Controls and Data Acquisition Systems Architecture for the DOE STEP 10 MWe Pilot Scale sCO2 Power Plant

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STEP utilizes separate Data Acquisition (DAQ) and Controls (DCS) systems

GE Mark VIe Distributed Control System (DCS)

- Robust, reliable control and protection functionality
- Widely used commercial product
- Measurement accuracy is not as high as NI-based systems

NI LabVIEW Data Acquisition System (DAQ)

- Ease of programming live performance calculations
- Code flexibility
- Existing SwRI experience/codebase

NI-based hardware boasts higher accuracy for temperature measurements

Hardware Measurement Accuracy

	Analog (4-20 mA)	Temperature (°C)
DCS	0.1% (Full scale)	1.1 - 3.3
DAQ	0.76% (Gain) / 0.04% (Offset)	0.7-1.1

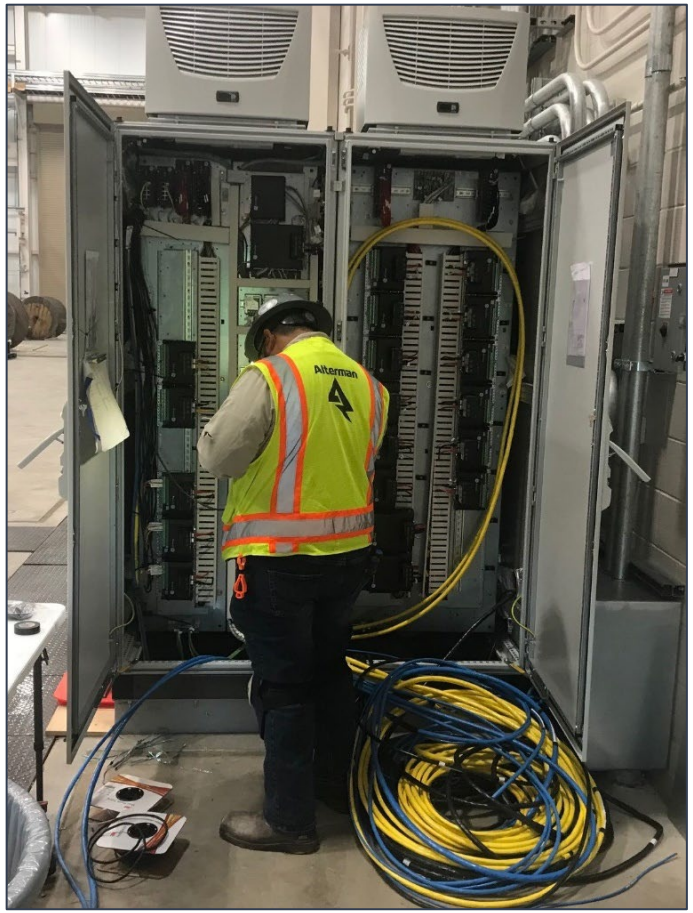
SwRI has extensive experience with and an existing codebase in NI LabVIEW

- Multiple other machinery labs at SwRI utilize LabVIEW for controls and data acquisition
- Utilizing existing codebase accelerated software development
- LabVIEW allows quicker changes and greater adaptability than Mark VIe codebase
- NI hardware has proven to be reliable and flexible enough for an R&D environment

STEP Distributed Control System (DCS)

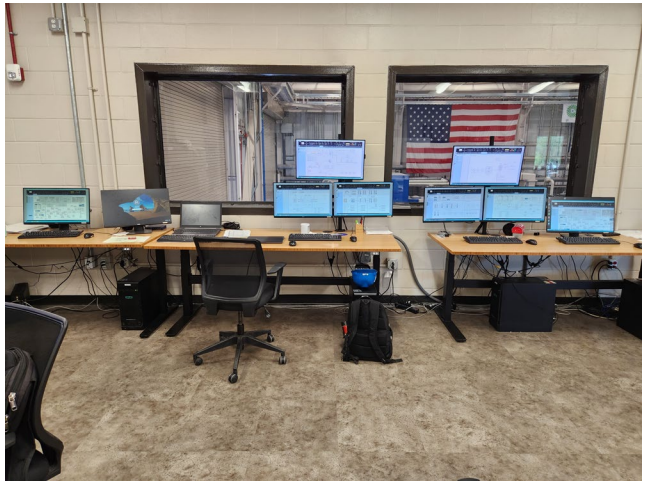
The DCS handles a large volume of information

- >550 hard IO points
- 7 DCS cubicles
- 10 large junction boxes (similar to picture below)
- >60,000 linear feet of cable installed
- ~20 PLCs with hard wired connections



