltage appears across the terminals. The voltage difference between the terminals and their associated phases of the power system is measured before any attempt is made to connect the machine to the system.

Two sets of voltmeters or a phase rotation meter, and potential transformers are required.

Also see Section 8.4.2 "Synchronization Test" for related information.

One person is sufficient to take readings while an operator sets up the unit. The actual test should require only a few minutes. Equipment setup may take a day if the system is not arranged with appropriate potential transformers.

Key Reference Documents

- IEEE Std 115, "IEEE Guide for Test Procedures for Synchronous Machines Part 1 – Acceptance and Performance Testing Part II – Test Procedures and Parameter Determination for Dynamic Analysis"

6.1.28.4 Coil Turn-to-Turn Insulation Tests

The purpose of this test is to detect shorted turns in either stator or rotor coils.

The test may be applied to any coil consisting of two or more turns that has been electrically isolated from the rest of the unit. The test is performed several times by the contractor during assembly. After stator coils are brazed together, this test is only performed to identify a known winding issue as winding disassembly would be required to perform this test.

The test coil is electrically isolated and the test equipment generates a suitable fast rise time impulse across the coil terminals to create a voltage difference between the turns of a coil.

An impulse voltage is applied to the coil leads and the voltage response to the impulse is recorded. The waveform is either compared to a known good coil (without shorted turns) or compared to another in-situ coil for comparison of waveshape. If the wave shape of the coil under test matches the known good coil, the tested coil is deemed to have no shorted turns. If the waveform of the coil under test matches an adjacent in-situ coil, the unit under test is also deemed to have passed the test with no evidence of shorted turns.

An impulse tester capable of producing a 0.1 μs front with a voltage up to 10,000 V per coil turn is typically required.

A test technician can perform this test. Coil isolation may take up to a day and the test can be done in minutes. Coil reconnection or extraction may take significantly longer.

Key Reference Documents

- IEEE Std 522, "IEEE Guide for Testing Turn Insulation of Form-Wound Stator Coils for Alternating-Current Electric Machines"

6.1.28.5 Conductor Resistance Testing

This test is used to locate high-resistance connections within the stator winding and the main field of the rotor. It can also be used on transformers. For ac windings, the resistance from phase to neutral should be recorded. Because the resistance of copper is affected by temperature, the data should be corrected to a constant temperature for trending and comparison purposes. Sufficient time should be allowed to permit the reading to stabilize before recording the data due to the inductive nature of most stator and rotor windings.

A low-resistance ohmmeter or a Kelvin bridge is required to make these sensitive measurements.

The time required to prepare for the test is dependent upon the equipment to be tested. It can vary from a few minutes to several hours if phase isolation is required. The test itself requires only a few minutes. Special care should be taken with high current connections on inductive test specimens, as an arc can be drawn if the current connection is removed before test current reaches zero at the end of testing.

Key Reference Documents

- IEEE Std 56, "IEEE Guide for Insulation Maintenance of Electric Machines"

- IEEE Std C57.152, "IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus – Part 1: Oil filled Power Transformers, Regulators, and Reactors"

Photograph 17 - Rotor assembly

6.1.28.6 Slip Rings/Brush Rigging Checks

The slip rings of the generator need to be thoroughly inspected for abnormal surface conditions and to ensure the supporting insulation components are intact and not heavily contaminated or physically damaged. Proper installation of the brushes, brush holders, and slip rings is very important to avoid mechanical, heat-related, and other potential damages that may result in an arcing fault causing an unscheduled outage.

A visual inspection must confirm there is no significant accumulation of carbon dust that will impair the insulators that support the energized rings and brush holders. Ensure the brushes move freely in the brush holders without binding against the applied spring pressure. Check that the adjustable brush springs are properly adjusted for equal brush pressure across the entire set of brushes. This ensures that current balance between brushes is optimal and avoids over-and-under loading of individual brushes.

Verify that there is zero, or minimum, contamination on the sliding surface of the rings, with the exception of patina (beneficial deposits on the surface of the rings during service time). Verify that the surfaces of the rings are free of nicks, scratches, dimples, or other physical damage that may cause the sliding surface(s) to abrade the carbon brushes at an accelerated rate.

Each new carbon brush must be pre-shaped to the radius of the slip rings to ensure the entire face is in contact with the ring surface. The brush holders and associated springs should maintain the brush face in contact with the rings under equal pressure. To avoid failure, the stationary brush holders must have adequate clearance to the rotating rings. This should be at least ¼" in most cases and more in others. The clearance should be set to manufacturer's recommendations as the rotor shaft and rings will exhibit precession (lateral movements) due to normal operation. Adequate clearance is required to ensure the stationary holders do not physically contact the rotating slip rings.

Check that brush holder alignment is perpendicular to the slip ring surface. Ensure that all brushes sharing a common ring are the same manufacturer, type, and part number. Do not mix brush types that contact the same ring.

Key Reference Documents

- Manufacturer's instructions
- CEATI Brushgear Maintenance Guide
- Commutator/Slip Ring Handbook – U.S. Department of the Navy Naval Sea Systems Command, August 1985

6.1.28.7 Temperature Measurement Equipment Checks

Typically, temperature measurement is performed with resistance temperature detectors (RTDs) that are installed in the generator. In order to check the RTDs reading instrumentation, disconnect the RTDs as close as possible to the RTD head. Connect the wires to a RTD test instrument, and using the test instrument, simulate different operating points. Verify the displayed temperature measurements are correct. Verification of the generator RTDs themselves can be observed if they are all read at the same ambient temperature when the stator core and windings are at a known stable temperature.

Key Reference Documents

- Manufacturer's instructions

Photograph 18 - Generator unit

6.1.29 Generator Line Cubicle

This section provides guidelines for the pre-commissioning of the generator line cubicle. After successful completion of this test, the generator line cubicle will be ready to be energized at the rated voltage.

Verify the following preliminary conditions are met:

- The cubicle is installed.
- All the terminations associated with this equipment are completed
- the generator leads and the high voltage breaker are disconnected

After the preliminary conditions are met, the generator line cubicle will be ready for testing. This test is composed of a visual inspection and electrical testing. Confirm and verify the following during the visual inspection:

- Check the external appearance of the cubicle for any signs of damage.
- Ensure there are no foreign materials in the cubicle (wood, loose fasteners, wires, etc.).
- Verify that the cubicle is clean of dust.
- Check that all anchor bolts are installed tightly.
- Verify that all doors close and latch correctly.
- Ensure the generator line side cables or bus are disconnected from the cubicle.
- Verify that the surge arrestors, surge capacitors, and cubicle enclosure are connected to the station ground system.
- Ensure all the cubicle doors are properly grounded.
- Verify the rating plate information with the finalized design drawings.
- Verify that all equipment and devices are installed and labelled in accordance with the design drawings.
- Verify the tightness of the accessible bolted electrical connections using a calibrated torque-wrench.
- Inspect the insulators for evidence of physical damage or contaminated surfaces.
- Ensure the CT secondary cables are properly terminated and tightened.
- Verify the continuity of the ac auxiliary service circuits (thermostat, humidistat, and heater).
- Perform a visual and mechanical inspection of the CTs.
- Verify visually the correct connection of the cables or bus to the generator. Compare this with the terminal drawing.

After the visual inspection is completed, the following tests will need to be performed on the line terminal cubicle:

- Insulation resistance test.
- High potential test.
- Partial discharge test.
- Low voltage tests, which include bus resistance tests on the medium voltage bus using a suitable dc current source. Measure the resistance of each phase by connecting the dc current source, in turn, between every cable entrance connection point and every cable exit connection point. The readings from the three phases must not vary substantially.
- The current transformers within the line terminal cabinet should be tested.
- Check that the nameplate ratings of the surge capacitors are in accordance with the design and verify that they are clean. The capacitance of each capacitor should be measured and compared with the drawings. After these verifications are made, perform insulation resistance measurement tests on each capacitor from phase terminals to ground.

After all these tests are successfully completed, perform function testing on the auxiliary devices such as the thermostat and humidistat and heater circuits. Record the thermostat and humidistat settings. After all functional testing has been completed, the generator line cubicle can be reconnected for on-line testing.

Key Reference Documents

- The single line diagram and the three-line diagram associated with the equipment
- A general arrangement drawing
- The wiring diagram
- Bill of materials
- International Electric Testing Association (NETA) Acceptance Testing Specification, for reference
- FIST 1-1, *Hazardous Energy Control Program*

Photograph 19 - Potential transformer and surge equipment cabinet

Photograph 20 - Surge equipment cabinet

6.1.30 Generator Neutral Cubicle

This section provides guidance on the steps to be followed for the pre-commissioning of the generator neutral grounding cubicle. After successful completion of this test, the generator neutral cubicle can be energized at the rated voltage.

The cubicle must be installed prior to testing and all the terminations associated with this equipment must be completed. Neutral current transformers are often in the generator air housing and the neutral grounding transformer is located outside the air housing in a separate cage or enclosure. Major precautions should be taken so that it is disconnected from the rest of the system. Especially ensure that the disconnect switch between the generator and the neutral cubicle is disconnected and that the generator leads are open circuited. In addition to the above, the installation must comply with all site safety and lock-out tag-out procedures.

This test is composed of a visual inspection and electrical testing. Confirm and verify the following during the visual inspection:

- Check the external appearance of the cubicle for any signs of damage.
- Ensure there are no foreign materials in the cubicle (wood, loose fasteners, wires, etc.).
- Verify that the cubicle is clean of dust.
- Check all anchor bolts are installed tightly.
- Verify that all doors close and latch correctly.

- Ensure the generator neutral side medium voltage cables or bus are disconnected from the cubicle.
- Verify that the transformer primary and secondary grounding cables, the cubicle enclosure, and the disconnect switch handle are connected to the station ground system.
- Ensure all the cubicle doors are properly grounded.
- Verify the rating plate information with the finalized design drawings submitted by the manufacturer.
- Verify that all equipment and devices are installed and labelled in accordance with the design drawings.
- Verify the tightness of the accessible bolted electrical connections using a calibrated torque-wrench.
- Inspect the insulators for evidence of physical damage or contaminated surfaces.
- Ensure the CT secondary cables are properly terminated and tightened.
- Verify the continuity of the ac auxiliary service circuits (thermostat, humidistat, and heater).
- Perform a visual and mechanical inspection of the CTs.
- Verify visually the correct connection of the cables or bus to the generator. Compare this with the stator terminal drawing.

After the visual inspection is completed, the following tests will need to be performed on the line terminal cubicle:

- Insulation resistance test.
- High potential test.
- Partial discharge test.
- Low voltage tests, which include bus resistance tests on the medium voltage bus using a suitable dc current source. Measure the resistance of each phase by connecting the dc current source, in turn, between every cable entrance connection point and every cable exit connection point. The readings from the three phases must not vary by more than 50% from the lowest reading.
- The current transformers within the line terminal cabinet should be tested for ratio, saturation, excitation, insulation resistance, and polarity.
- The disconnect switches should be tested so that correct blade alignment, blade penetration and operation are achieved. In addition, complete the following tests on the disconnector:
  - The operation of the auxiliary contact of the disconnect switches so that it indicates the correct position of the disconnect switch.
  - The contact resistance across each blade should be measured. Typically, they should not vary substantially.
  - The insulation resistance test must be performed on each phase-to-phase and phase-to-ground pole with the switch closed and across each open pole.

The next item to be tested is the grounding transformer. Before beginning any tests, check and verify that the nameplate rating of the grounding transformer is in accordance with the final design. After this is complete, perform the following tests:

- Open the ground connection and then perform insulation resistance measurement tests. The insulation resistance measurement is to be performed for ending to winding and for each winding to ground.

The next step is to check the grounding resistor, which includes verifying the grounding resistor nameplate information and confirming that the grounding resistor is clean for further testing. In addition, the following tests should be performed on the grounding resistor:

- The insulation resistance should be measured between the resistor terminal and the end frame.
- Measure the resistance using a low resistance ohmmeter.

After the above test, ensure the auxiliary devices are checked. This includes verification of the operation of the molded case circuit breakers, energization of the 120 Vac auxiliary services and verification of the operation of the cubicle anti-condensation heaters, thermostat, and humidistat.

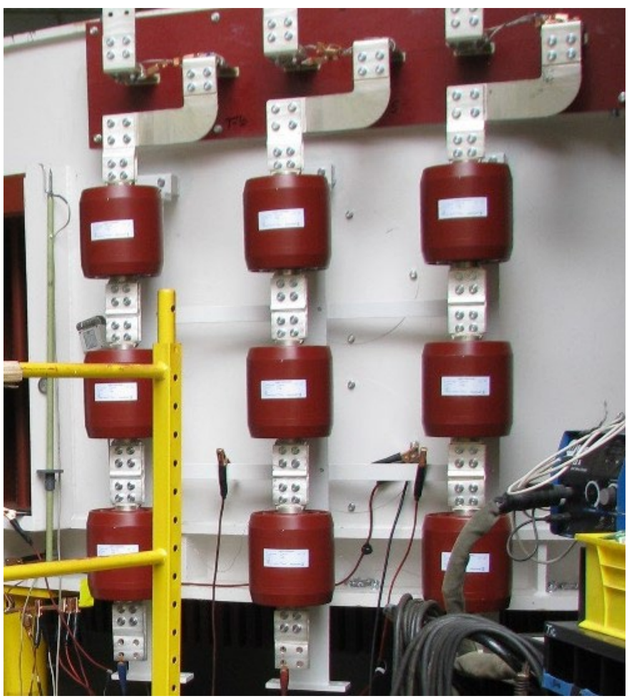
Verify also that the right signals are interfaced with the control panels. After all functional testing has been completed, the generator line cubicle can be reconnected for on-line testing and the next step of the commissioning process.

Key Reference Documents

- The single line diagram and the three line diagram associated with the equipment
- A general arrangement drawing
- The wiring diagram
- Bill of materials
- International Electric Testing Association (NETA) Acceptance Testing Specification, for reference.

Photograph 21 - Generator neutral grounding transformer

Photograph 22 - Neutral grounding transformer located outside generator air housing



Photograph 23 - Neutral and CTs - Inside generator housing

6.1.31 Generator Switchgear – Medium Voltage

This section provides guidance on the steps to be followed for the pre-commissioning of the medium voltage switchgear. In a hydro generating station, the medium voltage switchgear line-up typically contains switchgear cells with a generator circuit breaker, a station service feeder breaker, and any other necessary cells with voltage transformers. Pre-commissioning of the medium voltage switchgear includes testing and commissioning of the draw-out circuit breakers, the voltage transformer, the current transformer, and the accessory systems.

Verify the following prerequisite conditions:
- The switchgear is installed
- All cables and terminations are properly complete
- The installation checklist must be signed off prior to initiating commissioning activity
- The upstream breakers must be locked open, and the feeder cables must be isolated and kept in a safe condition.

The pre-commissioning test includes visual inspection and electrical testing on the switchgear components. The visual inspection checklist includes:
- Check the external appearance of the switchgear for signs of damage.
- Ensure there are no foreign materials (wood, loose fasteners, wires, etc.).
- Verify that the switchgear is clean.
- Check all anchor bolts are tight.
- Verify that all doors close and latch properly.
- Ensure the medium voltage cables are disconnected form the switchgear.
- Ensure all ground connections are properly connected to the ground bus, both internally and externally. The external ground connection should be directly connected to the ground grid of the facility.
- Ensure the control cabinets and the doors of the cabinets are properly grounded.
- Verify the rating plate information with the data indicated in the switchgear design drawings.
- Verify that all equipment and devices are installed and labelled as per the vendor drawings.
- Ensure the CT and Potential Transformer (PT) cables are properly terminated and tightened.
- Ensure other control cables are properly terminated.
- Verify the continuity of the ac auxiliary service circuits (convenience outlets, lights, humidistat, and heaters).
- While the circuit breakers are not in the switchgear, verify the continuity of the dc protection and control circuits as per the approved drawings.
- Perform the visual and mechanical inspection of the PTs and confirm that there are no unusual conditions or damage associated with the PTs.
- Perform a visual and mechanical inspection of the CTs and log and correct any deficiencies.
- Verify racking mechanism operation.
- Confirm operation of interlock systems.
- Record as-found breaker operation counter readings.

After the completion of the visual inspection, the following electrical tests should be performed on the switchgear line-up. These tests include:
- Insulation resistance measurement, high-potential, and partial discharge tests.
- The high-potential or high-voltage test should be performed at the recommended factory test voltage. The manufacturer should be consulted before performing this test.
- The low voltage test should be performed to measure the bus resistance.
- Perform insulation resistance tests on control wiring with respect to ground.
- Test metering devices.
- Test surge arresters.

The next step is to check the circuit breakers. A thorough visual inspection should be performed on the circuit breakers. In addition, the following electrical tests should be performed on the circuit breakers:

- The insulation resistance test on each pole, phase-to-phase and phase-to-ground with the breakers closed and across each open pole.
- Contact resistance test.
- Functional test of the closing and opening circuits.
- Minimum pickup.
- Dielectric withstand test.
- Timing test.
- Vacuum bottle integrity test, if applicable.

The test on the potential transformers involves visual inspection and electrical tests. The visual inspection includes:

- Verification of the nameplate information.
- The PT drawers shall be checked for any unusual conditions.
- The fuse ratings shall meet the design.
- The grounding is properly done.
- The polarity is checked.
- The termination and tightness are checked.
- The electrical tests on the PTs include:
  - Turns ratio test
  - Insulation resistance test
  - Polarity test

The current transformers within the switchgear should be checked and tested. The testing of the current transformers includes:

- Ratio test
- Saturation test
- Excitation test
- Insulation resistance test
- Polarity test

After completion of these tests, the ac auxiliary service systems should be tested.

After successful completion of all tests, the switchgear will be ready to be energized. The energization procedure will be performed together with the back feed procedure.

Key Reference Documents

- Single line and three-line diagram of the switchgear system
- Auxiliary system drawings associated with the switchgear
- General arrangement drawings
- Protection and control schematic
- O&M manual
- Latest version of the NETA Acceptance Testing Specification, for reference

6.1.32 Governors

6.1.32.1 Hydraulic Power Unit (HPU) Test

The main purpose of this test is to verify the proper functioning of the turbine governor HPU system.

CAUTION: Highly pressurized oil can cause serious injury, ensure piping system components are properly installed to prevent personnel death or injury.

As a prerequisite to commissioning:

- Verify piping system components are properly installed.
- The piping has been flushed, and pressure tested.
- Phase rotation has been checked on the HPU pump motor(s).
- All necessary tests on the ac motor are complete.
- Qualified personnel are available for equipment operations.

After all the above conditions and preparations are completed, the HPU will be ready for the pre-commissioning/dry testing activity. The following major tasks must be completed as a part of pre-commissioning activity on the hydraulic power system:

Verification and Adjustment of Instruments
All the instruments must be thoroughly checked during factory testing. The instruments within the hydraulic power unit will need to be verified again during the commissioning activities. At the time of oil filling, the level switches may be tested and checked. For quick verification purposes, the high and low levels and low-low level shall be marked on the tank sight gauges.

Verify the pressure switches and adjust as necessary by pressurizing the related circuits and monitoring the pressure on the pressure gauges installed on the HPU and/or a pressure gauge installed at the various pressure test ports.

Similarly, verify the function of temperature switches by lowering the set points. Once testing is complete, then reset the switches to theoretical values and record the adjustment values for these devices both in rising and falling temperatures.

Verification of Accumulators
After verification of the instrumentation, it is important to check, and if necessary, recharge the accumulators of the HPU with nitrogen. The pressure of the accumulator should match the desired pressure settings of the HPU.

Pressure System with Hydraulic Pumps
Before starting this part of the test, confirm the integrity of the piping supply and ensure that all security measures have been taken to prevent unwanted movement of the actuators.

Open the necessary drain valve before starting the pump. Start the pump manually from the motor control center and monitor the pressure rise in the system. Since the drain valve is open, there should be very little pressure rise until the valve is closed. Proceed to do so slowly and be attentive to any unusual sights or sounds. Watch the pressure rise and be prepared to abort the procedure should the pressure continue to rise above the acceptable limits.

Adjustment of Valves
At this stage, adjust the various pressure relief valves and flow control valves according to the requirements of the system. The valves shall be adjusted so that the:
- design timing for the wicket gate or nozzle open/close,
- wicket gate or nozzle/deflector emergency open/close,
- runner blade open/close, and
- the necessary hydraulic pressure of the brake circuit is achieved.

After completion of the above tests, the hydraulic system will be ready for further functional testing.

Key Reference Documents
- FIST 2-3, *Mechanical Maintenance of Mechanical and Digital Governors for Hydroelectric Units*
- Specifications and drawings

6.1.32.2 Speed Governor Tests
This section describes the procedure to perform the dry commissioning/pre-commissioning testing of the turbine digital speed governor systems. After the completion of these tests (as described in the sections below), the governor system will be ready for unit operation and any further tuning that needs to be performed during wet testing/commissioning testing.

Certain precautions need to be undertaken before performing the turbine governor testing. While the equipment is being tested, it will be the responsibility of the commissioning personnel to ensure all personnel are aware of any panels and instruments that are energized and that necessary safety precautions are taken. In order to ensure the safety of all personnel, safety tape is required near the turbine area while the gates are stroked.

As a prerequisite to starting the test, the following must be confirmed:
- Wicket gate linkages are all connected to the gate ring assembly.
- Unit control is fully powered up.
- Governor pressure and level sensors have been checked and are operational.
- The turbine oil head (for Kaplan type turbines) is installed.
- The wicket gate and runner blade position feedback transducers are installed.
- The governor piping is assembled, and the drain and the bleed valves are fully closed.
- The wicket gate and runner blades servo piping has been pressure tested and flushed.

A typical step by step procedure for the pre-commissioning testing of the turbine governor is provided below:
1. *Wicket Gate Position Transducers Calibration*
   Typically, the feedback calibration function is integrated with the specific turbine governor controller. The wicket gate feedback transducer is equipped with an interface that allows it to

convert the position of the transducer travel to the theoretical 0 to 100% value. By using this interface, a calibration of the wicket gate position transducer must be performed.

After calibrating the wicket gate servomotor feedback transducer, the wicket gate servomotor should be stepped and measurements should be recorded. The actual measured linear and wicket gate angular rotation distance along with the turbine governor controller readings should be recorded.

2. *Wicket Gate Servomotor Timing Adjustments (Hydraulic Adjustments)*
   After calibrating the feedback sensor, the servomotor timing has to be adjusted. During this test, an oscilloscope or an external encoder should be used to log the set point and the servomotor feedback signal. The graph should be plotted with time on the x-axis and feedback on the y-axis. With a milliammeter in the control loop, check the current for full activation to the servo valve. From the programming terminal, provide an output step change from 0-100% to the servo valve. Read the recorded time from the chart between 25-75% and double the time to calculate gate timing. Adjust the timing valve on the HPU to adjust the opening and closing gate timing values if necessary. Repeat this test until the wicket gate open/close time reaches the design value.

3. *Wicket Gate Response Test*
   In this step, tune the wicket gate servo positioning loop with the governor operating in manual control. This tuning is performed using the laptop communication, the governor, and the touch panel.

   Perform a ±1% step response around 50% gate while measuring rise time and overshoot of the response. This test is to verify the response in the servo position as quickly as possible with little to no overshoot. Adjust the control parameters of the servo loop as necessary.

4. *Runner Blade Position Transducer Calibration (Kaplan only)*
   In this step, the runner blade servomotor position transducer is calibrated. The calibration process is similar to the one explained in Step 1 for the wicket gate position transducer calibration. After the runner blade servomotor feedback transducer has been calibrated, the servomotor set point should be stepped and the data should be recorded.

5. *Runner Blade Servomotor Timing*
   A process similar to Step 2 is followed in order to check the runner blade servomotor timing.

   From the programming terminal, provide an output step change from 0-100% to the servo valve. Once again, measure the timing between 25-75% and double the time to calculate the timing. Read the recorded time from the chart and adjust the timing valve on the HPU if necessary. Repeat this test until the runner blade open/close time reaches the design value.

6. *Runner Blade Step Response Test*
   The commissioning process in this step is similar to that of Step 3. From the programming terminal, provide a ±1% step change around 50% blade position to verify the response. The response of the blade does not need to be as fast as the gate position response but should have no overshoot.

7. *Cam Curve Verification*
   In this step, the objective is to verify that the relationship between the position of the wicket gates and the position of the runner blades complies with the design cam curve, with simulation at different heads. Perform the manual ramping of the wicket gates while plotting and saving the curve for different simulated net heads. Compare the saved curves to the cam curves document and confirm that the recorded wicket gate and runner blade position for the different heads match the cam curves. Set the limits for allowed operation range.

8. *Quick Shutdown Function Test*
   Typically, in a hydro generating station, the quick shutdown is configured for the turbine control. After all the above tests are completed, this particular test is performed as a functional test of the turbine governor. In a typical quick shutdown (QSD) process, the wicket gates immediately begin to close, and the runner blades should open. After the wicket gates are fully closed, the runner blades should also be closed.

   In this test, open the runner manually to 40% and open the wicket gates to 80%. Activate the QSD through the turbine governor control panels and check the governor HMI as well as locally for the runner blade and the wicket gate positions during the quick shutdown process. At the same time, also check that the QSD valve on the HPU is de-energized. Verify also that the servo valve signal during the QSD drops to 4 milliamps in the fully closed position.

   An additional test should be performed to test for quick shutdown if the 4-20 milliamp signal to the proportional valve is lost. Once again, open the runner manually to 40% and open the wicket gates to 80%. Disconnect or power off the demand signal to the proportional valve and ensure the servo valve automatically ports oil to close the wicket gates on loss of power to the valve.

9. *Speed Sensor Test and Setting*
   The adjustment and function of the speed sensors should also be checked. A frequency generator is used to check the speed-sensing circuits to ensure that the speed channels are functioning properly.

   The overspeed function is also checked at this stage in order to verify the safety protection. Using the signal generator, the speed is raised to the overspeed trip limit and the associated protection shutdown activation is verified.

The necessary equipment to perform these tests typically includes:

- A multi meter.
- Laptop.
- Data acquisition system with at least 8 analog input channels.
- Frequency signal generator.

Key Reference Documents

- FIST 2-3, *Mechanical Maintenance of Mechanical and Digital Governors for Hydroelectric Units*
- Specifications and drawings for governor system
- High pressure oil schematic

- Servomotor arrangement together with the transducer assembly
- Governor commissioning procedure
- Hydraulic pressure unit commissioning procedure
- Cam curve relationship for Kaplan turbine application

Photograph 24 - Cabinet actuated governor

6.1.33 Ground System

6.1.33.1 Earth Resistivity Test

Earth resistance measurements are typically done during the preliminary design phase to support the design of the station or substation grounding system; estimating potential gradients including step and touch voltages; and design of cathodic protection systems.

This test is described here in case commissioning verification of the grounding system is warranted. The most accurate method of measuring the average resistivity of large volumes of undisturbed earth is the four-point method. Small electrodes are buried in four small holes in the earth, all at a depth of b and spaced (in a straight line) at intervals of a. A test current I is passed between the two outer electrodes and the potential V between the two inner electrodes is measured with a potentiometer or high impedance voltmeter. This procedure is repeated at several locations within the area. IEEE Std 81 describes the test and calculation methodology in detail.

Equipment required: An instrument capable of measuring the earth resistivity either by the two-, three-, or four-electrode method.

The time for setting up the instrumentation and collecting the data should be approximately 4-6 hours.

Key Reference Documents

- IEEE Std 81, IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Grounding System

6.1.34 High Pressure Lift and Jacking Systems

6.1.34.1 Checks and Tests

Most large vertical hydro units are provided with a high-pressure oil lift system on the thrust bearing, unless the thrust bearing uses polytetrafluoroethylene lined pads (in which case no high-pressure oil lift system is required). During start-up and shut-down of the turbine generator, the high pressure oil lift system raises the unit rotating assembly by injecting oil between the bearing's active and stationary elements. In this section, the commissioning process of the high-pressure oil lift system is provided.

CAUTION: Highly pressurized oil can cause serious injury, ensure piping system components are properly installed to prevent personnel death or injury.

The prerequisites that are required prior to testing include:

- Turbine and generator installation is complete.
- Oil piping installation is completed, flushed, leak and pressure tested. The pressure test report is properly signed by the responsible personnel.
- Phase rotation has been checked on the high lift pump motor(s).
- All the necessary safety precautions have been implemented in order to carry out the commissioning process.

If all the above conditions are satisfied, a visual inspection should be carried out on the oil lift skid to confirm:

- All the valves and couplings are properly tightened.
- All the drain valves are closed.
- There is no damage on the overall lubrication system.
- All the instrumentation is properly installed and identified in accordance with the P&ID.
- All the valves in the lubrication system are properly identified and are in accordance with the P&ID.
- The filters elements and strainers on existing systems are clean or replaced.

The pre-commissioning test activities include:

- A bump test is performed to check that the pump discharge flow, pressure, and direction of rotation are all within the required limits.
- All the valves in the lubrication circuit are opened to create a flow path through the bearings.
- The motor starting current and the running current are verified and the pump operating parameters are confirmed to be within the allowable range for further commissioning activities.
- Check the preliminary settings of all the instruments – which is typically done at the factory – at this stage. The instrumentation within the lubrication system consists mainly of pressure, flow, temperature, and level sensors; these items should be checked out and confirm the main control annunciation operates correctly.

- Confirm the flow in the visible flow indicator is as per the design requirement.
- On large vertical hydro units with thrust shoes, with the unit jacked and the thrust tub open allowing visual observation of each thrust pad, operate the high-pressure lift pump and observe that all shoes are discharging oil at the thrust shoe oil port.
- For horizontal units, set a dial indicator on the shaft periphery at both on the drive-end and the non-drive end. The dial indicators are used to confirm if the shaft has been lifted.
- On vertical units, set a dial indicator on a smooth surface at the top of the thrust block (collar) to measure that the shaft lifts on initiation of the high-pressure lift system.
- At this stage, adjust the pump pressure relief valves to set the desired pressure and flow in the oil lubrication system. It is important to verify the pressure rise or the motor current during this activity. In the event there is an unusual rise in pressure above the acceptable limit or if the motor current is higher than the acceptable limit, stop the test immediately and check for any unusual conditions.

No special equipment is required.

The time for the static test with the unit stationary will take approximately 2 hours. The generator thrust bearing oil tub will need to be opened to verify that oil is being ported to each respective thrust shoe. However, 3-4 hours will be needed when the bearing tests are being conducted and as the unit is first rotated. One person is stationed at each device and an operator is to be at the unit controls. Additional personnel should be located at the pump control panel to energize/deenergize the pump motors as required.

Key Reference Documents

- FIST 2-7, *Mechanical Overhaul Procedures for Hydroelectric Units*
- FIST 2-12, *Mechanical Maintenance of Hydroelectric and Large Pump Units*
- OEM instruction manual

6.1.35 Instrumentation

6.1.35.1 Calibration Tests

In a hydroelectric powerhouse there is an assortment of meters, instruments, detectors, and switches used to measure, detect, and control voltage, rotation, current, flow, motion, pressure, level, position, heat, light, quality, quantity, operation, failure, and protection. These devices will typically require some sort of calibration to help verify accurate readings and ensure signals are transmitted. The calibration generally requires a test instrument to measure the known quantity. The device is connected to another test instrument to measure the output of the device. The calibration procedure is a process of adjusting the device until its output correctly represents the known input quantity. Within the powerhouse, the most common instruments that need to be checked are the pressure transducers, pressure gauges, temperature elements, power transducers, wicket gate position transducers, and generator frequency transducers.

For security management systems, calibration involves making the proper sensitivity settings to detect intruders without producing false alarms caused by environmental conditions.

Again, because of the great variety of detectors and devices that require calibration, it is not possible to list the full complement of test equipment required. Usually, a commissioning person can accomplish a majority of the calibration needed for hydro plant commissioning with a multimeter capable of reading voltages in wide ranges and continuity. Previously calibrated bridges may be necessary for other critical devices. Protective relays require special test setups and equipment. All test equipment should be calibrated by a recognized test facility and be traceable to the calibration test.

The time necessary can vary from less than an hour for two or three individuals to a day for a single individual, depending on the equipment being calibrated. Generator switchboards instrument circuits can take days to check since the testing involves the verification of each circuit of continuity and also includes the calibration of all meters. An individual level switch may take minutes to adjust to a specific level. Position detection may take days to calibrate and adjust on large gate operators.

Key Reference Documents

- Instruments, detectors, and switches are usually supplied with instructions on the calibration techniques and adjustment procedures. Since the number and variety of these devices is abundant, it is not possible to list all the possible calibration references available; refer to the O&M manuals that are typically furnished with the equipment being installed.
- Overall station P&ID showing the instrumentation and the locations.
- Instrumentation loop diagrams.
- Instrumentation manual cut sheets.

6.1.36 Instrument Transformers

Instrument transformers provide critical data points that can be used in metering or instrumentation circuits. These devices safely isolate the primary and secondary circuits by transforming the voltage or current to levels that can be used by the facility.

Key Reference Documents

- IEEE Std C57.13, IEEE Standard Requirements for Instrument Transformers
- IEEE Std C57.13.1, IEEE Guide for Field Testing of Relaying Current Transformers
- IEEE Std C57.13.5, IEEE Standard for Performance and Test Requirements for Instrument Transformers of a Nominal System Voltage of 115kV and Above

6.1.36.1 Current Transformer (CT)

6.1.36.1.1 Current Transformer Saturation Test The purpose of this test is to verify CT saturation curves furnished by the manufacturer and to establish base-line curves for future measurements. The test consists of applying a variable ac test voltage to the secondary winding with the primary winding open circuited and measuring secondary current. The values of applied secondary voltage and measured secondary current are usually plotted on a log-log plot to match the factory data.

Equipment required: A CT test set, or a variable ac test voltage source of adequate capacity along with an average reading voltmeter and a rms ammeter.

Setup time depends on where the CT is located, and the time required to place a clearance. The test itself requires only a few minutes.

Key Reference Documents

- FIST 3-8, *Operation, Maintenance, and Field Test Procedures for Protective Relays and Associated Circuits*
- PEB 52, *Update to Protection System Testing Procedures*
- IEEE Std C57.13.1, IEEE Guide for Field Testing of Relaying Current Transformers
- Saturation curves provided by the manufacturer

6.1.36.1.2 Current Transformer Burden Test Instrument transformer secondary circuit burden tests are performed to verify design calculations; help confirm circuit wiring; verify satisfactory contact resistances of terminal blocks and test devices; and ensure that the transformer is not overloaded.

To determine the external connected burden in volt-amperes, disconnect the burden from the transformer by lifting the secondary leads as close as practicable to the instrument transformer and measure the voltage required to drive current through the connected burden. If both resistive and reactive components of the burden are desired, a suitable phase angle meter can be connected.

Equipment required:

- A CT test set is preferred. If a test set is not available, the following equipment is needed:
  - AC Power supply capable of suppling the required test current and voltage
  - Voltmeter
  - Ammeter
  - Phase angle meter

If the transformers are equipped with test blocks close to the instrument transformer to quickly disconnect the secondary circuit, it should be possible to measure the burden in approximately 1 hour per transformer set. If the secondary circuit must be unwired at the instrument transformer to disconnect the burden for the measurement, the duration will be dependent on the location of the instrument transformer and its accessibility.

Key Reference Documents

- FIST 3-8, *Operation, Maintenance, and Field Test Procedures for Protective Relays and Associated Circuits*
- PEB 52, *Update to Protection System Testing Procedures*
- IEEE Std C57.13.1, IEEE Guide for Field Testing of Relaying Current Transformers

6.1.36.1.3 Current Transformer Polarity Test The purpose of this test is to verify the polarity of current transformers.

The polarity of a transformer is a designation of the relative instantaneous directions of currents in the leads. Primary and secondary leads are said to have the same polarity when, at a given instant, the current enters the primary lead in question and leaves the secondary lead in question in the same direction as though the two leads formed a continuous circuit.

Polarity can be determined using a dc kick test with a dc ammeter or voltmeter and a battery. The dc voltmeter may be used, but better results are usually obtained using a dc ammeter when testing current transformers. The meter is connected to the secondary terminals of the transformer with the marked terminal connected to the positive terminal of the meter. Connect the negative terminal of the battery to the primary unmarked terminal of the current transformer and then sharply connect the positive terminal of the battery to the marked terminal of the current transformer.

If the polarity is correctly marked for the current transformer, the meter should show a positive or upscale "kick" when the contact is made and a negative or downside "kick" when it is broken. Current transformers must be de-magnetized following this test.

A CT test set performs this test. One method utilized it to inject a saw-wave test current into the primary of the current transformer and measuring the resultant waveform on the secondary circuits with a handheld probe. This probe will indicate if proper polarity is measured.

Equipment required: A CT test set or a dc voltmeter/ammeter and a battery supply (typically 12 Vdc)

Duration of testing is dependent upon the experience of the individuals testing and how much work is required in isolating the transformer for testing. The actual test duration when utilizing a CT test set is approximately 5 minutes per current transformer.

Key Reference Documents

- FIST 3-8, *Field Test Procedure for Protective Relays*
- PEB 52, *Update to Protection System Testing Procedures*
- Manufacturer's O&M manuals
- Three-line diagram and electrical schematics

6.1.36.1.4 Current Transformer Ratio Test The purpose of the test is to field verify current transformer ratios. This test is not intended to certify instrument transformer accuracy or phase angle. Ratio tests should be conducted prior to energization of equipment.

Current transformers ratios should be checked with low-voltage high-current primary injection or high voltage, low-current secondary injection.

The preferred method to perform this test is by using a CT test set and following the test setup instruction provided for the test set. If the current transformer ratio is not too large, then the test can be performed by injecting a high-current into the current transformer primary circuit and measuring the resultant secondary current. For high ratio current transformers, the CT test set cannot supply sufficient primary test current. The ratio test can then be performed by connecting a high voltage to the secondary circuit of the transformer and measuring the primary voltage. The applied high voltage should not exceed the current transformer saturation voltage as calculated from the excitation test results.

If a CT test set is not available, then a standard transformer (one having a known polarity and ratio) can be utilized. Connect the primary winding of the standard and test transformers in series and the secondary windings in a series loop with the ammeter as a balance bridge across them. If the ammeter reads zero, the CTs have the same polarity and ratio.

For wound CTs where the ratio is not too large, the polarity and ratio can be established by connecting the primary and secondary windings in series with the polarity marked on the open ends and applying a convenient voltage (5 V) to the secondary winding. If the total voltage across both windings is lower than the same test with the secondary winding of the current transformer connected reversed, the polarity is correct. The ratio can be stablished by:

E(secondary) = M(turn ratio) x E(primary)

Prerequisite tests check instrument transformer nameplate ratings against drawings and check connections and polarity against drawings.

The test requires a CT test set, or:

- Voltage source
- Current source
- Voltmeters
- Ammeters

Each set of current transformers can be expected to require about 1 hour to test with a CT test set or 4 hours using discrete test equipment. Time is also dependent on accessibility to the equipment.

Key Reference Documents

- FIST 3-8, *Field Test Procedure for Protective Relays*
- PEB 52, *Update to Protection System Testing Procedures*
- IEEE Std C57.13.1, IEEE Guide for Field Testing of Relaying Current Transformers
- NETA ATS, Standard for Acceptance Testing Specifications for Electrical Power Equipment and Systems
- Manufacturer's assembly drawings
- Three-line diagrams

6.1.36.2 Potential Transformer

6.1.36.2.1 Potential Transformer Burden Test Instrument transformer secondary circuit burden tests are performed to verify design calculations; help confirm circuit wiring; verify satisfactory contact resistances of terminal blocks and test devices; and ensure that the transformer is not overloaded.

To determine the external connected burden in volt-amperes, disconnect the burden from the potential transformer by lifting the secondary leads as close as practicable to the transformer and apply a voltage and measure the current flowing in the connected burden. If both resistive and reactive components of the burden are desired, a suitable phase angle meter can be connected.

Equipment required:

- A PT test set is preferred. If a test set is not available, the following equipment is needed:
  - Three-phase power supply
  - Voltmeter
  - Ammeter
  - Phase angle meter

If the transformers are equipped with test blocks close to the instrument transformer to quickly disconnect the secondary circuit, it should be possible to measure the burden in approximately 1 hour per transformer set. If the secondary circuit at the instrument transformer must be unwired to disconnect the burden for the measurement, the duration will be dependent on the location of the transformer and its accessibility.

Key Reference Documents

- IEEE Std C57.13, IEEE Standard Requirements for Instrument Transformers

6.1.36.2.2 Potential Transformer Polarity Test The purpose of this test is to verify the polarity of the potential transformers.

The polarity of a transformer is a designation of the relative instantaneous directions of voltage in the leads. Primary and secondary leads are said to have the same polarity when, at a given instant, the voltage at the primary lead in question matches (is in phase with) the secondary lead in question.

Polarity can be determined using a dc kick test with a dc voltmeter and a battery. The meter is connected to the secondary terminals of the transformer with the marked terminal connected to the positive terminal of the meter. Connect the negative terminal of the battery to the primary unmarked terminal of the potential transformer and then sharply connect the positive terminal of the battery to the marked terminal of the transformer.

If the polarity is correctly marked for the two windings, the meter should show a positive or upscale "kick" when the contact is made and a negative or downside "kick" when it is broken. When testing potential transformers, it is often necessary to connect the dc voltmeter across the primary terminals and the battery across the secondary terminals in order to obtain measurable "kick" voltage.

A PT test set performs this test. One method utilized is to inject a saw-wave test voltage into the primary of the potential transformer and measure the resultant waveform on the secondary circuits with a handheld probe. The probe will indicate if proper polarity is measured.

Equipment required: A PT test set or a dc voltmeter and a battery supply (typically 12 Vdc).

The test duration is dependent upon the experience of the individuals testing and how much work is required in isolating the transformer for testing. The actual test duration when utilizing a PT test set is approximately 5 minutes per potential transformer.

Key Reference Documents

- Manufacturer's O&M manuals
- Three-line diagram and electrical schematics
- FIST 3-8, *Field Test Procedure for Protective Relays*

6.1.36.2.3 Potential Transformer Ratio Tests The purpose of the test is to field verify potential transformer ratios. This test is not intended to certify instrument transformer accuracy or phase angle. Ratio tests should be conducted prior to energization of equipment.

Preferably, ratio tests for potential transformers are conducted initially with primary leads disconnected from equipment. The preferred method to perform this test is by using a PT test set and following the test setup instructions provided for the test. The test is performed by connecting the high-voltage test leads to the potential transformer high voltage terminals and measuring the resultant secondary voltage.

If a PT test set is not available, then a standard transformer (one having a known polarity and ratio similar to the potential transformer) can be utilized. Connect the primary winding of the standard and test transformers in parallel and measure and compare the secondary windings outputs of the standard and test transformers.

> M(turn ratio) = Ms(turn ratio of standard transformer) x Es(measured secondary voltage of standard transformer)/Et(measured secondary voltage of test transformer)

Prerequisite tests check instrument transformer nameplate ratings against drawings and check connections and polarity against drawings.

The test requires a turn-ratio test set, or:

- Voltage source sufficient to produce at least several secondary volts on standard and test transformers.
- Voltmeters.

If a PT test set is available, each set of potential transformers can be expected to require about 1 hour; otherwise, if discrete test equipment is used, about 4 hours is required depending on potential transformer accessibility.

Key Reference Documents

- IEEE Std C57.13, IEEE Standard Requirements for Instrument Transformers
- NETA AS, Standard for Acceptance Testing Specifications for Electrical Power Equipment and Systems
- Manufacturer's assembly drawings
- Three-line diagrams

6.1.37 Kaplan Turbine Systems

Kaplan turbines have double regulated flow regulation, whereby the control of the turbine is achieved by the combined effects of the wicket gates and the runner blades. The commissioning of the Kaplan turbine system includes successful commissioning of the wicket gate and blade systems. This includes commissioning of the individual instrumentation and hydraulic power unit, gate and blade correlation curve verification, and verification of the positioning of the gate and blade actuators. Simulation of the start-up in dry conditions needs to be checked.

Photograph 25 - Kaplan adjustable blade turbine runner

6.1.38 Machine Condition Monitoring Systems

For pre-commissioning information for machine condition monitoring systems, see Section 6.1.59 – Vibration and Other Monitoring Equipment.

6.1.39 Main Intake Gate

The main intake gate is located at the headworks and is used to shut off the water flow to the turbine water passage; it is normally fully raised during unit operation. The gate is usually operated by a dedicated hoisting system, either wire rope or hydraulic cylinder-operated type (both powered by electrical power). The gates are generally of the vertical, fixed-wheel, rollers, or slide gate design and have seals to minimize water leakage. The gate travels within embedded steel guides that have roller paths and seal paths. The gate seals at the bottom on the sill beam, at the top on the lintel beam, and along the two vertical sides of the guide seal paths. Depending on the design of the intake, the gate may have heaters to keep them ice free during cold weather.

The intake gate has two functions. The main function is to close in an emergency under unit maximum flow and unit design differential heads. The second function is to isolate the unit water passage for unit/water passage maintenance.

Photograph 26 - Main intake wheel-mounted gate

An information review of the specifications, drawings, and O&M manuals should be performed for the following items:

- The gate specifications will include, at a minimum, the gate speed for both downward and upward travel for normal operation by the hoist motor, as well as closing time under an emergency condition where the gate speed is typically controlled by a fan brake in a wire rope hoist or an orifice in a hydraulic hoist. The gate specification will also include the total allowable water leakage for a unit length of seal.
- Verify the signals that will automatically operate the gate in an emergency, such as low governor oil or unit overspeed.
- The hoist supplier O&M manual should also be reviewed as it provides a list of recommendations to be satisfied before the hoist can be operated, such as correct oil level in the main gear box.

The following checks and tests should be performed:

- Check the alignment of the drive system electrical motor to the gear box, non-encased gears, and alignment of any cross-shaft drive pinions to their respective bull gears.
- Check the backlash between pinion and gear and the tooth surface contact pattern.
- Check travel speed of the gate against the specifications for both the powered upward and downward motion with the gate in the dry condition.
- Check the number of wraps of the wire rope on the hoist drum with the gate sitting on the sill to ensure that the minimum number of wraps specified is on the hoist drum.
- Operate the gate a few times through a full cycle, from fully lowered to fully raised.
- Check the hoist system for smoothness of operation and for any unusual noise.
- A wire rope hoist will typically have an electromagnetic-type mechanical holding brake and a speed limiting fan brake. Check the mechanical brake operation to ensure that the brake is activated to prevent the gate from hitting the sill. The air fan brake is tested in the factory and is set to provide the specified lowering speed of the gate under emergency closure. The fan brake housing has a set of adjustable louvers that regulate air flow.

- Check the power supply voltage and phase current for the hoist motor as the gate is lowered and raised.
- Check the direction of rotation of the hoist motor.
- For hydraulic hoists, check the maximum pressure of the hydraulic system and the correct functioning of the piston end-of-stroke dampening.
- For guides with electrical resistance heaters, check for continuity and Megger them to check resistance to ground.
- Check the following instrumentation before the gate is operated in the dry, and after the water passage is flooded: sill position limit switch, upper travel limit switch, over-travel mechanically actuated circuit breaker, slack rope limit switch (for wire rope type hoists), penstock prime position limit switch, and position indicator (which is local at the headworks and at the governor/unit panel, and remote at the station control center).
- After watering up, operate the gate and measure the speed for lowering and raising the gate and compare with the design values. Check gate full travel as well as the function of all of the limit switches; local and remote position indication is also checked. Stop the gate at intermediate positions to check the operation of the hoist holding brake.
- Perform an emergency closure test.
- Following the emergency closure test, the position of the louvers is verified, and the louvers are mechanically fixed in position, usually by tack welding to ensure they remain in the same position. An orifice plate is used to control speed on gates using a hydraulic hoist.

Key Reference Documents

- FIST 2-13, *Gates and Valves*
- Specifications and drawings
- Operation and maintenance manuals for gate and hoist system

6.1.40 Motor Control Center

The motor control center in a hydro generating station is typically rated at 600 V. This section provides a basic guideline for the pre-commissioning of the motor control center (MCC).

Before beginning the commissioning process, the following prerequisites should be verified:

- The switchgear is installed in its final location for energizing the motor control center.
- The automatic transfer switch is ready for energizing.
- A temporary power supply is available.

The testing of the MCC includes both a visual inspection and electrical testing.

The following visual and mechanical inspections should be performed on the MCC:

- Check the external appearance for signs of damage and ensure that there are no foreign materials in the motor control center.
- Confirm the motor control center is clean and the anchor bolts are tight.
- Confirm all ground connections are properly connected to the ground bus internally and externally.
- Confirm that the rating plate information is correct.
- Verify that all equipment and devices are installed and labeled.
- Perform a visual and mechanical inspection of the current transformers.

- Ensure that the current transformer cables are properly terminated and tightened as well as shorted and grounded.
- Ensure the power and control cables are properly terminated.
- Verify the continuity of the ac auxiliary service circuits (convenience outlets, humidistats, and heaters).
- Verify the continuity of the direct current protection and control circuits.

In addition, perform a visual inspection confirming the mechanical integrity, completeness of the wiring, and the performance of the following systems and components:

- Magnetic starter.
- Overload protection.
- Fuses and fuse blocks.
- Control transformer.
- Start-stop pushbuttons/selector switch.
- Motor connections/power circuits (motor side).
- Mechanical features, such as shutter barriers.
- Verify that all bolts have been properly torqued and that there is no presence of corrosion, dirt, or condensation in the MCC.

After all these inspections have been performed, the system is now ready for electrical testing. The following electrical testing will be performed in accordance with the manufacturer's procedure and industry standards:

- Insulation resistance test.
- Bolted connection resistance of main bus and vertical branch buses.
- Phase rotation throughout the motor control center.
- Circuit breaker contact/pole-resistance test.
- Function test of every starter, feeder, etc.

When all the above testing has been completed, the motor control center is ready to be energized.

Key Reference Documents

- Single-line diagram
- Manufacturer's instructions
- NETA Acceptance Testing Specification

6.1.41 Pelton Turbine Systems

The Pelton turbine flow regulation consists of multiple nozzles with deflectors, which are hydraulically controlled. Dry check of the operation of all nozzles needs to be performed. The concept of the commissioning is similar to that for Kaplan turbines, with the exception being that the movement of the nozzles and deflectors are not related in the same sense as the wicket gates and runner blades of Kaplan turbines.

Photograph 27 - Runner for Pelton turbine

6.1.42 Piping Systems and Pressure Vessels

6.1.42.1 Leak Testing

This test is to be used as a guide to properly test an air, oil, or water system to validate that the system is capable of safe and efficient operation at its designated maximum operating pressure with no detectable leaks.

The test of an air, oil, or water system should include subjecting the equipment to a static pressure of its maximum designed operations pressure for a period specified by the OEM, or if this is not available, for a period of not less than 1 hour without showing any detectable leaks or drop in pressure.

This test requires an appropriate system capable of applying the required maximum desired test pressure. Any test other than basic visual inspection will require leak detection equipment, such as bubble, sonic, chemical, infrared, mass spectrometer, flow measurement, etc.

The duration of the test is 4-8 hours, but it may vary according to the size and complexity of the system being tested.

Key Reference Documents

- FIST 2-6, *Maintenance of Auxiliary Mechanical Equipment*
- FIST 2-9, *Inspection of Unfired Pressure Vessels*
- ASME Boiler and Pressure Vessel Code, Section V Code, Article 10, Leak Testing
- ASNT, Nondestructive Testing Handbook, Fourth Edition: Volume 2, Leak Testing
- ASTM E432, Standard Guide for Selection of a Leak Testing Method
- ASTM E479 (Withdrawn), Standard Guide for Preparation of a Leak Testing Specification
- OEM, assembly, or maintenance manual

6.1.42.2 Pressure Testing

All piping should be tested to a specified test pressure at 150% of design pressure for a length of time sufficient to determine tightness (not less than 1 hour). Air lines tested with water should be thoroughly dried after testing and before connecting to equipment.

Water supply and hydraulic systems are generally subjected to a static pressure test above the nominal system pressure.

Spiral case and the spiral case extension are hydraulically tested when units require field welding. The test should be performed at 150% of design head including water hammer.

For pressure vessels, verify shop test and required certificates are available.

A test pump is required on some of the tests. Additional equipment is not usually required other than that required for calibration.

The duration is variable depending on the size and complexity of the equipment or system. It can vary from several hours for an emergency power diesel generator fuel oil pump piping to several days for spiral case hydrostatic test.

Key Reference Documents

- FIST 2-6, *Maintenance of Auxiliary Mechanical Equipment*
- FIST 2-9, *Inspection of Unfired Pressure Vessels*
- ASME B31.1 Power Piping
- NFPA 13, Standard for the Installation of Sprinkler Systems

Photograph 28 - Pressure vessel/air receiver tank

6.1.42.3 Flushing

Prior to flushing of powerhouse piping systems, all piping needs to be pressure and leak tested. Pressure testing of powerplant piping is commonly conducted at one and one-half times the design pressure. Both the oil lubrication and governor piping systems should have a recommended cleanliness level that needs to be verified by taking a sample of the flushing solution while the flushing is in progress to verify that the proper cleanliness level has been reached.

Because of the small clearances employed in oil hydraulic valves and logic elements, the oil lubrication and governor piping systems require a more thorough cleaning and require additional effort as compared to the cleaning required for water piping systems. Water systems can usually be cleaned with a fast flush using water where the fluid velocities achieved are at least three times the design levels and are maintained until the water shows no discoloration.

Oil system piping needs to be flushed with the flushing solution’s flow rates at or above a Reynolds number of 3000. Flow rates at these velocities produce turbulent flows in the piping system and help transport contaminants to the filtering cart or skid assembly. By using a solution flow rate with a high Reynolds number, the time required to flush an oil piping system is reduced. Since the surface tension of the oil decreases with an increase in the flushing solution’s temperature, it is common to perform a fast flush with the fluid’s temperature at approximately 50 °C.

The test requires filter cart assemblies or skids with a properly sized pump, electric motor and heater, and flushing oil or solvents as recommended by the equipment manufacturer. For oil piping systems, oil sampling kits or contamination particle counter sensors can be used to determine when the piping cleanliness level has been achieved.

For water systems, the flushing times may be as short as a few hours, and for oil systems, the flushing time varies from several days to two weeks.

Key Reference Documents

- FIST 2-6, *Maintenance of Auxiliary Mechanical Equipment*
- ANSI/SAE J1165, Reporting Cleanliness Levels of Hydraulic Fluids
- ASME B31.1 Power Piping
- OEM Instruction Manual

6.1.43 Power Transformers

Power transformers transfer electrical energy between the generator and the distribution primary circuits. Distribution transformers transfer electrical energy between the distribution primary and secondary circuits. Power transformers found within the hydroelectric plant are typically the Generator Step-Up (GSU) power transformer and the Station Service Unit (SSU) power transformer. The GSU transformer transfers energy from generator voltage to grid voltage. The SSU is typically connected to the generator voltage system, but can be fed from a different source, and transfers energy to the station service grid for the plant. Typical distribution transformers would be used to transfer energy between the station service grid and other low-voltage distribution systems. This section will focus on power transformers and will not discuss distribution type transformers; although they are similar, many of the testing methods and steps for installation are reduced when compared to power transformers. Power transformers are categorized into two areas: dry-type and fluid-filled.

Typically, dry-type transformers are limited by power rating and voltage class; however, this isn't a defined standard characteristic. Dry-type transformers discussed in this section will be specific to air insulated transformers; other gaseous insulation mediums will be categorized under fluid-filled transformers. Air insulated dry-type transformers are common for power ratings at or below 5-MVA but can be found up to 30-MVA. A dry-type transformer footprint grows significantly when rated above 1-MVA to be able to handle the cooling required.

Fluid-filled transformers are the most common type for power ratings above 500-kVA. Fluid-filled transformers can be filled with gas (e.g., SF_6) or with liquid. Gas insulated transformers can use insulating medium that is compressed to a density that allows for better heat transfer. An example is SF_6 filled transformers which can reach extra-high voltage (500kV) and power ratings above 300-MVA. The most common type of large power transformer is liquid-filled, also referred to as liquid-immersed. Fluid-filled transformers can be categorized as either Class I or Class II as defined below.

