RECLAMATION
Managing Water in the West

Machine Condition/Vibration Monitoring

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EPRI Fleet-Wide and Generator On-line Monitoring Interest Group Meeting
Oct 22-24, 2012
Dallas, TX

U.S. Department of the Interior
Bureau of Reclamation
New Hydro Generator Condition Monitoring System

• The Hydropower Diagnostics and SCADA Group has been researching and evaluating various machine condition monitoring systems for use in Reclamation hydroplants over the past several years.

• The overall objectives of a hydrogenerator condition monitoring system are
  – to reduce operation and maintenance costs
  – increase plant availability
  – preserve Reclamation’s infrastructure by providing current and relevant information on the present condition of plant equipment.
Commercial vs. In-house System

- Evaluated 5 commercially available MCM systems
  - Typical cons
    - High initial cost
    - Limited ability to customize
    - Limited ability or expensive to expand
    - Hardware and software interdependent

- Evaluated several “low cost” data acquisition alternatives
  - Typical cons
    - Poor long term trending features
    - Limited display options
    - Hardware and software interdependent

What should I do?
Commericially Available Systems

• **Electronic/computer systems in general**
  – Ongoing support from electronic or software system is less than adequate
    • System becomes obsolete within a couple of years due to technical advancements
    • Technical support stops before system needs to be replaced
    • No ability to upgrade system – must purchase new system
    • Spare parts are not available
    • Manufacturer goes out of business or is bought out

• **In-house support is often required to keep these system running**
New Hydro Generator Condition Monitoring Program

• It was decided to pursue an in-house written software application.

• Main advantages
  – This approach allows for in-house expansion and customization of the software.
  – Works with a variety of commercially available DAQ equipment

• The development of the software for the Hydrogenerator Condition Monitoring system has been completed.
  – The initial release is now available and focuses on vibration monitoring.
New Hydro Generator Condition Monitoring Program

- This software package has several advantages over commercially available software, including:
  - Open-source code
  - Free to Reclamation powerplants
  - Expandable and adaptable to meet the end users changing needs
  - Plug In architecture
  - Works with a variety of data acquisition hardware
# Vibration Monitoring - Cost

<table>
<thead>
<tr>
<th>Item</th>
<th>Qty</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximity Probe</td>
<td>6</td>
<td>$3,600</td>
</tr>
<tr>
<td>Power Supply for Proximity Probes</td>
<td>1</td>
<td>$100</td>
</tr>
<tr>
<td>NI Compact DAQ Ethernet Backplane</td>
<td>1</td>
<td>$1,400</td>
</tr>
<tr>
<td>NI 9201 12-bit Analog Input Module</td>
<td>1</td>
<td>$400</td>
</tr>
<tr>
<td>Computer/monitor</td>
<td>1</td>
<td>$2,500</td>
</tr>
<tr>
<td>Software (FREE)</td>
<td>1</td>
<td>$0</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td></td>
<td><strong>$8,000</strong></td>
</tr>
</tbody>
</table>

• Users need to purchase the hardware and probes
• Cost for 4-units ~ $19,000
• Plus labor for installation and schematics
Open-source code

• The source code is fully accessible and is available to all Reclamation plants.
• End users have the option to modify and expand the software to meet their needs.
  – Writing new “plugins” for custom measurements, displays, calculations, alarms, etc., or
  – Changing the source code if necessary.
• The software is expandable.
  – The initial basic vibration monitoring system can be expanded to a full hydro generator machine condition monitoring system by adding new “plugins”.
Plugin Hardware Architecture

• The software can be expanded via “plugins” to communicate with virtually any existing or future hardware.

• Designed to work with a wide variety of plant equipment including
  – off-the-shelf data acquisition systems,
  – specialized monitoring systems, and
  – other computer systems.

• Plugins can be reused once the code has been fully developed and the performance has been verified; while also providing the option to easily make changes to each plugin to add additional functionality later.
## Hydroplant Machine Condition Monitoring System

### Core Measurements

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Sensor Locations</th>
<th>Output Displays</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotation</td>
<td>Keyphasor</td>
<td>Bar Graph, Trend</td>
</tr>
<tr>
<td></td>
<td>Lower Guide Bearing – X/Y</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Upper Guide Bearing – X/Y</td>
<td></td>
</tr>
<tr>
<td>Guide Bearing Temperature</td>
<td>Turbine Guide RTD</td>
<td>Bar Graph, Trend</td>
</tr>
<tr>
<td></td>
<td>Lower Guide RTD</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Upper Guide RTD</td>
<td></td>
</tr>
<tr>
<td>Thrust Bearing Temperature</td>
<td>Thrust Bearing RTD</td>
<td>Bar Graph, Trend</td>
</tr>
<tr>
<td>Stator Temperature</td>
<td>Stator RTDs</td>
<td>Bar Graph, Trend</td>
</tr>
<tr>
<td>Governor Status</td>
<td>Speed Changer Set Point, Wicket Gate Position</td>
<td>Bar Graph, Trend</td>
</tr>
</tbody>
</table>
## Core Measurements

