

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?



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Commercially 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



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Vibration Monitoring - Cost

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

- 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

Measurements	Sensor Locations	Output Displays
Rotation	Keyphasor	Bar Graph, Trend
Guide Bearing Vibration/Runout	Turbine Guide Bearing – X/Y Lower Guide Bearing – X/Y Upper Guide Bearing – X/Y	Waveform vs. Pole or 1/Rev Bar Graphs – Magnitude/Angle Orbit Plots, Trend, FFT, Waterfall
Guide Bearing Temperature	Turbine Guide RTD Lower Guide RTD Upper Guide RTD	Bar Graph, Trend
Thrust Bearing Temperature	Thrust Bearing RTD	Bar Graph, Trend
Stator Temperature	Stator RTDs	Bar Graph, Trend
Governor Status	Speed Changer Set Point, Wicket Gate Position	Bar Graph, Trend

Core Measurements

Measurements	Sensor Locations	Output Displays
Exciter Status	Field Current, Field Voltage, PSS Output	Bar Graph, Trend
Generator Status	Active Power, Reactive Power, Stator Current, Stator Voltage, Frequency, Air House Temperature	Bar Graph, Trend, Magnitude/Angle

Recommended Additional Measurements

Measurements	Sensor Locations	Output Displays
Rough Zone	Draft Tube Pressure	Waveform, Bar Graph, Trend
Governor Status	Oil Pump Running, Penstock Pressure	Bar Graph, Trend
Exciter Status	Voltage Regulator Set Point, Exciter Limiter Active, Field Breaker Operation	Bar Graph, Trend
Governor Status	Cooling Water Pressure, Cooling Water Flow, Cooling Water Inlet Temp, Cooling Water Outlet Temp, Bulkhead Oil Pump Running, Split Phase Current, Unit Breaker Operation, 86 Relay Operation	Bar Graph, Trend

Recommended Additional Measurements

Measurements	Sensor Locations	Output Displays
Plant Status	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	Bar Graph, Trend
Power Transformer Status	Oil Temperature, Gas Pressure, Cooling Fan Running	Bar Graph, Trend

Optional Measurements

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

Optional Measurements

Measurements	Sensor Locations	Output Displays
Cavitations	Draft Tube or Head Cover or Wicket Gate Shaft or Shaft	Trend, Bar Graphs
Shaft Voltage	Lower Guide Voltage	Waveform vs. Pole or 1/Rev, Bar Graph
Governor/ Turbine Status	Servo Motor Stroke Servo Motor Pressure Gate Limit Pilot Valve Stroke Servo System Friction	Trend, Bar Graphs, Waveform
Turbine Gate Leakage	Turbine or Penstock	Trend, Bar Graphs

Optional Measurements

Measurements	Sensor Locations	Output Displays
Generator Air Gap	Air Gap	Waveform vs. Pole or 1/Rev, Bar Graphs, Trend, Waterfall, Rotor Shape, Stator Shape, Airgap Plots
Air Gap Flux	Magnetic Flux	Waveform vs. Pole or 1/Rev
Generator Partial Discharge	Partial Discharge	Bar Graph, Trend
Generator Efficiency	Flow Measurement	Bar Graph
Condenser Operation	Makeup Air Valve Open	Trend

Optional Measurements

Measurements	Sensor Locations	Output Displays
Circuit Breaker	Trip Signal Bus Current	Time Delay Waveform

Other Measurements

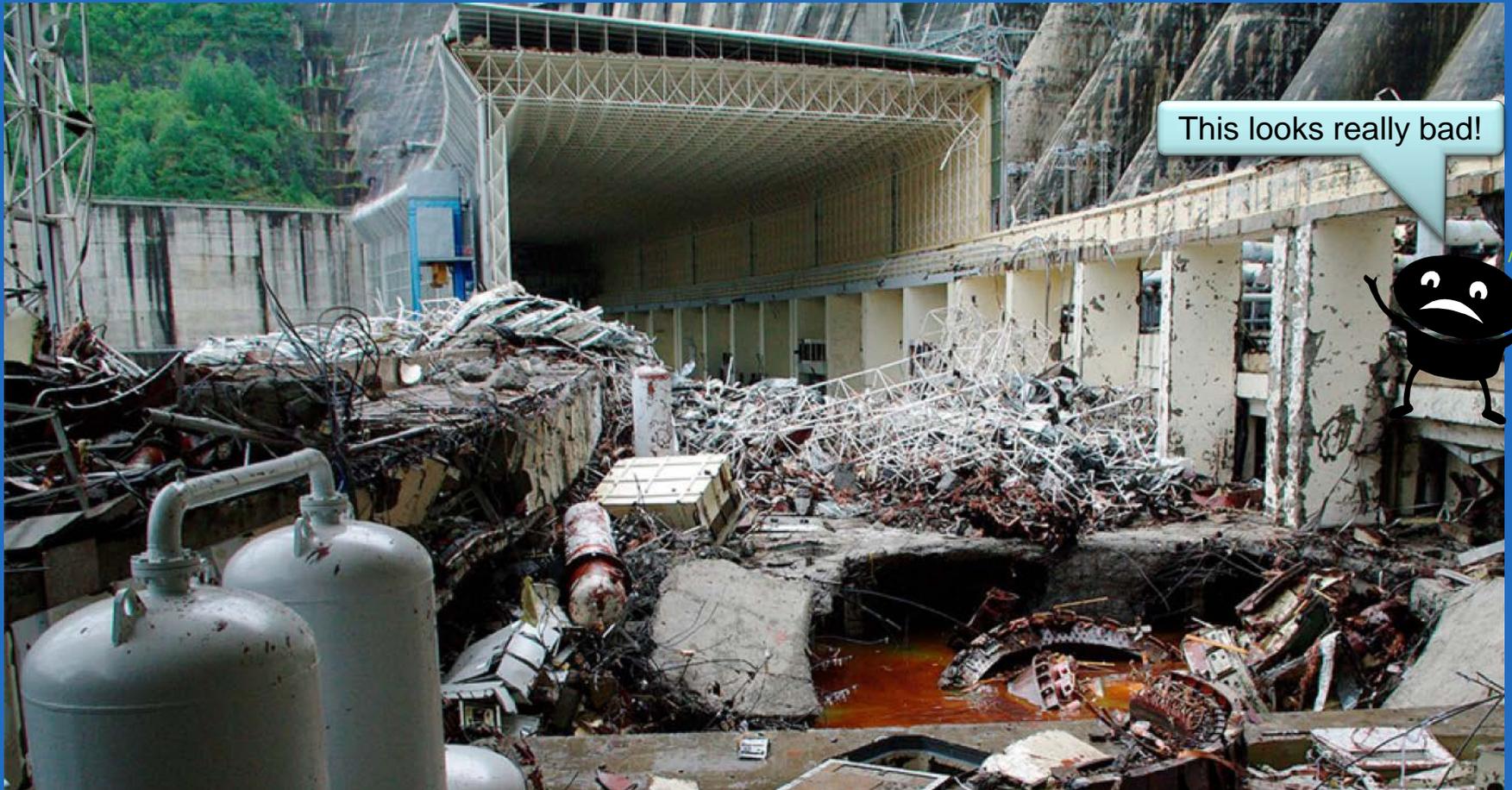
- Stator Frame/Core Vibration
- Stator Bar Vibration
- Ground Relay Voltage
- Stator Core Temperature
- Shear Pin Monitor
- Stator End Winding Temperature
- Rotor Pole Temperature
- Cooling Air Analysis (CHx)
- Cooling Air Ozone
- Relay Fault Waveforms