Table 2 - Power Transformer Classifications

Class	Nominal Voltage (kV)	Power Rating (kVA)
I	0-69	Undefined
	69-115	< 15,000
II	69-115	≥ 15,000
	115+	Undefined

Power transformer design, assembly, and testing parameters are defined by the class of the power transformer.

In addition to the class of transformer, there are many preservation system types such as free breathing, pressurized breathing, positive pressure with inert gas, sealed-tank, conservator, bladder/diaphragm, or a combination of these types. The type of preservation system can also impact the type of insulating fluid used. Types of fluid include SF_6, mineral oil, less-flammable hydrocarbons, ester fluids, or silicone.

Although all power transformers have similar stringent standards, each is custom built for the application. Many unique parameters, in addition to the ones listed above, for power transformers necessitates the involvement of a technical expert in this area throughout the duration of planning, design, construction, and commissioning stages. The power transformer is a large piece of the power train and typically requires multiple other systems to be tested or commissioned in concurrence with the power transformer. The following subpart will discuss high level processes for the pre-commissioning phase as defined in this document; however, a technical expert should be involved for a complete commissioning plan.

6.1.43.1 Document Reviews

The manufacturer of the transformer designs the equipment to meet prescriptive specifications written by the end user. Thorough reviews of the approval drawings and data as well as clear and constant communication are key components in a successful commission. The power transformer review not only includes the specifics to the transformer's ability to transfer energy, but also includes the protection circuit designs for the plant, communication metrics, interface connections, and coordination with outside entities receiving the generated power.

6.1.43.2 Factory Acceptance Testing
It is highly recommended that a technical expert from the end user attend the factory acceptance testing. During this testing period, which is typically 2 weeks for a 3-phase transformer, the testing procedures, setup, obtaining results, and analysis of each test should be well known by the technical expert. In many situations a decision addressing a modification of setup or interruption of results is needed by the end user. If the end user is not in attendance, the manufacturer is allowed to make the decision and move forward.

Although the official review and approval of the factory test results can be performed remotely, it is common that the transformer will have shipped from the factory by that time and any retesting would be difficult and costly. The approval of the factory testing should be performed in person during the test. This is another reason it is critical to have a technical expert in attendance at the factory testing of each power transformer.

A key component in the validation of the transformer is verifying the internal parts have not been modified from the time of factory testing. To get this information it is critical to perform a Frequency Response Analysis (FRA) measurement. Prior to disassembly and directly after all factory acceptance tests, the initial FRA in the fully assembled configuration must be performed. This measurement will later be compared to the fully assembled configuration when the transformer is installed in the final location. In addition, once the transformer has been disassembled and placed in shipping configuration, another FRA measurement should be performed. The shipping configuration FRA will be compared to the FRA performed once the transformer arrives on site and prior to assembly.

Key Reference Documents

- IEC 60076-15, Power Transformers – Part 15: Gas-filled Power Transformers
- IEEE Std C57.12.00, IEEE Standard for General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers
- IEEE Std C57.12.01, IEEE Standard for General Requirements for Dry-Type Distribution and Power Transformers
- IEEE Std C57.12.90, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers
- IEEE Std C57.12.91, IEEE Standard Test Code for Dry-Type Distribution and Power Transformers
- IEEE Std C57.13, IEEE Standard Requirements for Instrument Transformers
- IEEE Std C57.19.00, IEEE Standard General Requirements and Test Procedure for Power Apparatus Bushings

6.1.43.3 Shipment and Received Reports
During transportation the transformer is vulnerable to contamination or damage. Although SSU transformers are typically shipped with insulating fluid, GSU transformers may be shipped with or without insulating fluid based on the size and weight restrictions of transport. The most important aspect during shipping is keeping the internal part of the transformer isolated from contamination. If the transformer is not transported with fluid, it is usually shipped with dry air or nitrogen and a positive pressure system. This system must be monitored and analyzed to make sure the internal

parts are not exposed to the outside environment. Additionally, the internal parts can be damaged by high accelerations due to impacts. Impact recorders must be specified to be installed and analyzed during shipment.

Systems installed to prevent contamination and damage during shipment may require multiple inspection points during transportation and are typically performed whenever the transportation vessel is changed (e.g., ship to rail car, rail car to truck). Based on these inspections, an internal transformer inspection may be necessary. If internal inspection is warranted, the manufacturer should be involved for proper processes. At a minimum, the impact recorders and pressurization systems must be inspected prior to unloading from the transportation vessel. Dew point measurement must be taken and compared to the measurement at the factory prior to shipment.

In addition to the periodic inspections, testing is performed once the transformer has arrived onsite. Core insulation resistance must be measured to determine if there are any unintentional grounds. FRA measurement in the shipping configuration is performed and must be compared to the shipping configuration FRA that was performed at the factory. See 6.1.43.2 Factory Acceptance Testing. If the FRA measurements, when compared to the factory measurements, show questionable areas, a leakage reactance test should be performed. Additional electrical tests to be performed are winding turns ratio, insulation power factor, and winding insulation resistance. All results should be analyzed by a technical expert and compared to the factory acceptance test results.

Additional measurements should be performed on the bushings for power factor and capacitance.

Key Reference Documents

– IEEE Std C57.150, Guide for the Transportation of Transformers and Reactors Rated 10000 kVA or Higher

6.1.43.4 Storage and Preservation

Prior to installation, the power transformer may need to be stored for a period of time. The location of storage, timelines, and environment should be considered. Storage should be taken as an extension of the transportation phase where the main goal is to prevent damage and internal contamination. Post transportation testing and checks, all equipment should be stored in the original container with packaging/bracing. Due to each transformer being uniquely built for the application, manufacturer's storage instructions should be reviewed, understood, and followed prior to storage.

When possible, store a transformer in a climate-controlled environment with structure support for the applicable weight. When storing outdoors, dry-type transformers should have coverings installed on ventilations/openings to prevent buildup of dust and other contamination. Depending on the timeline, fluid-filled transformers may require the insulating fluid be installed for storage. The insulating materials of a fluid-filled transformer cannot maintain electrical dielectric properties during significant storage times when the transformer is filled with nitrogen or dry air from shipping. The longer the transformer sits without fluid, the higher the risk of dielectric weakening in the solid insulation. Typically, the storage metrics are as follows; however, the manufacturer should be consulted for specifics.

Table 3 - Fluid-Filled Power Transformer Storage Timeframes

Storage Timeframe	Actions for Storage
0-6 Months	May stay dry. Perform monthly checks.
6-12 Months	May stay dry. Perform monthly checks. Once ready for installation, the vacuum time must be doubled.
12-18 Months	May remain in shipping configuration. Must fill with insulating fluid. Once ready for installation, the vacuum time must be doubled.
18+ Months	Must be fully assembled except for heat exchangers. Must fill with insulating fluid. Once ready for installation, the vacuum time must be doubled.

When insulating fluid is installed during storage, the transformer should have temporary secondary containment in place.

The transformer should have bushings electrically connected and grounded with the tank, core ground, and other applicable grounding points to prevent damage during unexpected lightning strikes. During storage, monthly inspections should be performed to check for, and clean up, the buildup of moisture, dust, or other contaminants. Energization of accessory circuits could be warranted during storage periods. This will help prevent moisture buildup in control cabinets, conservator/bladders, and other ancillary devices. Fluid levels and/or internal gas pressures should be checked to verify positive pressure is maintained within the transformer. When fluid has been installed in conservator/bladder type transformers, the dehydrating breather should be energized and checked monthly for proper operations.

Once the transformer is ready to be relocated out of storage, impact recorders should be installed and a FRA measurement should be taken before and after the move. Additional protection measures may be used as described in 6.1.43.3 Shipment and Received Reports.

6.1.43.5 Installation

Depending on the transformer type, weight, and configuration, installation may vary for each project. Installation will involve multiple shifts that will work 24 hours a day to minimize exposure of the transformer's internals. Prior to installation, multiple checks should be performed to verify on-site materials are available and ready for installation. Checks should also verify acceptance of the following, as applicable:

Approved drawings and data

- Factory acceptance testing
- Shipment and received reports
- Structural pad and seismic anchorage installation
- Spill Prevention, Control, and Countermeasure (SPCC) plan
- Bushing field power-factor testing
- Cleanliness of transformer in ready-for-installation condition

- Grounding of transformer to ensure safety
- Local weather conditions acceptable for installation

Fluid-filled transformers may have had the fluid removed for transportation. In these instances, the transformer is filled with either dry air or nitrogen to keep the internals preserved. Prior to evacuating these gases, the temperature should be measured to minimize the creation of moisture within the transformer. Manufacturer's shipping reports should be checked for the applicable dew point measurement. Open the transformer in minimal locations to reduce the risk of air drafts. For installations where work within the transformer will take multiple days, the transformer should be sealed and pressurized with dry air or nitrogen overnight. Regulators should be used to prevent over pressurization.

During assembly, a continuous supply of breathable air must be maintained. Manufacturer's instructions should be strictly followed and may require removal of internal bracing, replacement of gaskets, and/or restrictions on duration of assembly. While accessible, bushing type CT serial numbers should be recorded/verified.

Fluid-filled transformers that have been shipped with the fluid removed require strict procedures to properly dry the insulation system. Procedures, hold times, verification of dryness, and final fluid filling are all based on the transformer class and size. Initial dryness of the transformer insulation system is critical for maximizing the transformer life. The most stringent requirements between international standards, manufacturer instructions, and owner specifications should be used for final dryness. During fluid filling volatile gases can be created and static charge can be accumulated from fluid passing through the hoses. Properly ground all permanent and temporary equipment to prevent possible dangers to the transformer and personnel. Once fluid filling is complete, fluid samples must be taken and analyzed.

After installation is complete, final checks should be performed that include:

- Leak checks on each flange and gasket location.
- Visual checks on protective devices.
- Liquid levels based on ambient temperature.
- Settings on overloads and cooling accessories.
- Grounding on bushings and transformer tank.
- Shorting of CT secondary circuits.
- Bolt torque verification at each location.
- Wait times may be experienced before energization can occur. These wait times depend on type and class of transformer.

Key Reference Documents

- IEEE Std C57.93, IEEE Guide for Installation and Maintenance of Liquid-Immersed Power Transformers
- IEEE Std C57.94, IEEE Recommended Practice for Installation, Application, Operation, and Maintenance of Dry-Type Distribution and Power Transformers

6.1.43.6 Field Testing

Field testing the power transformer ensures the configuration, electrical properties, and insulation system have not been damaged during transportation and that the transformer is ready for service. These tests are critical for comparing to the factory test reports and creating a baseline that will be used throughout the transformer's life. Test setup, process, and results analysis are crucial and should be performed by a technical specialist.

Prior to testing, verify accuracy of the top fluid, winding temperature, hot spot, and fluid level gauge readings. Verify that control relays or switches are operating correctly when alarm conditions are met. Operate auxiliary equipment, such as tap changers, fluid-circulating pumps, fans, or liquid or water flow meters in accordance with manufacturer's instructions.

Depending on the type and class of transformer, the following tests should be performed. Use international standards, manufacturer's recommendations, and user specifications for determining which tests are required.

Table 4 - Power Transformer Field Tests

Field Test	Dry-Type Transformer	Fluid-Filled Transformer
De-magnetize Transformer before beginning tests	X	X
Frequency Response Analysis compared to factory test report. See 6.1.43.2 Factory Acceptance Testing	X	X
Excitation Current If there is a Tap Changer, perform excitation current on each tap position.		X
Winding Ratio on each tap	X	X
Polarity and Phase Relation	X	X
Power Factor and Capacitance on Bushings C1 and C2 should be measured		X
Dielectric Frequency Response		X
Variable Frequency Power Factor		X
Insulation Resistance on Winding to ground, core to ground, and between windings	X	X
Insulation Power Factor on each winding to ground and between windings Capacitance should be measured on each connection	X	X
Applied Voltage	X	
Winding Resistance of all windings, including tap changers	X	X
Insulation Liquid: See 6.1.23 Electrical Insulating Fluids		X
Oxygen and Total Combustible Gas Content of sealed tank, nitrogen gas cushion transformer		X

Field Test	Dry-Type Transformer	Fluid-Filled Transformer
Instrument Transformers: resistance, ratio, and polarity Testing should be made at the terminal blocks of the control cabinet See 6.1.36 Instrument Transformers	X	X

Key Reference Documents

- IEEE Std C57.12.90 IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers
- IEEE Std C57.12.91 IEEE Standard Test Code for Dry-Type Distribution and Power Transformers
- IEEE Std C57.19.01 IEEE Standard for Performance Characteristics and Dimensions for Power Transformers and Reactor Bushings
- IEEE Std C57.93, IEEE Guide for Installation and Maintenance of Liquid-Immersed Power Transformers
- IEEE Std C57.94, IEEE Recommended Practice for Installation, Application, Operation, and Maintenance of Dry-Type Distribution and Power Transformers
- IEEE Std C57.149, IEEE Guide for the Application and Interpretation of Frequency Response Analysis for Oil-Immersed Transformers
- IEEE Std C57.152, IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus – Part 1: Oil Filled Power Transformers, Regulators, and Reactors
- IEEE Std C57.161, IEEE Guide for Dielectric Frequency Response Test

6.1.43.7 Wiring Checkout and Device Function

Once the transformer has passed all field-testing requirements, wiring checkout and device functionality testing can begin. Verification that protection and control circuits operate correctly prior to energization is key.

For projects where low voltage cabling has been replaced, modified, or re-terminated, cable insulation resistance measurement and point to point continuity verification must be made. See 6.1.8.1 Insulation Resistance and Polarization Index (PI) Testing and 6.1.15.1 Continuity Checks. Maintain the test measurements of each circuit for compliance reporting requirements.

Once all cables have been verified, functionality testing must be performed on each device. Maintain the test report of every device on the transformer for compliance reporting requirements. The following list does not include all devices for all type of transformers, but does provide a general overview of systems to be checked:

- Control Cabinets
  - Verify internal lighting.
  - Modify internal heater thermostat settings to activate and deactivate heaters. Return settings to as found.
  - Pull test on conductor terminations.
  - Label verifications for cable ends.
  - Programming check of transformer electronic control and monitoring system.

    - Programming of dissolved gas monitor.
- Cooling Systems
    - Temperature monitoring sensors.
        - Test in coordination with cooling system devices.
        - Internal winding temperatures use sensing CTs, RTDs, and calculations for determining temperatures.
        - Measure and record temperature and resistance values of all RTDs. Compare against temperature/resistance charts.
        - Artificially heat via acceptable methods to verify correct operations.
    - Test all cooling system devices (pumps, fans).
        - Test protection measures that are activated when cooling systems are deactivated (e.g., off position of hand-off-auto switches).
        - Verify correct rotation and running amperages for motors.
        - Record which temperature monitor sensor and at what temperature each stage of cooling activates.
- Protection Systems
    - Internally activated
        - Use manufacturer's operations and maintenance manual to functional test each protection device.
        - Injection of current to secondary circuits of CTs should be performed to verify activation of facility protection system.
        - For each alarm and tripping device, verify signals are received at the protection device and activation of appropriate measures occurs within the facility.
    - Externally activated
        - Facility devices (e.g., Fire Protection Systems) that activate or deactivate devices within the transformer must also be tested and verified.
- Tap Changers
    - De-energized Tap Changer (DETC)
        - Check manual locking device to maintain position.
        - Verify interlocking device that prevents rotation of tap changer prior to removing locking device.
        - Operate changer in ascending and descending methods to each position.
    - On-Load Tap Changer (LTC)
        - Motor protection settings.
        - Shaft lubrication and operation.
        - Electrical operation of all taps in ascending and descending.
        - Mechanical stop positions.
        - Manual operation interlocking switch.
        - Manual operation of all taps in ascending and descending.
        - Local and remote settings for control.
    - Once testing is complete, set tap changer to position required for operations and lock device.

Once wiring checkout and device functional testing is complete, an Energization Authorization or equivalent document can be provided to facility operations. More details on this document and next steps can be found in 8.4.12 Power Transformers.

Key Reference Documents

- IEEE Std C57.131 IEEE Standard Requirements for Tap Changers

6.1.44 Protective Relays - Accuracy Test

Protective relay operation is relatively infrequent. This raises the concern as to whether the relays will operate correctly in the event of a fault. Testing should subject the relays to the voltage and currents that would be experienced during a fault and would cause the relay to operate. Measurement devices should be capable of determining that the relay operated correctly within the specified time period. Specific test requirements are normally determined from manufacturer's bulletins. All settings should be verified to be correct for microprocessor-based relays including manufacturer's defaults. Microprocessor-based relay logic should also be verified along with verifying the proper operation of relay inputs (PT and CT analog inputs along with digital inputs) and relay digital outputs.

General purpose portable relay test sets are capable of testing most relay types. These test sets include an adjustable, variable-frequency, three-phase power supply along with appropriate timers and measurement devices. Some general-purpose portable relay test sets have computer interfaces that allow the test sequences to be automated. Many modern relays have computer interfaces. For these, the manufacturer's access programs and appropriate computer are needed.

The tests can be performed by one technician who is experienced in relay testing. Duration depends on the relay types and test equipment capability. A typical relay test session for one generator unit takes about three days, including equipment setup. Electromechanical relays will take more time than multi-function microprocessor-based systems.

Key Reference Documents

- IEEE Std. C37.102, IEEE Guide for AC Generator Protection

6.1.45 Relays and Fuses

The pre-commissioning test of the relays and fuses includes the following major steps:

- The visual inspection includes estimating that there are no loose terminals, damage, or foreign materials and the relay or fuse is in good shape in all aspects, and the wiring is properly connected with no visible damage.
- Energize the relays from the ac or dc power source, which is typically 120 Vac or 125 Vdc, and ensure the integrity of the wiring. Ensure there is no short within the circuitry.
- A function test on all the different relays should be performed.
- Verify the normally open and normally closed contacts match the drawings.
- Certain types of relays plug into a relay base. Ensure that pluggable relays are tightly secured in the base and not loose.
- Check for proper fuse ratings of all control circuits using drawings and schematic diagrams.
- Check for burned out fuses.

Key Reference Documents

- Manufacturer's O&M manuals
- Electrical schematics and wiring diagrams.

6.1.46 Servomotors and Wicket Gates

6.1.46.1 Differential Pressure Tests

The turbine servomotor differential pressure measurement is made with the servomotor moving in one direction at a slow controlled rate. The differential pressure across the effective piston area of the servomotor times the stroke of the servomotor is the required work to either open or close the turbine's gates or blades. Since the hydrodynamic forces on the turbine parts and forces generated from losses in the turbine's various mechanical components vary with the direction of the servomotor's movement, this test should be conducted in each direction. A servomotor differential pressure test provides information to confirm the adequacy of the servomotor's capacity at the governor's rated oil system pressure. Since the turbine runner design affects the test results, this test is most often conducted at or near the rated net head across the turbine.

In the simplest form for this test, each end of the turbine servomotor is instrumented with a calibrated pressure gauge and a scale is used to identify the position at every 10% of the servomotor's stroke. It is necessary to have good communications between an operator controlling the servomotor position at the governor control cabinet and the personnel monitoring and recording the data at the turbine servomotor.

The most basic test requires two pressure gauges and a calibrated scale located at the servomotor. More calibration testing can be made using calibrated pressure and position feedback transducers with a chart recorder.

At a minimum, two people for ½ day would be required to conduct the test. Note that the operating head across the turbine will limit when the test can be conducted at rated conditions.

Key Reference Documents

- FIST 2-7, *Mechanical Overhaul Procedures for Hydroelectric Units*
- FIST 2-12, *Mechanical Maintenance of Hydroelectric and Large Pump Units*
- ASME PTC 29, Speed Governing Systems for Hydraulic Turbine Generator Units

6.1.46.2 Servomotor Timing Tests

This test verifies the maximum rate timing of the turbine control servomotors. These servomotors are typically operated by hydraulic pressure from a dedicated hydraulic pressure system. Other types of turbine control actuators, such as electromechanical actuators, may also be used. The principles of measuring the servomotor timing are the same, regardless of the method of actuation.

For servomotors controlling water flow through the turbine, the servomotor maximum closing speed is particularly important in preventing the water hammer effect from causing the penstock to fail. A penstock failure can cause loss of life and severe damage to the surrounding area.

The timing of all turbine control servomotors contributes to the performance of the governing system, including the limitation of overspeed upon load rejection. Limitation of overspeed is important to prevent damage to the turbine and generator.

The wicket gate clearances are checked during the installation phase. The wicket gate clearances should be uniform and tight to limit water leakage through the gates while closed. Uniformity is critical in order to evenly distribute the servomotor force around the wicket gate linkages when the gates are in full squeeze. The adjustment of the wicket gates is performed during the installation stage, and it is one of the required prerequisites before starting pre-commissioning testing of the wicket gates.

A typical timing test consists of setting the governing system to operate the servomotor at its maximum rate through its full stroke. This is done in both directions of travel and may be done several times to verify the consistence of timing. Reclamation practice is to measure the stroke between 25% and 75% and double the result to avoid the effect that wicket gate cushion has at low gate openings, (see FIST 2-3). Opening tests are typically not performed in the commissioning phase. The timing is generally tested before watering up the unit, and again after watering up. Necessary adjustments may be made to the servomotor timing during the testing process in order to achieve the desired results. The opening and closing speeds of the servomotors is adjusted by placing a proper size orifice within the servomotor hydraulic circuit. This is critical for the safety of the plant operation in order to limit the amount of pressure rise within the water conveyance system. Certain applications may include more than one rate limiter in each direction to be employed under various operating conditions. In these cases, the servomotor timing should be tested for each distinct timing limiter.

The 0% position of the servomotor stroke is adjusted to provide a sufficient squeeze of the gates so there is minimal water leakage through the gates while the gates are closed. The position transducers associated with the servomotors are calibrated for the full open and full closed positions, which will eventually provide position feedback to the turbine governor for any position between 0% and 100% of the wicket gate servomotor stroke.

A similar approach is followed for the adjustment for the blade servomotor of Kaplan turbines.

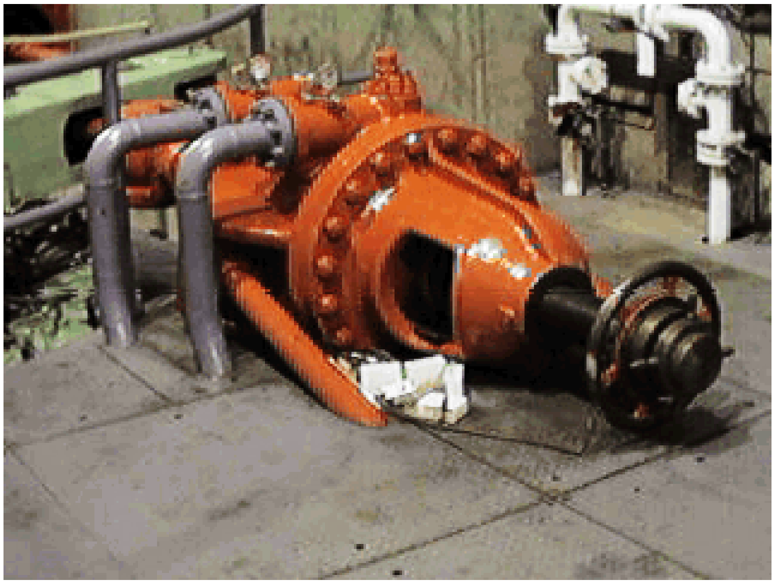
An indication of a servomotor position and a method of measuring time are required. This may consist of using a stopwatch while watching the servomotor position indicator, or it may consist of using an oscillograph recorder, or separate data acquisition, connected to a servomotor position transducer or timing function built into the digital governor. The method used to test the servomotor depends upon the degree of accuracy required along with the level of data documentation required for the installation.

The setup time can vary greatly, depending upon the type of instrumentation chosen for the test. The testing generally requires one person to operate the unit and one person to make the measurements. The duration of the actual testing can vary from 1 hour to several hours, depending upon the speed of the servomotor and the number of different timing settings. Other operational constraints may increase the time required for the test.

Key Reference Documents

- FIST 2-7, *Mechanical Overhaul Procedures for Hydroelectric Units*
- FIST 2-12, *Mechanical Maintenance of Hydroelectric and Large Pump Units*
- ASME PTC 29, Speed Governing Systems for Hydraulic Turbine Generator Units
- IEC 60308, Hydraulic Turbine – Testing of Control Systems
- IEC 61362, Guide to Specification of Hydraulic Turbine Governing Systems
- IEEE Std 125, IEEE Recommended Practice for Preparation of Equipment Specifications for Speed-Governing of Hydraulic Turbines Intended to Drive Electric Generators

- IEEE Std 1207, IEEE Guide for the Application of Turbine Governing Systems for Hydroelectric Generating Units
- IEEE Std 1010, IEEE Guide for Control of Hydroelectric Power Plants
- IEEE Std 1020, IEEE Guide for Control of Small (100 kVA to 5 MVA) Hydroelectric Power Plants



Photograph 29 - Servomotor

Photograph 30 - Servomotor connecting rod

6.1.46.3 Wicket Gate Shear Pin Failure Alarm System Check

The broken shear pin detector is a device that can take many forms depending on the design. Typically, all detectors of a unit are interconnected and are linked to the alarm panel. When a shear pin breaks, the pin of the detector breaks as well. This is indicated by an alarm signal and a detector that lights up to identify the broken shear pin.

Photograph 31 - Wicket gate shear pin

The pre-commissioning checks on the shear pin failure detection system involve verifying that the sensors are properly installed, as well as verifying electrical continuity and the operational state of the sensor.

Photograph 32 - Wicket gate and stay vanes

Key Reference Documents

- FIST 2-7, *Mechanical Overhaul Procedures for Hydroelectric Units*
- FIST 2-12, *Mechanical Maintenance of Hydroelectric and Large Pump Units*

– Design drawings and specifications

6.1.47 Static Excitation, Power Electronics

6.1.47.1 Harmonic Distortion Test

The characteristic harmonics produced by converters, excitation systems, etc., require balanced impedances in the ac system and equal firing of the thyristors. If the firing circuits do not operate symmetrically so that the commutation of each device is not correct, non-characteristic harmonics are produced. These normally are small, but with a parallel resonance at one of them, they can be amplified to a value that could cause problems.

A harmonic measurement or waveform evaluation (preferred method in Reclamation) should be performed as an acceptance test, to demonstrate that the equipment and the system's converter meets the performance specification.

The purpose of current and voltage harmonic measurements are to:

– Measure existing values of harmonics and comparison with recommended levels.
– Diagnose and troubleshoot situations in which the equipment performance is unacceptable to the utility or the user.
– Observe existing background levels and track the trends in time of voltage and current harmonics.
– Measure harmonic voltages and current with their respective phase angle to determine the harmonic driving point impedance at a given location.

The purpose of voltage waveform evaluation is:

– To observe balanced and proper firing of thyristor bridges.
– To observe proper functionality of snubber circuits.

Procedure (Voltage waveform evaluation)

Capture a voltage waveform snapshot similar to that pictured in Figure 3 using an oscilloscope with a high voltage probe or a high bandwidth voltage isolation amplifier that can handle at least 1.35x (low side exciter transformer voltage).

Test for balanced firing across all phases

Balanced firing across all phases helps ensure excessive harmonics are not being generated by exciter power electronics that are not working properly. It's important to observe balanced firing on test equipment to verify the thyristor bridges are working properly.

The waveform should look similar to the following figure when the thyristor bridge is firing correctly:

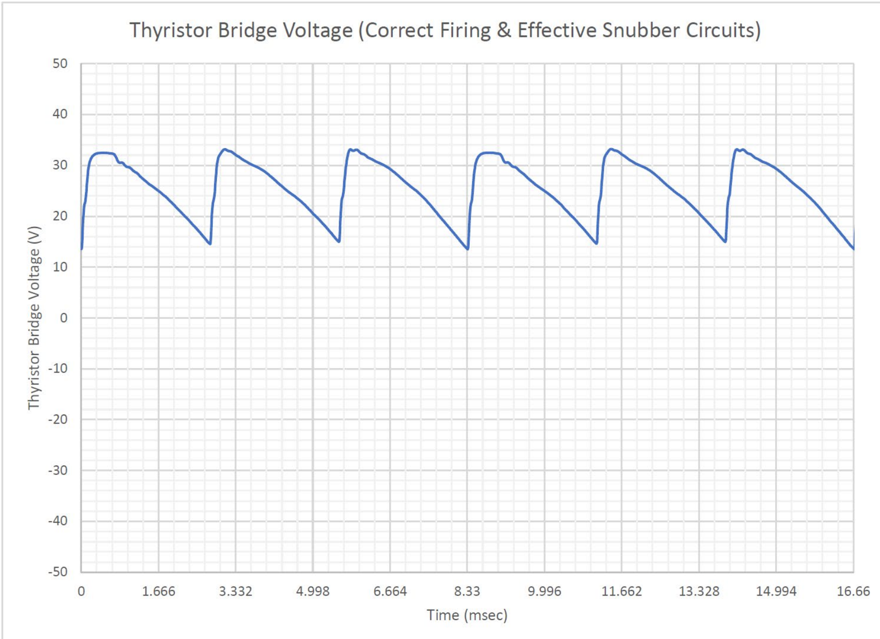


Figure 3 - Waveform example when thyristor bridge is firing correctly

Figures 4 and 5 show examples of waveforms of a thyristor bridge that is not firing correctly. If the waveform looks like the following curves, place the unit under clearance as necessary and check for blown fuses, loose connections, correct phase rotation, and functioning firing circuits. Then, check the waveform again and ensure the bridge is firing properly as shown Figure 3.

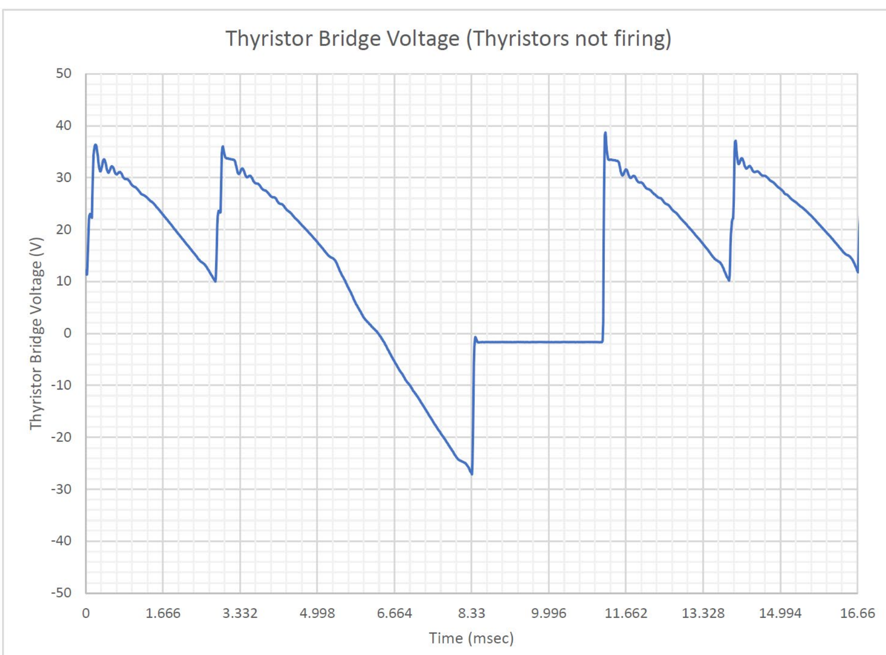


Figure 4 - Waveform example of misfiring thyristor bridge (thyrisotors not firing)

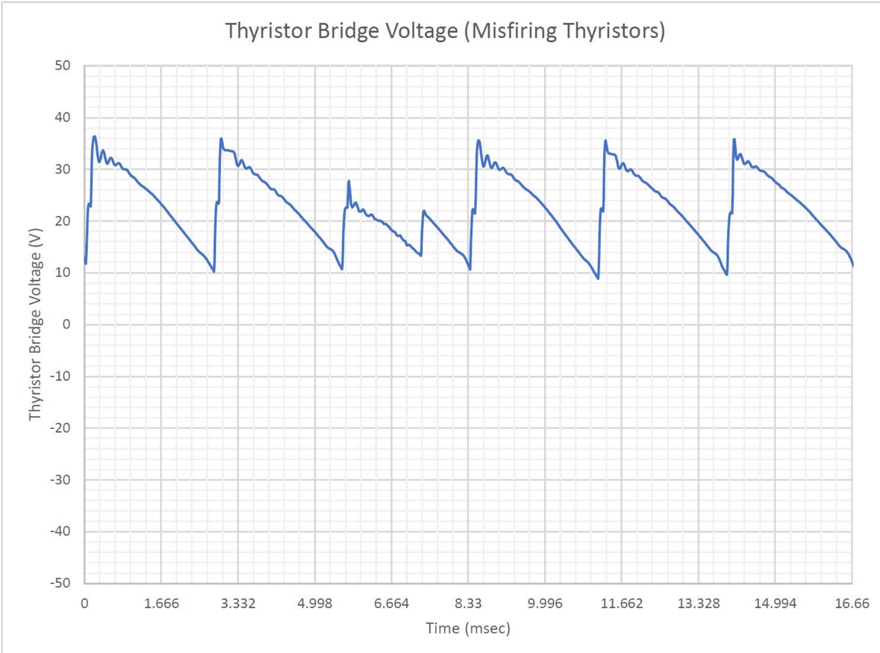


Figure 5 - Waveform example of misfiring thyristor bridge

Test snubber circuits for proper operation

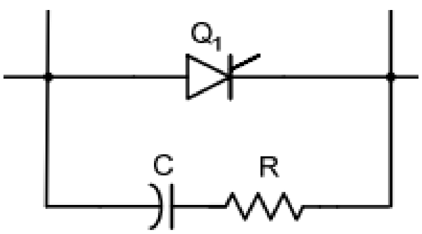


Figure 6 - RC snubber circuit

Snubber circuits are an important component to ensure proper firing of thyristor bridges. These circuits are intended to reduce peak turn on and turn off voltages and also to dampen ringing across the thyristor circuits. The waveform should look similar to Figure 3 showing correct firing and effective snubber circuits.

Figure 7 shows an example of a bridge waveform without snubber circuits. If the waveform looks like the following curve, the snubber circuits may need to be checked/adjusted and retested.

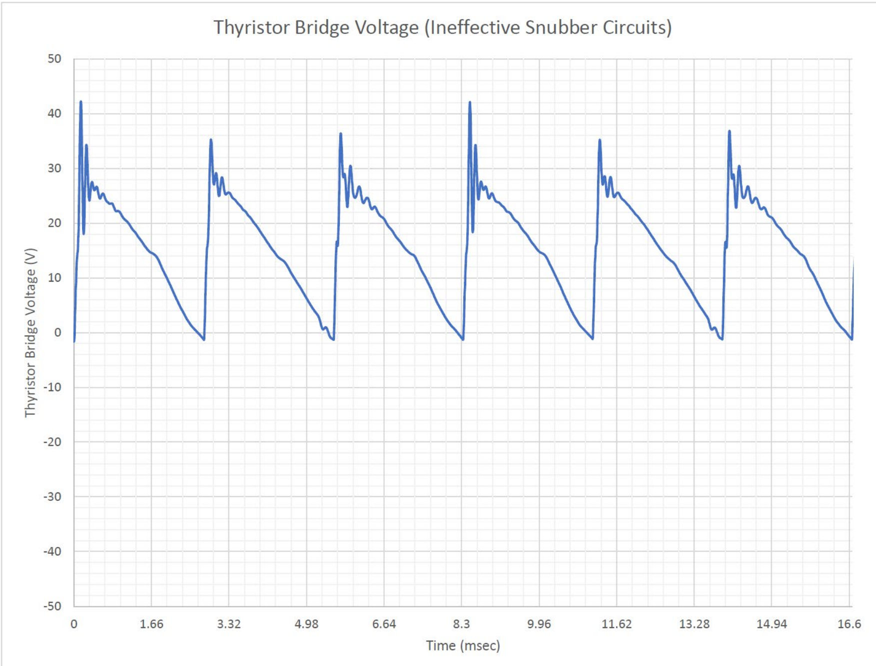


Figure 7 - Waveform example of thyristor bridge with ineffective snubber circuits

For the measurement and analysis of harmonics, the following equipment can be used:

- Spectrum analyzer. A range of frequencies are scanned, and all the components, harmonics, and inter-harmonics are displayed.
- Harmonic analyses or wave analyses. The amplitude and, depending on the equipment, the phase angle of a periodic function are measured.
- Distortion analyses. The total harmonic distortion is measured.
- Digital harmonics measuring equipment. The frequency range and the bandwidth are measured.

The measure and duration of these tests will depend on the number of devices and/or systems that will be analyzed. A typical test requires one person to perform the tests. Depending upon the equipment and/or system tested, and the number of measurements/analyses specified, the duration could range from less than 1 hour up to a few days. Additionally, the extensiveness of testing will determine the time required to perform the test.

Key Reference Documents

- IEC 61000-4-7+AMD1 CSV, Electromagnetic Compatibility (EMC)-Part 4-7: Testing and Measurement Techniques – General Guide on Harmonics and Inter-harmonics Measurements and Instrumentation, for Power Supply Systems and Equipment Connected Thereto
- IEEE Std 519, IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems

6.1.48 Station Ground Grid

6.1.48.1 Resistance Test

This test measures the true resistance to earth of the station ground grid, irrespective of the earth's resistance and condition. The purpose of this test is to:

- Determine the actual impedance of the ground grid.
- Provide a check on the ground calculation.
- Determine the rise in ground potential and its variation throughout an area that may result from ground fault currents in a power system.
- Determine resistance between station ground grid and a remote point.

The following instruments may be used for measuring ground resistance connections:

- Ground Grid test equipment.
- Wire to connect remote ground electrode and voltage probe to test set located at the ground grid.
- For large ground grids it may be necessary to use a higher voltage current source capable of delivering around 10 Amps along with a current and voltage meter. 60-Hz current sources need to be avoided as power system current in the earth will interfere with the test measurements.

The time for setting up the instrumentation and collecting the data should be approximately 1 to 2 days. The time depends on the size of the station ground grid, which determines the distance of the remote electrode from the ground electrode.

Key Reference Documents

- Swedish Std SS0EN-50522 R1, Earthing of Power Installations Exceeding 1 kV ac
- IEEE Std. 81, IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Grounding System

6.1.49 Station Service Power

6.1.49.1 Switchgear Lineup

The tests on the low voltage portion of station service switchgear are divided into two parts:

- Visual inspection
- Tests/system checks

The following safety considerations must be met prior to testing:

- Ensure that proper lock-out tag-out is performed on electrical energy sources before testing.
- Confirm all safety measures are taken to ensure the people in the vicinity of the test area are aware of high voltage testing.
- Verify the nameplate data for the switchgear and breakers match the approved drawings.
- Confirm correct operation and sequencing of interlock systems.
- Verify the anchorage, alignment, and grounding connections are satisfactory.
- Note the as-found breaker operation counter readings.
- Perform wiring checkout inspections to verify wiring in the switchgear matches the drawings.

After the visual inspection is complete, the system checks or tests include the following activities:

- Testing of all bolted connections for high resistance.
- Testing of the auxiliary ac and dc power circuits. This includes verification of accurate ac and dc power supply voltage and verifications of the heaters and lights in the system.
- Measurement of the contact resistance.
- Insulation resistance test for phase-to-phase and phase-to-ground.
- The dielectric test is performed between each phase-to-ground.
- Tripping the breakers by operation of each protective device.
- Correct operation of racking mechanisms.
- Performing a ground resistance test.
- Testing any instrument transformers in the switchgear.
- Testing metering devices.

Key Reference Documents

- Control sequence schematic drawings
- Wiring diagrams
- Manufacturer's O&M manuals
- Plant design criteria documents

6.1.49.2 Bus Transfer Test

Bus transfer tests should be included prior to placing station service switchgear in service, if applicable.

Bus transfer breakers are included to provide a backup or alternate source of station service power. Bus transfer breakers can be designed with interlocks to allow only one transfer breaker to be closed at a time. Other designs provide for both transfer breakers to be momentarily closed to provide a "no-break" transition. Typically, the design provides for automatic closing of the backup breaker if power should be lost on the preferred source breaker.

Bus transfer tests should be conducted prior to energization. When draw-out bus transfer breakers are provided, preliminary tests should be conducted with both breakers in the "test position".

Prerequisite tests include:

- Transfer time, if applicable.
- Visual inspection.
- Mechanical operation.
- Phase rotation.
- Phase relationships.
- Trip test.
- Trip and close coil continuity.

Once prerequisite tests are completed, a hand-held multimeter is the only test equipment required to diagnose any malfunction.

If no circuitry problems are encountered, bus transfer tests typically can be completed in 2 hours.

Key Reference Documents

- Control sequence schematic drawings

- Manufacturer's O&M manuals
- Plant design criteria documents

6.1.50 Stop Logs/Sectional Gates

Stop logs or sectional gates are used at the unit headworks and/or the tailrace to isolate and dewater the intake gate, the penstock, and the turbine. They are generally designed to be installed in still water and have no rollers. They are normally made of steel and are placed and stacked one on top of the other within steel-lined guides. They have pockets at each end for engagement by lifting beam hooks. Generally, they are handled by an electrically powered crane, monorail hoist, or a mobile crane.

Photograph 33 - Stoplog for main intake wheel-mounted gate

The following checks and tests should be performed:

- Check that each sectional gate or log travels freely inside the guides and confirm the operation of the lifting beam.
- Check lifting beam operation for the bottom-most gate/log to ensure it engages and releases under maximum water depth.
- Check the quantity of leakage past the seals with the head pond or tailrace elevation at or near the design level head for the sectional gates/stop logs.

Key Reference Documents

- FIST 2-13, *Gates and Valves*
- Design specifications and drawings

6.1.51 Strainers

Main strainers are installed in the service water piping and/or the cooling water piping and are used to remove debris and foreign objects from the water. They are typically of the duplex or double basket type, which are essentially two strainers operating in parallel (one in use and the other available for cleaning).

Photograph 34 - Automatic self-cleaning, motor-operated strainer

Large strainers will have differential pressure gauges to show the pressure drop across them so that a clogged strainer basket can be removed from service and cleaned. Automatic cleaning will occur when the operating strainer reaches a pre-set pressure differential.

The following checks and tests should be performed:

- Flush the connecting water pipes to the strainer.
- Perform a hydrostatic pressure test at the pressure and duration recommended by the supplier to ensure that all joints are watertight.
- Check for proper operation of the isolation valves for the strainer.

Key Reference Documents

- FIST 2-6, *Maintenance of Auxiliary Mechanical Equipment*
- Operation and maintenance manual

6.1.52 Substation (High Voltage)

Typically, the major high voltage equipment within a substation consists of:

- High voltage circuit breakers
- High voltage disconnect switch
- High voltage potential transformer
- High voltage current transformer
- High voltage cable or bus

This section provides pre-commissioning guidance for the high voltage substation equipment.

High Voltage Circuit Breaker

The commissioning process for a high voltage SF_6 circuit breaker is discussed below. Typically, most outdoor high voltage circuit breakers use SF_6 as an insulating gas and arc extinguishing medium.

The test on these breakers is divided into two sections:

- Visual inspection
- Tests/system checks

The following safety considerations must be met prior to testing:

- Ensure proper lock-out tag-out is performed on electrical energy sources before testing.
- Confirm that all safety measures are taken to ensure that people in the vicinity of the test area are aware of high voltage testing.
- Verify the nameplate data matches the approved drawings.
- The overhead line termination of the breaker must be checked. This includes confirmation of the torque values, as well as confirmation that no unusual conditions exist.
- The circuit breaker bushings must be checked for any cracks or unusual conditions.
- Ensure there are no gas leaks.
- Verify the anchorage, alignment, and grounding connections are satisfactory.
- Note the as-found operation counter readings.
- Perform wiring checkout inspections to verify wiring in the breaker cabinet matches the drawings.

After the visual inspection of the breaker is complete, the system check or test includes:

- Testing of all bolted connections for high resistance.
- Testing of the auxiliary ac and dc power circuits. This includes verification of accurate ac and dc power supply voltage and verifications of the heaters and lights in the system.
- Testing of the gas system, which includes verification of SF_6 gas pressure, detection of any gas leakage, and the gas alarm check.
- Testing of the charging and discharging operation, which will confirm that the spring mechanism is in proper working condition.
- Testing of the electrical interlocks with the associated disconnect switch(es) to confirm they are operational.
- Measurement of the contact resistance.
- Insulation resistance test for phase-to-phase and phase-to-ground. Typically, those tests can be done at a 5 kV voltage level.
- The high voltage test or dielectric test is performed between phase-to-phase and phase-to-ground. The test voltage should be determined based on the system voltage.
- The timing test should be performed to verify the opening and closing time of the breakers.
- Tripping the breaker by operation of each protective device.
- Testing any instrument transformers at the breaker.
- Performing hot-collar tests on the bushings. If the bushings have a power-factor/capacitance tap, a power-factor or dissipation-factor test may be performed instead.

High Voltage Disconnect Switch

High voltage disconnect switch testing is similar to high voltage circuit breaker testing. Before the test, the switch must be installed properly and anchored to the ground. The circuit breaker must be open and locked out.

The preliminary part of the testing includes a visual inspection. The method used for the visual inspection of the high voltage disconnect switch is similar to that used for high voltage breakers. Additional checks and inspections include verifying the switch operating platform is grounded by connection to the switch operating mechanism and not directly to the ground mat, recording the as-found operation counter, if equipped, and verifying the nameplate data matches the approved drawings.

The tests on the disconnect switch(es) includes:
- Testing of all bolted connections for high resistance.
- An insulation resistance test on each of the poles, including phase-to-ground and phase-to-phase measurements.
- High voltage phase-to-phase and phase-to-ground testing on each pole. The applied voltage for the high voltage test will depend on the system voltage and will be determined as recommended by the equipment supplier. The high voltage test is typically done for one minute.
- A contact resistance measurement test using a dc current source. The three phase readings must be checked for any significant variations.
- Manually check the operation of the disconnect switch and the interlocking conditions.
- Verifying the correct operation of indicating devices.

After all the above tests have been completed successfully, verify the tightness of all the connections and then the disconnect switches will be ready for operation.

High Voltage Current Transformer

Prior to testing the high voltage current transformer, the following prerequisites must be met:
- Confirmation of the overall condition of the current transformers. This is to ensure there is no visual damage. It is not possible to review the condition of bushing type current transformers.
- Confirm that the electrical connections are correct, and the grounding is in good condition.
- Check that the nameplate information is correct and in accordance with the design drawings.
- The current transformer secondary circuits must be grounded to one point. Verify that the secondary wires are connected to the proper ratio terminals.

After satisfactory completion of the visual inspection, the following tests should be carried out for the current transformers:
- A ratio test, which is necessary to check the turns ratio of the current transformer.
- Testing the polarity of the current transformers.
- Measurement of the current transformer saturation curves.
- The insulation resistance test should be performed using an appropriate insulation measurement device. It will measure the insulation resistance for primary to ground, primary to secondary, and secondary to ground.
- Measuring the current circuit burdens at the current transformer shorting block.
- The secondary circuits should be checked for continuity and insulation resistance.

High Voltage Potential Transformers

The high voltage potential transformers are checked in a manner similar to the method used for the current transformers. The following tests need to be performed on the high voltage potential transformers. A visual test is performed to ensure that the potential transformers are ready for operation. Visual testing includes:
- Check the overall condition of the potential transformers to ensure there is no damage.
- Check that the nameplate data of the potential transformer matches the design document requirements.

- Verify that all field cables meet the design requirements and are properly installed.
- Confirm that the overhead cable terminations are correct for the potential transformer.
- Check the bushings for any unusual conditions.

After satisfactory completion of the visual inspection, the following tests should be carried out for the current transformers:

- A ratio test, which is necessary to check the turns ratio of the potential transformer, at all tap positions.
- Testing of the polarity of the potential transformers.
- The insulation resistance test should be performed using an appropriate insulation measurement device. It will measure the insulation resistance for primary to ground, primary to secondary, and secondary to ground.
- Measuring of the voltage circuit burdens at the voltage transformer terminals.
- The secondary circuits should be checked for continuity and insulation resistance.

6.1.53 Sulfur Hexafluoride Gas (SF_6)

6.1.53.1 Gas Pressure Test

Gas pressure and density testing verifies the correct amount of insulating gas, commonly SF_6 is in the system at the correct pressure and density which ensures the circuit breaker interrupter will be able to properly quench and interrupt electrical current in the arc produced when the circuit breaker opens under load or fault. SF_6 gas also plays an important role in the mechanical performance of the circuit breaker. Care must be taken to not operate a circuit breaker using the main operating mechanism without the proper amount of gas; otherwise, damage to the circuit breaker may occur. If the breaker contacts need to be moved and gas is not present in the breaker, follow the manual operation instructions to bypass the main operating mechanism.

Static equipment such as switchgear, transformers, and bushings that are filled with SF_6 have guidelines that are defined in the O&M manual. Refer to O&M manual for specific guidelines that dictate how equipment should be tested and operated when insulated with SF_6 gas.

CAUTION: SF_6 gas is a harmful greenhouse gas regulated by Federal and State entities. Ensure personnel are trained in the proper handling and containment of SF_6 to prevent unintentional environmental release.

CAUTION: Equipment damage will occur if bad SF_6 gas is placed in service.

SF_6 gas should be tested for purity, water content, and arcing biproducts prior to energization using a calibrated SF_6 gas analyzer to ensure the gas will perform properly when interrupting faults or loads. Refer to the most up-to-date SF_6 gas purity guidelines for more details on acceptable gas properties. Some SF_6 analyzers will inform the user if the gas is unsafe to use. If in doubt about the gas analyzer results, do not put the gas into service and seek advice from an SF_6 expert or certified SF_6 gas handler. Gas that does not meet minimum standards should be properly recycled.

Care must be taken to accurately track the amount of gas used or lost while it is under the control of the organization. Use a calibrated scale suitable for weighing gas bottles up to 300lbs with precision of one tenth of a pound and track the weight carefully to ensure the facility is compliant with reporting requirements. If using a scale built into gas handling equipment, ensure the scale is functional prior to use. Use proper equipment that is designed for handling SF_6 to minimize losses. Failure to adhere to this can result in fines and criminal investigation.

Required. SF_6 gas handling equipment includes charging and testing equipment as applicable. Operators of equipment should have at least been trained and certified once in the last 5 years by a certified gas handling instructor. Operators are highly recommended to attend hands-on training prior to handling SF_6 gas. However, online training is available and is recommended for operators who have attended hands-on training at least once in their career. Refrigerant gas leak detectors can detect SF_6 gas leaks and should be used to ensure a freshly charged system does not have leaks prior to energization. Alternatively, system seal integrity can be vacuum tested prior to filling a vessel with SF_6.

Verification of pressure in bus or breaker bottles is a simple procedure and can be completed within hours. Charging and quality verification are more complex, require specialized equipment, and may take a day to a few days depending on the complexity and size of the system.

Key Reference Documents

- Operations and Maintenance Manuals
- IEEE Std C37.122.3, IEEE Guide for Sulfur Hexafluoride (SF_6) Gas Handling for High-Voltage (over 1000 Vac) Equipment
- IEC 60480, Guidelines for the Checking and Treatment of Sulfur Hexafluoride (SF_6) Taken from Electrical Equipment and Specification for its Re-use.
- IEC 62271-4, High-Voltage Switchgear and Control Gear – Part 4: Handling Procedures for Sulfur Hexafluoride (SF_6) and its Mixtures
- DILO SF_6 Gas Handling Manual

6.1.54 Sump Pumps and Dewatering Equipment

The dewatering system typically includes one or more dewatering sumps. The draft tube drain line from the units discharges directly into the dewatering sump. The flow from each draft tube drain line is controlled by a manually operated valve.

Typically, two pumps are located in the dewatering sump. They are used to discharge the collected water out to the tailrace. These two pumps operate in a lead and lag configuration and are controlled by a level control system. In a common design, an internal pressure transmitter measures the amount of pressure required to force the bubbles of air out of the bottom of the tube; this pressure is considered proportional to the depth of water in the sump.

A separate submersible level transmitter provides the dewatering sump water level indication signal to the control room. This transmitter does not control any pumps or devices.

Typically, a float switch or other device provides a high-level alarm in the event that the dewatering sump reaches a high level.

Photograph 35 – Sump pumping unit discharge assembly

The following items should be completed prior to functional testing of the system:

- The equipment is installed, including the associated motor control center and the pump control units.
- Pump motor checks are complete.
- Calibration and setting of the bubbles (or other) control system of the dewatering pump.
- Setting of devices (such as the pressure transmitter).
- Insulation test on the power cables.
- Ensure all the valves within the system are in the proper position.

Once all the above conditions are met, perform functional checks on the level controls, dewatering sump level transmitter, and dewatering sump high level alarm switch and then perform the following operational checks:

- Ensure that the dewatering sump hatch cover is closed and sealed.
- Verify that the dewatering sump level transmitter indicates an empty sump.
- Switch on the necessary power to the sump panel, set the selector switches to auto, and select the lead and lag pump.
- Fill the sump and observe the normal operation of the lead pump; record the lead pump start level elevation.
- Continue filling until the lag pump starts; observe the normal operation of the pump and record the level transmitter reading.
- To check the pump stopping logic, close the filling valve, run the lead and lag pumps in auto, and check that the lag pump stops at the desired elevation and that the lead pump stops after that.
- After the above test is completed, fill the sump again. As the level increases, ensure that the lead pump starts first followed by the lag pump.
- Test the high-level alarm in a similar manner.

Key Reference Documents

- FIST 2-12, *Mechanical Maintenance of Hydroelectric and Large Pump Units*
- Design specifications and drawings

6.1.55 Three-Phase Power System

6.1.55.1 Phase Relation Test

The phase relation tests are intended to confirm that phase relationships are consistent throughout the plant. The standard phase arrangement on three-phase assembled switchgear buses and primary connections should be 1, 2, 3 or A, B, C from front to back, top to bottom, or left to right, as viewed from the main switching device operating mechanism side. Certain types of equipment may require other phasing arrangements and a neutral conductor. In these cases, the phasing should be suitably indicated.

Panel mounting devices should be mounted in the same arrangement as described above as viewed from the front of the panel.

The phase sequence on connection diagrams should be such that, when considering voltage to neutral on a polyphase system with respect to the element of time, the voltage of phase 1 should reach a maximum ahead of the voltage for phase 2, phase 3, etc. This sequence should be designated as phase sequence in the order 1, 2, 3 unless otherwise suitably indicated.

Phase sequence test is made on a generator to ensure the terminal markings are in agreement with specified phase rotation. The test is performed by running the generator and connecting a phase sequence meter to the terminals.

The phase relationship should be verified prior to energizing any equipment at system voltage. Phase Relation Tests are essential for PT circuits used for generator protection and synchronization. Automatic Synchronizers and Sync-check protective relays cannot detect a mis-aligned phase relationship and closing a generator out of phase could occur which may result in significant damage to equipment.

Given that the phase relationships are identified at the plant terminals, all three-phase equipment including auxiliary motors, motor control equipment, station service switchgear, and transformers and generators must be phased correctly and continuously back to the plant terminals.

In some cases, the phase relationship can be verified by visually tracing bus duct and tray cable.

A fused single-phase low voltage source is preferred for initial phase relationship tests. Connect across phases 1-2 at source, and identify at end, then 2-3, then 3-1. With this method, each phase at end can then be identified.

As a prerequisite test, check that the 3-line drawings employ consistent phase relationships.

The phase sequence test requires a phase sequence meter. The phase relation test requires a low-voltage single-phase power source and a multimeter.

Duration of phase sequence and relationship depends entirely on access and stability. If the conductors can be visually traced back to plant terminals, approximately 1 hour per piece of equipment would be required for two people to remove covers and visually trace. If tests must be set up, approximately 4 hours per piece of equipment would be required.

Key Reference Documents

- IEEE Std C37.20.1, IEEE Standard for Metal-Enclosed Low-Voltage (1000 Vac and below, 3200 Vdc and below) Power Circuit Breaker Switchgear
- IEEE Std C37.20.3, IEEE Standard for Metal-Enclosed Interrupter Switchgear

6.1.56 Trashracks

Trashracks are provided to prevent floating or submerged debris from entering the water passage and damaging downstream equipment such as stay vanes, wicket gates and runners, and also to prevent debris from lodging in the runner (Francis-type turbines) and causing unbalance and vibration trips. They are installed at the headworks in front of the unit intakes and are made of rectangular or shaped steel bars or, in some cases, plastic bars.