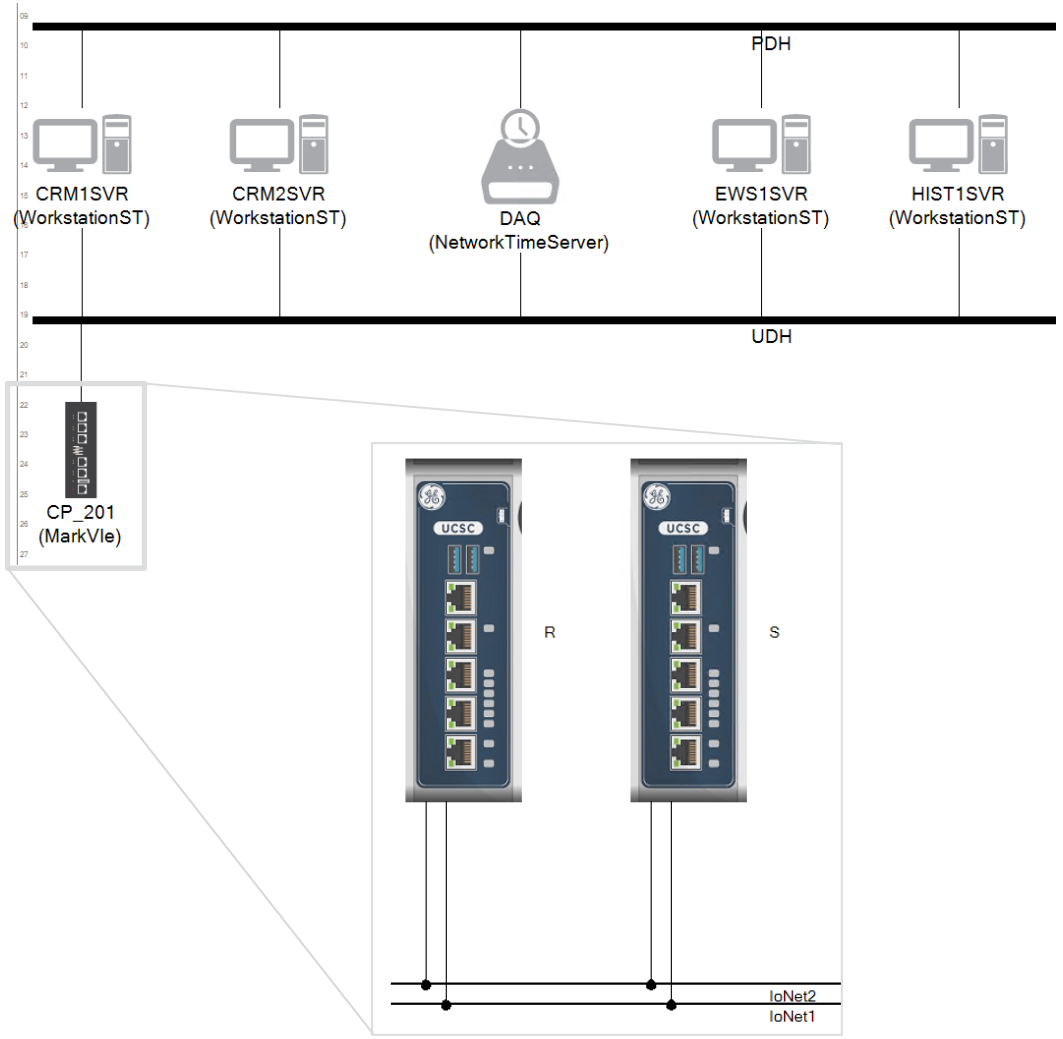
The DCS uses a distributed hardware layout

- 3 cabinets across the high bay
- Main network switch in control room
- 4 DCS stations
  - 1 Engineering workstation
  - 2 Operator Stations
  - 1 Historian station



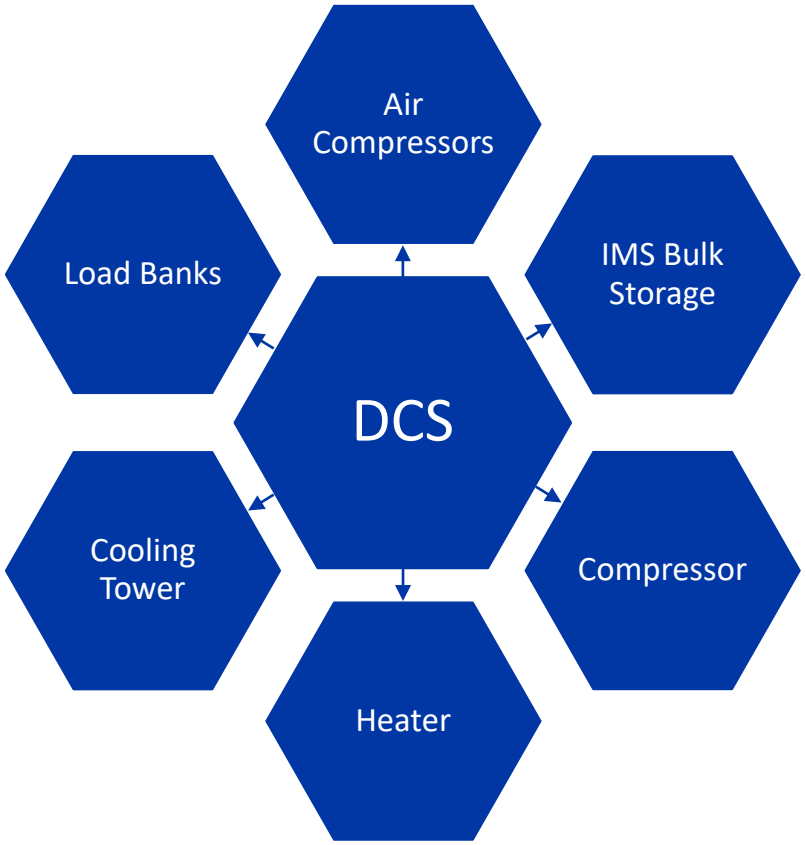
Hardware redundancy increases DCS reliability