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



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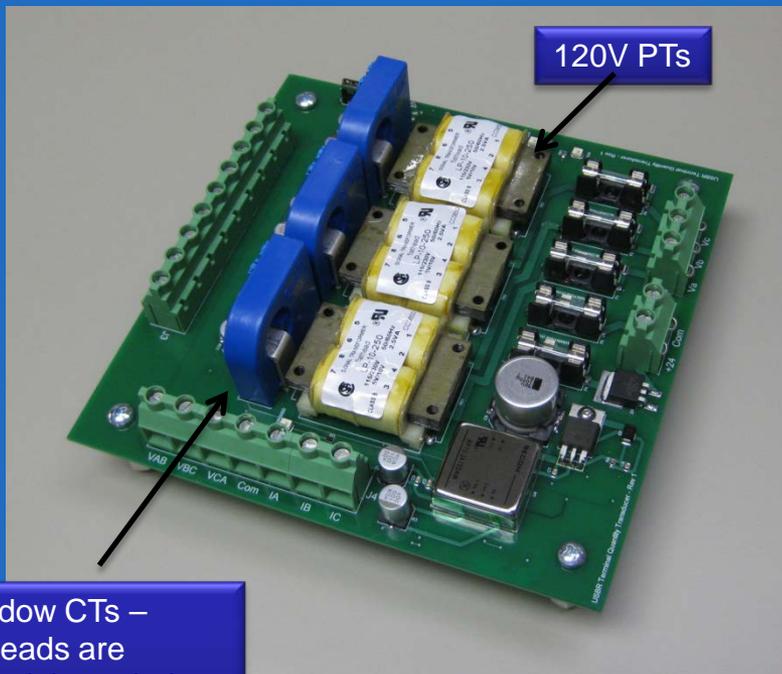
What Could Have Prevented the Accident?

- 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
 - or
 - 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



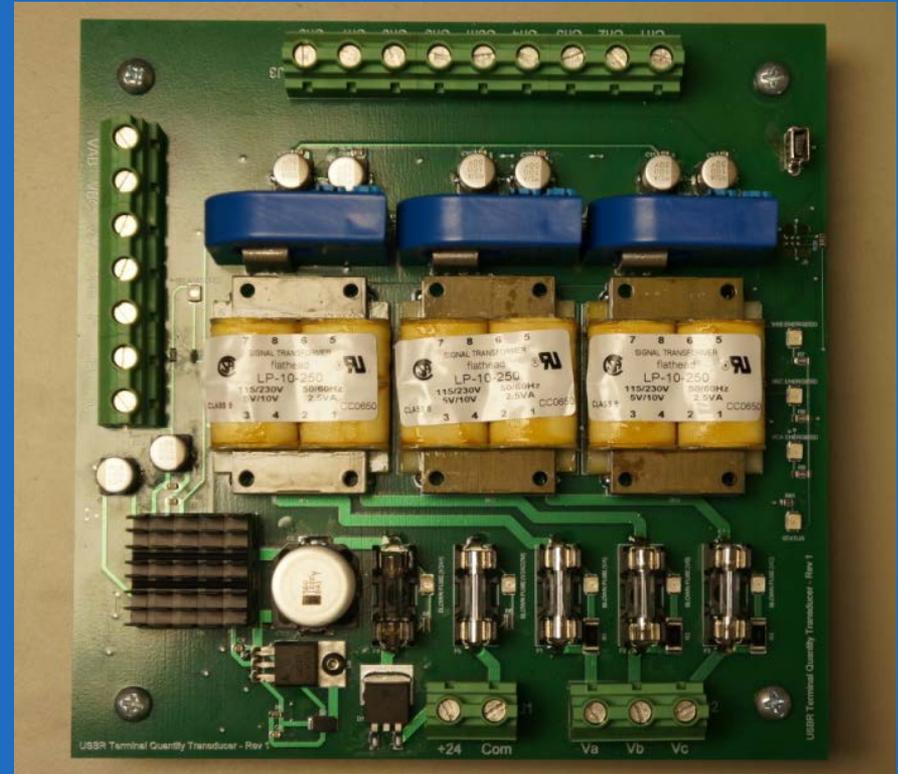
Window CTs –
CT leads are
routed through the
CTs and do not
terminate on board

- 3-Phase 120 Volt(PT Inputs)
- 3-Phase 5 Amp(CT Inputs)
- 8 Outputs(± 10 VDC)
(Each Channel = 20Hz Bandwidth)
 - Frequency Deviation
 - 0.002 Hz Res., 0.01-120Hz
 - Real Power
 - 0.03 W Res., ± 1000 W FS
 - Reactive Power
 - 0.03 Vars Res., ± 1000 W 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

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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



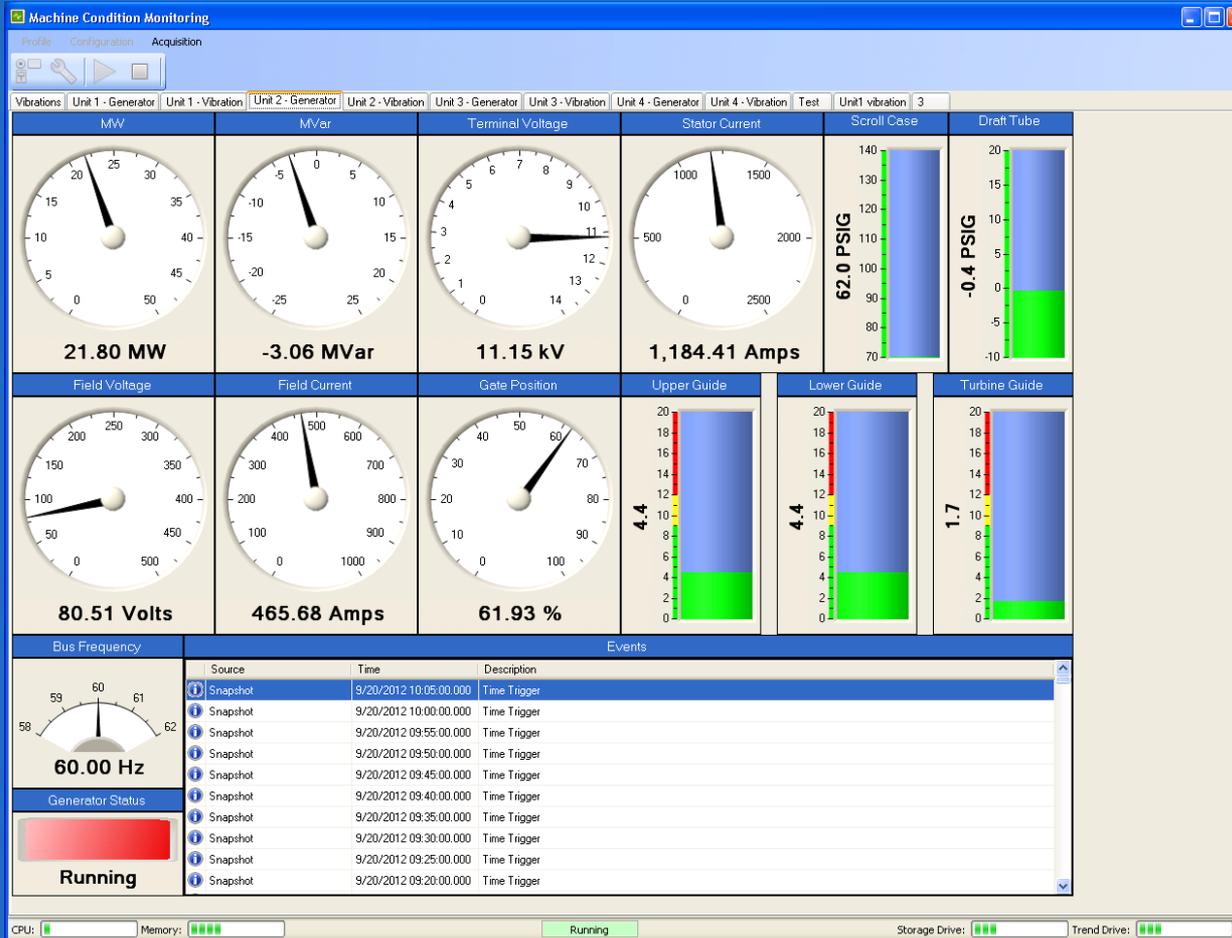
MCM Software – Version 1.0

- 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.



