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*Managing Water in the West*

Facilities Instructions, Standards, and Techniques
Volume 3-8

# Operation and Maintenance of Protective Relays and Associated Circuits

Previously Titled:
Field Testing Procedures for Protective Relays

U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

September 2006

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The Bureau of Reclamation (Reclamation) operates and maintains 58 hydroelectric powerplants and many switchyards, pumping plants, and associated facilities which are important to electric power and water delivery systems. These facilities house complex electrical and mechanical equipment, and protective relays and associated circuits play an essential role in protecting this equipment as well as the electric power system. This document defines Reclamation practices for operating, maintaining, and testing of protective relays and protection circuits. Western Electricity Coordinating Council, North American Electric Reliability Council, National Fire Protection Association, and Facilities, Instructions, Standards, and Techniques Volume 4-1B standards are the basis of these practices. Included in this document are standards, practices, procedures, and advice on day-to-day operation, maintenance, and testing of existing relaying systems which also includes periodically verifying relay settings furnished by others.

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**Facilities, Instructions, Standards, and Techniques**
**Volume 3-8**

# Operation and Maintenance of Protective Relays and Associated Circuits

**Hydroelectric Research and Technical Services Group**

**U.S. Department of the Interior**
**Bureau of Reclamation**
**Denver, Colorado**

**September 2006**

## Disclaimer

## Acronyms and Abbreviations

| | |
|---|---|
| **A** | ampere |
| **ac** | alternating current |
| **ANSI** | American National Standards Institute |
| **CCVT** | coupling capacitor voltage transformers |
| **CT** | current transformer |
| **EC&M** | Electrical Construction and Maintenance |
| **DB** | double-break |
| **dc** | direct current |
| **DGA** | dissolved gas analysis |
| **DIP** | dual in-line package |
| **FIST** | Facilities Instructions, Standards, and Techniques |
| **HMI** | Human-Machine Interface |
| **Hz** | Hertz |
| **IEC** | International Electrotechnical Commission |
| **IEEE™** | Institute of Electrical and Electronics Engineers |
| **JHA** | Job Hazard Analysis |
| **kV** | kilovolt |
| **kVA** | kilovoltampere |
| **MTA** | maximum torque angle |
| **NERC** | North American Electric Reliability Council |
| **NFPA** | National Fire Protection Association |
| **O&M** | operation and maintenance |
| **PO&M** | Power Operation and Maintenance |
| **ppm** | parts per million |
| **PT** | potential transformer |
| **Reclamation** | Bureau of Reclamation |
| **rms** | root mean square |
| **RTDs** | resistance temperature devices |
| **RTS** | Relay Testing Software |
| **SEL** | Schweitzer Engineering Laboratories |
| **Std.** | Standard |
| **V** | volt |
| **VA** | voltampere |
| **Vdc** | volts direct current |
| **WECC** | Western Electricity Coordinating Council |
| **°** | degree |
| **%** | percent |

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# 1. Introduction

The Bureau of Reclamation operates and maintains 58 hydroelectric powerplants and many switchyards, pumping plants, and associated facilities in the 17 Western States. These facilities are important to the electric power and water delivery systems relied on by many. These facilities house complex electrical and mechanical equipment which must be kept operational. Protective relays and associated circuits play an essential role in protecting this equipment as well as the electric power system.

Reclamation has been very proactive in the design, application, testing, and maintenance of protective relaying systems. Electromechanical relay installations, in some cases, have been replaced by solid-state relays as that technology matured. Now, microprocessor-based digital relays are becoming the norm for new installations and many replacements, because of their improved protective capabilities, reliability, and additional features. Keeping abreast of this new technology is a must to keep Reclamation's plants and the power system viable.

## 1.1 Purpose and Scope

The purpose of this document is to define Reclamation practices for operation, maintenance, and testing of protective relays and protection circuits. Western Electricity Coordinating Council (WECC), North American Electric Reliability Council (NERC), National Fire Protection Association (NFPA), and Facilities, Instructions, Standards, and Techniques (FIST) Volume 4-1B standards are the basis of these practices. Reclamation facilities following this FIST document on relay and relay systems testing and maintenance will be in compliance with NERC, WECC, NFPA, and FIST Volume 4-1B standards.

Included in this document are standards, practices, procedures, and advice on day-to-day operation, maintenance, and testing of existing relaying systems. This includes periodically verifying relay settings furnished by others.

This volume does not cover selection, design, or installation of new protective relaying systems or calculations of relay settings. For that information, see the *Protective Relay and Protection Circuit Design Considerations* document developed by the Electric Systems Group, 86-68440, at 303-445-2850.

This volume does not cover verifying circuits or testing devices involved with metering, such as watt-hour meters. For this, refer to the specific manufacturer's information.

## 1.2 Definitions

Appendix A is a glossary of relay terms used in protective relaying and protection circuits.

Appendix B is a glossary of electrical device numbers definitions and functions used in protective relaying and protection circuits.

## 1.3 References


American National Standards Institute (ANSI)/Institute of Electrical and Electronics Engineers (IEEE®) Standard (Std.) C57.13.3 – 1983, Guide for the Grounding of Instrument Transformer Secondary Circuits and Cases.

ANSI/IEEE C57.13.1-1981, IEEE Guide for Field Testing of Relaying Current Transformers.

Applied Protective Relaying, Westinghouse Electric Corporation, 1976.

*Commissioning Numerical Relays*, Mike Young and John Horak, Basler Electric Company.

*Electrical Power Equipment Maintenance and Testing*, Section 7.5.3, Paul Gill, 1998.

FIST Volume 4-1B, *Maintenance Scheduling for Electrical Equipment*, Bureau of Reclamation.

FIST Volume 3-23, *Instrument Transformer Secondary Grounding*, Bureau of Reclamation (included in this volume as appendix F).

General Electric, *The Art and Science of Protective Relaying*, C. Russell Mason.

*Handbook of Electric Power Calculations*, H. Wayne Beaty, Third Edition, Section 15.2, 2001.

IEEE Std. C37.2, Standard Electrical Power System Device Function Numbers and Contact Designations.

IEEE Std. 242, Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems, 2001.

IEEE Std. C57.13-1993, IEEE Standard Requirements for Instrument Transformers.

IEEE Tutorial Course, Microprocessor Relays and Protection Systems, Document Number: 88EH0269 1-PWR, June 1986.

GE Power Management Technical Publication, *Relay Testing and Maintenance*, Document Number: GET-3473B.

NFPA 70B, Recommended Practice for Electrical Equipment Maintenance, National Fire Protection Association, 2002.

North American Electric Reliability Council Reliability Standards PRC-001-0, PRC-004-1, PRC-005-1, PRC-016-0, PRC-017-0.

Northeast Power Coordinating Council, Maintenance Criteria for Bulk Power System Protection, Document Number: A-04.

Northeast Power Coordinating Council, Bulk Power System Protection Criteria, Document Number: A-05.

Northeast Power Coordinating Council, Guide for Maintenance of Microprocessor Based Protection Relays, Document Number: B-23.

Power Equipment Bulletin No. 6, *Lockout Relay Advisory,* Bureau of Reclamation (included in this volume as appendix H).

*Protective Relaying: Principles and Applications*, J. Lewis Blackburn, Second Edition, Sections 5.2 and 5.6.3, 1998.

Sacramento Municipal Utility District, Section 10, Transmission Substation Equipment Maintenance Details, May 1, 2004.

Schweitzer Engineering Laboratories (SEL), Philosophies for Testing Protective Relays, May 1994.

*Solid-State Protective Relay Maintenance*, Electrical Construction and Maintenance (EC&M), April 1, 2005.

*Western Electricity Coordinating Council Operating Committee Handbook*. See Web page http://www.WECC.B12/documents/LIBRARY/PUBLICATIONS/OC/OC_HANDBOOK_complete.pdf.

*What to Know About Protective Relays*, EC&M, February 1, 1995.

## 2. Reclamation Relay Regulatory Requirements

Reclamation protective relays and associated circuits must be properly maintained and tested to ensure proper protection of powerplants and switchyard equipment and systems. Protective relaying must function properly to protect the electric power system (western grid) as well.

Reclamation, as a significant generator of electricity in the Western United States, must meet the requirements established by WECC and NERC. These reliability organizations define minimum requirements for protection and control systems that affect power system stability and reliability. Reclamation fully endorses and cooperates with these entities and their requirements.

*Operating Committee Handbook* III.b.Part III – Minumum Operating Reliability Criteria states:

> "Each system shall provide for periodic testing of protective relay systems and remedial action schemes which impact the reliability and security of the interconnected system operation."

NERC Reliability Standards on system protection and control state:

> "To ensure all transmission and generation protection systems affecting the reliability of the bulk electric system (BES) are maintained and tested."

NERC standards require development and implementation of a protection system maintenance and testing program at Reclamation facilities.

NERC Reliability Standard PRC-004-1 requires that generator owners analyze protection system misoperations and develop and implement a corrective action plan to avoid future misoperations of a simlar nature.

To comply with this requirement, Reclamation personnel must analyze relay actions and determine if the protection system acted as designed. If the protection system did not act as designed, the misoperation must be analyzed and timely mitigation actions taken to prevent future misoperations. Any mitigation actions taken must be documented.

As provided in the Energy Policy Act of 2005, the Federal Energy Regulatory Commission has appointed NERC as the Electric Reliability Organization giving NERC the authority to develop and enforce ***mandatory*** reliability standards, including the assessment of sanctions for non-compliance.

Maintenance and testing requirements in this volume are reflected in the appropriate sections of FIST Volume 4-1B, *Maintenance Scheduling for Electrical Equipment*.

## 3. Relay Maintenance Summary Table

The operation, maintenance, and testing requirements defined in this document are summarized in the table below.

**Maintenance Schedule for Relays and Protection Circuits**

| Maintenance or Test | Required Interval | Reference |
|---|---|---|
| Fault/load study and recalculate settings | 5 years | Reclamation recommended practice |
| Electromechanical relays calibration and functional testing | Upon commissioning<br>1 year after commissioning, and every 2 years thereafter<br>After setting changes | NFPA 70B, 8.9.7 and 20.10.3<br>Annex Table I.1<br>Manufacturer's instructions<br>FIST Volume 4-1B<br>NERC PRC-005-1 |
| Solid-state relays calibration and functional testing | Upon commissioning<br>1 year after commissioning<br>Every 3 years thereafter<br>After setting changes | NFPA 70B, § 8.9.7 and 20.10.3<br>Annex Table I.1<br>Manufacturer's instructions<br>FIST Volume 4-1B<br>NERC PRC-005-1 |

**Maintenance Schedule for Relays and Protection Circuits (continued)**

| Maintenance or Test | Required Interval | Reference |
|---|---|---|
| Microprocessor (digital) relays and functional testing | Upon commissioning<br>1 year after commissioning<br>8 - 10 years thereafter<br>After setting changes | FIST Volume 4-1B<br>Manufacturer's instructions<br>NERC PRC-005-1 |
| Instrument transformer preventive maintenance and testing | As required by the references | FIST Volume 4-1B<br>Manufacturer's instructions |
| Instrument transformer burden measurements | 5 years and before adding or replacing any device in the secondary | Reclamation recommended practice |
| Instrument transformer secondary integrity testing | 5 years or after modifications | Reclamation recommended practice |
| Instrument transformer secondary grounding | After equipment or wiring modifications | FIST Volume 3-23<br>Appendix F |
| Protection circuit functional test, including lockout relays | Immediately upon installation and/or upon any changes in wiring and every 3-6 years | NFPA 70B<br>Annex Table H.4(c)<br>Manufacturer's instructions<br>Power Equipment Bulletin No. 6, Appendix H<br>NERC PRC-005-1 |
| Check red light lit for lockout relay and circuit breaker coil continuity<br>Note, Schweitzer relays can continuously monitor lockout and breaker trip coil continuity | Daily[1] (once per shift in manned plants) | Reclamation recommended practice |
| Lockout relays cleaning and lubrication. Note: Electroswitch lockouts may not need to be oiled or cleaned | 5 years | Power Equipment Bulletin No. 6, Appendix H<br>Manufacturer's instructions. |
| Drawings associated with relaying and protection current and accurate | Continuously update upon any changes in wiring or control | FIST Volume 4-1B, section 15<br>FIST Volume 6-1, section 16.1.C<br>Reclamation recommended practice |

[1] In staffed plants, in conjunction with daily operator control board checks. Otherwise, check each visit to the plant.

# 4. Protective Relays

## 4.1 Relay Settings

Protective relays monitor critical electrical and mechanical quantities and initiate emergency shutdown when they detect out-of-limit conditions. Protective relays must detect abnormal conditions, shut down appropriate equipment, and must not incorrectly operate and unnecessarily shut down equipment at any other time.

Electrical protective relays are calibrated with settings derived from system fault and load studies. Initial settings are provided when relays are installed or replaced. However, electrical power systems change as generation equipment and transmission lines are added or modified. This may mean that relay settings are no longer appropriate. Outdated relay settings can be hazardous to personnel, to the integrity of the powerplant and power system, and to equipment. Fault and load studies and relay settings are provided by the Electrical Design Group, 86-68440, at 303-445-2850. Protective relaying is crucial to protect plant equipment and the electric power system. Therefore:

**Relays and relay settings must not be changed from those furnished unless approved by the Electrical Design Group or by a qualified engineer. New settings must be recorded.**

## 4.2 Test Records and Power Operation and Maintenance (PO&M) Forms

Records must be maintained on calibration and testing and any mitigation action taken to correct misoperations of protective systems. This is essential for ongoing maintenance, and for the Review of Power Operation and Maintenance (O&M) process, to meet WECC and NERC verification requirements. It is recommended to schedule and record this testing in MAXIMO. However, details of tests may be recorded on PO&M forms or in databases associated with computerized testing software. PO&M forms that apply to electromechanical relays can be found at the Reclamation forms Web site: http://intra.usbr.gov/forms/pomforms.html

When settings have been verified, it is recommended that "last tested" stickers be applied to the front of the relay. These stickers should include the date of last tests, and initials of the person verifying the settings and calibration.

## 4.3 Relay Information System Database

The Reclamation Relay Information System database is presently being developed; however, it is currently available for use. Use of this system is highly recommended and will greatly assist facilities in managing all aspects of protective relaying. For more information on the Reclamation Relay Information

System, please contact relay_help@do.usbr.gov or the Electrical Systems Group, 86-68440, at 303-445-2850.

The Reclamation Relay Information System database is the final destination for all relay information. This includes:

- Relay Information –Type, part number, style, and instruction manual.
- Relay Settings – Complete listing of settings and templates to re-enter settings for replacement relays or for re-entry when settings are lost.
    - Past – Settings are maintained to record a history of changes with comments to explain reasons for changes.
    - Present – The most current settings.
- Test Results – Test data can be stored with supporting information such as scanned curves or downloads from a test set.
- Current Transformer (CT) and Potential Transformer (PT) Information – CT and PT ratings and locations are linked to each relay that uses the output of that specific instrument transformer.
- Generator Ratings – Complete listing of generator ratings.
- Transformer Ratings – Complete listing of transformer ratings.
- Breaker Ratings – Complete listing of breaker ratings, including breaker manufacturer, serial number, type, voltage, current, interrupting rating, and instruction manual.
- Drawings – Drawings and drawing links, up to date and available for information to aid in design and diagnosis of relay issues.
- Additional information is available on power equipment which is accessible but not alterable by the user. This data should be verified before use by contacting relay_help@do.usbr.gov.

Data in the Reclamation Relay Information System is jointly maintained and updated by facilities and/or field offices and the Electrical Systems Group, 86-68440, at 303-445-2850, and must be verified on a 5-year cycle with fault and load flow studies.

## 4.4 Qualifications, Peer Review, and Training

Staff who perform maintenance and testing on protective relays and associated circuits must be fully qualified. Qualifications vary and periodically change based on types and ages of relays at each facility. Because of the extreme importance of protective relays to powerplants and the western grid, a process of peer review and training must be established. Procedures used by relay calibration and testing personnel should receive a periodic peer review by a qualified individual. With small facilities, this may mean someone from another facility, or Relay Users Group may be the peer reviewer.

Staff must be properly trained, knowledgeable, and experienced in relay and protection system maintenance as well as testing techniques for specific protection equipment located at their facility. Training on automated relay testing software can enable staff to test any general type of relay. However, they must also be trained on specific relays and exact protection schemes at their facility. An indepth knowledge and understanding of the total protection system is critical to powerplant reliability and availability. The most effective training comes from a combination of classroom, personal study, on-the-job relay, and total protection system testing. Reclamation's Relay Users Group is available to provide assistance in all these training areas. More information can be found at: http://intra.usbr.gov/~hydrores/relaytest/index.htm or by phone at 303-445-2305.

### 4.5 Relay Users Group

Reclamation relaying specialists have formed a Relay Users Group to share knowledge, software, tools, equipment, experience, and provide assistance in relay testing and training. Anyone responsible for relay maintenance and testing is welcome and encouraged to join this group which is coordinated by 86-68450, at 303-445-2305.

The group coordinates Reclamation licensing of testing software to minimize costs to individual offices and sponsors annual and individual training in relay testing. It also assists individuals responsible for relay maintenance and testing to share software, test equipment, test routines, and relay specific information. For example, developing a test program for a complicated microprocessor-based relay could take several months. If the same relay is used in other Reclamation facilities, test programs can be shared among facilities. This alleviates the need for each facility to re-develop testing procedures and reduces time and costs. For more information, visit the Relay Users Group Web site located at: http://intra.usbr.gov/~hydrores/relaytest/index.htm or contact the Electric Power and Diagnostics Team at 303-445-2305.

