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

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**

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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

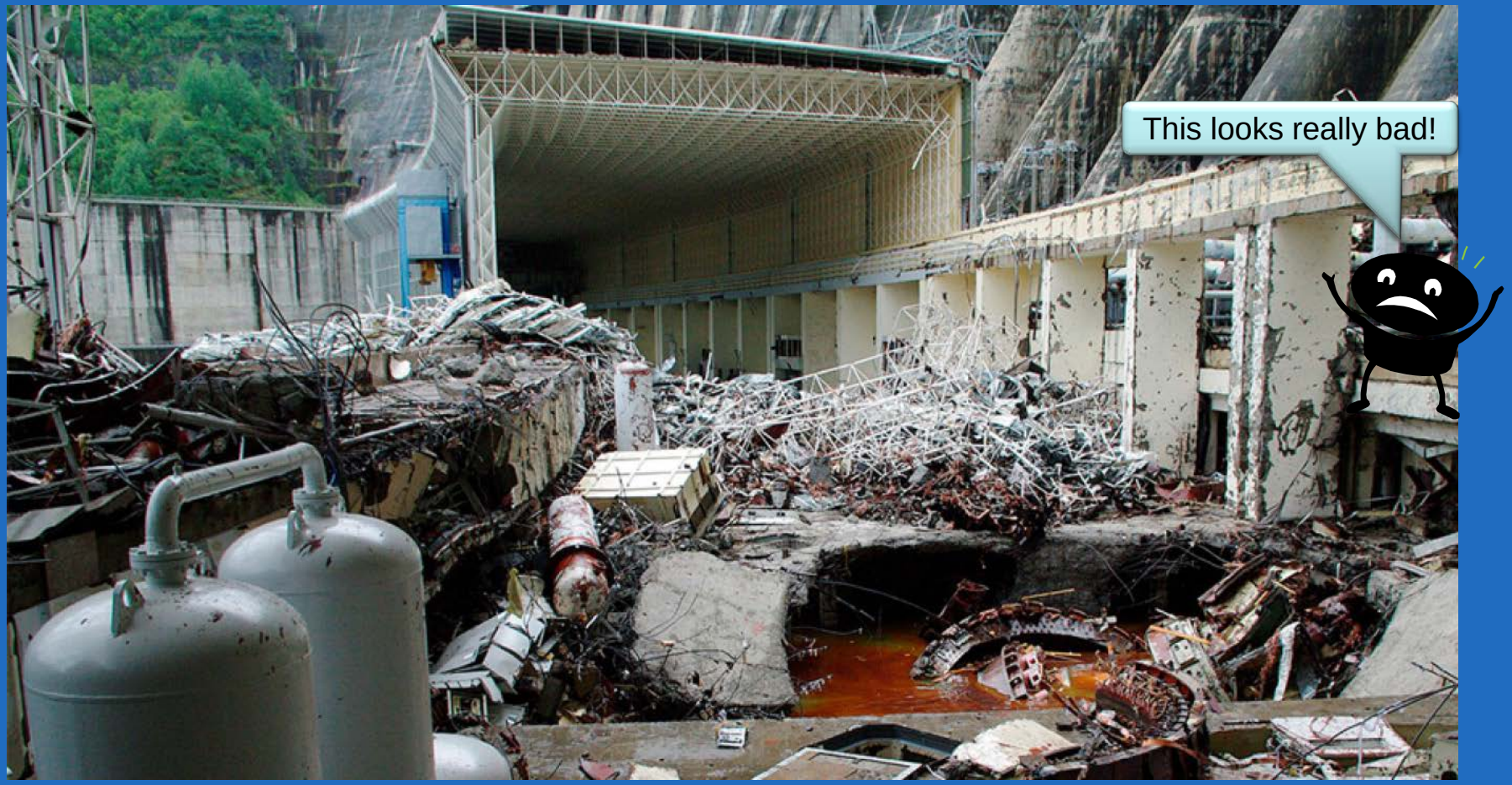
- Stator Frame/Core Vibration
- Stator Bar Vibration
- Ground Relay Voltage
- Stator Core Temperature
- Shear Pin Monitor
- Stator End Winding Temperature
- Rotor Pole Temperature
- Cooling Air Analysis (CHx)
- Cooling Air Ozone
- Relay Fault Waveforms

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.**

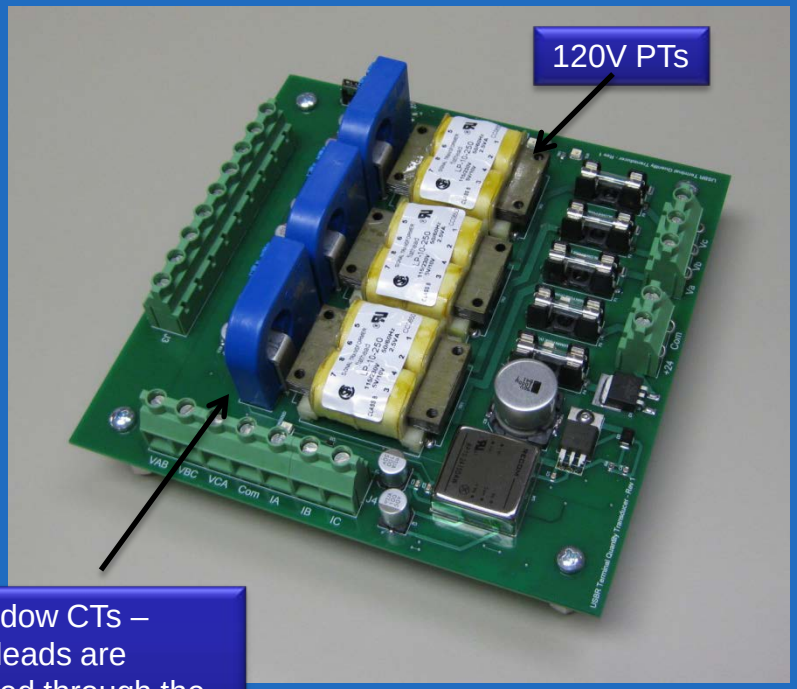
- **In response to this incident, Reclamation published Power Equipment Bulletin 42, which includes a Category 2 recommendation for installation of vibration monitoring systems for all Reclamation's units.**

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



- 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

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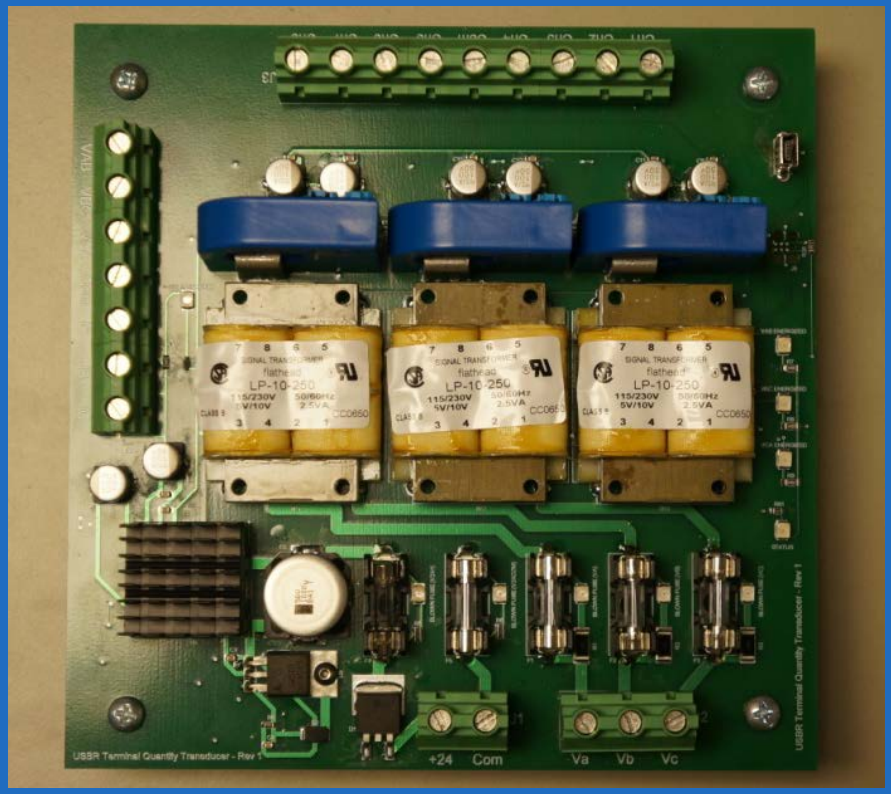
Terminal Quantity Transducer Features