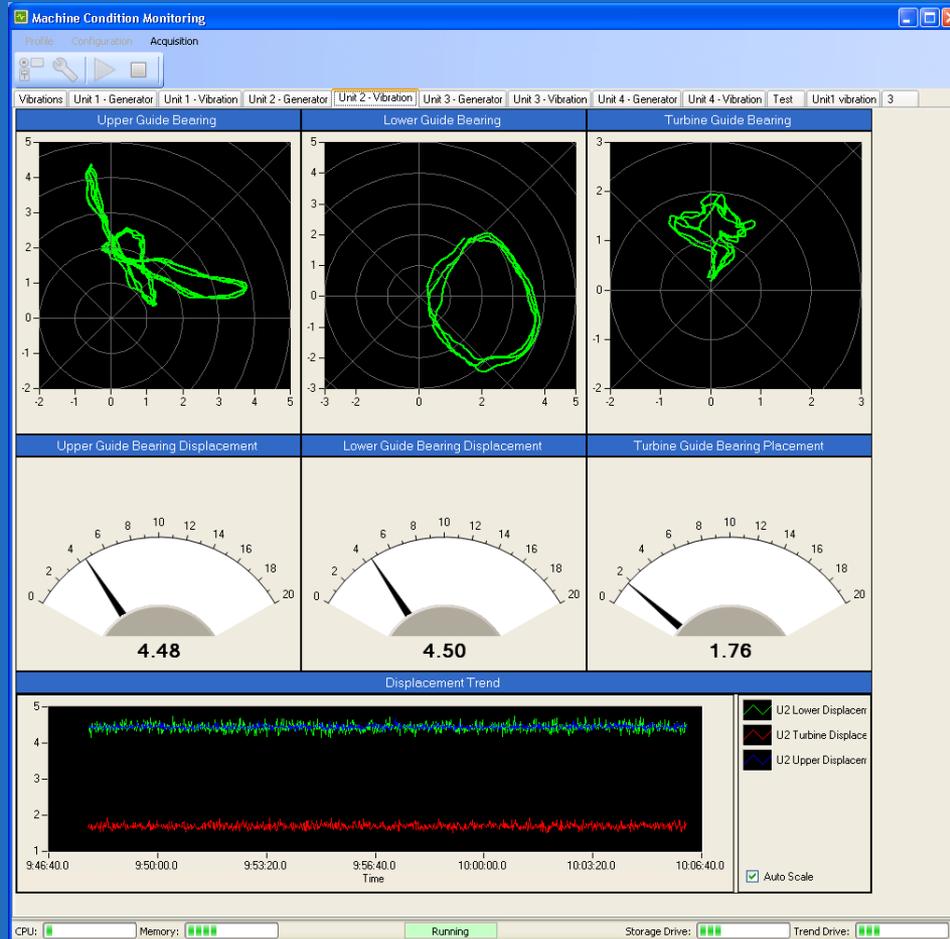
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MCM v1.0 – Palisades Example



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MCM v1.0 – Palisades Example