## 5. Instrument Transformers

Instrument transformers comprise current transformers, potential transformers, and coupling capacitor voltage transformers (CCVTs) which reduce current and voltage to levels useable by protective relays and other control devices. Instrument transformers must be properly sized and have the proper accuracy class for their specific applications. Instrument transformers must be maintained and tested according to section 31.4 of FIST Volume 4-1B, manufacturer's recommendations, and the provisions of this FIST volume. In the case of oil-filled instrument transformers, they must also be Doble tested according to FIST Volume 4-1B. For additional information on CT and PT accuracy classes, specifications, and testing, refer to appendices C, D, E, and F.

## 5.1 Polarity, Phasing, and Connections

For purposes of this document, it is assumed that instrument transformer polarities and both primary and secondary phasing were verified during design and installation. Whenever instrument transformers or their secondary circuits are modified, it is important to re-verify correct polarity and proper phasing.

Correct primary and secondary instrument transformer connections (e.g., wye-delta, delta-wye, wye-wye, etc.) are critical for proper relay operation. Phase angle relationships between voltages and currents are affected by these connections. For purposes of this document, it is assumed that instrument transformer connections were verified during design and installation. However, whenever instrument transformers or their secondary circuits are modified, it is imperative to re-verify correct connections. For assistance with polarity, phasing, and connections, contact the Electrical Systems Group, 86-68440, at 303-445-2850, or Relay Users Group at 303-445-2305, or relay_help@do.usbr.gov.

## 5.2 Burden Calculations and Measurements

Instrument transformers used for protective relaying often supply other loads as well, such as meters, alarms, indicating lights, transducers, or input modules of other systems. Each device supplied by instrument transformers is an electrical burden, and the transformer is capable of supplying only a limited total burden. PTs typically operate at constant voltage (typically 110 volts). As devices are added in parallel to the secondary circuit, the burden (current requirement) increases; and, at some point, it will exceed capacity of the PT.

CTs normally operate at constant current (typically 5 amps). As devices are added in series, the voltage requirement increases. At some point, the voltage capability of the CT will be exceeded.

If the capacity of either a PT or CT is exceeded, the transformer cannot accurately measure current or voltage, thus giving protective relays false information. The relay will misoperate or not operate at all, endangering the facility and workers. Therefore, instrument transformers must have their burdens checked and/or measured.

Reclamation instrument transformers used for protective relaying must have burdens checked at least every 5 years. For convenience, this can be done at the same time as the 5-year fault and load study and the relay setting verification. Also, burdens should be checked before adding or replacing any device in the secondary.

Techniques for calculating and measuring instrument transformer secondary burdens are shown in appendix D. Field testing for CTs is described in appendix D and appendix E for PTs.

## 5.3 Current Transformer Types and Construction

### 5.3.1 Bushing, Window, or Bar-Type CTs with Uniformly Distributed Windings

Current transformers of this type have no "primary winding" as such. The primary is the conductor on which the current is to be measured; it passes once through the center of a toroid core. A toroid is a donut of magnetic material used as a low reluctance path to concentrate magnetic flux (see figure 1). Since the secondary winding is wrapped uniformly distributed around the core, and only a single primary turn is used, essentially all flux which links the primary conductor also links the secondary winding as shown in figure 1. Note: even though the primary conductor passes straight through the toroid and is not actually wrapped around the core, it is still called a "turn."

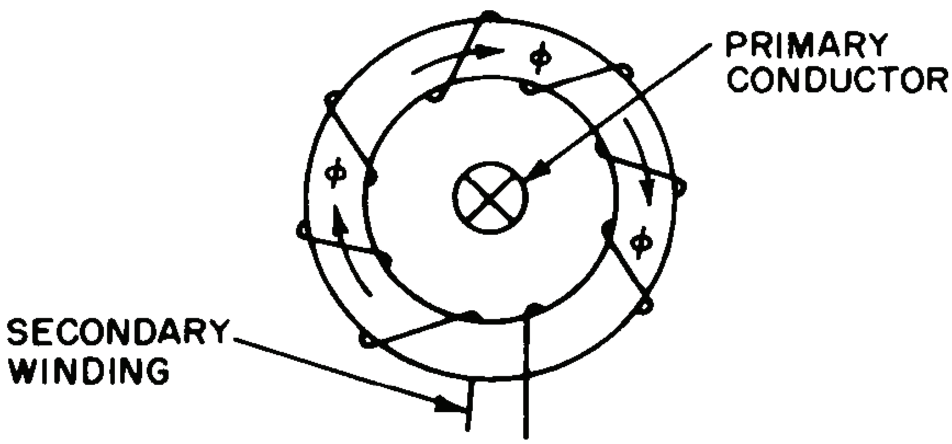



**Figure 1. Uniformly distributed secondary winding.**

Because there is essentially no leakage flux, there is negligible leakage reactance. Therefore, excitation characteristics can be used directly to determine performance. Current transformers of this type have a "C" accuracy classification per ANSI/IEEE C57.13-1978, indicating that the CT ratio can be calculated if the burden, secondary winding resistance, and the excitation characteristics are known. ANSI/IEEE C57.13-1978 states that "if transformers have a "C" classification on the full winding, all tapped sections shall be so arranged that the ratio can be calculated from excitation characteristics." For information on accuracy classes, see appendix C.

### 5.3.2 Wound Primary Current Transformers (Without Uniformly Distributed Windings)

Wound-type current transformers are usually constructed with more than one primary turn and unevenly distributed windings. Because of the physical space required for insulation, bracing of the primary winding, and fringing effects of non-uniformly distributed windings, leakage flux is present which does not link both primary and secondary windings. Figure 2 clearly illustrates the leakage flux but does not correctly represent how they are constructed.

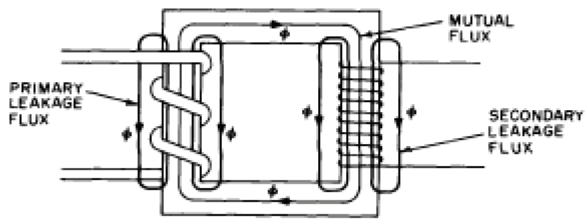



**Figure 2. Leakage flux.**

The presence of leakage flux has a significant effect on current transformer performance. When this flux is appreciable, it is not possible to calculate the CT ratio knowing the burden and the excitation characteristics. CTs of this type have a “T” accuracy classification according to ANSI/IEEE C57.13-1978, indicating that primary to secondary CT ratios must be determined by test. See appendices C and D.

## 6. Checking Grounds, CT and PT Circuits

For purposes of this document, it is assumed that the instrument transformer secondary circuit grounding was verified during design and installation. However, over time due to wiring modifications, insulation deterioration, relay, or instrument transformer replacement, secondary circuit grounds may have been compromised. In addition, grounding practices may have changed since existing systems were installed. Therefore, secondary grounding must be verified after equipment or wiring modifications and at least every 5 years, as stated below.

**The CT and PT circuits must be grounded at only one point.** Relay misoperations or failure to operate can be caused by grounding the neutral at two points, such as one ground at the PT or CT and another at the relay panel. The typical point of grounding for instrument transformers is at the first control board where the signal is used. Spurious grounds may develop, or intentional grounds may be lost as insulation ages and wiring errors occur; therefore, grounds must be checked as described below. See also appendix F which is excerpted from old FIST Volume 3-23 and is based on ANSI/IEEE Standard C57.13.3. This standard should be referenced for further information or contact the Relay Users Group at 303-445-2305.

At least once every 5 years with the primary de-energized, the intentional ground must be removed and the overall circuits checked for additional grounds and insulation breakdowns. Any additional grounds must be located and cleared prior to placing the circuit back into service.

### 6.1 Insulation Resistance Testing

Insulation resistance between the secondary circuit of the CT or PT and ground is checked using a standard Megger®. Before performing the test, the CT or PT should be isolated from the burden. Typical values should be 1megohm or above. Readings lower than one-half megohm should be carefully investigated, insulation integrity is questionable.

## 7. Current Transformer Open Secondary Circuits

Extreme caution must be exercised when performing modifications, maintenance, and testing in current transformer secondary circuits.

**Current transformer secondary circuits must never be open circuited when the primary is energized.**

Current transformers act as constant-current sources to whatever load is applied on the secondary. This means that the voltage changes to provide the same current, no matter what the impedance in the secondary. When the secondary is open circuited, the impedance—and thus the voltage—becomes extremely large. This high voltage will destroy the insulation, causing a fault that can destroy the CT, damage other equipment, and be hazardous to personnel. Extreme care must be taken to ensure that a reasonable secondary burden is always present **OR** that the CT secondaries have been shorted to prevent high voltages. Test switches with automatic CT shorting circuits are highly recommended to reduce the risk of opening the secondary. Also, CT shorting bars are normally placed on the secondaries by the manufacturer and should be used when CT shorting switches are not available.

## 8. Total Plant Protection System Functional Testing

For purposes of this document, protection circuits include all low-voltage devices and wiring connected to instrument transformer secondaries, all protective relays, lockout relays, and trip coils of circuit breakers. Protection circuits also include all indicators, meters, annunciators, and input devices such as governors, exciters, and gate closure control circuits. Although testing of individual components may take place on a regular basis (e.g., relay calibration and lockout relay testing), it is essential to test the entire protection circuit including wiring and all connections from "beginning to end" to ensure integrity of the total circuit. See the block diagram, figure 3, below.

If at all possible and the primary is de-energized, use primary injection techniques (see appendix G) which trigger protective relays and lockout relay, trip circuit breakers, and initiate annunciations and indications. This technique also tests the CT or PT ratios. PT and CT ratios and polarity should be verified in separate tests. If primary injection is not possible, use secondary injection techniques (see appendix G). These techniques locate and correct wiring errors, insulation failures, loose connections, and other problems that go undetected if only relays are tested. This is the only real assurance that emergency protective actions will take place as required.

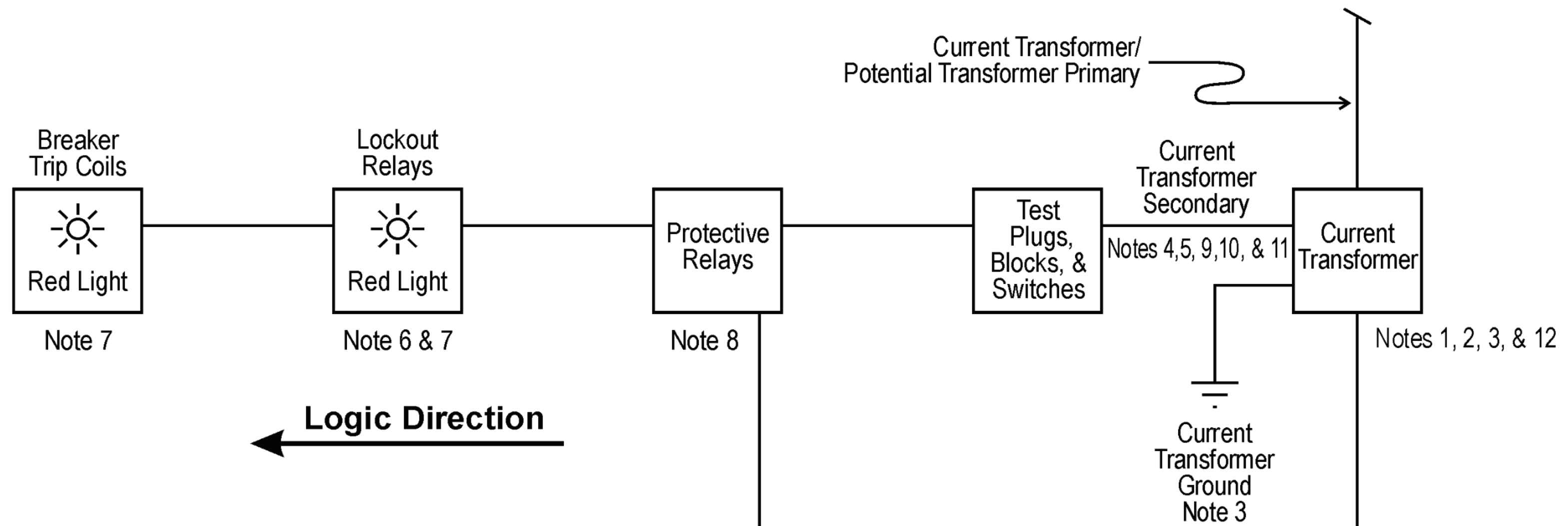
### 8.1 Protection System Failure Modes

It is imperative that instrument transformer secondary circuit integrity be tested on a regular basis. PTs and CTs provide information to protective relays and are subject to several possible failures:

- Failed instrument transformer (shorted or open turns)
- Blown fuse in the secondary (PTs only)
- Open secondary circuit wiring
- Short circuited CT secondaries (e.g., shorted at the shorting blocks at the generator, transformer, exciter, etc., or accidentally shorted in the wiring)
- Incorrect polarities or phasing
- Incorrect wiring
- Insulation failure
- Spurious grounds or loose grounds, multiple grounds
- Loose connections
- Excessive burdens

## 9. Lockout Relays and Lockout Circuit Functional Testing

Lockout relays are among the most important devices in a facility and should be carefully maintained according to Power Equipment Bulletin No. 6, *Lockout Relay Advisory* and manufacturer instructions. This document is included in appendix H.




Note: 1 Check shorting bars correct position (section 7)
2 Check current transformer's polarities & ratios (appendix D)
3 Check current transformer's & potential transformer's grounding (section 6 & appendix F)
4 Check secondary circuit - never opened while primary energized (section 7)
5 Check current transformer's secondary circuits (section 8)
6 Lockout relays functional testing (section 9)
7 Lockout relay & breaker trip coils red light check (section 9.1)
8 Relay testing (sections 12, 13, 14, & 15)
9 Test current transformer & potential transformer secondary circuit continuity (section 7)
10 Check insulation resistance with megger (section 6.1 & appendix D)
11 Test all auxiliary devices, indicators, relays, annunciators, etc. (section 8)
12 Test current transformer & potential transformer (appendices C, D, & E)

**Figure 3. Total plant protection system functional testing block diagram.**

If desired, test switches can be installed that permit isolation of inputs and outputs so that the lockout relay can be tested without affecting other devices. Extreme care must always be taken to ensure that test switches are in the proper position for testing (or inadvertent trips will occur) and returned to the normal position when protection is reinstated. Otherwise, protection will be defeated.

Complete lockout circuit functional testing must take place immediately upon installation and/or upon any change in wiring, upon any misoperation, and every 5 years. Some facilities perform all or part of this functional testing during unit maintenance outages. Functional testing must be conducted to prove that protective relay action will actually trip the lockout relays and that the lockouts will trip circuit breakers or other protective devices (e.g., governor, exciter, etc.). Steps that must be included:

- Conduct a Job Hazard Analysis (JHA) and verify that testing will not disrupt normal operation or endanger staff or equipment.
- With lockout relays in the "reset" position, initiate a lockout relay trip with the protective relay contact.[1]
- Visually and electrically, verify the lockout relay actually tripped from the protective relay action. Verify that circuit breakers actually tripped (or other protective action occurred) from the lockout relay action. Verify that every contact in the lockout relay has actually functioned properly. This may be done visually by removing the cover or with an ohmmeter from the relay terminal board.
- Activate the lockout relay from each protective device. After the first full test of the lockout relay and breakers, the trip bus may be lifted from the lockout relay so as not to repeatedly trigger the lockout coil—a meter, light, or buzzer may be substituted to verify contact operation. Reconnect the trip bus prior to the last test to verify correct operation of the final configuration.
- Visually check that all alarms, meters, lights, and other indicators have activated.
- Return all devices and wiring back to their normal "ready" positions.

**CAUTION: Do not forget to reconnect the trip bus to the lockout relay when testing is complete.**

[1] It is recommended that the protective device actually be operated where possible for best assurance. The ideal functional test is to actually change input quantities (e.g., instrument transformer primary or secondary injection) to the protective device to thoroughly test the entire protection path. However, it may be necessary to simulate contact operation with a "jumper" when device activation is not possible.

Where functional testing of EVERY protection circuit is impossible, testing of the most critical protection circuits and devices is mandatory. Design and wiring changes may be required to fully test the protection system; if so, these changes must be made.

## 9.1 Red Light Indications

Lockout relays and circuit breakers perform extremely critical functions, so much so that Reclamation standard designs for lockout relays and circuit breaker control circuits include the use of red (position/coil) status indicator lights. These lights monitor continuity through both the lockout relay coil and breaker trip coil. Figure 4 is an example of a monitoring circuit for a lockout relay. A breaker trip coil monitoring circuit is similar, so only the lockout relay circuit is shown. Both lockout relay and circuit breaker red lights must be visually checked at least once each shift to make sure they are "on" (lit), the lockout relay ready for an emergency trip, and the breaker trip coil ready to open the breaker. The drawing below shows the lockout relay in the "reset" position.

Schweitzer relays can be configured to continuously monitor lockout relay and breaker trip coil continuity. It is recommended to use this whenever possible.

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**NOTE: An example of a lockout relay indicating light circuit is shown below. A breaker trip coil indicating light circuit is very similar and is not shown.**

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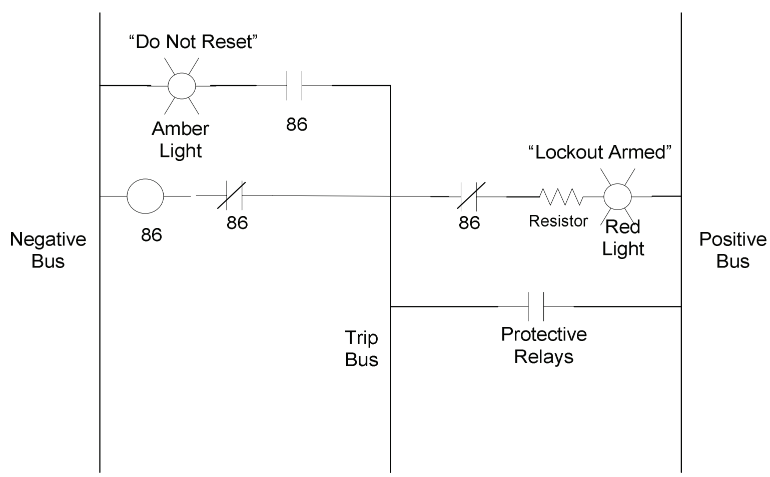


With lockout (86) reset: Red light indicates 86 coil intact. Resistor limits current to lockout coil. Amber lamp is out.