- 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



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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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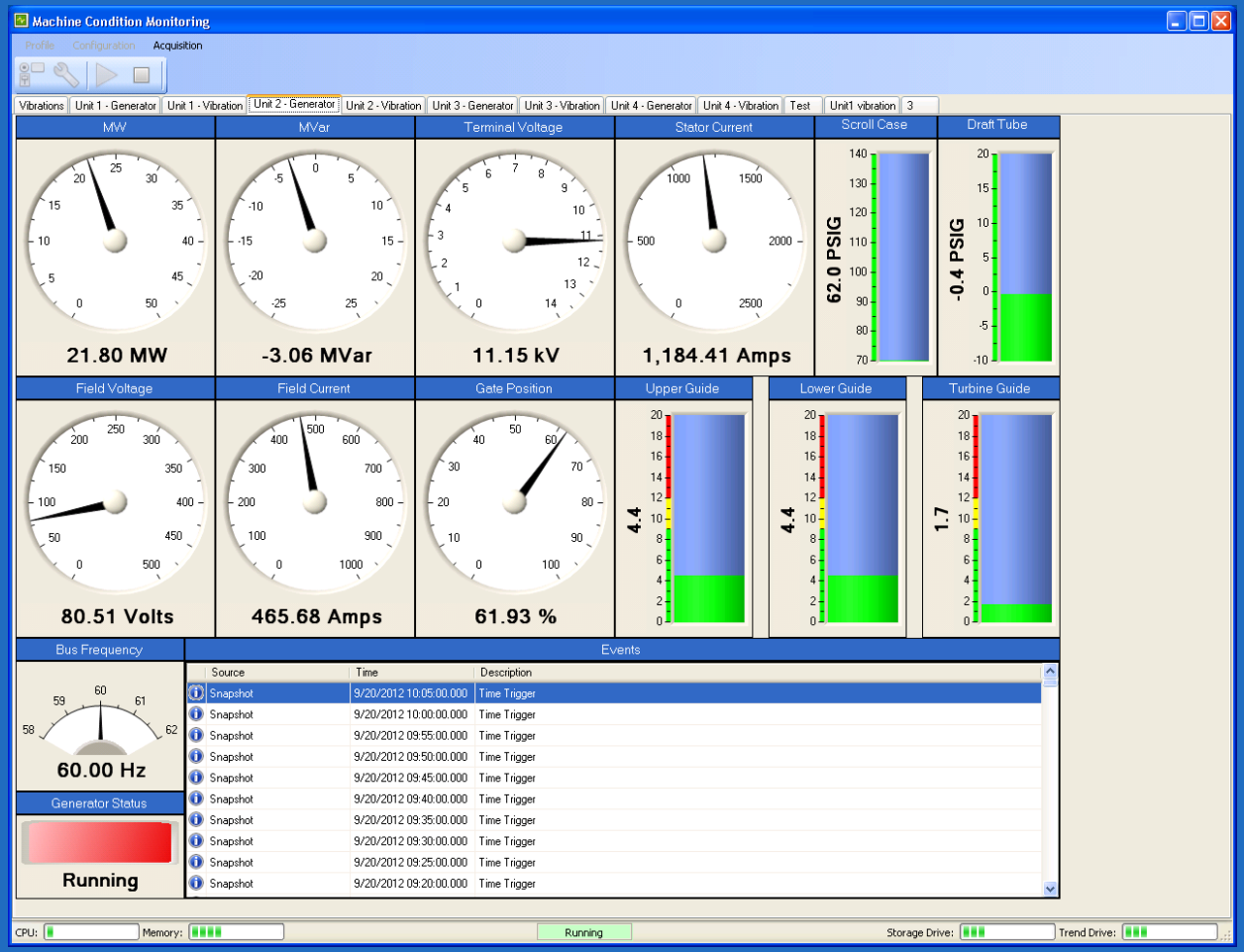
MCM v1.0 – Palisades Example



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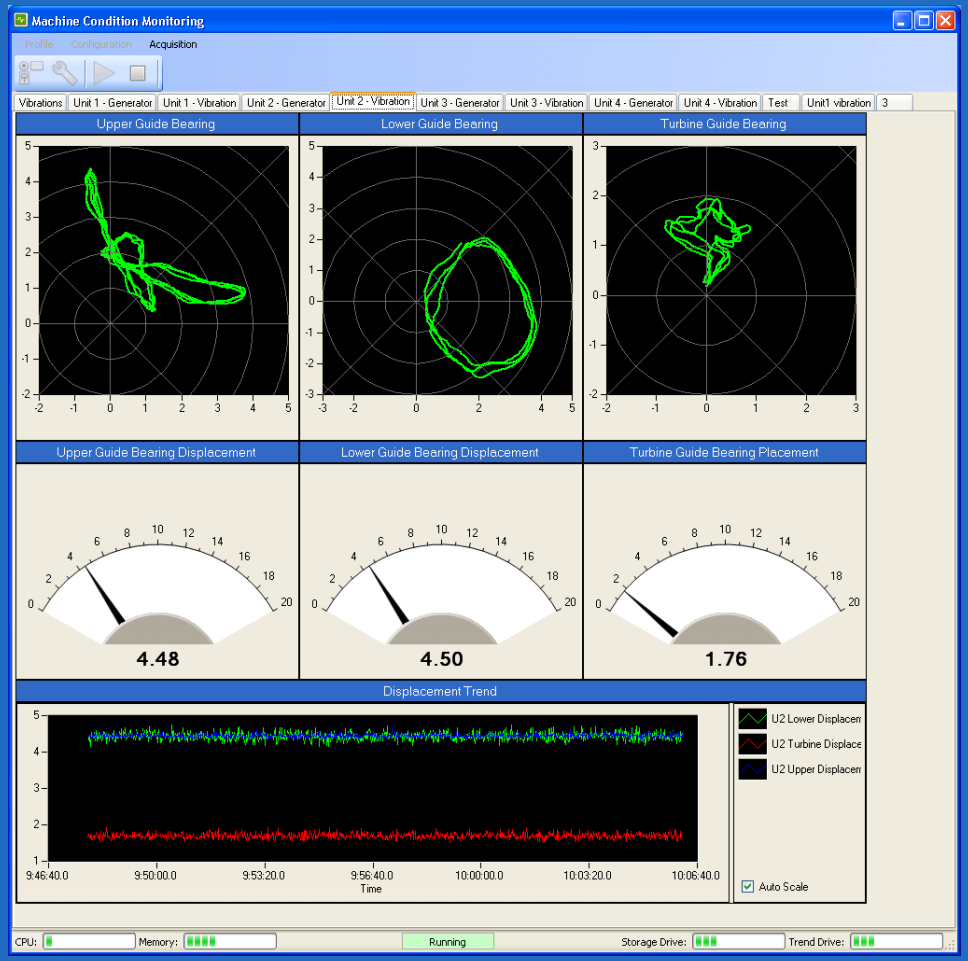
MCM v1.0 – Palisades Example



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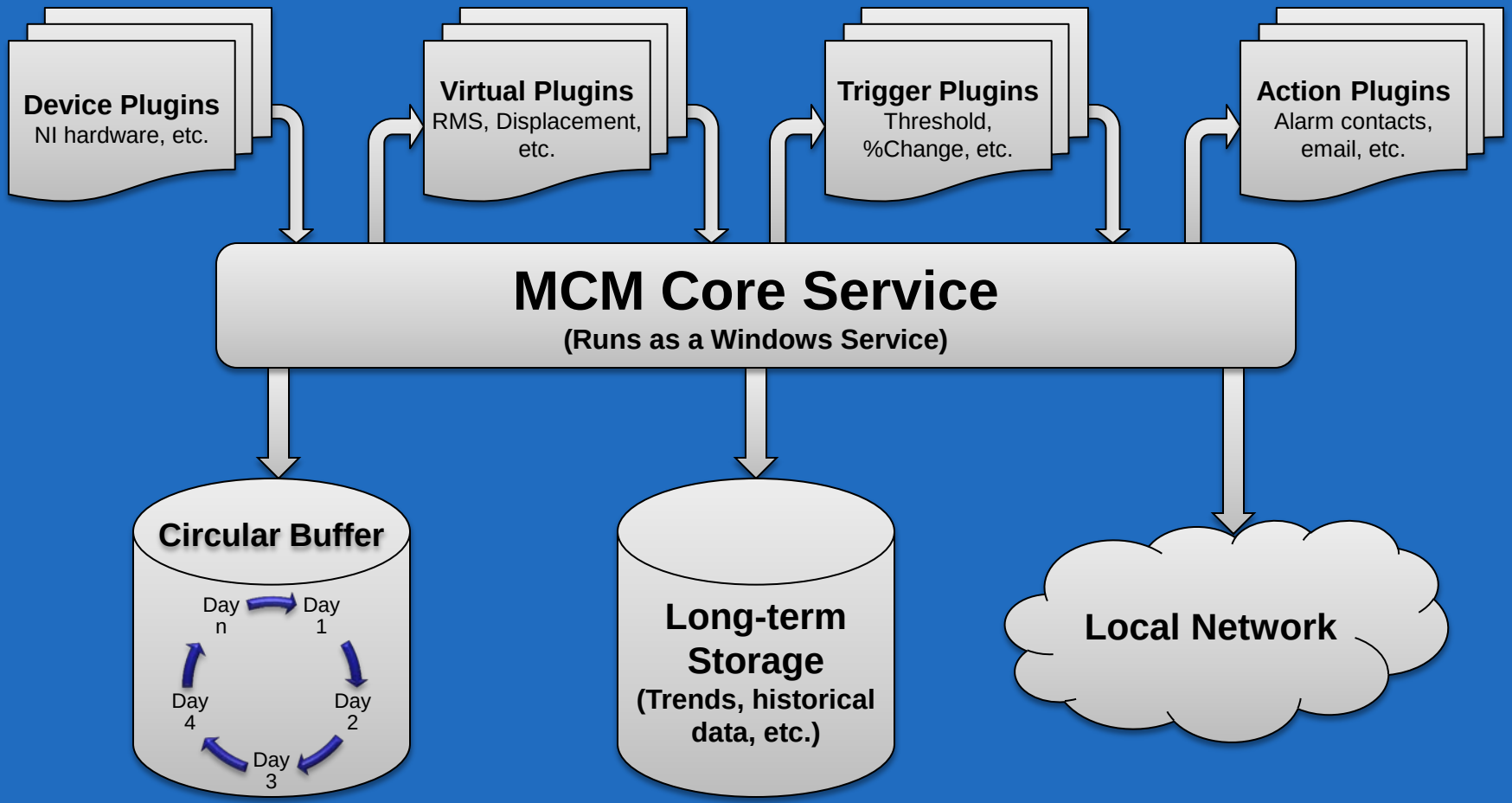
MCM Software – Version 2.0