- **Dual redundancy**
  - Controllers
  - Networking infrastructure
  - IO Cards (most)
- **Triple redundancy**
  - Facility Trip signals (level 2 and 3)
  - Critical sensors
    - Equipment efficiency calcs
- **Simplex (no redundancy)**
  - Valve IO
  - Non-critical sensors
    - Maintenance items like filter DP, some heat exchangers



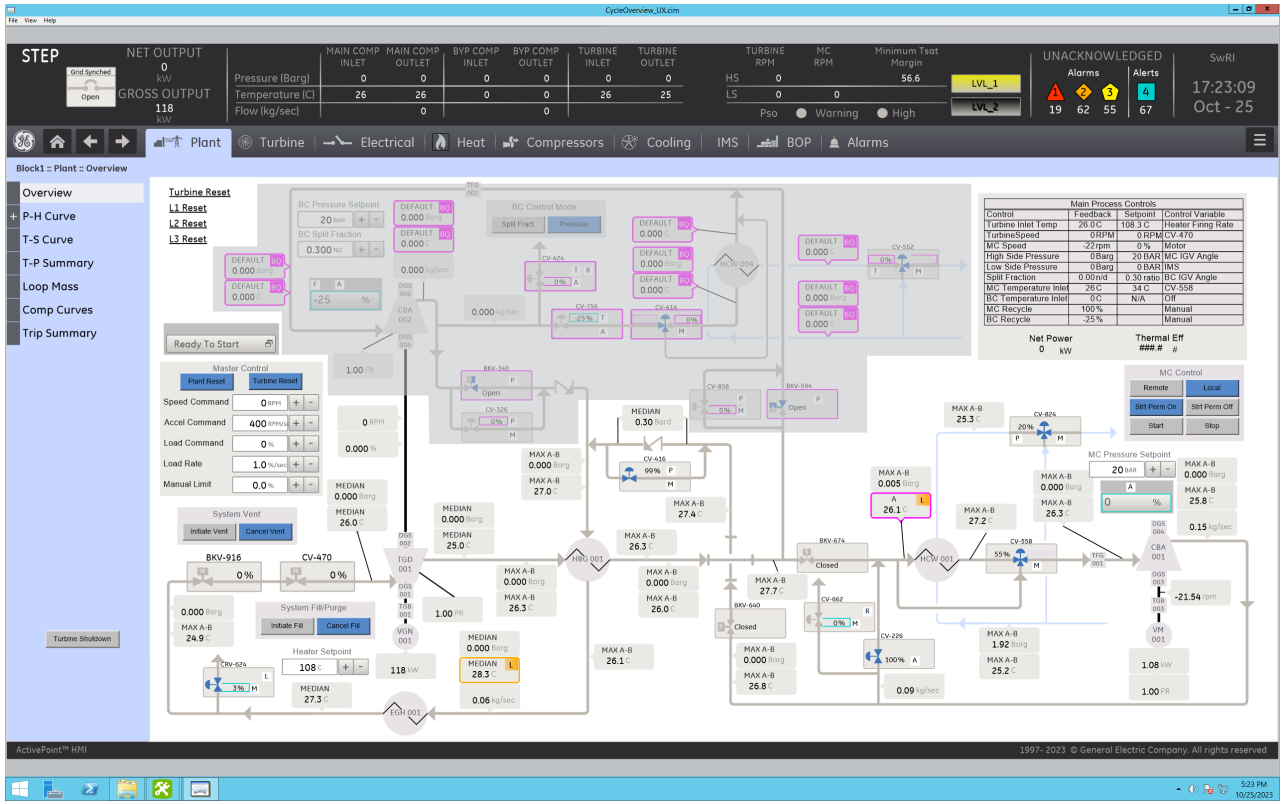
Modbus is used to communicate with system PLCs across plant

- Modbus protocol used for PLC data connections
  - Use both TCP/IP and RTU (serial)
- DCS is Master
- All other PLC's are Slaves
- Slaves store the data for the master to collect on demand
- Master can write to certain addresses as well as read all addresses