Protective relay trips 86:
Red light goes out. Amber lamp indicates trip bus still energized.

**Figure 4. Lockout relay, red light circuit.**

The red lockout monitor light (i.e., "Lockout Armed" in the above drawing), should always be lit when the lockout relay is in the "Reset" position and the trip coil is intact. Likewise, in the breaker control circuit, the red breaker monitor light should always be lit when the breaker is in the closed position and the coil intact. Under normal operating conditions in both circuits, the red light must be lit showing that the lockout relay and breaker trip coils are "armed and ready." If the light is not lit, one of three things has occurred:

1. The trip coil has failed open or the wiring has open circuited.

   Trip coils are, by design, underrated so that they will trip quickly. This also means they are subject to burnout if not de-energized immediately after tripping (thus, a clearing contact is in series with the coil). If the coil has been subjected to extended energization in the past, the coil may be burned out. A burned-out coil means that the lockout relay or breaker will not trip when required. It is very important to check the lights every day in both the lockout relay and breaker circuits.

2. The bulb has burned out. It is recommended that all incandescent lamps be replaced with LEDs due to long life.

   If an incandescent lamp is still being used, a "push to test" light socket is needed so that the bulb can be tested any time it is "out."

3. The lockout relay or breaker has actually tripped and the "reset" position switch is open. The associated breaker/s should also have tripped. When a trip actually occurs, the amber "Do Not Reset" light, shown in the drawing above (figure 4) warns not to reset the lockout relay until the problem is resolved.

If the lockout relay has tripped and the associated breakers have not opened, the lockout-to-breaker circuit has malfunctioned, and this must be corrected immediately.

Monitoring these indicating lights is very important. Therefore, red lights for both the lockout relay and circuit breaker coil continuity should be visually checked every day in staffed plants and checked every time the plant is visited at unstaffed plants. Spare coils and bulbs must be kept on hand. Any time conditions in 1 or 2 above are encountered, they must be corrected immediately.

## 10. Drawings

Electrical drawings associated with protective relays and protection circuits must be up-to-date and accurate for troubleshooting purposes. Drawings must be updated immediately to reflect any changes. Affected drawings include:

| DRAWING | INFORMATION SHOWN |
|---|---|
| Single-line diagram | Protective relays used in the application |
| Three-line diagram | Schematic representation of instrument transformer connections to relays |
| Protection schematic | Protective relay - lockout relay scheme |
| Tripping block diagram | Simplified representation of tripping scheme |
| Wiring diagrams | Detailed connections of protection system devices |
| Logic diagrams (Microprocessor based relays) | Detailed connections internal to the protective relay; changes are made with the programming of the relay |

Protective relaying and protection system components must be represented on the drawings using consistent nomenclature to reduce confusion. Where possible, relaying and protection nomenclature should conform to typical drawing 104-D-1150, Device Designations and Symbols to Be Used on Single-Line and Schematic Diagrams, which conforms to IEEE Std. C37.2. See appendix B for device numbers and explanations.

## 11. Testing Equipment and Software

A high quality relay test set and tools are important to test protective relays in an accurate and repeatable manner. Troubleshooting of microprocessor-based relays may also require specialized equipment, a laptop computer, communication cables, and software. Check manufacturer's recommendations for necessary tools and equipment. If not available at the facility, most test equipment and tools can be borrowed from 86-68450, phone 303-445-2305.

Microprocessor relay testing can be automated. These relays can be tested with computer-based software that communicates with both the relay and test set. It is preferable to test relays using automated testing procedures to reduce the time required and increase reliability and repeatability of tests being performed. However, it is critical that the person responsible for relay testing be totally familiar with the relays, external protective circuits, and all test procedures. All automated testing procedures must be validated by a qualified person before using them to test relays. Due to the critical nature of protective relays and enormous prohibitive cost of a failure-to-trip or false trip, only a thoroughly trained, experienced person should perform and/or oversee these tests.

In conjunction with automated relay testing software, relay specific software may be used to check relay operation. Most relay manufacturers have proprietary software which is used as a Human-Machine Interface (HMI). Using the HMI allows the technician to view, download, and change relay settings; view relay inputs and outputs; and download sequence of events from the relay. Always remember that an HMI user can change settings using this software; it is imperative that no settings are changed inadvertently or without approval. While it may not be necessary to use an HMI while testing a relay, it can be a valuable tool to assist in trouble shooting relay operations.

Reclamation owns corporate licenses on many different types of relay software programs such as the SEL - 5010 Relay Assistant and SEL – 5601 Analytic Assistant from Schweitzer Engineering Laboratories, Inc. (SEL). Reclamation-licensed software is available on Reclamation Users Group Web site http://intra.usbr.gov/~hydrores/relaytest/index.htm. Reclamation users may download and use many software packages from this site at no cost.

Reclamation also owns a corporate license for Relay Testing Software (RTS) by Enoserv. RTS may be used to automate relay testing procedures for solid-state, electromechanical, and microprocessor-based relays. A software key (dongle) is required for this package and may be purchased from the manufacturer. Once a key is purchased, facilities may obtain support and upgrades from both the Relay Users Group and directly from Enoserv. This software package is used for automated relay testing and communicates with relays and relay test sets available from numerous manufacturers. For more information, contact the Relay Users Group at 303-445-2305 or by email at relay_help@do.usbr.gov.

## 11.1 Testing Precautions

To preclude inadvertent trips, before starting any relay test with protected equipment in service, testing personnel must be familiar with relays and associated circuits. When test blocks are used, ensure that removing or inserting plugs will not open a CT secondary. Opening a secondary with the primary energized will result in high voltage which can destroy the CT or other equipment, be dangerous to personnel, and/or cause an inadvertent trip. If test blocks are not available, before the relay CT circuit is opened, CTs must be shorted by the shorting blocks provided by the manufacturer or by shorting switches.

Before removing any relay from service, be very cautious; the unit may need to shut down for relay testing, or the unit may have redundant protection and can continue to operate during testing. In any case, do not allow the unit to operate without any relay protection while testing.

## 11.2 Records

Records of instrument transformer preventive maintenance and testing should be maintained in MAXIMO. The Reclamation Relay Information System database mentioned above is designed to store information regarding CTs and PTs as well as relay information. This database should be updated by each facility, installing the latest information regarding new equipment and testing data. For more information on the Reclamation Relay Information System database, contact relay_help@do.usbr.gov or the Electrical Systems Group, 86-68440, at 303-445-2850, or the Relay Users Group at 303-445-2305.

A complete record must be kept of test data "as-found and as-left" and observations made during tests and inspections, including brands and serial numbers of test equipment used. This information should be recorded in MAXIMO and in the relay information database. Testing information should also contain the following:

- Region
- Area office
- Plant location
- Unit/equipment
- Device identification
- Circuitry
- Tested by
- Relay manufacturer
- Relay type
- Model/style
- Serial number
- IEEE device
- Install date

The following relay test report forms are available on the intranet at "intra.usbr.gov/forms." After this page appears, click on PO&M Forms.

**Form No.**

**PO&M 100** – Overcurrent relay test report

**PO&M 101** – Differential relay test report

**PO&M 102A** – Distance relay test report (Westinghouse)

**PO&M 102B** – Distance relay test report (General Electric)

**PO&M 106** – Miscellaneous test sheet

## 12. Electromechanical Relay Calibration Procedures

**NOTE: It is recommended that electromechanical relays be replaced by microprocessor relays due to their age. Experience has shown that digital relays are more dependable and require much less maintenance. One Schweitzer digital relay can replace up to ten electromechanical relays and are self diagnostic.**

Many electromechanical relays have been replaced by solid-state or microprocessor type relays. However, numerous electromechanical relays remain. Because of the nature of these relays, components age, and settings drift, frequent calibration is necessary.

## 12.1 Frequency of Testing

Per NFPA 70B, NERC Reliability Standard PRC-005-1, and FIST Volume 4-1B, electromechanical relays must be calibrated upon commissioning, after 1 year of service, and at least every 2 years thereafter. Relays in dusty atmospheres, subject to vibration, or in non-heated, non-air-conditioned control buildings typically found in switchyards, must be calibrated annually.

## 12.2 Commissioning

Before placing new equipment into operation, polarity of instrument transformers, relays themselves, and all associated wiring must be checked. In some cases, manufacturer's polarity markings are found to be incorrect. New relays must be inspected carefully and all blocking, put in by the manufacturer, removed. Testing personnel must read manufacturer’s instruction manuals to become familiar with construction and operation of the relays.

Initial checks must be made by manually operating relay contacts to ensure all devices operated by the relay function freely and properly, including auxiliary contacts and targets within the relay. Breaker trip coils and other devices operated by the relay must be checked to ensure that proper operation is obtained at voltages considerably below normal (approximately 56 percent of normal voltage for breaker trip coils). The value of 56 percent is 70 volts direct current (Vdc) for a 120-Vdc system. The voltage drop in trip circuits and tripping current must also be checked.

A visual inspection must be made of all relays, including tripping auxiliaries and accessories. Draw out type relays must be withdrawn for a closeup examination. All other relays, including auxiliaries, must have covers removed and be given a visual inspection. Always check for loose connections, broken studs, burned insulation, and dirty contacts. Each relay must be checked for proper settings. On some relays, including distance relays, it may have been necessary to reset the taps on other than specified values to get proper calibration. If taps are found on unspecified settings, check the prior calibration test report.

A test trip must be made of all relays. Each element which initiates protective functions must be checked.

## 12.3. Electromechanical Relay Maintenance Test Procedures

Tests to be performed during routine maintenance are determined by the type of relay to be tested. **The following tests should be included for all electromechanical relays.**

a. An initial "as-found" test of all disk type relays must be performed before the relay has been disturbed. The initial as-found tests should be performed in the same manner as a timing test, if appropriate. This is critical for electromechanical disk type relays to ensure that they would have detected abnormal conditions prior to the current tests.

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**EXAMPLE: On an overcurrent relay test at two times pickup to verify correct time delay and verify that the disk is free to rotate.**

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Notes should be made on the test record as to the "as-found" condition of the relay.

b. **Mechanical adjustments and inspection** should be made according to the following instructions:

(1) Check to see that all connections are tight. Loose connections could indicate excessive vibration which must be corrected. Check that rotating discs rotate freely.

(2) All gaps must be checked to ensure that they are free of foreign material. If foreign material is found, the case gasket should be checked and replaced, if necessary. If the relay has a rotating disc, be careful to check for foreign material between the magnets and rotating disc, especially under the disc. Bits of magnetic material, rust, and dirt between the disc and magnet will impede disc rotation and must be removed.

(3) All contact or armature gaps must be inspected. Large variations in the same type relay may indicate excessive wear. An adjusting screw could have worked loose and must be tightened. All of this information must be noted on the test record.

(4) When specified in the manufacturer's instruction manual, contacts can be burnished with a burnishing tool. Note a burnishing tool has a very fine abrasive for cleaning dirt and oxidation off contacts. Never touch a relay contact with sandpaper or file; the contact will be destroyed. Measure contacts for alignment and wipe, according to the manufacturer's instruction manual.

(5) Checking bearings or pivots usually involves dismantling the relay. It is recommended that these tests be performed only when the relay appears to be extremely dirty or when electrical tests indicate undue friction.

c. **Electrical tests and adjustments**

(1) Contact function. Manually close or open the contacts and observe that they perform their required function.

(2) Pickup. Gradually apply current or voltage to see that pickup is within limits. The current or voltage must be applied gradually to yield data which can be compared with previous or future tests and not be clouded by such effects as transient overreach.

(3) Dropout or reset. To test for excessive friction, reduce current or voltage until the relay resets. Observe the armature or disc movement. If the relay is slow to reset or fails to reset, the jewel bearing and pivot must be examined. A four-power magnifying glass is needed for examining the pivot. The jewel bearing can be examined by moving a needle across the surface which will reveal any cracks. If dirt is found, the jewel can be cleaned with an orange stick and the pivot wiped clean with a soft, lint-free cloth.

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**NOTE: An orange stick is a small "flat sharpened" stick which historically was made from the wood of an orange-tree. Today, the stick is typically made from birch; however, it is still called an "orange stick." This tool is normally used for manicures and may be obtained from a beauty or nail salon.**

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No lubricant should ever be used on the jewel or pivot.

(4) Using an ohmmeter, check the continuity of the total instrument transformer secondary circuit through the breaker trip coil and all auxiliaries. This includes all auxiliary relays, indications, alarms, and inputs to other devices.

## 12.4 Auxiliary Relays

In addition to tests described above, auxiliary relays employing devices for time delay (for example, capacitors or air bellows) should have an operating time test performed (either pickup or dropout, whichever is applicable). Plotting current and voltage at the coil terminals during pickup provides information that can be compared to previous data.

## 12.5 Time-Overcurrent and Time-Overvoltage Relays

All tests described above must be performed for time-overcurrent and time-overvoltage relays. If possible, these types of relays should always be tested "in-the-case" to duplicate "inservice" conditions. The relay case acts as a shunt for stray flux that travels outside the electromagnetic iron circuit due to saturation. If tested out of the case, the results will not match published curves. If it is impossible to test the relay in its case, it must be noted on the test report. Differing test conditions, such as being near a steel cabinet or working on a steel bench, will change results if the relay is tested out of the case. An initial "as-found" test should be performed prior to disturbing the relay. The next relay test should be a pickup[2] test. Pickup is defined as that value of current or voltage which will "just close" the relay contacts. This value should be within manufacturer specifications (typically ± 5 percent).

Testing current levels at three points on the time-current curve is generally sufficient for maintenance purposes. Always use the same points for comparison with previous tests.

The instantaneous trip unit should be checked for pickup using gradually applied current. Whenever possible, current should be applied only to the instantaneous coil to avoid overheating the time coil. The instantaneous current should be applied in short pulses, or the time coil may be jumpered out.

The target seal-in should also be tested using gradually applied direct current (dc). The main contacts must be blocked closed for this test.

## 12.6 Directional Overcurrent Relays

In addition to tests recommended for the overcurrent relay, the directional portion of the directional overcurrent relay must be tested for minimum pickup, maximum torque angle (MTA), contact gap, and clutch pressure. A test should also be made to check that the overcurrent portion operates only when the directional unit contacts are closed.

## 12.7 Distance Relays

When testing distance relays, tests should be made of pickup, maximum torque angle, contact gap, and clutch pressure, in addition to the applicable tests described above. (See appendix I for testing and adjustment of Westinghouse Type KD relays.)

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[2] Pick-up values: Pick-up voltage, current, or power is the minimum value for which contacts of a previously de-energized relay will always assume their energized position.

## 12.8 Differential Relays

A test of minimum pickup should be performed for differential relays. The differential characteristic (slope) should be checked with at least two points; and where applicable, the harmonic restraint should be tested.

Differential relays using ultrasensitive polarized sensing devices are slightly affected by previous history, such as heavy internal or external fault currents. Therefore, for this type relay, take two pickup readings and use the second reading for recording and for comparison with previous and future tests.

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**CAUTION: Extreme care must be taken to assure that shorting a CT will not cause an inadvertent trip or loss of protection elsewhere in the system. Shorting one CT in a differential relaying scheme with the system energized will definitely cause an inadvertent trip.**

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## 12.9 Temperature Relays and RTDs

Temperature relays used on bearings and other installations should be checked by placing the bulb in a container of water with a thermometer and gradually heating to the temperature at which the relay is set to operate. As the temperature rises, the water should be stirred and an alcohol thermometer used to read the temperature. Record the temperature at which the relay operates on increasing temperature and at which it resets on falling temperature.

Resistance temperature devices (RTDs) are generally extremely accurate; and when they fail, it is very obvious—it either works or it doesn't. It is not normally necessary to test them. If a test is needed for a faulty RTD, devices are available for testing RTDs which have a heater and temperature indicator built in, or they may be checked by heating them slowly in an enclosed air space with a thermometer. RTDs should not be immersed in water or other liquid unless they are rated for immersion.

Embedded RTDs (such as in the stator) can be checked by comparison of readings of various RTDs at room temperature. They can also be checked as temperature equalizes while the unit cools down following operations.

## 12.10 Pressure Relays

Pressure relays should be checked for correct operation by comparing with an accurate pressure gauge or manometer. Pressure should be slowly increased and decreased to determine the pressure at which the relay operates and resets.

Record the results on the proper forms or in MAXIMO.

## 13. Sudden Pressure and Buchholz Relays

The above does not apply to sudden pressure and Buchholz relays on transformers, which should be maintained according to manufacturer's recommendations. See FIST Volume 3-30 and 3-31 for sudden pressure and Buchholz relay testing.

## 14. Solid-State Relays

**NOTE: It is recommended that solid-state relays be replaced by microprocessor relays due to their age. Experience has shown that digital relays are more dependable and require much less maintenance. One Schweitzer digital relay can replace up to ten relay functions and are self diagnostic.**

### 14.1 Frequency of Testing

Per NFPA 70B, NERC Reliability Standard PRC-005-1, and FIST Volume 4-1B, solid-state relays must be calibrated and function tested upon commissioning, 1 year after commissioning, and every 3 years thereafter.