- 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



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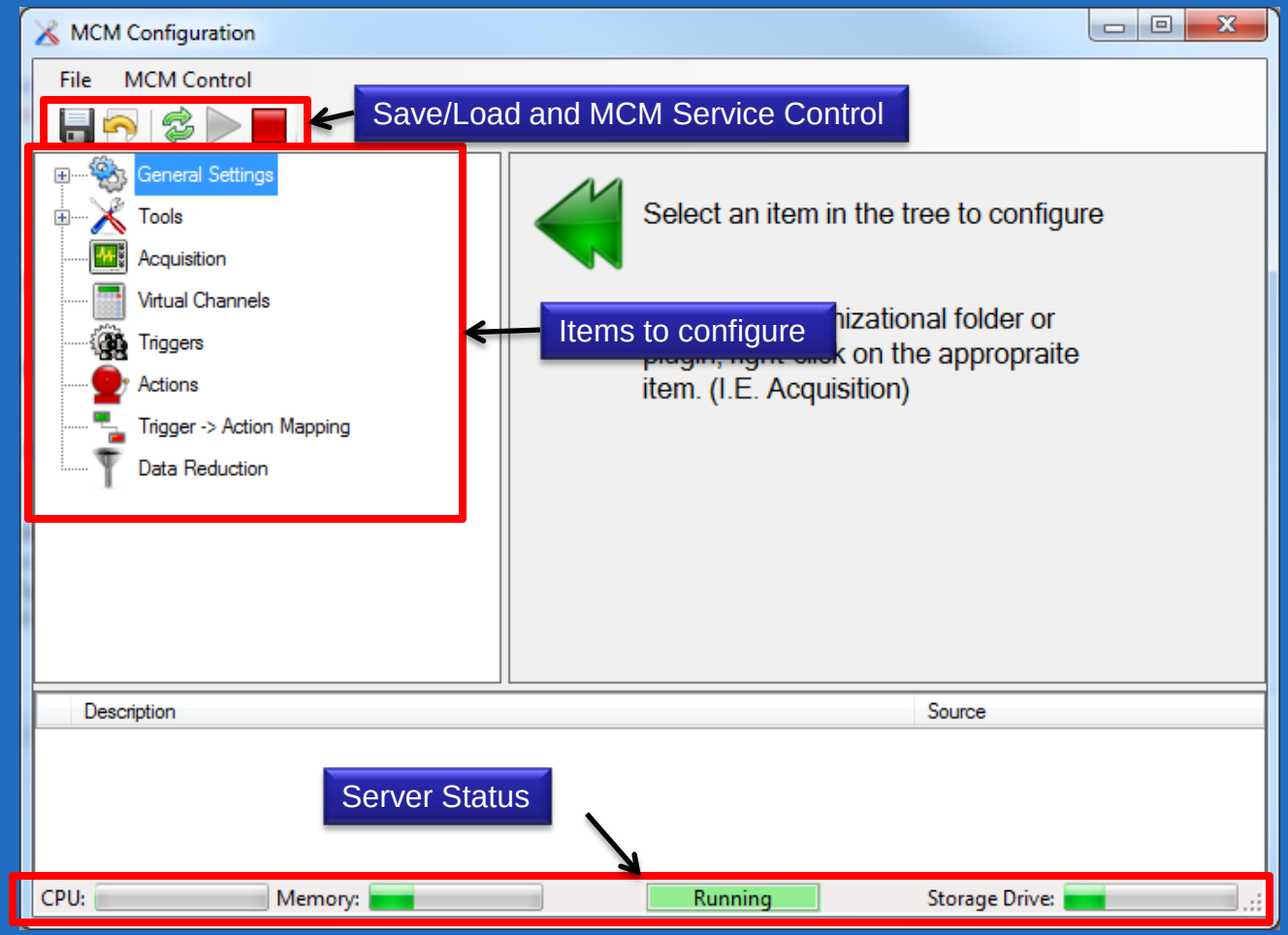
MCM v2.0 – Server Configuration



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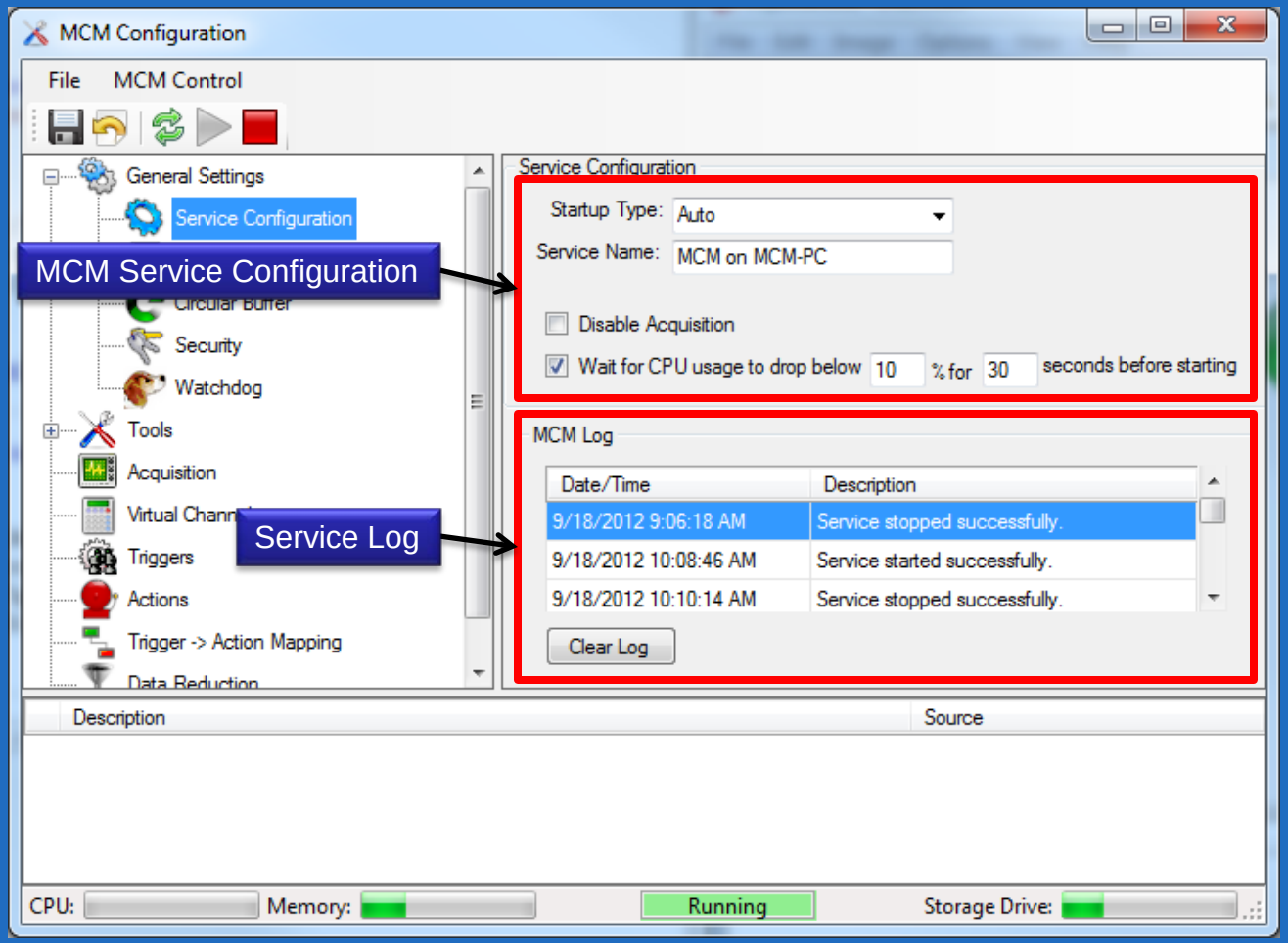
MCM v2.0 – Windows Service Setup