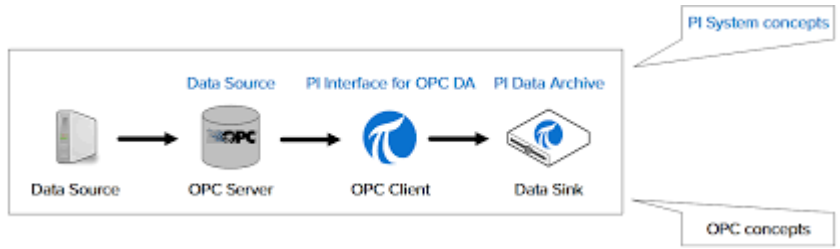
The DCS HMI allows quick access to key operation information and controls

- Cimplicity HMI integrated with ToolboxST and Mark VIe system
- Total of ~110 screens



The plant historian manages long term storage of operating data

- PI Historian integrated with ToolboxST and Mark VIe
- Up to 30,000 data points
- Booleans (on/off) log on status change
- Analogs record based on deadband
  - Attempted to set small deadband for critical instruments and larger deadbands for maintenance items



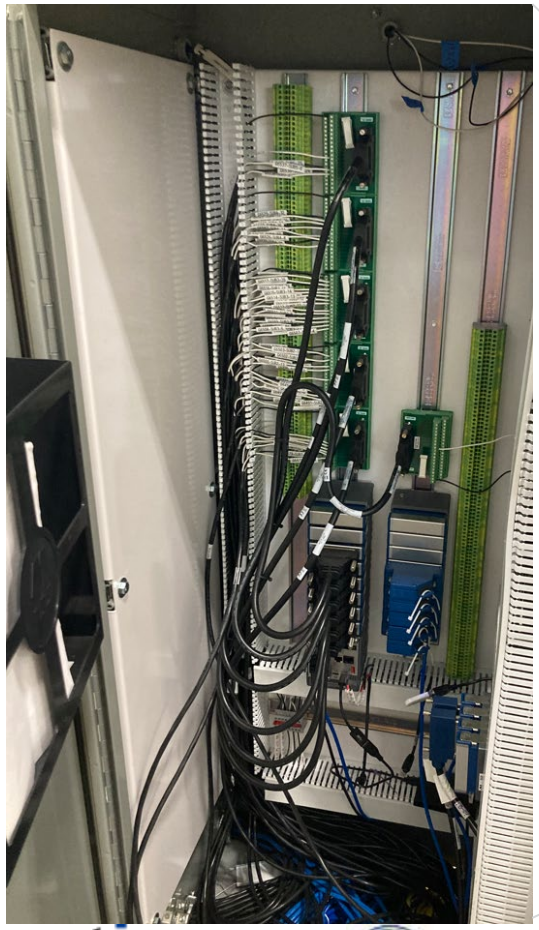
STEP Data Acquisition System (DAQ)

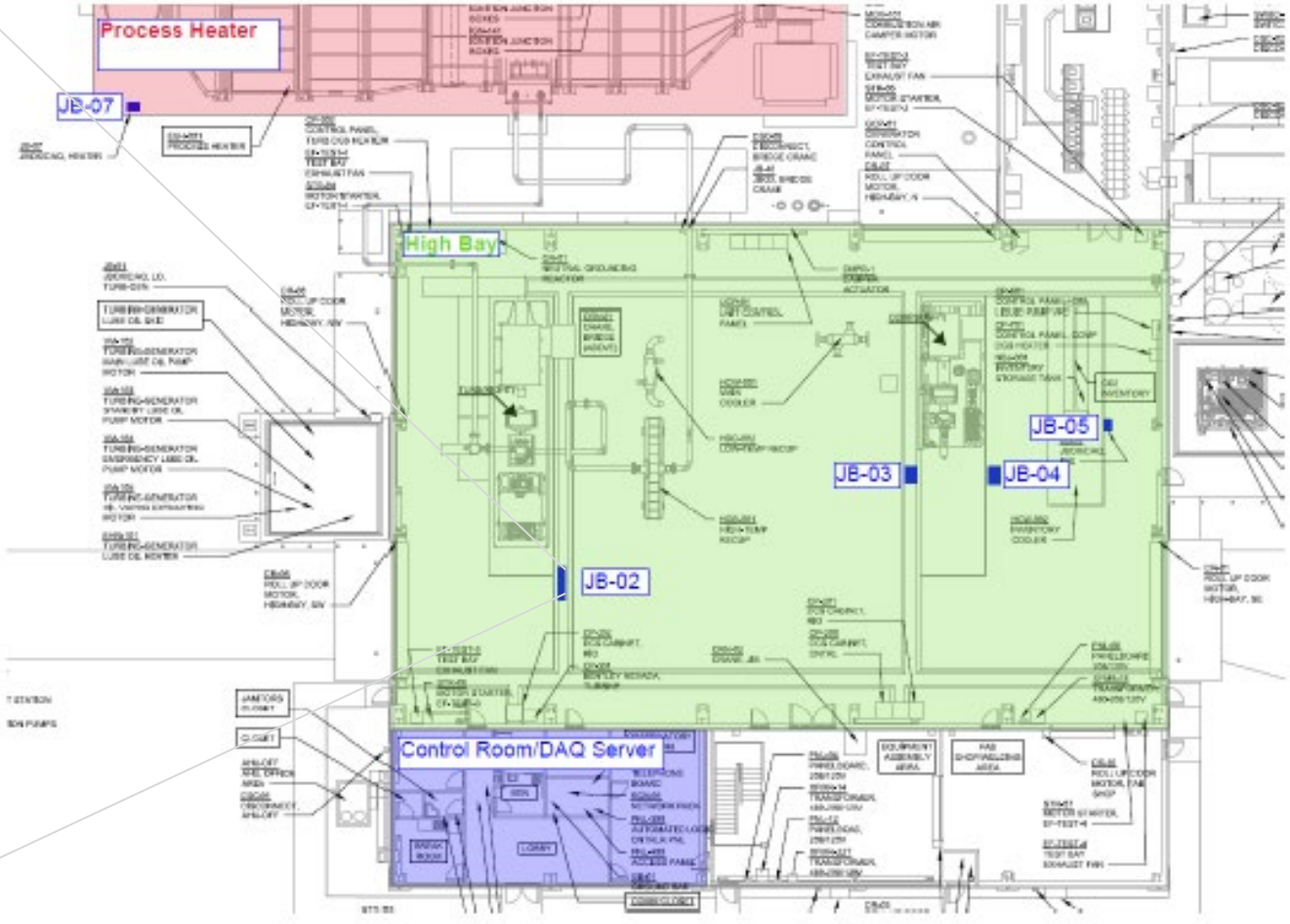
The DAQ system monitors 261 pressure and temperature instruments in the facility