Solid-state (analog type) relays are inservice in many applications. Settings typically do not drift as much as those in electromechanical relays and are less affected by dirt, vibration, humidity, and other environmental concerns. They require less current, have a higher seismic-withstand, and require less panel space. These relays also have fewer moving parts and require less maintenance compared to electromechanical relays. However, electronic component failure can go undetected; and frequent testing is required to discover these failures.

### 14.2 Testing Requirements

Solid-state relays must be tested according to FIST Volume 4-1B and the manufacturer's recommendations. There are no moving parts, no physical wear, and no need for lubricants. Prime causes of failure in electronic components are power supplies, over or under voltages, voltage transients, current surges, heat, age, vibration, and moisture. Overheating can be caused by voltage transients, current surges, or high ambient temperature. Vibration can loosen or break leads and connections and can crack component casings, circuit boards, and insulation resulting in equipment failure. Moisture can result in corrosion and oxidation of metallic elements which can result in circuit discontinuities, poor contacts, and short circuits. Preventive maintenance of solid-state relays should be directed toward removing causes of failure listed above by the following:

a. Check the supply voltage and the power supply output voltage.

b. Keep equipment clean by periodic vacuuming or blowing out dirt, dust, and other contaminants. Dust may be blown out with “dry canned air.” Do not use plant air or an air compressor due to moisture and static buildup.

c. Keep the equipment dry and protected against moisture and corrosion.

d. Inspect to see that all connections, leads, and contacts are tight and free as possible from effects of vibration.

e. Check to see that there is adequate ventilation to conduct heat away.

Preventive measures should not be applied unnecessarily since this may contribute to failures. For example, printed circuit cards should not be pulled from their racks to be inspected if there is no real need. Operating test switches unnecessarily may introduce damaging voltage transients.

## 14.3 Commissioning

**Before placing a new installation into operation, check polarity of instrument transformers, relays themselves, and all associated wiring.** In some cases, manufacturer's polarity marking was found to be incorrect. New relays should be inspected carefully and all blocking/packing put in by the manufacturer for shipment removed. Testing personnel should read manufacturer’s instruction manuals to become familiar with construction and operation of relays.

Initial checks must be performed by manually operating relay contacts to make sure all devices, operated by the relay, function freely and properly, including auxiliary contacts and targets within the relay. On solid-state relays, manufacturers typically include a test switch on the relay front. Breaker trip coils and other devices operated by the relay must be checked to see that proper operation is obtained at voltages considerably below normal (approximately 56 percent of normal voltage for breaker trip coils). The voltage drop in trip circuits and tripping current must also be checked and recorded.

## 14.4 Calibration and Testing Techniques

Calibration of protective relays should take place at the power facility by qualified and trained personnel. A firm understanding of electronics is required for repair or troubleshooting these relays. Avoid transporting relays to a remote location for testing as this introduces the possibility of damage to relays or changed settings from vibration or rough handling.

Calibration of solid-state relays requires a technician to adjust potentiometers, variable capacitors, or variable inductors to ensure correct operation. Eliminating a majority of moving parts within solid-state relays (versus electromechanical) has allowed easier and more precise adjustments to be made. However, solid-state relays are inherently sensitive to voltage transients and current surges. When calibrating solid-state relays, the following precautions should be taken to avoid static discharge damaging the relay:

- Work on a grounded, semiconductive mat or other suitable static protection system.
- Always touch a grounded metal surface before touching circuit boards, especially when relays are equipped with metal-oxide-semiconductors.
- Always try to use a differential input mode for measuring instruments when troubleshooting circuits to avoid introduction of ground loops.

It is important to remove the test plug from a relay before changing tap settings on the CT or in the relay itself. Removing the test plug will power down the relay, short CTs, and ensure that trip contacts remain in the correct position, reducing the risk of inadvertently tripping equipment offline. This will also ensure CT secondary circuits are not opened during the tap change, alleviating the risk of high voltage destroying the CT.

Refer to manufacturer's instruction manuals before performing insulation resistance tests on these relays. If manufacturer's information is not available, it is not recommended to perform this test on solid-state relays. While individual components may withstand test voltage levels, applying high dc voltages may introduce voltage spikes that could damage the relay.

If a circuit card must be removed for repair, cleaning, or maintenance, use extreme care removing and re-installing the card. Never force a board into place or bend it. If circuit cards must be removed, first touch a grounded metal frame. If circuit board contacts appear dirty, clean as needed. Before attempting to disassemble the relay, refer to manufacturer's instructions. Never touch electronic components on a circuit board with a bare hand.

Ensure the relay case is grounded as recommend by the manufacturer. All required grounds should be in place before testing or placing a relay into service.

## 14.5 Testing Procedures

a. Mechanical inspection:

(1) Check to see that connections are tight. Loose connections may indicate excessive vibration which must be corrected.

(2) The relay must be examined for excessive debris. Debris can cause an inadvertent path to ground causing the relay to trip or be damaged. Debris can be removed by using canned air available at most electronics stores. Never use an air compressor or plant air to remove debris due to possible static electricity and moisture.

b. Electrical tests and adjustments:

(1) Using a digital multimeter, check the input voltage to the relay. If the relay has a dual power supply, ensure jumpers are in the correct position to provide the correct voltage.

(2) If so equipped, the test function switch on the relay should be used to ensure that all indicators are working correctly. Also, the reset should be exercised to ensure this function is working.

c. Functional testing:

(1) Pickup. Gradually apply current or voltage to see that pickup is within limits. Current or voltage should be applied gradually to yield data which can be compared with previous or future tests.

(2) For timing tests, it is important to test the relay at multiple points on the timing curve. If a relay does not operate within given specifications, it may be necessary to adjust the relay. Typically solid-state relays will allow the user to adjust components such as potentiometers, variable capacitors, or variable inductors. However, dual in-line package (DIP) switches may also affect settings internal to the relay. Refer to the instruction manual for further details.

(3) For voltage, frequency, and current tests, it may be possible to test the relay at only one point on its operating curve. Adjustment of the relay can be handled in the same manner as for timing tests.

(4) Many of the procedures for testing solid-state relays are the same as testing electromechanical relays. The technician should read the section on electromechanical relays along with the relay specific instruction manual for further information.

## 15. Microprocessor (Digital) Relays

Microprocessor (computer-based) digital relays are replacing electromechanical and solid-state relays in many applications. It is recommended that electromechanical and solid-state relays be replaced by digital relays as systems are upgraded. Microprocessor relays have several advantages:

- Can take the place of several electromechanical or solid-state relays.
- Can detect conditions that other types of relays cannot.
- Settings are software-based and do not drift with time, ambient temperature, supply voltage changes, or aging.
- Can log input data and output data to other devices.

- Have built-in redundancy.
- Can log sequence of events for trouble shooting in case of faults.
- Are self-testing and self-diagnostic.
- Extremely fast operating times.
- Performance of digital components do not change from part to part (as long as numerical values, stored in the memory, remain). For example, if the number 2 remains a 2 in the memory, it does not matter where the number is stored.

## 15.1 Testing Precautions

To preclude inadvertent trips, before starting any relay test with protected equipment inservice, testing personnel must become familiar with relays and associated circuits. When test blocks are used, ensure that removing or inserting plugs will not open a current transformer, resulting in high voltage which may be dangerous to personnel, damage the CT or other equipment, or cause an inadvertent trip. In installations where test blocks are not available, before the relay current circuit is opened, CT circuits must be shorted by shorting blocks or shorting switches.

**CAUTION: Extreme care must be taken to ensure that shorting a CT will not cause an inadvertent trip or loss of protection elsewhere in the system. Shorting one CT in a differential relaying scheme with the system energized will definitely cause an inadvertent trip.**

Removing a digital microprocessor relay from service will remove all its protective functions. Extreme care must be taken to ensure that equipment left in service is adequately protected during testing. Do not allow equipment to operate without relay protection while relays are being tested.

## 15.2 Frequency of Testing

Per NFPA 70 B, NERC Reliability Standard PRC-005-1, and FIST Volume 4-1B, microprocessor-based relays must be function tested upon commissioning, 1 year after commissioning, and every 8-10 years thereafter.

## 15.3 Commissioning

Before placing a new installation into operation, polarity of instrument transformers, relays themselves, and all associated wiring must be checked. In some cases, manufacturer's polarity marking was found to be incorrect. New relays should be inspected carefully for physical damage that may have occurred in shipment. Testing personnel should read the manufacturer's instruction manuals to become familiar with the construction and operation of the specific relay.

Initial checks must be made by manually operating relay outputs to ensure all devices operated by the relay function freely and properly, including auxiliary contacts and targets within the relay. On microprocessor-based relays, it is typically necessary to operate the relay using a computer connected to the relay and input specific commands that will test each function. It may be possible to test functions without the use of a computer, but this can be much more difficult. Refer to the instruction manual for recommendations regarding manually tripping the relay. During the commissioning process, logic within the relay is also tested.

One microprocessor-based relay may replace 5 to 10 electromechanical or solid-state relays. Each of these functions must be tested to ensure they all operate as designed. Breaker trip coils and other devices operated by the relay must be checked to see that proper operation is obtained at voltages considerably below normal (approximately 56 percent of normal voltage for breaker trip coil). The voltage drop in trip circuits and tripping current must also be checked.

## 15.4 Functional Testing Techniques

Calibration of microprocessor relays is typically not required and not possible. The relay is operated by a microprocessor that is programmed in a manner similar to electromechanical or solid-state relays. There are no user adjustable components in the relay. If a relay does not pass a specific test, often the test point mismatches the relay settings. If the relay tests continue to fail, then relay test procedures should be examined to ensure the relay and test set are correctly configured. If everything is proven to be correct, the relay may need to be repaired or replaced; contact the relay manufacturer or the Hydroelectric Research and Technical Services Group at 303-445-2305.

In the past, electromechanical relays were used throughout Reclamation, and each relay served as one protective element. With the introduction of microprocessor-based relays, 5 to 10 electromechanical relays can be replaced with one relay. The technician is not able to see the relay "operate"; there are no moving parts. All functions are programmed into the relay using a laptop computer and related software. The software emulates electromechanical relay operation—thus, the importance of having firm relay knowledge and experience and knowledge in using relay testing software before testing these relays.

## 15.5 Functional Testing

Each digital relay must be tested functionally upon commissioning, 1 year after commissioning, and every 8 to 10 years thereafter, preferably with in service settings.  Protective relay functional testing includes operating the relay in place or on a bench to verify that:

- The settings are correct (note any differences).
- The appropriate output contacts close/open at the proper time and under the appropriate inputs.
- Analog and digital outputs are accurate and reliable.
- Indicating devices such as targets or indicating lights operate correctly.
- Logic functions operate as designed.

Steady-state function testing of microprocessor-based relays is typically performed using a laptop computer, or they may be networked together via ethernet LANs to a PC for testing and monitoring.  Steady-state testing is a process where each element of a relay is tested individually, one element at a time.  As microprocessor-based relays typically encompass several protection elements, it is often necessary to "isolate" a particular function to test it.  This is accomplished by routing the digital element output to an unused physical output. Another method is to temporarily disable any overlapping or interfering relay functions in software when they show up during testing.

Making changes to the inservice "as-found" settings for testing requires that the original settings be loaded back into the relay after testing.  It is highly recommended to download a copy of the as-found settings to a safe location before testing.  A backup copy of these settings should be saved to a jump drive, CD, or other form of media to ensure that settings can be restored.

It is also important to compare the as-found settings in the relay with the official settings that should be in the relay, and document any discrepancies.  After testing is complete, if the as-found copy has all the correct settings, reload these settings back into the relay from the saved copy instead of trying to reverse all the changes.  Most manufacturers' software allows a user to compare settings in the relay to settings on the disk; this will alleviate the possibility of file corruption during downloads and ensures the as-found settings match the as-left settings.

Each enabled element of a relay should be tested according to manufacturer's recommendations to ensure settings are correct and the relay is operating properly.  If a relay element is not enabled, it does not need to be tested. However, if relay settings are changed or an element is enabled, the entire relay should be function tested at that time, independent of the testing schedule.

## 15.6 Testing Programmable Logic

The programmable logic within a microprocessor-based relay allows the relay to act as numerous different electromechanical relays.  The programmable logic should be treated the same as switchboard wiring.  Logic diagrams should be produced and documented on drawings. These drawings should be available while function testing relays or troubleshooting. Testing of the programmable logic must be considered as important as functional testing traditional schemes.

The logic should be tested in the same manner as functional elements of electromechanical relays. This means all inputs, outputs, relay function blocks, controls, alarms, and switches perform as intended and do not operate with unintended consequences. Logic settings must be reviewed and tested anytime settings are changed. Drawings must be updated at this time. It is essential to keep a set of “as-built” relay logic settings and drawings at the facility. A hard copy of relay settings and logic is useful in case there is a situation where a computer is not available to communicate with the relay.

# Appendix A

# GLOSSARY OF TERMS PROTECTIVE RELAYING AND PROTECTION CIRCUITS

## Definitions of Relay Terms

The following definitions include terminology and nomenclature in common use. They have been compiled using information from the Institute of Electrical and Electronics Engineers and the National Association of Relay Manufacturers. In instances where different terms are used synonymously, one has been defined and others have been cross-referenced. When the phrase “sometimes used for” is employed, a preference is implied for the terminology following the phrase; when “same as” is used; no strong preference is inferred.

**Acceptance test:** A calibration and functional test of a new or replacement relay to ensure it is in proper working order prior to installation.

**Air gap:** Sometimes used for contact separation or for magnetic air gap.

**Ampere-turns:** The product of the number of turns in a magnetic coil and the root means square (rms) current in amperes passing through the coil.

**Armature:** Hinged or pivoted moving part of the magnetic circuit of an electromagnetic relay. Used in a general sense to mean any moving part which actuates contacts in response to a change in coil current.

**Armature contact:** Sometimes used for movable contact

**Armature relay:** A relay operated by an electromagnet which, when energized, causes an armature to be attracted to a fixed pole (or poles).

**Auxiliary relay:** A relay which operates in response to opening and closing of its operating circuit to assist another relay or device in performing a function.

**Back contacts:** Sometimes used for the stationary contact of single-pole normally closed contacts. Same as normally closed contacts.

**Backstop:** The part of a relay which limits movement of the armature away from the pole piece or core.

**Backup relaying:** Supplementary relaying designed to operate if a primary relay should malfunction or a circuit breaker fail to operate. Backup relaying usually disconnects more of the power system than just the part with the faulty element, since this is necessary to remove the abnormal condition and to minimize effect on the remainder of the system.

**Bar relay:** A relay so designed that a bar actuates several contacts simultaneously.

**Break-before-make contacts:** Contacts which interrupt one circuit before establishing another.

**Break contact:** Same as back contact.

**Break delay:** Sometimes used for release time.

**Bridging:** A term used to describe a contact transfer in which the movable contact touches the normally open contact before leaving the normally closed contact during the transfer action, thus never completely opening the circuit of the movable contact

**Brush:** Sometimes used for wiper.

**Chatter:** A sustained rapid opening and closing of contacts caused by variations in the coil current, mechanical vibration, shock, problems with laminations in the magnetic core, or incorrect travel of the armature.

**Clapper relay:** Sometimes used for armature relay.

**Close-differential relay:** Sometimes used for marginal relay.

**Coil:** A magnetic or thermal winding to which energy is supplied to activate the relay.

**Commissioning test:** This is a test of the total relay system after installation or modification or for troubleshooting purposes. It includes tests of the instrument transformers and all wiring and relay outputs with actual trip testing of the circuit breaker.

**Contact arrangement:** Refers to the combination of different basic contact forms to make up the entire relay switching structure.

**Contact bounce:** Uncontrolled making and breaking of contact when relay contacts are moved to the closed position.

**Contact follow:** The distance two contacts travel together after just touching.

**Contact gap:** Same as contact separation.

**Contact nomenclature:** Each movable contact of a relay is a pole. A combination of one stationary contact and one movable contact which are engaged when the coil is de-energized is referred to as back, break, form B, or normally closed contacts and is abbreviated NC. A combination of stationary contact and movable contact, which are engaged when the coil is energized is referred to as front, make, form A, or normally open contacts and is abbreviated NO. These are called single-pole, single-throw contacts and are abbreviated NC SPST or NO SPST.

A combination of two stationary contacts and one movable contact which engages one of them when the coil is energized and the other when the coil is de-energized is called transfer, form C, or single-pole double-throw contacts and is abbreviated SPDT.

ST NO and ST NC contacts are called single-throw normally open or normally closed contacts. The N stands for "normally," and this always refers to what position the contact is in when the coil is de-energized. So NO means the contacts are separated when the coil is de-energized, while NC means the contacts are closed when the coil is de-energized.

A combination in which a movable contact simultaneously makes and simultaneously breaks connection between two stationary contacts is called double-break contacts and is abbreviated DB. For normally open contacts, this combination may be called double-make contacts.

Relay contact notations are given in the following order:

1. Poles
2. Throws
3. Normal Position
4. DB, if double-break or double-make contacts

Examples: SPST NO DB designates single-pole, single-throw, normally open, double-break contacts.

All contacts are single-break except when noted as double break (DB). Relays having several sets of differently functioning contacts will have the contact forms listed in alphabetical order of their letter symbols.

Example: 1A2B refers to SPST NO contacts and DPST NC contacts.

For a relay on which the moving contact engages more than two stationary contacts during its cycle of operation, the contact arrangement is described as MPNT, where M is the number of poles and N is the number of throws (e.g., 8P 20T).

**Contact over travel:** Sometimes used for contact follow.

**Contact separation:** Maximum distance between mating relay contacts when the contacts are in the open position.

**Contact spring:** A current-carrying spring to which contacts are fastened.

**Contacts:** Current-carrying parts of a relay which engage or disengage to make or break electrical circuits.

**Contactor:** Sometimes used for a relay with heavy-duty contacts.

**Continuity-transfer contacts:** Same as make-before-break contacts.

**Continuous-duty relay:** A relay which may be energized with rated coil voltage or current at rated contact load for a period of 3 hours or more without failure and without exceeding specified temperature requirements.