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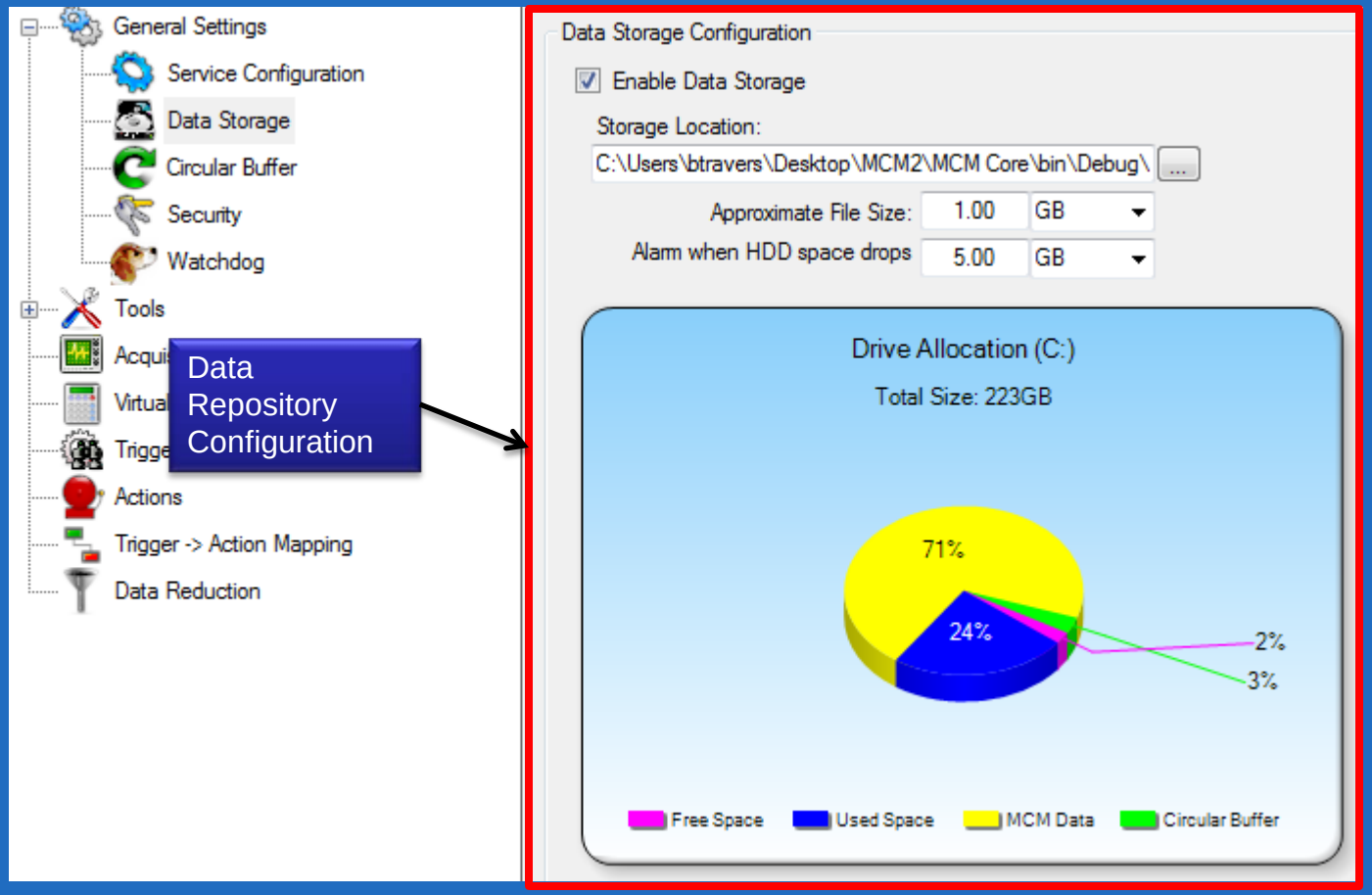
MCM v2.0 – Data Storage Setup



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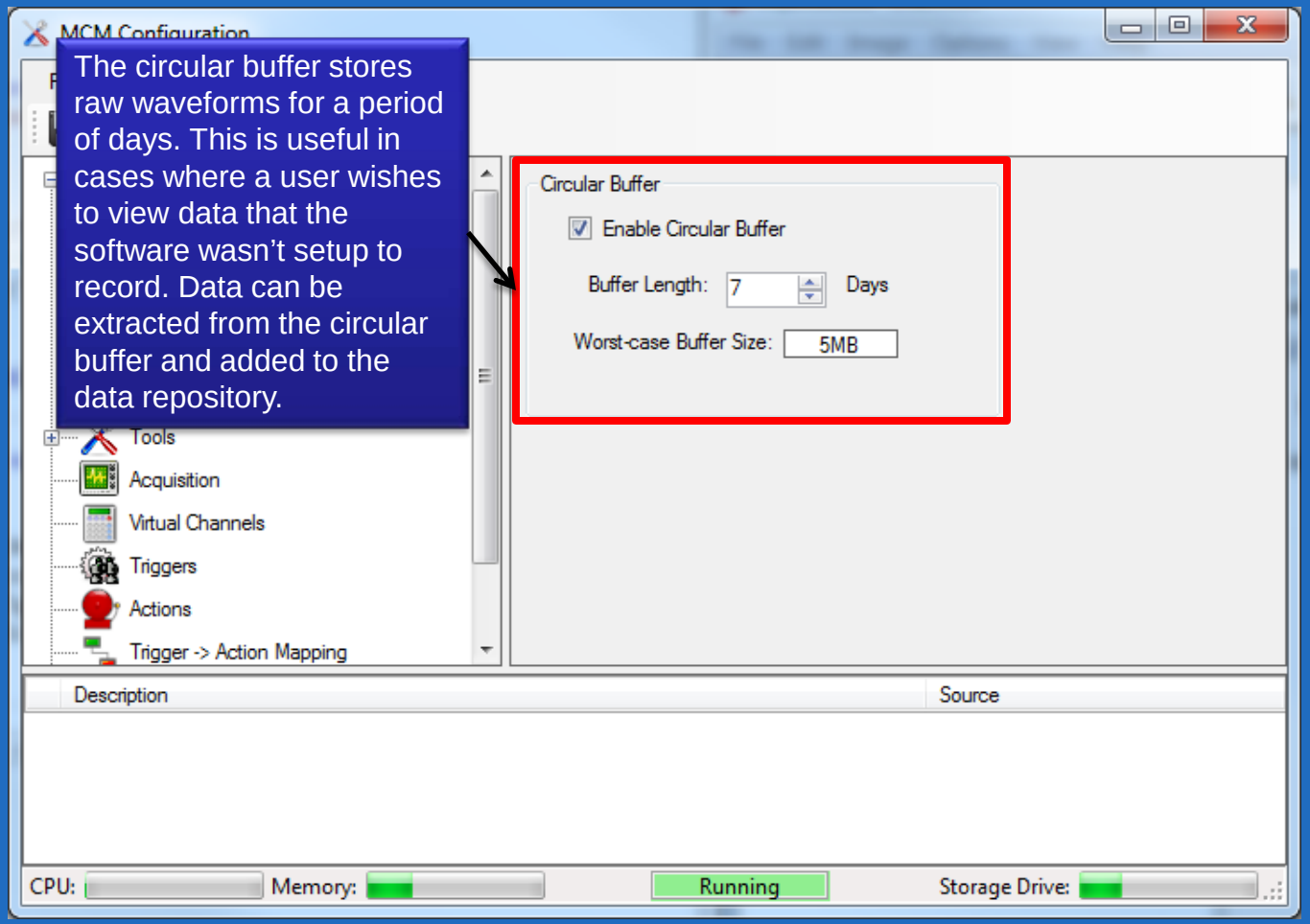
MCM v2.0 – Circular Buffer Setup