- 85 static pressures
- 50 differential pressures
- 126 temperatures
  - T-types
  - K-types
- 18 flow meters

- Sensor redundancy reduces measurement uncertainty of each data point and ensures test is successful even if a sensor is lost

Distributed cRIO chasses throughout the facility serve as data collection points





cRIO chasses are essentially small computers with slots for instruments I/O modules

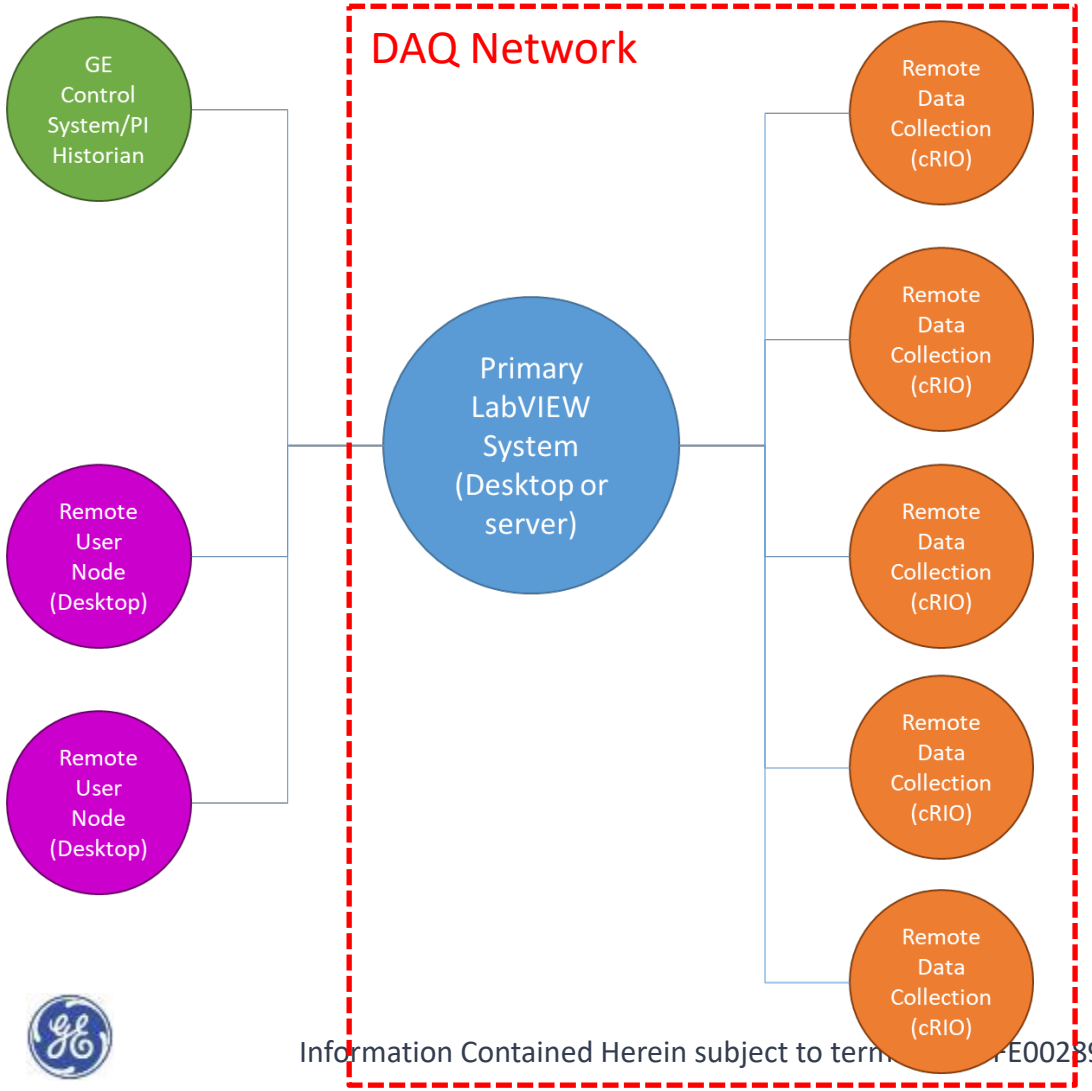
- Qty. 5 cRIO-9047 chasses
- NI 9208
  - Analog signal measurement (4-20 mA)
- NI 9214
  - Temperature measurement
  - Configurable TC-type
- Others available if needed:
  - NI-9234 Vibration card