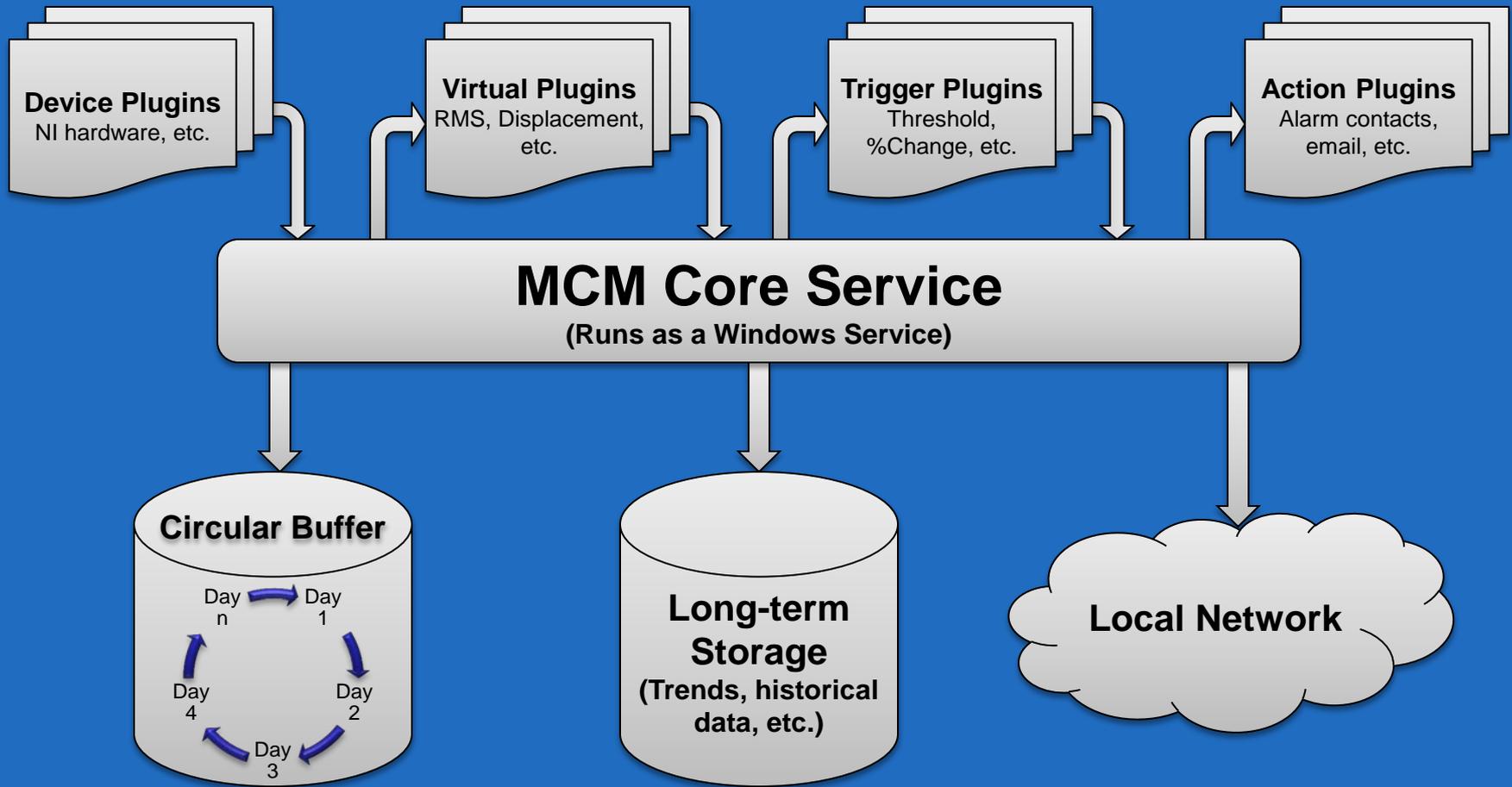


MCM Software – Version 2.0

- **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**

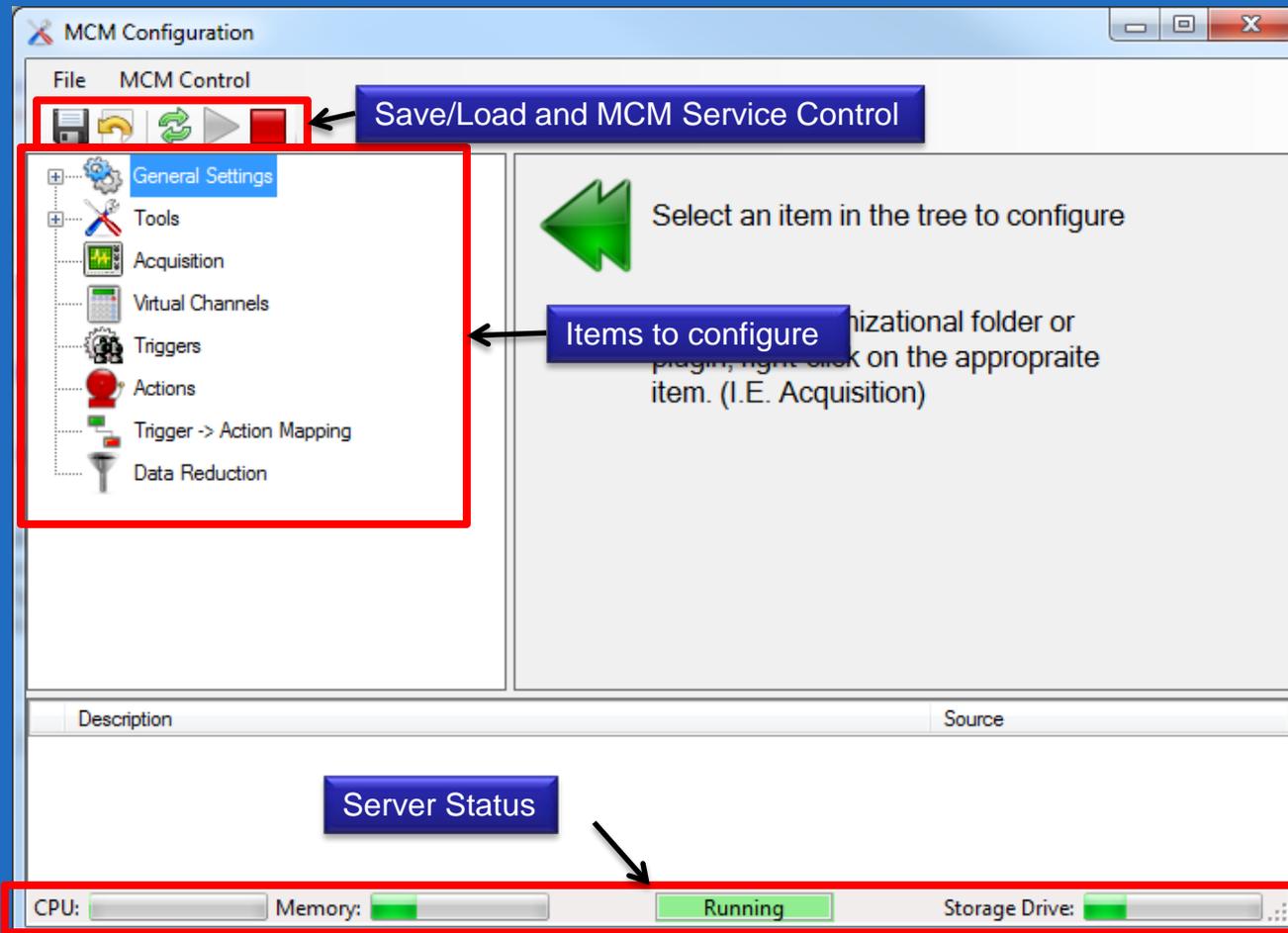
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MCM Server Framework v2.0

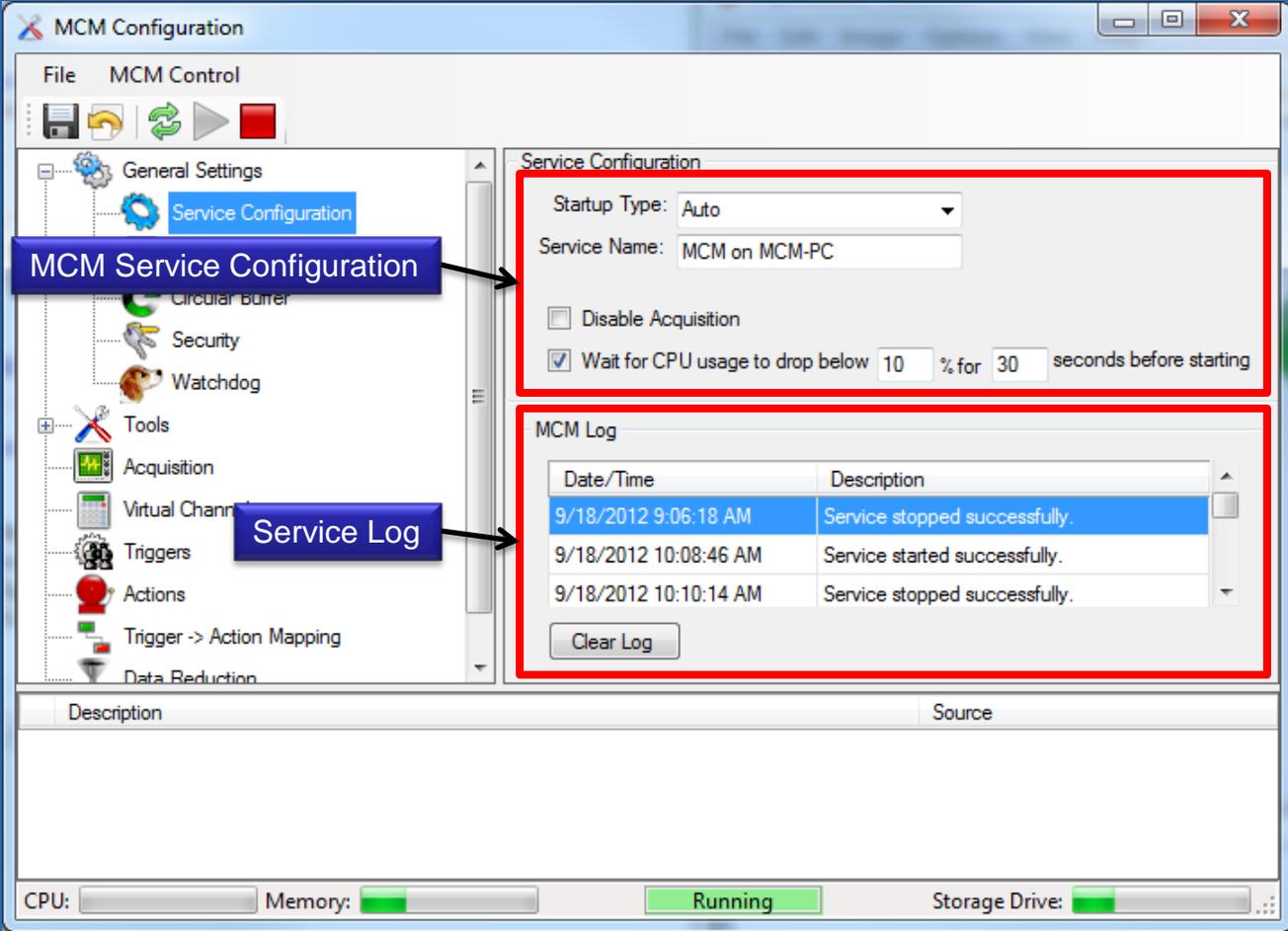


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MCM v2.0 – Server Configuration



MCM v2.0 – Windows Service Setup



The screenshot shows the MCM Configuration application window. The left sidebar contains a tree view with the following items: General Settings, Service Configuration, Circular Buffer, Security, Watchdog, Tools, Acquisition, Virtual Channels, Triggers, Actions, Trigger -> Action Mapping, and Data Reduction. The 'Service Configuration' item is selected and highlighted with a blue box. A blue callout box labeled 'MCM Service Configuration' points to this item. The main area is divided into two sections, both highlighted with red boxes. The top section, 'Service Configuration', contains the following settings: Startup Type: Auto (dropdown), Service Name: MCM on MCM-PC (text box), Disable Acquisition, and Wait for CPU usage to drop below 10 % for 30 seconds before starting. The bottom section, 'MCM Log', contains a table with the following data:

Date/Time	Description
9/18/2012 9:06:18 AM	Service stopped successfully.
9/18/2012 10:08:46 AM	Service started successfully.
9/18/2012 10:10:14 AM	Service stopped successfully.

A 'Clear Log' button is located below the table. A blue callout box labeled 'Service Log' points to the table. At the bottom of the window, there is a status bar with the following indicators: CPU: (empty bar), Memory: (green bar), Running (green bar), and Storage Drive: (green bar).