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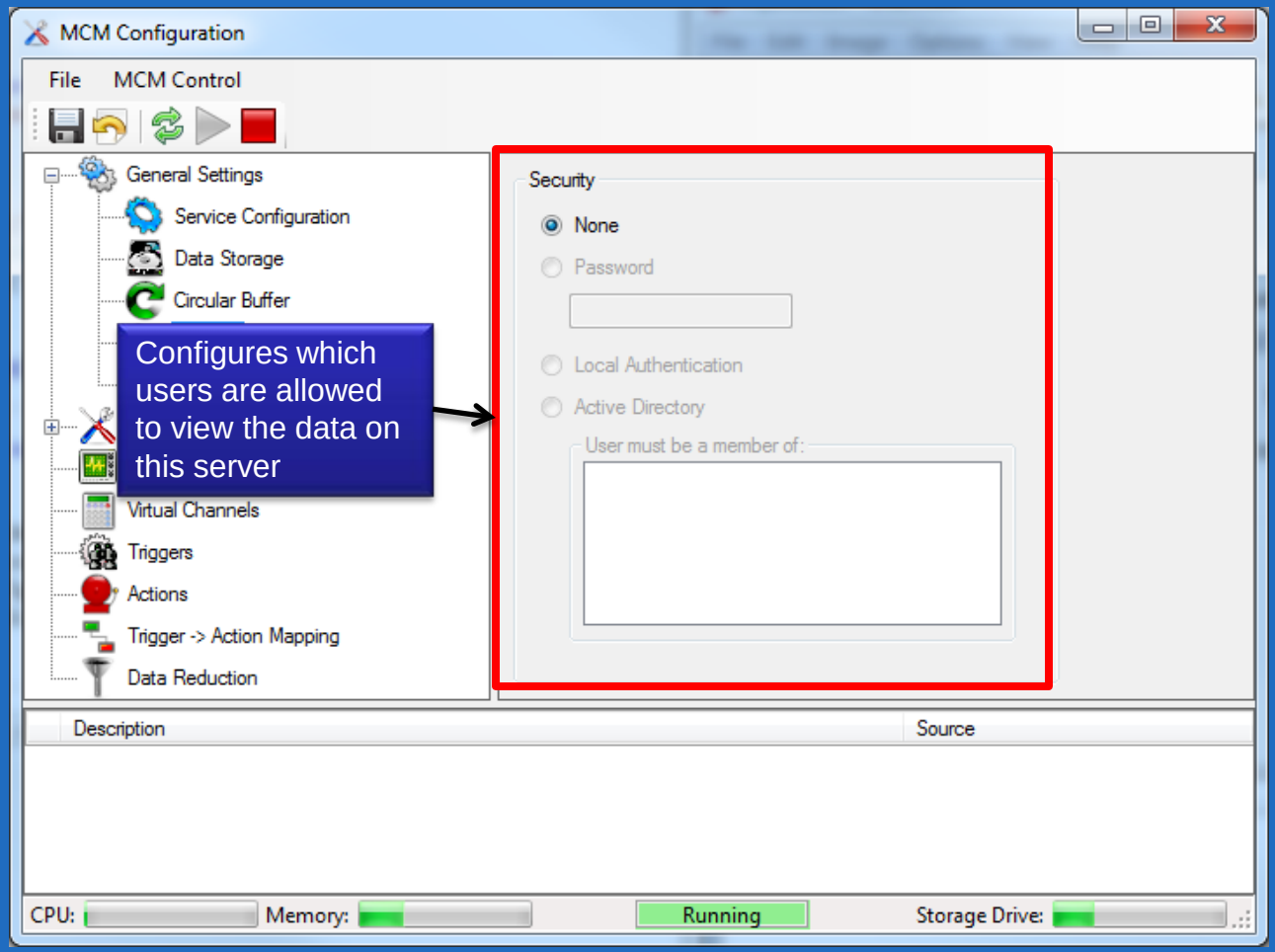
MCM v2.0 – Security Configuration



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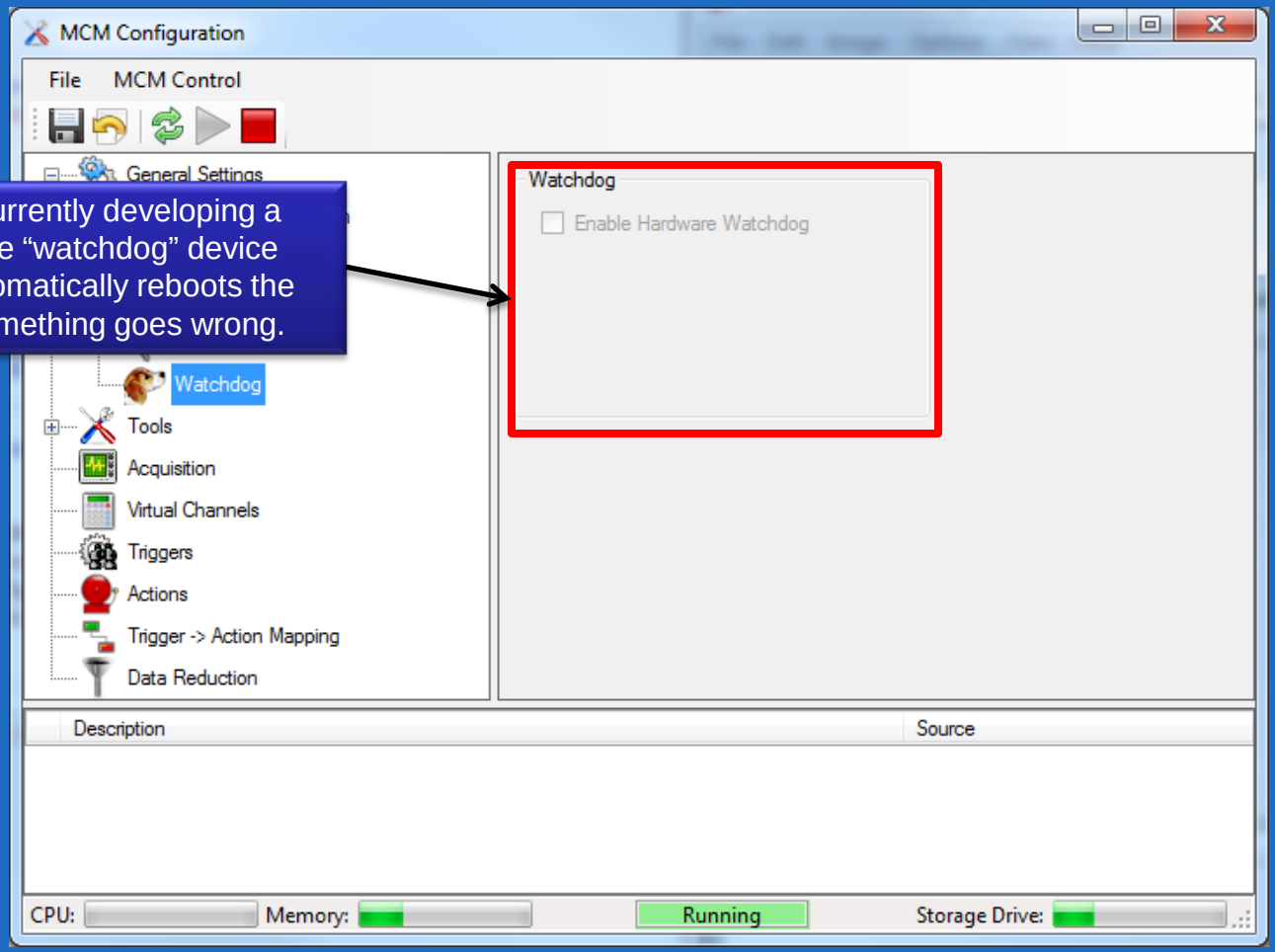
MCM v2.0 – Watchdog Configuration



We're currently developing a hardware "watchdog" device that automatically reboots the PC if something goes wrong.

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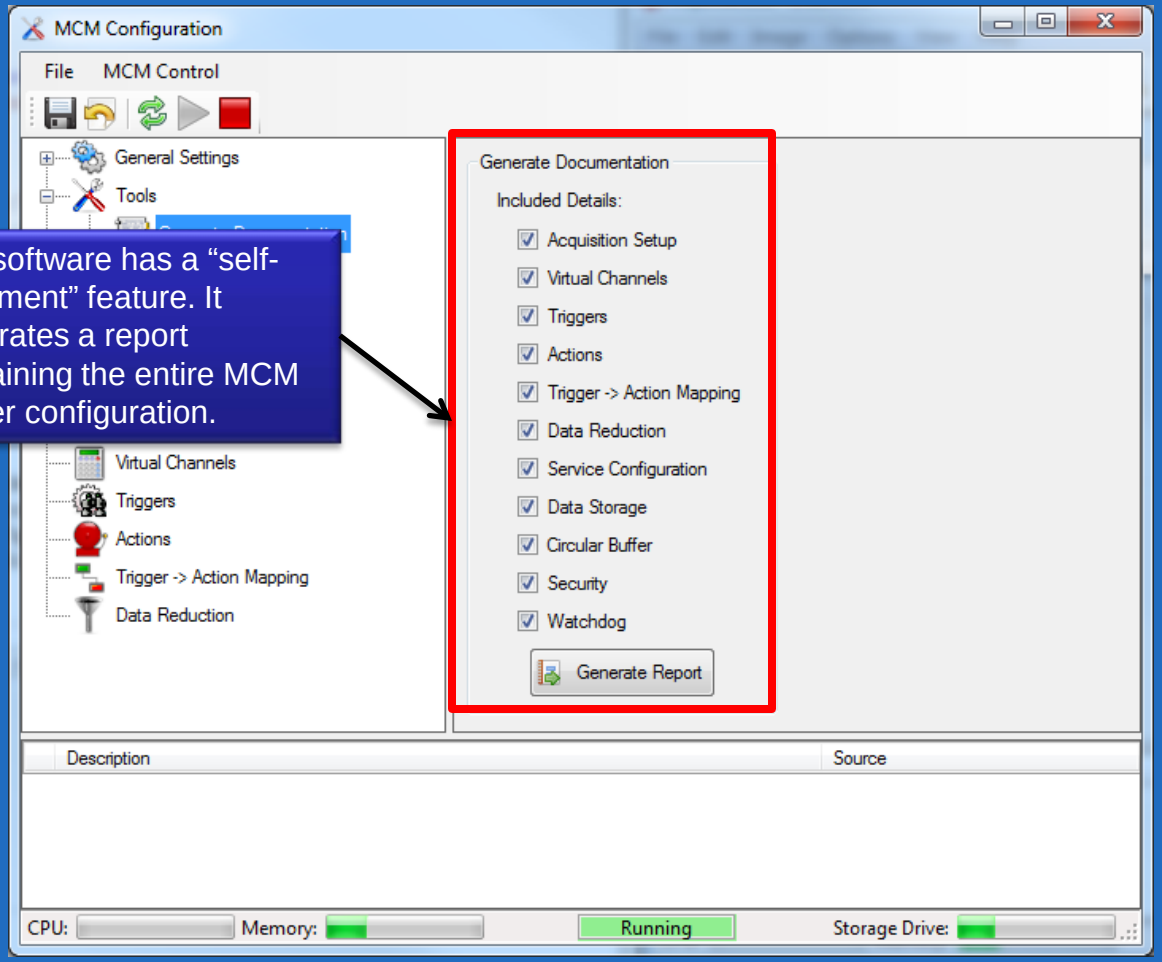
MCM v2.0 – Self-Documentation