**Current balance relay:** A relay that allows tripping whenever there is an abnormal change in the division of current between two circuits.

**Current rating:** See rated coil current and rated contact current.

**Current relay:** A relay which is designed to operate at a particular rated coil current rather than at a given rated coil voltage.

**Cycle timer:** A controlling mechanism which opens or closes contacts according to a preset cycle.

**De-energize:** To de-energize a relay is to disconnect the relay coil from its power source.

**Definite-purpose relay:** A relay which has a feature which distinguishes it from a general-purpose relay. Types of definite purpose relays are interlock, selector, stepping, sequence, latch-in, and time-delay.

**Delay relay:** A relay that is intentionally designed for a time delay between the energizing or de-energizing instant and the time that the relay contacts open or close.

**Diagnostic tests (troubleshooting):** Tests to find and correct relay settings, design or wiring errors, or malfunctions. These tests are usually conducted after a protective system problem is identified or suspected, such as failure to trip.

**Differential relay:** A relay having multiple elements which function when voltage, current, or power difference between elements reach a predetermined value.

**Directional relay:** A relay that trips when current flow is in one direction only.

**Directional test:** A test of directional relay elements to verify that the relay will operate or block properly when the relay input quantities are in the proper direction. A directional test is sometimes performed with the equipment carrying normal load. It is always performed as part of a relay system commissioning and as part of routine maintenance testing or troubleshooting tests.

**Double-break contacts:** See contact nomenclature.

**Double-make contacts:** See contact nomenclature.

**Double-throw contacts:** See contact nomenclature.

**Double-wound coil:** A double-wound coil is a winding consisting of two parts wound on the same core.

**Drop-out values:** Drop-out current, voltage, or power is the maximum value for which contacts of a previously energized relay will always assume their de-energized positions.

**Duty cycle:** Rated working time of a device compared to its idle time.

**Electric reset:** A term applied to a relay indicating that, following an operation, its contacts must be reset electrically to their original positions.

**Electromagnetic relay:** A relay whose operation involves use of a magnetic field which is produced by an electromagnet.

**Electrostatic spring shields:** Metallic shields between two relay springs to minimize capacitance between them.

**Enclosed relay:** A relay which has both coil and contacts protected from the surrounding medium by a cover not normally airtight.

**Energize:** To energize a relay is to apply rated voltage to its coil.

**Extension spring:** Same as restoring spring.

**Fast-operate relay:** A high-speed relay specifically designed for short operate time but not short release time.

**Fast-operate**, **fast-release relay:** A high-speed relay specifically designed for both short operate time and short release time.

**Fast-operate, slow-release relay:** A relay specifically designed for short release time but not short operate time.

**Fast-release relay:** A high-speed relay specifically designed for short release time but not short operate time.

**Fixed contacts:** Stationary contacts of a relay which are engaged and disengaged by moving contacts to make or break circuits.

**Flight time:** Sometimes used for transfer time.

**Follow-through contacts:** Contacts which have contact follow.

**Frame:** The structure on which the coil and contact assembly are mounted.

**Front contacts:** Sometimes used for the stationary contact of single-pole normally open contacts. (See contact nomenclature.)

**Front contacts:** Same as normally open contacts.

**Functional test:** A calibration, if required, and functional test of a relay to verify the relay functions according to its settings and specifications. Typical tests include characteristics tests, timing tests, pickup tests, and instantaneous trip (fault trip) tests. These tests are typically performed as part of the acceptance test, part of routine maintenance, or part of troubleshooting testing.

**Gasket-sealed relay:** An airtight relay, sealed with a gasket which is not bonded to the other sealing material.

**General-purpose relay:** A relay with ratings, design, construction, and operational characteristics, which make it adaptable to a wide variety of uses.

**Hand-reset:** A qualifying term applied to a relay indicating that following an operation the contacts must be reset manually.

**Header:** The part of a hermetically sealed relay through which electrical terminals pass.

**Hermetically sealed relay:** An airtight relay, the sealing of which involves fusing or soldering but does not use a gasket.

**High-speed relay:** A relay specifically designed for short operate time, release time, or both.

**Hold values:** The hold current, voltage, or power is the minimum value for which contacts of a previously energized relay will always maintain their energized positions.

**Homing:** A qualifying term applied to a stepping relay indicating that wipers, upon completion of an operational cycle, are stepped around or back to the start position.

**Hum:** As applied to relays, is the sound caused by mechanical vibration resulting from alternating current flowing in the coil.

**Impregnated coils:** Coils which have been permeated with phenolic or similar varnish to protect them from mechanical vibration, handling, fungus, and moisture.

**Inductive winding:** An inductive winding, as contrasted with a non-inductive winding, is a coil having a specifically designed inductance.

**Instrument relay:** A relay, the operation of which depends upon principles employed in electrical measuring instruments such as the electrodynamometer, iron-vane, and D'Arsonval.

**Interlock relay:** A relay composed of two or more coils with their armatures and associated contacts so arranged that freedom of one armature to move or its coil to be energized is dependent upon position of the armature.

**Intermittent-duty relay:** A relay which must be de-energized at occasional or periodic intervals to avoid excessive temperature.

**Latch-in relay:** A relay having contacts which lock in either the energized or de-energized position until reset, either manually or electrically.

**Level:** As applied to a stepping relay, the term, level, is used to denote one bank or series of contacts.

**Level contact:** Sometimes used for movable contact.

**Load test:** This test involves the measurement of the alternating currents and/or voltages applied to the relay when equipment is under normal load. The relative phase angles of the currents and/or voltages are also measured during the load test. This test may be performed while troubleshooting a suspected problem to ensure the relay is receiving the proper quantities.

**Locking relay:** Sometimes used for latch-in relay.

**Low-capacitance contacts:** A type of contact construction providing low intercontact capacitance.

**Make contact:** Same as front contact.

**Magnetic air gap:** A magnetic air gap is a nonmagnetic portion of a magnetic circuit.

**Magnetic freezing:** The sticking of a relay armature to the core, after de-energization, due to residual magnetism of the core.

**Magnetic switch:** Sometimes used for relay.

**Make-before-break contacts:** Double-throw contacts so arranged that moving contacts establishes a new circuit before disrupting the old one.

**Make delay:** Sometimes used for operate time.

**Mercury-contact relay:** A relay in which the contacting medium is mercury.

**Motor-driven relay:** A relay which is actuated by rotation of the shaft of some type of motor, for example, a shaded-pole, induction-disk, or hysteresis motor.

**Movable contact:** A contact which moves when the relay is energized or de-energized, to engage or disengage one or more stationary contacts.

**Multiple-break contacts:** Contacts so arranged that, when they open, the circuit is interrupted in two or more places.

**Multiple pile-up:** An arrangement of contact springs which is composed of two or more separate pile-ups.

**Multiple stack:** Same as multiple pile-up.

**Neutral relay:** A neutral relay, in contrast to a polarized relay, is a relay in which the movement of the armature is independent of direction of flow of current through the relay coil.

**Non-bridging:** A term used to describe a contact transfer in which the movable contact leaves one contact before touching the next.

**Non-homing:** A qualifying term applied to a stepping relay indicating that wipers, upon completion of an operational cycle, do not return to the home position but are at rest on the last used set of contacts.

**Non-inductive windings:** A type of winding in which the magnetic fields produced by two parts of the winding cancel each other and provide a non-inductive resistance.

**Non-magnetic shim:** A non-magnetic material attached to the armature or core of a relay to prevent iron-to-iron contact in an energized relay.

**Non-operate value:** The non-operate voltage, current, or power is the maximum value for which contacts of a previously de-energized relay will always maintain their de-energized positions.

**Normal position:** De-energized position, open or closed, of contacts due to spring tension or gravity.

**Normal sequence of operation:** The sequence in which all normally closed contacts open before closure of normally open contacts of the assembly.

**Normal-speed relay:** A relay in which no attempt has been made either to increase or decrease the operate time or the release time.

**Normally open contacts:** A combination of a stationary contact and a movable contact which are not engaged when the coil is de-energized.

**Off-limit contacts:** Contacts on a stepping relay used to indicate when the wiper has reached the limiting position on its arc and must be returned to normal before the circuit can function again.

**Off-normal contacts:** Stationary contacts on a homing stepping relay used to indicate when the wiper is not in the starting position.

**Operate time:** If a relay has only normally closed contacts, its operate time is the longest time interval given by definition (a) below. If a relay has normally open contacts (regardless of whether or not it has normally closed contacts), its operate time is the longest time interval given by definition (b).

> (a) **Operate time for normally closed contacts:** Operate time for normally closed contacts is total elapsed time from the instant the coil is energized until contacts have opened (i.e., contact current is zero).
>
> (b) **Operate time for normally open contacts:** Operate time for normally open contacts is total elapsed time from the instant the coil is energized until contacts are closed and all contact bounce has ceased.

**Operate values:** Same as pick-up values.

**Operating frequency:** The rated ac frequency of the supply voltage at which the relay coil is designed to operate.

**Overload relay:** A relay which is specifically designed to operate when its coil current reaches a predetermined value above normal.

**Partially enclosed relay:** A relay which has either contacts or coil (but not both) protected from the surrounding medium by a cover that is not airtight.

**Partially sealed relay:** A relay which has either contacts or coil (but not both) sealed.

**Periodic testing:** Time-based routine maintenance testing and calibration of the relays and overall protection system on a schedule.

**Pick-up values:** Pick-up voltage, current, or power is the minimum value for which contacts of a previously de-energized relay will always assume their energized position.

**Pile-up:** A set of contact arms, assemblies, or springs placed one on top of the other with insulation between them.

**Plant protection system testing:** This is a total end-to-end test of the relay system. It includes primary injection (if possible) of test currents or voltages in the primaries of the instrument transformers and an actual trip of the circuit breaker. This proves all the elements of the protection system, including wiring and tripping functions.

**Plunger relay:** A relay operated by energizing an electromagnetic coil which, in turn, operates a movable core or plunger by solenoid action.

**Polarized relay:** A relay which depends on the polarity of the energizing current to operate.

**Pole:** See contact nomenclature.

**Pole face:** The pole face is the part of the magnetic structure on the end of the core nearest the armature.

**Protective relay system:** The entire protective system, including the relays themselves, all associated wiring and terminals, all relay inputs and their current and voltage sources, control relays, and associated sensors and transducers. This includes all relay outputs and all devices in breaker trip circuits such as lockout relays, limit switches etc. This includes breaker trip coils and circuit breakers. This also includes both alternating current and direct current supply systems, including the battery, battery chargers, and all associated wiring and circuits.

**Pull-in values:** Same as pick-up values.

**Pull-on values:** Sometimes used for pick-up values.

**Ratchet relay:** A stepping relay actuated by an armature-driven ratchet.

**Rated coil current:** Steady-state coil current at which the relay is designed to operate.

**Rated coil voltage:** Coil voltage at which the relay is designed to operate.

**Rated contact current:** Current which the contacts are designed to carry for their rated life.

**Relay:** A device which is operated by variation in conditions of one electric circuit to affect operation of other devices in the same or other electric circuits by either opening circuits or closing circuits or both.

**Release factor:** Ratio, expressed in percent, of drop-out current to rated current or the analogous voltage ratio.

**Release time:** If a relay has only normally open contacts, its release time is the longest time interval given by definition (a) below. If a relay has normally closed contacts (regardless of whether or not it has normally open contacts), its operate time is the longest time interval given by definition (b).

(a) **Release time for normally open contacts:** Release time for normally open contacts is total elapsed time from the instant the coil current starts to drop from its rated value until contacts have opened (i.e., contact current is zero).

(b) **Release time for normally closed contacts:** Release time for normally closed contacts is total time from the instant the coil current starts to drop from its rated value until contacts are closed and all contact bounce has ceased.

**Release values:** Same as drop-out values.

**Repeating timer:** A timing device which, upon completion of one operating cycle, continues to repeat automatically until excitation is removed.

**Residual gap:** Length of magnetic air gap between the pole-face center and nearest point on the armature, when the armature is in the energized position.

**Residual pins or screws:** Nonmagnetic pins or screws attached to either the armature or core of a relay to prevent the armature from directly contacting the magnetic core.

**Residual setting:** Value of the residual gap obtained by the use of an adjustable residual screw.

**Residual shim:** Same as non-magnetic shim.

**Restoring spring:** A spring which moves the armature to and holds it in the normal position when the relay is de-energized.

**Retractile spring:** Sometimes used for restoring spring.

**Rotary relay:** Sometimes used for motor-driven relay.

**Rotary stepping relay:** Same as stepping relay.

**Rotary stepping switch:** Same as stepping relay.

**Sealed relay:** A relay which has both coil and contacts enclosed in an airtight cover.

**Self-cleaning contacts:** Sometimes used for wiping contacts.

**Selector relay:** A relay capable of automatically selecting one or more circuits from a number of circuits.

**Sequence control:** Automatic control of a series of operations in a predetermined order.

**Sequence relay:** A relay which controls two or more sets of contacts in a definite predetermined sequence.

**Shading coil:** Sometimes used for shading ring.

**Shading ring:** A shorted turn surrounding a portion of the core of an alternating current magnet, causing a delay in change of magnetic flux in that part, thereby preventing contact chatter.

**Slave relay:** Sometimes used for auxiliary relay.

**Slow-operate, fast-release relay:** A relay specifically designed for long operate time and short release time.

**Slow-operate relay:** A slow-speed relay designed for long operate time but not for long release time.

**Slow-operate, slow-release relay:** A slow-speed relay specifically designed for both long operate time and long release time.

**Slow-release relay:** A slow-speed relay specifically designed for long release time, but not for long operate time.

**Slow-speed relay:** A relay designed for long operate time, release time, or both.

**Slug:** A highly conductive sleeve placed over the core to aid in retarding the establishing or decay of flux within the magnetic path.

**Solenoid relay:** Sometimes used for a plunger relay.

**Solid-state relays:** Relays that use various low-power diodes, transistors, and thyristors, and associated resistor and capacitors. These components are designed into logic units used in many ways.

**Special-purpose relay:** A relay which has an application that requires special features which are not characteristic of conventional general-purpose or definite-purpose relays.

**Specified duty relay:** A relay which is designed to function with a specified duty cycle but which might not be suitable for other duty cycles.

**Spring buffer:** A bearing member made of insulating material which transmits motion of the armature to the movable contact and from one movable contact to another in the same pile-up.

**Spring pile-up:** Same as pile-up.

**Spring stud:** Same as spring buffer.

**Stack:** Same as pile-up.

**Stationary contact:** A contact member which is rigidly fastened to the relay frame and which is not moved as a direct result of energizing or de-energizing the relay.

**Stepping relay:** A relay whose contacts are stepped to successive positions as the coil is energized in pulses. Some stepping relays may be stepped in either direction. (The stepping relay is also called a rotary stepping switch or a rotary stepping relay.)

**Telephone-type relay:** Sometimes used for an armature relay with an end-mounted coil and spring pile-up contacts mounted parallel to the long axis of the relay coil.

**Tension spring:** Sometimes used for restoring spring.

**Thermal relay:** A relay operated by the heating effect of electric current flow.

**Throw:** See contact nomenclature.

**Time-delay relay:** A relay in which a delayed action is purposely introduced.

**Timing relay:** A motor-driven time-delay relay.

**Transfer time:** Total elapsed time between breaking one set of contacts and making of another set of contacts.

> (a) **Transfer time on operate:** Transfer time on operate is total elapsed time from the instant the normally closed contacts start to open until the normally open contacts are closed and all contact bounce has ceased.
>
> (b) **Transfer time on release:** Transfer time on release is total elapsed time from the instant the normally open contacts start to open until the normally closed contacts are closed and all contact bounce has ceased.

**Transit time:** Same as transfer time.

**Trip values:** Trip voltage, current, or power is rated value at which a bi-stable polarized relay will transfer from one contact to another.

**Undercurrent relay:** A relay specifically designed to function when its coil current falls below a predetermined value.

**Undervoltage relay:** A relay specifically designed to function when its coil voltage falls below a predetermined value.

**Unenclosed relay:** A relay which does not have its contacts or coil protected from the surrounding medium by a cover.

**Winding:** Same as coil.

**Wiper:** A moving contact on a stepping relay.

**Wiping contacts:** Contacts designed to have some relative motion during the interval from the instant of touching until completion of closing motion.

## Appendix B

# ELECTRICAL DEVICE NUMBERS DEFINITIONS AND FUNCTIONS

Devices in control and switching equipment are referred to by numbers, with appropriate suffix letters when necessary, according to the functions they perform.

These numbers are based on the Institute of Electrical and Electronics Engineers standard for automatic switchgear and are incorporated in American National Standard C37.2-1970.

| Device No. | Definition and Function |
|---|---|
| 01. | **Master Element** is the initiating device, such as a control switch, voltage relay, or float switch, which serves either directly or through such permissive devices as protective and time-delay relays to place an equipment in or out of operation. |
| 02. | **Time-Delay Starting or Closing Relay** is a device that functions to give a desired amount of time delay before or after any point of operation in a switching sequence or protective relay system, except as specifically provided by device functions 48, 62, and 79. |
| 03. | **Checking or Interlocking Relay** is a relay that operates in response to the position of a number of other devices (or to a number of predetermined conditions) in equipment, to allow an operating sequence to proceed, to stop, or to provide a check of the position of these devices or of these conditions for any purpose. |
| 04. | **Master Contactor** is a device, generally controlled by device function 1 or equivalent and the required permissive and protective devices, that serves to make and break necessary control circuits to place an equipment into operation under desired conditions and to take it out of operation under other or abnormal conditions. |
| 05. | **Stopping Device** is a control device used primarily to shut down an equipment and hold it out of operation. (This device may be manually or electrically actuated, but excludes the function of electrical lockout [see device function 86] on abnormal conditions.) |
| 06. | **Starting Circuit Breaker** is a device whose principal function is to connect a machine to its source of starting voltage. |
| 07. | **Anode Circuit Breaker** is a device used in anode circuits of a power rectifier for the primary purpose of interrupting the rectifier circuit if an arc-back should occur. |
| 08. | **Control Power Disconnecting Device** is a disconnecting device, such as knife switch, circuit breaker, or pull-out fuse block, used, respectively, to connect and disconnect the source of control power to and from the control bus or equipment.<br><br>**NOTE:** Control power is considered to include auxiliary power which supplies such apparatus as small motors and heaters. |
| 09. | **Reversing Device** is a device that is used to reverse a machine field or to perform any other reversing function. |

10. **Unit Sequence Switch** is a switch that is used to change the sequence in which units may be placed in and out of service in multiple-unit equipment.