MCM v2.0 – Data Storage Setup

Data Storage Configuration

Enable Data Storage

Storage Location: C:\Users\btravers\Desktop\MCM2\MCM Core\bin\Debug\

Approximate File Size: 1.00 GB

Alarm when HDD space drops: 5.00 GB

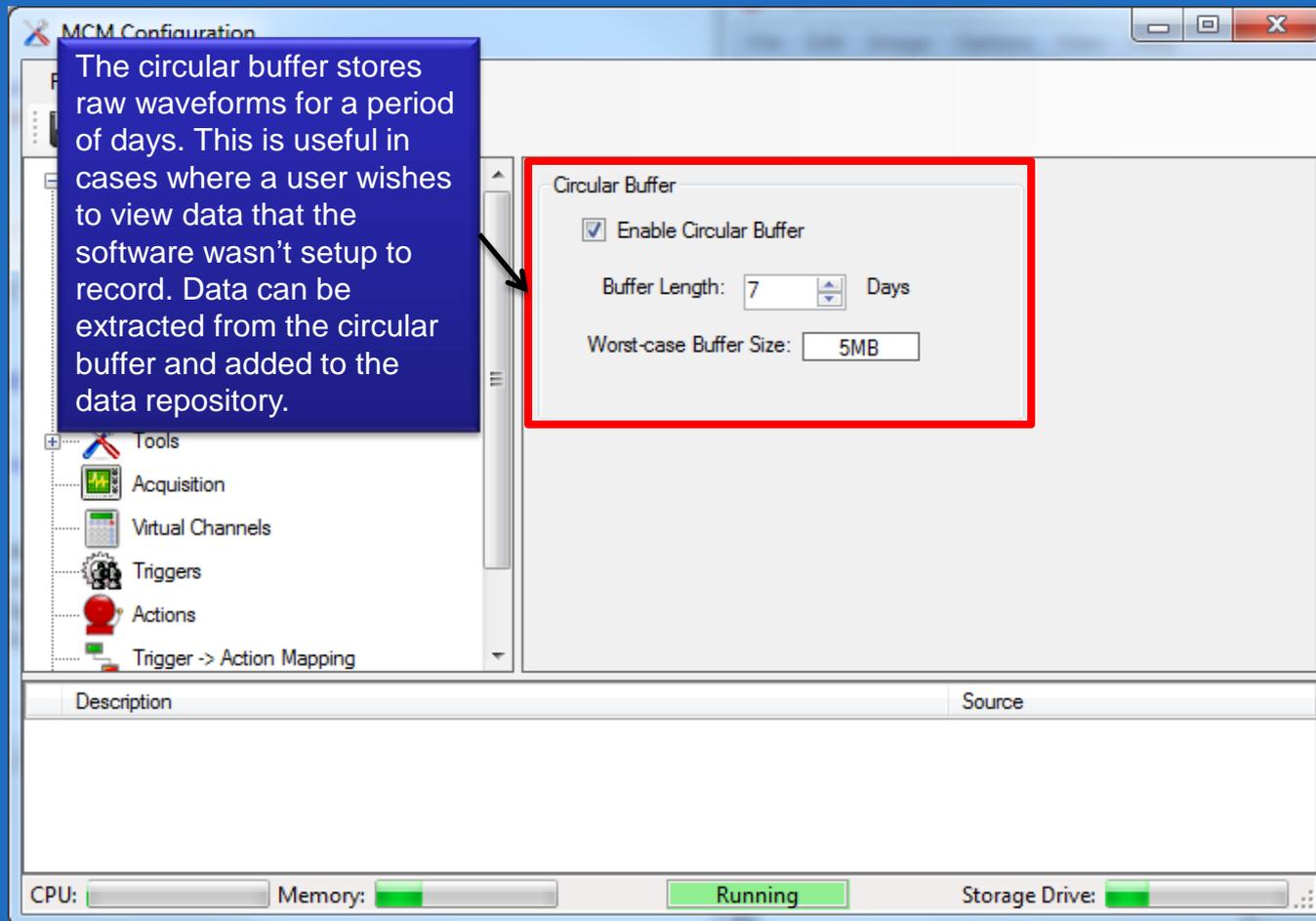
Drive Allocation (C:)
Total Size: 223GB

Category	Percentage
Free Space	2%
Used Space	24%
MCM Data	71%
Circular Buffer	3%

Legend: Free Space (Pink), Used Space (Blue), MCM Data (Yellow), Circular Buffer (Green)

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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.

Circular Buffer

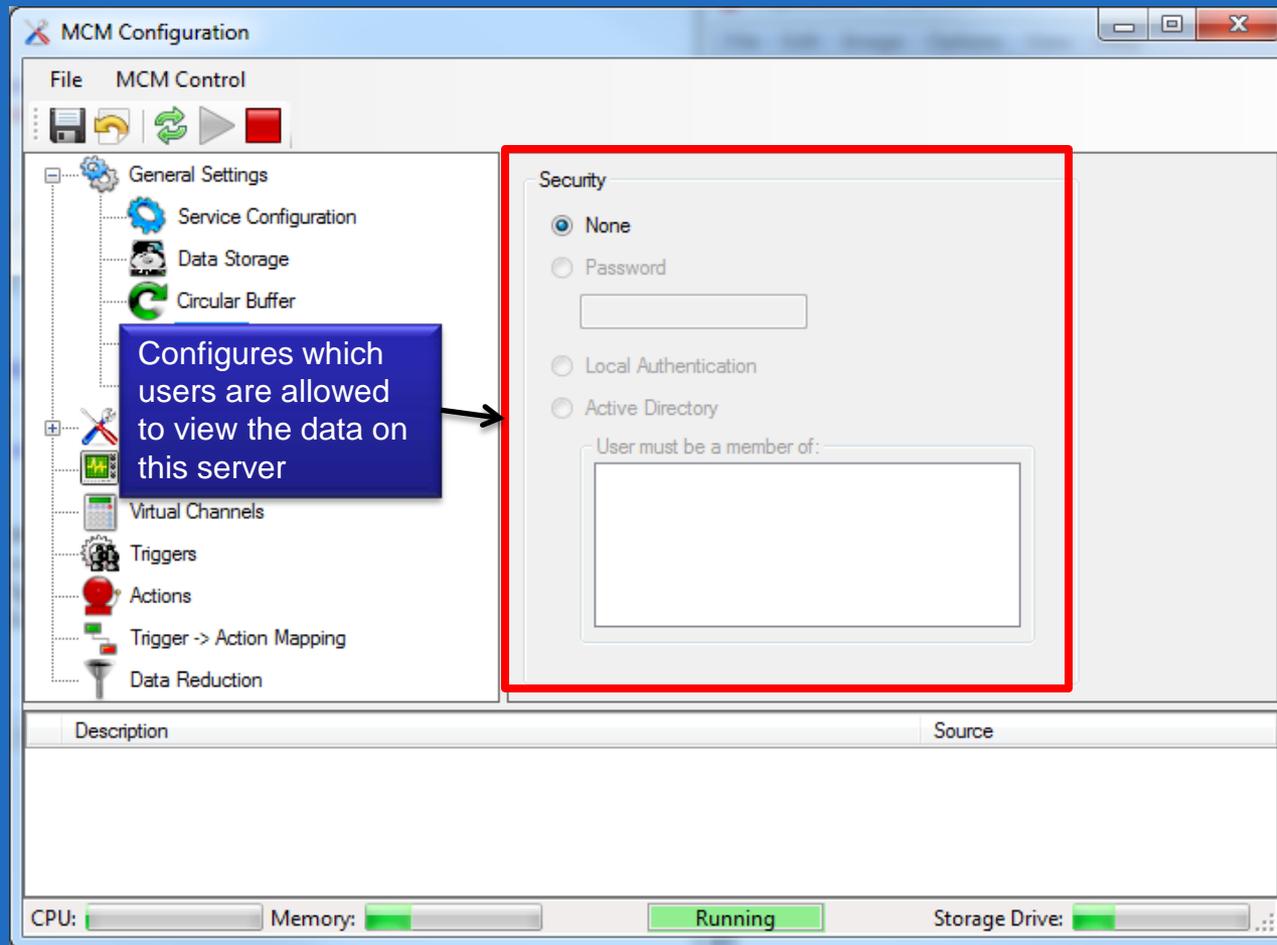
- Enable Circular Buffer
- Buffer Length: 7 Days
- Worst-case Buffer Size: 5MB