Collecting and processing this much data requires a powerful Primary computer

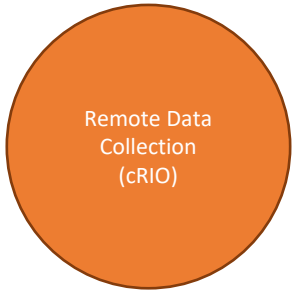
Specs for the primary DAQ PC:

- Processor — Intel(R) Core(TM) i9-10900X CPU @ 3.70GHz, 10 cores
- Installed RAM — 128 GB (128 GB usable)
- Video Card — Radeon Pro WX 5100, 1792 cores, 8 GB memory
- Storage — 11+ TB
- Networking — 4 active ports

Each cRIO connects to the isolated DAQ network which includes the Primary

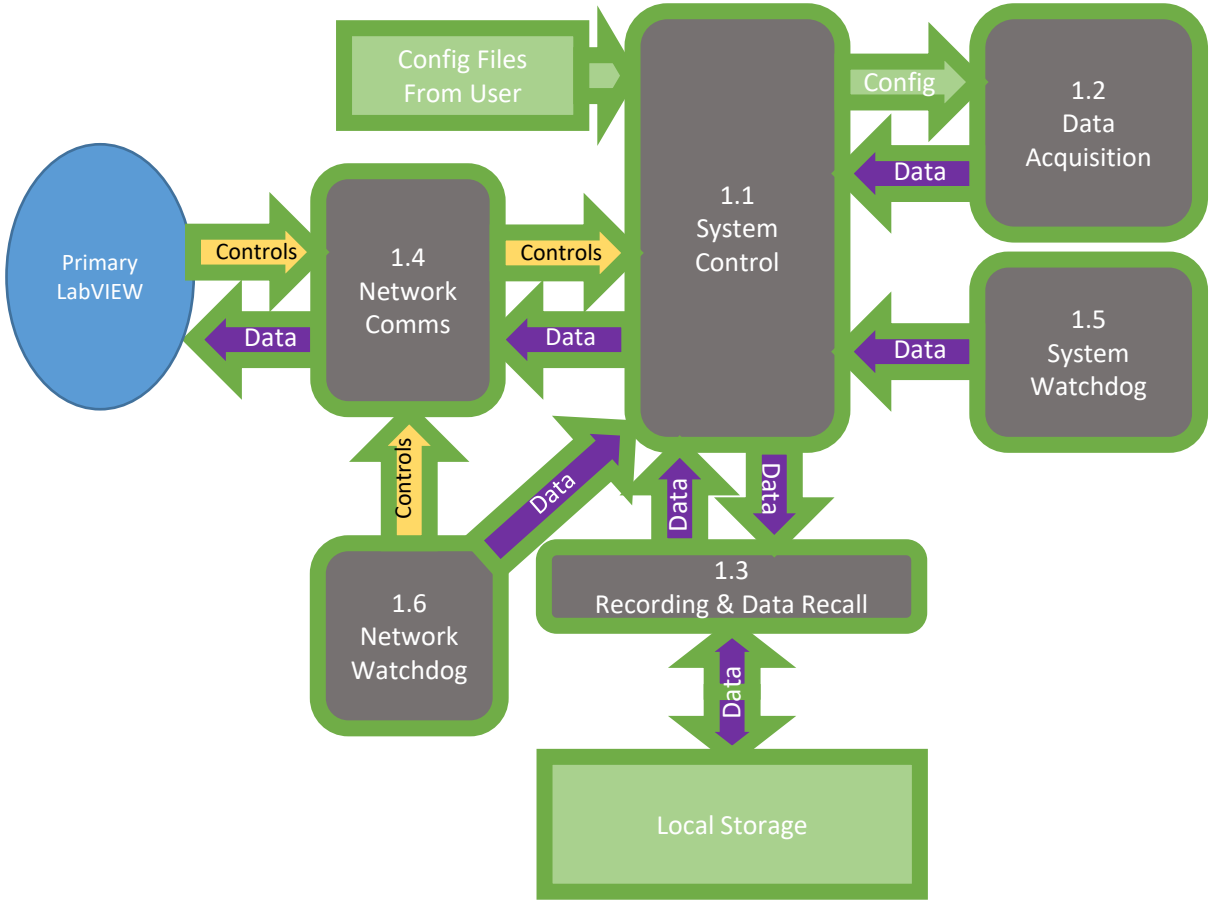


Each cRIO collects data, performs minimal processing, then passes along to the Primary