The debris that accumulates on the trashracks may be able to be cleaned manually using a hand rake in small hydro stations or using a motorized trash rake for medium to large-sized stations. Motorized trash rake cleaners can be of the wire rope type or hydraulic boom type.

Trash rake cleaning machines can be of the stationary or mobile type and can be manually or automatically operated and powered by electrical or hydraulic power.

Photograph 36 – Intake structure with exposed trashracks

The following checks and tests should be performed:

- Often, trashrack installations have instrumentation to measure head differential across the racks. Check functionality of the instrumentation before and after the water passage is filled.
- Check the travel of the cleaning rake against the design travel.
- For mobile trash cleaning machines that travel on steel rails, check the gauge of the steel rails at various locations before the machine is moved from one end of the dam to the other.
- For automatically operated cleaning machines, verify the correct operation of the limit switches to control travel of the cleaning rake from top to bottom.
- Check power required to operate the cleaning rake by measuring the voltage and phase current of the drive motor.

- For hydraulic motor operated cleaning machines, record the hydraulic pressure as the cleaning rake is moved from the bottom to top positions.

Key Reference Documents

- Operation and maintenance manual

6.1.57 Turbine-Generator Unit

6.1.57.1 Bearing Insulation Test

The purpose of this test is to help verify that satisfactory bearing insulation is present to prevent shaft voltages from creating damaging current flow through the oil films in thrust and/or guide bearings.

The need for shaft insulation is present in all electric machines; however, it is most important for large hydroelectric units with upper bearings. On hydroelectric units, the shaft system is usually grounded at the turbine end of the unit and the opposite bearing or shaft apparatus is insulated.

The unit assembly, including any equipment or parts adjacent to the insulated end of the shaft, should be completely assembled in order to check the insulation of all the appropriate parts.

An ohmmeter is used to measure across the insulation. If two isolation points are provided, an insulation resistance test may be performed.

An ohmmeter capable of reading high resistance (megaohms) should be used.

One person can easily perform the test; however, additional personnel may be needed to provide access to the required area. The test can be performed quite quickly. The actual reading only takes a moment or two.

Key Reference Documents

- IEEE Std. 43, IEEE Recommended Practice for Testing Insulation Resistance of Electric Machinery
- IEEE Std. 1095, IEEE Guide for Insulation of Vertical Generation and Generator/Motors for Hydroelectric Applications

6.1.57.2 Clearance Measurements

This test covers clearance and runout measurements of all critical hydroelectric turbine components. All measurements should be conducted by knowledgeable personnel experienced with the type of turbine to be tested. This test should be conducted both as a prestart test and during performance testing. The purpose of the test is to obtain measurements to confirm that there are no abnormalities in the condition or performance of the turbine components that could indicate improper functioning, efficiency, or incipient component failures. The following clearance measurements should be obtained:

- Runner seal or blade tip clearances and the surface roughness
- Blade operating system if required
- Wicket gate head-to-toe clearances, wicket gate top and bottom clearances, and wicket gate bearing dielectric clearances

- Shaft clearance and runout
- Guide bearing clearance and runout
- Shaft seal
- Servomotor (gate and blade)
- Discharge ring
- Spiral case and draft tube liner
- Cooling and seal water flow
- Greasing system
- Isolation valve control system
- Pressure relief valve (if any)
- Generator-turbine shaft coupling
- Thrust bearing
- Shaft speed sensors (governor)

Because of the great variety of equipment required for the clearance measurements, it is not practical to list all test equipment. Some of the equipment required are dial indicators, straight edges, feeler gauges, plumb bobs, measuring tapes, lasers, and levels.

Generally, up to four people are required for a measurement. An operator is needed to check the automatic process measuring items such as wicket gates, servomotors, etc. The time needed can vary from 1 to 8 hours.

Key Reference Documents

- FIST 2-7, *Mechanical Overhaul Procedures for Hydroelectric Units*
- FIST 2-12, *Mechanical Maintenance of Hydroelectric and Large Pump Units*
- Turbine Manufacturer's Instruction Book
- IEC 60041, Field acceptance tests to determine the hydraulic performance of hydraulic turbines, storage pumps, and pump-turbines
- IEEE Std 810, IEEE Standard for Hydraulic Turbine and Generator Shaft Couplings and Shaft Runout Tolerances
- IEEE Std 1095, IEEE Guide for the Installation of Vertical Generators and Generator/Motors for Hydroelectric applications

6.1.57.3 Shaft Runout

The purpose of this test is to determine the amount of runout that is present in the assembly of the shaft system.

The test applies to the shaft line assembly, in particular with large hydroelectric turbine generator units.

The shaft system is rotated slowly to a number of positions, and readings are taken from fixed datum points that are axially aligned. Precision levels and dial indicators, laser systems, or four plumb wires are commonly used. The amount of shaft sideways motion and the amount of play in the system are measured.

The shaft system should be fully assembled, and the bearings should be ready for slow rotation.

Equipment required: Precision levels and dial indicators, or laser systems, or plumb wires with oil damping pots or other vertically aligned measurement equipment accurate to about 1/1000 in.

Generally, a small number of people are needed to rotate the unit and one person is needed at each bearing to record measurements. Once the rotation is able to be made, a full set of readings can usually be taken in under half a day.

Key Reference Documents

- FIST 2-7, *Mechanical Overhaul Procedures for Hydroelectric Units*
- FIST 2-12, *Mechanical Maintenance of Hydroelectric and Large Pump Units*
- IEEE Std 810, IEEE Standard for Hydraulic Turbines and Generator Shaft Couplings and Shaft Runout Tolerances
- IEEE Std 1095, IEEE Guide for the Installation of Vertical Generators and Generator/Motors for Hydroelectric Applications

Photograph 37 – Shaft and coupling

6.1.57.4 Initial Rotation Test

The test is intended to verify that there are no mechanical obstructions preventing free rotation of the turbine or generator.

The test applies to all rotating apparatus such as pumps, motors, generators, and turbines.

The unit should be ready in all aspects for rotation. It should be inspected for loose or inappropriate hardware, and any bearing forced lubrication should be operative.

The unit is slowly rotated using small amounts of force such as turning by hand for small machines or turning utilizing a few people (ropes, boots) on larger units. Several people may need to be stationed in various parts of the unit to listen for obstructions.

No special equipment is required.

A simple rotation test will typically take only about 2 hours to set up and execute.

Key Reference Documents

- FIST 2-7, *Mechanical Overhaul Procedures for Hydroelectric Units*
- FIST 2-12, *Mechanical Maintenance of Hydroelectric and Large Pump Units*
- IEEE Std 1095, IEEE Guide for the Installation of Vertical Generators and Generator/Motors for Hydroelectric Applications

6.1.57.5 Alignment of Shaft System

The rotational alignment of the unit shaft system (the generator and turbine shaft assembly) consists of checking:

- The verticality of the axis of rotation.
- The static shaft runout at all guide bearings.
- The concentricity of the runner and turbine guide bearing journal within their associated stationary boxes/enclosures and the generator rotor within its stator.

Verticality

The verticality of the unit axis of rotation is checked following the assembly of the unit. The unit thrust bearing is installed but the oil pot is empty. The unit is raised on the brakes and lubricant is sprayed between the thrust bearing pads and the runner plate. To prevent skating of the shaft assembly, its radial movement at the thrust bearing is temporarily restrained to a maximum of 0.1 mm.

A prerequisite for carrying out the alignment is that the shaft must hang free on the thrust bearing. Freedom of movement can be checked by manually pushing the shaft in two perpendicular planes and observing the magnitude of its displacement. The shaft should move in either plane freely. To ensure that the shaft can move freely, the guide bearings are not installed (or the segments are backed away from the shaft) and the shaft seal is not installed.

Runout

The static runout of the turbine and generator shaft is checked to ensure that the angular misalignment (dog leg) at the generator shaft to turbine shaft flanged joint is within tolerance and the perpendicularity at the thrust bearing is also within tolerance.

The runout can be checked by measuring the radial displacement of the shaft journals using electronic sensors, inside micrometers or dial indicators. The shaft assembly is rotated manually to a minimum of four angular positions: 0 degrees, 90 degrees, 180 degrees, and 270 degrees. One set of readings is taken in the x axis and one set of readings is taken in the y axis at each elevation and rotational position.

The readings should be taken close to the generator bearing, above and below the shaft's coupling and at the turbine guide bearing, subject to accessibility.

Concentricity

The unit rotating assembly including the rotor, shaft(s), and runner must be centered within the stator bore, bearing housings, and runner enclosures wear rings, respectively. The turbine runner is centered within the stationary water passage first. The rest of the components are centered to respective boxes. Most guide bearing designs have provisions for radial adjustment of individual segments and the bearing housing support on the head cover to ensure that concentricity can be achieved. The generator stator can also be moved radially to ensure the rotor is concentric to the stator.

To check for rotating assembly concentricity, radial measurements of the generator air gap, guide bearings, and runner clearances are taken. Generally, starting with pole no. 1 with the rotor aligned in the upstream direction of the water passage, the rotor is rotated manually to various positions and the air gap is measured at a set vertical distance from the bottom of the poles and from the top of the poles. At the same time, the guide bearing housing clearances and the runner clearances are measured. For turbines with Francis-type runners, clearances are taken at the band and crown seals. For turbines with propeller type runners, the blade tip clearance is measured for each of the blades.

Both the stator to rotor air gap and the runner radial clearances can be plotted as polar graphs, to help with the analysis of the concentricity.

To carry out the alignment, a variety of tools can be used, including precision electronic levels or a laser system. Both methods require the slow rotation of the unit rotating assembly, typically done manually. Other equipment used includes electronic sensors, inside micrometers, or dial indicators.

Turning the unit assembly is typically accomplished by one person for small machines, while larger units may require several people to turn the unit and several people stationed in various parts of the unit to listen for obstructions.

A simple rotation test will typically take about 2 hours to set up and execute.

Key Reference Documents

- FIST 2-1, *Alignment of Vertical Shaft Hydro Units*
- FIST 2-7, *Mechanical Overhaul Procedures for Hydroelectric Units*
- FIST 2-12, *Mechanical Maintenance of Hydroelectric and Large Pump Units*
- IEEE Std 1095, IEEE Guide for the Installation of Vertical Generators and Generator/Motors for Hydroelectric Applications
- CEATI Erection and Alignment Guide

6.1.58 Turbine Inlet Valve

The turbine inlet valve is the main valve within the water passage system and a critical safety device. This valve is open when the turbine is in operation and is closed when the turbine is in a shutdown condition.

The following prerequisites must be met prior to performing the pre-commissioning checks and tests:

- Check that the turbine inlet valve is properly installed, and the installation checklist has been signed off.
- All necessary hydraulic connections between the turbine inlet valve and the hydraulic power unit are completed.
- Proper torque is provided on the couplings' flange bolts. This is a critical requirement.
- The electrical point-to-point check has been completed. This ensures that the interconnections of the control cables are correct.

- The pre-commissioning testing of the hydraulic power unit is completed, and it is placed in service.
- Ensure that all on-site personnel are removed from the inside of the penstock and turbine near the turbine inlet valve and from areas around the turbine inlet valve servomotor and operating lever.

Once all the above prerequisites have been completed, the pre-commissioning testing of the turbine inlet valve can be performed; the tests and checks include:

- Adjust the turbine inlet valve opening control valve in order to operate slowly, and during the opening of the valve, verify that the operation of the valve is smooth and uniform.
- Once the valve is fully open, check the opening position of the valve.
- In the next stage, adjust the close control valve to slowly operate the turbine inlet valve and close the valve. Verify that the movement of the valve during closing is smooth and constant.
- Perform operation of the turbine inlet valve a few times to confirm that its operation is smooth and constant.
- Measure the opening and closing time of the valve during operation. In order to comply with the hydraulic transient constraints, the opening and closing time of the turbine inlet valve may need to be adjusted. Accordingly, adjust the orifice in the hydraulic circuit of the turbine inlet valve to ensure that the opening and closing time of the valve matches with the design calculations.
- After the above tests are done, simulate a dry emergency shutdown and measure the closing time. The closing time of the valve should match the plant design requirements.

Key Reference Documents

- FIST 2-13, *Gates and Valves*
- Turbine inlet valve general arrangement drawing
- The high-pressure hydraulic power unit schematic associated with the turbine inlet valve operation
- P&ID of the overall system
- Other related documents, such as operation and maintenance manual

6.1.59 Vibration and Other Monitoring Equipment

The vibration monitoring system is typically part of the overall machine condition monitoring system in a hydro generating station. In this section, the commissioning process for the vibrational monitoring system is discussed and can also be applied to other components of the machine condition monitoring system.

The following prerequisites must be met in order to start the pre-commissioning testing of the vibration monitoring system:

- The dc power supply system is commissioned.
- The wiring of the vibration monitoring systems is checked against the diagram.
- The insulation of the incoming cables and the power cables has been checked.
- The plant unit control panel is tested and commissioned.

After all the prerequisites are met for the vibration monitoring system, a complete visual inspection needs to be performed on the equipment. The components of the visual inspection include:

- Check the external appearance of the assembly for signs of damage.
- Ensure that the assembly is completely clean.
- Check all the ground connections.
- Confirm that all mounting bolts are tight.
- Verify that all power and control wiring has been properly terminated and completed.

Once the pre-conditions are met and the vibration monitoring system visual inspection is complete, the next step will be to perform the electrical test and the configurational programming. The electrical tests include:

- Mechanical adjustment and verification of the proximity probes to ensure their corresponding outputs comply with the equipment manufacturer's recommendations and that the proximity probe distance to its target is set correctly.
- Once the probes are correctly adjusted, it is possible to program the probes into the corresponding channels on the central processing unit (CPU) board.
- At the same time, the corresponding alarm levels should be set in the system in accordance with the design documentation.
- When the generating unit is in running condition, measure the average vibration levels at no load unexcited, no load excited, and a continuous sweep from 0% to 100% load.

Proximity probes will be required to perform these tests.The time required to prepare and perform these tests will typically take 2 people about 2 days to complete.

Key Reference Documents

- FIST 2-7, *Mechanical Overhaul Procedures for Hydroelectric Units*
- FIST 2-12, *Mechanical Maintenance of Hydroelectric and Large Pump Units*
- Design drawings, schematics, and specifications

7.0 Functional System Testing

For the purposes of this document, functional system testing is considered to be part of the pre-commissioning phase and is also known as pre-commissioning testing. These test procedures provide all tests and checks necessary to verify that each hydroelectric generating unit support system (especially protection and control systems) is functional before startup testing of the hydroelectric generating unit. The purpose of the functional testing is to ensure each system and its components perform in accordance with design requirements and is complete and safe to energize or operate.

7.1 Initial Operational Tests

This test is usually thought of as the energization and first operation of powerhouse equipment. The process started with the simpler tests of system components and now has culminated in the actual operation of the equipment itself. Individual circuits are energized sequentially, and component operation is verified along with proper adjustments and indications (see calibration Section 6.1.35). After this process is completed on the auxiliary circuits, the final and full operation of the equipment or system is initiated. Usually, the equipment is brought up to a level below full operating condition and observations are made for proper operation. Then, in gradual steps, the equipment is brought up to full and complete operation. Again, verification is made for the proper control action, indication, and response to specific conditions. The final initial operation test is to observe the proper shutdown sequence of the equipment.

7.1.1 Supporting Documents

Since the variety of equipment and systems is so great, it is impossible to list all the references necessary for this test. The reader is referred to the O&M manuals furnished with the equipment that usually cover the necessary verifications and observations to be made for initial operation. Some complex systems that consist of a multitude of subsystems, such as a hydroelectric generator, require a startup individual.

7.1.2 Equipment Required

Additional equipment is not usually required other than that required for calibration. The necessary indicators or readouts are furnished with the equipment or system.

7.1.3 Duration/Work Required

The duration varies depending on the size and complexity of the equipment or system. It can vary from several hours for a battery charger to several days for a hydroelectric generator. The work effort reflects the same variance for the same reasons. For larger systems, it is probably not practical to perform the initial test with a single individual. Starting a hydroelectric generator, for example, requires several individuals for the entire test period.

7.2 Functional Testing

The concept behind functional testing is to test the entire system as a whole. The purpose is to verify as much as possible by simulating real operation. This will identify, to the greatest extent possible, any problems and issues before electrical energy and rotation is applied to the unit. Potential damage to the unit can be avoided and lost time minimized during wet commissioning if most, if not all, the interface problems can be determined during this stage. Wet commissioning interruptions are costly as many specialists and supervisory staff (from both equipment suppliers and owner) are effectively on hold, waiting for testing to resume. Functional testing is done with less people and consumes fewer person-hours.

Functional testing:

- Tests all the electrical and mechanical interconnection between systems.
- Tests multiple systems simultaneously and (most importantly) their interaction.
- Reveals problems and issues that dry testing of systems separately cannot discover.

Functional testing can be done in parts, but the goal is to eventually carry out a complete start to 100% load and back to stop simulation of the unit.

7.3 Startup of the Protection and Control System

By this stage, all protection systems (electrical power and mechanical equipment) have been dry tested. This means all pieces of equipment taken individually are operable. For example:

- All breakers can be tripped by all protection relays/control system and all telemetry has been verified to the controller (distributed control system [DCS] or PLC) and SCADA.
- All auxiliary systems are complete, dry tested, and powered (i.e., cooling water systems, oil lubrication systems, HPU, digital governor, etc.).

The excitation system is usually not part of this simulation.

The control system and SCADA are completely operational and dry tested; however, the remote-control SCADA link does not need to be operational.

7.4 Back Feed

For rehabilitation projects, the plant is usually already connected to the grid and ac station service is already in operation and this step may be skipped.

How far down the system to energize is dependent on many factors. For small- and medium-sized units, where a medium voltage generator breaker is installed, a decision must be made whether the main step-up transformer will be energized with full voltage (generator breaker open) or the voltage slowly built up with the generator (and disconnected from grid). Please consult the transformer manufacturer for recommendations. Generally, this is done for higher voltage and larger transformers. Another option is to test the transformer, bus CTs, and current protections by shorting 3-phases and using the generator to increase voltage from zero to establish full load amps.

This will confirm that all CT circuits and current protections (most importantly, the differential circuit protections) are operating properly, and equipment is run at full current prior to operation.

Although for a new construction project it is possible to complete commissioning up to the electrical run with temporary construction power feeding the unit ac station service, it is desirable to have the utility grid connection energized and supplying unit ac station service much sooner. This saves time by reducing this step during wet commissioning and reducing the potential for delay in wet commissioning if problems need to be resolved.

As all electrical distribution designs are different, it is important to study the electrical single line diagram and write an electrical energization plan with site-specific details, including actual site device nomenclature for the plan. The plan has to be unit specific to reduce the risk of turning on the wrong device (e.g., close transformer disconnect switch 89-1).

The prerequisites for this step are:

- All electrical testing completed on equipment.
- All electrical protections operational.
- Control and SCADA operational for this equipment (including alarms).
- Energization checklist and an energization plan needs to be prepared, reviewed, and accepted by all parties.

Start of energization:

1) Communicate the plan well in advance during weekly or daily construction meetings to all site personnel, including the emergency response teams.
2) Barricade or cordon off affected areas using warning tape and signage explaining the event.
3) Evacuate all non-essential personnel. Close breakers and switches from a remote location via SCADA if possible. This will remove all personnel risk. If this is not possible, have one person and assistant energize equipment. Proper PPE for this task must be worn. Choosing a time when the powerhouse would be ordinarily vacant is desirable. For example, choose before or after a work shift. The end of the work shift is best as there is no time pressure of people waiting to start work and the commissioning team has the entire day to prepare for energization.
4) Close breakers and switches one at a time from utility to generator breaker and lowest station service feeder in order. Observe correct voltage feedback from telemetry for each bus as each section is put into service.

After energization:

1) Communicate to all plant personnel which equipment will remain energized and off limits.
2) Remove barricades but leave appropriate signage about energized equipment.
3) Do not load the transformer until a 24-hour initial energization period is complete.
4) Monitor telemetry for the transformer in early stages, especially during initial loading.
5) Take fluid samples of the transformer based on the following for the first year in operation:
   a) Day 0: Beginning of energization (voltage soak 24-hours).
   b) Day 1: End of energization (voltage soak).
   c) Day 3: End of initial loading.
   d) Day 4: 24-hours after normal loading.
   e) Day 6: 72-hours after normal loading.

f) Day 13: First week of first month.
g) Day 20: Second week of first month.
h) Day 27: Third week of first month.
i) Day 34: Fourth week of first month.
j) Day 153: Four months after first month.
k) Day 272: Eight months after first month.
l) Day 398: Twelve months after first month.

7.5 System Tests

The first step toward "real world" operation of the unit is described in this section.

7.5.1 Simulation of Start/Stop Sequences

This is a functional test of the unit control system. Dry commissioning of the unit control system (PLC or DCS and SCADA) should already have been completed. Effort should be made to simulate as much as possible, to enable a full system test. Some signals and interlocks will have to be simulated, as the turbine inlet valve or gate will be closed, and the line side generator breaker disconnect switch will be open (no electrical back feed to generator breaker).

It is very possible (depending on control system complexity) that only the following telemetry signals would have to be simulated:

- Generator line side disconnect closed (physically open).
- Pressure in scroll case or intake shutoff device open.
- Governor speed signal (no physical rotation).
- Close breaker using manual synchronizer controls on generator panel. The sync check relay may have to be temporarily bypassed.

Once interlocks 1 and 2 are simulated, the commissioning engineers would issue a unit start command via SCADA. For digitally controlled units, a check of pre-conditions should be performed prior to starting the auxiliaries. Pre-conditions include verifying that power breakers are closed, lockouts are not tripped, the headgate is open, the unit is stopped with brakes on, etc. Checking the pre-conditions for digitally controlled units is similar to the tasks performed by the operators using a pre-start checklist for manually controlled systems. The unit should start all auxiliaries (i.e., bearing high lift, all cooling waters, release brakes, etc.). The tester then can issue an automated start command to the governor. The governor then should open the wicket gates. At this time, the governor speed signal, item 3 above, should be simulated from 0 to 100% speed (gradual ramp). The governor should control wicket gates accordingly and reach steady state position (speed no load).

At speed no load, the generator breaker can be physically closed by manual synch control and a load set point of 100% issued to the unit controls (gate mode).
The shutdown sequence at full load then can be tested by issuing a stop command from the unit controls. The unit should automatically unload and trip the breaker at speed no load wicket gate setting, and the simulated governor speed decreased from 100% to 0 %. The unit should close wicket gates (adjust runner blades of Kaplan turbines, etc.), apply bearing high lift oil, apply brakes, and shut off auxiliaries as per the programmed automation sequence.

It is important, if possible, to try all other automated operations (e.g., station service transfers, manual stop sequence, aborted start/stop) in both auto and manual during subsequent tests.

All issues and problems discovered and resolved during this stage will save time during wet commissioning and avoid possible equipment damage from improper automated sequence.

7.5.2 Simulation of Shutdown Sequences

During the simulation of start/stop sequences at 100% gate opening with the generator breaker closed, the following shutdown sequence should also be tested:

- Emergency stop (E-STOP)
- Turbine inlet valve or intake gate close
- Emergency shutdown (ESD)
- Quick shutdown (QSD) (Mechanical)
- Immediate shutdown (Electrical trip i.e., generator over current)

Observe the sequence of events during the shutdown and compare with the trip matrix. For example, on quick shutdown, the generator breaker should delay opening until approximately the gate position reaches speed no load.

7.5.3 Simulation of Protection System Trip Sequences

Testing of all protection system trip sequences at once (right before wet commissioning) is a worthwhile task. Even though all these devices have been individually tested over the course of dry commissioning, those individual tests spanned many weeks/months, and were performed by many different commissioning engineers and technicians. It may have been the case that they were not tested in stages from the source to the end device. It is also possible that subsequent testing or even construction crews could have accidentally disconnected or shorted a protection device, even after it has been dry commissioned.

Testing all protection signals at once right before wet commissioning proves that nothing has been accidentally disabled. This detailed procedure is created from the "Unit Trip Matrix" which defines all the trip functions both mechanical and electrical. The trip list is then detailed with actual unit-specific nomenclature (test switches, terminals, relays, etc.). Two to three technicians familiar with the protection system can complete this procedure in a few hours, if well planned.

7.5.4 Verify Unit Control by HMI/SCADA System (Local and Remote)

Local HMI control will be function tested during the simulation of the start and stop sequences. If the remote SCADA connection is complete, then it should be verified during functional testing of the unit. Since the complete link between local HMI and remote SCADA should have been formally tested during the dry commissioning stage, only a few commands from SCADA are required (i.e., unit start, etc.). The most important test would be to confirm bumpless transfer when switching between local and remote (with the unit in simulated power production).

8.0 Commissioning Testing Phase

The commissioning testing phase is also known as startup, on-line (wet) testing, or commissioning testing and should be accomplished by the lead test engineer, plant owner's organization, and the vendor/contractor representatives to demonstrate satisfactory operation of the equipment being commissioned. This testing is performed with the various structures and equipment pressurized and the unit and systems powered up and ready to be placed into operation. These test procedures include mechanical and electrical runs. The mechanical runs are performed first. This phase includes all tests and checks that are necessary to facilitate satisfactory station commercial operation. This phase should include placing all systems in operation and ultimately operating the unit being commissioned at full load, including tests performed to demonstrate the operational performance of the turbine-generator unit.

In general, the commissioning phase involves the following major steps:

- Verification that all activities for the pre-commissioning phase have been completed including dry (off-line) testing and functional testing.
- Equipment start-ups for all major mechanical and electrical equipment and auxiliary systems should be completed to verify operation and warranty validation.
- Preparation for wet (on-line) commissioning checks, tests, and procedures.
- Watering up.
- Mechanical run.
- Electrical run.
- Off-line (not synchronized) electrical testing.
- Synchronization testing.
- On-line (synchronized to the grid) electrical testing, up to full load.

After these commissioning phase steps have been completed, the unit should be fully commissioned and ready for the trial run.

The lead test engineer usually directs all activities to ensure a smooth effective commissioning program and is typically responsible for the overall conduct of the commissioning program for all project equipment and systems. Whether the energy is electrical or fluid pressure, important safety factors must be addressed and controlled before energizing systems and components. There has to be agreement on which organization's work safety procedures all parties will adhere to. The lead test engineer usually has primary responsibility for scheduling and directing the efforts of those assigned to the performance of commissioning activities. The lead test engineer also typically coordinates the interface activities of the contractor for construction and the owner's personnel required to accomplish the commissioning program.

8.1 Commissioning Tests and Procedures

The contract specifications should dictate which entity is in charge of conducting commissioning tests. The unit startup and commissioning phase should be coordinated by the lead test engineer and the owner's or contractor's representative. Support services are normally arranged according to the following procedures:

- Contractors normally provide trade labor as requested by the lead test engineer in support of construction and pre-commissioning activities.
- The owner normally provides O&M personnel to support the startup pre-commissioning and commissioning activities.
- Construction contractors requiring vendor or sub-contractor service support should coordinate their requests with the lead test engineer.
- The lead test engineer should help ensure commissioning tests of contractor-furnished equipment and systems are performed.

Complete systems undergo commissioning testing to ensure systems and subsystems work together as intended. These test procedures include mechanical and electrical runs. The mechanical runs are performed first. This begins with the first rotation, also known as 'initial slow roll', tests under increasing load, and ends with mechanical overspeed testing. After the mechanical overspeed test, the unit should be dewatered and fully inspected. The generator can then be excited for the first time and all the off-line electrical tests can be performed. Synchronization tests and first connection to the grid occurs and allows the on-line electrical testing to be completed.

Commissioning testing of electrical systems generally consists of energization and placing the equipment in service. It may include tests for breaker and protection coordination, operating temperature, and power quality.

Commissioning testing of the turbine-generator unit generally includes, but is not limited to:

- Hydraulic operation of headgate or spiral case shut-off valves and proper setting of opening and closing times.
- Wicket gate or nozzle alignment and verification of proper opening and closing times.
- Governor control setting verification.
- Verification of proper lubrication and cooling of generator and turbine bearings.
- Final check of unit braking system.
- Initial operation of the turbine-generator and bearing run in.
- Electrical and mechanical overspeed trip tests.
- Final setting of vibration shutdown sensors.
- Voltage regulator and excitation system tests.
- Verification of proper generator-to-system phase rotation and synchronization.
- Testing and verification of electrical protection systems with load.
- Load rejection tests.
- Operation and monitoring via plant control systems (local and remote).
- Coordinated testing with all plant units.

Commissioning testing typically includes mechanical, electrical, and instrumentation aspects as shown in the following sections.

8.1.1 Preconditions

It is important to have the system functional tests complete prior to performing commissioning testing. This is a major milestone and there is usually documentation that contains a list of sign-off items and key signatures from the constructor and the owner confirming that the unit is ready for first rotation. Certain functional tests may not be able to be accomplished until certain clearances are removed and after the unit is watered up or control power to equipment is restored.

8.1.1.1 Safety Systems Operational

All safety systems must be operational. All critical systems should be confirmed to be operational by each commissioning specialist during the Pre-First Rotation meeting. The most important systems and actions are:

1) The E-STOP (emergency stop) of the unit that closes the wicket gates or turbine nozzles.
2) The emergency close of the main turbine shutoff device (i.e., head gates, turbine inlet valve, etc.).
3) The unit fire suppression system has been commissioned and pre-tested. In certain cases, the unit fire protection system can be disabled during functional and off-line tests to avoid inadvertently initiating the system during testing. It is then enabled for on-line testing. Alternate fire protection procedures should be placed to protect the unit and plant if this is done.
4) Protective relaying has been calibrated and tested.

If there are any doubts as to these systems, a quick test to confirm operational status should be completed prior to watering up the unit.

8.1.1.2 Dewatering Equipment Operational

It is very important that the dewatering system is operational and is placed in fully automatic mode. This includes any turbine pit dewatering pumps (including dc or ac redundant pumps) and all sump dewatering equipment. Many systems have small jockey pumps for second operations and switch-in larger dewatering pumps for emergency situations. Check that all drains are clear and that all valves are in their proper positions. The oil water separator should already be in operation at this point, since the governor hydraulics, the transformer, and the bearings have previously been filled.

8.1.2 Preparatory Work

8.1.2.1 Safety Considerations

Safety planning is important. Identify and list all risks, and plan appropriate safety procedures. Identify and list all personnel involved. Before each day of the mechanical run, it is important to have a safety and coordination meeting with all the people involved. Go over the tests for the day in detail, assign the time for starting, and assign individual duties to the team members. The team leader should designate an area for all other personnel not participating in the tests. Personnel not participating in the tests should be restricted from the test area.

The main safety risks are shaft rotation and water pressurization (i.e., flooding). This will be the first time the scroll case or distributor is pressurized and the first time the shaft will turn under water power. These tests are mechanical only; therefore lock-out and tag-out all electrical sources such as:

– The generator breaker.
– The exciter and dc field flashing.
– Any rotor field ground protection that may apply electrical signal to the rotor field.

Once off-line tests are completed, the main safety risk is fire. Generator clearances should be removed and the fire-suppression system should be enabled.

It is also important to apply proper physical personnel barriers and install warning signs during all testing.

Do not get in a hurry to complete testing. In general, any problems encountered during a test should be addressed with all parties, resolved, and corrected prior to continuing to the next commissioning step. Adequate time to review and analyze test findings should be allowed prior to reperforming the test or moving on to the next step.

8.1.2.2 Testing Instrumentation Installed and Connected

Some key points regarding instrumentation are:

- A complete list of signals that will be recorded during testing should be compiled well in advance and distributed to all parties for review and comments. This is important as there is no time for tests to be repeated for missing recorded parameters. It also allows for efficiency as one data collection system can be designed to serve multiple commissioning specialists. This will reduce the number of duplicated transducers.
- It is important in some cases, to have two different types of transducers monitoring the same key parameter. For example, it is good practice to measure unit speed with extra sensors (i.e., a proximity probe with a temporary target on the shaft) to compare with the permanently installed governor speed signals. Scroll case pressure or penstock pressure signals duplication would also be a good practice.
- Consider a second vibration monitoring system to compare with the permanent vibration monitoring system.
- It is a good practice to record important duplicate signals in order to dynamically compare them over time. For example, trend the governor derived speed signal with the temporary speed signal, or with other installed speed signals.
- Properly calibrate all signals and zero (if necessary) before the test.
- Define and list the data acquisition rates.
- Define the data filtering for some signals. Some microprocessor transducers have this built in. Raw data can be processed after testing but it can be a very time-consuming process. Consider applying strategic data processing on-line during the test.
- With newer larger data acquisition units, it may be easier to connect all the signals if possible, and to record them for all the tests (irrelevant channels will be ignored), rather than disconnect and reconnect relevant signals for each test.

A general signal list (not necessarily complete but based on a typical vertical three bearing design turbine generator with a combined generator thrust and guide bearing) could include:

Unit

- Unit speed (use 2 devices or more)
- Shaft axial Z displacement

Vibration Monitoring System

- Key phasor
- Generator upper guide bearing shaft runout X
- Generator upper guide bearing shaft runout Y
- Generator upper bearing housing velocity X
- Generator upper bearing housing velocity Y
- Generator upper bearing housing axial velocity Z

- Generator lower guide bearing shaft runout X
- Generator lower guide bearing shaft runout Y
- Generator lower bearing housing velocity X
- Generator lower bearing housing velocity Y
- Generator lower bearing housing axial velocity Z
- Turbine bearing shaft runout X
- Turbine bearing shaft runout Y
- Turbine bearing housing velocity X
- Turbine bearing housing velocity Y
- Turbine bearing housing velocity Z

Turbine

- Servo displacements (e.g., wicket gates, runner blades, turbine nozzles, deflectors, etc.)
- Servomotor open pressure
- Servomotor close pressure
- Turbine head cover axial Z displacement
- Turbine guide bearing temperatures – all
- Turbine guide bearing oil temperature
- Air admission valve – digital signal
- Shaft seal temperatures
- Shaft seal water flow

Hydraulic Power Unit (HPU)

- Accumulator tank pressure
- Governor pump pressure (lead and lag)
- Oil tank temperature

Generator

- Generator lower bracket axial Z displacement
- Generator thrust bearing temperatures – all
- Generator guide bearing temperatures – all
- Generator bearing oil temperatures – all
- Generator bearing inlet cooling water temperature
- Generator bearing outlet cooling water temperature
- Generator bearing cooling water flow
- Generator stator temperatures – all
- Generator stator inlet cooling water temperature
- Generator stator outlet cooling water temperature
- Generator stator cooling water flow
- Generator air temperature at exit of coolers – all
- Generator core temperatures – all
- Generator slip ring temperature
- Generator brakes applied – digital
- Generator shaft current

Water Passage

- Forebay water level
- Net head pressure tap – upstream

- Scroll case pressure
- Penstock flow or Winter-Kennedy pressures
- Head cover pressure
- Net head pressure tap – downstream
- Draft tube pressure
- Tailwater level

Electrical

- Generator current phase A, B, C
- Generator voltage phase A-B, B-C, C-A
- Generator power
- Generator reactive power
- Generator breaker closed
- Electrical lockout relay operated
- Mechanical lockout relay operated
- Overspeed switch operated
- E-STOP switch operated

Exciter

- Rotor field amps
- Rotor field voltage
- Excitation transformer temperature

8.1.3 Resources Organized

One major challenge is to have all the required commissioning team members present at the appropriate time. Specialists in governors, exciters, hydraulics, generators, turbines, protection and control, etc. have to be present and actively involved at various times during the commissioning tests. To complicate matters, some members are required to be present at more than one time during the testing program. Travel and other commitments for their services can make this difficult. The only way to help efficiently organize manpower is to shorten the testing time by having a complete and well-designed commissioning plan with all of the equipment ready and connected.

8.1.4 Required Documentation

The following commissioning documents are required before starting the commissioning tests:

- Unit design data (mechanical, hydraulic, electrical).
- Key reference documentation. This includes the list of all the design parameters and their associated thresholds (i.e., nominal, alarm level, trip level).
- Test description.
- List of signals to be recorded.
- Pre-condition checklists. These are detailed, device-specific checklists that need to be reviewed and checked-off before a test can begin. Key checklists are:
    - Pre-condition for watering up
    - Pre-condition checklist for first rotation
    - Pre-condition checklist for electrical energization
    - Pre-condition checklist for synchronization

- Availability of the most up-to-date drawings, O&M manuals, and other important maintenance and operational documents.

There is no one set of checklists that suits every turbine generator set. It is important that the checklists are generated by the entire commissioning team, even the designers.

- Test procedures. These are the detailed instructions for performing the testing. They need to be written and reviewed well in advance by all the commissioning team members. They should not be general documents, but must be unit-specific with unique references to avoid misinterpretations and time loss during the actual tests.
- Test sheets or data to be recorded. These are the datasheets that will be filled out and signed after each test. Data acquisition systems now record much of the data and hand recording of parameters during tests is no longer required. However, it is important that some key parameters and observations are officially recorded and signed for each test. Data files from recorders must be downloaded and backed up on a daily basis.

8.2 Watering Up

It is very important to have a good procedure for the first filling to avoid a sudden pressure rise or flooding. In this test, the turbine and associated water passages will be filled with water for the first time, and many components will be inspected for leakage while subjected to full hydrostatic pressure. Emergency closure devices such as the intake gates or inlet valves will be tested in water for the first time. This test prepares the unit for safely undergoing the subsequent mechanical and electrical tests.

Data to be Recorded

- Forebay water level
- Net head pressure tap – upstream
- Scroll case pressure
- Flow meter or Winter-Kennedy pressures
- Head cover pressure
- Net head pressure tap – downstream
- Draft tube pressure
- Tailwater level

Preconditions

- Removal of the waterway clearance
- Brakes applied
- Wicket gates closed
- Unit ready for rotation, all installation personnel physically off the unit
- Packing adjusted or mechanical shaft seal applied
- Shaft seal water system ready
- Head cover drainage pumps in automatic service
- All instrument lines closed
- Station drainage system ready and in auto
- Turbine drainage system ready and in auto
- All access doors to water passages closed and bolted

- List all important valves and their correct position

Safety Concerns

- Alert powerhouse personnel to the test. Cordon off and barricade areas with caution tape where required.
- Assemble the team and assign duties. It is important that people are stationed in key areas and safe areas to monitor the filling.

Procedure

The detailed step-by-step procedure will be different for each type of machine. The following list describes the basic ideas:

1) Wet and flush the shaft seal. If the unit has a mechanical or fiber packing, prepare to adjust the packing as the turbine is watered up.
2) Start by slowly filling the unit from the tailrace. Use bypass valves if so equipped.
3) Monitor all pressure gauges below the tailrace level. Bleed air out and flush all pressure gauges and pressure transducers.
4) When readings stabilize, record the values.
5) Observe the leakage. Adjust the packing if leakage is excessive.
6) Remove or raise all tailrace gates or stop logs.
7) If not done already, fill the penstock and the tailrace tunnel, not exceeding the rate defined by the civil designers.
8) Monitor all pressure gauges below the tailrace level. Bleed the air out and flush all pressure gauges and pressure transducers.
9) When full, record the values and follow the designer-specified wait times for the first fill.
10) Start to fill the scroll case slowly using the bypass fill valve or crack open the intake gate.
11) Monitor all pressure gauges below the tailrace level. Bleed the air out and flush all pressure gauges and pressure transducers.
12) When full, record the values.
13) Raise the intake gate or open the turbine inlet valve.
14) Monitor the shaft seal leakage and consider adjustment the packing if necessary.
15) Perform any submerged intake gate or turbine inlet valve tests, i.e., any timing tests. When closing, use a different initiation means each time (i.e., E-STOP, gate close button, etc.).
16) Start the penstock flow meter and measure leakage flow.

Key Reference Documents

- All necessary civil water passage drawings

8.3 Mechanical Run

Mechanical testing will commission and prove the unit mechanically before electricity is excited in the generator. After these tests, the unit should be able to start and stop in automatic mode from the control system with no issues. All mechanical systems will be armed, and the unit will have had functional testing of most of the mechanical safety systems. For example, the E-STOP, the main turbine inlet shutoff device, and most importantly, the overspeed protection will be verified. After these tests, the unit should be able to be left unattended and in a ready-for-service state (up to synchronous speed no load). However, it is still advisable to leave the unit, while unattended, with the main inlet device shut off, as at this time the unit is not usually formally under the control of the owner's operators and consequently, is not monitored 24 hours a day from the local or remote-control room.

8.3.1 First Rotation

Data to be recorded

Unit

- Unit Speed – (use 2 devices or more)

Turbine

- Servo displacement (e.g., wicket gates, runner blades, turbine nozzles, deflectors, etc.)
- Servomotor open pressure
- Servomotor close pressure
- Turbine guide bearing temperatures – all
- Turbine guide bearing oil temperature
- Shaft seal temperatures
- Shaft seal flow

HPU

- Accumulator tank pressure
- Governor pump pressure (lead and lag)
- Oil tank temperature

Generator

- Generator thrust bearing temperatures – all
- Generator guide bearing temperatures – all
- Generator bearing oil temperature – all
- Generator brakes applied – digital

Water Passage

- Forebay water level
- Tailwater level

Pre-Conditions

- Dry commissioning of unit mechanical systems complete.
- Turbine head cover dewatering systems in automatic.
- MPS ready in manual.
- All bearing high lift pumps ready in manual.
- Turbine maintenance seal off.
- Shaft seal water system on.
- All bearing lubrication in manual.
- Generator brakes ready in manual.
- Cooling water available to bearing in manual if necessary.
- Control system telemetry running.
- Commissioning data recording running.
- Governor fully operational – run in manual for this test.

- All personnel moved to various safe and monitoring positions. Tasks and roles for each member must be exactly identified (e.g., who will operate the governors in manual, who will operate the brakes in manual, etc.). Proper communication (radios or other) must be established and tested before the first rotation test begins.
- Remove all stop logs or sectional gates.
- Raise or open the main inlet shutoff device (intake gate or turbine inlet valve).
- Reduce ambient noise in the powerhouse. Consider halting other construction activities and stopping adjacent units if necessary.

Safety Concerns

- Rotation of the unit. Move all personnel to safe locations, and after movement, carefully inspect areas of concern and maintain constant communication with the commissioning leader.

Procedure

First rotation is achieved by:

1) Running the bearing high lift pump for an appropriate period of time.
2) Setting the governor limiter to a value appropriate to the specific turbine just above the estimated first spin wicket gate opening or nozzle opening value. The amount is specific to the unit, and 5% might be suitable for a high head machine, while 35% or more might be required for a low head unit.
3) Opening the wicket gates or nozzles a small amount, appropriate to the unit, to rotate the unit away from standstill. Note that the amount is very unit-specific, and while 2%-4% might be suitable for a high head machine, 30% or more might be suited to a low head unit. As soon as rotation has been established, close the wicket gates or nozzles. All personnel will listen for rubbing or unfamiliar noises by generator air gap (specifically air seals and shrouds) and at the bearings.
4) When finished, apply the brakes manually and observe their performance.
5) Shut down the bearing high lift pump.
6) Evaluate the results, make any needed repairs, and repeat if necessary.

Key Reference Documents

List of key parameters and limits defined:

- Bearing temperature limits
- Shaft seal temperature limits
- Shaft seal water flow limits

8.3.2 Testing of the Emergency Stop (E-STOP)

The first spinning test of the emergency stop should be completed at the end of the 25% synchronous speed first mechanical rotation. This apparatus was tested during dry and functional testing, but it is good practice to shut down the unit by this method as an additional check, after the 25% synchronous speed bearing run is complete. Record all events and compare with the intended design E-STOP sequence.

It is important to take the opportunity to shut down the unit in a different way after each test, for both the mechanical and the electrical runs. Construct a chart and cross off each method of shutdown as they are performed.

Retest the E-STOP during the electrical run at 25% synchronous speed and 100% synchronous speed, as a minimum.

Data to be recorded

Unit

- Unit Speed – (use 2 devices or more)

Turbine

- Servo displacement (e.g., wicket gates, runner blades, turbine nozzles, deflectors, etc.)
- Servomotor open pressure
- Servomotor close pressure

HPU

- Accumulator tank pressure
- Oil tank temperature

Water Passage

- Forebay water level
- Scroll case pressure
- Head cover pressure
- Draft tube pressure
- Tailwater level

Pre-Conditions

- 25% synchronous speed mechanical bearing run complete

Safety Concerns

- Rotation of the unit. Move all personnel to safe locations, and after movement, carefully inspect areas of concern and maintain constant communication with the commissioning leader.

Procedure

After the 25% synchronous speed mechanical no-load bearing heat run, press the E-STOP, observe the results, and compare to the design.

Key Reference Documents

- dc protection schematics
- Unit trip matrix

8.3.3 Testing of Braking System

This is a two-part test:

- Test 1 is to test the brakes in auto mode. Usually, hydro generator brakes are designed to be applied at approximately 30% synchronous speed, and therefore the first opportunity to test this is at the end of the 50% synchronous speed no-load bearing run.

- Test 2 is the deceleration test. This test is to verify the time it takes for the unit to run down from synchronous speed to standstill with the brakes being applied at the correct shaft speed.

Make sure the entire stopping sequence is correct. If the brakes do not come on or do not stay on at the correct time, abort the test and apply the brakes manually. Also, if the high lift pump does not come on at the right time, abort the test and apply the brakes manually.

Data to be recorded

Unit

- Unit Speed (use 2 devices or more)

Vibration Monitoring System

- Key phasor
- Generator upper guide bearing shaft runout X
- Generator upper guide bearing shaft runout Y
- Generator upper bearing housing velocity X
- Generator upper bearing housing velocity Y
- Generator upper bearing housing axial velocity Z
- Generator lower guide bearing shaft runout X
- Generator lower guide bearing shaft runout Y
- Generator lower bearing housing velocity X
- Generator lower bearing housing velocity Y
- Generator lower bearing housing axial velocity Z
- Turbine bearing shaft runout X
- Turbine bearing shaft runout Y
- Turbine bearing housing velocity X
- Turbine bearing housing velocity Y
- Turbine bearing housing velocity Z

Turbine

- Servo displacements (e.g., wicket gates, runner blades, turbine nozzles, deflectors, etc.)

Hydraulic Power Unit (HPU)

- Accumulator tank pressure
- Governor pump pressure (lead and lag)
- Oil tank temperature

Generator

- Generator brakes applied – digital
- Generator brakes retracted – digital
- Generator brake air pressure, if available

Water Passage

- Forebay water level
- Tailwater level

Pre-Conditions

- Test 1: 50% synchronous speed mechanical no-load bearing heat run complete.
- Test 2: 100% synchronous speed mechanical no-load bearing heat run complete.

Safety Concerns

- Rotation of the unit. Move all personnel to safe locations, and after movement, carefully inspect areas of concern and maintain constant communication with the commissioning leader.

Procedure

Test 1 – Auto braking:

1) After the 50% synchronous speed no-load test is complete, put the brakes in auto.
2) Issue a stop command from the control system.
3) Observe that the brakes function correctly and that the stop sequence is correct as per design.
4) If successful, the brakes can remain in auto.

Test 2 – Deceleration Test:

1) After the 100% synchronous speed, the no-load test is complete.
2) Issue a stop command from the control system.
3) Record the time trend of speed against time and when the brakes are applied.

Key Reference Documents

- DC schematics for braking system if required

8.3.4 Speed Increase of Steps 25%, 50%, 75%, and 100% Synchronous Speed

After the first rotation, the progression to 100% synchronous speed should be accomplished in steps. It can take more than one day to achieve 100% synchronous speed. All the tests and acceptance criteria must be made at each step before the next higher speed can be achieved.

CAUTION: Uncontrolled rotation of an untested unit can cause serious personnel injury or equipment damage. Ensure personnel are clear of equipment and in contact with the operator. Abort testing if there are any test concerns and resolve all issues prior to moving forward.

Data to be recorded

Unit

- Unit Speed (use 2 devices or more)
- Shaft axial Z displacement

Vibration Monitoring System

- Key phasor
- Generator upper guide bearing shaft runout X
- Generator upper guide bearing shaft runout Y
- Generator upper bearing housing velocity X
- Generator upper bearing housing velocity Y

- Generator upper bearing housing axial velocity Z
- Generator lower guide bearing shaft runout X
- Generator lower guide bearing shaft runout Y
- Generator lower bearing housing velocity X
- Generator lower bearing housing velocity Y
- Generator lower bearing housing axial velocity Z
- Turbine bearing shaft runout X
- Turbine bearing shaft runout Y
- Turbine bearing housing velocity X
- Turbine bearing housing velocity Y
- Turbine bearing housing velocity Z

Turbine

- Servo displacements (e.g., wicket gates, runner blades, turbine nozzles, deflectors, etc.)
- Servomotor open pressure
- Servomotor close pressure
- Turbine head cover axial Z displacement
- Turbine guide bearing temperatures – all
- Turbine guide bearing oil temperature
- Air admission valve – digital signal

Hydraulic Power Unit (HPU)

- Accumulator tank pressure
- Governor pump pressure (lead and lag)
- Oil tank temperature

Generator

- Generator lower bracket axial Z displacement
- Generator thrust bearing temperatures – all
- Generator guide bearing temperatures – all
- Generator bearing oil temperatures – all
- Generator bearing inlet cooling water temperature
- Generator bearing outlet cooling water temperature
- Generator bearing cooling water flow

Water Passage

- Forebay water level
- Net head pressure tap – upstream
- Scroll case pressure
- Winter-Kennedy pressures
- Head cover pressure
- Net head pressure tap – downstream
- Draft tube pressure
- Tailwater level

Pre-Conditions

- First rotation complete

Safety Concerns

- Rotation of the unit. Move all personnel to safe locations, and after movement, carefully inspect areas of concern and maintain constant communication with the commissioning leader.

Procedure

For each speed step performed, make sure that the unit is started with:

- Brakes retracted
- Bearing cooling water on in manual
- Shaft cooling water on
- Turbine drainage system on
- High lift oil system on for appropriate speed range (confirm with bearing designed the speed at which it can be shut off).
- Governor will be controlled in manual.

With the unit ready to start, the governor in manual will be used to start the unit and the testing team will perform the following sub-tests:

25% synchronous speed
  - Vibration and balance testing (see Section 8.3.4.1)
  - Bearing temperature stabilization (see Section 8.3.4.2)
  - Monitoring all telemetry in the control system/SCADA (see Section 8.3.4.3)
  - Testing of the emergency stop (see Section 8.3.2)

50% synchronous speed
  - Vibration and balance testing (see Section 8.3.4.1)
  - Bearing temperature stabilization (see Section 8.3.4.2)
  - Monitoring all telemetry in the control system/SCADA (see Section 8.3.4.3)
  - Testing of the brakes in Auto (see Section 8.3.3)

75% synchronous speed
  - Vibration and balance testing (see Section 8.3.4.1)
  - Bearing temperature stabilization (see Section 8.3.4.2)
  - Monitoring all telemetry in the control system/SCADA (see Section 8.3.4.3)

100% synchronous speed
  - Vibration and balance testing (see Section 8.3.4.1)
  - Bearing temperature stabilization (see Section 8.3.4.2)
  - Monitoring all telemetry in the control system/SCADA (see Section 8.3.4.3)
  - Testing of the brakes – deceleration test (see Section 8.3.3)
  - Testing of the emergency stop (see Section 8.3.2)

Key Reference Documents

- Bearing temperature design limits
- Vibration design limits
- Machine data sheet

8.3.4.1 Vibration and Balance Testing

The purpose of this test is to determine the amount of dynamic unbalance present in the rotating system due to inherent mechanical unbalance or due to magnetic effects. The test applies primarily to the main unit shaft system but is applicable to most rotating equipment. The unit should be ready to be rotated at speeds up to and slightly above normal operating speed. Shaft position measurement equipment should be installed and ready to use. The test consists of measuring the shaft position versus rotation. The direction of maximum runout on the rotor is related to the location of the unbalance force. Trial weights are added to establish a response on a subsequent test and the test is performed iteratively until a suitably low amount of runout is achieved.

Vibration testing is required to confirm satisfactory operation of the unit. If possible, it is often very worthwhile to connect a second vibration monitoring system to validate the readings of the permanently installed system.

The following turbine components should be checked for abnormal vibration to verify that the components are in satisfactory operating condition:

- Blade operating system (if required)
- Wicket gates
- Guide bearing
- Cooling and seal water flow system
- Oil supply system including pumps and motors
- Greasing system
- Thrust bearing (if part of turbine)

Be sure to have the design data limits for comparison with the measured results.

Data to be recorded

Unit

- Unit Speed (use 2 devices or more)
- Shaft axial Z displacement

Vibration Monitoring System

- Key phasor
- Generator upper guide bearing shaft runout X
- Generator upper guide bearing shaft runout Y
- Generator upper bearing housing velocity X
- Generator upper bearing housing velocity Y
- Generator upper bearing housing axial velocity Z
- Generator lower guide bearing shaft runout X
- Generator lower guide bearing shaft runout Y
- Generator lower bearing housing velocity X
- Generator lower bearing housing velocity Y
- Generator lower bearing housing axial velocity Z
- Turbine bearing shaft runout X
- Turbine bearing shaft runout Y
- Turbine bearing housing velocity X
- Turbine bearing housing velocity Y
- Turbine bearing housing velocity Z

Turbine

- Servo displacements (e.g., wicket gates, runner blades, turbine nozzles, deflectors, etc.)
- Servomotor open pressure
- Servomotor close pressure

- Turbine head cover axial Z displacement
- Turbine guide bearing temperatures – all
- Turbine guide bearing oil temperature
- Air admission valve – digital signal

Hydraulic Power Unit (HPU)
- Accumulator tank pressure
- Governor pump pressure (lead and lag)
- Oil tank temperature

Generator
- Generator lower bracket axial Z displacement
- Generator thrust bearing temperatures – all
- Generator guide bearing temperatures – all
- Generator bearing oil temperatures – all
- Generator bearing inlet cooling water temperature
- Generator bearing outlet cooling water temperature
- Generator bearing cooling water flow

Water Passage
- Forebay water level
- Net head pressure tap – upstream
- Scroll case pressure
- Winter-Kennedy pressures
- Head cover pressure
- Net head pressure tap – downstream
- Draft tube pressure
- Tailwater level

Pre-Conditions
- First rotation complete

Safety Concerns
- Rotation of the unit. Move all personnel to safe locations, and after movement, carefully inspect areas of concern and maintain constant communication with the commissioning leader.
- If balancing weights need to be added to the rotor, strict lock-out tag-out procedures need to be followed:
    - Intake gate or turbine inlet valve closed and locked out and tagged out
    - Wicket gates mechanically locked
    - Generator brakes ON (tagged out)
    - Stop logs in draft tube
    - Unit dewatered with drain valves open (locked)
    - Scroll case drain valve open (locked)
    - Exciters locked out and tagged out
    - Generator breakers locked out and tagged out
    - Generator armature and exciter field grounded

Procedure
Hold the unit speed at each speed step for at least 15 minutes. To ensure the reliability of the vibration readings, it may be necessary to run the unit for a period after the bearing temperatures stabilize. Be sure to walk around the generator and turbine areas to visually (and audibly) confirm satisfactory operation. Both vibration monitoring systems (temporary and permanent) should display similar readings. Confirm that the readings on the unit HMI and SCADA match the vibration controller. The vibration readings must be found acceptable at each speed step before moving on to the next speed step.

If vibration levels are not acceptable, shut down the unit and rebalance as required.

Upon restart, repeat the previous steps to confirm acceptable vibration of the unit has been achieved. Note that final balancing may be required after completing full load, overspeed, or load rejection tests.

Key Reference Documents
- Vibration design data
- FIST 2-2, *Field Balancing Large Rotating Machinery*
- FIST 2-7, *Mechanical Overhaul Procedures for Hydroelectric Units*
- FIST 2-12, *Mechanical Maintenance of Hydroelectric and Large Pump Units*
- IEEE Std 1095, IEEE Guide for the Installation of Vertical Generators and Generator/Motors for Hydroelectric Applications
- ISO 21940-11, Mechanical Vibration – Rotor Balancing – Part 11: Procedures and Tolerances for Rotors with Rigid Behavior
- IEC 60545, Guide for Commissioning, Operation and Maintenance of Hydraulic Turbines
- ISO 20816-1, Mechanical Vibration – Measurement and Evaluation of Machine Vibration
- Turbine manufacturer's instruction book

8.3.4.2 Bearing Temperature Stabilization at Each Step
The purpose of this test is to determine that bearing temperatures are stable and in the appropriate range for continued operation or further machine testing. The test applies to all thrust and guide bearings of hydroelectric units. The unit should be ready for prolonged operation at rated speed. It is not necessary to energize the unit unless a test is needed with hydraulic turbine loads applied.