Tools
Acquisition
Virtual Channels
Triggers
Actions
Trigger -> Action Mapping

Description	Source
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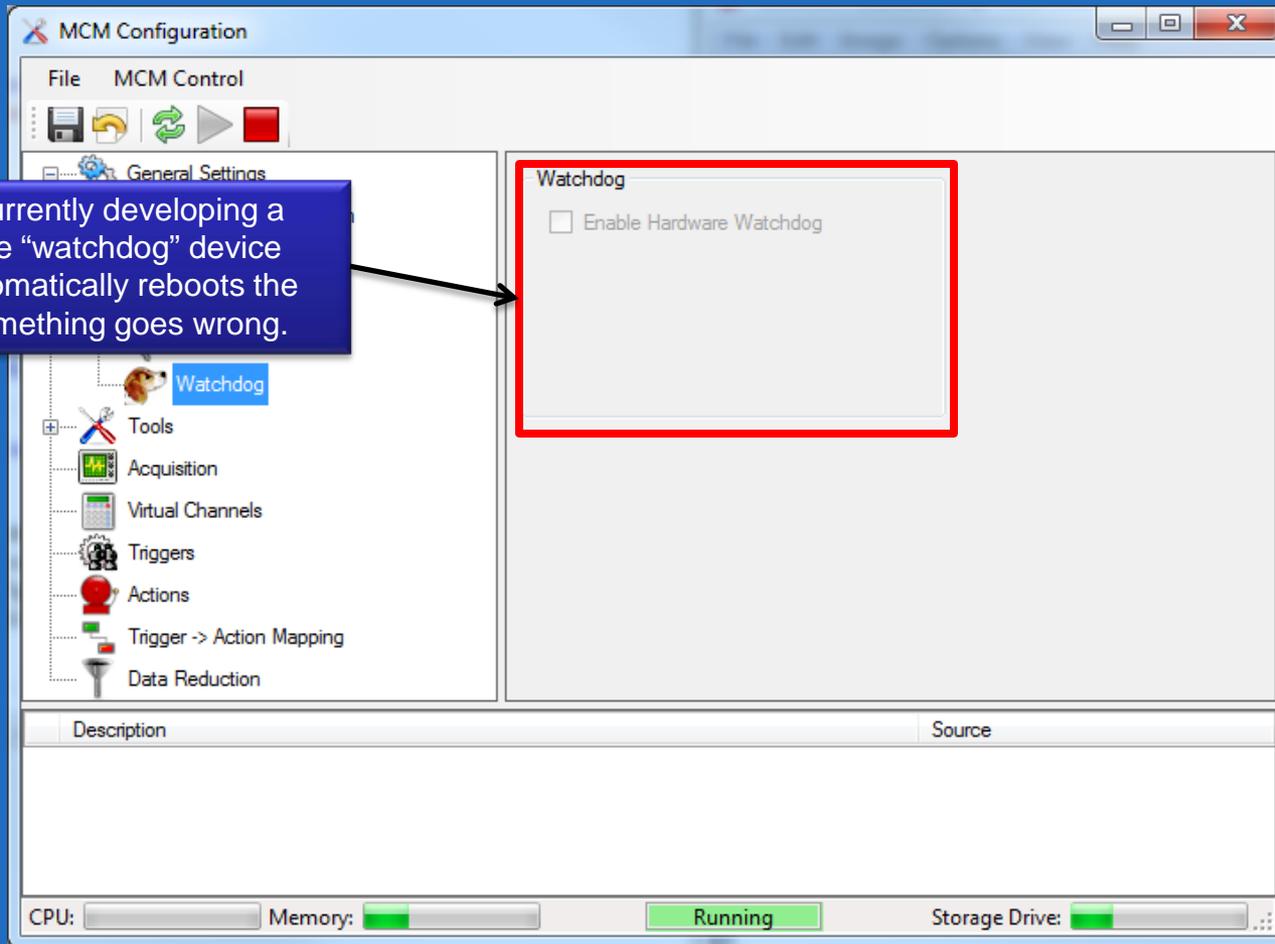
CPU: Memory: Running Storage Drive:

MCM v2.0 – Security Configuration



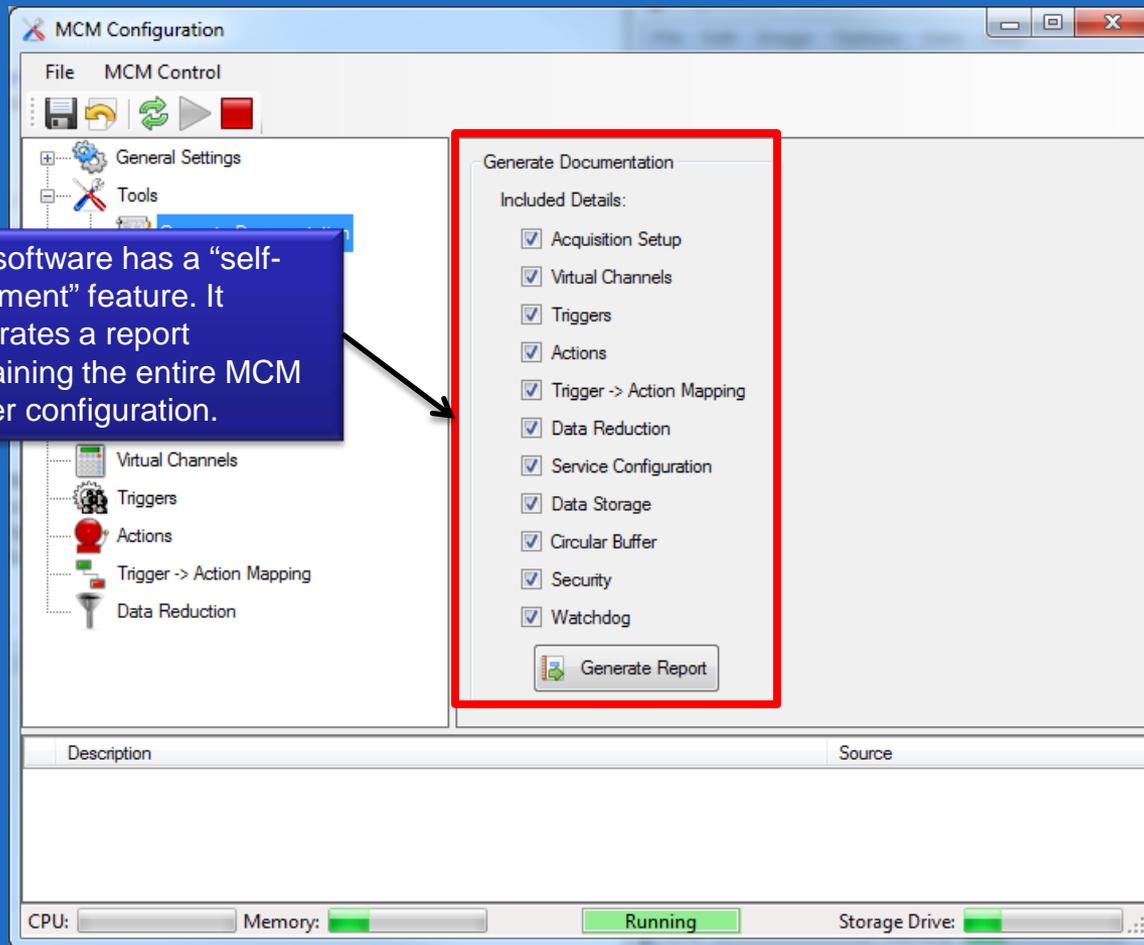
MCM v2.0 – Watchdog Configuration

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.