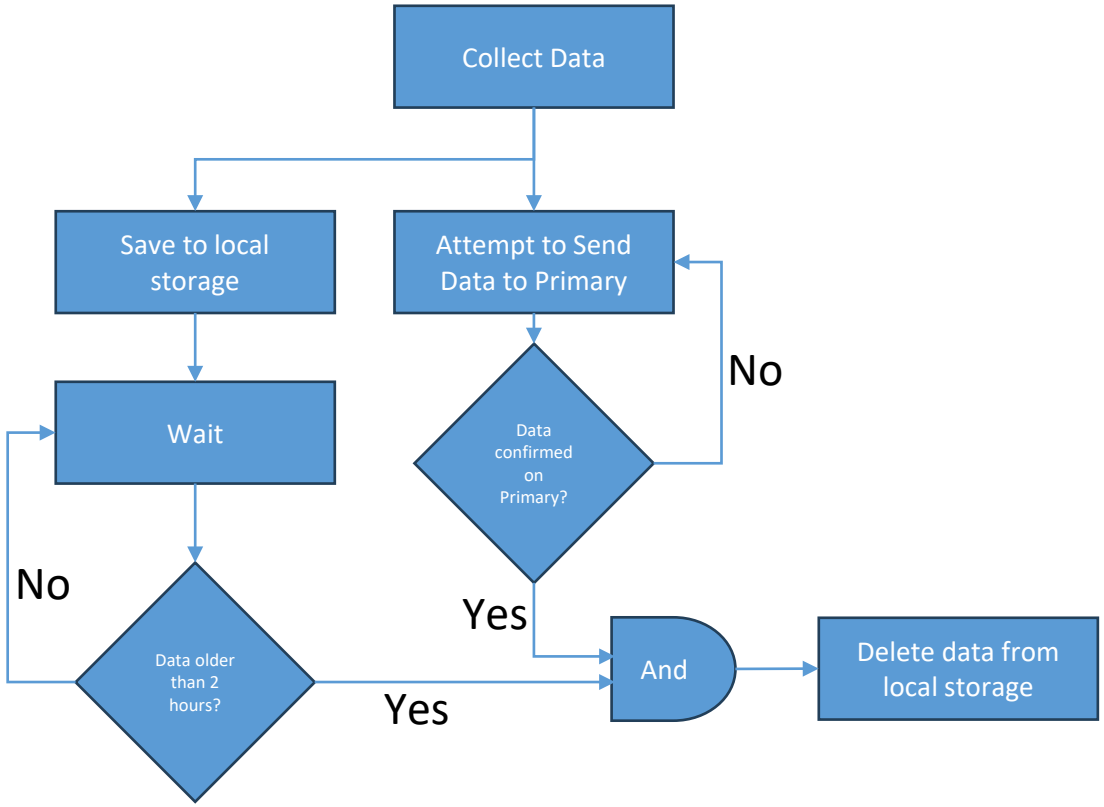


Remote Data Collectors

- Collect measurements from sensors
- Transfer measurement data to primary LabVIEW system
- Store local set of data until transfer confirmed
- Perform some local calculations
  - Scaling of data