The software has a "self-document" feature. It generates a report containing the entire MCM server configuration.

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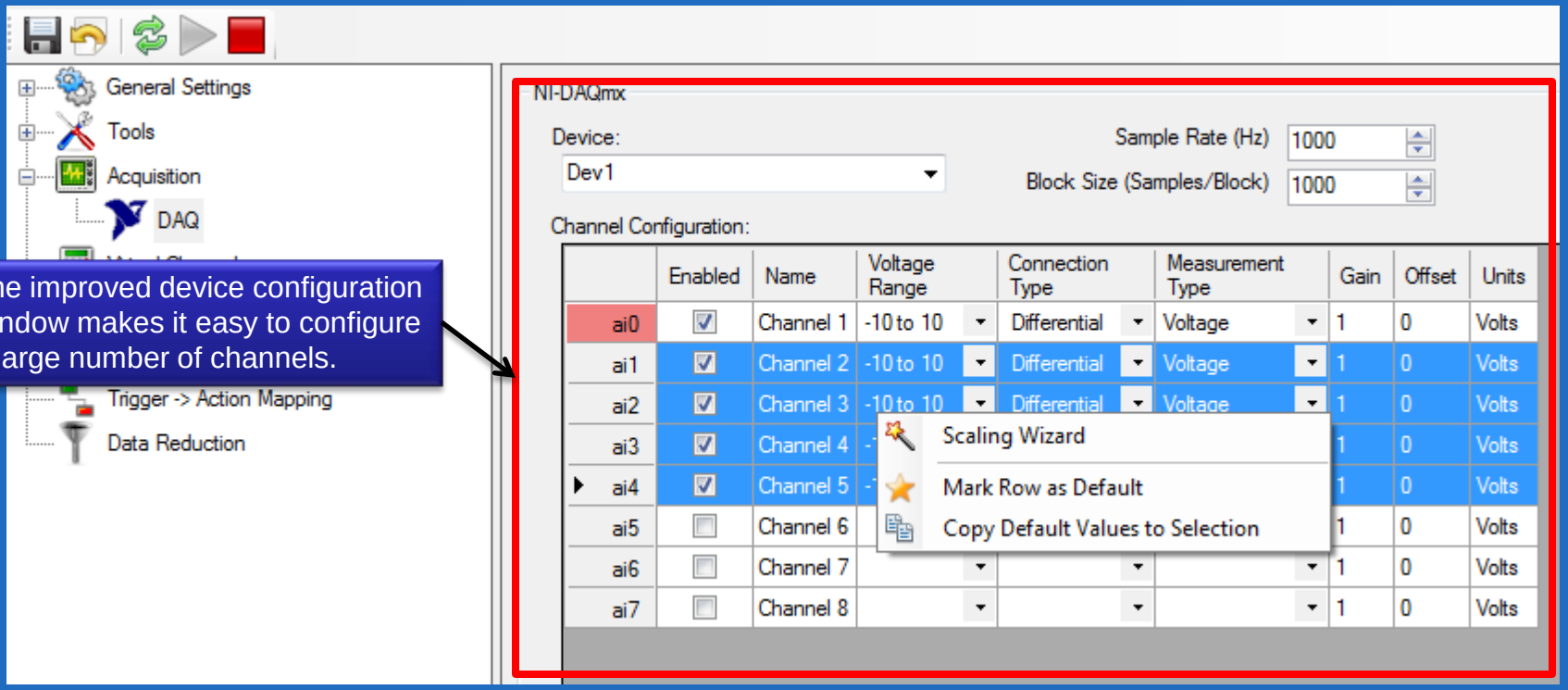
MCM v2.0 – Data Acquisition Setup



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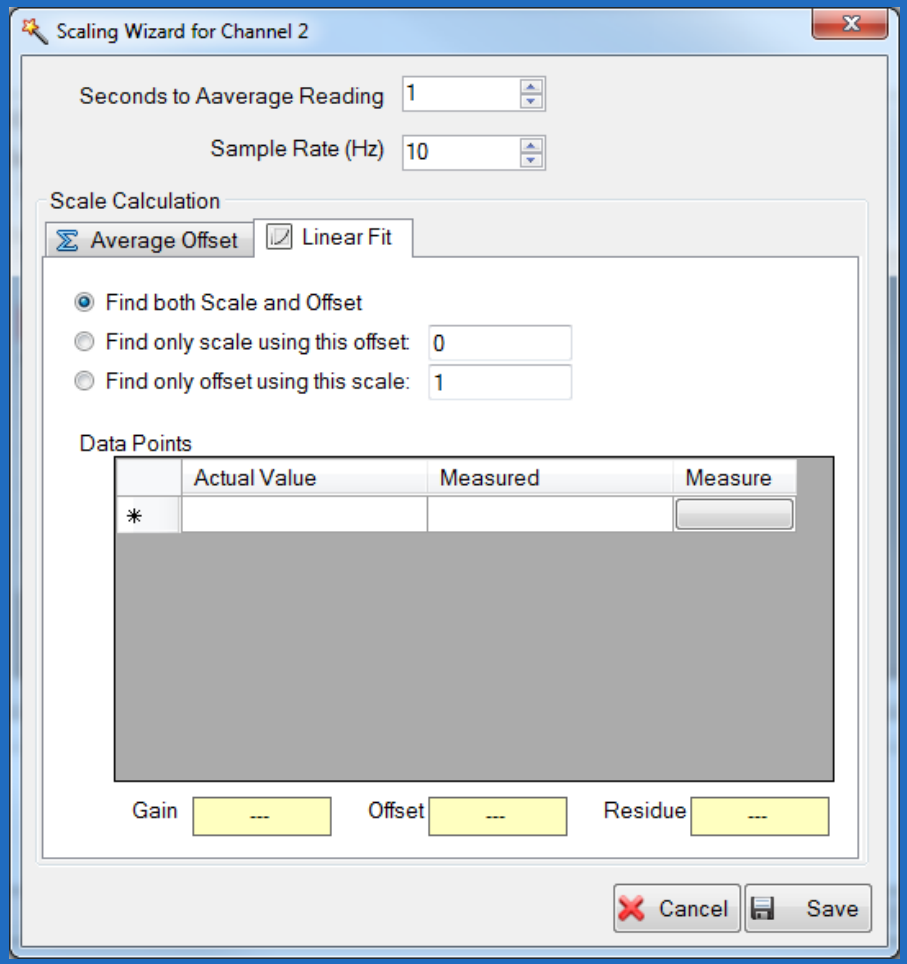
MCM v2.0 – Channel Scaling Wizard