For each speed step (at 25%, 50%, 75%, and 100% synchronous speed), all bearings must reach a steady state temperature before proceeding to the next step. The definition of steady state is less than 1 °C rise per hour. For this test, it is important to have a steady wicket gate or nozzle opening. This is best achieved by pushing the governor up against the gate limiter, rather than engaging the speed controller. Speed can be approximately at target (+/- 1% is fine).

For 25%, 50%, and 75% synchronous speed, the less than 1 °C rise per hour criteria is flexible as long as the trend clearly shows stabilization.

Always observe the bearing temperature limits defined by the manufacturer and abort the test if they are exceeded.

The 100% synchronous speed bearing no-load heat run could take as much as 4 hours, so it is good practice to schedule this test at the end of the day to avoid a lot of personnel wait time.

Data to be recorded
The key information to be recorded is all related to bearing temperatures (metal, oil, and cooling water).

Unit

- Unit Speed (use 2 devices or more)
- Shaft axial Z displacement

Vibration Monitoring System

- Key phasor
- Generator upper guide bearing shaft runout X
- Generator upper guide bearing shaft runout Y
- Generator upper bearing housing velocity X
- Generator upper bearing housing velocity Y
- Generator upper bearing housing axial velocity Z
- Generator lower guide bearing shaft runout X
- Generator lower guide bearing shaft runout Y
- Generator lower bearing housing velocity X
- Generator lower bearing housing velocity Y
- Generator lower bearing housing axial velocity Z
- Turbine bearing shaft runout X
- Turbine bearing shaft runout Y
- Turbine bearing housing velocity X
- Turbine bearing housing velocity Y
- Turbine bearing housing velocity Z

Turbine

- Servo displacements (e.g., wicket gates, runner blades, turbine nozzles, deflectors, etc.)
- Servomotor open pressure
- Servomotor close pressure
- Turbine head cover axial Z displacement
- Turbine guide bearing temperatures – all
- Turbine guide bearing oil temperature
- Air admission valve – digital signal

Hydraulic Power Unit (HPU)

- Accumulator tank pressure
- Governor pump pressure (lead and lag)
- Oil tank temperature

Generator

- Generator lower bracket axial Z displacement
- Generator thrust bearing temperatures – all
- Generator guide bearing temperatures – all
- Generator bearing oil temperatures – all
- Generator bearing inlet cooling water temperature
- Generator bearing outlet cooling water temperature
- Generator bearing cooling water flow

Water Passage

- Forebay water level
- Net head pressure tap – upstream
- Scroll case pressure
- Winter-Kennedy pressures
- Head cover pressure
- Net head pressure tap – downstream
- Draft tube pressure
- Tailwater level

Pre-Conditions

- First rotation complete.
- Bearing cooling water system must be functional and in auto.

Safety Concerns

- Rotation of the unit. Move all personnel to safe locations, and after movement, carefully inspect areas of concern and maintain constant communication with the commissioning leader.

Procedure

1) Start the unit with all appropriate auxiliary systems functional (especially important are the bearing cooling water systems).
2) With the governor in manual, increase the unit speed to the target speed. This is best achieved by pushing the governor up against the gate limiter, rather than engaging the speed controller. Speed can be approximately at target (+/- 1% is fine).
3) Trend all bearing temperatures. The recording frequency can be slow; typically, every 5-10 minutes is acceptable.
4) Hold the unit speed steady, until all bearings reach steady state temperature. Criterion is less than 1 °C per hour.
5) If any temperature reaches the alarm level or trip value, abort the test and consult the manufacturer.
6) Once temperature stabilization is complete, proceed to the next speed step.

Key Reference Documents

- FIST 2-7, *Mechanical Overhaul Procedures for Hydroelectric Units*
- FIST 2-12, *Mechanical Maintenance of Hydroelectric and Large Pump Units*
- Bearing manufacturer's operational temperature alarm and trip limits
- IEEE Std 1095, IEEE Guide for the Installation of Vertical Generators and Generator/Motors for Hydroelectric Applications

8.3.4.3 Monitoring of All Telemetry and Verification

This is when the control system's start/stop system is commissioned up to synchronous speed no load. The goal is to have the unit start and stop in full automatic mode with no manual intervention required. It is important to closely monitor the starting and stopping of critical auxiliary systems (i.e., shaft seal water, bearing high lift, brakes, etc.) and to turn them on or off immediately in manual mode if necessary.

These tests are usually conducted in conjunction with the work in Section 8.3.4.4 to save valuable time. They both share the machine and can coordinate starting and stopping together.

Data to be recorded

- No data to be recorded, only monitoring and verification.

Pre-Conditions

- No load heat run at 100% synchronous speed complete.

Safety Concerns

- Rotation of the unit. Move all personnel to safe locations, and after movement, carefully inspect areas of concern and maintain constant communication with the commissioning leader.

Procedure

Prepare the following test sheets for testing:

1) Start blocks or interlocks that prevent starting. List all and test some important ones by operating the interlocks and attempting to start. If the unit starts, shut down immediately.
2) List the entire sequence of operations of semi-automated mode (if programmed). Test and check off the sequence of events.
3) List the entire sequence of operations for the auto start/stop mode. Test and check off the sequence of events.
4) List the entire sequence of operations for an aborted start. Test and check off the sequence of events.
5) Test all other modes not listed.

Key Reference Documents

- Unit control system logic diagram or (block) diagrams

8.3.4.4 Governor Speed Controller Tuning

The governor commissioning engineer tests and tunes the governor function and control from standstill to synchronous speed. All the telemetry, especially speed measurement, can now be verified. With the first auto start to synchronous speed no load, the engineer can tune the start parameters for a smooth start and with no speed overshoot. Once at synchronous speed, the speed controller can then be tuned.

The verification and basic troubleshooting really begin during the 25% synchronous speed step tests, in conjunction with the other tests, and continue until after the 100% synchronous speed bearing heat run. It is important for the governor engineer not to interfere with these tests that require a very stable wicket gate or nozzle opening, but the governor engineer can do what he or she can otherwise fit into the test. After the 100% synchronous speed bearing heat run, the governor speed controller and the acceleration to synchronous speed can be tuned.

After tuning the speed controller, a number of off-line governor tests should be completed (see Procedure below).

Data to be recorded

Unit

– Unit speed (use 2 devices or more)

Turbine

– Servo displacements (example: wicket gates, runner blades, turbine nozzles, deflectors, etc.).

Water Passage

– Forebay water level
– Tailwater level

Pre-Conditions

– Complete the dry testing of the governor and the turbine (i.e., step response, dead band, dead time, permanent and temporary droop) for all servomotors, which includes the servomotors of the wicket gates or nozzles, and runner blades, if provided.
– For off-line tests at 100% synchronous speed, the 100% synchronous speed bearing heat run must be complete.

Safety Concerns

– Rotation of the unit. Move all personnel to safe locations, and after movement, carefully inspect areas of concern and maintain constant communication with the commissioning leader.

Procedure

As all governor systems are different, it is not the intent of this commissioning guide to give detailed instructions, but instead to list the tests that should be performed. A detailed procedure or work method will have to be written for each powerplant based on the specific equipment installed.

Tests at synchronous speed no load:

– Speed dead band and dead time (according to ASME PTC 29 4-2.2.1)
– Steady-state governing speed band test procedure (according to ASME PTC 29 4-2.3.1)
– Set point adjustment (according to ASME PTC 29 4-4.2.6)

Key Reference Documents

– FIST 2-3, *Mechanical Maintenance of Mechanical and Digital Governors for Hydroelectric Units*
– ASME PTC 29 Speed Governing Systems for Hydraulic Turbine Generator Units

8.3.4.5 Overspeed Testing

The purpose of the overspeed test is to prove that the machine is capable of withstanding the condition and to function test all overspeed protection devices (all mechanical and electrical devices). The test consists of mechanically operating the unit using the prime mover at its maximum operating speed. The test is basically intended to check the mechanical integrity of the unit, its bearings, and its design. The unit should be thoroughly visually inspected before the test to verify that there are no loose hardware or loose parts, especially on the rotor. The unit is run without excitation and the speed is increased up to the agreed-upon limits of turbine gate position, speed, or vibration. After shutdown, the unit is re-inspected to see if any effects are noticeable. This is a very important test that should not be skipped. Most, if not all, settings should be tested independently. This requires careful planning as some overspeed settings may have to be temporarily programmed to higher values or disabled via test switches or other means. Care must be taken to rearm these protections after the test. The test usually ends with the highest speed protection (i.e., the mechanical overspeed device). The machine vibration and balance can be checked as well; however, this is an abnormally short time duration event and obviously the same criteria cannot be used for operation at synchronous speed.

The overspeed protections are an ESD, meaning that the governor system (digital or hydraulic) has lost control of the unit and therefore the intake gate or turbine inlet valve must be closed. It is not necessary to close the gate/valve every time. It is acceptable to block this protection and record that the signal was sent for closure for some of the tests. Having actual operation of the intake gate or the turbine inlet valve on the first and last test is acceptable.

A simple procedure is given below for a unit with three independent speed relays.

- Speed relay 1 (electrical) – stage 1: 110% synchronous speed for 10 seconds.
- Speed relay 1 (electrical) – stage 2: 150% synchronous speed instantaneous
- Speed relay 2 (electrical): 155% synchronous speed instantaneous
- Speed relay 3 (mechanical): 160% synchronous speed instantaneous

Note that the speed relay settings and operating times specified above are only examples and are not universally applicable.

These tests for Francis and Kaplan units can produce high water flow rates. It is important to check transient pressures during the emergency close of each test. If the pressure is approaching the design limits of the scroll case or penstock, the tests should be stopped and consultation with the hydraulic designers should be undertaken before proceeding with higher speeds.

Data to be recorded

Unit

- Unit speed (use 2 devices or more)
- E-STOP pushbuttons

Vibration Monitoring System

- Key phasor
- Generator upper guide bearing shaft runout X
- Generator upper guide bearing shaft runout Y
- Generator upper bearing housing velocity X
- Generator upper bearing housing velocity Y
- Generator upper bearing housing axial velocity Z
- Generator lower guide bearing shaft runout X
- Generator lower guide bearing shaft runout Y
- Generator lower bearing housing velocity X
- Generator lower bearing housing velocity Y
- Generator lower bearing housing axial velocity Z
- Turbine bearing shaft runout X
- Turbine bearing shaft runout Y
- Turbine bearing housing velocity X
- Turbine bearing housing velocity Y
- Turbine bearing housing velocity Z

Turbine

- Servo displacements (e.g., wicket gates, runner blades, turbine nozzles, deflectors, etc.)
- Servomotor open pressure
- Turbine head cover axial Z displacement
- Turbine bearing temperatures – all
- Mechanical overspeed switch
- Electrical overspeed switch

Hydraulic Power Unit (HPU)

- Accumulator tank pressure
- Oil tank temperature

Generator

- Generator lower bracket axial Z displacement
- Generator bearing temperatures – all

Water Passage

- Forebay water level
- Net head pressure tap – upstream
- Scroll case pressure – monitor and compare with limit
- Winter-Kennedy pressures
- Head cover pressure
- Net head pressure tap – downstream
- Draft tube pressure
- Tailwater level

Pre-Conditions

- Bearing no load heat run complete.

Safety Concerns

- Rotation of the unit. Move all personnel to safe locations, and after movement, carefully inspect areas of concern and maintain constant communication with the commissioning leader.

The pre-test meeting organized by the commissioning leader is important to assign tasks, establish which areas are off limits and where everyone should be located. The important points are:

- Establish a wicket gate opening or nozzle opening limit at which the test will abort. Try to have more than one team at different positions to monitor the unit speed and E-STOP the machine when this limit is achieved.
- The governor will usually be operated in manual mode by the governor engineer.
- The intake gate or turbine inlet valve should be monitored by one team (if safe to do so) having radio contact with the commissioning leader, and they should be ready to operate in manual mode if requested by the commissioning leader.
- Everyone else should be located at a safe distance (i.e., in the control room).
- Establish communications and test them between all stations prior to starting the test.

Procedure

Test 1: Speed relay 1 (electrical) – stage 1: 110% synchronous speed for 10 seconds

1) Start the unit and operate it at synchronous speed until the bearings reach normal operating temperatures.
2) Switch the governor to manual control mode.
3) Slowly open the wicket gates or nozzles and increase the unit speed to 112% synchronous speed and hold for at least 12 seconds. At 10 seconds at 110% synchronous speed, the unit should shut down and the intake gate or turbine inlet valve should close. During the test, monitor the bearing temperatures and if they are considered to be excessive, abort the test and rebalance the unit.

Test 2: Speed relay 1 (electrical) – stage 1: 150% synchronous speed instantaneous

1) Set or disable speed relay 1 – first stage time to 2 minutes or similar.
2) Disable the intake gate or turbine inlet valve emergency closing capability via the overspeed relay. Maintain closure capability via manual or E-STOP should closure be required.
3) Start the unit and operate it at synchronous speed until the bearings reach normal operating temperatures.
4) Switch the governor to manual control mode.
5) Open the wicket gates or nozzles at a controlled pace (not too slowly) and increase the speed to the pre-determined limit. At 150% synchronous speed the unit should shut down but the intake gate or turbine inlet valve shouldn't close. During the test, monitor the bearing temperatures and if they are considered to be excessive, abort the test and rebalance the unit.

Test 3: Speed relay 2 (electrical): 155% synchronous speed instantaneous

1) Set or disable speed relay 1 – first stage time to 2 minutes or similar.
2) Set or disable speed relay 1 – 2nd stage above test limit speed.
3) Disable the intake gate or turbine inlet valve emergency closing capability via the overspeed relay. Maintain closure capability via manual or E-STOP should closure be required. Monitor the blocked signal from the relay to close the intake gate or turbine inlet valve.
4) Start the unit and operate it at synchronous speed until the bearings reach normal operating temperatures.
5) Switch the governor to manual control mode.
6) Open the wicket gates or nozzles at a controlled pace (not too slowly) and increase the speed to the pre-determined limit. At 155% synchronous speed the unit should shut down but the intake gate or turbine inlet valve shouldn't close. During the test, monitor the bearing temperatures and if they are considered to be excessive, abort the test and rebalance the unit.

Test 4: Speed relay 3 (mechanical): 160% synchronous speed instantaneous

1) Set or disable speed relay 1 – first stage time to 2 minutes or similar.
2) Set or disable speed relay 1 – 2nd stage above test limit speed.
3) Set or disable speed relay 2 – to above the test limit speed.
4) Disable the intake gate or turbine inlet valve emergency closing capability via the overspeed relay. Maintain closure capability via manual or E-STOP should closure be required.
5) Start the unit and operate it at synchronous speed until the bearings reach normal operating temperatures.
6) Switch the governor to manual control mode.
7) Open the wicket gates or nozzles at a controlled pace (not too slowly) and increase the speed to the pre-determined limit. At 160% synchronous speed the unit should shut down but the intake gate or turbine inlet valve shouldn't close. During the test, monitor the bearing temperatures and if they are considered to be excessive, abort the test and rebalance the unit.

8) Reset and enable all overspeed protections back to their appropriate settings.

Key Reference Documents

- FIST 2-7, *Mechanical Overhaul Procedures for Hydroelectric Units*
- FIST 2-12, *Mechanical Maintenance of Hydroelectric and Large Pump Units*
- dc protection schematics
- Penstock pressure limit
- IEC 60545, Guide for Commissioning, Operation, and Maintenance of Hydraulic Turbines
- IEC 60034-1, Rotating Electrical Machines – Part 1: Rating and Performance
- IEEE Std 115, IEEE Guide for Test Procedures for Synchronous Machines Part I – Acceptance and Performance Testing Part II – Test Procedures and Parameter Determination for Dynamic Analysis

8.3.5 Unit Dewatering and Complete Mechanical Inspection

It is important to completely inspect the unit after all the mechanical tests are complete. Inspection is especially important as a result of the above normal stresses imposed on the unit, specifically to the generator rotor and turbine runner from the overspeed tests. Key areas to check are the tightness of the rotor keys and the turbine runner for signs of contact with surrounding parts.

Data to be recorded

- Runner and rotor for signs of contact with surrounding parts
- Assessment results of a review of vibration readings of previous tests
- Assessment results of a review of temperature readings of previous tests
- Assessment of generator air gaps and runner clearances
- Results of inspection of tightness of rotor keys
- Check for presence of loose fasteners

Pre-Conditions

- Mechanical run complete

Safety concerns

- Dewater the unit and lock out and tag out all sources of energy (except the brakes).
- Wicket gate locks in place.
- HPU de-pressurized, pumps locked out and tagged out, accumulator drained.
- Bearing high lift pump locked out and tagged out.
- Brakes on in manual mode.
- Intake gate or turbine inlet valve closed and locked out and tagged out.
- Stop logs installed in tailrace gains.
- For the runner inspection, water level lowered in draft tube.
- Generator breakers locked out and tagged out.
- Excitation system locked out and tagged out.
- Rotor field ground relay de-energized.

Key Reference Documents

- FIST 2-7, *Mechanical Overhaul Procedures for Hydroelectric Units*
- FIST 2-12, *Mechanical Maintenance of Hydroelectric and Large Pump Units*
- Generator rotor assembly protocols

8.4 Electrical Run

The following electrical testing will commission and fully test the electrical power system from the generator to the high voltage connection to the transmission systems grid. Testing will start with off-line (not synchronized) electrical testing, followed by synchronization tests, and then finally on-line tests (synchronized to the grid), up to full load. After these tests, the unit should be fully commissioned and ready for the trail run.

After a complete mechanical inspection, the rotor electrical tests should be repeated to confirm that no damage has occurred during the overspeed tests. Record the following values on the original rotor insulation test sheet:

- Rotor insulation (Megger)
- Rotor resistance (be sure to measure and record the winding temperature)
- Rotor capacitance

After the rotor is re-tested, prepare the unit for rotation. Repeat the pre-initial rotation checklist. Make sure all doors, covers, safety systems, and the automation system are fully operational. Start the unit to speed no load in automatic mode and let the bearings warm up to verify that the unit is 100% mechanically operational.

The electrical run can now officially start.

8.4.1 Off-line Generator Testing

This section contains all the electrical testing of the unit up to synchronizing of the generator to the grid.

8.4.1.1 Preparation for Off-line Exciter Commissioning

Pre-Condition

- Overspeed testing is complete and the unit is shut down and locked out and tagged out and guaranteed not to start.
- The shorting bar for the short circuit saturation test can be installed during the mechanical inspection after the overspeed testing, to combine work and reduce the overall schedule.

Safety Concerns

- The unit must be electrically de-energized and locked out and tagged out and mechanically guaranteed from rotating. The lock out and tag out procedure will vary slightly from one unit design to another. One example could compromise the following intake gate or turbine inlet valve mechanically locked closed, draft tube stoplogs/sectional gates installed, wicket gates mechanically locked closed, generator brakes on, generator breaker locked open, and grounding switch closed on the generator side of the breaker.

Key Reference Documents

- Generator and generator bus duct drawings
- Generator line cubicle (if installed)
- Generator circuit breaker

8.4.1.2 Preliminary Exciter Commissioning

The exciter commissioning engineer's first task is to make sure that the auxiliary supply is connected correctly and that the shunt connected transformer is isolated from the temporary supply (to avoid back feeding generator voltage onto the generator terminals from the temporary exciter power supply).

The rest of the preliminary checks are listed in the procedure section.

Data to be Recorded

- Fill out SAT checklist

Pre-Conditions

- Auxiliary supply for exciter connected

Safety Concerns

- Ensure that the excitation transformer is isolated from generator via the temporary supply
- Beware of energized circuits and exposed energized electrical bus.

Procedure

Complete the following SAT checklist:

- Record nameplate data.
- Check for transport damage.
- Check for correct assembly and external electrical connections.
- Check all electrical connections for tightness.
- Power on the circuit from the mains to all auxiliaries. Measure and record the voltages.
- Confirm or download the correct exciter parameters or settings into the controller.
- Check the PT and CT circuits according to the electrical schematics.
- Check the external interlocks.
- Check the interlocking between the generator breaker and the field breaker. The best method is to safely isolate the generator breaker and then with the excitation breaker closed, close the generator breaker (sync check and automation interlocks probably will have to be defeated). Immediately after, attempt to reclose the generator breaker, this time with the excitation breaker open. The generator circuit breaker should not close.

Key Reference Documents

- Exciter commissioning SAT

8.4.1.3 Partial Discharge Test

Partial discharge testing is an ac test performed to establish a baseline for future tests to assess the condition of transformers and stator winding insulation. Partial discharge measurements may be performed during ac hi-pot testing during construction testing, or when the generator is energized at rated voltage as part of the startup testing, or both.

Construction tests are performed using an ac hi-pot to energize the winding. This is typically done after the generator winding is complete but before final stator painting.

For online systems, partial discharge couplers will need to be calibrated form proper operation during construction. Generator testing can be performed at full-speed isolated from the grid, synchronized no-load, low-load cold (ambient prior to the transformer or generator warming up), full-load cold, full-load hot (transformer or generator at operating temperature), and low-load hot conditions. For transformers, tests are commonly performed at low-load cold and full-load hot.

Equipment Required

- For calibration, required equipment may include a signal generator, oscilloscope, and other equipment as recommended by the coupler manufacturer. Construction tests require an ac hi-pot. Corona detection probes, cameras, and similar instruments can be used for detection and evaluation.

One or two people can calibrate the couplers in a day during construction. Partial discharge testing readings take several minutes at each operating condition; however, the test may take 4-6 hours to allow the generator temperatures to stabilize at full load. An off-line test typically takes a day.

Key Reference Documents

- IEEE Std 1434, IEEE Guide for the Maintenance of Partial Discharges in AC Electric Machinery

8.4.1.4 Shaft Voltage Measurement

After the open circuit test, as the voltage is decreased, stop at 100% generator nominal voltage and measure the shaft voltage and current (if possible). IEEE 115 offers four different methods to measure the shaft voltage on a running machine. Two methods are summarized here.

Method 1 involves measuring the voltage with a voltmeter between both ends of the shaft (on either side of the generator). This usually will require an extra shaft brush to connect at the non-drive end of the shaft. Usually there is a permanent shaft brush installed between the generator and the turbine on the drive end of the shaft. Disconnect the drive end shaft brush from ground and measure the voltage between the drive end shaft brush and the non-drive end shaft brush with a low resistance insulated conductor (#4 AWG) voltmeter or a current meter in series (take readings with both the ac and dc ranges as the reading might not be a perfect 50/60 Hz signal). An oscilloscope reading is optional.

Method 2 involves leaving the permanent shaft brush at the drive end connected to ground or, if none is installed, adding a shaft brush to ground at the drive end. This shorts the drive end bearing oil film and bearing insulation to the station grounding system (it is preferrable to connect directly to the station ground conductor rather than to the machine or bearing frame). The shaft voltage is measured between the non-drive end temporary shaft brush and ground with a voltage meter or a current meter in series. This method uses the machine ground bonding as the return path to the drive end shaft.

A final test would be (with the non-drive end bearing not shorted) to measure the current in the permanent drive end shaft brush. This could be tested with an ac/dc clamp on ammeter. There should be little or no current flow recorded. This value could be compared and confirmed with a shaft current CT if one is installed.

8.4.1.5 Complete Off-line Exciter Commissioning

The temporary supply is removed from the exciter and the permanent shunt supply is reconnected for these tests. The goal for the exciter commissioning engineer is to have a functioning exciter ready for synchronizing the generator to the grid.

Data to Be Recorded

Unit

- Unit Speed (use 2 devices or more)

Electrical

- Generator voltage phase-to-phase A-B, B-C, C-A

Exciter

- Rotor field amps
- Rotor field voltage
- Exciter firing angle
- Thyristor firing sequence
- Excitation transformer temperature

Pre-Conditions

- Temporary exciter supply removed
- Exciter transformer and exciter reconnected to the generator bus (for shunt connected supply)

Safety Concerns

- Rotation of the unit. Move all personnel to safe locations, and after movement, carefully inspect areas of concern and maintain constant communication with the commissioning leader.
- Full generator voltage will be applied.
- The excitation transformer and the exciter will be energized.
- Remove all unnecessary personnel from the exciter and excitation transformer areas.

Procedure

See the following two sections.

Key Reference Documents

- Exciter commissioning SAT
- Exciter circuit diagrams

8.4.1.5.1 Initial Voltage Application

Field Ground-Detector Test

Test the field ground detection system by connecting a resistor (about 1000 ohms) from one field slip ring to the ground. It may be necessary to close the field breaker, close the ac supply breaker feeding the rectifier bridges, start the machine, or jump some relay contacts to activate the field ground detection device.

Open and Short-Circuit Saturation Tests

Before performing other tests, the generator manufacturer will sometimes execute open-circuit and short-circuit saturation tests. Typically, the generator terminals are open-circuited by removing the generator bus links outside the generator air housing for the open-circuit test. A copper bar is connected directly across the synchronous machine terminals for the short-circuit test. If the exciter is usually fed from the machine terminals, connect a separate power source to the excitation system.

During this test, a generator manufacturer representative will record field current, field voltage, and armature current data. Usually, the procedure involves stepping up the terminal voltage to 120% of the rated terminal voltage for the open-circuit test, raising the excitation current to a high level, and then reducing it in steps for the short-circuit test. Use the manual dc regulator for these tests.

Voltage Buildup
During commissioning tests, gradually build up the voltage the first-time applying excitation to a new winding. Check shaft runout, bearing isolation, and vibration while increasing voltage. Usually, plant personnel perform these functions. Verify phase rotation of the excitation transformer. Excitation systems fed from the machine terminals connect to a separate power source.

Here are two options to try if a separate source is not available. In option one, for excitation systems employing a rotating exciter, it may be possible to drive the exciter field with an individual portable power supply. Option one permits a slow buildup of machine voltage for initial PT phase rotation checks, exciter polarity checks, and voltage regulator phasing checks. In option two, the generator or exciter field can be "flashed" from the station batteries with the excitation system disabled. Option two provides a temporary voltage for initial checks. Follow this by using reduced excitation levels of presets and limiters.

Build voltage using the manual dc regulator; record terminal voltage, field voltage, and field current as the excitation steps increase. Then, construct the actual saturation curve and calculate the field resistance of the synchronous machine. If the excitation system includes a rotating exciter, record the field voltage and current in this device. Rotating exciter polarity may need to be verified. The short circuit radio (SCR) bridge voltage can be used as a feedback quantity to the dc regulator to test this polarity.

Upon completing this test, set the manual regulator adjuster to a minimum. Then, adjust the manual regulator bias to produce about 80 percent of the rated terminal voltage. Next, remove the excitation (by opening the field breaker or operating the excitation stop switch) and stop the synchronous machine. Reconnect the regular excitation supply and enable field flashing.

8.4.1.5.2 Off-Line Exciter Commissioning

Typical Voltage Application
Enable the excitation system (by closing the field breaker or operating the excitation start switch) with the manual dc regulator in control and its setpoint at 80 percent. Record the voltage buildup. Suggested quantities to record are terminal voltage, field voltage, field current, and regulator quantity. For systems having rotating exciters, record the exciter field voltage and possibly the exciter field current.

At low levels of terminal voltage, due to inadequate power supply, internal regulator transducers may not function properly.

Observe the voltage buildup and decide on the adequacy of the field flashing level. Most systems require 20 to 30 percent terminal voltage before the SCR firing circuits function reliably. After a successful buildup to 80 percent has been obtained, repeat this test with the manual, dc, regulator setpoint increased to 100 percent.

Manual, DC, Regulator Step Response

Apply a step input of about ±1 percent to the manual dc regulator that typically controls either primary field voltage or main field current. Adjust the response of this regulator so the controlled quantity has a reasonable response time and no overshoot when the step is applied. This regulator should be slower than the automatic ac regulator. Repeat the regular voltage application when making parameter changes to verify satisfactory large-signal performance. Now set the minimum level of the manual, dc, and regulator adjuster. The minimum range level requires the determination of the excitation full load requirement.

Balance, Transfer, and Auto Tracking Functional Checks

Test the regulator balance circuit with the unit running at full speed no-load, and in dc regulator mode. The movement of the ac adjuster should result in unbalance of the regulator balance meter. Perform the test by disturbing the right and left, and then rebalancing to the center.

Note: this test is only necessary on analog controllers as digital controllers typically auto-track between the dc and ac regulator.

Transfer to automatic ac regulator after a balanced indication. Using observation and review of a chart recording, verify stable operation of terminal voltage, field voltage, and other quantities of interest. When transferring to the automatic ac regulator, observe the correct process of the indicator lights.

If the excitation system has an automatic setpoint track, check this feature. A unit breaker auxiliary relay may need to be enabled before this function will operate. If so, jump the relay and verify that the automatic tracking system works. Observe changes in both directions.

Automatic, AC, Regulator Step Response

Apply a step input of about ±1 percent to the automatic ac regulator. On a chart recorder, record the response. Adjust the regulator for proper operation. Typically, a 15 percent overshoot response followed by rapid damping indicates adequate performance. For insight into accurate tuning for each specific plant, consult system studies.

AC Regulator Bias and Range Adjustment

The automatic ac regulator adjuster is usually adjusted to provide a control range of 90 to 109 percent of the rated terminal voltage. Cam switches typically control light indication and preset positioning. Make these adjustments now. Plant operating staff should have input into the range and operation of these controls.

AC Regulator Frequency Response Tests

Checks to see if the ac regulator responds correctly to changes in system frequency. Also, these responses will aid in excitation system parameter identification for simulation studies. An overall system closed-loop response with the unit off-line is essential. In addition, responses of each transfer function block are helpful for parameter identification. If the excitation system includes a rotating exciter, measure the transfer function from exciter field voltage to primary field voltage.

V/Hz (Ratio) and Overvoltage Limiter Test

The V/Hz limiter should reduce the terminal voltage of the unit whenever the frequency drops. It should operate in coordination with the V/Hz relay. Typically, the relay operates if the V/Hz ratio exceeds 118 percent nominal, so the limiter is usually adjusted to maintain a ratio of 110 percent nominal. To test this limiter, increase the voltage of the synchronous machine to 110 percent while decreasing the speed. Record the voltage and frequency simultaneously and calculate the limiter ratio for several different speed values (commonly 48 to 60 Hz). Devise a table containing this information.

When the unit has an overvoltage limiter, incorporate the V/Hz ratio test into the V/Hz limiter test sequence. Set the limiter with the smoothest limit-cycle operation with the lowest ratio. Usually, the V/Hz limiter has this characteristic; in most cases, the V/Hz limiter will be the primary terminal voltage limiter. Set the overvoltage limiter about 2 percent above the primary (V/Hz) limiter if it's a harsh limiter that directly affects the bridge firing.

The overvoltage limiter is typically set to 110% if this limiter operates with a smooth limit-cycle operation. In this case, the V/Hz limiter is generally set to 111% to coordinate the limiter with the V/Hz protection.

V/Hz (Ratio) Relay Test

To test the V/Hz relay, disable the V/Hz limiter (and overvoltage limiter) and repeat the procedure in the preceding subparagraph. Lift the wire from the trip circuit of the lockout relay to prevent a unit lockout. Remove excitation when reaching a condition that would have tripped the lockout to prevent damage. Record the voltage and frequency when the relay operates and calculate the V/Hz ratio.

Standard Voltage Application – AC Regulator

Since the ac regulator has been previously tuned and the V/Hz and overvoltage limiters settings applied, raise the voltage using the ac regulator. First, turn the excitation off using the excitation stop switch or field breaker (whichever is applicable). Then, wait for the terminal voltage to decay to near zero. When this occurs, turn the excitation on while recording terminal voltage, field voltage, and other desired excitation quantities.

Exciter Overvoltage Relay Tests

Normally, two exciter overvoltage relays are installed and are connected to the generator lockout relay. Instantaneous relays should be set above the ceiling, forcing the voltage of the exciter. The ceiling value is typically at least 150 percent of the full-load rating of field voltage. Timed exciter overvoltage relays are usually connected through time delay relays and should be set at a value of about 120 to 130 percent of standard full-load excitation voltage. The time delay should be about 25 to 40 seconds, depending on the setting. When properly coordinated, the overexcitation limiters operate before instantaneous overvoltage relay trips.

The overvoltage relays can be tested easily during voltage application when the exciter reaches its ceiling voltage. Typically, control this ceiling level by limiting the voltage regulator output. Set the relays to appropriate levels and test them by adjusting the exciter voltage. When there is no easy control of the exciter voltage, set the relays and thoroughly test them with a relay test set.

Perform a functional test of the connection to the lockout relay and set and verify any time delay relays present.

Automatic Start Sequence Tests
Test the generator's automatic start sequence while recording frequency, terminal voltage, and field voltage. Use this test to verify that the excitation system energizes at the correct speed and has adequate large-signal performance under dynamic conditions.

The following tests are performed:

- Exciter field flashing start up in manual field current mode. In the test, the voltage is built up slowly, as this is the first time the excitation transformer is energized.
- DC (and ac if equipped) field flashing tests are performed.
- Full auto start with residual voltage from generator. It is important to test this after a period of rest (to prove the exciter's ability to do it).
- Bump-less transfer between auto and manual modes.
- Open circuit – exciter automatic voltage regulator (AVR) step response. Small 5% voltage set point steps are performed while recording the voltage response.
- Component failure tests – loss of bridge or fan, switch over to redundant bridge, loss of PT fuse, and automatic switching to manual current control modes are tested here.
- Field ground protection tests.
- Verification of thyristor firing sequence.
- Limiter verification. All the limiters are functionally tested for current, voltage, V/Hz etc.
- Overcurrent relay used for excitation transformer over current protection is functionally tested.
- External control: Must prove control of voltage by SCADA, synchronizer, and manual raise/lower synchronization controls.

8.4.1.6 Complete Unit Control Commissioning of Start and Stop Automation
Testing of the unit control system (hardwired and/or software) is an ongoing and evolving task, as the engineer/programmer on every start or stop is always checking performance. After extensive pre-testing, simulation, and testing during the mechanical run, it is important to leave a time slot for any troubleshooting, where the engineer/programmer has complete control of the machine and is not interrupted by other tests. Note that some tests, up until this point, were performed with some systems in manual mode.

This is the point in the testing program where the engineer/programmer is able to work on the site testing plan and complete the necessary on-site tests to do so. The control system for a hydro-electric unit is usually a custom design, and so it will have its own unique testing plan. However, following are some general tests common to most machines that need to be completed:

- Auto start sequence to speed no load with excitation
- Auto stop sequence to complete standstill
- Sequence step-by-step start
- Bump-less transfer between modes
- Testing of start interlocks to prevent starting without proper auxiliaries on
- Testing from all HMI panels and control room
- Testing from remote SCADA
- Proper safe stopping from emergency condition
- Shutdown and trip timing
- Creep monitoring and control
- Testing of alarm annunciations
- Testing of trending software

Data to Be Recorded

- Only signals and equipment that are controlled by the automation system need to be recorded (temperatures will be clearly monitored during the heat run)
- Unit speed
- Brakes applied
- Creep signal
- High pressure oil lift (all pumps and alarms)
- Bearing lubrication system (all pumps and level alarms)
- Generator stator and bearing cooling water pumps, valves, and flows
- Wicket gate or nozzle opening
- Exciter breaker status
- Unit breaker status
- Generator voltage

Pre-Conditions

- Off-line testing of exciter to rated voltage at rated generator speed

Safety concerns

- Rotation of the unit. Move all personnel to safe locations, and after movement, carefully inspect areas of concern and maintain constant communication with the commissioning leader.

Procedure

Complete the custom unit automation SAT plan up to the synchronization to the grid.

Key Reference Documents

- Unit logic or block diagrams
- Automation SAT

8.4.2 Synchronization Test

The synchronization tests are required prior to the first closure of the generator breaker on to the grid. Closure of the generator breaker out of phase, or with the wrong rotation, may cause serious damage to equipment, specifically to the generator windings. This test should be carefully carried out.

Important: If the exciter is new or the CT circuit wiring has been changed, the exciter should either be in manual mode or all limiters should be disabled just in case the CT signal is backwards. If the exciter is in AVR with limiters active, the exciter could run away in the over or under excited direction with a backwards CT.

The first part of the procedure is to verify if the rotation sequence of the generator matches the grid phase rotation, and that the phase angle at the synchroscope and synchronization check relay and auto synchronizer are wired correctly in phase.

The fool-proof way is to connect the phase rotation meter at one point only and test the generator and then the grid to the same point. To do this, one of the tests must be performed with the generator breaker closed. To test with the generator breaker closed, the generator must be disconnected either by the disconnect switch or by removing bus links or disconnecting cables. By testing to the same point (do not remove the rotation meter), any risk of improper connection of the meter or a mistake in the synchronization wiring is eliminated. The test will discover any mistake in the protection wiring.

The test can be broken into smaller parts, and these tests are usually completed in order.

- Testing of phase rotation and phase with the generator breaker closed.
- Testing of phase rotation with the generator breaker open
- Manual synchronization
  - Manual synchronization simulation test or "manual dummy test". This is a manual synchronization, with the breaker racked out and in the test position or with the disconnect switch open. This is a real-world simulation of synchronization.
  - First synchronization of the unit to the grid.
- Auto synchronization
  - Auto synchronization simulation test on "auto dummy test". This synchronization is performed by automatic synchronization hardware, with the breaker racked out and in the test position or with the disconnect switch open. This is a real-world simulation of synchronization.
  - Second synchronization of the unit to the grid.

Data to Be Recorded

Electrical

- Phase rotation on synchronizing PT circuits (consider using two different meters for redundancy)
- Voltage difference at synchronization check relay and synchronizing relay (oscilloscope)

Generator

- Generator current phase A, B, C
- Generator voltage phase-to-phase A-B, B-C, C-A
- Generator power (observed when breaker closed)
- Generator reactive power (observed when breaker closed)
- Generator breaker closed

Pre-Conditions

- All electrical off-line tests complete

– Permission from utility to connect to grid

Safety Concerns

– Rotation of the unit. Move all personnel to safe locations, and after movement, carefully inspect areas of concern and maintain constant communication with the commissioning leader.
– During these tests, all personnel should be removed from the generator, all bus duct, generator breaker, transformer, station transformer if shunt connected, and high voltage systems.
– When the generator is disconnected by removing cables or flexible leads, care must be taken to properly secure the loose leads to prevent accidental connection with the live bus bars.

Procedure

To check for phase rotation and proper wiring of synchronizing equipment, complete the following steps:

CAUTION: Do not disconnect the phase rotation meter at any time during the synchronization testing to ensure proper phase rotation and prevent personnel injury and equipment damage.

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1) Check rotation and phase of the electrical grid. This is done by physically isolating the generator from the unit breaker, closing the generator breaker, and then checking the phase rotation and the synchroscope/synchronization check relay and auto synchronizer. With the breaker closed, the synchroscope must read synchronized or at 12 o'clock, since it is supplied by the same source from both sides of the generator breaker. Next, the phase rotation is recorded. It is important to do these tests immediately before the real synchronization attempt, to avoid the slight risk of other commissioning activities altering the synchronization circuits. If the synchroscope does not read steady synchronized (12 o'clock), stop the test and troubleshoot the PTs and synchronizing circuits. After any corrective work, retest as described above. Proper phase and rotation at the synchronization check relay and auto synchronizer should also be verified at this time.
2) If there is no disconnect switch at the generator, or if it is difficult to isolate the generator by lifting the generator connection to the bus, the isolation can be performed between the generator and the transformer, or on the high voltage side of the transformer. In this test, the phase rotation meter would be placed between the transformer and the generator breaker. The test would be reversed, checking the phase and rotation with the generator breaker closed and the second test would be checking rotation of the grid with the generator breaker open.
3) Reconnect the generator and open the generator breaker. Start the unit to speed no load with full voltage. Check that the phase rotation meter is reading the same rotation as during the first test.
4) Check the synchroscope with a lower generator frequency – it should be rotating counter-clockwise and with a slightly higher frequency – it should be rotating clockwise.
5) If the rotation is not the same as the above, one set of main power leads in the power circuit must be swapped. It does not matter which leads. Phase A swapped with B, or B swapped with C, or A swapped with C. After swapping one set of leads, repeat step number 2 and

confirm correct rotation. When power circuit leads are swapped, most likely changes will need to be made to the protection and control PT and CT secondary leads as well. These secondary circuits may also need to be swapped and then these circuits retested to ensure proper phasing and polarity.

6) Depending on the unit, it may be difficult to swap power leads. This is especially the case in larger generators with bus duct. The swapping of leads of larger generators might have to be done on the high voltage side of the step-up transformer or at the generator terminals. It is good practice early on in the project, to confirm the phase rotation of the incoming transmission line to make sure it matches the correct phase rotation of the generator. It is easier to rotate the high voltage lines in the construction stage than during commissioning.
7) Now that correct phase and rotation are confirmed, the first closure of the generator breaker can be performed.

Key Reference Documents

- Generator and synchronizing protection drawings
- Generator breaker dry commissioning report (need the breaker timing data)

8.4.2.1 Manual Synchronization

Simulation of Manual Synchronization ("dummy manual" synchronization):

1) Rack out the generator breaker to the test position, or open and lock out the generator breaker disconnect switch (isolating the generator from the grid). Note that the disconnect switch must not isolate either the grid or generator synchronization PT circuits.
2) Connect the monitoring equipment (data recorder or oscilloscope)
   a) Across the synchronization circuit (at the same location as the synchroscope is connected, as this was confirmed to be correct when tested with the generator disconnected and the generator breaker closed).
   b) Direct breaker closed position contact (try not to connect to the position multiplying relay as this will add delay).
3) Consider placing generator fire protection system (e.g., CO_2) in manual mode. (The necessity of this step should be discussed with the contractor, test engineer, and plant personnel. Improper wiring of the differential relay could trigger the generator fire protection system. Placing the generator fire protection system in manual mode would block automatic operation while still allowing the system to be manually activated if necessary.)
4) Place the synchronization system in manual mode.
5) Start the unit to speed no load and full voltage
6) Have the operator manually raise and lower the voltage to match the generator voltage with the grid voltage (or slightly higher).
7) Have the operator manually raise and lower speed until the synchroscope reads a very small overspeed on the generator side (a very slow motion on the synchroscope).
8) Have the operator close the generator breaker at the in-phase moment on the synchroscope (at the top of scope 12 o'clock) or slightly before.
9) Observe the voltage across the breaker at the time of closure. This is a manual synchronizing attempt so it will not be perfect. If there are any gross errors, do not continue until these are resolved. Repeat the simulation if required.

Manual synchronization (first synchronization to grid):

1) Rack in the generator breaker and close all disconnect switches.

2) Place the synchronization system in manual mode.
3) Start the unit to speed no load and full voltage.
4) Have the operator manually raise and lower the voltage to match the generator voltage with the grid voltage (or slightly higher).
5) Have the operator manually raise and lower speed until the synchroscope reads a very small overspeed on the generator side (a very slow motion on the synchroscope).
6) Have the operator close the generator breaker at the in-phase moment on the synchroscope (at the top of scope 12 o'clock) or slightly before.
7) Check the generator voltage, current and power (real and reactive). Increase the governor (open the wicket gates) slightly to maintain a small export of power. Adjust the exciter accordingly to the reactive power level desired by the utility.
8) Observe the voltage across the breaker at the time of closure. This is a manual synchronizing attempt so it will not be perfect.
9) Check current across differential relays to ensure proper operation.

It may be faster to perform both manual and auto dummy synchronizations at the same time and then proceed with the manual and auto "real" synchronizations. This depends on the effort required for opening the disconnect switch and placing the generator breaker in the test position.

8.4.2.2 Auto Synchronization

Procedure

Simulation of Auto Synchronization ("dummy auto" synchronization):

1) Rack out the generator breaker to the test position, or open and lock out the generator breaker disconnect switch (isolating the generator from the grid). Note that the disconnect switch must not isolate either of the synchronization PT circuits. For example, the disconnect switch must close the generator breaker inside the 2 PT circuits.
2) Connect the monitoring equipment (data recorder or oscilloscope)
   a) Across the synchronization circuit (at the same location as the synchroscope is connected, as this was confirmed to be correct when tested with the generator disconnected and the generator breaker closed).
   b) Direct breaker closed position contact (try not to connect to the position multiplying relay as this will add delay).
3) Consider placing generator fire protection system (e.g., CO_2) in manual mode. (May not be necessary if proper operation was confirmed during manual synchronization testing.)
4) Place the synchronization system in auto mode.
5) Start the unit to speed no load and full voltage.
6) Have the operator issue a synchronization command via the control system.
7) Observe the voltage across the breaker at the time of closure. Adjust the synchronizer timing based on the recorded data. The goal is to have voltage across the breaker near zero. Increase or decrease the frequency or the voltage gain if required. Repeat the simulation if required.

Auto Synchronization (second synchronization to the grid):

1) Rack in the generator breaker and close all disconnect switches
2) Repeat auto dummy synchronization procedure.

It may be faster to perform all the dummy synchronizations at the same time and then proceed with the manual and auto "real" synchronizations. This depends on the effort required for opening the disconnect switch and placing the generator breaker in the test position.

8.4.3 On-Line Exciter Commissioning

Once the unit is energized, the excitation engineer will usually immediately check to see that the exciter seamlessly changes to auto mode with a pre-defined set point. When the unit is synchronized, the excitation engineer will verify proper synchronization characteristics along with proper power readings on the unit.

CAUITON: Exciters with AVR limiters active could cause a run away over or under excitation condition due to a backward CT. Operate the exciter in manual or disable all limiters after CT wiring changes or new installations.

Step and frequency responses will be performed at various loading. The under- and over-excitation limiter will also be checked at different power levels. Consult with the excitation engineer to determine exactly what he/she would like to conduct in the overall wet commissioning test schedule.

Data to Be Recorded

Exciter

- Rotor field amps
- Rotor field voltage
- Exciter firing angle
- Excitation transformer temperature (if applicable)
- Temporary exciter supply voltage (Vac)
- Temporary exciter supply current (A ac)

Generator

- Generator current phase A, B, C
- Generator voltage phase-to-phase A-B, B-C, C-A
- Generator power
- Generator reactive power
- Generator breaker closed

Pre-Conditions

- Synchronization test complete
- Unit loaded between 0% to 5% power for initial tests
- More tests will be performed after the unit reaches 75% to 100% power.

Safety Concerns

- The unit is mechanically and electrically energized and active. Observe all the safety precautions of an operating hydro generator.
- Limit personnel from close proximity to the unit.

Procedure
The following excitation tests require different loadings. They can only be performed before the shutdown and load rejections at that power level. Usually, the excitation engineer performs the checks at 0-5% power and then the rest at full load before the load rejection test and heat runs are complete.

Check Phasing and Calibration of CT Circuits
When the unit is first loaded, verify the phase relationship of the CT (current transformer) signal for the PSS (power system stabilizer), reactive current compensation, and under excitation limiter circuits. Also, check the calibration of this signal.

AC Regulator Step and Frequency Response Tests
The online step response test indicates the speed and stability of the generator and power system combination. In some cases, a control system with excellent off-line response characteristics may produce oscillations when the generator is online to the power system. Therefore, the performance of the on-line step response is a required test.

For the online step response test, operate the unit at 0-5% load and full load at unity power factor. Apply a step input of about ±1 percent to the automatic ac regulator. Adjust the regulator for proper power system operation based on field data and power system simulation results. If the regulator settings are modified, repeat these tests: off-line step response, frequency response, and large-signal performance.

Perform an overall frequency response (at full load) of the voltage regulating control system to verify the online regulator performance. If the generator has PSS, perform a frequency response at a load of 0-5% nominal power; this response will be used for PSS tuning.

Unit conditions for testing:
- 0-5% nominal power, PSS off
- 100% nominal power, PSS off
- 100% nominal power, PSS on

Current Compensation Test
Perform reactive droop compensation if one step-up transformer connects several generators. This compensation is necessary for the units to share VARs properly. Reactive droop compensation causes the regulator to control voltage at a point inside the synchronous machine terminals. The amount of reactive droop compensation determines the location of this point. Typically, a setting of about 5-10 percent internal compensation is needed. Test droop compensation by operating the parallel synchronous machines at the same Megawatt and MegaVAR loads. Then raise the voltage (VARs) on one unit and observe the reaction of the other. Usually, the reacting unit should decrease its VAR output by one-half to two-thirds of the VAR load applied to the other generator.

In some cases, generators with high-impedance step-up transformers or long transmission paths may require line-drop compensation. This type of compensation is the opposite of reactive droop compensation. The step response in magnitude without compensation should be smaller than that of a step response with the compensation.

Perform this test at a load point of 0-5% nominal power.

Under Excitation Limiter (UEL) Tests

The under-excitation limiter increases the excitation of the synchronous machine before an out-of-step condition or overloading occurs through under-excitation VARs. This limiter must operate in coordination with the loss-of-field relay. Test the limiter by running the generator at various real power settings and decreasing the excitation until the limiter works. Record a table of real and reactive power levels, terminal voltage, and field current. Then, construct a graph of the generator operating points, as shown in the following figure. During these tests, keep the voltage within reasonable limits. Temporarily adjust the limiter to functionally test if the voltage at the generator terminals will be unacceptable.

Typical testing for the UEL:

- Start the unit and load to 0-5%, then 25%, then 50%, then 75%, and finally 100% nominal power.
- At each step, test the under excitation limiter.
- Reduce the reactive power close to the under-excitation limiter.
- Perform a small lower step reactive power set point that is lower than the limiter.

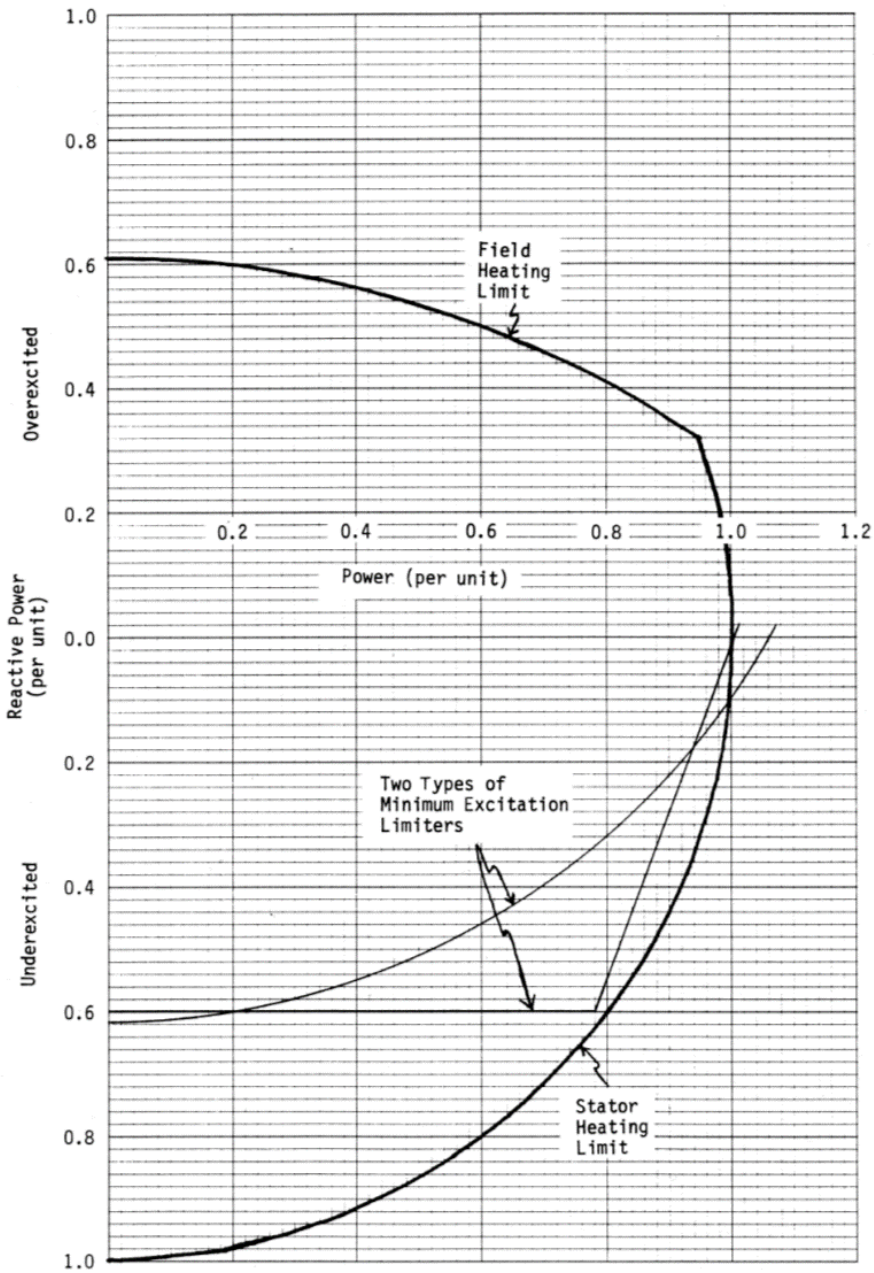

Figure 8 - Generator capability curve showing under excitation limiters

Overexcitation Limiter (OEL) Tests

Usually, two types of overexcitation protection are provided: instantaneous limit and timed limit. Instantaneous overexcitation limit is set at 120 to 200 percent of full-load field current. An inverse-time curve below the instantaneous level is set for timed overexcitation limiting. Testing the instantaneous limiter at a reduced level is common. When testing finishes, return the setting to the proper level. It is common to test the timed overexcitation limiter at a reduced setting. These tests are performed by placing significant steps into the voltage regulator and observing the excitation levels on a chart recorder. Giant steps cause the instantaneous function to activate and bring the voltage back to limits quickly. Small steps cause the inverse time function to start, and the voltage goes back to limits after a short period. Test these functions at several points along the overexcitation limit of the capability curve. After testing these limiters, reset the pickup point to allow the generator to produce 100% full load current. Since this level is asymptotic to the inverse-time curve, the time delay at this point should be infinite.

Usually, coordination exists between these limiters and the protective devices that may transfer regulator control to the manual dc regulator or trip the unit through the lockout relay. These protective devices may have an inverse-time characteristic. Older installations will probably have a fixed voltage pickup and time delay performing this function. Therefore, coordinating the overexcitation limiters and these protective devices must be done wisely. Verify the correct operation of the over-excitation limiter by completing a one-hour full load with the operating point against OEL continuously to ensure no coordination issues exist between the over-excitation limiters and protection.

Perform black testing at loading of 0-5%, 25%, 50%, 75%, and finally 100% nominal power.

The following figure shows typical:

- Short-time overload capability of the generator (from [4]),
- Typical overexcitation limiter curves, and
- Typical coordinated overexcitation protection curves.