11. Reserved for future application.

12. **Overspeed Device** is usually a direct-connected speed switch which functions on machine overspeed.

13. **Synchronous-Speed Device** is a device such, as a centrifugal-speed switch, a slip-frequency relay, a voltage relay, an undercurrent relay, or any type of device, that operates at approximately synchronous speed of a machine.

14. **Under-Speed Device** is a device that functions when the speed of a machine falls below a predetermined value.

15. **Speed or Frequency Matching Device** is a device that functions to match and hold speed or frequency of a machine or of a system equal to, or approximately equal to, that of another machine, source, or system.

16. Reserved for future application.

17. **Shunting or Discharge Switch** is a switch that serves to open or close a shunting circuit around any piece of apparatus (except a resistor), such as a machine field, a machine armature, a capacitor, or a reactor.

    **NOTE:** This excludes devices that perform such shunting operations as may be necessary in the process of starting a machine by devices 6 or 42, or their equivalent, and also excludes device function 73 that serves for the switching of resistors.

18. **Accelerating or Decelerating Device** is a device that is used to close or to cause closing of circuits which are used to increase or decrease the speed of a machine.

19. **Starting-to-Running Transition Contactor** is a device that operates to initiate or cause the automatic transfer of a machine from starting to running power connection.

20. **Electrically Operated Valve** is an electrically operated, controlled, or monitored valve used in a fluid line.

21. **Distance Relay** is a relay that functions when circuit admittance, impedance, or reactance increases or decreases beyond predetermined limits.

22. **Equalizer Circuit Breaker** is a breaker that serves to control or to make and break equalizer or current-balancing connections for a machine field, or for regulating equipment, in a multiple-unit installation.

23. **Temperature Control Device** is a device that functions to raise or lower temperature of a machine or other apparatus, or of any medium, when its temperature falls below or rises above, a predetermined value.

    **NOTE:** An example is a thermostat that switches on a space heater in a switchgear assembly when temperature falls to a desired value as distinguished from a device that is used to provide automatic temperature regulation between close limits and would be designated as device function 90T.

24. Reserved for future application.

25. **Synchronizing or Synchronism-Check Device** is a device that operates when two alternating current (ac) circuits are within the desired limits of frequency, phase angle, or voltage to permit or to cause the paralleling of these two circuits.

26. **Apparatus Thermal Device** is a device that functions when temperature of the shunt field or amortisseur winding of a machine, or that of a load limiting or load shifting resistor or of a liquid or other medium, exceeds a predetermined value; or if temperature of the protected apparatus, such as a power rectifier, or of any medium, decreases below a predetermined value.

27. **Undervoltage Relay** is a relay that functions on a given value of undervoltage.

28. **Flame Detector** is a device that monitors the presence of pilot or main flame in such apparatus as a gas turbine or a steam boiler.

29. **Isolating Contactor** is a device that is used expressly for disconnecting one circuit from another for purposes of emergency operation, maintenance, or test.

30. **Annunciator Relay** is a nonautomatically reset device that gives a number of separate visual indications upon functioning of protective devices and which may also be arranged to perform a lockout function.

31. **Separate Excitation Device** is a device that connects a circuit, such as shunt field of a synchronous converter, to a source of separate excitation during starting sequence, or one that energizes the excitation and ignition circuits of a power rectifier.

32. **Directional Power Relay** is a device that functions on a desired value of power flow in a given direction or upon reverse power resulting from arc-back in the anode or cathode circuits of a power rectifier.

33. **Position Switch** is a switch that makes or breaks contact when the main device or piece of apparatus which has no device function number reaches a given position.

34. **Master Sequence Device** is a device such as a motor-operated multi-contact switch or equivalent or a programming device, such as a computer, that establishes or determines the operating sequence of major devices in equipment during starting and stopping or during other sequential switching operations.

35. **Brush-Operating or Slip-Ring Short-Circuiting Device** is a device for raising, lowering, or shifting brushes of a machine, for short-circuiting its slip rings, or for engaging or disengaging contacts of a mechanical rectifier.

36. **Polarity or Polarizing Voltage Device** is a device that operates, or permits operation of, another device on a predetermined polarity only or verifies presence of a polarizing voltage in equipment.

37. **Undercurrent or Underpower Relay** is a relay that functions when current or power flow decreases below a predetermined value.

38. **Bearing Protective Device** is a device that functions on excessive bearing temperature or on other abnormal mechanical conditions associated with the bearing, such as undue wear, which may eventually result in excessive bearing temperature or failure.

39. **Mechanical Condition Monitor** is a device that functions when an abnormal mechanical condition occurs (except that associated with bearings as covered under device function 38), such as excessive vibration, eccentricity, expansion, shock, tilting, or seal failure.

40. **Field Relay** is a relay that functions on a given or abnormally low value or failure of machine field current, or on excessive value of the reactive component of armature current in an ac machine indicating abnormally low field excitation.

41. **Field Circuit Breaker** is a device that functions to apply or remove field excitation of a machine.

42. **Running Circuit Breaker** is a device whose principal function is to connect a machine to its source of running or operating voltage. This function may also be used for a device, such as a contactor, that is used in series with a circuit breaker or other fault protecting means, primarily for frequent opening and closing of the circuit.

43. **Manual Transfer or Selector Device** is a manually operated device that transfers control circuits in order to modify the plan of operation of switching equipment or of some of the devices.

44. **Unit Sequence Starting Relay** is a relay that functions to start the next available unit in a multiple-unit lineup upon failure or nonavailability of the normally preceding unit.

45. **Atmospheric Condition Monitor** is a device that functions upon occurrence of an abnormal atmospheric condition, such as damaging fumes, explosive mixtures, smoke, or fire.

46. **Reverse-Phase or Phase-balance Current Relay** is a relay that functions when the polyphase currents are of reverse-phase sequence or when polyphase currents are unbalanced or contain negative phase-sequence components above a given amount.

47. **Phase-Sequence Voltage Relay** is a relay that functions upon a predetermined value of polyphase voltage in the desired phase sequence.

48. **Incomplete Sequence Relay** is a relay that generally returns equipment to normal, or off, position and locks it out if normal starting, operating, or stopping sequence is not properly completed within a predetermined time. If the device is used for alarm purposes only, it should preferably be designated as 48A (alarm).

49. **Machine or Transformer Thermal Relay** is a relay that functions when temperature of a machine armature or other load-carrying winding or element of a machine or temperature of a power rectifier or power transformer (including a power rectifier transformer) exceeds a predetermined value.

50. **Instantaneous Overcurrent or Rate-of-Rise Relay** is a relay that functions instantaneously on an excessive value of current or on an excessive rate of current rise—thus, indicating a fault in apparatus or circuit being protected.

51. **AC Time Overcurrent Relay** is a relay with either a definite or inverse time characteristic that functions when current in an ac circuit exceeds a predetermined value.

52. **AC Circuit Breaker** is a device that is used to close and interrupt an ac power circuit under normal conditions or to interrupt this circuit under fault or emergency conditions.

53. **Exciter or Direct Current (dc) Generator Relay** is a relay that forces the dc machine field excitation to buildup during the starting or which functions when the machine voltage has built up to a given value.

54. Reserved for future application.

55. **Power Factor Relay** is a relay that operates when the power factor in an ac circuit rises above or falls below a predetermined value.

56. **Field Application Relay** is a relay that automatically controls application of field excitation to an ac motor at some predetermined point in the slip cycle.

57. **Short-Circuiting or Grounding Device** is a primary circuit switching device that functions to short-circuit or to ground a circuit in response to automatic or manual means.

58. **Rectification Failure Relay** is a device that functions if one or more anodes of a power rectifier fail to fire, or to detect an arc-back, or on failure of a diode to conduct or block properly.

59. **Overvoltage Relay** is a relay that functions on a given value of overvoltage.

60. **Voltage or Current Balance Relay** is a relay that operates on a given difference in voltage or current input or output of two circuits.

61. Reserved for future application.

62. **Time-Delay Stopping or Opening Relay** is a time-delay relay that serves in conjunction with the device that initiates shutdown, stopping, or opening operation in an automatic sequence or protective relay system.

63. **Pressure Switch** is a switch which operates on given values or on a given rate of change, of pressure.

64. **Ground Protective Relay** is a relay that functions on failure of insulation of a machine, transformer, or of other apparatus to ground, or on flashover of a dc machine to ground.

    **NOTE:** This function is assigned only to a relay that detects flow of current from the frame of a machine or enclosing case or structure of a piece of apparatus to ground, or detects a ground on a normally ungrounded winding or circuit, it is not applied to a device connected in the secondary circuit of a current transformer, or in the secondary neutral of current transformers, connected in the power circuit of a normally grounded system.

65. **Governor** is the assembly of fluid, electrical, or mechanical control equipment used for regulating flow of water, steam, or other medium to the prime mover for such purposes as starting, holding speed or load, or stopping.

66. **Notching or Jogging Device** is a device that functions to allow only a specified number of operations of a given device, or equipment, or a specified number of successive operations within a given time of each other. It is also a device that functions to energize a circuit periodically or for fractions of specified time intervals, or that is used to permit intermittent acceleration or jogging of a machine at low speeds for positioning.

67. **AC Directional Overcurrent Relay** is a relay that functions on a desired value of ac overcurrent flowing in a predetermined direction.

68. **Blocking Relay** initiates a pilot signal for blocking of tripping on external faults in a transmission line or in other apparatus under predetermined conditions, or cooperates with other devices to block tripping or to block reclosing on an out-of-step condition or on power swings.

69. **Permissive Control Device** is generally a two-position, manually operated switch that, in one position, permits closing of a circuit breaker, or placing equipment into operation, and in the other position prevents the circuit breaker or equipment from being operated.

70. **Rheostat** is variable resistance device used in an electric circuit, which is electrically operated or has other electrical accessories, such as auxiliary, position, or limit switches.

71. **Level Switch** is a switch which operates on given level in a container or on a given rate of change of level.

72. **DC Circuit Breaker** is a circuit breaker that is used to close and interrupt a dc power circuit under normal conditions or to interrupt a circuit under fault or emergency conditions.

73. **Load-Resistor Contactor** is a contactor that is used to shunt or insert a step of loading limiting, shifting, or indicating resistance in a power circuit, or to switch a space heater in circuit, or to switch a light or regenerative load resistor of a power rectifier or other machine in and out of a circuit.

74. **Alarm Relay** is a relay other than an annunciator, as covered under device function 30, that is used to operate, or to operate in connection with, a visual or audible alarm.

75. **Position Changing Mechanism** is a mechanism that is used for moving a main device from one position to another in an equipment—for example, shifting a removable circuit breaker to and from the connected, disconnected, and test positions.

76. **DC Overcurrent Relay** is a relay that functions when current in a dc circuit exceeds a given value.

77. **Pulse Transmitter** is used to generate and transmit pulses over a telemetering or pilot-wire circuit to a remote indicating or receiving device.

78. **Phase-Angle Measuring or Out-of-Step Protective Relay** is a relay that functions at a predetermined phase angle between two voltages or between two currents or between voltage and current.

79. **AC Reclosing Relay** is a relay that controls automatic reclosing and locking out of an ac circuit interrupter.

80. **Flow Switch** is a switch which operates on a given flow or on a given rate of change of flow.

81. **Frequency Relay** is a relay that functions on a predetermined value of frequency (either under or over or on normal system frequency) or rate of change of frequency.

82. **DC Reclosing Relay** is a relay that controls automatic closing and reclosing of a dc circuit interrupter, generally in response to load circuit conditions.

83. **Automatic Selective Control or Transfer Relay** is a relay that operates to select automatically between certain sources or conditions in an equipment or perform a transfer operation automatically.

84. **Operating Mechanism** is the complete electrical mechanism or servo-mechanism, including operating motor, solenoids, position switches, etc., for a tap changer induction regulator. or any similar piece of apparatus which otherwise has no device function number.

85. **Carrier or Pilot-Wire Receiver Relay** is a relay that is operated or restrained by a signal used in connection with carrier-current or dc pilot-wire fault directional relaying.

86. **Lock-Out Relay** is an electrically operated hand, or electrically, reset relay or device that functions to shut down or hold an equipment out of service, or both, upon occurrence of abnormal conditions.

87. **Differential Relay** is a protective relay that functions on a percentage or phase angle or other quantitative difference of two currents or of some other electrical quantities.

88. **Auxiliary Motor or Motor Generator** is one used for operating auxiliary equipment, such as pumps, blowers, exciters, rotating magnetic amplifiers, etc.

89. **Line Switch** is a switch used as a disconnect, load-interrupter, or isolating switch in an ac or dc power circuit, when this device is electrically operated or has electrical accessories, such as an auxiliary switch, magnetic lock, etc.

90. **Regulating Device** is a device that regulates a quantity, or quantities, such as voltage, current, power, speed, frequency, temperature, and load, at a certain value or between certain (generally close) limits for machines, tie lines, or other apparatus.

91. **Voltage Directional Relay** is a relay that operates when voltage across an open circuit breaker or contactor exceeds a given value in a given direction.

92. **Voltage and Power Directional Relay** is a relay that permits or causes connection of two circuits when the voltage difference between them exceeds a given value in a predetermined direction and causes these two circuits to be disconnected from each other when the power flowing between them exceeds a given value in the opposite direction.

93. **Field-Changing Contactor** is a contactor that functions to increase or decrease, in one step, the value of field excitation on a machine.

94. **Tripping or Trip-Free Relay** is a relay that functions to trip a circuit breaker, contactor, or equipment, or to permit immediate tripping by other device, or to prevent immediate reclosure of a circuit interrupter if it should open automatically even though its closing circuit is maintained closed.

95. Numbers from 95 to 99 should be assigned only for those functions in
96. specific cases where none of the assigned standard device function
97. numbers are applicable. Numbers which are "reserved for future
98. application" should not be used.

# Appendix C

# INSTRUMENT TRANSFORMER ACCURACY CLASSES

## American National Standards Institute/Institute of Electrical and Electronics Engineers Standard Current Transformer Accuracy Classes

The typical nomenclature for classifying current transformers (CTs) using the American National Standards Institute (ANSI)/Institute of Electrical and Electronics Engineers (IEEE) method is as follows:

C200

- 200 — Secondary Terminal Voltage Rating
- C — Classification

Standard values for relaying CTs are:

| | |
|---|---|
| Classification: | C, K, T, H, or L |
| Secondary Terminal Voltage Rating: | 10, 20, 50, 100, 200, 400, or 800 volts |

The classification rating of the transformer describes the characteristics of the CT. For example, a C rating would indicate that leakage flux is negligible, and the excitation characteristic can be used directly to determine performance. A good rule of thumb to minimize CT saturation is to select a CT with a C rating of at least twice that required for maximum steady-state symmetrical fault current. Thus, the CT ratio error can be calculated. The K rating is the same as the C rating, but the knee voltage must be at least 70 percent of the secondary terminal voltage. This provides an extended linear region before the CT approaches saturation. T indicates that the ratio error must be determined by testing the CT. The T classification has a significant core leakage flux contributing to the ratio error. The H and L ratings are the old ANSI classifications and are only applicable to very old CTs manufactured before 1954. The L ratings were rated at a specified burden and at 20 times normal current. The H ratings were at any combination of burden from 5 to 20 times normal current.

## International Electrotechnical Commission (IEC) Standard CT Accuracy Classes

The typical nomenclature for classifying CTs using IEC method is as follows:

XX VA Class XX P XX

- XX (last) — Accuracy Limit Factor
- P — For Protection
- XX (after Class) — Accuracy Class
- XX VA — Continuous Voltampere (VA)

Standard values for relaying CTs are

| | |
|---|---|
| Continuous VA: | 2.5, 5, 10, 15, and 30 |
| Accuracy Classes: | 5 and 10 percent (%) |
| Accuracy-limit Factor: | 5, 10, 15, 20, and 30 |
| Rated Secondary Amperes: | 1, 2, 5 (5A preferred) |

The following CT, 30 VA Class 10 P 30 rated at 5 amps could output 30 VA/5 amperes (A) = 6 volts. It would have no greater than 10% error up to 30 X 6 = 180 volts secondary. The maximum permissible burden would be 30 VA/(5 A)$^2$ = 1.2 ohms. This would be equivalent to an ANSI/IEEE C180 CT.

The secondary terminal voltage rating is the voltage the CT will deliver to a standard burden at 20 times the rated secondary current without exceeding a 10% ratio correction. The ratio correction shall maintain within 10% for any secondary current from 1 to 20 times the secondary current.