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



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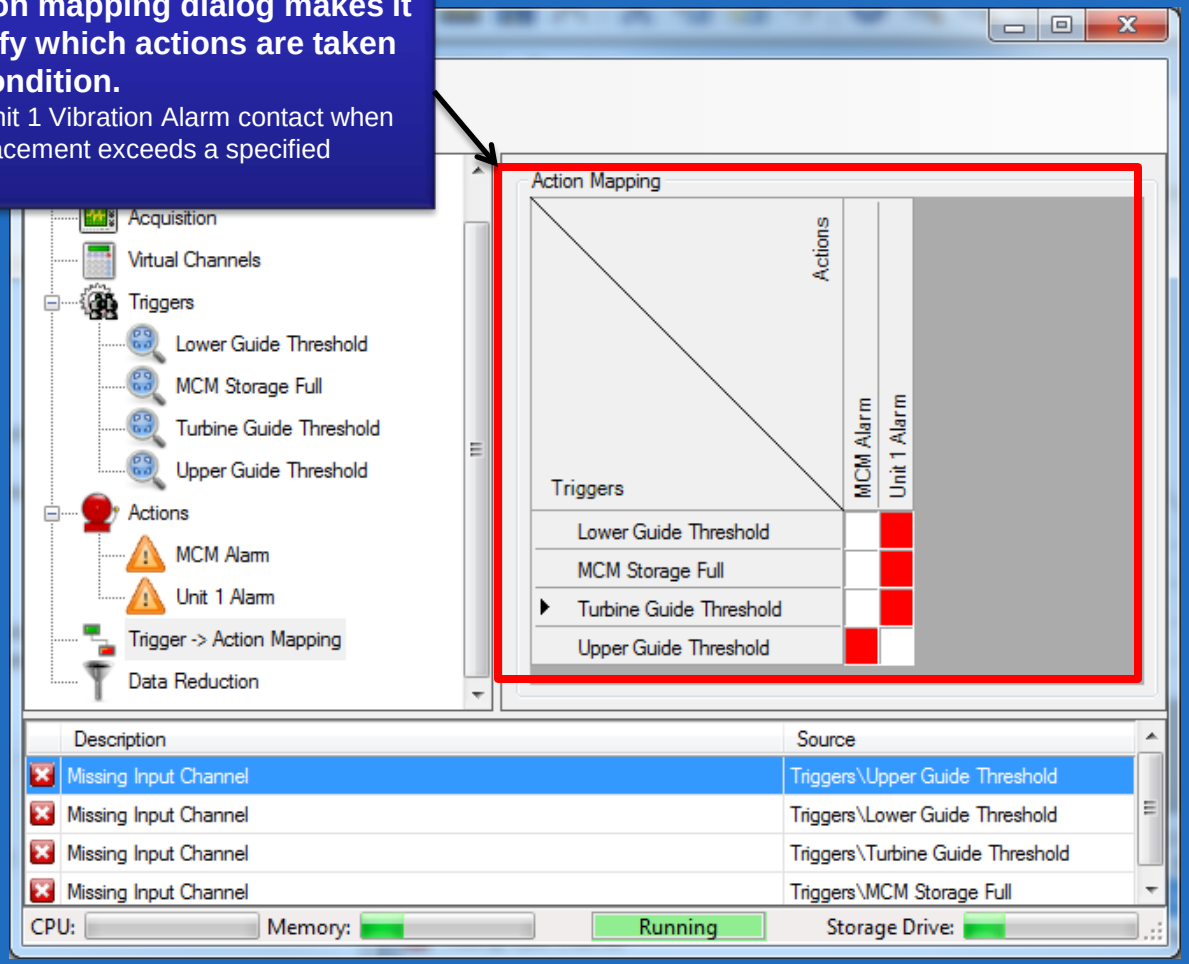
MCM v2.0 – Trigger/Action Mapping

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.)



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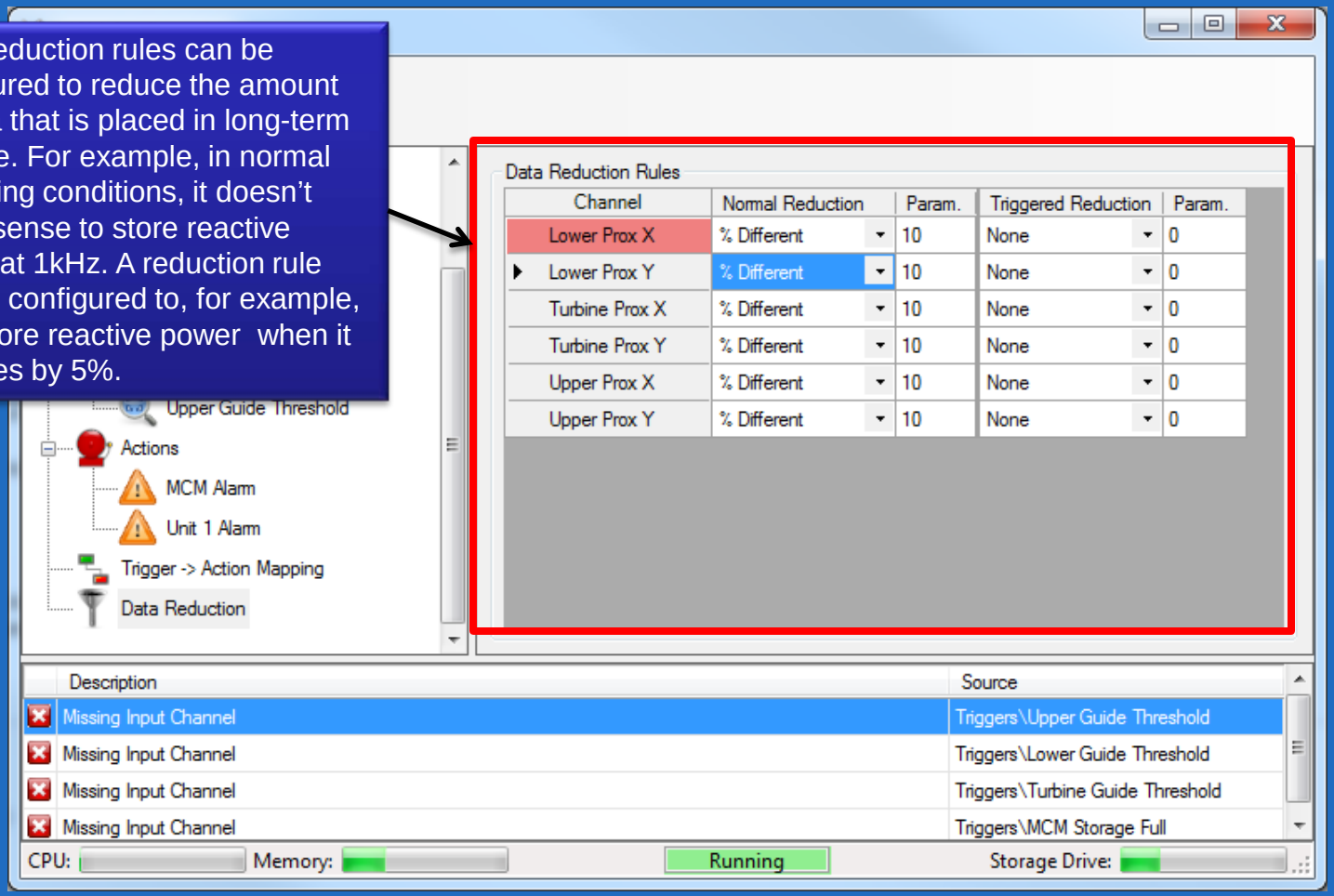
MCM v2.0 – Data Reduction

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%.



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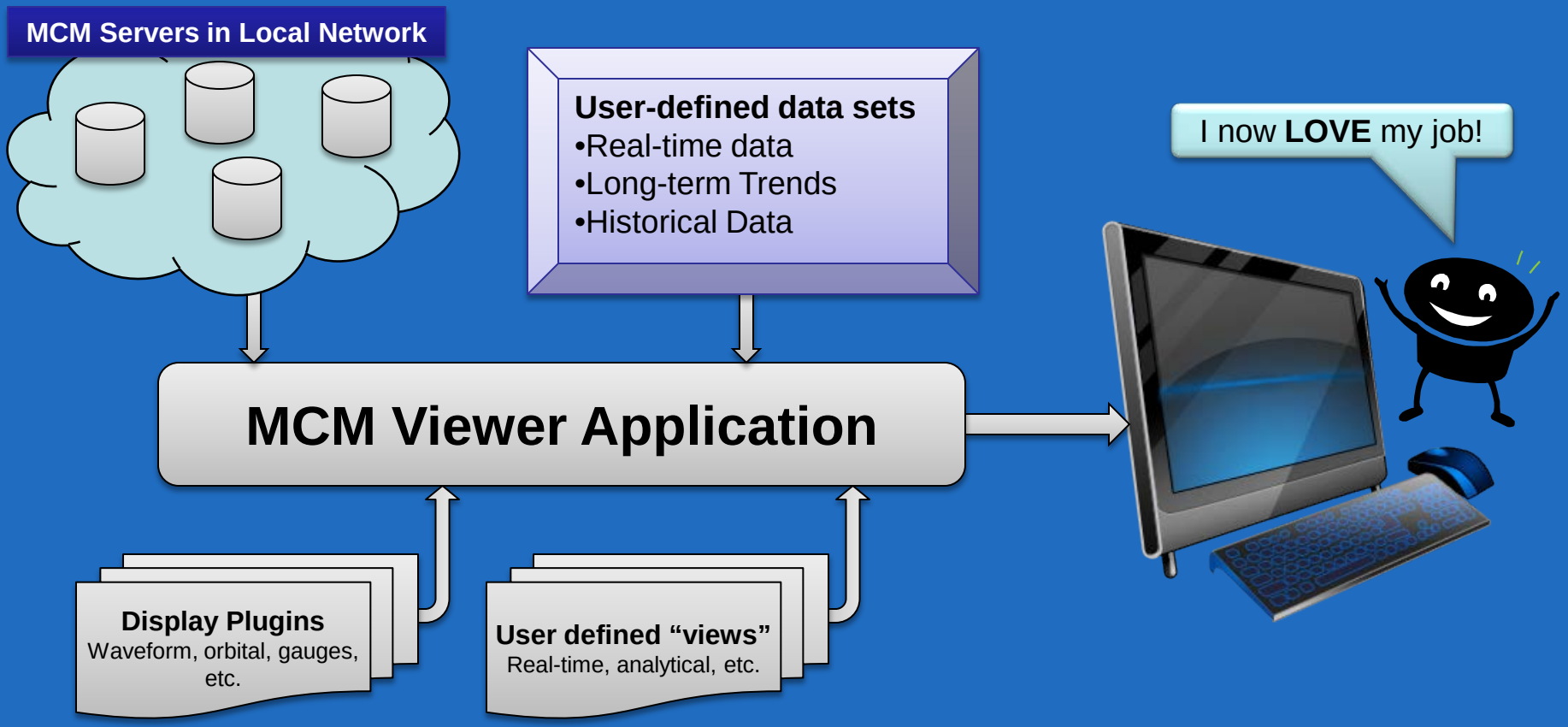
MCM Viewer Framework v2.0