NI-DAQmx

Device: Dev1

Sample Rate (Hz) 1000

Block Size (Samples/Block) 1000

Channel Configuration:

	Enabled	Name	Voltage Range	Connection Type	Measurement Type	Gain	Offset	Units
ai0	<input checked="" type="checkbox"/>	Channel 1	-10 to 10	Differential	Voltage	1	0	Volts
ai1	<input checked="" type="checkbox"/>	Channel 2	-10 to 10	Differential	Voltage	1	0	Volts
ai2	<input checked="" type="checkbox"/>	Channel 3	-10 to 10	Differential	Voltage	1	0	Volts
ai3	<input checked="" type="checkbox"/>	Channel 4	-10 to 10	Differential	Voltage	1	0	Volts
ai4	<input checked="" type="checkbox"/>	Channel 5	-10 to 10	Differential	Voltage	1	0	Volts
ai5	<input type="checkbox"/>	Channel 6	-10 to 10	Differential	Voltage	1	0	Volts
ai6	<input type="checkbox"/>	Channel 7	-10 to 10	Differential	Voltage	1	0	Volts
ai7	<input type="checkbox"/>	Channel 8	-10 to 10	Differential	Voltage	1	0	Volts

Context Menu:

- Scaling Wizard
- Mark Row as Default
- Copy Default Values to Selection

MCM v2.0 – Channel Scaling Wizard

The new “Scaling Wizard” can automatically calculate scale factors for a given channel.

The screenshot shows a dialog box titled "Scaling Wizard for Channel 2". It contains the following elements:

- Seconds to Average Reading: 1
- Sample Rate (Hz): 10
- Scale Calculation section with two tabs: "Average Offset" (selected) and "Linear Fit".
- Three radio button options:
 - Find both Scale and Offset
 - Find only scale using this offset: 0
 - Find only offset using this scale: 1
- Data Points section with a table:

	Actual Value	Measured	Measure
*			
- Gain, Offset, and Residue fields, each with a yellow button containing "...".
- Buttons for "Cancel" and "Save" at the bottom right.

MCM v2.0 – Trigger/Action Mapping

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.)

The screenshot displays the MCM v2.0 software interface. On the left, a tree view shows the configuration hierarchy: Acquisition, Virtual Channels, Triggers (Lower Guide Threshold, MCM Storage Full, Turbine Guide Threshold, Upper Guide Threshold), Actions (MCM Alarm, Unit 1 Alarm), Trigger -> Action Mapping, and Data Reduction. The main window is titled 'Action Mapping' and contains a grid. The grid has 'Triggers' on the vertical axis and 'Actions' on the horizontal axis. The triggers listed are Lower Guide Threshold, MCM Storage Full, Turbine Guide Threshold, and Upper Guide Threshold. The actions listed are MCM Alarm and Unit 1 Alarm. Red boxes in the grid indicate the following mappings: Turbine Guide Threshold to MCM Alarm, and Upper Guide Threshold to Unit 1 Alarm. Below the grid is a table with the following data:

Description	Source
Missing Input Channel	Triggers\Upper Guide Threshold
Missing Input Channel	Triggers\Lower Guide Threshold
Missing Input Channel	Triggers\Turbine Guide Threshold
Missing Input Channel	Triggers\MCM Storage Full

At the bottom of the interface, a status bar shows system metrics: CPU: [Progress Bar], Memory: [Progress Bar], Running [Green Button], Storage Drive: [Progress Bar].

MCM v2.0 – Data Reduction

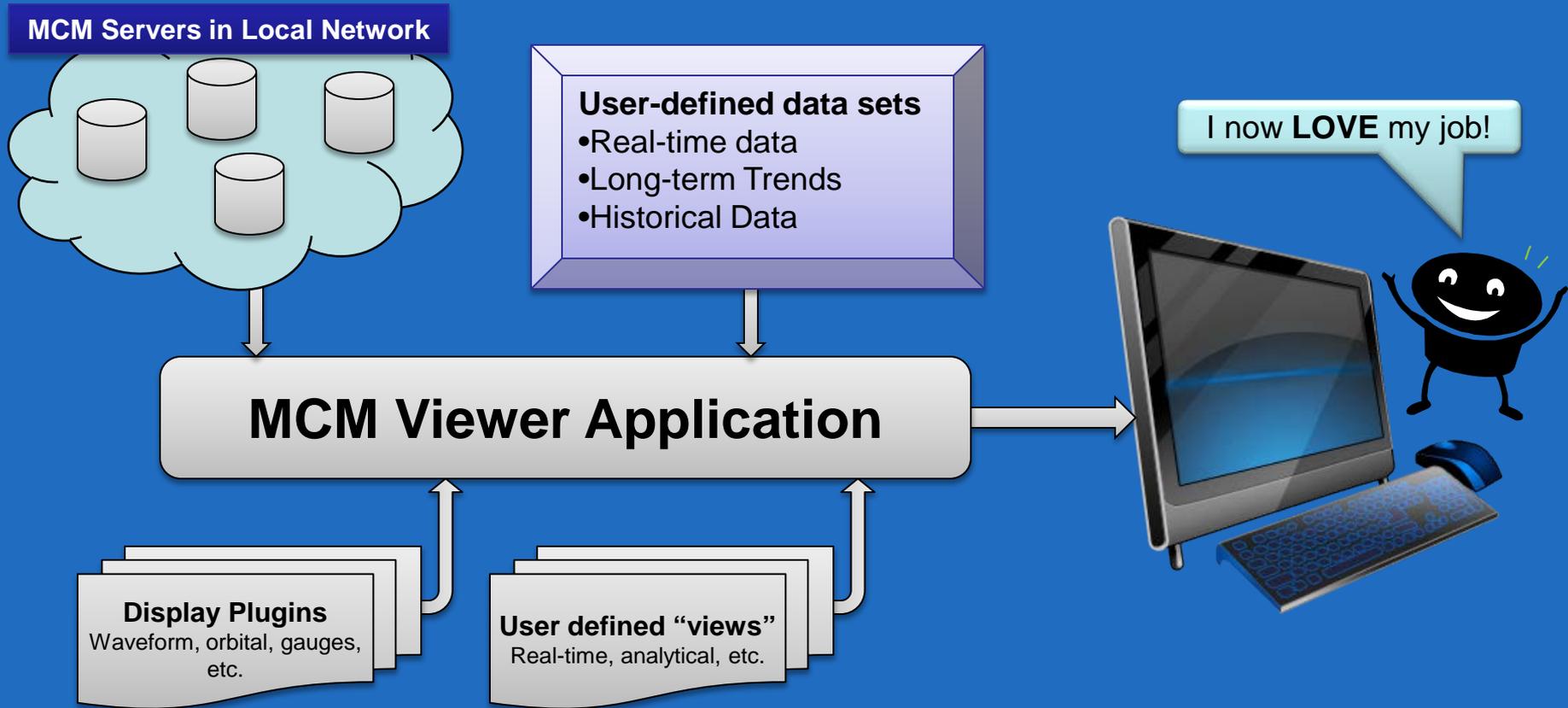
Data reduction rules can be configured to reduce the amount of data that is placed in long-term storage. For example, in normal operating conditions, it doesn't make sense to store reactive power at 1kHz. A reduction rule can be configured to, for example, only store reactive power when it changes by 5%.

The screenshot displays the 'Data Reduction Rules' configuration window. The table below shows the configured rules:

Channel	Normal Reduction	Param.	Triggered Reduction	Param.
Lower Prox X	% Different	10	None	0
Lower Prox Y	% Different	10	None	0
Turbine Prox X	% Different	10	None	0
Turbine Prox Y	% Different	10	None	0
Upper Prox X	% Different	10	None	0
Upper Prox Y	% Different	10	None	0

The interface also includes a left-hand menu with options like 'Upper Guide Threshold', 'Actions', 'MCM Alarm', 'Unit 1 Alarm', 'Trigger -> Action Mapping', and 'Data Reduction'. At the bottom, there is a status bar showing 'CPU', 'Memory', 'Running', and 'Storage Drive' indicators.