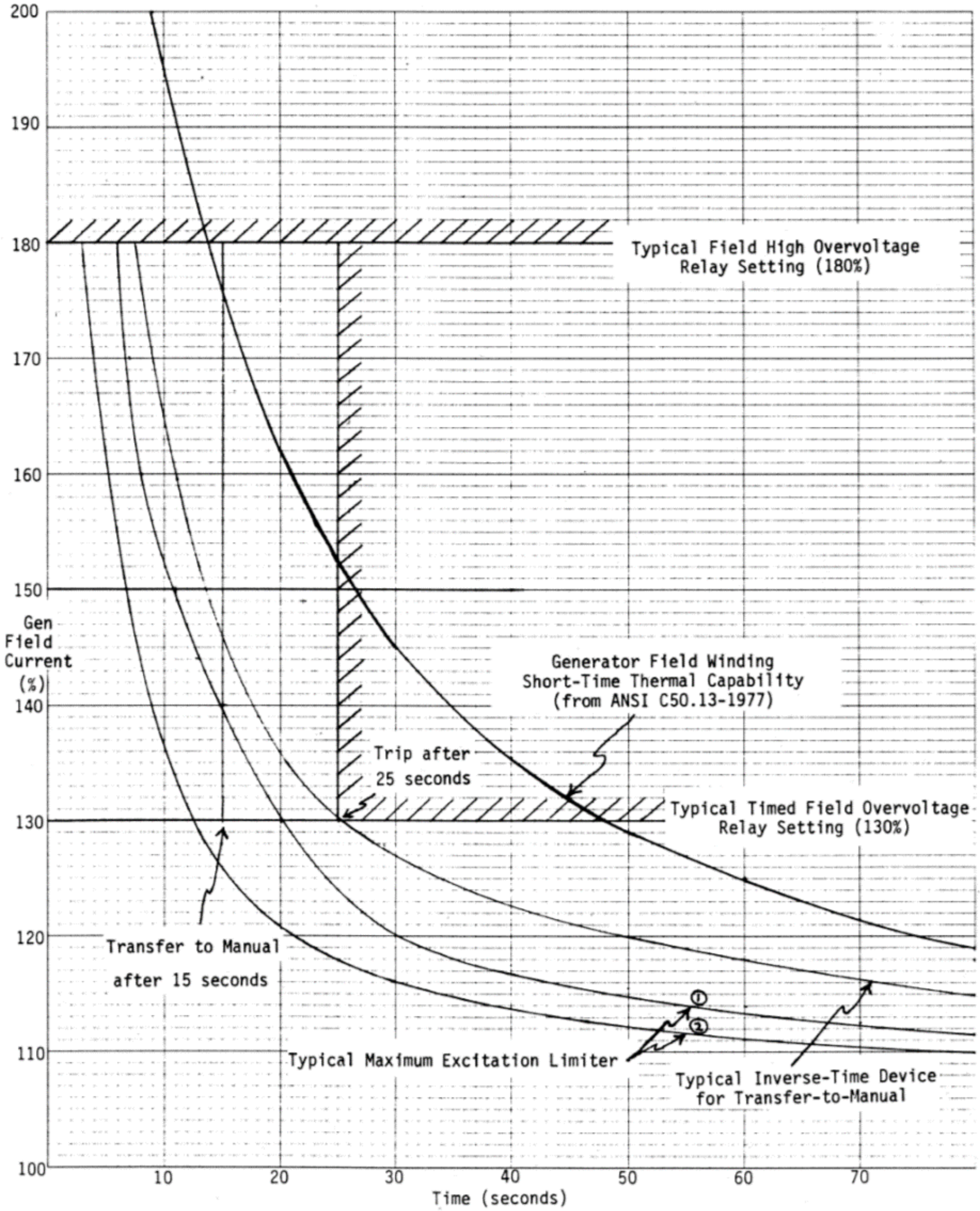

Figure 9 - Generator field winding protection coordination diagram. Overexcitation protection coordination curves are shown.

Since the overload curve represents field overheating, when the overexcitation protection devices are overvoltage relays, a hot field temperature of 75 °C should be assumed when converting from field voltage to field current. If the field winding starts cold, it can be forced harder and longer without damage.

Regulator Transfer Protection Test

Test transfer from automatic ac regulator to manual dc regulator if equipped with a sustained field overvoltage or field over-current device. The test is much like an overexcitation limiter test. Reduce the pickup level of the device to approximately the field current required to operate the generator at rated load and unity power factor. Then raise the excitation slightly above this level. The device should work at its predicted time delay and transfer control to the dc regulator. Then return the device to a level that coordinates with the overexcitation limiter.

DC Regulator Bias and Range Adjustment
After the field current required to produce full load rated power factor operation has been determined, set the dc regulator to produce 105% of this value at its maximum setpoint. The typical minimum setting value for the dc regulator adjuster is 80 percent of rated terminal voltage with the unit off-line; it could be lower. The minimum value must, however, be high enough for the SCR bridges to fire correctly and any cooling fans to run properly.

Key Reference Documents

- Exciter SAT

8.4.3.1 PSS Alignment

If the excitation system includes a power system stabilizer (PSS), align it during commissioning using the 5-year realignment test procedure.

PSS Circuit Checkout (Analog PSS only)
Check all stages of the PSS for functionality and accuracy of parameter adjustments. Check gain and time constant potentiometer at several values against manufacturer's curves for making analog exciter adjustments. If not tested before, test the PSS frequency transducer for gain and bandwidth if it is a new type. Use the voltage-controlled frequency (VCF) input of a signal generator, and the frequency response analyzer (FRA) to do the bandwidth test. In addition, investigate the control circuits for turning the PSS on and off for proper fail-safe operation if the PSS malfunctions.

Open-Loop Compensation Adjustment
Set the PSS compensation after checking PSS circuits. The traditional WECC PSS tuning procedure advocates placing the PSS lead time constants at the frequency where the overall automatic voltage regulator online frequency response passes through 90 degrees. (Refer to the Online Tests paragraph under AC Regulator Step and Frequency Response Tests above.) The PSS lag time constants are then selected to be 8 to 10 times smaller than the lead time constants. The initial lag time constant is a reasonable initial estimate; however, this method often results in under-compensation at the local mode.

Add the frequency response of the PSS lead-lag circuits to the overall automatic voltage regulator online frequency response to examine the PSS compensation. An over-plot of these signals may be helpful. The peak phase advance (60 to 100 degrees) of the PSS should occur near the local mode for optimum local mode damping and minimum noise. In many cases, the lead and lag time constants must be increased from their initial estimates to obtain this characteristic. The ratio should be maintained at 8 to 10 to prevent high-frequency noise.

Gain Selection Test/Damping Determination
The traditional WECC method for selecting PSS gain consists of increasing the gain until sustained oscillations occur and then reducing the gain to one-third of this value (can be raised, but no more than one-half of this value). Raising the PSS gain in small steps and executing an impulse test (or step test) at each gain value gives a better insight into PSS operation. Then, the responses can be characterized with damping ratios and oscillation frequencies and plotted on a root-locus diagram.

Select an operating gain with the best damping ratio. Operate large generators with a gain as high as possible to help system damping. Operate smaller machines (generators and motors) with a lower gain if the local mode is well damped. The PSS tuning process should also consider information obtained from system simulation studies.

Systems with rotating exciters may not be able to improve local mode damping significantly. Concentrating on the inter-area modes, which range in frequency from 0.2 to 0.7 Hz, should result in better damping. Systems with static excitation should be able to damp local mode oscillations and inter-area modes.

Perform this test at 100% nominal load.

Final adjustments
Adjust the PSS output limits to permit approximately –5 to +10 percent changes in terminal voltage. PSS output limits may differ in some cases due to system constraints. Set the PSS reset time constant to 30 seconds. Usually, these two settings dictate the adjustment of the PSS failure detection circuits. Set these circuits to allow normal operations such as starting or stopping the synchronous machine. However, failure of the PSS circuitry should be detected. If PSS Undervoltage or Overvoltage cutoff circuits are present, set them to ±10 percent of the nominal terminal voltage.

8.4.4 Compressed Air Systems

8.4.4.1 Mechanical and Electrical Equipment Start-ups

Equipment and systems should be carefully checked during and shortly after start-up procedures to ensure that they are operating as expected prior to commissioning activities. It is suggested that representatives from the various equipment manufacturers or suppliers be present to assist in start-up and provide additional insight into the expected operation of each piece of equipment, if required by the commissioning team. Owner representatives should also be invited to all equipment start-ups. It is also recommended that the Variable Frequency Drive (VFD) (if part of the system) is set up and started for the first time by the VFD manufacturer or supplier's representative to ensure that all parameters are set up correctly.

Energizing System
Once the commissioning team is confident that the compressed air system is ready to be commissioned, the system should be energized. Monitor the system for any abnormalities or electrical faults when energizing the system.

Equipment Start-Ups
Equipment start-ups for compressed air systems include OEM start-up procedures for the following equipment:

- Control systems
- Motors
- Dryers
- Air compressors
- Cooling systems (if applicable)

8.4.4.2 On-Line Commissioning

Isolated Testing

Isolated testing (sometimes known as off-line testing) refers to testing the system, with all equipment energized and functioning, in isolation from the rest of the facility. Manual bleed valves are generally used to simulate system demand (i.e., the anticipated flow rates required by the facility).

The system should be tested at the typical flow ranges required by the facility, as well as at the transition between them. During these tests, the compressors should be tuned for optimal operation (or best efficiency) while maintaining the system pressure and air quality within project specifications.

The following should be measured during isolated testing, using either permanent or temporary measurement devices:

- Compressor and dryer current(s) and voltage(s) – before VFD(s), if applicable
- Compressor discharge pressure(s)
- System discharge pressure (at a single agreed-upon location)
- Dryer flow(s)
- Dryer purge flow(s) and pressure(s)

Isolated compressed air system testing, and the air system inspection test plan, can follow the following typical procedure:

1) Pressurize system to 25% rated pressure and hold, as per contract specification; monitor for leaks.
2) Increase pressure to 50% and hold, as per contract specifications; monitor for leaks.
3) Increase pressure to 75% and hold, as per contract specifications; monitor for leaks.
4) Increase pressure to 100% and hold, as per contract specifications; monitor for leaks.
5) Increase pressure to 125% and hold, as per contract specifications; monitor for leaks.
6) Confirm correct operation of the pressure relief valves and other protective/control systems.
7) Reduce pressure to rated pressure and operate at typical flow ranges, while:
   a) Monitoring for leaks.
   b) Monitoring pressures and flows.
   c) Monitoring motor amperage and temperature for over-current and high temperature.
   d) Monitoring noise (dBA) and confirming that it conforms to contract specifications.
   e) Monitoring air quality (humidity, etc.) and confirming that it conforms to contract specifications.
8) Tune compressor(s) for optimal efficiency.

All pressure testing should be performed in accordance with ASME BPVC Section VIII Division 1. Leak detection should be performed using a bubble (snoop) test with soap solution at all system joints and connections.

If leaks are detected in any of these steps, the leak point(s) should be identified, and the compressor shut down as soon as possible. The compressor should be shut down and the system pressure drained/relieved prior to any repairs. All required repairs should be performed by a qualified technician prior to re-starting and re-initiating this procedure.

The procedure should be tailored to the specific system being commissioned, with input from the manufacturer(s) and supplier(s) of the system. All testing should be performed according to the manufacturer's instructions and where applicable, in accordance with ASME PTC 9 and 10 Performance Test Codes, or equivalent. If motor testing is required, motors should be tested in accordance with IEEE 112. The results of the system testing should be well documented by the commissioning team.

On-Line Testing

On-line testing, in the context of compressed air systems, refers to testing the system "live" while connected to the facility, as per the design intent. System demand will be driven by other equipment during on-line testing. The procedure for on-line testing should be similar to that of off-line testing, with the same measurements taken for consistency. The system will need to be connected to the remainder of the facility (by removing isolation protections) prior to on-line testing.

The following should be measured during on-line commissioning, using either permanent or temporary measurement devices:

- Compressor and dryer current(s) and voltage(s) – before VFD(s), if applicable
- Compressor discharge pressure(s)
- System discharge pressure (at a single agreed-upon location)
- Dryer flow(s)
- Dryer purge flow(s) and pressure(s)

On-line compressed air system testing, and the air system inspection test plan, should follow this generalized procedure:

1) Start compressor(s) and pressurize system to 25% rated pressure and hold; monitor for leaks.
2) Increase pressure to 50% and hold, as per contract specifications; monitor for leaks.
3) Increase pressure to 75% and hold, as per contract specifications; monitor for leaks.
4) Increase pressure to 100% and hold, as per contract specifications; monitor for leaks.
5) Increase pressure to 125% and hold, as per contract specifications; monitor for leaks.
6) Confirm correct operation of the pressure relief valves and other protective/control systems.
7) Reduce pressure to rated pressure and operate at typical flow ranges, while:
    a) Monitoring for leaks.
    b) Monitoring pressures and flows.
    c) Monitoring motor amperage and temperature for over-current and high temperature.
    d) Monitoring noise (dBA) and confirming that it conforms to contract specifications.
    e) Monitoring air quality (humidity, etc.) and confirming that it conforms to contract specifications.
    f) Tune compressor(s) for optimal efficiency.

All pressure testing should be performed in accordance with ASME BPVC Section VIII Division 1. Leak detection should be performed using a bubble (snoop) test with soap solution at all system joints and connections.

If leaks are detected in any of these steps, the leak point(s) should be identified, and the compressor shut down as soon as possible. The compressor should be shut down and the system pressure drained/relieved prior to any repairs. All required repairs should be performed by a qualified technician prior to re-starting and re-initiating this procedure.

The procedure should be tailored to the specific system being commissioned, with input from the manufacturer(s) and supplier(s) of the system. All testing should be performed according to the manufacturer's instructions and where applicable, in accordance with ASME PTC 9 and 10 Performance Test Codes, or equivalent. If motor testing is required, motors should be tested in accordance with IEEE 112. The results of the system testing should be well documented by the commissioning team.

Key Reference Documents

- CEATI Commissioning Guide for Hydroelectric Generating Stations – Auxiliary Systems and Equipment
- ASME BPVC-VIII-1: 2017 Rules for Construction of Pressure Vessels
- ASME PTC-9: 1970 Displacement Compressors, Vacuum Pumps and Blowers
- ASME PTC-10: 1997 Performance Test Code on Compressors and Exhausters
- IEEE 112-2017 Standard Test Procedure for Polyphase Induction Motors and Generators
- ISO 1217: 2009 Displacement Compressors – Acceptance Tests
- ISO 2151: 2004 Noise Test Code for Compressors and Vacuum Pumps-Engineering Method (Grade 2)
- ISO 5388: 1981 Stationary Air Compressors-Safety Rules and Code of Practice
- ISO 8573: 2010 thru 8573-9: 2004 Compressed Air Quality Standards and Testing
- ISO 11011: 2013 Compressed Air-Energy Efficiency- Assessment
- ISO 12500: 2007 thru 12500-4: 2009 Filters for Compressed Air Testing
- ISO 18740: 2016 Turbo-compressors-Performance Test Code – Simplified acceptance Test

8.4.5 Direct Current (DC) Power System

8.4.5.1 Load Balance Test

For redundancy, station service chargers are typically operated in parallel. Under this condition each charger will contribute its share of the load current under all system loading and charging conditions. This is generally referred to as load sharing or load balance.

If the battery charger is designed for load sharing operation, the manufacturer's instruction manual should contain procedures for testing and adjusting load balance. Recommendations should be given for determining the current load to be applied during adjustment as well as the acceptable level of current imbalance for the equipment under test.

The equipment required for this test includes two digital voltmeters and a dc load bank. The load bank is only required if the station service load it too low to perform adjustments to the load balance. The load bank should be connected main dc distribution panel. In some installations this may require considerable setup time. Once the load bank is properly connected, the test usually proceeds quickly, probably lasting no more than a couple of hours.

Most chargers can be connected in parallel prior to performing load balancing, or even if they do not have a load sharing option. Under these conditions the voltage at each charger should be adjusted so that they are nearly identical. One charger may carry most, or all, of the station service load, but the other charger will immediately pick up load if it should suddenly fail.

Key Reference Documents

- O&M manuals for battery and charger

8.4.6 Load Testing

After synchronization tests and exciter tuning at 25% power, the unit can be loaded in steps (usually 25% power increments) up to 100% power. This is a slow, deliberate process that electrically and mechanically proves each level before increasing the power and the flow to the unit. Therefore, shutdown tests and load rejection tests will be completed together at each load level.

After the last shutdown test, the generator is run until steady state temperature is achieved. At this point, the owner has a proven unit that can operate at rated power.

After load testing, more specialized tests can be performed.

8.4.6.1 Shutdown Tests

In the event of a unit malfunction, the unit must be shut down safely. The type of event determines the method to shut down and isolate the unit. Slight variations in shutdown methods are usually defined in a document called the "Trip Matrix" of the unit. This document lists all the shutdown modes on one axis and all the main isolating devices on the other. The matrix allows the operator to see what device will operate for each shutdown mode. Each shutdown mode should list the events that will trigger its operation. Examples of the key isolating devices are:

- Wicket gates or nozzles or deflectors
- Turbine inlet valve, ring gate or intake gate
- HPU shutdown valves
- Proportional hydraulic valves
- Main generator breaker
- Excitation breaker dc or ac

Examples of shutdown modes and the events that trigger them (listed in increasing order of severity) are:

QSD (Quick Shutdown) Mechanical

The water to the unit is shut off by closing the wicket gates by the governor hydraulic proportional valve as quickly as the servomotor allows, with the generator breaker still closed. This connection to the grid prevents overspeed, and the generator breaker is opened by the protection system at approximately the speed no load wicket gate position or by a zero power reading from the protection relay. This is used for all mechanical faults where overspeed would probably make the failure worse. An example is the bearing over temperature trip. This cannot be used where electrical energy must be immediately removed from the generator.

ISD (Immediate Shutdown) Electrical

An electrical fault needs to be cleared as fast as possible. This shutdown opens generator and excitation breakers immediately and operates the governor shutdown solenoid to close the wicket gates or nozzles as fast as possible. As the generator breaker has been opened, the speed of the generator will increase depending on the amount of load on the generator at the time. This may cause an overspeed condition.

This is used for all electrical faults that would require immediate shutdown of the unit. Examples include internal generator protection faults such as generator differential fault, split phase unbalance, 27TN, and rotor faults.

ESD (Emergency Shutdown)
This is similar to the ISD where everything is tripped or shut down simultaneously with an additional step to close the main inlet valve or intake gate. This is important because for ESD, we have to assume that the governor may have lost control of the unit. In the event that the wicket gates cannot be closed by the governor, the closing of the inlet valve or intake gate will eventually secure the unit. Examples of events that would trigger ESD are:

- Emergency stop push button (hardwired SCADA), namely the E-STOP
- Loss of accumulator pressure in the governor
- Governor failure (computer failure, wicket gate positioning failure, etc.)
- High water level in turbine or powerhouse
- Unit creep detected
- Overspeed trip. The governor should be able to control any overspeed condition before the unit's speed reaches the overspeed protection thresholds. Therefore, if the overspeed protection is tripped, there is a major problem and ESD must be operated.

CAUTION: Verify ESD protection is available at 25% power prior to performing higher power tests to ensure equipment safety.

A common test schedule includes the following:

- QSD mechanical at 100% power
- ISD electrical at 75% power
- ESD at 25% and 100% power (the 25% ESD is the first test and the 100% ESD is the last test)

These tests are conducted at the same time as the load rejections. All shutdown tests and load rejection tests are completed for the same power level, before increasing power to the next level.

Data to Be Recorded
Important signals are identified with * and are in bold font.
Unit

- **Unit Speed (use 2 devices or more) ***
- Shaft axial Z displacement

Vibration Monitoring System

- Key phasor
- Generator upper guide bearing shaft runout X
- Generator upper guide bearing shaft runout Y
- Generator upper bearing housing velocity X
- Generator upper bearing housing velocity Y
- Generator upper bearing housing axial velocity Z

- Generator lower guide bearing shaft runout X
- Generator lower guide bearing shaft runout Y
- Generator lower bearing housing velocity X
- Generator lower bearing housing velocity Y
- Generator lower bearing housing axial velocity Z
- Turbine bearing shaft runout X
- Turbine bearing shaft runout Y
- Turbine bearing housing velocity X
- Turbine bearing housing velocity Y
- Turbine bearing housing velocity Z

Turbine

- Servo displacements (e.g., wicket gates, runner blades, turbine nozzles, deflectors, etc.)
- Servomotor opening differential pressure over the opening stroke
- Servomotor closing differential pressure over the closing stroke
- Turbine head cover axial Z displacement
- Turbine guide bearing temperatures – all
- Air admission valve – digital signal

Hydraulic Power Unit (HPU)

- Accumulator tank pressure
- Governor pump pressure (lead and lag)

Generator

- Generator lower bracket axial Z displacement
- Generator thrust bearing temperatures – all
- Generator guide bearing temperatures – all
- Generator slip ring temperature

Water Passage

- Forebay water level
- **Net head pressure tap – upstream ***
- **Scroll case pressure ***
- Winter-Kennedy pressures
- Head cover pressure
- Net head pressure tap – downstream
- Draft tube pressure
- Tailwater level

Electrical

- Generator power
- Generator reactive power
- Generator breaker closed
- Electrical lockout relay operated
- Mechanical lockout relay operated
- Overspeed switch operated
- E-STOP switch operated

Pre-Conditions

- Exciter testing at 25% power
- Permission from the utility for loading and off-loading the unit at various load levels

Safety Concerns

- The unit is mechanically and electrically energized and active. Observe all the safety precautions of an operating hydro generator.
- Limit personnel from close proximity to the unit.

Procedure

ESD at 25% Active Power

1) Start the unit and load to 25% power. If the automation is not fully operational, adjust the governor in manual mode.
2) Let the unit stabilize for 10 minutes or so to allow the bearings and the bearing oil to warm up.
3) Trigger an ESD. Use a different mode than tested before. For example, turn off the governor controller.
4) Ensure the following occurred:
   a) The wicket gates immediately start to close via the hydraulic shutdown valves and the main inlet device to the turbine closes.
   b) The generator breaker and the exciter breaker open.
   c) Record the maximum overspeed, maximum overpressure in the penstock, or the scroll case and the minimum pressure in draft tube. Be sure to take into account the location (elevation) of the pressure transducers and adjust the pressure accordingly to the reference point of the design data.
   d) Analyze the data (vibration, shaft and bracket movements, bypass valves, etc.) and compare with the design specifications.
5) If the pressure rise or other mechanical data are above the design thresholds, stop all further tests and consult with the mechanical and hydraulic designers before proceeding. Servomotor timing (a smaller orifice) or other alterations may be required. Even if measured results are below but close to the thresholds, please consult engineering as the next step load rejection will probably exceed the thresholds.
6) Only advance to the next step when all tests at 25% are complete and are within the expected limits.

ISD Electrical at 75% Active Power

1) Start the unit and load to 75% power. If the automation is not fully operational, adjust the governor in manual mode.
2) Let the unit stabilize for 10 minutes or so to allow the bearings and the bearing oil to warm up.
3) Trigger a ISD Electrical. Use a different mode than tested before. For example, simulate a generator differential fault.
4) Ensure the following occurred:
   a) The wicket gates immediately start to close via the governor proportional valve and the main inlet device to the turbine closes.
   b) The generator breaker and the exciter breaker open.

   c) Record the maximum overspeed, maximum overpressure in the penstock, or the scroll case and the minimum pressure in draft tube. Be sure to take into account the location (elevation) of the pressure transducers and adjust the pressure accordingly to the reference point of the design data.
   d) Analyze the data (vibration, shaft and bracket movements, bypass valves, etc.) and compare with the design specifications.
5) If the pressure rise or other mechanical data are above the design thresholds, stop all further tests and consult with the mechanical and hydraulic designers before proceeding. Servomotor timing (a smaller orifice) or other alterations may be required. Even if measured results are below but close to the thresholds, please consult engineering as the next step load rejection will probably exceed the thresholds.
6) Only advance to the next step when all tests at 75% are complete and are within the expected limits.

QSD Mechanical at 100% Active Power

1) Start the unit and load to 100% power. If the automation is not fully operational, adjust the governor in manual mode.
2) Let the unit stabilize for 10 minutes or so to allow the bearings and the bearing oil to warm up.
3) Trigger a QSD Mechanical condition. Use a different mode than tested before. For example, simulate a high vibration trip.
4) Ensure the following occurred:
   a) The wicket gates immediately start to close via the governor proportional valve and the main inlet device to the turbine closes.
   b) The generator breaker and the exciter breaker remain closed until approximately zero power is attained.
   c) Record the maximum overspeed, maximum overpressure in the penstock, or the scroll case and the minimum pressure in draft tube. Be sure to take into account the location (elevation) of the pressure transducers and adjust the pressure accordingly to the reference point of the design data.
   d) Analyze the data (vibration, shaft and bracket movements, bypass valves, etc.) and compare with the design specifications.
5) If the pressure rise or other mechanical data are above the design thresholds, stop all further tests and consult with the mechanical and hydraulic designers before proceeding. Servomotor timing (a smaller orifice) or other alterations may be required. Even if measured results are below but close to the thresholds, please consult engineering as the next step load rejection will probably exceed the thresholds.

ESD at 100% Active Power

1) Start the unit and load to100% power. If the automation is not fully operational, adjust the governor in manual mode.
2) Let the unit stabilize for 10 minutes or so to allow the bearings and the bearing oil to warm up.
3) Trigger an ESD. Use a different mode than tested before. For example, simulate the loss of accumulator pressure.
4) Ensure the following occurred:

a) The wicket gates immediately start to close via the hydraulic shutdown valves and the main inlet device to the turbine closes.
b) The generator breaker and the exciter breaker open.
c) Record the maximum overspeed, maximum overpressure in the penstock, or the scroll case and the minimum pressure in draft tube. Be sure to take into account the location (elevation) of the pressure transducers and adjust the pressure accordingly to the reference point of the design data.
d) Analyze the data (vibration, shaft and bracket movements, bypass valves, etc.) and compare with the design specifications.

5) If the pressure rise or other mechanical data are above the design thresholds, stop all further tests and consult with the mechanical and hydraulic designers before proceeding. Servomotor timing (a smaller orifice) or other alterations may be required. Even if measured results are below but close to the thresholds, please consult engineering as the next step load rejection will probably exceed the thresholds.
6) The shutdown tests are now complete.

Key Reference Documents

- FIST 2-7, *Mechanical Overhaul Procedures for Hydroelectric Units*
- FIST 2-12, *Mechanical Maintenance of Hydroelectric and Large Pump Units*
- PEB 42, *Recommendations for Reclamation Facilities in Response to the Sayano-Shushenskaya Powerplant Accident*
- Contractual hydro unit specifications
- Unit's hydraulic design data (i.e., maximum allowable penstock/scroll case pressure, overspeed limits)

8.4.6.2 Load Rejection Tests and Governor Tuning

A load rejection is caused by the immediate loss of the electrical connection to the electrical grid. This is the result of a generator breaker trip or sudden breaker opening while exporting power. The unit will immediately overspeed, and the governor's role is to quickly return the speed of the unit to its nominal speed, thus ensuring it is ready to reconnect to the grid.

The load rejection test is a unit overspeed test on load rejection. Load rejections will produce the maximum controlled operational overspeed event, as there is sometimes a slight delay in the governor recognizing and responding to the overspeed excursion.

The load rejection testing purpose is:

- To test governor performance to control overspeed (keep the maximum overspeed under the machine specifications and the overspeed protection setting) and to return the unit to its nominal speed. The governor system should meet the requirement of 4.1.2 of IEEE Std. 125. Following the load rejection, the speed should be returned to the set point as influenced by the speed droop/speed regulation setting.
- To measure and confirm that the transient overpressure in the penstock and draft tube are within the design limits.
- To measure the watered gate closing time. Measure the time it takes for the gates to travel from 75% to 25% when closing and double the time.
- To measure the mechanical unit performance (shaft uplift/movement, vibration, head cover uplift, lower bracket deflection) and confirm that they are within design limits.

- To test the exciter operation during the overspeed event. The exciter must reduce voltage or shutoff during overspeed, to prevent overvoltage and during under speed to prevent high V/Hz over fluxing.
- Some hydraulic turbine systems are equipped with a pressure relief valve to reduce penstock pressure rises when the wicket gates close rapidly on load rejection. Verify that the valve operates as designed, if so equipped.
- To test the performance of the active bypass valve (if installed) to keep overpressure in the penstock within the design limits.
- To test the setpoint of the main overspeed device. The headgate should not close for a full load rejection as long as the governor brings down the speed within a reasonable time. If the main overspeed device locks out the unit during a full load rejection, the main overspeed setpoint should be evaluated and possibly changed.

CAUTION: Do not advance to the next higher load rejection test until all shutdown tests are confirmed to be within the design limits to prevent equipment damage.

Load rejections are usually performed at 25%, 50%, 75% and 100% power, (optional at the turbine limit, which may be at 100% wicket gate opening). It is important to consult the mechanical and hydraulic designers with the results obtained during the testing.

Some units require additional special load rejection tests. Examples include some Pelton units that have certain nozzle combinations that may produce maximum overspeed. Some units with shared penstocks may require a load rejection test with all units that share the same penstock. Load rejecting multiple units on the same penstock will produce the maximum pressure rise in the penstock.
The equipment required for this test includes:

- Multi-channel data recorder
- Peak holding voltmeter
- Pressure gauges
- Dial indicators
- Vibration analyzers
- Transducers for speed and gate position
- Transducers for real and reactive power
- Transducers for generator terminal voltage, field voltage and current

The testing generally requires 3-4 people and an operator to set up the unit. The actual test time depends on the number of load rejections and the time needed to coordinate with power system requirements.

Data to Be Recorded
Important signals are identified with * and are in bold font.
Unit

- **Unit Speed (use 2 devices or more) ***
- Shaft axial Z displacement

Vibration Monitoring System

- Key phasor
- Generator bearing shaft runout X
- Generator bearing shaft runout Y
- Generator bearing housing velocity X
- Generator bearing housing velocity Y
- Generator bearing housing axial velocity Z
- Turbine bearing shaft runout X
- Turbine bearing shaft runout Y
- Turbine bearing housing velocity X
- Turbine bearing housing velocity Y
- Turbine bearing housing velocity Z

Turbine

- Servo displacements (e.g., wicket gates, runner blades, turbine nozzles, deflectors, etc.)
- Servomotor opening differential pressure over the opening stroke
- Servomotor closing differential pressure over the closing stroke
- Turbine head cover axial Z displacement
- Turbine guide bearing temperatures – all
- Air admission valve – digital signal

Hydraulic Power Unit (HPU)

- Accumulator tank pressure
- Governor pump pressure (lead and lag)

Generator

- Generator lower bracket axial Z displacement
- Generator thrust bearing temperatures – all
- Generator guide bearing temperatures – all
- Generator slip ring temperature

Water Passage

- Forebay water level
- **Net head pressure tap – upstream ***
- **Scroll case pressure ***
- Winter-Kennedy pressures
- Head cover pressure
- Net head pressure tap – downstream
- Draft tube pressure
- Tailwater level

Electrical

- Generator power
- Generator reactive power
- Generator breaker closed
- Electrical lockout relay operated
- Mechanical lockout relay operated
- Overspeed switch operated
- E-STOP switch operated

Pre-Conditions

- Exciter testing at 25% power
- Permission from the utility for loading and off-loading the unit at various load levels

Safety Concerns

- The unit is mechanically and electrically energized and active. Observe all the safety precautions of an operating hydro generator.
- Limit personnel from close proximity to the unit.

Procedure

Load Rejection at 25% Active Power

1) Start the unit and load to 25% active power. If the automation is not fully operational, adjust the governor in manual mode.
2) Let the unit stabilize for 10 minutes or so, to allow the bearings and the bearing oil to warm up.
3) Open the generator breaker manually.
4) Ensure the following occurred:
    a) The governor controls the unit speed back to speed no load. As per IEEE 125-1988 3.1.2., there shall be only one 5% underspeed deviation followed by not more than one 5% overspeed deviation. The percentage speed is based on the initial overspeed event. If out of specification, adjust the governor tuning parameters and re-test.
    b) Record the maximum overspeed, the maximum overpressure in the penstock or the scroll case, and the minimum pressure in the draft tube. Be sure to take into account the location (elevation) of the pressure transducers and adjust the pressure accordingly to the reference point of the design data.
    c) Analyze the data (vibration, shaft and bracket movements, bypass valves, etc.) and compare with the design specifications.
    d) Observe that the exciter operation during the event was as per design (in some cases the exciter should not stay on during overspeed or underspeed events).
5) If the pressure rise or other mechanical data are above the design thresholds, stop all further tests and consult the mechanical and hydraulic designers before proceeding. Servomotor timing (a smaller orifice) or other alterations may be required. Even if the measured results are close to the thresholds, please consult engineering as the next step load rejection will probably exceed the thresholds.
6) Only advance to the next step when all tests at 25% are complete and within the expected limits.

Load Rejection at 50% Active Power

1) Repeat step 1, except at 50% active power.
2) Only advance to the next step when all tests at 50% are complete and within the expected limits.

Load Rejection at 75% Active Power

1) Repeat step 1, except at 75% active power.
2) Only advance to the next step when all tests at 75% are complete and within the expected limits.

Load Rejection at 100% Active Power

1) EXTRA STEP: As a precaution, start the unit from 75% power, and increase the power in small increments while observing the servomotor pressure and position. Abort the test and consult engineering if the servomotor seems to stall and can't achieve the power set point at this high flow rate.
2) Continue with step 1, except at 100% active power.
3) Load rejections are only complete when all tests at 100% are within the expected limits.

With Kaplan units, runner control during load rejection is important. It is important to plot the runner blade position (including the open and close pressure) with wicket gate position and unit speed, and confirm that it follows its intended operation during these events. Modifications to runner control parameters during load rejection may be necessary to meet the intended performance criteria.

The test program can be expanded to include different methods of initiating the load rejection. For example, generator breaker opening can be initiated for some tests by operating a minor electrical protection or by SCADA, instead of by a manual control. Load rejection could also be tested by opening an upstream breaker. Varying the test initiation will simultaneously test other parts of the overall system and combine more testing into each test. When testing new excitation systems, it is important to perform a 100% active power lockout to ensure the crowbar and field discharge circuits operate appropriately.

Reactive power can be added to some tests to verify that the generator breaker is capable of interrupting full rated generator current.

Key Reference Documents

- FIST 2-7, *Mechanical Overhaul Procedures for Hydroelectric Units*
- FIST 2-12, *Mechanical Maintenance of Hydroelectric and Large Pump Units*
- FIST 2-3, *Mechanical Maintenance of Mechanical and Digital Governors for Hydroelectric Units*
- Contractual hydro unit specifications
- Unit's hydraulic design data (i.e., maximum allowable penstock/scroll case pressure, overspeed limits)
- IEEE 1248-1998 Guide for the Commissioning of Electrical Systems in Hydroelectric Power Plants
- ASME PTC 29-2005 Speed Governing System for Hydraulic Turbine Generator Units
- IEEE Std 115, IEEE Guide for Test Procedures for Synchronous Machines Part I – Acceptance and Performance Testing Part II – Test Procedures and Parameter Determination for Dynamic Analysis
- IEEE Std 125, IEEE Recommended Practice for Preparation of Equipment Specifications for Speed-Governing of Hydraulic Turbines Intended to Drive Electric Generators
- Original equipment instruction manuals

8.4.6.3 Unit Deceleration Test and Braking

This test charts the stopping operation from 100% load to standstill. This is a second test for the owner's operation planning on the time required to stop the unit. Also, the braking time is tested for comparison to track future brake performance and wear. The speed when the high-pressure lift system turns on is also verified.

If there are different unloading times programmed, they should be recorded as well.

Data to Be Recorded

Unit

- Unit speed. A data recorder which will record rotational speed shaft orbit and wicket gate position versus time is preferred.

Generator

- Generator brakes applied. High pressure oil lift system starts.

Electrical

- Generator power
- Generator breaker open

Pre-Conditions

- Generator heat run complete

Safety Concerns

- The unit is mechanically and electrically energized and active. Observe all the safety precautions of an operating hydro generator.
- Limit personnel from close proximity to the unit.

Procedure

- With unit at speed no load, off-line, or on-line, zero power, initiate a normal shutdown. Record the time from initiation to full stop. Record the time when the brakes engage, and the high-pressure lift pump starts.

Key Reference Documents

- FIST 2-7, *Mechanical Overhaul Procedures for Hydroelectric Units*
- FIST 2-12, *Mechanical Maintenance of Hydroelectric and Large Pump Units*
- Control system operations manual

8.4.7 Completion of Protection and Control Testing

This is the continuation of the testing in Section 7.0.

With the unit able to run continuously at 100% power, the engineer/programmer is able to complete the site testing plan with the automation tests from partial to full load.

Following are some general tests that are common to most machines and that have to be completed:

- Auto start sequence to 100% load
- Auto stop response to complete standstill
- Bumpless transfer between modes (i.e., MW control mode, gate control mode, voltage control mode, Mvar control mode, power factor control mode, forebay level control mode, best efficiency mode, etc.)
- Changing of set points
- Loading and unloading rates, etc.

- Continue testing from all HMI panels and control room
- Continue testing from remote SCADA
- Testing of alarm annunciation
- Testing of trending software

Data to Be Recorded

- Only signals and data that are controlled by the automation system need to be recorded (temperature will be closely monitored during heat runs).
- Unit speed
- Brakes applied
- Creep signal
- High pressure oil lift (all pumps and alarms)
- Bearing lubrication system (all pumps and level alarms)
- Generator stator and bearing cooling water pumps, valves, and flows
- Wicket gate or nozzle opening
- Exciter breaker status
- Generator voltage
- Generator breaker
- Generator current

Pre-Conditions

- All shutdown and load rejection tests at 100% power complete and generator heat run complete.

Safety Concerns

- The unit is mechanically and electrically energized and active. Observe all the safety precautions of an operating hydro generator.
- Limit personnel from close proximity to the unit.

Procedure

- Complete custom unit automation SAT.

Key Reference Drawings

- Unit logic diagrams (or block diagrams)
- Automation SAT

8.4.8 Vibration and Remaining Turbine Testing

The following are some miscellaneous mechanical tests.

Pre-Conditions

- All load testing complete.

Safety Concerns

- The unit is mechanically and electrically energized and active. Observe all the safety precautions of an operating hydro generator.
- Limit personnel from close proximity to the unit.

8.4.8.1 Vibration Signature Measurement

The initial vibration analysis and dynamic balancing (if required) have already been performed during the mechanical run.

The purpose of this test is to create a baseline vibration signature from speed no load (with and without excitation) up to 100% load.

Data to be Recorded

Unit

- Unit Speed (use 2 devices or more)
- Shaft axial Z displacement

Vibration Monitoring System

- Key phasor
- Generator upper guide bearing shaft runout X
- Generator upper guide bearing shaft runout Y
- Generator lower guide bearing shaft runout X
- Generator lower guide bearing shaft runout Y
- Generator upper bearing housing velocity X
- Generator upper bearing housing velocity Y
- Generator upper bearing housing axial velocity Z
- Generator lower bearing housing velocity X
- Generator lower bearing housing velocity Y
- Generator lower bearing housing axial velocity Z
- Turbine bearing shaft runout X
- Turbine bearing shaft runout Y
- Turbine bearing housing velocity X
- Turbine bearing housing velocity Y
- Turbine bearing housing velocity Z

Turbine

- Servo displacements (e.g., wicket gates, runner blades, turbine nozzles, deflectors, etc.)
- Air admission valve status

Generator

- Generator lower bracket axial Z displacement
- Generator air gap measurement

Water Passage

- Forebay water level
- Net head pressure tap – upstream
- Scroll case pressure
- Winter-Kennedy pressures
- Head cover pressure
- Net head pressure tap – downstream
- Draft tube pressure
- Tailwater level

Electrical

- Generator current phase A, B, C
- Generator voltage phase-to-phase A-B, B-C, C-A
- Generator power
- Generator reactive power

Exciter

- Rotor field voltage

Procedures

- Start the data recorder.
- Start the unit manually and record vibration at 25%, %0%, 75% and speed no load with no excitation.
- Apply and remove field excitation and note shaft movement and orbit change.
- Synchronize the unit.
- Increase the load in 10% steps to full nominal power (and to the turbine limit, if appropriate). Note any operating range where rough operation (partial load rough zone occurs.
- Ramp the unit down from 100% load to speed no load and conduct a normal shutdown. Record data during the ramp down.
- Reconduct the test in condense mode. Record vibration while condensing.

Key Reference Documents

- FIST 2-7, *Mechanical Overhaul Procedures for Hydroelectric Units*
- FIST 2-12, *Mechanical Maintenance of Hydroelectric and Large Pump Units*

8.4.8.2 Noise Measurements

This test consists of recording noise levels at intervals of 1.0 meters around the equipment to be tested. This test may be performed on the turbine-generator unit, auxiliary rotating equipment, power transformers, etc. Tests should be made at multiple locations and elevations and with the equipment at all expected operating conditions.

This is usually a contractual requirement with specific limits. This testing is usually done at 100% load at very specific locations and distances from the equipment. Consult the equipment specifications for details. This test can usually be completed in parallel with other tests that require the unit to operate at 100% power.

For transformers, the starting point is normally in front of the main drain valve and proceeding in a clockwise direction with no fewer than four microphone locations. Noise levels should be recorded at one-third and two-thirds tank height with the transformer energized at rated voltage and frequency with no load. For transformers that have an overall tank height of less than 2.4 meters, measurements should be made at half height. Microphones should be 0.3 meters from the major sound-producing surfaces except where fans are in operation, where the microphones should be 2.0 meters away from any portion of the transformer radiators, coolers, or cooling tubes. Setup time is minimal. A taut string stretched around the periphery of the transformer should be utilized to locate microphone positions.

For generators the test is normally performed around the sides of the air housing and on top if personnel access is provided. Tests may be done with doors and covers opened and closed. Record noise levels at the draft tube entrance and near the draft tube door. Record levels outside and inside the turbine pit. For turbine noise levels record both steady state and transient levels such as when the unit is operating in the partial rough zone.

For reference and correction purposes, levels of the ambient noise level should be recorded with the equipment shutdown or deenergized before and after measurements at operating conditions.

A noise meter with a response curve is required to take the measurements.

Key Reference Documents

- FIST 2-7, *Mechanical Overhaul Procedures for Hydroelectric Units*
- FIST 2-12, *Mechanical Maintenance of Hydroelectric and Large Pump Units*
- ANSI/ASA S1.4, American National Standard Electroacoustics – Sound Level Meters
- IEC 61672, Electroacoustics – Sound Level Meters
- ISO 1680, Acoustics – Test Code for the Measurement of Airborne Noise Emitted by Rotating Electrical Machines
- IEEE Std C57.12.90, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers

8.4.8.3 Servomotor Indication of Force Test

The purpose of this test is to measure the opening and the closing differential pressures across servomotors from 0% power to 100% wicket gate or turbine power limit. The results are useful as a baseline for future comparison that might show servomotor wear or binding wicket gates. They also allow the hydraulic designer to see how much reserve pressure is available above the force required to overcome the hydraulic forces and friction acting on the wicket gates.

Consult the equipment specifications for the details. The test can usually be completed in parallel with other tests that require the unit to operate between 0% and 100% power.

Data to Be Recorded

Important data identified with * and are in bold font.

<u>*Turbine*</u>

- Servo displacements (e.g., wicket gates, runner blades, turbine nozzles, deflectors, etc.)
- **Servomotor open pressure ***
- **Servomotor close pressure ***

<u>*Hydraulic Power Unit (HPU)*</u>

- Accumulator tank pressure
- Governor pump pressure (lead and lag)
- Oil tank temperature

<u>*Water Passage*</u>

- Forebay water level
- Net head pressure tap – upstream
- Scroll case pressure
- Winter-Kennedy pressures

- Head cover pressure
- Net head pressure tap – downstream
- Draft tube pressure
- Tailwater level

Electrical

- Generator power

Procedures

1) Start the unit and set to 0% power.
2) Place the governor in manual mode.
3) Start the data recorder.
4) Slowly increase the wicket gate opening (best is to program a slow ramp) up to 100% (or the turbine limit).
5) Hold for a short time period and then slowly decrease the wicket gate opening back to 0% power.

Key Reference Documents

- FIST 2-7, *Mechanical Overhaul Procedures for Hydroelectric Units*
- FIST 2-12, *Mechanical Maintenance of Hydroelectric and Large Pump Units*

8.4.9 Governor On-Line Testing

Governor testing is completed by the governor engineer. The scope of this guide does not cover detailed governor testing, but describes in general the test that will be performed. After the 100% load rejection test, the following tests are performed to prove proper governor operations.

Data to Be Recorded

Unit

- Unit speed

Turbine

- Servomotor displacements (e.g., wicket gate, runner, nozzle, deflector, etc.)

Water Passage

- Forebay water level
- Tailwater level

Electrical

- Generator power

Pre-Conditions

- All load tests complete.

Safety Concerns

- The unit is mechanically and electrically energized and active. Observe all the safety precautions of an operating hydro generator.
- Limit personnel from close proximity to the unit.

Key Reference Documents

- FIST 2-3, *Mechanical Maintenance of Mechanical and Digital Governors for Hydroelectric Units*
- ASME PTC 29-2005 Speed Governing Systems for Hydraulic Turbine Generator Units

8.4.9.1 Steady State Governing Power Band Test – On-Line Method

This test quantifies the power oscillations created by the governor power controller. The test is performed by running at a power set point and recording the power oscillations (peak to peak), and then reducing the wicket gate limiter just below the power set point to remove the controller from operation. The power oscillations that are recorded with the limiter in place quantify the natural machine performance. The difference between the two is the oscillation of the governor power controller. The oscillation should not typically be more than 3% of rated power output.

Repeat this test at 10% intervals between typically 40%, or a gate opening above the rough operating zone (Kaplan and Peltons might start at a lower percent of power), and 100% power.

8.4.10 Turbine Inlet Valve/Intake Gate Full Flow Closure Testing

This test will test the ability of the main inlet shutoff device, namely the turbine inlet valve or the intake gate, to shut off full water flow through the turbine. In real operation, this would only happen if the unit were to be in runaway condition (i.e., complete loss of wicket gate or nozzle control).

The challenge in this test is to keep the unit wicket gates open while the main inlet shutoff device is closing. The purpose of maintaining the wicket gates in the open position during the full flow gate closure test is to ensure that an unbalanced head is maintained throughout the closure test. If the wicket gates close prior to full closure of the intake gate, the sections of penstock between the intake gate and the wicket gate begin to fill which will result in the failure of achieving a true unbalanced head condition. Special cases will have to be taken to defeat certain protections in the governor and electrical protection as flow decreases. Consult the manufacturer before proceeding with this test.

Data to Be Recorded

Unit

- Unit speed – (use 2 devices or more)

Turbine

- Air admission valve status

Main Inlet Shut Off Device (Turbine Inlet Valve or Intake Gate)

- Valve or gate position (analog)

Water Passage

- Forebay water level
- Net head pressure tap – upstream
- Scroll case pressure
- Winter-Kennedy pressures
- Head cover pressure
- Net head pressure tap – downstream
- Draft tube pressure

– Tailwater level

Electrical

– Generator current phase A, B, C
– Generator voltage phase-to-phase A-B, B-C, C-A
– Generator power
– Generator reactive power
– Generator breaker closed

Pre-Conditions

– Load testing complete.

Safety Concerns

– Same as for an operational hydroelectric unit.
– Remove all people from the intake structure or the inlet to the penstock (if the wicket gates close at the wrong time, a wave can be reflected back up the partially filled penstock, or the inlet tunnel).

Procedures

1) Block the required protections that close the wicket gates in order to allow the turbine to continue to operate as water is being shut off to the turbine during the intake gate/valve closure test. This will probably require blocking the shutdown circuit in the governor and commanding the wicket gates to remain in the open position. Be ready to re-engage the shutdown valve if required.
2) Start and load the turbine to rated flow.
3) Take manual command of the wicket gates.
4) Close the main inlet gate/valve.
5) When the main inlet gate/valve is completely closed, slowly close the wicket gates or nozzles.
6) The unit should stay under automatic control as normal. Monitor activities to make sure the bearing high lift and the brakes, etc. come on at the appropriate time/speed.
7) After the turbine inlet device is closed, slowly close the wicket gates. This is to prevent any large waves reflecting back up the inlet penstock, tunnel, or channel. There have been instances of such waves reflecting and creating damage in the intake building.

Key Reference Documents

– FIST 2-13, *Gates and Valves*

8.4.11 Draft Tube Depression System Test

The test is intended to check the draft tube water depression system and its design. The performance testing should be conducted during the initial operation. Normally, the system can be initiated manually by an operator or automatically whenever the unit is motoring with the wicket gates closed. The following tests should be performed:

– Manual control by an operator: Initiate the draft tube depression system with the unit stationary. Observe the system air injection valve open and close within the design time. Observe the station air pressure supplying the depression system. Verify that the pressure is above the minimum system operating pressure. Observe that the system make-up air valve operates due to leakage of air through the shaft gland and leakage through the wicket gates.

- Automatic control (if equipped): Set the system control to automatic mode upon satisfactory manual system test. Start-up the unit and place the unit on-line. Close the wicket gates. With no primary mover (water) the unit will motor. At that point, observe the system air injection valve open and close within the design time. Observe that the unit power consumption decreases as the draft tube water level is depressed below bottom of the turbine runner. Check the station air pressure adequacy. Observe that the system make-up air valve operates on demand.

One person is normally sufficient to observe the system operation while an operator sets up the unit.

Equipment Required
No special equipment is required.

Key Reference Documents
- FIST 2-7, *Mechanical Overhaul Procedures for Hydroelectric Units*
- FIST 2-12, *Mechanical Maintenance of Hydroelectric and Large Pump Units*
- IEEE Std 1010, IEEE Guide for Control of Hydroelectric Power Plants

8.4.12 Power Transformers

All final testing and inspections should be completed and documented from Section 6.1.43 Power Transformers before moving to commissioning. An Energization Authorization notification should be sent from the Reclamation technical approver to the facility manager and facility operations lead. At a minimum, the Energization Authorization notification should include:
- Confirmation that all documents have been received.
- Confirmation that all pre-commissioning testing has been performed with acceptable results.
- Authorization to remove the clearance.
- Start-up procedures.
- Energization steps with voltage and no load.
- Transformer loading steps and required hold times.
- Transformer checks and fluid samples to be taken during initial start-up.
- Transformer data gathering tasks for the first year of operations.

Specifics for the above items are listed below and example documents can be found as part of the Appendices. The Energization Authorization notification will form part of the commissioning record for the project and should be shared with all parties involved. The commissioning phase should not begin until the Energization Authorization notification is received.

Confirmation that all testing has been performed successfully and documentation has been received and approved is critical for commissioning. Typically, power transformers' manufacturers' warranties are voided if the appropriate tests are not performed prior to energization. Many of the testing procedures found in Section 6.1.43 Power Transformers cannot be performed once the transformers are energized.

The clearance should be maintained on the transformer until documentation has been received and the start-up date and time is scheduled and approved by all parties. In addition to specific facility requirements, removal of the clearance should not begin until the start-up procedures checks are performed.

Qualified personnel should be involved for the walkdown of the transformer and associated circuits prior to energization. This would include checking:

- Split type terminals are closed and secured. These are typically opened during pre-commissioning testing and should be checked and verified to be secure.
- Transformer cooling systems are in the auto position. If the transformer is water cooled, check that water is flowing in the coolers at the appropriate pressure and flow.
- Current Transformer secondary circuits are verified in the correct position with the appropriate single point ground or shorting method. It is recommended that all shorting screws be removed and shorting jumpers used for spare current transformer circuits. This will prevent the possibility of shorting screws backing out due to vibrations in the transformer.
- Tap changer is in the correct position and locked.
- Grounds placed during clearance have been removed.
- Secondary oil containment has been secured.
- Fire protection system is energized and in normal operations.
- If a bus system is connected to the power train circuit, verify that it has been cleaned and/or pressurized with dry air for a minimum of 5-days prior to energization.
- Potential transformer circuits are in normal configuration.
- The control room is clear of all alarms.
- Test switches are closed for each associated relay.
- Clearance has been fully removed.

Initial energization of the transformer should be with voltage and no-load for a predetermined amount of time; this is commonly reference to as the voltage soak time. This period of time is helpful to understand and evaluate characteristics of the transformer for future diagnostics as well as confirm unforeseen conditions prior to loading. Additionally, hold times should be followed for cold weather start-up procedures. Check with the manufacturer for hold times during initial energization; however, a minimum hold time of 8-hours should be observed. Hold times for transformers are adjusted based on voltage and should be explicitly stated in the Energization Authorization notification. During this period, the following should be performed:

- Fluid sample taken at the start of energization (if fluid filled). See Section 6.1.23 Electrical Insulating Fluids.
- Check for excessive audible noise and vibration.
- Monitor temperature of fluid; recordings to be taken at time intervals (every hour) until stabilization. Take recordings from gauges and from electronic monitoring (if applicable).
- Monitor temperature of windings (LV and HV); recordings to be taken at time intervals (every hour) until stabilization. Take recordings from gauges and from electronic monitoring (if applicable).
- Monitor ambient temperature; recordings to be taken at time intervals (every hour).
- Check performance of coolers. Record temperatures for each staged cooling as it is activated. Often, the cooling stages will not be activated during the initial energization phase.
- Inspect for fluid leaks and check all fluid level indicators. Fluid levels should rise as temperatures rise.

- Fluid sample taken at the end of initial energization (if fluid filled).See Section 6.1.23 Electrical Insulating Fluids.

Once the initial energization is complete, the transformer is ready for incremental loading. Loading should be performed as defined below and held for a period of time to allow for stabilization of the transformer temperature. For SSU transformers, loading is provided via station service loads. For GSU transformers, loading is performed with the generators at the facility. If loading interferes with generator rough zones, adjust as necessary. Loading should be incremented up to 100% or as close as possible to verify the transformer during full load operations. During incremental loading, use an infrared (IR) scanner to check for hot spots on the tank, bushings, and cooling systems as well as monitor for excessive audible noise and vibration. Loading should be performed based on the transformer type:

Table 5 - Station Service Unit (SSU) Transformer Incremental Loading

Loading	Hold Time
10%	15-minutes
25%	30-minutes. Allows for relaying to be verified.
50%	15-minutes
75%	15-minutes
100%	Hold until stabilized temperatures

Table 6 - Generator Step-Up (GSU) Transformer Incremental Loading

Loading	Hold Time
10%	15-minutes
20%	15-minutes
30%	30-minutes. Allow for relaying to be verified.
40%	15-minutes
50%	15-minutes
60%	15-minutes
70%	30-minutes
80%	15-minutes
90%	15-minutes
100%	Hold until stabilized temperatures

Once full load is achieved, hold for the necessary time to allow temperatures to stabilize. A stabilized temperature is less than 1°C change over a 3-hour period. During this time perform hourly checks for the following:

- Check for excessive audible noise and vibration.
- Use IR scan to monitor for hot spots on bushings, tank, and cooling systems.
- Check performance of coolers. Record temperatures for each staged cooling as it is activated.
- Inspect for fluid leaks, and check all fluid level indicators. Fluid levels should rise as temperatures rise.

At the end of the incremental loading and after temperatures have stabilized, take a fluid sample. See 6.1.23 Electrical Insulating Fluids. The transformer is now commissioned and ready for normal operations.

During normal operations over the first year, it is critical to gather substantial data on the transformer conditions. Depending on the transformer type, the following should be performed.

Table 7 - SSU Transformer Schedule for First Year

Fluid Sample Schedule	Temperature Record Schedule
Beginning of Energization (voltage soak 24-hours)	End of Initial Loading
End of Energization (voltage soak)	24-Hours After Normal Loading
End of Initial Loading	1-Week After Normal Loading
24-Hours After Normal Loading	1-Month After Normal Loading
1-Week After Normal Loading	3-Months After Normal Loading
1-Month After Normal Loading	6-Months After Normal Loading
3-Months After Normal Loading	9-Months After Normal Loading
6-Months After Normal Loading	12-Months After Normal Loading

Table 8 - GSU Transformer Schedule for First Year

Fluid Sample Schedule	Temperature Record Schedule
Beginning of Energization (voltage soak 24-hours)	End of Initial Loading
End of Energization (voltage soak)	First Week of First Month
End of Initial Loading	Second Week of First Month
24-Hours After Normal Loading	Third Week of First Month
72-hours After Normal Loading	Fourth Week of First Month
First Week of First Month	End of Second Month
Second Week of First Month	End of Third Month
Third Week of First Month	End of Fourth Month
Fourth Week of First Month	End of Fifth Month
4-Months After 1st Month	End of Sixth Month
8-Months After 1st Month	End of Seventh Month
12-Months After 1st Month	End of Eighth Month
	End of Ninth Month
	End of Tenth Month
	End of Eleventh Month
	End of First Year

Once the first year of operations is complete, document all recorded information and store in the transformer Operations and Maintenance Manual book. Contact the technical approver of the transformers and provide a copy of the documentation for trending and analysis.

9.0 Trial Run

The trial run is executed after the final on-line electrical test is completed and is performed under normal operating conditions based on available flows. A hold point in the schedule and release is recommended for this transition point since any safety related deficiencies or poorly performing components that were identified during commissioning testing will need to be corrected prior to the start of the trial run. The focus is primarily on ensuring the unit can operate safely. The trial run is performed to ascertain if the unit is meeting the contractual requirements for unaided operation for a specific period of time with very little downtime. After the trial run is completed, the unit is usually handed over for commercial operation.