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Sensor Locations</th>
<th>Output Displays</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exciter Status</td>
<td>Field Current, Field Voltage, PSS Output</td>
<td>Bar Graph, Trend</td>
</tr>
<tr>
<td>Generator Status</td>
<td>Active Power, Reactive Power, Stator Current, Stator</td>
<td>Bar Graph, Trend, Magnitude/Angle</td>
</tr>
<tr>
<td></td>
<td>Voltage, Frequency, Air House Temperature</td>
<td></td>
</tr>
</tbody>
</table>
## Recommended Additional Measurements

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Sensor Locations</th>
<th>Output Displays</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rough Zone</td>
<td>Draft Tube Pressure</td>
<td>Waveform, Bar Graph, Trend</td>
</tr>
<tr>
<td>Governor Status</td>
<td>Oil Pump Running, Penstock Pressure</td>
<td>Bar Graph, Trend</td>
</tr>
<tr>
<td>Exciter Status</td>
<td>Voltage Regulator Set Point, Exciter Limiter Active, Field Breaker Operation</td>
<td>Bar Graph, Trend</td>
</tr>
<tr>
<td>Governor Status</td>
<td>Cooling Water Pressure, Cold Water Flow, Cold Water Inlet Temp, Cold Water Outlet Temp, Bulkhead Oil Pump Running, Split Phase Current, Unit Breaker Operation, 86 Relay Operation</td>
<td>Bar Graph, Trend</td>
</tr>
</tbody>
</table>
## Recommended Additional Measurements

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Sensor Locations</th>
<th>Output Displays</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant Status</td>
<td>Fore Bay Elevation, Tail Bay Elevation, Air Compressor Running, Sump Pump Running, Motor (General) Running, Bus Voltage, Bus Current, Bus Breaker Operation, Plant Temp, Outside Temp</td>
<td>Bar Graph, Trend</td>
</tr>
<tr>
<td>Power Transformer Status</td>
<td>Oil Temperature, Gas Pressure, Cooling Fan Running</td>
<td>Bar Graph, Trend</td>
</tr>
</tbody>
</table>
## Optional Measurements

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Sensor Locations</th>
<th>Output Displays</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thrust Bearing Oil Film Thickness</td>
<td>Bearing Shoes</td>
<td>Waveform vs. 1/Rev Bar Graphs – Magnitude/Angle Orbit Plots, Trend, FFT, Waterfall</td>
</tr>
<tr>
<td>Bearing Supports</td>
<td>Turbine Bearing Support - X/Y</td>
<td>Waveform vs. Pole, Orbit Plots, Trend, FFT, Waterfall</td>
</tr>
<tr>
<td></td>
<td>Upper Guide Bearing Support – X/Y</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lower Guide Bearing Support – X/Y</td>
<td></td>
</tr>
<tr>
<td>Wear Ring Clearance</td>
<td>Wear Ring</td>
<td>Waveform vs. Pole or 1/Rev, Trend, Gap Plot</td>
</tr>
<tr>
<td>Shaft Torque</td>
<td>Shaft – Z</td>
<td>Waveform vs. Pole or 1/Rev, Bar Graphs – Magnitude/Angle, Orbit Plots, Trend</td>
</tr>
<tr>
<td></td>
<td>Bridge – Z</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shaft Torque</td>
<td></td>
</tr>
</tbody>
</table>
# Optional Measurements

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Sensor Locations</th>
<th>Output Displays</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cavitations</td>
<td>Draft Tube or Head Cover or Wicket Gate Shaft or Shaft</td>
<td>Trend, Bar Graphs</td>
</tr>
<tr>
<td>Shaft Voltage</td>
<td>Lower Guide Voltage</td>
<td>Waveform vs. Pole or 1/Rev, Bar Graph</td>
</tr>
<tr>
<td>Governor/ T Side Status</td>
<td>Servo Motor Stroke Servo Motor Pressure Gate Limit Pilot Valve Stroke Servo System Friction</td>
<td>Trend, Bar Graphs, Waveform</td>
</tr>
<tr>
<td>Turbine Gate Leakage</td>
<td>Turbine or Penstock</td>
<td>Trend, Bar Graphs</td>
</tr>
</tbody>
</table>
## Optional Measurements