The above CT is a C200. This indicates that the CT has a C classification rating, and the error can be calculated from the manufacturer's data. The 200 indicates that for a typical 5 amp CT, at 20 times overcurrent, the CT can deliver 200 volts into a burden of 2 ohms.

$$200V = 2\Omega * 5A * 20$$

## Consideration of Remanence

Performance of both C and T class current transformers is influenced by remanence or residual magnetism. The available core materials are all subject to hysteresis. The phenomenon is shown by plotting curves of magnetic flux density as a function of magnetizing force. When the current is interrupted, the flux density does not become zero when the current does.

When the current contains a dc component, the magnetizing force in one direction is much greater than in the other. The curves resulting are both displaced from the origin and distorted in shape, with a large extension to right or left in the direction of the dc component. If the current which is interrupted is high, or if it contains a large dc component and is interrupted when total flux is high, remanence will be substantial, perhaps being above the flux equivalent of the knee point shown on the excitation curve.

When the current transformer is next energized, the flux changes required will start from the remanent value, and if the required change is in the direction to add to the remanent flux, a large part of the cycle may find the current transformer saturated. When this occurs, much of the primary current is required for excitation, and secondary output is significantly reduced and distorted on alternate half cycles.

This condition can be corrected by demagnetizing the current transformer. It is accomplished by applying a suitable variable alternating voltage to the secondary, with initial magnitude sufficient to force the flux density above the saturation point, and then decreasing the applied voltage slowly and continuously to zero. If there is any reason to suspect that a current transformer has been recently subjected to heavy currents, possibly involving a large direct current (dc) component, or been magnetized by any application of dc voltage, it should be demagnetized before being used for any test requiring accurate current measurement. Test connections are identical to those required for the excitation test.

# Appendix D

# FIELD TESTING OF RELAYING CURRENT TRANSFORMER

There are a number of tests that can be performed on current transformers (CT) to ensure proper operation. Refer to American National Standards Institute (ANSI)/Institute of Electrical and Electronics Engineers (IEEE) Standard (Std.) C57.13.1-1981 for additional information on CT testing.

When testing CTs, it is important to understand remanence flux that may be present within the CT. The maximum remanent flux is obtained when the primary current is interrupted while the transformer is in a saturated state. In addition, testing that requires direct current (dc) to flow in the transformer winding will also result in remanence. Once the remanent flux is established, it is dissipated very little under service conditions.

When the remanent flux is of the opposite polarity to the flux due to the transient component of fault current, the CT tends to produce an undistorted secondary current. If the remanent flux is of the same polarity as the flux due to the transient component of fault current, then a distorted secondary waveform is probable.

The remanent flux will remain until the core is demagnetized. Demagnetizing the CT can be accomplished by applying a variable alternating current (ac) voltage to the CT secondary. The initial magnitude of the ac voltage should be at a level that will force the CT into saturation. The voltage is then slowly and continuously decreased to zero.

To avoid loss of performance due to remanence, CTs need to be demagnetized after each major disturbance on the system, continuity checks, or after resistance measurements on the system.

## Instrument Transformer Burden Measurements for CTs and Potential Transformers (PTs)

Current and potential transformers are used to reduce a primary current or voltage to a secondary value that is easier to work with. The load on the secondary side of the CT or PT is called the burden. The burden for CTs and PTs are defined as:

For CTs

$$Z_B = \frac{VA}{I^2}\Omega$$

For PTs

$$Z_B = \frac{V^2}{VA}\Omega$$

Where voltampere (VA) is the voltampere burden and I or V is the amperes or volts at which the burden was measured or specified.

In most cases, measuring the voltage and current on the system and then using ohms law will yield an estimate of the burden.

$$Z_B = \frac{V_{MEASURED}}{I_{MEASURED}}$$

This method is easy to perform with standard tools; but if more accurate values are warranted, then a phase angle meter is needed. The use of a phase angle meter will yield the angle between the voltage and current in the system. In this case, we will allow the voltage to have a reference angle of 0 degrees (°). The angle measured by the phase angle will be θ. Using this convention, the equation for the burden will yield:

$$Z_B = \frac{V_{MEASURED}\angle 0°}{I_{MEASURED}\angle \theta}$$

This equation will yield an answer in one of the following forms:

| | |
|---|---|
| Rectangular Coordinates: | $Z_B = r + xi\ \Omega$ |
| Polar Coordinates: | $Z_B = r\angle\delta°\ \Omega$ |

## Current Transformer Detailed Burden Explanation:

The total burden on the CTs is the combination of internal CT burden and the external burden on the system. The internal CT burden is the resistance of the secondary winding plus the resistance of the leads from the short-circuiting terminal block converted to voltamperes at rated current.

Measuring the internal resistance of the CT secondary winding can be accomplished by a digital ohmmeter. It is acceptable, in most cases, to use the average value of resistance of the CT in the three phases for calculations. If internal resistance and external impedance are needed for additional calculations, individual readings are needed, then the resistance of the full winding and tap should also be measured. It is acceptable to assume that all turns of the CT are of equal resistance, thus allowing calculation of per-turn and lead resistances. All measurements should be taken at the CT shorting terminal block.

Once the internal resistance of the CT has been determined, the externally connected burden can be calculated or measured. To determine the external connected burden in voltamperes, measure the voltage required to drive rated current (typically 5 amps) through the connected load. This method will yield only the resistive portion of the burden. If the reactive portion of the burden is also desired, a phase-angle meter must be used. Before taking any measurements, there are four basic conditions that should be considered:

1. To best represent inservice burden, the relays and other external devices must be on the correct tap.

2. Phase-to-neutral measurements of relay circuits can be high, especially if ground relays with sensitive settings are involved.

3. Phase-to-neutral and phase-to-phase measurements of bus differential circuits can yield high results due to impedance of the electro-mechanical differential relay operating coil.

Burden measurements can be compared to calculated values to confirm circuit wiring and satisfactory contact resistances of terminal blocks and test devices. These comparisons will also give indications to the performance of the system.

## Ratio Tests for CTs

There are typically two accepted methods for testing ratios of CTs.

### Voltage Method

A suitable voltage, below saturation, is applied to the full secondary winding; and the primary voltage is then measured using a high-impedance voltmeter. Saturation occurs with voltages above the knee of the saturation curve (see the curves at the end of this section). The turns ratio should be about the same as the voltage ratio. While performing this test, it is also possible to determine the tap selection ratios by measuring the tap selection voltage and comparing this to the voltage across the full winding.

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**The ANSI relay accuracy class voltage rating should never be exceeded during this test.**

---

### Current Method

This method requires a high current source, an additional current transformer of known turns ratio, a loading transformer, and two ammeters. Any CTs in series with the CT under test should be shorted and isolated if there is a chance of damage to other meters or relays or accidental tripping. The source of current for this test should be a loading transformer with a ratio that is approximately 120/240 - 6/12 volt (V) with a secondary capable of driving the rated secondary burden for 30 minutes.

The loading transformer should be driven using a variable auto transformer to control the output current. The test is performed by controlling the loading current over a range of values and comparing the output of the two secondary currents.

$$N_t = N_r \frac{I_r}{I_t}$$

Where: $N_r$ is the number of turns of the reference CT
$I_r$ is the measured current of the reference CT
$I_t$ is the measured current of the test CT

**NOTE: The accuracy of the reference transformer should be at least three times greater than the desired accuracy.**

## Polarity Check

There are generally three accepted testing methods to perform a polarity check on a CT.

### DC Voltage Test (Not Intended for Window Type CTs)

The dc test is performed by momentarily connecting a 6- to 12-Volt battery across the secondary of the CT. A millivoltmeter or milliammeter is connected across the primary side of the CT. While connecting to both the primary and secondary sides of the CT, careful attention to polarity should be observed. If the positive terminal of the battery is connected to the secondary terminal, $X_1$, and the meter is connected to the primary terminal, $H_1$, the meter hand should read a pulse in the positive direction when the dc voltage is applied and in the negative direction when the dc voltage is removed.

It is advisable to demagnetize any CT to be tested. Demagnetizing the CT can be accomplished by applying a variable ac voltage to the CT secondary. The initial magnitude of the ac voltage should be at a level that will force the CT into saturation. The voltage is then slowly and continuously decreased to zero. Additional methods of demagnetizing CTs are outlined in IEEE Standard Requirements for Instrument Transformers, IEEE Std. C57.13-1993, section 8.2.

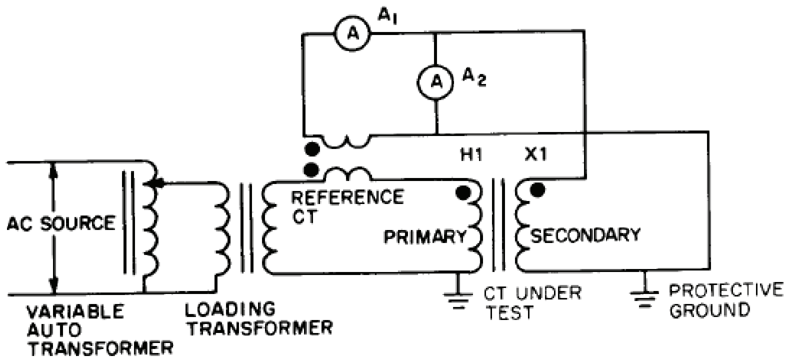
**CAUTION: A dangerous voltage may be generated while disconnecting the battery from the CT winding. The proper personal protective equipment should be used.**

### AC Voltage Test

Utilizing a dual channel oscilloscope, connect the primary to channel 1 and the secondary to channel 2. Apply an ac voltage to the secondary winding and then compare this value to the voltage induced on the primary winding. If the resulting waveforms are in agreement, the polarity is correct. If the scope is in calibration, then it may be possible to determine the turns ratio while performing the polarity check by measuring the magnitude of the voltage waveforms and multiplying by the scale factor of the oscilloscope.

### Current Method

If the current method was used for the ratio test, then the same method can easily be used to determine the polarity of the CT. The reference CT secondary should be paralleled with the test CT secondary. One ammeter is connected across the reference CT, while the second is connected in series with both the reference and the test CTs. If the polarity markings and the wiring is correct, then the two currents will sum in the $A_2$ ammeter; thus, if the $A_2$ ammeter reads higher than $A_1$, then the polarity is correct. An oscilliscope may also be used to easily determine the polarity.




**Drawing from ANSI/IEEE C57.13-1-1981, section 7.3.**

## Winding and Lead Resistance (CT Internal Resistance)

In order to calculate the ratio correction for a class C, CT, we must measure the internal resistance and external impedance (including the secondary lead resistance). Measuring the internal resistance and the external impedance of the system can be accomplished by utilizing a digital ohmmeter. It is acceptable in most cases to use the average value of resistance of the CT in the three phases for the calculations. If the internal resistance and the external impedance are needed for additional calculations individual readings are needed; then the resistance of the full winding and tap should also be measured. It is also acceptable to assume that all turns of the CT are of equal resistance, thus allowing us to calculate the per-turn and lead resistances. All measurements should be taken at the CT shorting terminal block.

Once the tests are complete, it is recommended to demagnetize the CT.

## Excitation Test

Excitation tests can be performed on both C and T class CTs, allowing for comparison with published or previously measured data. As with all field testing, it is highly recommended to trend current field data with previous results. Any major deviations should be noted and reviewed.

Before performing the excitation test, the CT should be demagnetized. Demagnetizing the CT can be accomplished by applying a variable ac voltage to the CT secondary. The initial magnitude of the ac voltage should be at a level that will force the CT into saturation. The voltage is then slowly and continuously decreased to zero.

Connect a high voltage ac test source to the secondary of the CT. The primary circuit should be open for the test. The input voltage to the secondary is then varied, and the current drawn by the winding at each selected value of voltage is recorded. Readings located near the knee of the curve are the most important. The secondary root mean square (rms) exciting current should be plotted on the abscissa, x-axis, while the secondary rms exciting voltage is plotted on the ordinate, y-axis. See the curves below for bushing type CTs. The point at which a 45° line is drawn tangent to the curve is called the "knee" of the excitation curve. Any deviations from the manufacturer's data or past test results should be investigated. Deviations from the curve may be an indication of turn-to-turn shorts internal to the CT, distortion of the supply voltage, or the presence of a completed conduction path around the CT core.

The selection of equipment for this test is very important. The ammeter should be able to read true rms current; a digital multimeter should be capable of taking these values. A digital rms multimeter should be sufficient for taking voltage measurements.

The test can also be performed by energizing the primary winding of the CT and measuring the secondary winding open-circuit voltage. The current must then be divided by the CT turns ratio in order to compare this data to standard curves provided by the manufacturer.

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**CAUTION: If voltage is applied to a portion of the secondary winding, the voltage across the full winding will be proportionately higher because of the autotransformer action. Current transformers should not remain energized at voltages above the knee of the excitation curve any longer than is necessary to take measurements. DO NOT EXCEED 1,500 VOLTS!**

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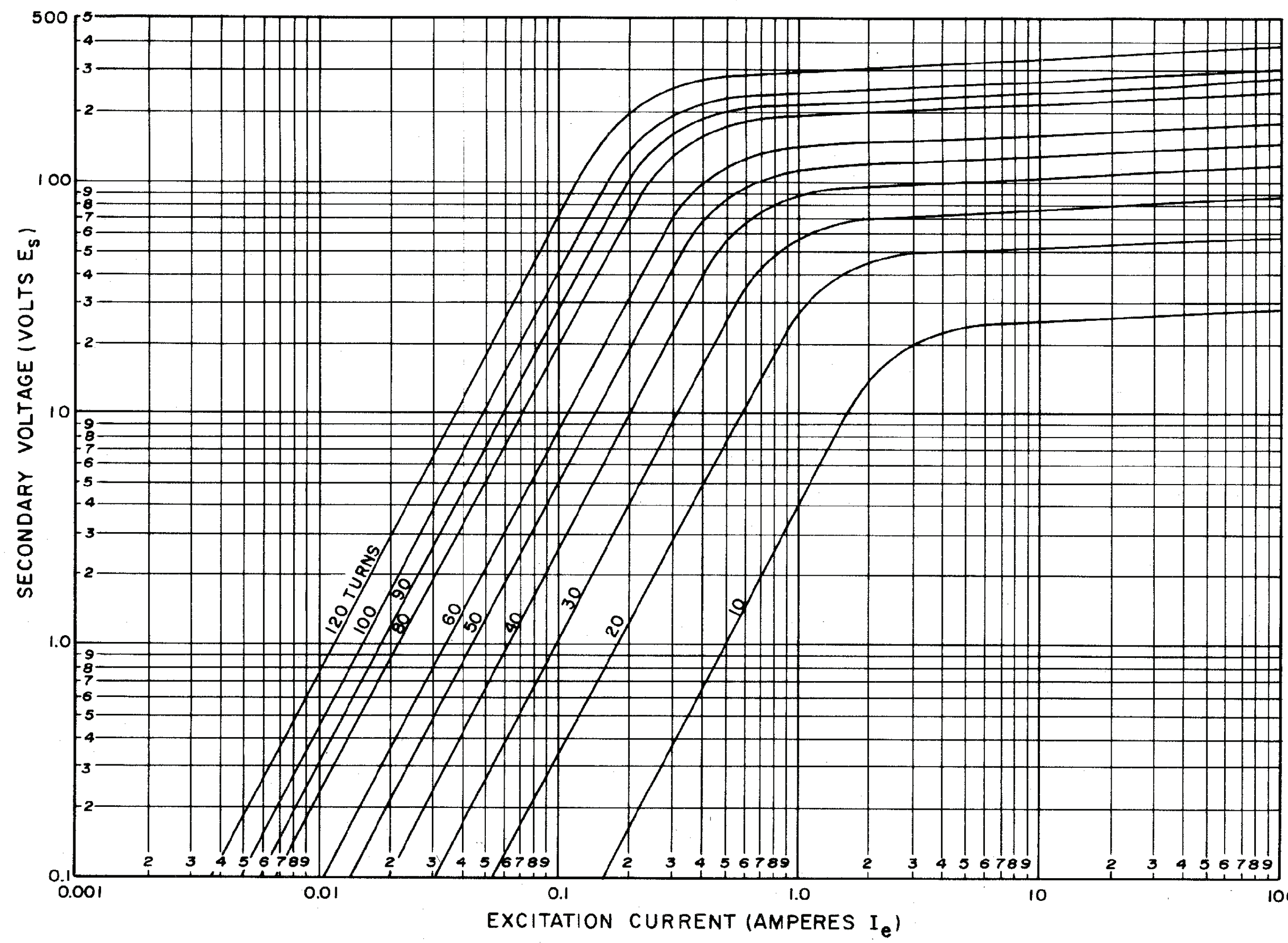
## Excitation Curves for CTs

Auxiliary CTs tend to saturate at much less secondary current and burden than large multi-ratio bushing type CTs. Excitation curves should be available for all CTs, especially for auxiliary CTs used in protective relaying circuits (see the figure below). Such curves can be derived by open-circuiting the primary and supplying the secondary with a 60-Hertz source while measuring voltage and current. Readings should be taken up to two times rated secondary current or to the point where voltage applied is 1,500 volts. Do not exceed 1,500 volts applied.




TYPICAL EXCITATION CURVES FOR 69 KV. MULTI-RATIO BUSHING TYPE CURRENT TRANSFORMERS

# Appendix E

# FIELD TESTING OF RELAYING POTENTIAL TRANSFORMER

## Burden Measurements

For secondary circuit burden measurements, see appendix D.

## Accuracy Test

With the relay at 100 percent of rated primary voltage at rated frequency and no burden (i.e., open circuited secondary), a ratio and phase angle test should be performed. These tests should also be repeated at rated primary voltage at rated frequency with rated burden.