The trial run is usually a contractual requirement and occurs at the end of wet commissioning to prove that the unit can run without intervention for a specified period of time, such as 10 days or 30 days. There are usually strict requirements for the amount of downtime allowed, usually with a small amount of time defined for the constructor to fix and return the unit back to service if it trips (i.e., 95% run with no more than 12 hours per outage, etc.). The constructor usually has to arrange for commissioning, electrical, and support staff to remain for a quick service call in the event of an outage. Depending on the location and other circumstances, this can be challenging and may require a skeleton staff to stay at the plant. Usually, there is a deficiency list of small items that need to be addressed, and therefore the skeleton staff can be assigned to clean up these items and remain available for work in the event of an outage. Although in a perfect world, all operator training should have taken place well in advance of the trial run, any training missed or remaining can be completed during this time.

The owner usually takes full operational control of the unit at this point. The operator staff must be fully involved in the wet commissioning testing and realistically, the operators should have slowly taken control of unit operation through this process, so that when this last test is complete, they are confident in operating the unit.

The unit is formally transferred to the owner at the end of the trial run. Depending upon the amount of deficiencies that are remaining, the commissioning and construction team will start to plan for complete de-mobilization from the site.

An adequate supply of spare parts and consumables is critical to the commissioning and hand over process. The need for these at the site increases as the commissioning process advances. Delays to procure and deliver replacement parts or, for example, oil filters during dry commissioning can set the schedule back by several days. If this happens during wet commissioning, the entire testing program stops and if it occurs during the trial run, there is a risk of starting the entire trial run over again.

Pre-Conditions

- Wet commissioning complete and signed off by the owner or the owner's engineers.
- Existence of an agreed deficiency list that contains only items that can be completed with running a unit or at a later scheduled shutdown.

Safety Concerns

- The owner's plant safety system is in full effect. Full operational control is handed over to the owner. All site safety (e.g., lock-out tag-out, etc.) is controlled by the owner's operators.

Key Reference Documents

- Construction and equipment supply contract(s)

10.0 Acceptance

Acceptance is a milestone in the commissioning schedule in which the work has been completed and the owner accepts the equipment and systems, and releases the contractors and suppliers from a number of contractual liabilities. The owner will need a good understanding of the unresolved issues and how to manage them before accepting the equipment and systems.

10.1 Typical Handover Conflicts

The commissioning process typically leads to the handover or transfer of the facilities or the unit to the owner. This usually happens when the work has been completed to meet contractual requirements and to achieve reliable and safe operation of the equipment/systems. Listed below are some examples of typical handover conflicts:

Withholding of payments – Owners withhold payments to contractors and suppliers because of issues that have been identified during commissioning, or items that were missed and not recorded during the commissioning process. This usually leads to a significant amount of work that needs to be repeated, and the ability to secure the proper personnel at site to perform the necessary corrections is more difficult. In addition, new issues may continue to be identified during the corrective process. Uncertainty, withholding of payments, and lack of resources often results in the delay of the resolution of issues and deficiencies.

Hesitation to transfer to owner's operations group – Owners sometimes struggle with the transfer of safety and operational responsibilities to their internal operations and maintenance staff. Stringent expectations for documentation and training are usually required by experienced operators and maintenance staff. Completion of training and documentation normally extends past the end of the commissioning activities, so there has to be a plan for the interim period. This may include agreements on the means to capture information in the facility documents while final versions are being prepared, and on the minimum extent of training that must be completed.

Difficulty to access facility for corrective work – In most cases, access to the facility and the units to perform corrective actions becomes much more difficult after handover. The main reason is simply that the ability to shut down a unit for repairs or modifications may be controlled by grid operators or other agencies, thereby limiting when or how soon the work can be accomplished.

Scheduling of commissioning and testing activities for optimal hydraulic conditions – Certain commissioning tests have to be deferred until the head and flow conditions meet the requirements to allow the tests to be performed. It is important to consider this factor and to have an approach and understanding on how to accomplish this as part of the commissioning plan and schedule. This affects the timing of performance testing in particular, which requires specific head and flow conditions.

11.0 Post Commissioning

The post-commissioning phase includes the performance of all remaining regulatory testing. This is the step between the end of planned commissioning, and the point where all contractual obligations have been resolved. This phase also includes the performance of all remaining regulatory testing. Recommissioning and additional testing of repairs to address identified deficiencies are completed during scheduled outages. Inspections are performed during a scheduled outage as part of the contractual requirements for warranty.

Operation of the equipment is monitored as part of normal plant operations, and communication and signal issues are resolved. Contractor and supplier resources are focused on the correction of deficiencies and gradually demobilize and perform a final clean up.

Training of the owner's operations and maintenance staff is performed, spare parts and tools are inventoried and stored, and the commissioning reports and final project documentation is collected.

11.1 Defining Completion of Commissioning

When using the word "commissioning" to describe this phase of the project, the understanding of most suppliers, vendors, and project stakeholders is that once the planned commissioning activities, as defined by various commissioning documents, have been completed, the commissioning phase is complete, and the warranty period begins.

There are a number of activities owners, operators, and technical support staff consider to be important prerequisites to take on the operating control of the facility and before the demobilization of project staff. Once regular production begins, the requirements for reporting to grid operators and meeting the requirements of river management plans begins as well. Naturally, this requires information on the actual capabilities of the equipment, knowledge of how to operate the plant systems, and how to respond to alarms or changes. The types of information and activities to be completed to achieve full operational and engineering control by the owner often include:

- Operational and maintenance training
- Resolution of critical deficiencies
- Documents demonstrating test results
- Alarm lists – Sometimes with information about their triggers and the required response.
- Equipment demonstrated capacities – Whether they be turbine, generators, or spillway gates, this information is often required for operational controls and forecasts.
- Information on isolation procedures, the use of isolating devices, and any equipment isolated when the owner takes over operations.
- Operating diagrams, drawings, and manuals to operate and troubleshoot the facility
- Any permits, licenses, and registrations required to operate

Not surprisingly, when discussing a "commissioning" phase with the operations staff, they have additional expectations to the ones described above. This often leads to confusion between vendors and owners as to where a "commissioning" phase ends. It is common for owners to discover they require additional information or activities to assume control of the facility or units during the project commissioning activity phase.

It is important to recognize that the standard forms of construction contracts used in many projects are complicit in this confusion and that commercial conditions create a basic conflict in the timing and management of the transition from commissioning to operation. In practice, there is often strong incentive for both the owners and vendors to begin regular production as soon as possible. Placing the units in service relieves the vendor of penalties for delay and provides the owners with revenue and relief of costly financial commitments to the project budgets. This is almost always in conflict with the readiness of the owner's operations and engineering staff to take over the facility and allow the vendors to leave.

On completion of the trial run, much information is not finalized and is still changing. The facility will likely have a prioritized list of deficiencies to resolve and new issues may still be arising. In particular, the control programs are often still being cleaned up to resolve bugs, false alarms, and so on. There will often be numerous alarms and unplanned trips in the early days after commissioning that will require troubleshooting. The owner's operations staff may have difficulty in dealing with this without substantial support from the vendors or programmers.

There is a need to recognize and plan for a transition phase between the planned commissioning activities and full operational control by the owner. Simply put, this is the timeframe during which all the training and documentation are completed. It is always recommended to make this part of the project plan and to link this to project milestones and conditions to encourage vendors and the project team to complete these activities in a timely manner. This document uses the term "Ramp Up Phase" for this phase.

The owner's organization size, experience, and management policies for labor and safety will influence the expectations for such a transition. Naturally, large utilities with deep operations and engineering experience will expect a well-regimented and defined transition. New developers with new operators may not know what to expect and can make the transition appear simpler.

11.2 Ramp Up Phase Activities

At the beginning of this phase, the commissioning activities are completed, and the facility or units have been deemed to be in service. This means that production, with all its implications, has begun as perceived by regulators and other stakeholders. The vendors are still at site and have a fair bit of work to do and the operational staff is in the facility, beginning to exercise these responsibilities.

Whether it is captured formally in the contract documents or done informally, the following sections are suggested activities to complete, in order to support full operational and engineering control of the facility. The end state of this phase is to ensure that the operation and engineering groups have sufficient training and information to operate the facility safely, make adjustments, and troubleshoot independently; meet reporting requirements; manage river flows; and plan production.

11.2.1 Unit Operation and Monitoring

During the Ramp Up Phase, the units may be off-line on some days to make corrections and changes and will operate steadily the rest of the time. This situation implies that everyone must come to terms with who is responsible to "operate" the unit or facility and who should be monitoring the units during off hours. Owners will quickly realize that this question does not have a simple answer as it entails a number of liability questions including the safety of staff and assets.

In some organizations, the operators take charge right away and make efforts to gain the training and documentation required. In other organizations, operators will not take over officially until the training and documentation are sufficient.

It is important for the owner to determine how this is best handled to confirm to the contracts and other internal policies. Clarification with the vendor or the commissioning team in the contract documents or project plans is essential. A proposed approach to consider is as follows:

- The Commissioning Manager is deemed to be responsible for operating the units, systems, and facility during commissioning activities in a safe manner, under the work protection programs agreed to by the owner and vendors.
- Make it part of the Commissioning Manager's responsibility to continue to operate the unit safely and to coordinate start/stop events with the owner's operators during the Ramp Up period with the same work protection program. The Commissioning Manager will advise the owner whether the unit cannot be operated safely during the off hours or will define restrictions.
- The owner's operators provide off-hours monitoring. Operators are given guidelines to try and correct problems as they arise or otherwise wait until project staff can assess the situation. The operators performing off-hours monitoring must be provided with immediate training and sufficiently marked-up documents.

This approach may not be suitable for every organization or situation but must be tailored to local regulatory requirements for safety, the owner's organization policies, and the contractual allocation of liabilities.

Many projects have remote monitoring control centers. In these cases, the operators at those control centers require training and documentation before the equipment is placed in service if they will be expected to monitor units during off-hours. They also rarely have the advantage of being able to be on site extensively during commissioning and to gain experience in this manner. This should be considered when planning training and documentation submittals during the commissioning phase.

11.2.2 Management of Deficiencies

At the risk of repeating this issue, it is important to recognize that in the post-commissioning phase of the project there will be deficiencies to resolve while new ones continue to appear, albeit with decreasing frequency.

The owners must maintain a good system of tracking deficiencies and their resolutions. Resolution may not mean that the problem is corrected, but that the owner has reached some agreement with the vendor in the interest of closing the project and controlling cost. The completion of the Ramp Up phase can be linked to a categorization system for deficiencies based on criticality rules.

After the commissioning activities are complete, the owner should define the deficiencies that must be resolved during the Ramp Up phase. These would be the deficiencies that affect safety or must be done to support reliable operation. Any new deficiency found during this stage would have to be evaluated as to whether it is added to the list.

The Ramp Up phase should be managed to maximize the ability of vendors to resolve deficiencies by allowing more frequent unit shutdowns and by avoiding changes to the established construction stage work protection and safety programs if possible.

Attempting to track deficiencies in the preparation of control programs can be daunting. The ultimate goal is that the control programs for all units are identical and the versions have not been mixed up. The pace is fast and by the time the programming deficiencies are written down, they have often changed.

More experienced people may have developed systems to track program deficiencies and ensure they are resolved, but for those who have less experience, it is a real challenge. There may be many issues and when the dust settles, there may be a number of "forced" signals, and differences in the codes between units that can be bewildering.

It is often preferable for the owner to have a dedicated resource to learn the control system and the codes, and to monitor the situation during commissioning. In selecting this person technical skills need to be considered as well as the ability to work successfully with often frustrated programmers in the high-pressure commissioning environment.

11.2.3 Training

To achieve a state of reliable operation in a timely manner requires that the owner's staff become knowledgeable of the new facility's systems and controls and the associated maintenance needs. The operations and technical support staff should achieve a good level of competence with the specific knowledge required to operate and troubleshoot the facility. This includes knowledge of alarms and their implications, where devices are located, how to adjust the equipment properly, and so on. Formal training may have begun during the commissioning stage but must be completed prior to the completion of the Ramp Up phase. It is useful to consider focusing the training on key individuals who can later train others to support good knowledge transfer from vendors to the owner's staff.

When large numbers of units are to be commissioned over a number of years, it is prudent to plan for training to be repeated to cover the effect of operations and technical staff attrition.

It is often the owner's expectations that informal, hands-on training during and after commissioning is valuable. Some more formal training activities should also be planned. There is a general assumption that those to be trained are experienced hydropower plant operators, engineers, and maintenance staff. For first-time owners of new facilities, this may not be the case and this fact needs to be considered in the early stages of the project.

The bulk of owner staff that will be required to support the facility will usually be trained in a structured program after the planned commissioning activities are completed, because the best people to perform the training are tied up during commissioning. The Commissioning Manager can be assigned to organize and execute the training, with support from a combination of supplier specialists and the key individuals trained during commissioning.

Training needs vary greatly from one owner to another, both in the extent of the training required and the number of people to be trained. Training programs should address three main categories:

1) Facility Operations Training – Training requires that plant operators learn how to operate the facility on a day-to-day basis. This implies an understanding of the following elements:
   a) All the controlled components that make up the facility.
   b) The operating sequences and control modes of the facility, and the interaction between control elements
   c) Alarm annunciations, their source, and the required operator response
   d) The safeguards, hazardous energy control proceedures, and emergency systems.
   e) The plant instrumentation, actuators, and related documentation.
   f) The SCADA functions and utilizing the HMI.
2) Facility Maintenance Training – Training will require knowledge of the required maintenance activities, equipment construction, dismantling methods, and safety lock-out tag. This implies an understanding of the following elements:
   a) Equipment designs to permit routine maintenance and repair activities with related documentation and use of special tools.
   b) The safeguards, hazardous energy control proceedures, and emergency systems.
   c) Routine maintenance activities with related parts, special tools, and access.
3) Facility Engineering Training – Training will require the knowledge necessary to make adjustments to the equipment and controls. This implies an understanding of the following elements:
   a) Understanding setpoints of all devices and the basis for them.
   b) Knowledge of any adjustment requiring special tools and techniques.
   c) Working knowledge of software tools and associated program code with access methods to systems.
   d) Equipment designs for troubleshooting and related documents.
   e) Understanding of available project documentation.

11.2.4 Documentation and Software

In most cases, the number of changes to the information contained in control programs, drawings, diagrams, manuals, and standard operating procedures slow to a trickle over time until eventually they are taken over by the owner. The operations staff and technical support group need to have accurate information to work with until final documents are issued, and they will need a set with clear mark-ups to work with until then. This affects primarily programs, operating diagrams, and standard operating procedures. It is recommended that owners identify a series of submittals of key packages with increasing levels of completion to coincide with the beginning and end of the Ramp Up phase.

A proposed approach is to stipulate:

– Red mark-ups of all operating diagrams and tables upon completion of planned commissioning activities.
– Either final or red mark-up versions of all drawings, diagrams, and manuals at the end of the Ramp Up phase.
– Final version of the control programs with strict version control at the end of the Ramp Up phase.

It is clearly desirable to have all documents in their final version by the end of the Ramp Up phase and all efforts should be directed that way. Sometimes, the ability of vendors or various project participants to achieve a version of every document that is considered "final" by all parties can be challenging. The owner must consider to what extent the documentation must be complete, but it is also reasonable that an "almost" complete version of all documents must be available; conversely, missing documents are not acceptable.

It is important to note that an adjunct activity to the completion of drawings and diagrams is the tagging, signage, and labelling of components, devices, and equipment in the plant. This allows owners to track down devices and components to troubleshoot. This is an activity that should also be completed prior to the completion of the Ramp Up phase.

One of the important challenges the project team will face are differences in the expectations about the content of documents to be submitted between those preparing the information and those receiving it. Manuals are a prime area of concern if the material submitted is not considered sufficient by the owner's staff. It is best when manuals include the following at a minimum; equipment descriptions, operational descriptions, standard operating procedures, operating limits, setpoints, system drawings, and maintenance procedures. If the organization has well-defined requirements, then it is best captured in the contract documents. Often, a sufficiently detailed table of contents will provide good guidance.

11.2.5 Transfer of Site Safety

It is important to recognize that the responsibility for safety transfers from the vendor to the owner in this phase. The owner must give good consideration on how the transfer will occur. It is worthwhile considering whether the construction safety program remains in place and the vendor maintains control of safety and work protection during this phase. Some owners will not wish to have their employees working under any safety or work protection program other than their own, while others might be more flexible. The solution must suit the owner and the project must be well-defined and clearly understood by all parties.

11.3 Managing Demobilization

In an effort to control costs, vendors or project team members may wish to wrap up and leave once the facility or units have been placed in production. This is a simple reflection that post commissioning activities are rarely budgeted and scarce resources (e.g., experienced commissioning engineers) are often needed elsewhere.

The only concern for the owner is that key vendor resources or the project team are not demobilized too early. There is a knowledge transfer challenge to address, as those who have completed the commissioning must pass their knowledge and experience to the owner's operators and technical support staff. In addition, these persons are needed to resolve deficiencies since they best understand the issues and contribute to ongoing documentation and troubleshooting activities.

The best tools available to the owner are both formal and informal training, joint troubleshooting experiences, and defining ongoing support roles in the contract documents or agreements.

There is likely to be a progressive demobilization of the vendor through this phase and it is worthwhile to schedule the final cleanup and demobilization to coincide with the defined end of the

Ramp Up phase. This means that past this point the owner will be able to operate the facility under its own safety and work protection program without having to work around others.

11.4 Regular Operation

This document recommends that the transition from the Ramp Up phase to regular production be a defined milestone with defined conditions. It can be the last milestone appearing in the project team's schedule.

At this point, the owner's operators are fully in control of facility safety, operation, and maintenance. The main activities that remain can include the collection of final facility documents and the planning of outages to resolve remaining deficiencies on warranty items. The key difference is that the units will only be taken out of service for corrective activities during planned events or due to a major failure. This means that the owner must work closely with vendors to organize outages to complete any remaining corrections of deficiencies or warranty items. Owners will often find themselves deciding at what point they will choose to correct the balance of deficiencies, to close the project and avoid the need to plan outages.

11.5 Managing Outstanding Testing

The availability of water or the desired operating heads can cause some commissioning or performance testing to be postponed. In some cases, these are postponed long after regular production is well under way. There is clearly a need to reach agreements with the vendors and key project individuals, to define the manner in which these tests will be completed. Owners can give conditional releases from various project milestones and may limit the operating range of the units to those that could be tested.

12.0 Grid Regulatory Compliance Testing

The commissioning process should also include efforts to prove to the regulatory agencies that all their equipment and performance requirements have been met.

12.1 Scope and Objectives

The purpose of commissioning a hydroelectric generation station is to verify that all equipment has been installed correctly and operates as designed, and to meet all regulatory agency requirements.

In addition to electrical grid operators, regulators often include environmental agencies and waterway management agencies. Any number of agreements with such agencies may have elements that need verification once the facility is in service. In most cases, these requirements will have been integrated into the commissioning process, but some may extend beyond the commissioning period for seasonal reasons or for the need to have optimal conditions, such as specific river flows, available.

While the specific requirements for environmental agencies or waterway management agencies are normally site specific, the requirements for grid operators are fairly (but not completely) universal. The commissioning tests must demonstrate that the new or updated facility meets the performance criteria set out in the agreement with the grid operator. This implies that the requirements are well-defined, specifically tested, and the results are captured in a commissioning report.

The specific performance requirements for each hydro facility are normally defined through an interconnection agreement and study performed by the regulator for that facility. The requirements are influenced largely by whether the facility will be connected to a high voltage transmission system or a medium voltage distribution system, the capacity of the facility, and the expected contribution of the facility to grid stability or recuperation from a power loss.

Note that in many jurisdictions, the process followed is similar for new stations and for upgraded existing plants, where component characteristics (e.g., capacity or inertia) are changed.

12.2 Regulatory Agencies and Grid Operators

12.2.1 North American Electric Reliability Corporation (NERC)

The North American Electric Reliability Corporation (NERC) is an international regulatory authority based in the United States, whose purpose is to assure the reliability of the bulk power system in North America. It develops and enforces Reliability Standards and its jurisdiction includes owners, operators, and users of the bulk power system.

NERC also interacts with regulatory agencies through Regional Entities, such as the Western Electric Coordinating Council (WECC). Regional Entities develop and enforce some of their own Reliability Standards to suit local requirements. The Reliability Standards of NERC and the Regional

Entities are mandatory in the U.S., and NERC relies on the Regional Entities to enforce them with bulk power system owners, operators, and users.

NERC Reliability Standards are high level standards that instruct member agencies and other entities on how to assure the reliability of the bulk power system in their jurisdictions.

12.3 Testing

12.3.1 Specifications

Obtaining regulatory agency approval to connect a new or modified hydroelectric generation facility to a transmission system is a long multi-stage process. The process is described in the websites of the regulatory agencies.

The process starts with the owner of a new generation facility submitting an application and providing the technical data of the new facility to the system operator to connect the generation facility to the grid. The system operator then performs an interconnection study, which results in an agreement between the owner and the system operator. The agreement includes the technical specifications detailing the equipment and performance requirements of the new generation facility. Usually, the agreement also requires the owner to submit the commissioning procedure of the new generation facility well in advance of the start of commissioning. The system operator observes the commissioning tests and, if all the requirements of the agreement have been met, approves connection of the new generation facility to the grid.

The equipment and performance requirements are usually based on published system operator specifications (if such are available), specific requirements are added for the new generation facility.

The most important regulatory requirements specify how the generation facility must perform during transient system disturbance events so that it can ride through such disturbances and support the system, instead of quickly disconnecting from the system.

Therefore, the commissioning procedure must include not only tests to verify that all the equipment has been installed correctly and operates as designed under normal operating conditions, but also tests that prove that the station meets all the regulatory agency requirements, including performance during transient system disturbance events.

Performance under transient conditions depends on the capabilities of the generator, generator exciter, and turbine governor and the settings of the protection system. The requirements may vary for different facilities, but the commissioning procedure should include, but not be limited to, the following tests.

12.3.2 Test Requirements

Active Power and Reactive Power

The load testing detailed in Section 8.4.6 should include testing the generator at all active and reactive power loads to verify the generator capability curve, especially stable operation at leading (under excited) power factor.

Power System Stabilizer (PSS)
The Power System Stabilizer (PSS) is part of the excitation system and must be tuned and tested during the commissioning of the excitation system. NERC Standard VAR-501-WECC-3.1 contains detailed technical, documentation, and notification requirements that must be completed within 180 days of commissioning.

Armature and Field Limiters
NERC standards PRC-019 requires that limiters must be properly coordinated with protective elements and documented. The limiters should be tested as described in Section 8.4.3.

12.3.3 Validation of Generator, Exciter, and Governor Model Parameters

It should be noted that only one generator parameter, the direct axis synchronous reactance X_d, can be determined from the generator open circuit and short circuit saturation tests. Other test methods described in IEEE Standard 115 are required to determine the other generator parameters and time constants. These tests require more time and special equipment.

The Transmission Planner will require estimated dynamic models for generators, exciters, and governors for interconnection study. Final models validated through testing must be submitted to the Transmission Planner within 180 days of commissioning per NERC MOD standards.

If all the necessary tests are included in the commissioning procedure and the procedure is reviewed and approved by the regulatory agency, no special post-commissioning tests are required.

12.3.4 Service Provider Qualifications

There are many companies qualified to commission most of the equipment in a hydroelectric generation station. However, special expertise is required for commissioning of the generator, generator exciter, and turbine governor and performing the tests required to prove that regulatory agency requirements have been met. The company best suited for this work is usually the manufacturer of the equipment.

It is advisable for the owner to include the requirement to commission the equipment in the contract for the supply of the generator, generator exciter, and turbine governor. The supplier/manufacturer then has the responsibility to prove that all the regulatory agency requirements have been met before the equipment is accepted by the owner.
There are also independent companies with expertise and special equipment that are qualified to perform generator control and regulatory compliance tests and the owner may elect to engage such a company to oversee or perform some of the work. That may be necessary when the generator, exciter, or governor are not new but have been modified or upgraded.

12.3.5 Reports and Certificates

The purpose of the commissioning report is to prove to the regulatory agency or other entities that all the requirements of commissioning and the interconnection agreement have been met. That includes operation of all the generation facility equipment under normal operating conditions and most importantly, the response of the generation facility to transient transmission system disturbance events. Therefore, the commissioning report must match the approved commissioning procedure. The regulatory agency or other entities must approve the commissioning report and have the right to require additional testing if any deficiencies are found in the report.

After completion of commissioning, the procedures for obtaining the final approval to connect the new generation facility to the transmission system will vary.

13.0 Performance Testing

Performance test procedures are developed to verify equipment performance meets manufacturer's stated guarantees and to establish initial baseline operational performance for future reference. Head, flowrate, and power output are typically tested, and unit efficiency is calculated. This testing is normally performed after the unit is released for commercial operation and the owner and supplier have agreed on the readiness of the equipment and a schedule that ensures specified operating conditions are met/optimized such as water flow and water reservoir level (head).

Performance testing is accomplished by the lead test engineer, the owner's plant organization, and the vendor's representatives necessary to demonstrate performance of the equipment, systems, and unit.

Performance tests should be coordinated by the lead test engineer, plant operations, and the owner's representative. Support services are normally arranged according to the following procedures:

- The owner or contractors normally provide trade labor in support of performance testing.
- The owner normally provides operations and maintenance (O&M) personnel to support the startup pre-commissioning and commissioning activities.

Performance testing typically includes electrical, mechanical and instrumentation aspects as shown in the following sections.

13.1 Purpose and Scope of Performance Testing

Performance testing is carried out to determine key performance parameters of a hydroelectric generator unit, usually to establish one or more of the following:

- Maximum power output associated with a specific head value.
- Efficiency at a point, at peak efficiency and a range of power outputs, often for a specific head value.
- Turbine discharge over a range of heads and power outputs.

Note that performance tests are usually carried out under a limited range of heads, and the test results are adjusted and displayed for a single gross head (units) or a single net head (turbines). This is quite different from the situation of a precision scale model being tested in a hydraulic laboratory, where the test team is able to subject the turbine to a broad range of heads. For low head units, the optimum efficiency point (e.g., a specific wicket gate servomotor stroke percentage) derived from a field performance test may not yield optimum operation if the actual operating plant head varies by a significant percentage from the test head.

As used in this guide, the term "performance testing" does not include testing to establish stability of operation, transients experienced during load changes, over-speed characteristics, or other unit behavior parameters. Performance testing, as used in this guide, does not include efficiency testing of the generator alone, but refers to the testing that determines the efficiency of the unit (turbine and generator together). When the generator efficiency variation with output is known, the turbine's efficiency can be calculated.

13.1.1 Purpose

The information provided by a performance test can serve many purposes, including:

- To determine if generating unit efficiency has deteriorated after many years of operation.
- To determine if the turbine generator manufacturer (or the replacement turbine runner manufacturer) met the contractual guarantees for efficiency, output, and best efficiency gate opening.
- To determine the performance profile for the preparation of the operation optimization algorithms in multi-unit plants. This is particularly important where several units share water conveyance facilities, such as a penstock.
- To prepare Unit Operating Rating Tables and Unit Capacity Tables (Flow-Output-Head Tables).
- To enable accurate sharing of water and to track water usage, such as is required on boundary waters, where more than one entity operate hydro facilities “side-by-side” and, in effect, share the available water in the river.

13.1.2 Performance Test Scope

The performance test is carried out in the powerhouse and at the intake, on one or more turbine generator sets, by simultaneously measuring the following typical parameters:

- Station headwater elevation
- Station tailwater elevation
- Unit headwater elevation (typically upstream of the trashracks, and at each intake opening, downstream of the trashracks)
- Unit tailwater elevation (in each draft tube outlet)
- Unit scroll case inlet pressure.
- Winter-Kennedy differential pressure (for index efficiency test)
- Servomotor stroke (wicket gates, runner blades, nozzle openings)*
- Wicket gate angle*
- Generator output
- Flow (for absolute efficiency tests)

* (As appropriate to the turbine type)

If absolute efficiency does not need to be determined, the performance test is simplex, as flow is not measured, and often other measurements serve as a proxy for flow.

When multiple units share a common water conveyance (e.g., a penstock), the test becomes somewhat more complex, depending on the purpose. It may be necessary to test each unit operating on its own as well as both units operating together (for two units sharing a common penstock feeding into a bifurcation). With multiple units supplied from the same penstock, the number of combinations is increased, and the test scope expands.

Performance tests on double regulated units (Kaplan) are also more complex when the goal is to establish the optimum relationship between runner blades and wicket gates.

As mentioned, performance tests are carried out in the powerplant and at the intake, which may be at a distance from the powerhouse. Measurements are taken at multiple points, often distant from the test control center where the recording instrument is located. Due to this fact and because a significant number of specialized measuring instruments need to be installed for the test, considerable time is required for the dismantling of test instrumentation after the test has been completed.

13.1.3 Generating Unit Considerations

The execution of a performance test requires careful consideration of the type of turbine (impulse or reaction), type of regulation (single or double), and the presence or absence of shared water conveyance elements such as penstocks, canals, and tunnels.

Because of the large variety of unit designs and hydroelectric plant arrangements, it is not possible to provide a definitive guide on performance testing which encompasses every variation of unit and plant. This section of the guide is written using a single regulated reaction turbine as a focus, such as a Francis or propeller machine, with no shared water conveyance elements.

In some paragraphs and tables, an effort is made to caution the reader to be aware that the language and concepts need to be adapted for other unit types and conditions. In general, the content should be carefully applied when considering units and water conveyance arrangements which vary from the "focus" case noted above.

For most types of performance tests, the unit being tested will be operating and generating electricity but will be strictly controlled to achieve steady state operation at each point of test. Thus, the output will vary throughout the test over the intended test range.

13.1.4 Performance Test Structure

Regardless of the type of performance test to be performed, tests generally consist of six steps covering planning, execution, and reporting:

Pre-test Inspection of Site and Unit(s)

A pre-test inspection is necessary:

- To determine the piezometer taps' condition and clean the surface area around the taps.
- To verify the net head piezometer taps' location and the area of the associated cross-section.
- To verify the scroll case differential pressure piezometer taps' locations.
- To verify, if possible, the tailrace and draft tube exit cross-section and the draft tube piezometer taps' locations.

The pre-test inspection for Kaplan units is more complex in that the runner blade opening and angle range also needs to be measured to confirm the relationship between runner blades and wicket gates.

Mobilization and Test Setup

Mobilization includes getting all instrumentation checked for the test and ensuring that calibration certificates are valid and available. It also includes packing the test equipment and moving it to the site.

The test setup consists of setting up the test equipment and arranging it for easy access by the test team; running signal cables; mounting instrumentation; calibrating pressure, displacement, and differential pressure instruments; setting up flow measurement test equipment; checking all test system parameters; surveying temporary benchmarks for water level measurements; and calibrating servomotor stroke and wicket gate angle. The setup time depends on the power station size and the physical distances between the measuring locations. It typically requires between two days to two weeks to complete.

Test Performance
The actual test involves simultaneously carrying out the measurement of the above- mentioned parameters.

The performance test will be tailored to suit the stable operating range of the unit and the intended operating need of the owner. Typically, for a propeller or low head Francis turbine, the performance test should consist of a minimum of 12 test points, covering speed no load to full load as follows:
- One run at speed no load.
- One run at each of 5 or 10 percent increments from 50% to 100% wicket gate opening.
- Two additional points in the vicinity of the best efficiency point, each being performed three times.

Relative (index) test runs are made at approximately 8- to 15-minute intervals. At the beginning of each run, the wicket gates are set at a fixed opening. About 3 to 5 minutes are allowed for conditions to stabilize, although this can be substantially longer for units with long canals, pipelines, tunnels, and penstocks.

During the remaining time, the data acquisition system collects all measured parameters simultaneously.

Absolute test runs are made at approximately 15- to 90-minute intervals. At the beginning of each run the wicket gates are set at a fixed opening. About 3 to 5 minutes are typically allowed for conditions to stabilize.

During the remaining time, the data acquisition system measures all parameters simultaneously.

Total test duration for a relative (index) test of one unit is one to two days, and for an absolute test, depending on the test methodology, 2 to 7 days.

Dismantling and Demobilization
Dismantling instrumentation, signal cables, and all test equipment including flow measurement equipment, then moving out of the power station, typically takes one to three days.

Data Analysis and Draft Report Preparation
Data analysis and preparing a draft report normally takes two to five weeks, depending on the report content.

Report Finalization
Receipt of customer comments (often includes owner's engineer, and turbine generator supplier), reviewing the comments, discussing any concerns, and finalizing the report takes two to three weeks.

13.2 Classes and Types of Performance Tests and Methodologies

There are three general classes of performance testing often used for hydroelectric plant equipment, known as:

- Absolute tests (code accepted tests)
- Relative tests (or index tests)
- Capacity tests

Absolute Tests
Absolute tests, other than the thermodynamic method, measure all the parameters listed above to determine the absolute value of efficiency for the turbine (assuming generator efficiency is known) and for the turbine generator overall unit.

The thermodynamic method determines efficiency without measuring the water flow, which can, however, be calculated from the test results:

Absolute efficiency = Power Out/Power In

where Power In is a direct function of head and flow.

Relative (Index) Tests
Relative tests measure all test parameters except the absolute flow and thus deliver relative efficiency based on relative flow, typically using a differential pressure measurement, such as that provided by the Winter-Kennedy piezometer taps on reaction turbines:

Relative efficiency = Power Out/Relative Power In

where Relative Power In is a direct function of head and a differential pressure instead of flow, and thus absolute flow is not known.

Capacity Tests
Capacity tests, as the name implies, basically measure a unit's power output against a basis such as wicket gate opening.

The power requirements for all tests are usually taken at a head which varies very little and then are adjusted to a single head from the actual heads experienced during the individual test runs.

Since the head available during a test is most often not controllable, test results are typically displayed for one head. When a large percentage of head variation is experienced by the turbine generators, testing at several heads may be necessary to produce the information to help achieve optimum operation.

13.2.1 Absolute Tests

The purpose of this efficiency test is to determine the losses present in the turbine.

The key challenge is accurate measurement of flow through the turbine. The test codes provide requirements and expected accuracy calculations depending on the method used. The absolute level of uncertainty will depend upon the design of the machine. It will generally be easier to achieve high accuracy with a high head than a low head machine. The detailed design of the turbine will also be important. It will be easier for instance, to achieve high accuracy where there is access to a straight length of pipe in which to install a flow meter than on a turbine with many bends. On higher head machines, the direct measurement of efficiency using a flowmeter or thermodynamic method can often provide a relatively low cost and accurate alternative.

Since the means for measurement of flow is the major difference between the absolute types of performance tests, the absolute test types are named by the flow measurement technology used, for example the Ultrasonic Method, the Intake Current Meter Method, etc.

Absolute test methods, as stated by both major test codes (ASME PTC-18 and IEC 60041), can measure the flow and determine the efficiency for a variety of generating station and unit configurations, having differences in:

– Head
– Number of intakes and number of draft tube outlets
– Length of penstock
– Availability of suitable piezometer taps
– Number of penstocks (or tunnels)
– Semi spiral and full spiral scroll cases
– Reaction and impulse turbine types

There are several methods in common use to measure the turbine flow, including:

– Current meter method (also called Velocity-Area Method)
– Pressure time method (also called the Gibson Method)
– Tracer method (Dye Dilution or Allen Salt Method)
– Ultrasonic method
– Thermodynamic method (flow is actually calculated, not measured)
– Acoustic scintillation (under development, not as yet approved by the test codes)

Each of these methods, as well as the limitations for each, are individually described below:

Current Meter Method (Velocity-Area Method)

The current meter method is based on installing a set of propeller flow meters upstream of the turbine entrance either inside the penstock or at the intake. **Note**, only electric-signaling current meters shall be used. These meters will measure local flow velocities, and by integrating these local flow velocities, the flow passing through that cross-section is determined. Current meters and methods of measurement should fulfill the requirements of ISO 2537 and 3455 respectively.

Where the intake is provided with gains for service gates, a frame, with the current meters mounted on it, is a convenient means to perform this test. The alternative method of mounting the meters inside a penstock requires a longer outage for mounting the meters, running conduit for wiring, and penetrating the penstock wall along with a second outage to remove the meters and other equipment. Both means require a regularly shaped section volume within which the meters are mounted.

Limitations of Intake Current Meter

1) Presence of severe flow
2) Undefined top of intake
3) Current meter proximity to trashrack's supporting beams
4) Existence of oblique flow beyond the current meter calibration accuracy
5) Unstable flow/turbulence

Limitations of Current Meters in the Penstock

1) For 20 diameters upstream of the measuring section, the penstock should not have any bends or elbows or change of cross-section.
2) For 5 diameters downstream of the measuring section, the penstock should not have any bends or elbows or change of cross-section.
3) Varying uncertainties due to intake structure shape and penstock diameter.
4) Calibration every 300 hours of use until repeatability is successful.

Pressure Time Method (Gibson Method)

The pressure time method is based on the conversion of the kinetic energy of the flow to potential energy (pressure) during a sudden wicket gate closure.

The method can be used in unit configurations that have a distance between the four upper piezometer taps and the four lower piezometer taps not less than 33 feet and is suitable for units having multiple intakes, as each intake is measured simultaneously.

The pressure time method measures the differential pressure wave between the upper piezometer taps and the lower piezometer taps (which are located in the penstock), while the wicket gates are closed from the test gate opening to the fully closed position, typically within 6 to 30 seconds, for close coupled units and longer for units with long water conveyances. Intake gate closure time will be slower than load rejection wicket gate closure.

By measuring the pressure wave and the time it occurs and integrating the pressure over time, the flow is determined.

There are two types of instrumentation used for the pressure time method. The classical Gibson instrument uses a mercury differential manometer and the other means is to use a pressure transducer with a high-speed data acquisition system.

The classical Gibson instrument takes a continuous photographic picture of the pressure wave during the wicket gate closure. It also records the time from the start of the wicket gate movement toward closure to the fully closed wicket gates.

The test code (ASME PTC 18 and IEC 60041) has the full procedure of how to calculate the flow from the Gibson diagram.

Limitations of Pressure Time (Gibson) Method:

1) L x V = 500 ft^2/s minimum, where L is the distance between measuring sections and V is the mean velocity of water with the unit at full load.
2) No intermediate free surface between two measuring sections.
3) Leakage through wicket gates must be determined.

4) Cross-section between measuring sections must have no irregularity and distance between measuring sections must not be less than 33 feet.
5) A minimum of two taps shall be used in each measuring section.
6) Cross-sections between upper and lower measuring cross-section must be measured within 0.2%.
7) It is not recommended to measure at multiple intake units but if this is done, one instrument per each intake must be used and simultaneously measuring the closure time must be carried out with high accuracy.

Tracer Method
There are three methodologies using the tracer method. The first methodology is based on a constant-rate-injection method and the second is based on a sudden injection method. Both methods rely on dilution analysis. The third methodology is based on measuring the transit time for the dye to move with the flow over the distance from the injection section to the sampling section.

The dye dilution method is based on injecting a known quantity and concentration of dye (recommended dye for this method is fluorescent dye Rhodamine WT) in the penstock at one section, and at a downstream section collecting a diluted sample of the dye after it fully mixes with the flow. By then analyzing the dilution, the amount of flow is determined.

The constant rate inspection method is based on continuous injection of the tracer dye in the penstock at a determined measured rate and then collecting samples far enough downstream from the injection point to ensure full mixing in the penstock. The sample is then analyzed using a fluorometer or spectrofluorometer to determine the amount of water flow.

A variation on the transit time method is the Allen salt velocity method, which is based on measuring the travel time between the injection section and the sampling section, then determining the velocity and the quantity of flow.

Note, only two tracer methods are recognized by the test codes: constant rate injection (ASME PTC 18 and IEC 60041) and the transit time methods (IEC 60041).

Limits of Dye Dilution Method
- Minimum of 200 diameters must exist between inspection section and sampling section, to ensure full mixing of dye in the water.
- No inflow or outflow between injection section and sampling section.
- If using transit time, then high accuracy time measurements must be used.

Ultrasonic Method
The ultrasonic method is based on measuring the transit time of a sonic pulse in the water flow and comparing it to the transit time of the same pulse in still water. The difference is the flow velocity component in the sonic pulse direction, and then the flow velocity is calculated in the pipe axial direction.

A cross path sonic pulse gives the flow velocity calculated with positive and negative values corresponding to the axial flow velocity.

The ASME PTC 18 test code requires, as a minimum, a 4-path system (one plane) to be able to adequately measure the flow velocity profile across the conduit cross-section. The 4-path system of acoustic transducers can be used for any diameter.

Depending on the required accuracy of the measurement, an eight-path system (4-path in two crossing planes) may yield the most favorable combination of cost and accuracy for turbine flow measurements, providing that the measuring section is at least ten diameters (ASME PTC 18: five diameters downstream of smooth elbows not exceeding 55-deg turning angle, and with a ratio of elbow radius to conduit diameter of at least three.) downstream and three diameters upstream from any bends in the penstock, cross-section changes, and any conditions that may cause streamline distortion. For small units under 5 MW, a four-path system may be adequate based on having no changes in the penstock diameter or bends for ten diameters upstream of the measuring section or alternatively accepting higher uncertainty due to the diameter changes or bends in the penstock.

The IEC 60041 test code recommends straight pipe without any bends or cross-section changes for 20 diameters upstream of the measuring section and 3 diameters downstream of the measuring section for a 4-path (one plane). For a 4-path in two planes, 10 diameters upstream of the measuring section and 3 diameters downstream of the measuring section. Any changes from those requirements will influence the measurement accuracy and the uncertainty values.

If the unit configuration does not conform to the IEC 60041 test code requirements, then the uncertainty band will be much wider than the theoretical published instrument uncertainties or additional acoustic paths could be required to achieve the accuracy requirements of the code.

The uncertainty on the measured flow should be calculated in every case.

The uncertainty determination will depend on a number of factors. For example, the instrument selection suitability for penstock pressure and flow velocities, unit configuration, instrument installation, measurement accuracies between transducers, transducers obstruction to the flow, the control panel accuracy in time measurements, and the algorithm to determine the flow velocity.

Limits of Ultrasonic Method

- For 10 diameters upstream and 3 diameters downstream of the measuring section, the penstock should not have any bends, or elbows, or change of cross-section for an 8-path, (4-path in two-crossing planes) flowmeter. Increasing acoustic paths could be required to achieve the accuracy per the code or there could be a decrease in uncertainty for sections that are not favorable.
- The cross-section between the measuring sections must have no irregularity.
- Minimum 4-path system is required.

Thermodynamic Method

The thermodynamic method is based on the first law of thermodynamics or the Law of Conservation of Energy. The thermodynamic test measures the temperature rise of the water passing through the turbine, which occurs due to the losses of the hydraulic to mechanical energy conversion process.

This is accomplished by measuring the water temperature at the turbine entrance and at the turbine exit. There should be no water entrance or exit between the measuring sections (drains, generator cooling water, etc.). This method will determine the turbine efficiency and, then knowing the head, turbine flow can be determined from the efficiency equation.

This method can be utilized with medium and high-head plants having a net head of not less than 33 ft. It requires high accuracy thermometers, measuring the true average of the turbine water temperature at the entrance and at the exit which may require several measurements of temperature on a grid particularly at the turbine exit.

For further details on the method, the reader is referred to the ASME PTC 18 or IEC 60041 International Standard.

Limits of Thermodynamic Method:

- Requires a minimum of 33 ft head.
- No inflow or outflow should occur between the two measuring sections.
- Measurement upstream of impulse runner must be immediately before the nozzles.
- Measurement of temperature downstream of the turbine must be as close as possible to the turbine exit.

Test Procedure and Equipment Required

The unit should be ready in all respects for normal operation. A test procedure covering steps and all relevant settings and connections should be in place to ensure that correct testing steps are followed. Protection and control device settings need to be in place for each phase of the test.

Extensive equipment is required. The test should be planned, set up, and executed by experienced personnel. Basic parameters to be measured are flow, head, and output (MW). Tests are usually performed by one or two people; however, several electricians or mechanics may be needed to set up for the tests. Efficiency tests can be accomplished in one to ten days depending on the complexity of the setup.

Key Reference Documents

- ASME PTC 18, Hydraulic Turbines and Pump Turbines
- ASME B31.1, Power Piping
- IEC 60041, Field Acceptance Tests to Determine the Hydraulic Performance of Hydraulic Turbines, Storage Pumps and Pump-Turbines
- IEC 60193, Hydraulic Turbines, Storage Pumps and Pump-Turbines – Model Acceptance Tests
- IEC 60545, Guide for Commissioning, Operation and Maintenance of Hydraulic Turbines

13.2.2 Relative (Index) Tests

Relative Flow Measurement

The relative test is also known by the name 'Index Test' or 'Winter-Kennedy Test'.

Relative tests measure all the primary parameters of unit output, and head, but only relative flow. As a result, this test will be able to determine only relative, and not absolute, values of flow and efficiencies.

The relative test, as stated by both major test codes, ASME PTC-18 (non-mandatory appendix) and IEC 60041, can measure the relative flow and relative efficiency with a variety of unit configurations, using the scroll case differential (Winter-Kennedy) pressure measurements.

The relationship between the flow and the differential pressure can be determined by the following formula:

$$Q = K*(P_1-P_2)^n$$

Where:

Q = Flow

K = constant coefficient

P = Pressure

^{n} = Theroretically equal to 0.5

In some cases, both K and n are known from homogenous model tests or from absolute tests on other units of the same design, and thus flow can be calculated. However, it should be recognized that this approach may introduce additional uncertainty, which can impact the values for the calculated "Absolute Efficiency".

An index test identifies relative turbine performance characteristics. The test requires calibration of a differential pressure system to measure relative flow through the turbine, usually Winter-Kennedy taps, either by utilizing stepped-up data from a scale model test or an absolute efficiency test performed on the prototype. A turbine characteristic curve can be developed utilizing relative flow data and power measurements from the generator at incremental loads at a given head. The relative efficiency is computed at each test point from head, relative flow, and generator power. The test can be repeated at various heads to obtain the complete family of curves, or an existing family of curves can be proportionately adjusted based on a test of a single head.

While the index test provides only relative and not absolute efficiency, an index test can also indicate the absolute change of efficiency if a previous test has been performed on the turbine.

The index test is a test of relative efficiency and does not constitute an absolute efficiency test. The test is referenced to model data for approximate turbine efficiency. In the case of Kaplan units, it can be used to adjust or fine-tune the Kaplan cam curve to optimize the efficiency of the unit.

The information is valuable to hydraulic engineers to evaluate turbine performance before the unit has the full efficiency test (which sometimes, for a variety of reasons, occurs a year after the end of commissioning).

The unit is loaded from minimal wicket gate or nozzle opening to the maximum wicket gate opening in measured steps (i.e., 10% steps), while recording net head (upstream pressure, minus downstream pressure), relative flow (differential pressure across Winter-Kennedy taps), and generator output power (MW meter). Sometimes, more measurements at smaller steps are made around the more efficient gate openings.

For a Kaplan unit, 5 or 6 runner blade angles are chosen and for each fixed runner blade angle, the wicket gates are varied from minimal to maximum gate. Again, more measurements are made around the more efficient points.

Particularly in the case of Kaplan turbine index testing, the more efficient points are often easily heard during testing. The unit becomes quieter when the efficiency increases. When the unit is at an optimal blade position, it does not require much blade movement in either direction with fixed wicket gate opening before you can hear an increase in turbine noise.

The type of equipment required varies with the type of test instrumentation selected as follows:

- Classical index tests utilize manometers for flow, floats for head, governor instruments for gate and blade position, and a power meter. Each test station's data is recorded by a person with an instrument or measuring device.
- Semiautomatic index tests utilize manometers or differential pressure transducers for flow, floats or pressure transducers for head, governor instrumentation or position transducers for gate and blade positions, and a power meter or transducer. Some data are recorded by personnel and some data are taken by automatic devices.
- Automatic index tests utilize a differential pressure transducer for flow, pressure transducers for head, position transducers for gate and blade position, a power transducer, and electronic data recording equipment.

Numbers of personnel and test duration varies with type of test instrumentation and methodology selected. Generally, a classical test can be performed in 4 hours on non-Kaplan units, excluding instrumentation installation and setup.

Data to Be Recorded
Key information is in **bold** with an *.

Unit

- Unit Speed (use 2 devices or more)
- Shaft axial Z displacement

Turbine

- **Servo displacements (e.g., wicket gates, runner blades, turbine nozzles, deflectors, etc.) ***

Water Passage

- **Forebay water level ***
- **Scroll case inlet pressure tap – upstream ***
- Scroll case pressure
- **Winter-Kennedy pressures ***
- Headcover pressure
- **Draft tube pressure tap – downstream ***
- Draft tube pressure
- **Tailwater level ***

Electrical

- Generator current phase A, B, C

- Generator voltage phase-to-phase A-B, B-C, C-A
- **Generator power ***
- Generator reactive power

<u>*Exciter*</u>

- Rotor field amps
- Rotor field voltage

Key Reference Documents

- ASME PTC 18, Hydraulic Turbines and Pump Turbines

13.3 Measured Quantities (other than Flow)

The following parameters are measured/calculated for either the absolute or relative methods.

13.3.1 Primary Parameters

Primary parameters are those required to establish the efficiency of the unit or the turbine, assuming the generator efficiency is known.

- Generator Output
  - Generator output is measured by a power meter that is connected to the metering PTs and CTs.
- Gross Head
  - Gross head is the station headwater level minus the station tailwater level. This measurement is used for unit overall performance or water-to-wire unit performance, or for unit capacity tests.
- Station Headwater Level Measurement
  - Station headwater is the water level measured upstream of the trashracks.
- Station Tailwater Level Measurement
  - Station tailwater is the water level downstream of the turbine draft tube exit.
- Net Head
  - Net head is the total energy elevation at the turbine entrance minus the total energy elevation at the turbine exit.
  - Net head is used to establish turbine performance.
- Total Energy Elevation at the Turbine Entrance
  - The total energy elevation at the turbine entrance is the summation of the pressure elevation measurement at the turbine entrance plus the velocity head at the section where pressure is measured.
  - Pressure measurement should be done (as per test code requirements) with a header on four piezometer taps on the measured cross-section plane at the inlet of the scroll case. The velocity head elevation is calculated from the flow values and the cross-sectional area of the pressure measurement plane.
- Total Energy Elevation at the Turbine Exit
  - The total energy elevation at the turbine exit is the summation of the pressure elevation measurement at the draft tube exit and the velocity head at the pressure measured section.

   - Pressure measurement should be done (as per test code requirements) with a header on all piezometer taps on the measured cross-section plane (if applicable). The velocity head elevation is calculated from the flow values and the cross-sectional area of the pressure measurement plane.
- Unit Water Temperature, Elevation, and Latitude
   - Measurements used for density of water calculation for efficiency calculations per ASME PTC 18.

13.3.2 Secondary Parameters

Secondary parameters are those that are measured and used to display performance variation (i.e., power, efficiency, and flow) and to permit performance assessment against guaranteed values and for optimizing operation.

Scroll Case Differential Pressure

The scroll case differential pressure is measured using the Winter-Kennedy piezometer taps. The purpose of this measurement is to create a relationship between the absolute values of the flow and the differential pressure, which amounts to a calibration of the Winter-Kennedy taps. Thus, in the future, by measuring the differential pressure, which is a simple and reliable measurement, the flow can be derived based on having the same conditions of these piezometer taps as in the initial absolute test. Flushing of the piezometer taps is recommended prior to testing.

Wicket Gate Servomotor Stroke

Servomotor stroke is measured to determine the wicket gate opening. To determine the unit or turbine performance (typically shown in graphical form in the performance test report), the performance test is conducted over 10 wicket gate openings from speed to no load to the maximum gate opening using the servomotor stroke as the base measurement for gate openings.

Wicket Gate Angle

Wicket gate angle is measured to establish the relationship between the servomotor stroke and the wicket gate angle. The relationship is needed to relate the turbine manufacturer's model test results (which are based on wicket gate angle in degrees) to the field performance test (which is based on servomotor stroke measurements). This is only conducted with the unit dewatered and access to the wicket gate opening.

Runner Blade Angle (Kaplan Turbines)

Runner blade angle is measured to determine the cam design (the relationship between the wicket gate opening and the runner blade angle to optimize the turbine operation).

Needle Servomotor Stroke (Impulse Turbine)

Needle servomotor stroke is measured to determine the opening for Pelton needles. It should be measured for every combination of active nozzles to determine the optimum mode of operation for various power outputs.

13.4 Test Uncertainties

The uncertainty on the measured flow should be calculated in every case as it will depend on a number of factors, for example:

- Instrument selection
- Suitability for penstock pressure and flow velocities
- Unit configuration
- Instrument installation
- Measurement accuracies between transducers
- Transducers obstruction to the flow
- Control panel accuracy in time measurements
- Algorithm to determine the flow velocity

Uncertainty calculation and typical values are found in ASME PTC 18. The performance test uncertainties are determined by calculating the square root of the sum of the squares of the systematic and random uncertainties.

Systematic uncertainty is the square root of the sum of the squares of the test methodology parameters.

For example, for the current meter method, these parameters are number of measurements, distribution of local velocity measurements, velocity profile across the measuring cross-section, blockage effects, oblique flow, and so on.

Random uncertainty is the square root of the sum of the squares of the measurement parameters like head, power output, flow measurements, and scatter points on each measurement.

The number of repeats will impact the confidence level and the overall values of uncertainty. For example, at a 95% confidence level (as recommended by the IEC 60041 test code) for one test point with no repeats, the student t value for 5 repeats is 1.241. See IEC 60041 for further details – Appendix C.

The uncertainties should be determined for every test based on the test measurement conditions, instrumentation, and unit configuration.

13.5 Test Preparation Best Practices

The station owners should supply the test engineer with the following information:

- General cross-section of the unit and general plan view
- Drawings showing all piezometer taps locations
- Main benchmark data (monument benchmark data)
- Drawing showing the PTs and CTs of the metering circuit to determine where the power meter will be connected to measure generator output.
- Documents showing the classes and accuracy of the PTs and CTs that will be used for measuring the generator output

- Graph or table of generator efficiency or generator losses against power, to determine turbine output and efficiency
- Drawing showing intake dimensions (for Intake Current Meter tests)
- Drawings showing net head taps' locations and net head taps' section measurements to determine the cross-sectional area
- Drawings showing the draft tube exit dimensions to determine the exit velocity head

The owner should also be prepared to support the test team with:

- A safety orientation and emergency information
- Isolation and de-energization of equipment
- Arranging inspections (piezometer taps inspection)
- Connection/installation of piping or manifolds
- General tools such as ladders and platforms
- Assistance of electrical and mechanical trades

Well before starting the performance tests, the test engineer should prepare a performance test procedure for acceptance by all stakeholders such as the owner, the owner's engineer, the design build contractor, and the turbine (or turbine generator) manufacturer. Should there be contractual issues such as whether the performance targets were met, this step effectively removes one element from the conflict.

The test engineer should provide all the test personnel and equipment necessary. These resources should measure unit output, gross head, net head, water levels, turbine flow, and relative flow in accordance with the requirements of the latest editions of IEC Publication 60041, "International Code for Field Acceptance Tests of Hydraulic Turbines" and/or the American Society of Mechanical Engineers, PTC 18, latest edition. This is to determine unit and turbine (when generator efficiency is known) absolute and relative efficiency, while also measuring other parameters such as gate opening, blade opening, and nozzle opening, as appropriate to the equipment under test.

The performance test engineer should set up the appropriate instrumentation to measure and record each parameter for the test.

Each instrument should be calibrated on site with all signal cables installed between the measuring instruments and the data loggers (data acquisitioning and control unit), with the exception of the power meter and some specific instruments that cannot be calibrated on site. The performance test engineer must have valid calibration certificates from independent laboratories for these instruments. All calibration data should be available on site during the test.

The test engineer should survey to each water level measurement location and to the pressure measurement location at the entrance of the turbine (headwater, tailwater, net head) to establish the true elevations of the water level measurements. The survey should be to certified monument by certified benchmarks.