MCM Viewer Framework v2.0



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MCM v2.0 – Editing a View

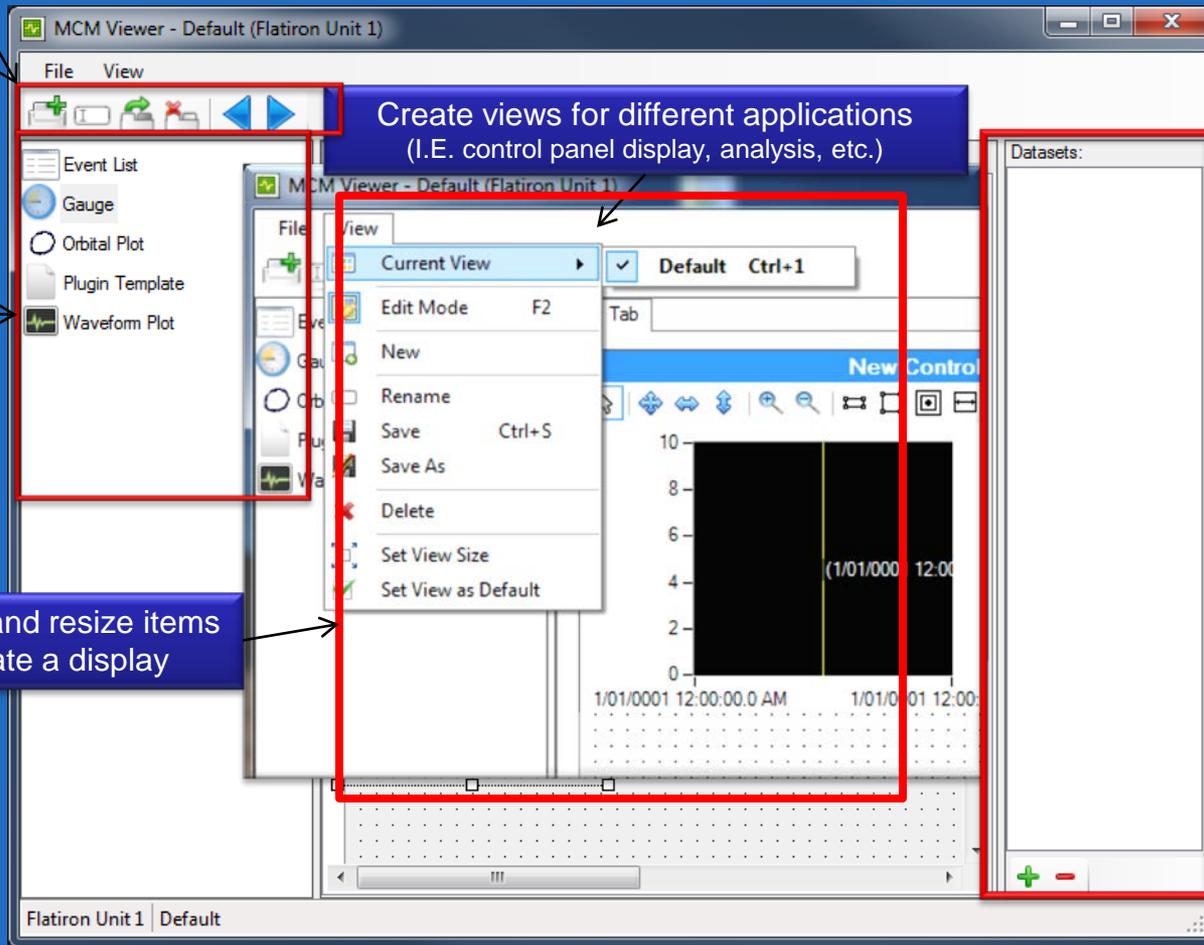
Create and edit view tabs

Create views for different applications
(I.E. control panel display, analysis, etc.)

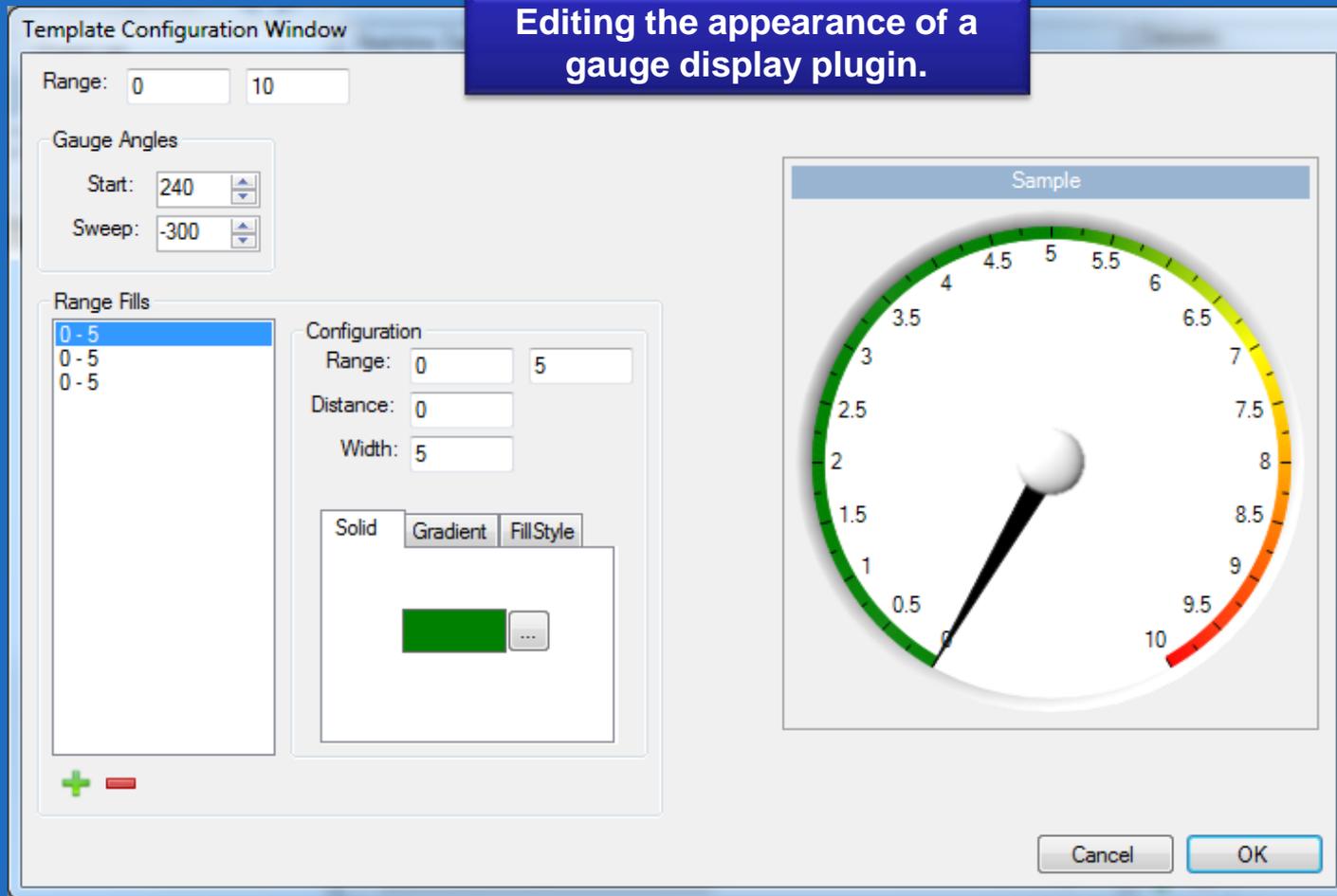
Display plugins
toolbox. Drag
an item into the
display.

Drag and resize items
to create a display

Create datasets
to view
historic
data



MCM v2.0 – Display Properties



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Questions?

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