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**Many of the tests called for in this section involve high voltage. Therefore, they should be performed only by experienced personnel familiar with hazards that exist in test setups and procedures. While some dangers are specifically pointed out herein, it is impractical to list all necessary precautions.**

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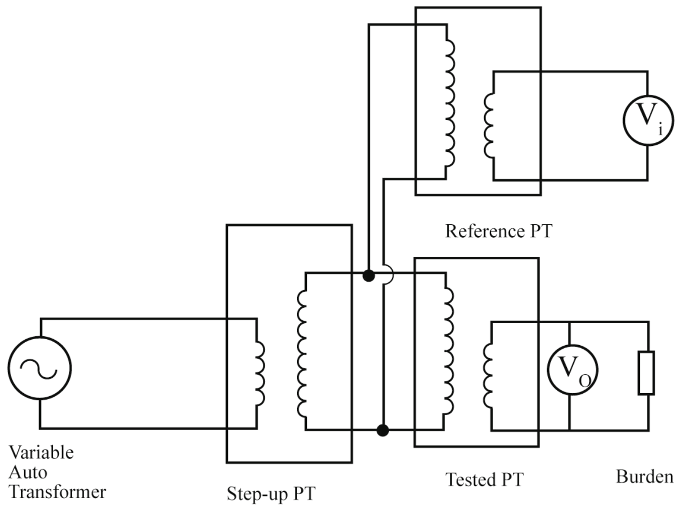
## Comparative Null Method

For testing the ratio of a PT, the recommended method for field use is to use a calibrated PT to compare the measured PT. Additional test methods for checking PT accuracy are outlined in Institute of Electrical and Electronics Engineers (IEEE) Standard (Std.) Requirements for Instrument Transformers, IEEE Std. C57.13-1993. Most PT tests outlined within Std. C57.13-1993 require specialized equipment. For additional assistance with testing of instrument transformers, contact the Electric Power and Diagnostics Team at 303-445-2305.

A PT of known calibration is required for this method, called the reference PT. Connect the secondary side of the step-up PT to a variable auto transformer. The primary side of the step-up PT is then connected to the primary side of the reference and tested PT. The secondary side of the PT under test will be connected to a resistive load that will emulate the burden as seen in the field. Two high-precision digital voltmeters will be used to compare the input voltage to the reference PT and the output voltage of the tested PT. See the following figure.




$$T_{Test} = \frac{V_i x T_{REFERENCE}}{V_O}$$

| | |
|---|---|
| $T_{Test}$: | Turns ratio of the tested PT |
| $T_{REFERENCE}$: | Turns ratio of the reference PT |
| $V_i$: | Measured input voltage |
| $V_o$: | Measured output voltage |

## Polarity Check

There are generally three accepted testing methods to perform a polarity check on a PT.

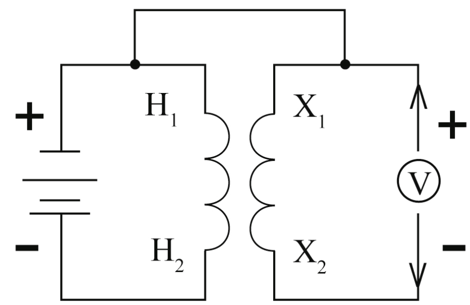
### Direct Current Voltage Test

To determine the polarity of a PT using this method, the following steps should be followed. See the following figure.

- Connect terminal 1 of the primary to terminal 1 of the secondary.
- Connect a direct current (dc) voltmeter across the primary of the PT.
- Connect a battery across the primary side of the PT ensuring the voltmeter reads a positive value.
- Disconnect the voltmeter from terminal 2 of the primary side of the PT and connect the voltmeter to terminal 2 of the secondary.
- Check the results of the test by remaking and breaking the battery circuit. If both H1 and X1 terminals are of the same polarity, the voltmeter will kick in the positive direction on make and in the negative direction on break.

**A dangerous voltage may be generated while disconnecting the battery from the transformer winding. The proper personal protective equipment should be used.**

**It is preferable to apply the battery voltage to the high-turn winding in order to minimize high-inductive kicks that might injure personnel or damage equipment. This is why the voltage is applied to the primary on a PT and secondary on a current transformer (CT).**




## Direct Comparison of Winding Voltages

To determine the polarity of a PT using the direct comparison method, follow the directions below.

- Connect the primary winding across a 60 Hertz (Hz) controlled voltage source. Connect H1 and X1 together. Connect terminal H2 to one terminal of a voltmeter and X2 to the other terminal of the voltmeter.
- Energize the circuit from the controlled voltage source at terminals H1 and H2.
- Read the value present on the voltmeter connected from H2 to X2 and also the voltage present at H1 to H2.

  If the voltage across H2 to X2 is less than the voltage from H1 to H2, then the polarity is correct.
- Use a scope to determine if signals are in phase.

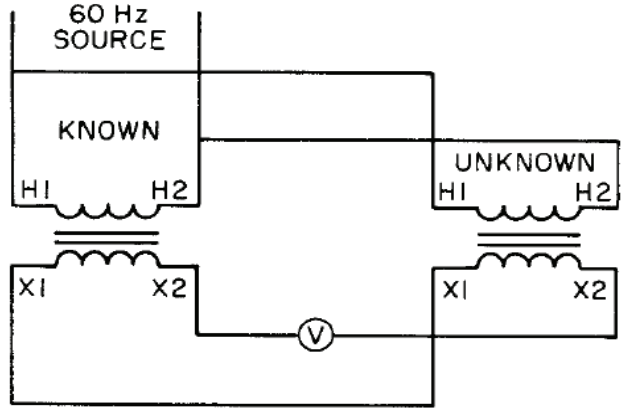



**Figure from IEEE Std. C57.13-1993, section 8.4.2.2.**

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**A dangerous voltage will be present on the high voltage terminals of both transformers.**

**The source voltage should always be impressed across the primary side of the PT; otherwise; dangerously high voltages might be encountered.**

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# Appendix F

# INSTRUMENT TRANSFORMER SECONDARY GROUNDING

Refer to American National Standards Institute/Institute of Electrical and Electronics Engineers Standard C57.13.3 - Guide for the Grounding of Instrument Transformer Secondary Circuits and Cases, for greater detail if needed. This standard contains the following important grounding requirements:

1. Instrument transformer secondary circuits should be connected to ground at only one point. This holds true regardless of the number of instrument transformer secondary windings connected to the circuit. The reasons for grounding at a single point are as follows:

   a. The flow of fault current through ground can cause potential difference at different ground points. If the instrument transformer secondary circuit is grounded at more than one point, this potential difference will result in flow of current through the relay, instrument, and meter coils. This results in instrument inaccuracies, relay misoperations, and possible destruction of relays. Also, high neutral conductor currents resulting from multiple ground connections can cause thermal damage to the neutral insulation.

   b. The use of a single grounding point facilitates the temporary removal and re-establishment of the ground connection when desired in order to test for insulation deterioration or spurious grounds in the instrument transformer secondary circuit.

2. The point of grounding in the instrument transformer secondary circuit should be at the first point of application. Grounding at the first point of application, rather than at the transformer, is preferred for the following reasons:

   a. Instrument transformers, their enclosures, and connections are more capable of withstanding the effects of voltage rise than control board components.

   b. The increased use of sensitive solid-state, and microprocessor devices in instrument transformer secondary circuits requires that voltage levels in the control boards be limited.

   c. It provides the maximum protection for personnel at the point where they are most apt to be exposed to circuit over voltages—the control board.

We are aware that instrument transformer secondary grounding is not according to the above recommendations at some Reclamation facilities. In some cases, the arrangement of secondary windings or devices in the circuit makes it necessary to ground at some point other than the control board in order to obtain correct equipment performance; however, all other instrument transformer secondary circuits that do not conform with the recommended grounding practices should, be modified to be in compliance. Contact the Relay Users Group, 86-68450, at 303-445-2305, if you need assistance.

# Appendix G

# INSTRUMENT TRANSFORMER PRIMARY AND SECONDARY INJECTION

## Primary Injection

Primary injection testing of protection systems is the preferred method to perform testing of the protection system.

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**CAUTION: The primary circuits must be de-energized, locked, and tagged out prior to beginning any primary injection testing.**

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Primary injection testing is performed by injecting primary currents and/or voltages onto the primary windings of the current transformers and potential transformers. A source(s) capable of supplying voltages and currents equal to normal and abnormal operation values must be available. Upon injecting currents and or voltages, instrument transformers then output secondary values to protective relays, annunciators, indicators, and other devices. As outlined in figure 3 (the block diagram in section 8), all components connected to the outputs of the relays are then tested. This also allows the user to test for correct polarity of the system while performing ratio checks on instrument transformers. Depending upon the primary voltage and current values and the need for de-energizing primaries, this method may not be feasible. Extreme care should be taken when performing primary injection testing as the currents and voltages injected into the instrument transformers can be hazardous. Only personnel trained, experienced, and qualified should be testing protective relay systems.

Primary test sets are commercially available that are capable of reaching most standard operating voltages and currents. The Hydroelectric Research and Technical Services Group, 86-68450, has a primary test set available for loan; contact 303-445-2300 for more information.

Primary injection testing is suited for the commissioning of new equipment or after a circuit modification, or the 3-6 year functional test, see FIST Volume 4-1B to ensure that all components of the system are correctly connected and operating properly. Primary injection testing will also provide valuable information as to the saturation level of the instrument transformers.

## Secondary Injection

Secondary injection testing of protection systems is the method used most often to perform routine maintenance. Secondary testing is accomplished by injecting single-phase or three-phase currents and voltages into the relay or into the CT or PT secondary that would emulate the secondary outputs both during normal and abnormal conditions. Each individual component of the system is then function tested to insure they operate as designed. Each individual component within the protection circuit needs to be tested to ensure correct operation, see figure 3 (the block diagram in section 8). Secondary voltages typically are 120 volts phase-to-phase, and secondary currents are typically 0-5 amps for timed functions of the relays. Higher currents (20 plus amps) may be required for instantaneous fault trip tests. These values can be obtained easily using multiple power supplies or a single modern relay test set (also known as a secondary test set). With secondary injection techniques, a primary outage is not normally required; and risks are reduced due to lower required voltages.

The downside to this form of testing is that instrument transformers must be tested separately. The polarity of the system must be confirmed using a different method to ensure that all components of the protection circuit are correctly interconnected. This form of testing also does not determine if the instrument transformers are becoming saturated and giving false information during normal operation; neither does it test them for correct ratios and correct outputs.

Therefore, separate tests must be performed on the instrument transformers when using secondary injection testing techniques. See appendices D and E.

# Appendix H

# POWER EQUIPMENT BULLETIN NO. 6

This document was extracted from Power Equipment Bulletin No. 6.

# Power Equipment Bulletin No. 6

**LOCKOUT RELAY ADVISORY**

**October 2, 2000**

The purpose of this bulletin is to inform Bureau of Reclamation (Reclamation) facilities of a lockout relay failure which greatly increased severity and duration of a bus fault incident.

## Background

During a recent incident at a Reclamation facility, failure of a lockout relay to trip protective breakers greatly increased the extent of the damage. In addition, production-related losses were extensive; and a worker was seriously injured. Proper operation of this relay would have greatly limited the scope of the incident.

## Possible Lockout Relay Failure Modes

One or more of failure modes 1 through 4 below were involved in this incident. The last two failure modes were not involved but should be checked when lockout relays are being tested.

**1. Wiring installation may twist the relay:** Many lockout relays have more than one stage (sets of contacts) added to the shaft to increase the number of breakers that can be tripped upon relay activation. Most of these relays were installed many years ago and were wired with solid conductors with "square pack" type wiring. These bundles of conductors are bent in perfect 90 squares and laced with waxed twine. These bundles are rigid and can twist the relay as they exit the cover, preventing proper operation of the contacts. This problem can be detected by electrical functional testing (preferred) or hand operation of the relay and closely observing the positions of all contacts. To operate the relay by hand, you must remove the cover and operate the solenoid armature manually. The relay cannot be activated from the front of the panel with the handle.

**2. Crowded wiring may block individual contacts:** On multi-staged relays, space for conductors is limited. All wires run along the top and bottom of the contacts, and individual contacts may be impeded when the cover is installed. With the cover off, the contacts may be free and operate properly; so this problem will not be obvious. The only way to detect this problem is to check individual contacts with an ohmmeter from the external terminal strip before the cover is removed.

**3. Shaft binding may twist the relay:** On longer relays (several stages), contacts near the handle may operate properly; and contacts further along near the other end can fail to operate. This is due to binding along the shaft and is associated with accumulated dust, dirt, rust, etc. Because the shaft is not perfectly rigid, the shaft may twist a little upon relay activation, causing some contacts to fail to operate. This problem can be detected by hand operating the relay or, preferably, by electrical functional testing.

**4. Aged relays and lack of exercise:** When the relay is activated, the shaft is rotated by springs along the shaft. Many of these relays are "original equipment" and may be as old as 70 years. They sit in a "ready" position for many years with the springs tensed. Over time, the springs weaken; and dirt and rust particles accumulate, partially binding the shaft. When called upon to operate, the springs only 'partially rotate' the shaft; and the contacts cannot trip protective breakers. This problem can be detected by hand operating the relay or, preferably, by electrical functional testing.

**5. Failed operating coils:** The relays are electrically activated by energizing a coil usually located on the end of the shaft opposite the handle. If a coil has failed (burned open), the relay cannot be activated to trip protective breakers. Electrically functionally testing (preferred) or checking the coil with an ohmmeter will detect this problem.

**6. Wiring errors or activation device failure:** Lockout relays cannot operate if there are wiring errors or if an activation device such as a differential relay fails to send a trip signal to the lockout relay. Electrical functional testing will reveal these problems.

## References

Manufacturer's instructions require that these relays be inspected and functionally tested on an annual basis. Also, National Fire Protection Association (NFPA) 70B, appendix H requires functional testing of all types of controls, protective relays, interlocks, and safety devices at least every 3 to 6 years. Facilities Instruction, Standards, and Techniques (FIST) Volume 3-8, *Field Test Procedure for Protective Relays*, section 8, requires an annual inspection and test trip. For circuit breakers, American National Standards Institute (ANSI)/Institute of Electrical and Electronics Engineers (IEEE) Standard (Std.) 37.20.3-5.3.4.1 requires "actual electrical operation of the component control devices or individual circuit continuity checks."

## Additional Information

A sister relay (not involved in this incident) on a related bus was also checked, and it too was in a failed state. Since there were no maintenance or test records for either relay, they could have been in a failed state for many years. Both lockout relays failed because of one or a combination of failure modes (1 thru 4), described above. The coils actuated properly but shafts failed to rotate fully, allowing many contacts to remain open when they should have closed.

## Recommendations

1. It is strongly recommended that facility management and staff take immediate steps to comply with manufacturer's instructions for functional testing and maintenance of lockout relays. NFPA, FIST volumes, and ANSI/IEEE also require proper maintenance for all control devices, protective relays, (including lockout relays), interlocks, and safety devices on a regular basis.

**It is extremely important that regular inspections, functional testing, and maintenance be performed on all lockout relays and all other safety and protective circuits.** Proper maintenance includes cleaning, manually exercising (if possible), electrical exercising, and functionally testing.

2. It is recommended that lockout relays be replaced if they are more than 15 years old. Lockout relays currently being purchased by Reclamation are similar to Electroswitch high speed multi-contact lockout relays type LOR-1. Please contact 86-68440 for more information. Information on these relays may also be viewed at www.electroswitch.com.

## Information Sources and Links

NFPA and ANSI/IEEE codes are not available on the web unless you are a member. The Reclamation Service Center is a member, and the referenced codes/standards may be ordered from the library in Denver free of charge.

Manuals on General Electric type HEA relays can be found at www.ge.com.

# Appendix I

## ADJUSTMENT OF WESTINGHOUSE TYPE KD RELAYS

Reclamation personnel have experienced considerable difficulty with Westinghouse Type KD relays due to inadequate contact restraint upon loss of restraint potential. When the relay is adjusted according to the manufacturer's instructions, the restraint in the contact opening direction is so slight that vibration or jarring of the switchboard panel will close the contacts, and they sometimes remain closed. This causes a problem on schemes where the restraint potential is obtained from the line (in a ring bus scheme, for example) or when loss of main bus potential occurs (when restraint potential is obtained from the bus) since it is impossible to close the breaker under this condition. Present design practice is to provide overcurrent supervision of distance relays where potential is line connected. In older installations where overcurrent supervision is not provided, the existing relay adjustment instructions should be modified to ensure that the relays will rest when they are de-energized. Westinghouse relay engineers have provided the following supplementary instructions.

> If minimum voltage at the relay, for a fault at the balance point setting, is less than 30 volts secondary line-to-line, then the spring restraint should be adjusted as per pages 25 and 27 of I.L.41-491H for Type KD and KD-1 relays, or as per pages 24 and 25 of I.L. 41-491.4N for Type KD-4 and KD-41 relays. However, if with this adjustment the relay contacts fail to reset when relay is de-energized, the spring restraint should be increased only enough to hold the moving contact against the backstop while the relay is de-energized.
>
> Where minimum voltage at the relay, for a fault at the balance point setting, is 30 volts line-to-line or more, the spring restraint for both three-phase and phase-to-phase element may be set as follows: Connect relay to Test No. 1 except reverse the voltage phase sequence by interchanging the connections to Brush 1 and Brush 2. Adjust voltages VlF2F and V2F3F for 3.5 volts each. Position the moving contact spring adjuster so that the moving contact just restrains against the backstop. This adjustment will make the three-phase unit characteristic somewhat nonlinear with respect to balance point voltage, but the effect is almost negligible at 30-volt line-to-line and above.
>
> There is one other possible problem due to loss of potential on these relays. If the relays are de-energized because of the tripping of remote source circuit breakers, the contacts may momentarily blip closed due to the transient decay of energy in the potential circuit of the relay. If it is desired to prevent tripping under such conditions where the relay can be de-energized without opening the "52 a" contact; the recommended solution is to use fault detectors as stated on page 3 of I.L. 41-491H and page 1 of I.L. 41-491.4N.