A zero check should be carried out to demonstrate that all instrumentation is functioning properly. The zero check is a test run while the generating unit is shut down, to demonstrate that all headwater and pressure elevations at the entrance of the scroll case, when connected for elevation, are reading the same (likewise for the tailwater, and draft tube pressure elevation gauge), the generator output is reading zero, and the Winter-Kennedy differential pressure, wicket gate, and servomotor stroke are reading zero. The zero check should be carried out before the test starts and at the end of the day's tests for every day of testing.

Piezometer taps should be inspected to confirm that they are operable according to IEC 60041 test code requirements. The piezometer tap piping should be flushed well to eliminate all rust, accumulated dirt, and trapped air in the piezometer piping.

13.6 Test Planning and Execution

For a new station or a station receiving upgrade runners, at least one unit should be tested by an absolute method to confirm if guaranteed efficiency performance has been achieved. As a minimum, the other units or at least some similar units in the same station should be tested by the (lower cost) relative test method to verify similarity of performance curves. If a station contains units of more than one design and these are being upgraded, an absolute efficiency test on at least one unit of each design should be considered.

In case of two units that share water conveyance facilities, such as a common penstock or a common tailrace tunnel, each unit will first need to be tested while the other unit is shut down, and then both units are tested together. Three or more units with shared water conveyance facilities will require a corresponding increase in test program, to establish the performance of the various combinations. This will permit the development of optimum operation of the units for various amounts of available water or for various levels of power demand.

It is important to perform each test run when stable flows for that point have been achieved. Depending on the design of the station, this may require allowing from 10 minutes to 2 hours form each run.

13.7 Report Content

After completing the test measurements and checking the results, the test engineer prepares and issues a draft and later a final test report.

Depending on the needs of the owner and the purpose of the test, a comprehensive test report for an absolute efficiency test should contain:

- Executive Summary
- Table of Contents
- List of Tables
- List of Figures
- Introduction
- Summary of Test Results
- Turbine Test Results
- Overall Unit Test Results
- Test Procedure
- Test Parameters and Measurement Procedures
- Turbine Flow

- Measurement of Head
- Headwater Elevation
- Unit Headwater Elevation
- Pressure at Scroll Case Entry
- Tailwater Elevation
- Unit Tailwater Elevation
- Pressure at Draft Tube
- Wicket Gate Servomotor Stroke
- Power Output
- Equations
- Test Confidence and Uncertainty Analysis
- Conclusions
- References
- Appendices
- Appendix I – Computational Methods and Sample Calculations
- Appendix II – Uncertainty Analysis
- Appendix III – Flow Measurement System Specifications
- Appendix IV – Turbine Test Results (Tables and Graphs)
- Appendix V – Overall Unit Test Results (Tables and Graphs)
- Appendix VI – Electrical Measurement
- Appendix VII – Witnessed Data
- Appendix VIII – Instrument Calibration Data
- Appendix IX – Test Data

Comparisons with stepped-up model test results, guaranteed performance specifications, and/or pre-upgrade performance may be part of the test report, as appropriate to the owner's specified requirements.

Test results are often displayed graphically for ease of understanding. They can also demonstrate how performance varies with load, flow, or servo stroke and show achievement (or not) of guaranteed values.

13.8 Optional Services/Report Content

The test engineer may offer the following services to the owner to verify that performance guarantees have been achieved or to support the owner in developing tools to ensure the optimum use of the tested unit or plant.

13.8.1 Performance Comparisons

Comparison of the results of the performance test is often useful to the owner and can be the driver for the test and an essential part of the independent test engineer's role.

The test engineer can perform comparisons between the test results and results of other tests such as other absolute tests performed many years ago, index tests, and model tests, as well as guaranteed results for new or upgraded units.

These services could satisfy the need to:

- Compare the absolute tested units and report on the similarity and differences.
- Review and verify the combined unit rating tables for absolute tested units.
- Compare test results of absolute tested units and the relative tested units.
- Compare test results of each unit with the turbine manufacturer's performance guarantees for power and efficiency
- Create an average of unit results for units that include comparisons between absolute tested units.
- Review the combined test results with the model test to determine the gate drift.

13.8.2 Rating Tables

Rating tables display the performance of a turbine generator set at a number of discrete points over a wide range of heads and power outputs. The associated flows for each point of operation are determined and the most efficient operating point for each head is identified. An owner may require operating rating tables to optimize the use of reliable water.

Typically, the rating tables are prepared after final approval and release of the test report. Achieving reasonable accuracy over a large range of heads and power outputs will require the owner to provide a hill chart for the turbine that was performance tested. Within a hill chart, or if the range of expected operating heads is outside the range of the hill chart, calculations and extrapolation will result in higher uncertainties for the values given.

The rating table development process requires the performance test engineer to:

- Review the gate shift to determine the data input to create the unit rating table.
- Review the model test and the field performance test to expand the results to all required rating table heads.
- Submit the draft rating table to the client for review and approval. This can typically be done within 8 weeks after final performance test report is approved.
- Submit the final rating tables after receiving and considering comments from the client.

Table 9 summarizes the test result parameters that commonly used types of performance tests can provide:

Table 9 - Sample Unit Rating Table

Discharge (cfs)								
	Head (ft)							
Power (MW)	**180**	**185**	**190**	**195**	**200**	**205**	**210**	**215**
SNL	100	100	100	100	100	100	100	100
5	440	430	420	410	400	390	380	370
10	860	845	830	815	800	785	770	755
15	1180	1160	1140	1120	1100	1080	1060	1400
20	1380	1375	1350	1325	1300	1275	1250	1225

Discharge (cfs)								
	Head (ft)							
Power (MW)	180	185	190	195	200	205	210	215
25	1720	1690	1660	1630	1600	1570	1540	1510
30	2040	2005	1970	1935	1900	1865	1830	1795
35	2360	2320	2280	2240	2200	2160	2120	2080
40	2880	2835	2790	2745	2700	2655	2610	2565
45	3550	3500	3300	3250	3200	3150	3100	3050
50	3920	3865	3810	3755	3700	3645	3590	3535

SNL = (synchronous) speed no load

13.9 Test Types, Measurements and Deliverables

Table 10 summarizes the parameters typically measured for each of the common types of performance tests:

Table 10 - Measurements by Test Type

Measurements Taken	Absolute Efficiency Test	Relative Efficiency Index Test	Capacity or Power-Gate Test
Generator Output	Yes	Yes	Yes
Absolute Flow	Yes	No	No
Station Headwater	Yes	Yes	Yes
Station Tailwater	Yes	Yes	Yes
Gross Head for Operation	Yes	Yes	Yes
Unit Headwater	Yes	Yes	No
Trashrack Differential		Yes	No
Net Head	Yes	Yes	No
Unit Tailwater	Yes	Yes	No
Net Head	Yes	Yes	No
Turbine Output	Yes	Yes	Yes

Measurements Taken	Absolute Efficiency Test	Relative Efficiency Index Test	Capacity or Power-Gate Test
Scroll Case Differential Pressure (Winter-Kennedy)*	Yes	Yes	Yes
Servomotor Stroke	Yes	Yes	Yes
Wicket Gate Angle	Yes	Yes	No

Note * = Not all reaction turbines have thee taps

Table 11 summarizes the test result parameters that commonly used types of performance tests can provide.

Table 11 - Results by Test Type

Measurements Taken	Absolute Efficiency Test	Relative Efficiency Index Test	Capacity or Power-Gate Test
Absolute Efficiency	Yes	No	No
Relative Efficiency**	Yes	Yes	No
Generator Output*	Yes	Yes	Yes
Turbine Output	Yes	Yes	Yes
Absolute Flow	Yes	Yes	No
Relative Flow**	Yes	Yes	No
Absolute Performance Graphs		No	No
Relative Performance Graphs**	Yes	Yes	No
Absolute Best Efficiency	Yes	No	No
Best Efficiency Gate Opening	Yes	Yes	No

Notes: * = Actually a measured quantity, shown here for completeness
** = if Winter-Kennedy taps or other means are available

13.10 Test Team Qualifications and Experience

To be able to carry out the test successfully, the test team’s previous experience is very important. This test team should have at least one professional engineer, ideally with a minimum of 10 years testing experience. The test technicians should ideally have at least 3 years of experience.

13.11 Witnessing the Test and Stakeholder Sign-off

Witnessing of performance tests should be strongly encouraged or made mandatory, so that the stakeholders can verify that the test procedure, calibration, and data collection were performed according to the test codes and the previously approved test procedure. Test witnesses should sign-off their acceptance on the test calibration sheets and the collected test data sheets, thus indicating their verification of the actual tests steps and the actual records of the measured test parameters.

13.12 Compliance with Test Codes

In many cases, the unit's physical configuration, especially the hydraulic configuration, does not match with the test code requirements. The performance test engineer will provide a test procedure for the contractor and other stakeholders to review and accept; this will help produce valid and acceptable test results that satisfy the test requirements while dealing with the deviations from the test code. Contractors are welcome to conduct a parallel performance test.

13.13 Acceptance and Performance Tests for Generators

13.13.1 Generator Acceptance Tests

13.13.1.1 Short Circuit Saturation Test

The purpose of this test is to verify that the stator short circuit saturation characteristic curve is close to the calculated values. Sufficient agreement ensures there are no errors in the winding connection configuration. Generator characteristic curves are also obtained by saturation test results to determine the generator field current, armature current, and armature voltage operating characteristics, and to determine machine parameters for direct-axis reactance X_d, Potier reactance X_p, and SCR.

Test preparation includes installing the motor shorting bar across all three phases, upstream of the generator line terminals. The shorting bar must be able to withstand 100% continuous generator stator current and a temporary 125% of full load amps generator current for several minutes. Some special considerations for certain generator configurations should be observed, if applicable:

- If the generator doesn't have the main CTs in neutral, the shorting bar must be installed upstream of the generator CTs on the line side. Temporary calibrated CTs may also be used.
- If an electrical braking switch is installed, this can often be used for this test, provided that it is rated for 100% generator full load amps.
- Some generator breakers have provisions for shorting bars to be added.

Please note that it is important to plan the location, design, and installation of this bar well in advance of the test. The most convenient time is for this to be fabricated and test fitted during construction of the generator.

If the exciter is shunt connected (between the generator and the generator breaker), it must be disconnected from the generator terminals and supplied from a separate source. The most convenient method is to supply the exciter transformer from the power system by closing the generator breaker. This method works well if the exciter feed is located external to the generator terminals. Another method is to disconnect the exciter from the excitation transformer and supply the power form the low voltage switchgear breaker or an external engine generator. Check with the excitation commissioning engineer that the station service voltage and current rating will be adequate for testing.

The short circuit test is usually applied to large hydroelectric generators as an initial check of predicted characteristics. The generator should be fully assembled and ready to operate. The terminals of the generator are disconnected from the bus and shorted with a shorting bar (or equivalent) that is capable of carrying up to 125% rated armature current. Calibrated field current, armature current, and rotation speed measurement equipment should be ready to use. The excitation system must be ready to use and placed in manual control operation. If the power for the excitation is obtained from the generator terminals, then an alternate source of power needs to be used during this test.

The test consists of bringing the unit to its normal speed with the armature short circuited and then applying excitation to obtain 125% rated armature current. The current is decreased in steps and includes one measurement at 100% rated armature current. Significant test preparation and planning is required for this test. Protection system engineers will need to modify relay settings to ensure proper operation during the test. A set of connections designed for installation on the main leads in order to form the three-phase short is required. Appropriate current transformers and shunts are required to read the stator and field currents respectively. A separate source of field excitation is also needed if the exciter is the potential source type that is fed from the generator terminals. A small crew may be required to install the connections; the test can be accomplished by one instrument reader and an operator. A total of two days should be allowed for set up, test, and tear-down.

This is also a good time for the protections system engineer to check and verify all of the protection relay and metering current values in all phases.

Data to be Recorded

Unit

- Unit Speed (use 2 devices or more)

Generator

- Generator thrust bearing temperatures – all
- Generator guide bearing temperatures – all
- Generator bearing oil temperatures – all
- Generator bearing inlet cooling water temperature
- Generator bearing outlet cooling water temperature
- Generator bearing cooling water flow
- Generator stator temperatures – all
- Generator stator inlet cooling water temperature
- Generator stator outlet cooling water temperature
- Generator stator cooling water flow
- Generator air temperature at exit of coolers – all
- Generator core temperatures – all
- Generator slip ring temperature

– Generator brakes applied – digital

Electrical

– Generator current phase A, B, C
– Split phase neutral currents (if applicable)
– Stator equalization currents (if applicable)

Exciter

– Rotor field amps
– Rotor field voltage
– Exciter firing angle
– Excitation transformer temperature (if applicable)
– Temporary exciter supply voltage (Vac)
– Temporary exciter supply current (A ac)

Protection Relays and Meters

– All phase currents (including phase angle)

Pre-Conditions

– Unit mechanically operational.
– Exciter fed from external source (for shunt exciters).
– Exciter pre-commissioning complete.
– Fire detection system and fire suppression system must be active at this stage. (May be placed in manual fire mode during testing.)
– Temporarily remove or block any relay protections that may shut down the turbine.

Safety Concerns

– Rotation of the unit. Move all personnel to safe locations, and after movement, carefully inspect areas of concern and maintain constant communication with the commissioning leader.
– Generator breaker locked out and tagged out.
– Electrical energy is supplied to the generator terminal short circuit. All exposed electrical bus and connections should be covered and barrier taped and signage applied where necessary.
– Remove all unnecessary personnel from the generator area until the test is complete.
– Remove all unnecessary personnel from the exciter area and tape off the exciter area with caution barrier tape and signage.
– Alert the firefighting crew and have them ready for assistance.

Procedure

With the exciters in manual mode, the field current is raised to produce the target stator current from 125% to 25% full load amps. Typically, four steps are recorded including one step at 100% rated armature current. At each step, field current and stator armature current of each phase are recorded and plotted, while the unit is held at steady state nominal speed (50 or 60 Hz).

Speed should not fall more than 0.2 Hz below nominal speed. To maintain steady winding temperature during test it is better to start at 125% and then decrease the generator full load amps to 25% full load amps. Other important conditions are:

- Do not hold 125% full load amps for long periods, as this is usually above the generator continuous rating and heating of the shorting bar is significant. Hold only long enough to achieve a stable current reading, and then continue. Consult the generator specifications and the manufacturer for recommendations.
- It is important to try and maintain approximately the same generator temperature throughout the test. To achieve this, hold at each data point only as long as it takes to get stable readings.
- If any points are missed, the test will have to be repeated. Do not go back up to measure the missed higher stator current data point.
- Current imbalance between phases should be low. Please consult the generator specifications for the limit (e.g., 2% imbalance is typical).
- Potier reactance, Xp, is determined by the measured open-circuit saturation curve and data from the zero-power factor test performed a rated current.

Key Reference Documents

- Generator datasheet
- Exciter datasheet
- Reclamation Design Standard No. 12, *Plant Testing- Chapter 1: Synchronous Generator, Motor and Generator/Motor Field Tests*
- IEEE 112-1996, Standard Test Procedure for Polyphase Induction Motors and Generators
- IEC 60034-4, Rotating Electrical Machines – Pat 4-1: Methods for Determining Electrically Excited Synchronous Machine Quantities from Tests
- IEEE Std 115, IEEE Guide for Test Procedures for Synchronous Machines Part I – Acceptance and Performance Testing Part II – Test Procedures and Parameter Determination for Dynamic Analysis

13.13.1.2 Open Circuit Saturation, Waveform Deviation, and Telephone Interference Factor Test

The generator open circuit test is performed to produce the generator armature voltage characteristic curve. The purpose of this test is to confirm that required generator electromagnetic design parameters have been satisfied. Generator characteristic curves are also obtained by saturation test results to determine the generator field current, armature current, and armature voltage operating characteristics, and to determine machine parameters for direct-axis reactance X_d, Potier reactance X_p, and SCR.

The test is normally applied to most hydroelectric generators. The unit should be fully capable of operation in all regards. The terminal measurement equipment should be ready to use. The excitation system must be ready to use and placed in manual control operation.

The test consists of bringing the unit to its normal speed then slowly increasing excitation while measuring terminal voltage. Voltmeters and potential transformers are needed to measure the terminal voltage, and ammeters or shunts are needed to measure the field excitation current. The test can generally be done by one operator and one test person. Once set up, the test can be accomplished in about 1 hour.

The generator voltage is increased from 10% to 120% in this test.

Additional tests are performed:

- The harmonic content of the unit can be measured at the same time for the telephone interference factor (TIF) requirements.
- This is also a good time for the protection system engineer to check and verify all of the protection relay and metering voltage values for all phases (including phase angle).
- Vibration data should be measured at 100% voltage.
- After the generator voltage test is complete, this test can be extended to slowly increase the voltage in the main transformer for the first time. This is done by opening the high voltage disconnect switch, closing the generator breaker, and slowly increasing the voltage on the main transformer up to the rated voltage. This slow increase is usually recommended for large transformers for the first energization.

Data to be Recorded

Unit

- Unit Speed (use 2 devices or more)

Vibration Monitoring System

- Key phasor
- Generator upper guide bearing shaft runout X
- Generator upper guide bearing shaft runout Y
- Generator upper bearing housing velocity X
- Generator upper bearing housing velocity Y
- Generator upper bearing housing axial velocity Z
- Generator lower guide bearing shaft runout X
- Generator lower guide bearing shaft runout Y
- Generator lower bearing housing velocity X
- Generator lower bearing housing velocity Y
- Generator lower bearing housing axial velocity Z
- Turbine bearing shaft runout X
- Turbine bearing shaft runout Y
- Turbine bearing housing velocity X
- Turbine bearing housing velocity Y
- Turbine bearing housing velocity Z

Generator

- Generator lower bracket axial Z displacement
- Generator slip ring temperature
- Generator brakes applied – digital
- Generator shaft current (if possible)

Electrical

- Generator voltage phase Va, Vb, Vc
- Harmonic voltages
- Generator voltage waveform

Exciter

- Rotor field amps
- Rotor field voltage

- Exciter firing angle
- Excitation transformer temperature (if applicable)
- Temporary exciter supply voltage (Vac)
- Temporary exciter supply current (A ac)

Pre-Conditions

- Block or increase any voltage protection settings that would interfere with achieving the 120% nominal voltage.
- The exciter may or may not be on a separate supply for the test. If the exciter can operate shunt excited from 10% stator voltage, then the test can be completed with the exciter shunt connected.

Safety Concerns

- Rotation of the unit. Move all personnel to safe locations, and after movement, carefully inspect areas of concern and maintain constant communication with the commissioning leader.
- Generator breaker locked out and tagged out during test preparation.
- Electrical energy is supplied to the generator during this test and the voltage will reach 120% of nominal. All exposed electrical bus and connections downstream of the generator should be covered and barrier-taped and signage applied where necessary.
- Remove all unnecessary personnel from the generator area until the test is over.
- Remove all unnecessary personnel from the exciter area and tape off the exciter area with caution barrier tape and signage.
- Alert the firefighting crew and have them ready for assistance.

Procedure

With the exciters in manual mode, the field current is raised to produce the target stator voltage from 0% to 120% nominal voltage. At each step, the field current and stator armature voltage of each phase-to-ground are recorded and plotted, while the unit is held at steady state nominal speed (50 Hz to 60 Hz). Speed should be within +/- 0.04 Hz of nominal speed (the governor might require special settings for this test).

Other important conditions are:

- Do not hold 120% and 115% for long periods, as this is usually above the generator continuous rating. Hold only long enough to achieve a stable voltage reading, and then continue. Consult the generator specifications and the manufacturer for recommendations.
- Voltage imbalance between phases should be low. Please consult the generator specifications for the limit (e.g., 2% imbalance is typical).
- It is important to gradually increase the voltage between steps.
- Allow the voltage to stabilize for at least 1 minute at each step.
- Measurements should always be taken with increased armature voltage, to avoid any hysteresis effect. Do not lower the voltage to take a reading. If one step is missed, then repeat the test starting at 0%.
- Potier reactance, Xp, is determined by the measured open-circuit saturation curve and data from the zero-power factor test performed a rated current.

Key Reference Documents

- Generator datasheet

- Exciter datasheet
- Reclamation Design Standard No. 12, *Plant Testing- Chapter 1: Synchronous Generator, Motor and Generator/Motor Field Tests*
- IEEE 112-1996, Standard Test Procedure for Polyphase Induction Motors and Generators
- IEC 60034-4, Rotating Electrical Machines – Pat 4-1: Methods for Determining Electrically Excited Synchronous Machine Quantities from Tests
- IEEE Std 115, IEEE Guide for Test Procedures for Synchronous Machines Part I – Acceptance and Performance Testing Part II – Test Procedures and Parameter Determination for Dynamic Analysis

Voltage Waveform Deviation Test

The purpose of this test is to determine the amount of deviation of the sinusoidal voltage waveform of the generator from the ideal sinusoid.

The test is commonly applied to any large salient pole synchronous machine. The unit is capable of running at rated speed and rated voltage.

The unit is run at rated speed and rated voltage and a line-to-line cycle of voltage waveform is recorded. The harmonics are analyzed and the deviation between the actual voltage waveform and the fundamental alone should be less than a prescribed amount.

A high-speed scope or wave analyzer is required to get a good waveform and to analyze the fundamental magnitude. The test can be performed with a test technician and an operator. The test should take moments once the unit is running at the required conditions.

Key Reference Documents

- Reclamation Design Standard No. 12, *Plant Testing- Chapter 1: Synchronous Generator, Motor and Generator/Motor Field Tests*
- IEEE Std 115, IEEE Guide for Test Procedures for Synchronous Machines Part I – Acceptance and Performance Testing Part II – Test Procedures and Parameter Determination for Dynamic Analysis
- IEC 60034-4, Rotating Electrical Machines – Pat 4-1: Methods for Determining Electrically Excited Synchronous Machine Quantities from Tests

Telephone Interference Factor (TIF) Test

This test measures distortion, harmonics, and waveform deviation on the generator. The purpose of this test is to measure the harmonic content of the stator voltage waveform, especially in frequencies of interest to telephone communications interference. This test is no longer relevant for use with modern telephone systems but is still used to determine generator waveform deviation.

A harmonic signal analyzer is connected to the generator via the permanently installed PTs, to record the line-to-line and the line-to-neutral harmonic spectrum. The exciter may be fed from the alternative source to avoid possible harmonic content due to exciter electronics. A suitable high-speed voltage waveform recording or analyzing device is required. An operator and test technician are required. Once the machine is running, the test takes a very short time.

The test is normally applied to any large salient pole synchronous machine. The machine should be ready for operation at rated speed and rated voltage.

Once at rated speed and voltage, the voltage is recorded and analyzed for harmonic content. The various harmonic contents are tabulated with either IEC or IEEE weighting factors to arrive at balanced and residual Telephone Influence Factor (TIF) or total harmonic factor.

Key Reference Documents

- Reclamation Design Standard No. 12, *Plant Testing- Chapter 1: Synchronous Generator, Motor and Generator/Motor Field Tests*
- IEC 60034-4, Rotating Electrical Machines – Pat 4-1: Methods for Determining Electrically Excited Synchronous Machine Quantities from Tests
- IEEE Std 115, IEEE Guide for Test Procedures for Synchronous Machines Part I – Acceptance and Performance Testing Part II – Test Procedures and Parameter Determination for Dynamic Analysis

13.13.1.3 Generator Heat Run

The generator heat run test is a significant milestone. It is important to perform this test right before or after the first 100% load rejection test, provided that the pressure rise in the penstock is acceptable; this is because the test is key to proving that the unit's bearings, stator, rotor, and other auxiliary systems are fully functional. This is usually the first time that the unit will run continuously for a few hours at 100% load.

The heat run test will determine the temperature rise (temperature above ambient) of all components, most importantly the generator stator, generator rotor, and all unit bearings. The objective of the test is to hold the unit at a specified condition of armature current, power, voltage, and frequency, which is almost always chosen to be at rated armature current, voltage, and power factor. The most common procedure is to hold the unit at 100% nominal current and close to nominal voltage. It is important to put the AVR in manual mode (if possible) to reduce intermittent fluctuations in rotor current.

At stable and constant conditions, all temperatures, specifically all stator and bearing temperatures, are recorded every 30 minutes until all the stator and bearing temperatures have become constant within +/- 2 °C for three consecutive 30-minute intervals; note that some additional devices such as oil heads may also be closely monitored. If the unit's external cooling water supply temperature is not constant, the test should be continued until the unit's stator and bearings do not rise for three consecutive 30-minute intervals. It is important for the cooling water air cooler discharge temperature to stabilize and not to vary more than 2°C for three consecutive intervals.

It is critical to hold the test until the commissioning engineer is confident that the temperatures have stabilized. The test will usually run for at least 3 hours and often many more hours depending on the size of the machine. A good planning practice is to have this test start near the end of a commissioning shift and continue on into the evening as most of the commissioning and engineering staff can be relieve. A small number of operators and a commissioning engineer will remain present until the end of the test.

Data to Be Recorded (all temperatures - key temperatures shown in bold *)

<u>*Unit*</u>

- Unit Speed

Vibration Monitoring System

- Key phasor
- Generator upper guide bearing shaft runout X
- Generator upper guide bearing shaft runout Y
- Generator upper bearing housing velocity X
- Generator upper bearing housing velocity Y
- Generator upper bearing housing axial velocity Z
- Generator lower guide bearing shaft runout X
- Generator lower guide bearing shaft runout Y
- Generator lower bearing housing velocity X
- Generator lower bearing housing velocity Y
- Generator lower bearing housing axial velocity Z
- Turbine bearing shaft runout X
- Turbine bearing shaft runout Y
- Turbine bearing housing velocity X
- Turbine bearing housing velocity Y
- Turbine bearing housing velocity Z

Turbine

- Servo displacements (e.g., wicket gates, runner blades, turbine nozzles, deflectors, etc.)
- **Turbine guide bearing temperatures – all ***
- **Turbine guide bearing oil temperature ***
- **Oil head temperature (Kaplan) ***

Hydraulic Power Unit (HPU)

- Oil tank temperature

Generator

- **Generator thrust bearing temperatures – all ***
- **Generator guide bearing temperatures – all ***
- **Generator bearing oil temperatures – all ***
- Generator bearing inlet cooling water temperature
- Generator bearing outlet cooling water temperature
- Generator bearing cooling water flow
- **Generator stator temperatures – all ***
- Generator stator inlet cooling water temperature
- Generator stator outlet cooling water temperature
- Generator stator cooling water flow
- Generator air temperature at exit of coolers – all
- Generator core temperatures – all
- Generator slip ring temperature
- Generator shaft current

Water Passage

- Forebay water level
- Tailwater level

Electrical

- Generator current phase A, B, C
- Generator voltage phase-to-phase A-B, B-C, C-A
- Generator power
- Generator reactive power
- Frequency

Exciter

- Rotor field amps
- Rotor field voltage
- Excitation transformer temperature

Pre-Conditions

- 75% or 100% shutdown and load rejection tests complete.

Safety Concerns

- The unit is mechanically and electrically energized and active. Observe all the safety precautions of an operating hydro generator.
- Limit personnel from close proximity to the unit.

Procedure

- Measure generator ambient air temperature by installing temperature monitoring sensors in the air coolers' discharge air path.
  (An initial test is typically performed to determine the location on the air coolers to mount the temperature sensors that will result in reading the average air cooler temperature.)
- Start the unit and load to 100% rated stator current, voltage, and power factor.
- Adjust the AVR to achieve nominal voltage. Switch the AVR to manual mode to keep the field current constant. Monitor the stator voltage, which should not deviate more than +/- 2%. An adjacent unit can be used to regulate terminal voltage.
- Adjust all cooling circuits to achieve balanced and adequate cooling conditions (bearing cooling water flows, air baffles on generator stator coolers, air baffles on top and bottom of rotor, cooling water flows in stator coolers, etc.).
- Continue the test with constant machine operating parameters until all the temperatures stabilize. Stable temperature is defined as being constant within +/- 2 °C of the rise value for three consecutive 30-minute readings. If the coolant temperature is not constant, the test may be completed when all the temperatures do rise above recorded maximum for three consecutive 30-minute readings.

Key Reference Documents

- Reclamation Design Standard No. 12, *Plant Testing- Chapter 1: Synchronous Generator, Motor and Generator/Motor Field Tests*
- IEEE Std 115-1995 Test Procedure for Synchronous Machines

13.13.2 Generator Performance Tests

13.13.2.1 Efficiency Test

Performance tests will determine the combined turbine generator performance. Determining the turbine efficiency requires that the generator efficiency be known so it can be factored out of the result. Separating the two may be necessary for operational reasons or simply to determine whether contractual performance guarantees have been met.

There are established standards, such as IEEE 115 Guide for Test Procedures for Synchronous Machines, that define the details on the methods for measuring and establishing generator efficiencies. When procuring new generators and if the size is small enough, their efficiency can be determined in the factory. Including this in the factory testing program is always useful, but it is necessary if the turbine efficiency is to be determined later.

If generators are already installed or too large to test in the factory, then determining the generator efficiency is a more involved process that has to be carried out with the equipment in situ. In this case, the services of specialized teams and calibrated equipment are usually required. Cost considerations may affect how performance guarantees are defined.

The purpose of these tests is to determine friction and windage, open circuit core, stary load, and I^2R losses present in the generator.

This test can be applied to most hydroelectric generators. However, there can be measurement or logistical difficulties where units are designed without their own bearings.

The two main methods of doing efficiency testing on hydroelectric generators are the retardation and calorimetric methods. In the former, the unit is repeatedly driven to speeds just above the normal rated speed and allowed to coast down under the appropriate conditions of current and voltage. Repeated runs are made to establish the losses at several short-circuit current levels and several open-circuit voltage levels in order to establish a relationship of loss at rated speed for each case. In calorimetric testing, several heat runs are done at specific loading conditions in order to establish the heat loss through the cooling systems and enclosure. With a good measurement of turbine flow, generator efficiency testing may be combined with turbine testing for a combined unit efficiency that does not segregate losses.

The unit should be ready in all respects for normal operation. A test procedure covering steps and all relevant settings and connections should be in place to ensure that correct testing steps are followed. Protection and control device settings need to be in place for each phase of the test.

Extensive equipment is required. The test should be planned, set up, and executed by experienced personnel. One or more additional units may be required to provide back-to-back starting, acceleration, and excitation supply for the retardation tests.

Tests are usually performed by one or two people; however, several electricians or mechanics may be needed to help set up for the tests.

Efficiency tests can be accomplished in three to ten days depending on the complexity of the setup.

Key Reference Documents

- IEC 60034-2, Rotating Electrical Machines – Part 2-1: Standard Methods for Determining Losses and Efficiency from Tests (excluding machines for traction vehicles)

- IEEE Std 115, IEEE Guide for Test Procedures for Synchronous Machines Part I – Acceptance and Performance Testing Part II – Test Procedures and Parameter Determination for Dynamic Analysis
- Reclamation Design Standard No. 12, *Plant Testing- Chapter 1: Synchronous Generator, Motor and Generator/Motor Field Tests*

13.13.2.2 Temperature Rise Test

This test determines the operating temperature characteristics of various parts of the unit. The unit is operated at a steady load point and the relevant temperatures are recorded periodically until steady state is reached.

The desired accuracy of the test results should determine the level of extra instrumentation required. For simple recommissioning of an older unmodified unit, station equipment may suffice to verify that nothing has changed significantly. Tests intended for performance characterization of new units or parts may be made with separate calibrated instruments and more careful loading procedures.

A single load test of a small unit may be done in 3-4 hours while a set of four to six runs at various loads with detailed instrumentation on larger units may take 3-4 days. Test can be combined the Generator Heat Run Acceptance Test.

Key Reference Documents

- IEC 60034-1, Rotating Electrical Machines – Part 1: Rating and Performance
- IEEE Std 115, IEEE Guide for Test Procedures for Synchronous Machines Part I – Acceptance and Performance Testing Part II – Test Procedures and Parameter Determination for Dynamic Analysis

Appendix A - Example Commissioning Plan - Turbine and Generator

Example Commissioning Plan for Hydroelectric Generating Unit (Turbine and Generator)

COMMISSIONING PLAN

Note: Once each subset is checked and values recorded, initial online for major heading.

Items highlighted in yellow will be confirmed/verified during commissioning.

CONTRACTOR TURNOVER

After the Contractor has completed their portion of the reassembly work and it is mutually agreed that work is complete and commissioning can proceed and that the unit is given back to Government control for startup, the following procedures can occur. The contractor shall remove his lock from all clearances.

SAFETY

Daily toolbox safety meetings will be held each morning in the control room before start of work.

Daily meetings on the daily testing to be performed and test schedules will be held.

Individual Job Hazard Analyses will be written and reviewed by plant and test personnel for each separate test or group of tests as per RSHS and local policy.

All plant, contractor, and test personnel will adhere to Reclamation and area office safety criteria. Plant, contractor, area office, and TSC test personnel will lock on to all clearances prior to access within clearance boundaries.

Standard Unit annual clearance will be placed. locking out waterway and high voltage electrical areas.

Separate clearance shall be placed on CO_2.

Separate clearance shall be placed on governor.

Clearances in place for runner ____________ will be released.

FINAL INSPECTION

Equipment Check:
It's imperative to carefully check all equipment including gauges, instruments, controls, valves, lubricating devices, flow indicators, filters, pumps, etc., when the spiral case is empty and before rotating or initial start of the unit.

Pre-Start Electrical Testing: (Electricians, C&I, and Electrical Engineer)
Calibrate existing turbine, lower guide bearing and upper guide bearing proximity probes. Complete attached checklist for unwatered items.

Clearance Measurements: (Plant Mechanics and Facility Manager)
Check that a complete set of as-built heel-to-toe wicket gate clearance readings are documented.

Heel-to-toe clearances should be in compliance with FIST 2-7. Record/verify check sheets.

Check adequate clearance between the bearing covers, vapor guards, rotor fan blades, etc.

Bearing and wear ring clearances are measured during unit alignment prior to the final inspection. Check that the final alignment data is available and satisfactory.

Spiral Case, Generator Housing and Turbine Pit: (Plant Mechanics, C&Is, and Electricians)
Thoroughly inspect areas for any debris or materials like bolts, nuts, tools, etc.

Spiral case starting at the lower drain and finishing at the end plate of the spiral case. Check that the drain ports, piezometers ports, and flowmeter transducer heads are clean and free from debris.

Generator air housing and the top of the rotor. After these areas have been inspected and verified to be clean, no one will be allowed back in. If it is necessary for someone to go back into these areas, they must remove everything from their pockets and make a list of every tool that is taken in so that they can verify nothing is left inside when they are finished.

Turbine pit. Check for any obstructions with the wicket gate linkage system and ensure all grease system lines are clear and secure.

Bearing Lubrication: (Plant Mechanics and Operators)
All bearing lubricant levels should be checked for proper level just prior to startup. If the lubricant level is indicated by a sight glass, the valve to the sight glass should be checked to make sure it is open and the level in the sight glass is accurate.

Manually cycle the auto grease system for the above-water wicket gate bushings, leakage, and shift ring bushings.

Manually cycle the auto grease system for the below-water wicket gate linkage bushings.

Manually cycle the auto grease system for the butterfly valve bushings.

The high-pressure lube system was needed for unit alignment and therefore should have already been checked for proper operation. Verify that full pressure is available. Manually operate.

GOVERNOR SYSTEM TESTS

Governor System – dry test: (C&I, Electrician, Plant Mechanic, Mechanical Engineer)
Purpose is to check that the servo loop is operating properly and check all parts and pieces for failure and redundancy.

Verify that the governor alignment as outlined in FIST 4-1A, Section 2 was conducted prior to commissioning. In addition to the alignment, complete the following:

Before releasing the governor clearance, carefully inspect the wicket gate operating mechanism to ensure that it's clear of all foreign material and tools.

Release governor clearance ________.

Close drain valves on the servomotors.

Fill governor system with oil, set-up accumulator tank, and purge air from system.

Verify that governor is on main valve and no governor auxiliary system is bypassed when operation of the unit is controlled at the governor control board.

Calibrate wicket gate travel and gate limit. Check movement of wicket gates through full travel and perform gate timing tests. (If alignment was not performed.)

Verify cushion of servomotors. (If alignment was not performed.)

Check system oil level and add oil if necessary.

Check turbine vent valve. Manually operate during commissioning if required to reduce rough zone at part gate. Note wicket gate opening range that air is required.

Check calibration between servo scale, governor panel, CSA board, and SCADA. Check that wickets touch closed at "0" on the servo scale. Check wicket gate squeeze.

Verify that dashpot compensation is in 'auto' mode at unit control panel.

AUXILIARY SYSTEM CHECKS

Check auxiliary systems - cooling water, thrust & turbine bearing oil, air valve: (Plant Mechanics)

Check cooling water supply to the turbine packing box. Record pressure: ______ psi.

Check for oil or water leaks. With full pressure and flow, check threaded and flanged joints of the various water lines to the unit for leaks. Check oil piping and bearing oil tubs for leaks at joints.

<u>Brake Air System:</u> (Plant Mechanics)
If the brake system has been used by the contractor for lifting of the unit

Verify that the brake system has been changed from oil lift to air.

Manually operate the brake system. Verify that all brake shoes are against the brake ring when pressurized and release when depressurized. Check each brake for air leakage. Check for brake indication at CSA.

ELECTRICAL SYSTEM FUNCTIONAL TESTS

<u>Prewatered up unit functional test</u> (Plant electricians and mechanics)
Complete all functional tests that can be performed in an unwatered/deenergized state, including:

> <u>Generator Bus</u> (Electricians, C&I, and Electrical Engineer)
>
> <u>Relay, Metering, and Indication, Protection and Control Circuits to CSA and SCADA</u> (Electricians, C&I, and Electrical Engineer)

WATERED UNIT FUNCTIONALS AND PRE-ROTATION CHECKLIST

Verify Pre-rotation check list has been completed.

Release penstock and generator clearance (Operator).

Fill the unit in accordance with the plant operating instructions (SOP) (Operator).

As full head pressure is established in the spiral case, inspect for leaks (Operator and Plant Mechanic):

> Wicket gate stem seals.
>
> Main shaft packing box.
>
> Check and listen for leaks at man doors, headcover, and various parts of the turbine that are subject to water pressure.
>
> Inspect expansion joints and sleeve couplings below butterfly valve for leaks. Tighten packing glands as required.
>
> Check unit butterfly valve for leaks. Check penstock air vent valve is closed and not leaking.

After full head pressure is established, record flow from penstock flowmeter and reservoir elevation. If greater than 10 cfs, stop to investigate. Record: ________ cfs

Device and wiring functional checks (Electricians, C&I, and Electrical Engineer).
Similar to what is done at the end of the unit annual. This will include all unit control, protection, and alarm checks normally done on the unit that were not completed in the dry.

PRE-START MECHANICAL TESTS

Startup tests: The Technical Service Center mechanical equipment group will monitor and perform vibration and shaft run-out tests on the unit. Specialized equipment will be set up for these tests.

Test Equipment Installation:
Clean areas around unit and in the control room. Perform basic housekeeping; dispose of outdated drawings; pick up tools; dispose of trash, used or stripped wiring and terminals, etc.

Set up test tables. For Reclamation tests, a table will be required for mechanical test instrumentation.

The existing vibration system will be used to record shaft runout and vibration. Verify calibration of existing turbine, lower guide bearing, and upper guide bearing proximity probes.

Verify flow meter probes and cabling are functional. Clean face of flow meter probes. Check continuity.

Butterfly valve: Test unit upstream plant butterfly valve under balanced conditions.
Open valve: Record travel time and hydraulic pressure. Normal unwatered time to open the valve is ______ minutes and to close the valve is _____ minutes. Check limit switches.

Close valve: Record travel time and hydraulic pressure. Verify valve is closed and in auto status. Compare readings to historical data.

Cooling Water:
Turn on the cooling water system and verify the non-running pressure readings of the turbine bearing and packing box. Record below. Run for 1 hour and record any variations in the readings.

	Pressure (psi)
Packing Box	

Check cooling water pressure to the generator and bearing coolers.
Upper guide/thrust bearing: [ ] psi
Lower guide bearing: [ ] psi

Record pressures:

Component	Pressure (psi)
Stator Air Coolers	
Upper Guide/Thrust Bearing	
Lower Guide Bearing	

Check for oil or water leaks. With full pressure and flow, check threaded and flanged joints of the various water lines to the unit for leaks. Check oil piping and bearing oil tubs for leaks at joints.

Verify that all protective circuit tests are complete.

Verify that all control circuit tests are complete.

Verify that all auxiliary circuit tests are complete.

Verify that all governor tests are complete.

Verify that all test equipment and instrumentation required for start-up are set up, calibrated, and operational.

Mechanical test equipment: Mechanical testing that includes vibration and shaft runout analysis will be performed by the Technical Service Center, Turbines and Pumps Group 86-68470. Connections to the unit shaft proximity probes and vibration monitor will be required. Other sensors that measure draft tube, scroll case, and head cover pressure, speed, and gate position will be installed.

RTD temperature readings will be taken by the plant's SCADA system.

We certify that the unit is ready to be rotated:
Reclamation test coordinator: ______________________
Contractor Representative: ________________________
Facility Representative: ___________________________
Operations Representative: ________________________

INITIAL BREAKAWAY TESTS

Communications Systems organized: Personnel should be stationed with two-way radios at strategic locations near the unit to listen and watch for anything unusual when the unit is started. In addition to within the control room and at the governor cabinet, it is suggested that a person be located at the following locations: 1) Turbine pit; 2) Generator air housing door; 3) Near draft tube main door; and 4) Top of unit.

Status: Verify that all clearances, danger tags, special condition tags, and jumpers affecting unit operation are removed.

Verify that Initial Breakaway Check list has been completed.

Bearing temperatures must have a tendency toward stabilization before proceeding to the next step. Investigations must be performed if this criterion is not met. If bearing temperature rise rates increase dramatically during any of these tests, the unit must be immediately stopped, and the cause must be determined. Print temperatures off data recorder.

After each rotational test, verify that the protection systems and devices (RTD's, switches, etc.) are functioning properly and all alarms are clear. Correct any malfunction prior to further testing.

Shaft runout will be measured during each test. Verify with the TSC mechanical equipment group engineer that vibration levels are within tolerance before proceeding to the next test. If the shaft vibrations are equal to or greater than the bearing diametrical clearances, the unit should be evaluated to see if balancing is required before proceeding to temperature stabilization and overspeed test. Nominal radial clearances are [ ] mils for the upper and lower generator guide bearing, and [ ] mils for the turbine bearing.

CRITERIA
Peak to peak vibration levels for unit bearings are classified as following for units running at [ ] RPM. (verify)

Minor Vibration	Up to [ ] mils
Major Vibration	[ ] to [ ] mils
Critical Vibration	Greater than [ ] mils

<u>Breakaway test</u>: The purpose of this test is to check for problems, determine the unit's breakaway characteristic, and determine the speed no load wicket gate setting for this particular head. The breakaway test shall be initiated through the manual start sequence as outlined in the plant's SOP. Speed will be measured at the governor cabinet or at the exciter cabinet.

Record date/time/water elevations.

Date	Time	Reservoir Elevation	Tailwater Elevation

With an operator at the governor board and thrust bearing lube pump on, release the brakes. The wicket gates may have sufficient leakage to cause the unit to creep. Record the speed and other conditions. Check for "rubs", abnormal noises, or other problems.

Perform an initial bump roll in manual mode by increasing gate limit a few percent and then returning to zero as soon as the unit begins to rotate. Let the unit coast without application of brakes, observing the unit for any unusual noise or shaft runouts. Check for "rubs" or other problems and listen for unusual noise. Measure shaft runouts and record data on worksheet provided. Apply brakes manually, check brake operations, ensure that leakage is low, and brakes are effective.

Repeat the preceding step again, going to a higher speed. Checking again for "rubs" or other problems. Also check effectiveness of brakes. Place brakes in AUTO and verify that they apply at about _____ RPM.

<u>50% Speed</u>: If no problems were noted, increase speed slowly up to 50% of synchronous speed ([ ] RPM) under manual control of governor. With unit at 50% speed, observe operation and record data.

Measure vibration. TSC test personnel will measure and store baseline data from proximity probes on the shaft in average measurements expressed in mils peak to peak. Verify measurements with TSC test personnel. Record other test values on the spreadsheet provided. Print Temperature Data.

NOTE: If the shaft vibrations are greater than 70% of the bearing diametrical clearances, the unit should be balanced at this time, before proceeding to temperature stabilization and overspeed test. Balancing should not be necessary. The new runner should have been dynamically balanced prior to shipping it to the plant. If there is excessive vibration, potential causes are listed on page 1 of FIST 2-2.

75% Speed: When the unit appears to run satisfactorily without abnormal rate of temperature rise on bearing, or shaft runout, increase speed to 75% of rated speed ([ ] RPM and record data.

100% Speed: When the unit appears to run satisfactorily without abnormal rate of temperature rise on bearing, or shaft runout, manually open wicket gates to increase speed to 100% of rated speed ([ ] RPM). Record data.

If at any point observers notice unusual noise or other problems, they should notify the operator to immediately shut the unit down. If no problems are noted, the unit should continue to operate at speed no load until bearing temperatures stabilize. Evaluate turbine roughness. Note/record draft tube pressure surges.

Overspeed Protection: After all bearing temperatures have stabilized for 2-3 hours and all responsible test personnel have indicated that the equipment is operating normally, the overspeed protection is to be verified operational. Overspeed should be set at _____% speed. *Per spec, must not exceed runaway of [ ] RPM; this is sustained runaway at full open and [ ] ft head.* Reset at ____ RPM.

Control the unit at the governor. Gradually increase the speed by opening the gates with the gate limit. Speed increase should not be too fast to take into account the inertia of the rotating parts, but at the same time, not too slow to limit operation at off-design condition. Should trip around 115% speed ([ ] RPM) for 10 seconds and ____% speed (____ RPM) instantly.

Speed is not increased more than 5% in excess of the required setting to verify the overspeed switch actuation. DO NOT EXCEED _____ RPM.

Shutdown: Shutdown via wicket gates, expect about ___ minutes. Verify ____ % speed for brakes on and thrust pump on. May recheck/adjust brake speed setting. May decide to recheck balance data. Final shutdown should allow unit to creep to check out the creep detector circuit (located at governor board).

Governor System (offline testing without excitation - watered up) (Mechanic and Operator)

Start-up test (manual and governor control)

Stop Unit.

INITIAL ENERGIZATION TESTS

The generator will be energized during this step but not put online. The CO_2 system clearance must be released.

Verify that the Initial Energization Check sheet has been completed.

Governor System – offline testing: Watered up (in conjunction w/bearing heat run and shaft runout tests).

Bearing heat run: With the unit running at speed no load, the bearing metal and oil temperatures should be recorded until the temperatures stabilize. If a data logger is not available, the temperatures should be recorded manually every 5 minutes for the first 30 minutes of operation and every 15 minutes after that until the temperatures stabilize. After the unit is brought online, again monitor temperatures as the unit is loaded.

Shaft runout: Verify runout measurements are acceptable with TSC test personnel.

CAUTION: Do not proceed with testing until the unit is properly balanced to prevent equipment damage.

Balance the unit at this time.

COMMISSIONING ON-LINE TESTS

Coordinate on-line testing with control center and water scheduling. Operations shall be notified in advance of MW production.

NOTE: Servomotor stroke has not changed and due to the new runner design, full gate will not be at 100% stroke. Do not over gate – will cause outlet edge cavitation. See performance hill chart for limitation based on tailwater elevation and net head on the units.

Remove CO_2 clearance. Place CO_2 system back in service and verify that it is in automatic operation mode prior to applying the field for the first time.

<u>Loading tests</u>: For each test, load the unit at increments of 5% gate position starting at speed no load, but not to exceed the maximum capacity of the unit ([ ] MW). The load shall be held at this level for at least 5 minutes to stabilize water flow. After the unit is brought online, again monitor temperatures and shaft runout as the unit is loaded. Each load will include bearing heat run and shaft runout as described in the Initial Startup procedures. Record test values on the spreadsheet provided. Print Temperature Data.

NOT*E: These tests do not* include turbine efficiency tests, which will be conducted at a later date after unit commissioning.

Conduct several starts and shutdowns to verify that unit will start and shutdown in manual, local auto, and supervisory control.

Governor System – online testing (TSC):

Online parameter tuning
Online step response
Auto start/stop sequences and control tests

Governor System (offline testing with excitation - watered up) (Mechanic):

Automatic Synchronizing Tests
Speed Stability Index test
Final Off-line Step and Frequency Response

Draft tube pressure: Per spec, draft tube pressure pulsations shall be less than 5% peak-to-peak of the head at the unit. Check data from gauges.

Downward thrust: Per spec, the maximum downward thrust shall be less than [ ] lbs. Primarily, the downward thrust will be evaluated by thrust bearing temperature. Headcover pressure should also be recorded for future comparisons. Record Head Cover Pressure.

Load rejection test: Since a new runner has been installed, the TSC recommends a full load rejection test. The wicket gate timing has not changed and is still set to close no faster than 15 seconds. Test at lower loads before a full load test. Mechanical engineers from 86-68470 group will be providing the pressure transducers and data acquisition system needed for this test. Record Data on the load rejection worksheet and attach it to checklist.

When the unit load reaches [ ] MW, about 25% of full gate, the load shall be held at this level for at least 5 minutes to stabilize water flow; then a load rejection can be conducted. (Open generator and field breaker simultaneously.) Record spiral case peak pressure and compare the pressure to the penstock and spiral case design pressures. Maximum design pressure [ ] psi. If recorded pressures exceed design pressures, gate closure time shall be adjusted.

The testing will proceed in this fashion conducting load rejection tests at 40% ([ ] MW), 60% ([ ] MW), 80% ([ ] MW), and 100% ([ ] MW). (Open generator and field breaker simultaneously.)

Heat run: Electrical Engineering (86-68450) has stated the importance of performing a heat run at full load ([max] MW) after the unit overhaul is complete and when reservoir water levels permit full load operation. This test would have to be scheduled with Operations. It is recommended that the unit be operated at full load for 24 continuous hours, with the first 12 hours supervised.

Synchronous condense commissioning test:
Cooling water to upper and lower stationary wear rings, verify pressure/flowrate.
Upper Wear Ring: __________cfs __________psi
Lower Wear Ring: __________cfs __________psi
Ensure adequate flowrate/pressure is supplied equally to upper and lower stationary wear rings.
Record power input: __________kW

FINAL INSPECTION

Set clearance on unit. Inspect air housing, turbine pit and draft tube and scroll case access. Contractor releases Unit 1 special work permit.

REVIEW TEST DATA, DOCUMENTATION

CONTACT CONTROL CENTER, WATER SCHEDULING.

Confirm unit is now available for power and water scheduling.

TEST LIMITATIONS & SETTINGS

Pre-teardown/pre-disassembly readings

Clearances
Air gap: [ ]-inches (design)
Generator guide bearing
Upper Guide: [ ] to [ ]-inch Radial Clearance
Lower Guide: [ ] to [ ]-inch Radial Clearance
Turbine guide bearing: [ ] to [ ]-inches Radial Clearance
Wearing rings, Per Drawing No. [ ]:
Upper: [ ] to [ ]-inches clearance
Lower: [ ] to [ ]-inches clearance
Gate end clearance: [ ] to [ ]-inches
Wicket gates: Heel-to-toe compliance with FIST 2-7
Generator guide bearing cover _____to _____-inches
Thrust bearing oil baffle ____ and ____-inches
Turbine guide bearing cover clearance: _____-inches

Shaft Runout (Manufacturer to provide)
Shaft Center of Runout: Total Out of Plumb from Thrust Bearing to Turbine Bearing: __________
Plumb of Centerline of Shaft:

Runout	0-180	90-270	Allowable
Lower Guide			
Turbine Guide			

Temperatures (See attached table)

Governor
Settings:

Tm = [ ] seconds
Tw = [ ] second (@[max] MW and full gate - full reservoir)

Gate Timing (Opening & Closing) not measured for full stroke - chart data from various tests indicates ____ seconds

Governor Parameters:

Parameter	Dial Setting	Per Unit Value/Notes
Droop	5	___ per unit – 5% (Set at maximum head based on ___ MW)
SNL Adjust	___	Setting will vary depending on reservoir elevation

Restoring Ratio Linkage Setting [ ]:1

Effective Gate Time Constant

On-line: [ ] seconds
Bypassed: [ ] seconds

Servo stroke, max: [ ]-inches
Gate timing: [ ] seconds
Gate squeeze:

<u>Loading limitations: power/pressures/load rejection</u>
[ ] MW capacity ([ ] kVa, [ ] pf)
Maximum power reservoir: El. [ ]. Minimum power reservoir: El. [ ].
Overspeed switch: ____ RPM
Runaway: [ ] RPM max at [max] ft head
Draft tube pressure pulsations shall not exceed 5% of head
Rough zone: (with old runners, it's been [ ] to [ ] MW).
WR^2 = [ ] lb-ft

DATA COLLECTION

Speed	Breakaway	50% speed ([ ] RPM)	75% speed ([ ] RPM)	100% speed ([ ] RPM)
TIME				
FOREBAY ELEVATION				
TAILRACE ELEVATION				
GATE OPENING				
U. GUIDE Metal TEMP.				
U. GUIDE RUNOUT				
L. GUIDE Metal TEMP.				
L. GUIDE RUNOUT				
THRUST BRG. TEMP.				
TURB. BRG. Metal TEMP				
TURB. BRG. RUNOUT				
FLOW METER READING @ 0% GATE OPENING				
TIME TO STOP UNIT				

Net Head (ft) = Reservoir Elevation – Tailwater Elevation – Head Loss
Head loss (ft) = [   ]*Q^2 (where Q is flowrate in cubic feet per second).

Speed	Speed No Load	Over Speed Trip	40% (__ MW)	60% (__ MW)	80% (__ MW)	100% (__ MW)
Time						
MW and Power Factor						
Reservoir Elevation (ft)						
Tailwater Elevation (ft)						
Net Head (ft)						
Water Temp (˚F)						
Flowrate (cfs)						
Gate Opening / Stroke (%)						
Gate Timing during load rejections (seconds)						
Load Rejection Max Pressure Peak (psi)						
Maximum Speed (RPM)						
Upper Guide Bearing Temp (˚F/˚C)						
Upper Guide Bearing Runout (mils)						
Lower Guide Bearing Temp (˚F/˚C)						
Lower Guide Bearing Runout (mils)						
Thrust Bearing Temp (˚F/˚C)						
Turbine Guide Bearing Metal/Oil Temp (˚F/˚C)						
Turbine Guide Bearing Runout (mils)						
Air Admission Open? (Y/N)						
Water Pressures (psi)						
Upper/Lower Seal Water (psi)						
Packing Box (psi)						
Penstock Pressure (psi)						
Spiral Case Pressure (psi)						
Draft Tube Pressure (psi)						
Headcover Pressure (psi)						

Pre-rotation checklist:

All control circuits checked as noted on pre-commissioning checklist.
Data recorder and mechanical instrumentation in service.
Air compressors in service.
Butterfly valve in service for U1 penstock.
Record forebay and tailbay water elevations.
Test control board lamps for expected operation.
Circuit breaker 163 open and disabled.
DC field flashing breaker in OFF position.
125 Vdc control circuit disconnected at exciter.
CO_2 fire protection ready and on clearance.
Main (102GM) overspeed switch contact disabled in the emergency shutdown circuit.
Trip feature of creep detector disabled. Annunciator enabled.
Timing relays set.