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Sensor Locations</th>
<th>Output Displays</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generator Air Gap</td>
<td>Air Gap</td>
<td>Waveform vs. Pole or 1/Rev, Bar Graphs, Trend, Waterfall, Rotor Shape, Stator Shape, Airgap Plots</td>
</tr>
<tr>
<td>Air Gap Flux</td>
<td>Magnetic Flux</td>
<td>Waveform vs. Pole or 1/Rev</td>
</tr>
<tr>
<td>Generator Partial Discharge</td>
<td>Partial Discharge</td>
<td>Bar Graph, Trend</td>
</tr>
<tr>
<td>Generator Efficiency</td>
<td>Flow Measurement</td>
<td>Bar Graph</td>
</tr>
<tr>
<td>Condenser Operation</td>
<td>Makeup Air Valve Open</td>
<td>Trend</td>
</tr>
</tbody>
</table>
## Optional Measurements

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Sensor Locations</th>
<th>Output Displays</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circuit Breaker</td>
<td>Trip Signal</td>
<td>Time Delay</td>
</tr>
<tr>
<td></td>
<td>Bus Current</td>
<td>Waveform</td>
</tr>
</tbody>
</table>

### Other Measurements

- Stator Frame/Core Vibration
- Stator Bar Vibration
- Ground Relay Voltage
- Stator Core Temperature
- Shear Pin Monitor
- Stator End Winding Temperature
- Rotor Pole Temperature
- Cooling Air Analysis (CHx)
- Cooling Air Ozone
- Relay Fault Waveforms
Additional Factor Supporting MCM Implementation

• Reclamation-wide recommendation to add vibration monitoring to all generators following Russian Hydro incident (Sayano-Shushenskaya power station)

• WECC Testing Requirements
Russian Hydro Accident
August 17, 2009

This looks really bad!
What Could Have Prevented the Accident?

• A condition monitoring system could have detected the onset of this vibration and alerted the operators that there was a problem before the failure occurred.

• In response to this incident, Reclamation published Power Equipment Bulletin 42, which includes a Category 2 recommendation for installation of vibration monitoring systems for all Reclamation’s units.
WECC Testing

- **WECC requires model validation testing every 5 years**
- **Test can be accomplished**
  - Off-line
  - On-line
- **MCM system can be used to capture system transients and generator response.**
  - Info can be used to validate WECC generator model
  - Requires high bandwidth generator terminal quantity transducer
Reclamation Designed and Built
Terminal Quantity Transducer Overview

- 3-Phase 120 Volt (PT Inputs)
- 3-Phase 5 Amp (CT Inputs)
- 8 Outputs (±10VDC)
  (Each Channel = 20Hz Bandwidth)
  - Frequency Deviation
    • 0.002 Hz Res., 0.01-120Hz
  - Real Power
    • 0.03 W Res., ±1000W FS
  - Reactive Power
    • 0.03 Vars Res., ±1000W FS
  - Terminal Voltage
    • 0.004 VAC Res., 0-240 VAC
  - Stator Current
    • 0.001 A RMS Res., 0-35 Amps RMS
  - 3 Spares
- 3 voltage waveform outputs
- 3 current waveform outputs
Terminal Quantity Transducer Features

- 9-36 Volt DC Powered
- Isolated Power Supply
- Reverse & Over Voltage Protection
- Onboard Fuses PTs & PSU
- 5 Blown Fuse Indicators
- Microprocessor based
- Simultaneous Sampling
- Digital Calibration
- Mini USB Bootloader
MCM Software – Version 1.0

• The initial development cost was about $150k.
  – The core application is written in VisualBasic.NET 3.5
  – Data analysis is performed using National Instruments’ “Measurement Studio” libraries
  – Software configuration and data file references are stored in a Microsoft SQL Server database

• The system has been installed at Palisades Power Plant and has been acquiring data for almost a year.
MCM v1.0 – Palisades Example
MCM v1.0 – Palisades Example
MCM Software – Version 2.0

- Version 2 cost about $90k to develop
- Written in VisualBasic.NET 4.0
- Added many features including:
  - Server/client model
    - Server computer acquires, analyzes, and stores all data
    - Server application runs as a Windows service
    - Any computer on the same network can access real-time
      and/or historical data using a MCM viewer application
  - Improved configuration interface
  - Improved data storage
  - Improved trending and plotting abilities
  - Ability to plot historical and real-time data on the same plot
MCM Server Framework v2.0

Device Plugins
NI hardware, etc.

Virtual Plugins
RMS, Displacement, etc.

Trigger Plugins
Threshold, %Change, etc.

Action Plugins
Alarm contacts, email, etc.

Circular Buffer

Long-term Storage
(Trends, historical data, etc.)