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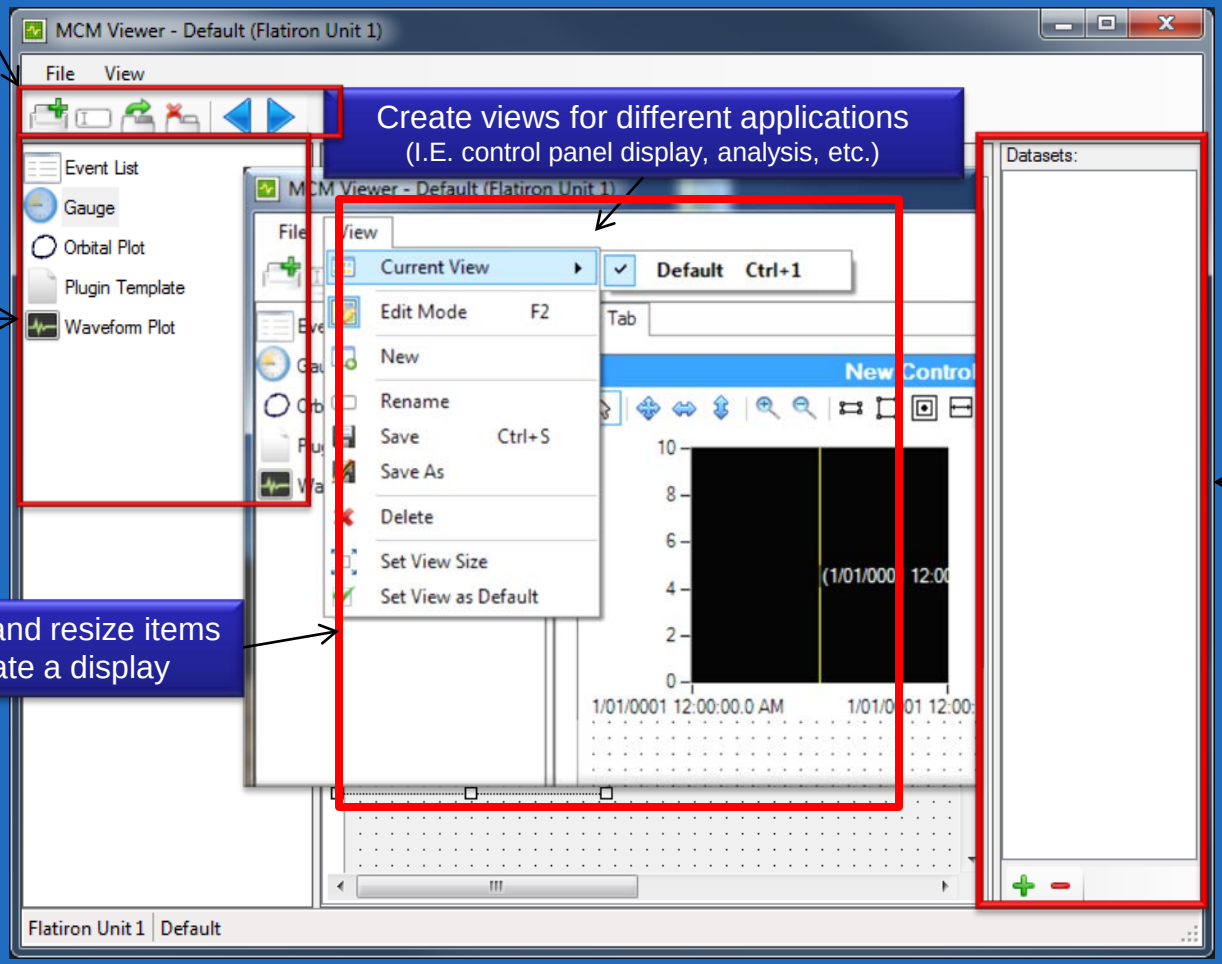
MCM v2.0 – Editing a View

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

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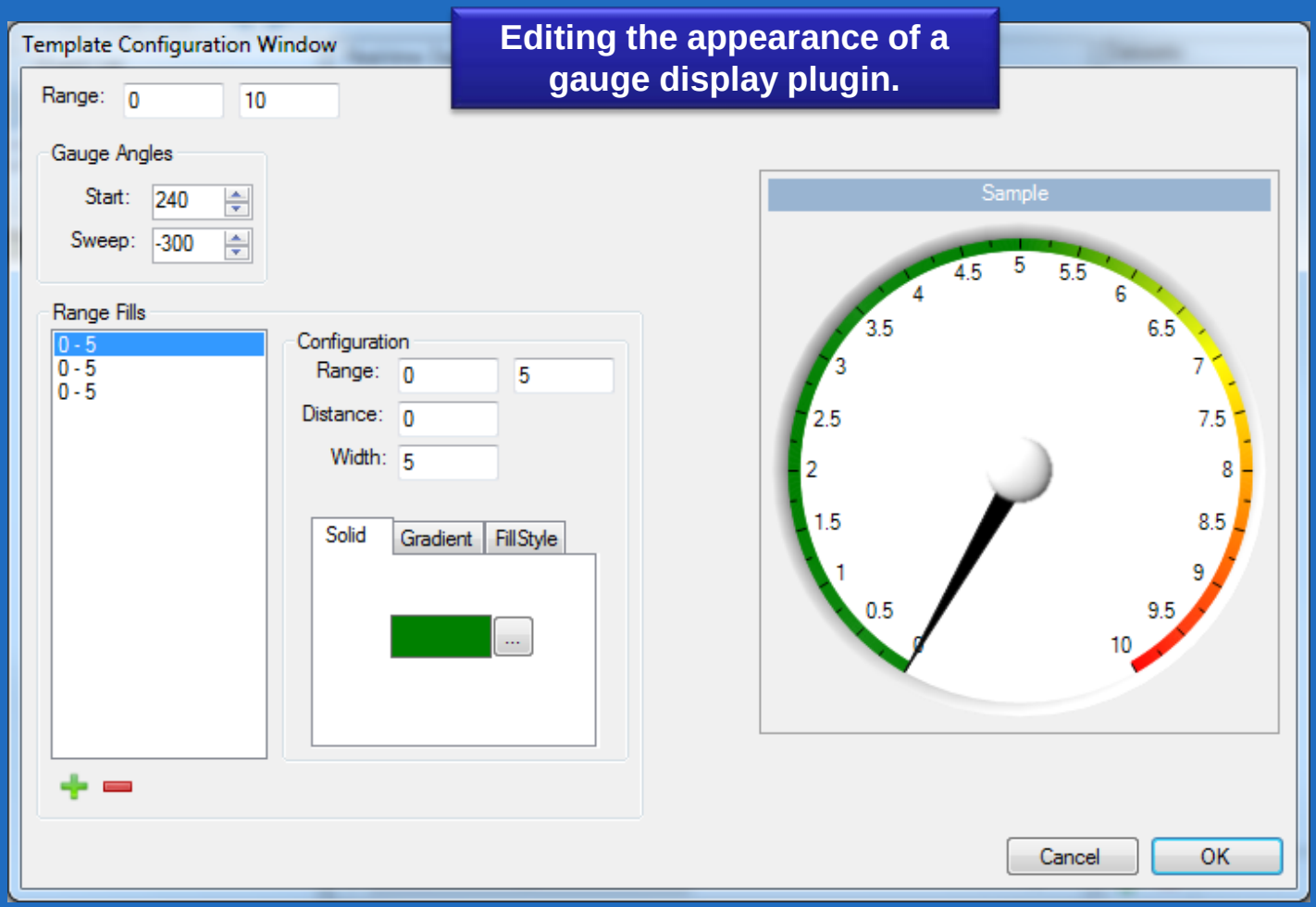
MCM v2.0 – Display Properties



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Questions?

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