INTITAL BREAKAWAY CHECKLIST:

Check the following equipment in service or ready for operation:

Plant air compressor
Governor oil pressure system
Governor actuator
Governor remote indication
High pressure oil pump
Creep detector
Draft tube gate hoist crane
U1 butterfly valve operational
Unit annunciator
Plant annunciator
Turbine, generator bearing ac and dc lube oil pumps
Governor lead/lag oil pump
125 Vdc field flashing breaker locked OFF
125 Vdc excitation control circuit breaker ON
125 Vdc breaker control circuit breaker OFF?
125 Vdc unit protection breaker ON
125 VdcCO_2 control circuit breaker ON, clearance released
125 Vdc butterfly valve control breaker ON
125 Vdc generator differential relay control breaker ON
125 Vdc plant protection control breaker ON
125 Vdc plant annunciator control breaker ON
125 Vdc synch selector control breaker ON

Verify the following equipment status:

Generator bearing oil reservoir level- normal
Governor oil pressure tank level -normal
Governor oil reservoir level- normal
Brake air supply -normal
Governor emergency shutdown solenoid reset

Initial Offline Energized tests:
Verify the following breaker status:

125 Vdc field flashing breaker ON
125 Vdc excitation control circuit breaker ON
125 Vdc breaker control circuit breaker ON
125 Vdc unit protection breaker ON
125 Vdc CO_2, control circuit breaker ON, CO_2 clearance released
125 Vdc butterfly valve control breaker ON
125 Vdc generator differential relay control breaker ON
125 Vdc plant protection control breaker ON
125 Vdc plant annunciator control breaker ON
125 Vdc annunciator horn control breaker ON
125 Vdc transformer differential breaker ON, water valved off
125 Vdc synch selector control breaker ON

Check or place the following controls in the position indicated:
Switchboard CSA Unit Control:
Auxiliaries ON at least 10 minutes
Control mode selector switch 143UC-Local
Generator brakes control switch 101GB AUTO
Gate limit control switch 101AL preset
Speed changer 101AS preset
Voltage regulator switch 101ER AUTO
Synch selector switch 125JS OFF
Selector switch 143ER Auto
Normal shutdown solenoid SHUTDOWN ready to RESET

On-line test check sheet:

Verify the following breaker status:
125 Vdc field flashing breaker ON
125 Vdc excitation control circuit breaker ON
125 Vdc breaker control circuit breaker ON
125 Vdc unit protection breaker ON
125 Vdc CO_2, control circuit breaker ON, CO_2 clearance removed
125 Vdc butterfly valve control breaker ON
125 Vdc generator differential relay control breaker ON
125 Vdc plant protection control breaker ON
125 Vdc plant annunciator control breaker ON
125 Vdc annunciator horn control breaker ON
125 Vdc transformer differential breaker ON
125 Vdc synch selector control breaker ON

Check or place the following controls in the position indicated:
Switchboard CSA Unit Control:
Auxiliaries ON at least 10 minutes

Control mode selector switch 143UC-Local
Generator brakes control switch 101GB AUTO
Gate limit control switch 101AL preset
Speed changer 101AS preset
Voltage regulator switch 101ER AUTO
Synch selector switch 125JS AUTO
Selector switch 143ER Auto
Normal shutdown solenoid SHUTDOWN ready to RESET

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Appendix B - Example Wiring Checkout Sheet - Transformer

Stamped By: [redacted]

Control Wiring Associated with [redacted] Transformer Bank Installation

Engineering Verified: [redacted]
Date: 12/29/2022

START POINT								END POINT							
Panel	Terminal Block	Terminal #	Signal	Conductor Label	Conductor Size	Color ((bk) means black insulated conductor)	Cable Label	Panel	Terminal Block	Terminal #	Conductor Label	Continuity	Insulation Resistance (Ohms) ((500VDC for 300V Cable and 1000VDC for 600V Cable)	Testing Personnel	Date
CCD3F	A	04	JF5P	J-A:04-BC:08	12	Grey	N/A	CCD3F	BC	08	J-BC:08-A:04	YES	N/A	[redacted]	11/29/2022
CCD3F	BC	01	JF5N	J-BC:01-AA:L1	12	Grey	N/A	CCD3F	AA	L1	J-AA:L1-BC:01	YES	N/A	[redacted]	11/29/2022
CCD3F	BC	01	JF5N	J-BC:01-HA:B	12	Grey	N/A	CCD3F	HA	B	J-HA:B-BC:01	YES	N/A	[redacted]	11/29/2022
CCD3F	CA	B17	K5DN	J-CA:B17-CA:B19	12	Grey	N/A	CCD3F	CA	B19	J-CA:B19-CA:B17	YES	N/A	[redacted]	11/29/2022
CCD3F	CA	B19	K5DN	J-CA:B19-CA:B21	12	Grey	N/A	CCD3F	CA	B21	J-CA:B21-CA:B19	YES	N/A	[redacted]	11/29/2022
CCD3F	CA	B21	K5DN	J-CA:B21-CA:C33	12	Grey	N/A	CCD3F	CA	C33	J-CA:C33-CA:B21	YES	N/A	[redacted]	11/29/2022
CCD3F	K	11	LINE	CCD3F-K:11-CCD2F-K:11	10	Black	1CCD3F-CCD2F:2/C-10	CCD2F	K	11	CCD2F-K:11-CCD3F-K:11	YES	> 4000M	[redacted]	11/29/2022
CCD3F	K	12	NEUTRAL	CCD3F-K:12-CCD2F-K:12	10	White	1CCD3F-CCD2F:2/C-10	CCD2F	K	12	CCD2F-K:12-CCD3F-K:12	YES	> 4000M	[redacted]	11/29/2022
CCD3F	M	01	FCV50	J-M:01-AC:12	12	Grey	N/A	CCD3F	AC	12	J-AC:12-M:01	YES	N/A	[redacted]	11/29/2022
CCD3F	M	01	FCV50	CCD3F-M:01-CCR2R-T4TB1:05	16	Black	2CCD3F-CCR2R:2/C-16	CCR2R	T4TB1	05	CCR2R-T4TB1:05-CCD3F-M:01	YES	> 4000M	[redacted]	11/29/2022
CCD3F	M	01	N/A	J-M:01-M:05	12	Grey	N/A	CCD3F	M	05	J-M:05-M:01	YES	N/A	[redacted]	11/29/2022
CCD3F	M	02	787	J-M:02-AC:11	12	Grey	N/A	CCD3F	AC	11	J-AC:11-M:02	YES	N/A	[redacted]	11/29/2022
CCD3F	M	02	787	CCD3F-M:02-CCR2R-T4TB1:04	16	Red	2CCD3F-CCR2R:2/C-16	CCR2R	T4TB1	04	CCR2R-T4TB1:04-CCD3F-M:02	YES	> 4000M	[redacted]	11/29/2022
CCD3F	X	05	5TDQA	CCD3F-X:05-U5A-TB5:01	10	(bk) Black	1CCD3F-U5A:4/C-10	U5A	TB5	05	U5A-TB5:01-CCD3F-X:05	YES	> 4000M	[redacted]	11/30/2022
CCD3F	X	06	5TDQB	CCD3F-X:06-U5A-TB5:02	10	(bk) Red	1CCD3F-U5A:4/C-10	U5A	TB5	03	U5A-TB5:02-CCD3F-X:06	YES	> 4000M	[redacted]	11/30/2022
CCD3F	X	07	5TDQC	CCD3F-X:07-U5A-TB5:03	10	(bk) White	1CCD3F-U5A:4/C-10	U5A	TB5	01	U5A-TB5:03-CCD3F-X:07	YES	> 4000M	[redacted]	11/30/2022
CCD3F	X	08	5TDQ0	J-X:08-TA:06	12	Grey	N/A	CCD3F	TA	06	J-TA:06-X:08	YES	N/A	[redacted]	11/30/2022
CCD3F	X	08	5TDQ0	CCD3F-X:08-U5A-TB5:04	10	(bk) Green	1CCD3F-U5A:4/C-10	U5A	TB5	02	U5A-TB5:04-CCD3F-X:08	YES	> 4000M	[redacted]	11/30/2022
CCD3F	X	09	6TDQA	CCD3F-X:09-U6A-TB5:01	10	(bk) Black	1CCD3F-U6A:4/C-10	U6A	TB5	05	U6A-TB5:01-CCD3F-X:09	YES	> 4000M	[redacted]	11/30/2022
CCD3F	X	10	6TDQB	CCD3F-X:10-U6A-TB5:02	10	(bk) Red	1CCD3F-U6A:4/C-10	U6A	TB5	03	U6A-TB5:02-CCD3F-X:10	YES	> 4000M	[redacted]	11/30/2022
CCD3F	X	11	6TDQC	CCD3F-X:11-U6A-TB5:03	10	(bk) White	1CCD3F-U6A:4/C-10	U6A	TB5	01	U6A-TB5:03-CCD3F-X:11	YES	> 4000M	[redacted]	11/30/2022
CCD3F	X	12	6TDQ0	J-X:12-TA:02	12	Grey	N/A	CCD3F	TA	02	J-TA:02-X:12	YES	N/A	[redacted]	11/30/2022
CCD3F	X	12	6TDQ0	CCD3F-X:12-U6A-TB5:04	10	(bk) Green	1CCD3F-U6A:4/C-10	U6A	TB5	02	U6A-TB5:04-CCD3F-X:12	YES	> 4000	[redacted]	11/30/2022
E5A	480V	AΦ	N/A	E5A-480:AΦ-D6B-6-1:AΦ	1	Brown (Tape)	3E5A-D6B:3-1/C-1	D6B	6-1	AΦ	D6B-6-1:AΦ-E5A-480:AΦ	YES	> 4000	[redacted]	11/30/2022
E5A	480V	BΦ	N/A	E5A-480:BΦ-D6B-6-1:BΦ	1	Orange (Tape)	3E5A-D6B:3-1/C-1	D6B	6-1	BΦ	D6B-6-1:BΦ-E5A-480:BΦ	YES	> 4000	[redacted]	11/30/2022
E5A	480V	CΦ	N/A	E5A-480:CΦ-D6B-6-1:CΦ	1	Ye low (Tape)	3E5A-D6B:3-1/C-1	D6B	6-1	CΦ	D6B-6-1:CΦ-E5A-480:CΦ	YES	> 4000	[redacted]	11/30/2022
E5A	4T5	B2X	N/A	J-4T5:B2X-27K5ACP:A2X	12	Grey	N/A	E5A	27K5ACP	A2X	J-27K5ACP:A2X-4T5:B2X	YES	N/A	[redacted]	11/30/2022
E5A	4T5	B2Y	N/A	J-4T5:B2Y-63WT5LX:B1Y	12	Grey	N/A	E5A	63WT5LX	B1Y	J-63WT5LX:B1Y-4T5:B2Y	YES	N/A	[redacted]	11/30/2022
E5A	4T5	B3X	N/A	J-4T5:B3X-27K5ACP:A3X	12	Grey	N/A	E5A	27K5ACP	A3X	J-27K5ACP:A3X-4T5:B3X	YES	N/A	[redacted]	11/30/2022
E5A	4T5	B3Y	N/A	J-4T5:B3Y-63WT5LX:B2Y	12	Grey	N/A	E5A	63WT5LX	B2Y	J-63WT5LX:B2Y-4T5:B3Y	YES	N/A	[redacted]	11/30/2022
E5A	4T5	K1	N/A	J-4T5:K1-TBK5A1:02	12	Grey	N/A	E5A	TBK5A1	02	J-TBK5A1:02-4T5:K1	YES	N/A	[redacted]	11/30/2022
E5A	GND BAR	N/A	N/A	N/A	8?	Grey	N/A	E5A	CABLE TRAY	GND	N/A	YES	> 4000	[redacted]	11/30/2022
E5A	GND BAR	N/A	N/A	N/A	8?	Grey	N/A	E5A	BACKPANEL	GND	N/A	YES	> 4000	[redacted]	11/30/2022
E5A	GND BAR	N/A	N/A	E5A-GND BAR-K5A1-GND BAR:02	10	(bk) Green	11E5A-K5A1:3/C-8 & 1/C-10 GND	K5A1	GND BAR	02	K5A1-GND BAR:02-E5A-GND BAR	YES	> 4000	[redacted]	11/30/2022
E5A	GND BAR	N/A	N/A	E5A-GND BAR-K5A2-GND BAR:02	10	(bk) Green	11E5A-K5A2:3/C-8 & 1/C-10 GND	K5A2	GND BAR	02	K5A2-GND BAR:02-E5A:GND BAR	YES	> 4000	[redacted]	11/30/2022
E5A	GND BAR	N/A	N/A	E5A-GND BAR-K5A3-GND BAR:02	10	(bk) Green	11E5A-K5A3:3/C-8 & 1/C-10 GND	K5A3	GND BAR	02	K5A3-GND BAR:02-E5A-GND BAR	YES	> 4000	[redacted]	11/30/2022
E5A	TB1	01	K5ATX	J-TB1:01-TBK5A1:01	12	Grey	N/A	E5A	TBK5A1	01	J-TBK5A1:01-TB1:01	YES	N/A	[redacted]	11/30/2022
E5A	TB1	01	K5ATX	J-TB1:01-FU1:02	12	Grey	N/A	E5A	FU1	02	J-FU1:02-TB1:01	YES	N/A	[redacted]	11/30/2022
E5A	TB1	01	N/A	N/A	12	Grey	N/A	E5A	TB1	02	N/A	YES	N/A	[redacted]	12/12/2022
E5A	TB1	02	K5ATX	J-TB1:02-TBM:01	12	Grey	N/A	E5A	TBM	01	J-TBM:01-TB1:02	YES	N/A	[redacted]	12/12/2022
E5A	TB1	02	N/A	N/A	12	Grey	N/A	E5A	TB1	03	N/A	YES	N/A	[redacted]	12/12/2022
E5A	TB1	03	K5ATX	J-TB1:03-27K5ACP:K1	12	Grey	N/A	E5A	27K5ACP	K1	J-27K5ACP:K1-TB1:03	YES	N/A	[redacted]	12/12/2022
E5A	TB1	06	K5ATY	J-TB1:06-4T5:K2	12	Grey	N/A	E5A	4T5	K2	J-4T5:K2-TB1:06	YES	N/A	[redacted]	12/12/2022
E5A	TB1	06	K5ATY	J-TB1:06-XFMR:X2	12	Grey	N/A	E5A	XFMR	X2	J-XFMR:X2-TB1:06	YES	N/A	[redacted]	12/12/2022
E5A	TB1	06	N/A	N/A	12	Grey	N/A	E5A	TB1	07	N/A	YES	N/A	[redacted]	12/12/2022
E5A	TB1	07	K5ATY	J-TB1:07-63WT5LX:K2	12	Grey	N/A	E5A	63WT5LX	K2	J-63WT5LX:K2-TB1:07	YES	N/A	[redacted]	12/12/2022
E5A	TB1	07	N/A	N/A	12	Grey	N/A	E5A	TB1	08	N/A	YES	N/A	[redacted]	12/12/2022
E5A	TB1	08	K5ATY	J-TB1:08-27K5ACP:K2	12	Grey	N/A	E5A	27K5ACP	K2	J-27K5ACP:K2-TB1:08	YES	N/A	[redacted]	12/12/2022
E5A	TBA1	01	FCV50	E5A-TBA1:01-CCR2R-T3TB1:08	18	Black1	39E5A-CCR2R:8PR-18-SHD	CCR2R	T3TB1	08	CCR2R-T3TB1:08-E5A-TBA1:01	YES	> 2000	[redacted]	12/12/2022
E5A	TBA1	01	N/A	J-TBA1:01-63WT5LX:A1Y	12	Grey	N/A	E5A	63WT5LX	A1Y	J-63WT5LX:A1Y-TBA1:01	YES	N/A	[redacted]	12/12/2022
E5A	TBA1	01	N/A	N/A	12	Grey	N/A	E5A	TBA1	02	N/A	YES	N/A	[redacted]	12/12/2022
E5A	TBA1	02	FCV50	J-TBA1:02-TBM:05	12	Grey	N/A	E5A	TBM	05	J-TBM:05-TBA1:02	YES	N/A	[redacted]	12/12/2022
E5A	TBA1	02	N/A	N/A	12	Grey	N/A	E5A	TBA1	03	N/A	YES	N/A	[redacted]	12/12/2022
E5A	TBA1	03	FCV50	J-TBA1:03-TBK5A1:03	12	Grey	N/A	E5A	TBK5A1	03	J-TBK5A1:03-TBA1:03	YES	N/A	[redacted]	12/12/2022
E5A	TBA1	03	N/A	N/A	12	Grey	N/A	E5A	TBA1	04	N/A	YES	N/A	[redacted]	12/12/2022
E5A	TBA1	04	FCV50	J-TBA1:04-TBK5A2:03	12	Grey	N/A	E5A	TBK5A2	03	J-TBK5A2:03-TBA1:04	YES	N/A	[redacted]	12/12/2022
E5A	TBA1	04	N/A	N/A	12	Grey	N/A	E5A	TBA1	05	N/A	YES	N/A	[redacted]	12/12/2022
E5A	TBA1	05	FCV50	J-TBA1:05-TBK5A3:03	12	Grey	N/A	E5A	TBK5A3	03	J-TBK5A3:03-TBA1:05	YES	N/A	[redacted]	12/12/2022
E5A	TBA1	05	N/A	N/A	12	Grey	N/A	E5A	TBA1	06	N/A	YES	N/A	[redacted]	12/12/2022
E5A	TBA1	07	789	E5A-TBA1:07-CCR2R-T3TB1:07	18	Red1	39E5A-CCR2R:8PR-18-SHD	CCR2R	T3TB1	07	CCR2R-T3TB1:07-E5A-TBA1:07	YES	> 2000	[redacted]	12/12/2022
E5A	TBA1	07	789	J-TBA1:07-TBK5A1:04	12	Grey	N/A	E5A	TBK5A1	04	J-TBK5A1:04-TBA1:07	YES	N/A	[redacted]	12/12/2022
E5A	TBA1	08	790	E5A-TBA1:08-CCR2R-T3TB1:09	18	Red2	39E5A-CCR2R:8PR-18-SHD	CCR2R	T3TB1	09	CCR2R-T3TB1:09-E5A-TBA1:08	YES	> 2000	[redacted]	12/12/2022
E5A	TBA1	08	790	J-TBA1:08-TBK5A2:04	12	Grey	N/A	E5A	TBK5A2	04	J-TBK5A2:04-TBA1:08	YES	N/A	[redacted]	12/12/2022
E5A	TBA1	09	791	E5A-TBA1:09-CCR2R-T3TB1:10	18	Black2	39E5A-CCR2R:8PR-18-SHD	CCR2R	T3TB1	10	CCR2R-T3TB1:10-E5A-TBA1:09	YES	> 2000	[redacted]	12/12/2022
E5A	TBA1	09	791	J-TBA1:09-TBK5A3:04	12	Grey	N/A	E5A	TBK5A3	04	J-TBK5A3:04-TBA1:09	YES	N/A	[redacted]	12/12/2022
E5A	TBA1	10	792	E5A-TBA1:10-CCR2R-T3TB1:12	18	Red3	39E5A-CCR2R:8PR-18-SHD	CCR2R	T3TB1	12	CCR2R-T3TB1:12-E5A-TBA1:10	YES	> 2000	[redacted]	12/12/2022
E5A	TBA1	10	792	J-TBA1:10-TBK5A1:05	12	Grey	N/A	E5A	TBK5A1	05	J-TBK5A1:05-TBA1:10	YES	N/A	[redacted]	12/12/2022
E5A	TBA1	11	793	E5A-TBA1:11-CCR2R-T3TB1:13	18	Black3	39E5A-CCR2R:8PR-18-SHD	CCR2R	T3TB1	13	CCR2R-T3TB1:13-E5A-TBA1:11	YES	> 2000	[redacted]	12/12/2022
E5A	TBA1	11	793	J-TBA1:11-TBK5A1:06	12	Grey	N/A	E5A	TBK5A1	06	J-TBK5A1:06-TBA1:11	YES	N/A	[redacted]	12/12/2022
E5A	TBA1	12	794	E5A-TBA1:12-CCR2R-T3TB1:15	18	Red4	39E5A-CCR2R:8PR-18-SHD	CCR2R	T3TB1	15	CCR2R-T3TB1:15-E5A-TBA1:12	YES	> 2000	[redacted]	12/12/2022
E5A	TBA1	12	794	J-TBA1:12-TBK5A2:06	12	Grey	N/A	E5A	TBK5A2	06	J-TBK5A2:06-TBA1:12	YES	N/A	[redacted]	12/12/2022
E5A	TBA1	13	795	E5A-TBA1:13-CCR2R-T3TB1:16	18	Black4	39E5A-CCR2R:8PR-18-SHD	CCR2R	T3TB1	16	CCR2R-T3TB1:16-E5A-TBA1:13	YES	> 2000	[redacted]	12/12/2022
E5A	TBA1	13	795	J-TBA1:13-TBK5A3:06	12	Grey	N/A	E5A	TBK5A3	06	J-TBK5A3:06-TBA1:13	YES	N/A	[redacted]	12/12/2022
E5A	TBA1	14	796	E5A-TBA1:14-CCR2R-T3TB1:18	18	Red5	39E5A-CCR2R:8PR-18-SHD	CCR2R	T3TB1	18	CCR2R-T3TB1:18-E5A-TBA1:14	YES	> 2000	[redacted]	12/12/2022
E5A	TBA1	14	796	J-TBA1:14-TBK5A1:07	12	Grey	N/A	E5A	TBK5A1	07	J-TBK5A1:07-TBA1:14	YES	N/A	[redacted]	12/12/2022

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1/20/2023

Appendix C - Example Device Functional Test Sheet - Transformer

[redacted] Transformer

Device Name	Device Number	Type	State	Contact	Signal	Start Point Panel	Start Point Terminal Block	Start Point Terminal	End Point Panel	End Point Terminal Block	End Point Terminal	Control Room Annunciation / Operation	Correct Operation?	Testing Personnel	Date	Comments
Current Transformer #1	CT1	HV		X1	78TDQB	TRANSFORMER	TB6	1X1	CCD4F	CA	203	Transformer Lockout (817) / HA	YES	[redacted]	1/27/2022	
				X4	78TDQB0	TRANSFORMER	TB6	1X4	CCD4F	CA	202					
Current Transformer #2	CT2	Spare		X1	N/A	TRANSFORMER	TB6	2X1	K7A2	TB61	2X1	NONE- SPARE	NOT TESTED			
				X5	N/A	TRANSFORMER	TB6	2X5	K7A2	TB61	2X5					
Current Transformer #3	CT3	WAPA		X1	1TB7QB	TRANSFORMER	TB6	3X1	CHC1F	TH	12	Switchyard Trip / Transformer Lockout (817) / HA	YES	[redacted]	1/27/2022	
				X5	1TB7QB0	TRANSFORMER	TB6	3X5	CHC1F	TH	10					
Current Transformer #6	CT6	Spare		X1	N/A	TRANSFORMER	TB6	6X1	K7A2	TB61	6X1	NONE- SPARE	NOT TESTED			
				X5	N/A	TRANSFORMER	TB6	6X5	K7A2	TB61	6X5					
Current Transformer #7	CT7	LV		X1	7TQB	TRANSFORMER	TB6	7X1	CCA16	MW XDUCER	1	Check Amperage Meter	NOT TESTED			
				X5	7TQB0	TRANSFORMER	TB6	7X5	CCA16	METER	1					
Current Transformer #9	CT9	Spare		X1	N/A	TRANSFORMER	TB6	9X1	K7A2	TB61	9X1	NONE- SPARE	NOT TESTED			
				X5	N/A	TRANSFORMER	TB6	9X5	K7A2	TB61	9X5					
Transformer Dehydrating Breather	SG-1	Alarm	N.C.	4	FCV53	TRANSFORMER	TB4	57	CCR2R	J27	ANNUNC.	Phase B Air Cell or Breather Alarm (834)	YES	[redacted]	1/31/2022 & 2/2/2022	Rechecked after CCR card replaced
			N.C.	5	834	TRANSFORMER	TB4	58	CCR2R	J27	ANNUNC. 834					
O I Temperature Indicator (65C Spare)	26Q	Spare	C	11	N/A	TRANSFORMER	TB4	89	K7A2	TB41	89	NONE- SPARE	YES	[redacted]	1/28/2022	At Interface Cabinet Terminals
			N.O.	14	N/A	TRANSFORMER	TB4	90	K7A2	TB41	90					
O I Temperature Indicator (70C Spare)	26Q	Spare	C	21	N/A	TRANSFORMER	TB4	91	K7A2	TB41	91	NONE- SPARE	YES	[redacted]	1/28/2022	At Interface Cabinet Terminals
			N.O.	24	N/A	TRANSFORMER	TB4	92	K7A2	TB41	92					
Oil Temperature Indicator (77C Alarm)	26Q	Alarm	C	31	FCV53	TRANSFORMER	TB4	93	CCR2R	J27	ANNUNC.	Phase B Hot Liquid Temperature Alarm (844)	YES	[redacted]	1/28/2022	
			N.O.	34	844	TRANSFORMER	TB4	94	CCR2R	J27	ANNUNC. 844					
Oil Temperature Indicator (85C Trip)	26Q	Trip	C	41	K7DP	TRANSFORMER	TB4	112	CCD4F	BD	11	All Phase Fault Trip (820) / HB - Trans Lockout (817) / HA	YES	[redacted]	1/28/2022	
			N.O.	44	K7D22	TRANSFORMER	TB4	113	CCD4F	CA (IN202)	B20					
			N.C.	42	N/A	TRANSFORMER	TB4	111	K7A2	TB41	65					
					N/A				K7A2	TB41	66					
					N/A				K7A2	TB41	67					
HV Winding Temperature Indicator (70C Spare)	49T-1	Spare	C	11	N/A	TRANSFORMER	TB4	95	K7A2	TB41	95	NONE- SPARE	YES	[redacted]	1/28/2022	At Interface Cabinet Terminals
			N.O.	14	N/A	TRANSFORMER	TB4	96	K7A2	TB41	96					
HV Winding Temperature Indicator (75C Spare)	49T-1	Spare	C	21	N/A	TRANSFORMER	TB4	97	K7A2	TB41	97	NONE- SPARE	YES	[redacted]	1/28/2022	At Interface Cabinet Terminals
			N.O.	24	N/A	TRANSFORMER	TB4	98	K7A2	TB41	98					
HV Winding Temperature Indicator (87C Alarm)	49T-1	Alarm	C	31	FCV52	TRANSFORMER	TB4	99	CCR2R	J26	ANNUNC.	Phase B Winding Temperature Alarm (822)	YES	[redacted]	1/28/2022	
			N.O.	34	822	TRANSFORMER	TB4	100	CCR2R	J26	ANNUNC. 822					
HV Winding Temperature Indicator (95C Trip)	49T-1	Trip	C	41	K7DP	TRANSFORMER	TB4	115	CCD4F	BD	11	All Phase Fault Trip (820) / HB - Trans Lockout (817) / HA	YES	[redacted]	1/28/2022	
			N.O.	44	K7D22	TRANSFORMER	TB4	116	CCD4F	CA (IN202)	B20					
			N.C.	42	N/A	TRANSFORMER	TB4	114	K7A2	TB41	70					
					N/A				K7A2	TB41	71					
					N/A				K7A2	TB41	72					
LV Winding Temperature Indicator (70C Spare)	49T-2	Spare	C	11	N/A	TRANSFORMER	TB4	101	K7A2	TB41	101	NONE- SPARE	YES	[redacted]	1/28/2022	At Interface Cabinet Terminals
			N.O.	14	N/A	TRANSFORMER	TB4	102	K7A2	TB41	102					
LV Winding Temperature Indicator (75C Spare)	49T-2	Spare	C	21	N/A	TRANSFORMER	TB4	103	K7A2	TB41	103	NONE- SPARE	YES	[redacted]	1/28/2022	
			N.O.	24	N/A	TRANSFORMER	TB4	104	K7A2	TB41	104					
LV Winding Temperature Indicator (87C Alarm)	49T-2	Alarm	C	31	FCV52	TRANSFORMER	TB4	105	CCR2R	J26	ANNUNC.	Phase B Winding Temperature Alarm (822)	YES	[redacted]	1/28/2022	
			N.O.	34	822	TRANSFORMER	TB4	106	CCR2R	J26	ANNUNC. 822					
LV Winding Temperature Indicator (95C Trip)	49T-2	Trip	C	41	K7DP	TRANSFORMER	TB4	118	CCD4F	BD	11	All Phase Fault Trip (820) / HB - Trans Lockout (817) / HA	YES	[redacted]	1/28/2022	
			N.O.	44	K7D22	TRANSFORMER	TB4	119	CCD4F	CA (IN202)	B20					
			N.C.	42	N/A	TRANSFORMER	TB4	117	K7A2	TB41	75					
					N/A				K7A2	TB41	76					
					N/A				K7A2	TB41	77					
Winding Temperature (HV or LV bsed on Fiber) TECM Relay 4 (95C Trip)	23T-2	Trip	C	TECM TB1:12	K7DP	TRANSFORMER	TB4	4	CCD4F	BD	11	All Phase Fault Trip (820) / HB - Trans Lockout (817) / HA	YES	[redacted]	2/3/2022	
			N.O.	TECM TB1:11	K7D22	TRANSFORMER	TB4	3	CCD4F	CA (IN202)	B20					
Winding Temperature (HV or LV based on CTs) TECM Relay 5 (95C Trip)	23T-1	Trip	C	TECM TB1:19	K7DP	TRANSFORMER	TB4	6	CCD4F	BD	11	All Phase Fault Trip (820) / HB - Trans Lockout (817) / HA	YES	[redacted]	2/3/2022	
			N.O.	TECM TB1:18	K7D22	TRANSFORMER	TB4	5	CCD4F	CA (IN202)	B20					
Oil Temperature Indicator (RTD-1 or Fiber) TECM Relay 6 (85C Trip)	2 Q	Trip	C	TECM TB1:22	K7DP	TRANSFORMER	TB4	8	CCD4F	BD	11	All Phase Fault Trip (820) / HB - Trans Lockout (817) / HA	YES	[redacted]	2/3/2022	
			N.O.	TECM TB1:21	K7D22	TRANSFORMER	TB4	7	CCD4F	CA (IN202)	B20					
Winding Temperature (RTD-1 or Fiber) TECM Relay 7 (90C Alarm)	2 Q	Alarm	C	TECM TB1:25	FCV52	TRANSFORMER	TB4	10	CCR2R	J26	ANNUNC.	Phase B Winding Temperature Alarm (822)	YES	[redacted]	2/3/2022	
			N.O.	TECM TB1:24	822	TRANSFORMER	TB4	9	CCR2R	J26	ANNUNC. 822					
O I Temperature Indicator (RTD-1 or Fiber) TECM Relay 8 (80C Alarm)	2 Q	Alarm	C	TECM TB1:28	FCV53	TRANSFORMER	TB4	12	CCR2R	J27	ANNUNC.	Phase B Hot Liquid Temperature Alarm (844)	YES	[redacted]	2/3/2022	
			N.O.	TECM TB1:27	844	TRANSFORMER	TB4	11	CCR2R	J27	ANNUNC. 844					
Sudden Pressure Relay (Trip)	63SPR	Trip	C	2	K7DP	TRANSFORMER	TB4	121	CCD4F	BD	11	All Phase Fault Trip (820) / HB - Trans Lockout (817) / HA	YES	[redacted]	1/28/2022	
			N.O.	1	K D32	TRANSFORMER	TB4	122	CCD4F	CA (IN302)	C36					
			N.C.	3	N/A	TRANSFORMER	TB4	120	K7A2	TB41	80					
		Alarm			N/A				CCR2R	J27	ANNUNC.	TECM Cooler or Relay State Alarm (846)				
					N/A				CCR2R	J27	ANNUNC. 846					
Pressure Relief Device 1 (cooler side) (Trip)	63PRD-1	Trip	C	1.14	K7DP	TRANSFORMER	TB4	20	CCD4F	BD	11	All Phase Fault Trip (820) / HB - Trans Lockout (817) / HA	YES	[redacted]	1/28/2022	
			N.O.	1.13	K7D32	TRANSFORMER	TB4	22	CCD4F	CA (IN302)	C36					
			C	1.22	K7DP	TRANSFORMER	TB4	20	CCD4F	BD	11					
			N.C.	1.21	N/A	TRANSFORMER	TB4	21	K7A2	TB41	21					
Pressure Relief Device 1 (cooler side) (Alarm 1)	63PRD-1	Alarm	C	2.14	FCV53	TRANSFORMER	TB4	23	CCR2R	J27	ANNUNC.	Phase B Pressure Relief Alarm (837)	YES	[redacted]	1/28/2022	
			N.O.	2.13	837	TRANSFORMER	TB4	25	CCR2R	J27	ANNUNC. 837					
			C	2.22	FCV53	TRANSFORMER	TB4	23	CCR2R	J27	ANNUNC.					
			N.C.	2.21	N/A	TRANSFORMER	TB4	24	K7A2	TB41	24					
Pressure Relief Device 2 (control cabinet side) (Trip)	63PRD-2	Trip	C	1.14	K7DP	TRANSFORMER	TB4	26	CCD4F	BD	11	All Phase Fault Trip (820) / HB - Trans Lockout (817) / HA	YES	[redacted]	1/28/2022	
			N.O.	1.13	K7D32	TRANSFORMER	TB4	28	CCD4F	CA (IN302)	C36					
			C	1.22	K7DP	TRANSFORMER	TB4	26	CCD4F	BD	11					
			N.C.	1.21	N/A	TRANSFORMER	TB4	27	K7A2	TB41	27					
Pressure Relief Device 2 (control cabinet side) (Alarm 1)	63PRD-2	Alarm	C	2.14	FCV53	TRANSFORMER	TB4	29	CCR2R	J27	ANNUNC.	Phase B Pressure Relief Alarm (837)	YES	[redacted]	1/28/2022	
			N.O.	2.13	837	TRANSFORMER	TB4	31	CCR2R	J27	ANNUNC. 837					
			C	2.22	FCV53	TRANSFORMER	TB4	29	CCR2R	J27	ANNUNC.					
			N.C.	2.21	N/A	TRANSFORMER	TB4	30	K7A2	TB41	30					
Transformer O I Level (Lo Alarm)	71Q-1	Alarm	C	11	FCV53	TRANSFORMER	TB4	32	CCR2R	J27	ANNUNC.	Phase B Liquid Level Alarm (840)	YES	[redacted]	2/3/2022	
			N.O.	14	840	TRANSFORMER	TB4	34	CCR2R	J27	ANNUNC. 840					
Transformer Oil Level (Hi Alarm)	71Q-1	Alarm	C	21	FCV53	TRANSFORMER	TB4	32	CCR2R	J27	ANNUNC.	Phase B Liquid Level Alarm (840)	YES	[redacted]	2/3/2022	
			N.O.	24	840	TRANSFORMER	TB4	33	CCR2R	J27	ANNUNC. 840					
			C	11	K7DP	TRANSFORMER	TB4	124	CCD4F	BD	11					

[redacted] Transformer

1 of 2

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Appendix D - Example Energization Authorization Notification – Transformer

[redacted]

From: [redacted]
Sent: Tuesday, April 26, 2022 09:41
To: [redacted]
Cc: [redacted]
Subject: Energization Authorization: [redacted] GSU Transformers
Attachments: USBR Transformer Basics Maintenance and Diagnostics.pdf; FIST 3-30 Transformer Maintenance.pdf; Schedule of Events.pdf

Importance: High

All,

Reclamation has received all of the necessary documentation and performed the required device testing to allow energization of the [redacted] bank of GSU transformers at [redacted]. You may proceed with the clearance removal and start-up per the following procedures in conjunction with [redacted] and [redacted]. The following information is due to the new transformers and must be performed in addition to any existing startup procedures. It is recommended to print this email and cross off each item when executed. I have also attached a schedule of events to estimate times if we were to energize Wednesday, April 27th [redacted] at 13:00.

Please forward, or print out and provide, this email to any personnel involved in the startup of the new transformers. Note that each step is listed per transformer and must be performed on all three transformers.

Start-Up Procedure:

1. Visual Checks:
    - Transformer Deck to verify:
        1. All split type terminal blocks (sliding screws) are closed. No terminals should be in the open position. (Check the transformer interface cabinet as well as the transformer control cabinet.)
        2. Cooling water is running and at acceptable pressure (25PSI).
        3. All pumps are in 'auto' mode in the transformer control cabinet. There are three position switches that should be in the 'auto' mode for both pumps.
        4. CT shorting screws have been removed from the transformer control cabinet and interface cabinet.
            1. All shorting screws associated with CT circuits must be removed. For all CT connections that are not being used (spare CTs), the connections are shorted with jumper wires (not shorting screws) and grounded to the ground bar in the transformer interface cabinet. For spare CTs, the shorting screws can be used in addition to the jumper wires. [This is already the state in the transformer interface cabinet as long as installation matches drawings.]
            2. Shorting jumper wires in the transformer interface cabinet should match the drawings taped to the inside of the cabinet.
        5. Tap changer is in correct position for system voltage on all three transformers. [tap changer position is #2]

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        1. Make sure to check this for all three transformers. Field test reports show that transformer [redacted] may be in the wrong position currently.
    6. Grounds have been removed from the high voltage lines.
    7. Oil Containment doors are closed and tightened to the deck.
- Generator Level to verify:
    1. [redacted] panel doors have been closed.
    2. Fire suppression supply gate valves are open and maintenance switches are in the 'normal' position.
    3. Fire alarm panels are clear of alarm, trouble, and supervisory signals.
    4. Air compressor for isolated phase bus is on and positive pressure has been in the bus for a minimum of 5-days.
    5. PT cabinet doors are closed and locked.
    6. PT control cabinets have the fuse blocks inserted and all connections are correct.
- Control Room to verify:
    1. Alarms are clear on the 300G and 487 relays.
    2. Annunciator windows are clear on the [redacted] bank.
    3. Test Switches are all closed on the [redacted] panel.
    4. Clearances are removed.

2. Energize the transformers, and hold at rated voltage and no load for 24-hours. This period of energization at no load is helpful to understand and evaluate the characteristics of the transformer for future diagnostics. During this energizing period, before loading the transformer, it is recommended to do the following surveillance actions:
    - Take fluid sample from Dissolved Gas Monitor (DGM) sampling port. Take sample **at beginning of energization period**.
        1. Follow procedures in Transformer Insulating Fluid Samples.pdf
        2. **Liquid Sample #1 (Day 000)**: Beginning of Energization [complete spreadsheet: Fluid Sample Plan.xlsx]
        3. Use prepopulated forms in [redacted] Fluid Samples folder.
            1. There is a form for each transformer and each sample.
    - Check for excessive audible noise and vibration (compare against different phase units and against [redacted] transformers).
    - Monitor temperature of fluid, recordings to be taken at time intervals (every hour) until stabilization. (Take recordings from gauges and TECM)
    - Monitor temperature of windings (LV and HV), recordings to be taken at time intervals (every hour) until stabilization. (Take recordings from gauges and TECM)
    - Monitor ambient temperature, recordings to be taken at time intervals (every hour). (Take recordings from TECM)
    - Check performance of coolers. Stage 1 will turn on when the liquid temperature reaches 10-degrees C and stage 2 will turn on at 50-degrees C. (Record temperatures of liquid and windings when coolers turn on for each stage.)
        1. Liquid temperature may not reach 50-degrees C and thus stage 2 cooling will not turn on.
    - Inspect for fluid leaks, and check all fluid level indicators. Fluid levels should rise as temperatures rise.
    - Take fluid sample from DGM sampling port. Take sample **at end of the energization period**. **Note: DGA results with the transformer energized and in no-load condition obtained at the end of the energizing period will be kept for reference and trending.
        1. Follow procedures in Transformer Insulating Fluid Samples.pdf
        2. **Liquid Sample #2 (Day 001)**: End of Energization [complete spreadsheet: Fluid Sample Plan.xlsx]
        3. Use prepopulated forms in [redacted] Fluid Samples folder.
3. Transformer is now ready for loading tests. Load transformers in small increments as defined below and hold for the time specified at each increment. If any stage interferes with the generator rough zones, adjust outside of rough zone.

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- At each of the following load increments:
  1. Monitor the load percent of the transformer bank and temperatures of fluid and windings (LV and HV); recording to be taken at time intervals (every hour).
     1. Note that the transformer bank 100% load is 375MW.
  2. Use IR scan to monitor for hot spots on bushings, tank, and cooling systems. (record any areas and send to [redacted] ASAP)
  3. Check for excessive audible noise and vibration.
- Load Schedule: The generators are rated at 165MW but only 96MW are possible due to water levels.
  1. 15minutes at 17MW – G8 (10% load)
  2. 15minutes at 33MW – G8 (20% load)
  3. 15minutes at 50MW – G8 (30% load) [adjust to stay out of rough zone]
  4. 15minutes at 66MW – G8 (40% load) [adjust to stay out of rough zone]
  5. 15minutes at 83MW – G8 (50% load) [adjust to stay out of rough zone]
  6. 15minutes at 95.7MW – G8 (58% load) [probably max generation due to water levels]
     1. Existing water limitations.
- Load Schedule: This schedule focuses on loading using G8 at full load (assuming 95.7MW) and incrementing G7.
  1. **30minutes at 112.2MW – G8 (58% load) G7 (10% load)**
     1. Hold at this level to allow for CT circuits to be checked for differentials prior to going higher in generation.
  2. 15minutes at 128.7MW – G8 (58% load) G7 (20% load)
  3. 15minutes at 145.2MW – G8 (58% load) G7 (30% load) [adjust to stay out of rough zone]
  4. 15minutes at 161.7MW – G8 (58% load) G7 (40% load) [adjust to stay out of rough zone]
  5. 15minutes at 178.2MW – G8 (58% load) G7 (50% load) [adjust to stay out of rough zone]
  6. **30minutes at 191.4MW – G8 (58% load) G7 (58% load) [max generation due to water levels]**
     1. Hold at this level to allow for temperature stabilization.

4. Once at full load (maximum available for both generators), hold load for 24-hours, minimum.
   - We want to wait until the transformer temperatures have stabilized; less than 1-degree C change over 3-hour period [approximately 4-hours]. Also to hold for maximum gas generation.
   - Perform hourly checks to monitor:
     1. Check for excessive audible noise and vibration (compare against different phase units and against [redacted] transformers).
     2. Use IR scan to monitor for hot spots on bushings, tank, and cooling systems. (record any areas and send to [redacted] ASAP)
     3. Check performance of coolers. Stage 1 will turn on when the liquid temperature reaches 10-degrees C and stage 2 will turn on at 50-degrees C. (Record temperatures of liquid and windings when coolers turn on for each stage.)
        1. Liquid temperature may not reach 50-degrees C and thus stage 2 cooling will not turn on.
     4. Inspect for fluid leaks, and check all fluid level indicators. Fluid levels should rise as temperatures rise.
   - Take fluid sample from DGM sampling port. Take sample **at end of the loading period**.
     1. Follow procedures in Transformer Insulating Fluid Samples.pdf
     2. **Liquid Sample #3 (Day 003)**: End of Full Load [complete spreadsheet: Fluid Sample Plan.xlsx]
     3. Use prepopulated forms in [redacted] Fluid Samples folder.
     4. Send all three liquid samples off to the lab for analysis.
5. [redacted] Transformers can now be operated normally. Loading may follow the generation schedule.
6. Make a daily inspection during the first few days to look for any fluid leaks, sudden increases of temperatures or any abnormal operation of the gas detector relay, and any abnormal operation of accessories (bushings, coolers, relays, etc.).
7. Take fluid samples at 24-hours and 72-hours after going to normal loading and temperature stabilization.
   - **Liquid Sample #4 (Day 004)**: 24-hours after normal load.

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- **Liquid Sample #5 (Day 006)**: 72-hours after normal load.
- Send both (2) samples off to the lab for analysis.

8. Download gas analysis from DGM. Laptop with [redacted] software installed is needed.
9. Send results of downloaded gas analysis data from DGM to [redacted].
10. The air compressor for the isolated phase bus system can be turned off now.
    - Normal operation of the transformers will maintain the necessary heat for internal pressures in the isolated phase bus.
11. For the first year of service:
    - Fluid Samples:
        1. Follow procedures in Transformer Insulating Fluid Samples.pdf
        2. See spreadsheet for exact days of sample: Fluid Sample Plan.xlsx]
        3. Use prepopulated forms in [redacted] Fluid Samples folder.
            1. Fluid sample once every week for the first month (total of 4 samples in the first month).
            2. Fluid sample once every 3-months after the first month (total of 3 samples in the first year).
        4. [redacted] will order the sampling kits 1-month before the date of sampling.
        5. Download gas analysis from DGM and send to [redacted].
    - Temperature Recordings:
        1. Record LV, HV, and Top Oil temperatures in correlation with MW of generation every week for the first month (total of 4 recordings in the first month).
        2. Record LV, HV, and Top Oil temperatures in correlation with MW of generation every month after the first month (total of 11 recordings in the first year).
        3. Send results to [redacted] in May 2023.
            1. All 15 temperature recordings with correlated MW of generation.
12. Follow *Transformers: Basics, Maintenance, and Diagnostics* and FIST 3-30. [attached to this email]

The latest planned schedule:

- April 27 2022: [redacted] Energized
- May 03 2022: [redacted] Complete with Initial Startup
- [redacted]

If you have any questions please bring them to the meeting today at 12:30 [redacted]. For anyone not invited to the meeting currently, but would like to join:

Energization Authorization: [redacted] GSU Transformer Bank

Join on your computer or mobile app

Click here to join the meeting

Learn More | Meeting options

Thank you to everyone on the team for their hard work and continued dedication.

v/r

[redacted], P.E.
Transformer Subgroup Lead
Electrical Equipment Group
Bureau of Reclamation
Technical Service Center
Denver, Colorado
Phone: [redacted]

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Appendix E - Example Schedule of Events and Hourly Records - Transformer

Date	Time	Event
Wednesday, April 27, 2022	07:00	Start Visual Checks from Energization Authorization email
Wednesday, April 27, 2022	13:00	Start Voltage no load and Liquid Sample #1
Thursday, April 28, 2022	13:00	End Voltage No Load and Liquid Sample #2
Thursday, April 28, 2022	14:00	Start Incremental loading [G8 10% load]
Thursday, April 28, 2022	14:15	Start Incremental loading [G8 20% load]
Thursday, April 28, 2022	14:30	Start Incremental loading [G8 30% load]
Thursday, April 28, 2022	14:45	Start Incremental loading [G8 40% load]
Thursday, April 28, 2022	15:00	Start Incremental loading [G8 50% load]
Thursday, April 28, 2022	15:15	Start Incremental loading [G8 58% load]
Thursday, April 28, 2022	15:30	Start 30-min Incremental loading [G8 58% load & G7 10%]
Thursday, April 28, 2022	16:00	Start Incremental loading [G8 58% load & G7 20%]
Thursday, April 28, 2022	16:15	Start Incremental loading [G8 58% load & G7 30%]
Thursday, April 28, 2022	16:30	Start Incremental loading [G8 58% load & G7 40%]
Thursday, April 28, 2022	16:45	Start Incremental loading [G8 58% load & G7 50%]
Thursday, April 28, 2022	17:00	Start 30-min Incremental loading [G8 58% load & G7 58%]
Thursday, April 28, 2022	17:30	Start 24-hour hold at full load
Friday, April 29, 2022	17:30	End of 24-hour at full load but maintain until liquid sample can be taken.
Saturday, April 30, 2022	07:00	Liquid Sample #3
Saturday, April 30, 2022	08:00	Move to Normal Loading
Sunday, May 1, 2022	08:00	24-hours at normal loading and Liquid Sample #4
Tuesday, May 3, 2022	08:00	72-hours at normal loading and Liquid Sample #5

Hourly Temperature and Power Recordings

			LV Winding Temps (°C)		HV Winding Temps (°C)		Top Fluid Temps (°C)		Ambient (°C)	Temp. Rise (°C)	
Day of Recording	Time of Recording	MW on Xfmr Bank	Gauge	TECM	Gauge	TECM	Gauge	TECM	TECM	Guage	TECM
Wed, Apr 27	12:00	0	23	17.9	22	18	23	18	28.1	-5.1	-10.1
Wed, Apr 27	13:00	0	25	19.8	24	19.8	25	19.8	28.7	-3.7	-8.9
Wed, Apr 27	14:00	0	26	21.1	25	21.1	26	21.1	29	-3	-7.9
Wed, Apr 27	15:00	0	26	21.7	25	21.7	26	21.7	28.8	-2.8	-7.1
Wed, Apr 27	16:00	0	25	21.5	25	21.5	26	21.6	28.7	-2.7	-7.1
Wed, Apr 27	17:00	0	25	21.6	25	21.6	26	21.6	28	-2	-6.4
Wed, Apr 27	18:00	0									
Wed, Apr 27	19:00	0									
Wed, Apr 27	20:00	0	21	21.1	21	21.1	22	21.2	25.8	-3.8	-4.6
Wed, Apr 27	21:00	0	21	20.9	21	20.9	21	20.9	25	-4	-4.1
Wed, Apr 27	22:00	0	21	20.6	21	20.7	21	20.6	24.4	-3.4	-3.8
Wed, Apr 27	23:00	0	21	20.4	21	21.4	21	20.4	23.8	-2.8	-3.4
Thu, Apr 28	00:00	0	21	20.1	20	20.2	20	20.1	22.5	-2.5	-2.4
Thu, Apr 28	01:00	0	19	18.6	19	18.6	19	18.6	22	-3	-3.4
Thu, Apr 28	02:00	0	18	18.3	18	18.2	18	18.2	21.3	-3.3	-3.1
Thu, Apr 28	03:00	0	19	18	19	18	18	18	20.2	-2.2	-2.2
Thu, Apr 28	04:00	0	18	18	18	18	18	18	19.7	-1.7	-1.7
Thu, Apr 28	05:00	0	18	17.9	18	17.9	18	17.8	19.3	-1.3	-1.5
Thu, Apr 28	06:00	0	17	17.6	17	17.6	17	17.5	18.3	-1.3	-0.8
Thu, Apr 28	07:00	0	17	17.5	17	17.5	17	17.5	18.3	-1.3	-0.8
Thu, Apr 28	08:00	0	17	17.4	17	17.4	17	17.4	18.1	-1.1	-0.7
Thu, Apr 28	09:00	0	17	17.6	17	17.6	17	17.5	19.6	-2.6	-2.1
Thu, Apr 28	10:00	0	19	18	19	18	17	18	21.4	-4.4	-3.4
Thu, Apr 28	11:00	0	20	19.1	20	19.1	20	19	25	-5	-6
Thu, Apr 28	12:00	0	23	20.3	21	20.3	21	20.2	26.2	-5.2	-6
Thu, Apr 28	13:00	0	26	21.9	23	21.9	25	21.9	28	-3	-6.1
Thu, Apr 28	14:00	38	29	23.4	27	23.6	27	22.9	28.3	-1.3	-5.4
Thu, Apr 28	15:00	112	30	24.3	29	25.1	27	23.3	28.8	-1.8	-5.5
Thu, Apr 28	16:00	178	29	26.4	30	28.2	27	23.6	29.2	-2.2	-5.6
Thu, Apr 28	17:00	184	30	27.9	32	29.4	27	25.5	27.8	-0.8	-2.3
Thu, Apr 28	18:00	184	30	27.9	32	30	26	24.8	27.7	-1.7	-2.9
Thu, Apr 28	19:00	184	30	27.8	32	29.9	24	24.7	26.4	-2.4	-1.7
Thu, Apr 28	20:00	184	30	27.4	31	29.6	24	24.3	25	-1	-0.7
Thu, Apr 28	21:00	184	30	27.2	31	29.3	23	24	24.2	-1.2	-0.2
Thu, Apr 28	22:00	184	29	27	31	29	22	23.8	23.6	-1.6	0.2
Thu, Apr 28	23:00	184	29	26.8	30	28.9	22	23.6	22.7	-0.7	0.9
Fri, Apr 29	00:00	184	29	26.7	30	28.8	22	23.6	22.4	-0.4	1.2
Fri, Apr 29	01:00	184	29	27.6	30	29.6	22	24.4	21.9	0.1	2.5
Fri, Apr 29	02:00	184	30	27.4	31	29.5	21	24.3	21.7	-0.7	2.6
Fri, Apr 29	03:00	184	30	27.2	31	29.3	21	24.1	21.5	-0.5	2.6
Fri, Apr 29	04:00	184	30	27	31	29.1	20	23.9	20.9	-0.9	3
Fri, Apr 29	05:00	184	29	26.9	30	29	20	23.8	20.5	-0.5	3.3
Fri, Apr 29	06:00	184	27	26.7	29	28.7	21	23.5	19.3	1.7	4.2
Fri, Apr 29	07:00	183	27	26.6	29	28.5	21	23.4	18.9	2.1	4.5
Fri, Apr 29	08:00	184	27	26.6	29	28.6	23.5	21	19.1	4.4	1.9
Fri, Apr 29	09:00	184	28	26.6	29	28.6	21	23.5	18.6	2.4	4.9
Fri, Apr 29	10:00	184	28	26.8	30	28.9	22	23.7	19.3	2.7	4.4
Fri, Apr 29	11:00	184	28	26.8	30	28.9	22	23.7	19.3	2.7	4.4
Fri, Apr 29	12:00	184	32	30.4	33	32.5	27	27.3	23.8	3.2	3.5
Fri, Apr 29	13:00	184	35	32	35	34	30	28.8	25.2	4.8	3.6
Fri, Apr 29	14:00	184	36	32.9	37	34.9	31	29.7	26.6	4.4	3.1
Fri, Apr 29	15:00	184	37	32.9	37	34.9	31	29.7	27.5	3.5	2.2
Fri, Apr 29	16:00	184	35	32	36	34.1	30	28.9	26.8	3.2	2.1
Fri, Apr 29	17:00	184	34	31.3	35	33.4	29	28.1	27	2	1.1
Fri, Apr 29	18:00	184	33	30.5	34	32.5	26	27.3	25.5	0.5	1.8
Fri, Apr 29	19:00	184	32	30	33	32	25	26.8	24.7	0.3	2.1
Fri, Apr 29	20:00	184	32	29.2	33	31.2	24	26	23.8	0.2	2.2
Fri, Apr 29	21:00	184	30	28.6	32	30.6	24	25.4	22.5	1.5	2.9
Fri, Apr 29	22:00	184	30	28	31	30.1	23	24.9	21.9	1.1	3
Fri, Apr 29	23:00	184	30	27.8	31	29.7	22	24.6	21.4	0.6	3.2
Sat, Apr 30	00:00	184	30	27.4	30	29.4	21	24.3	21.3	-0.3	3
Sat, Apr 30	01:00	184	28	26.2	30	28.2	20	23	20.1	-0.1	2.9
Sat, Apr 30	02:00	184	28	25.7	29	27.8	20	22.4	19.1	0.9	3.3
Sat, Apr 30	03:00	184	27	25.5	28	27.5	19	22.2	18.7	0.3	3.5
Sat, Apr 30	04:00	184	27	25.2	28	27.6	18	22	18.1	-0.1	3.9
Sat, Apr 30	05:00	184	25	25	28	27.1	18	21.8	17.5	0.5	4.3
Sat, Apr 30	06:00	184	25	24.8	27	26.8	19	21.7	17.2	1.8	4.5
Sat, Apr 30	07:00	184	25	24.8	27	26.8	19	21.6	16.9	2.1	4.7

Appendix F - Example Fluid Sample Plan - Transformer

Liquid Sampling Schedule

Status	Planned Sample	Day from Commissioned	Date Taken	Date To Send In For Testing	Type of Testing to Be Performed	Results Report
Results Received	Beginning of Energization (voltage soak 24-hours)	0	Wednesday, April 27, 2022	Saturday, April 30, 2022	Light Testing Package	267534
Results Received	End of Energization (voltage soak)	1	Thursday, April 28, 2022	Saturday, April 30, 2022	Light Testing Package	267534
Results Received	End of Initial Loading	3	Saturday, April 30, 2022	Saturday, April 30, 2022	Light Testing Package	268325
Shipped	24-Hours After Normal Loading	4	Sunday, May 1, 2022	Tuesday, May 3, 2022	Light Testing Package	268325
Shipped	72-hours After Normal Loading	6	Tuesday, May 3, 2022	Tuesday, May 3, 2022	Light Testing Package	268325
Sample Taken	First Week of First Month	13	Tuesday, May 10, 2022	Tuesday, May 10, 2022	Full Testing Package (Baseline)	268120
Not Yet	Second Week of First Month	20	Tuesday, May 17, 2022	Tuesday, May 17, 2022	Light Testing Package	268498
Not Yet	Third Week of First Month	27	Tuesday, May 24, 2022	Tuesday, May 24, 2022	Light Testing Package	268639
Not Yet	Fourth Week of First Month	34	Tuesday, May 31, 2022	Tuesday, May 31, 2022	Light Testing Package	268838
Not Yet	4-Months After 1st Month	153	Tuesday, September 27, 2022	Tuesday, September 27, 2022	Light Testing Package	274375
Not Yet	8-Months After 1st Month	272	Tuesday, January 24, 2023	Tuesday, January 24, 2023	Light Testing Package	
Not Yet	12-Months After 1st Month	398	Tuesday, May 30, 2023	Tuesday, May 30, 2023	Full Testing Package (Year Results)	

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