Local Network

MCM Core Service
(Runs as a Windows Service)
MCM v2.0 – Server Configuration

- Save/Load and MCM Service Control
- Items to configure
- Select an item in the tree to configure
  - Organizational folder or plugin, right-click on the appropriate item (I.E. Acquisition)
- Server Status
  - CPU: Running
  - Memory: Running
  - Storage Drive: Running
MCM v2.0 – Windows Service Setup

MCM Service Configuration

Service Log

Service Configuration

Startup Type: Auto
Service Name: MCM on MCM-PC

- Disable Acquisition
- Wait for CPU usage to drop below 10 % for 30 seconds before starting

MCN Log

<table>
<thead>
<tr>
<th>Date/Time</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/18/2012 9:06:18 AM</td>
<td>Service stopped successfully.</td>
</tr>
<tr>
<td>9/18/2012 10:08:45 AM</td>
<td>Service started successfully.</td>
</tr>
<tr>
<td>9/18/2012 10:10:14 AM</td>
<td>Service stopped successfully.</td>
</tr>
</tbody>
</table>
MCM v2.0 – Data Storage Setup

Data Repository Configuration

Data Storage Configuration
- Enable Data Storage
- Storage Location: C:\Users\bravers\Desktop\MCM2\MCM Core\bin\Debug
- Approximate File Size: 1.00 GB
- Alarm when HDD space drops: 5.00 GB

Drive Allocation (C:)
- Total Size: 223GB
- 71%: Used Space
- 24%: MCM Data
- 2%: Free Space
- 3%: Circular Buffer
MCM v2.0 – Circular Buffer Setup

The circular buffer stores raw waveforms for a period of days. This is useful in cases where a user wishes to view data that the software wasn’t setup to record. Data can be extracted from the circular buffer and added to the data repository.
MCM v2.0 – Security Configuration

Configures which users are allowed to view the data on this server.
We’re currently developing a hardware “watchdog” device that automatically reboots the PC if something goes wrong.
MCM v2.0 – Self-Documentation

The software has a “self-document” feature. It generates a report containing the entire MCM server configuration.
MCM v2.0 – Data Acquisition Setup

The improved device configuration window makes it easy to configure a large number of channels.

<table>
<thead>
<tr>
<th>Enabled</th>
<th>Name</th>
<th>Voltage Range</th>
<th>Connection Type</th>
<th>Measurement Type</th>
<th>Gain</th>
<th>Offset</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ai0</td>
<td>Channel 1</td>
<td>-10 to 10</td>
<td>Differential</td>
<td>Voltage</td>
<td>1</td>
<td>0</td>
<td>Volts</td>
</tr>
<tr>
<td>ai1</td>
<td>Channel 2</td>
<td>-10 to 10</td>
<td>Differential</td>
<td>Voltage</td>
<td>1</td>
<td>0</td>
<td>Volts</td>
</tr>
<tr>
<td>ai2</td>
<td>Channel 3</td>
<td>-10 to 10</td>
<td>Differential</td>
<td>Voltage</td>
<td>1</td>
<td>0</td>
<td>Volts</td>
</tr>
<tr>
<td>ai3</td>
<td>Channel 4</td>
<td>-</td>
<td>Differential</td>
<td>Voltage</td>
<td>1</td>
<td>0</td>
<td>Volts</td>
</tr>
<tr>
<td>ai4</td>
<td>Channel 5</td>
<td>-</td>
<td>Differential</td>
<td>Voltage</td>
<td>1</td>
<td>0</td>
<td>Volts</td>
</tr>
<tr>
<td>ai5</td>
<td>Channel 6</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ai6</td>
<td>Channel 7</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ai7</td>
<td>Channel 8</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The new “Scaling Wizard” can automatically calculate scale factors for a given channel.
The new action mapping dialog makes it easy to specify which actions are taken for a given condition. (I.E. Close the Unit 1 Vibration Alarm contact when a bearing’s displacement exceeds a specified value.)
Data reduction rules can be configured to reduce the amount of data that is placed in long-term storage. For example, in normal operating conditions, it doesn’t make sense to store reactive power at 1kHz. A reduction rule can be configured to, for example, only store reactive power when it changes by 5%.
MCM Viewer Framework v2.0

MCM Servers in Local Network

User-defined data sets
- Real-time data
- Long-term Trends
- Historical Data

MCM Viewer Application

Display Plugins
Waveform, orbital, gauges, etc.

User defined “views”
Real-time, analytical, etc.

I now LOVE my job!
MCM v2.0 – Editing a View

Create views for different applications (i.e., control panel display, analysis, etc.)

Create and edit view tabs

Display plugins toolbox. Drag an item into the display.

Drag and resize items to create a display

Create datasets to view historic data
MCM v2.0 – Display Properties

Editing the appearance of a gauge display plugin.
Questions?

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