Software controls are in place to ensure zero loss of data during operation

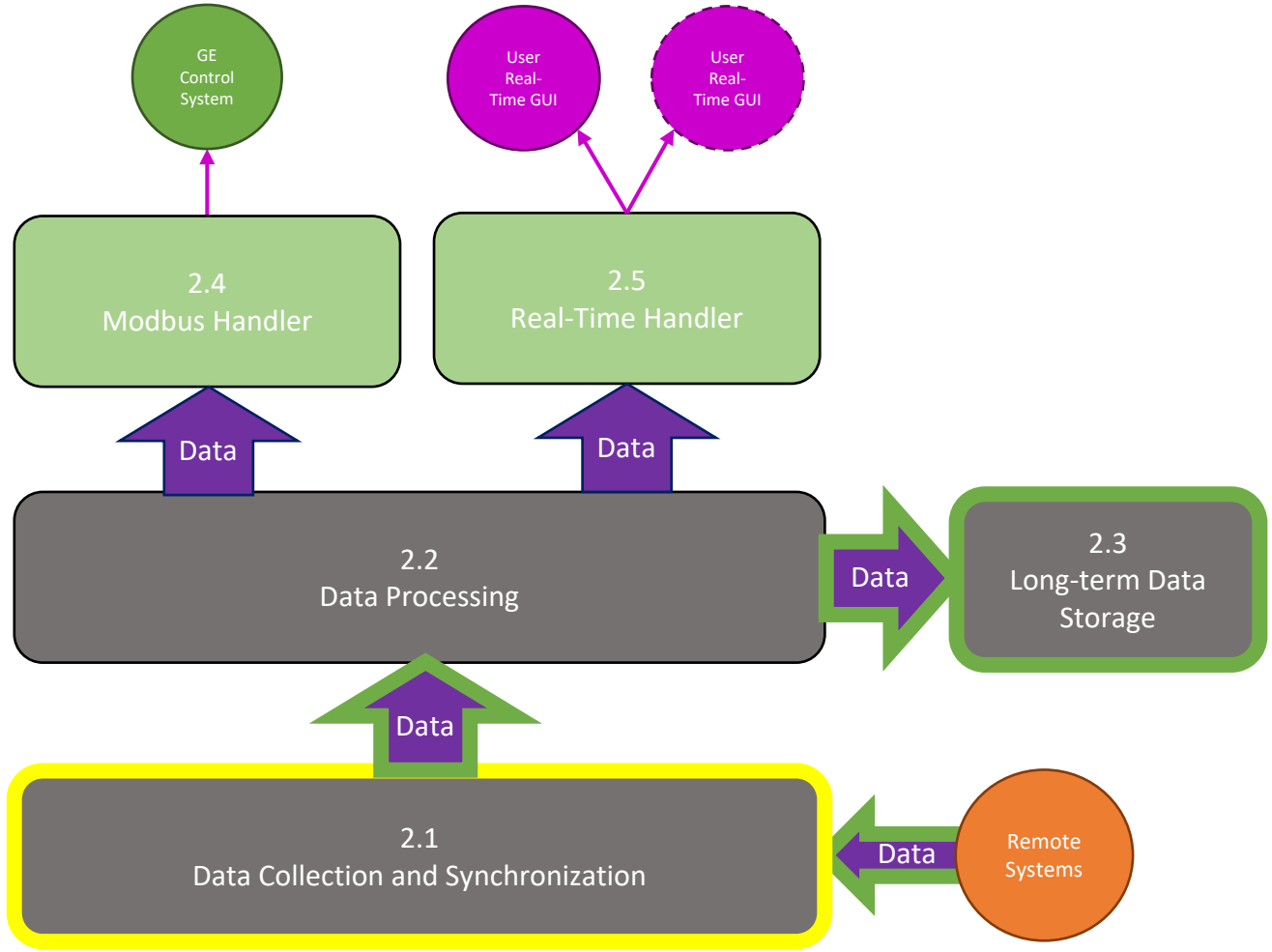


The Primary always stores processed data, but can gather raw data, too, if desired

Primary LabVIEW System (Desktop or server)

Primary LabVIEW System – Data Collection

- Receive data from remote data collection nodes
- Perform calculations for global data set
  - Averages
  - Performance Parameters
- Store historical data



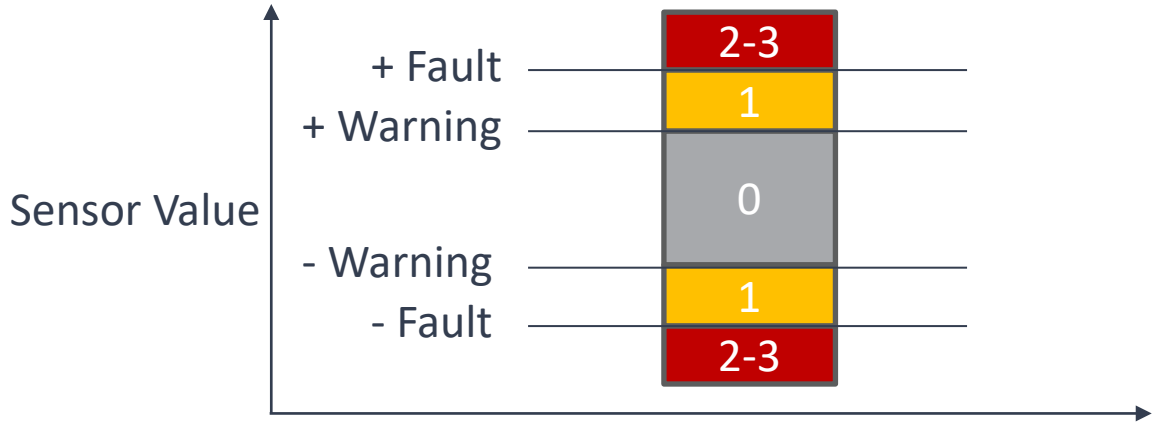
- Raw data speed: 25 Hz
- Processed data speed: 1 Hz

The Primary performs data averaging, quality checks, and performance calculations

> TC-XXX = Average(TC-XXXA, TC-XXXB, TC-XXXC, etc.)

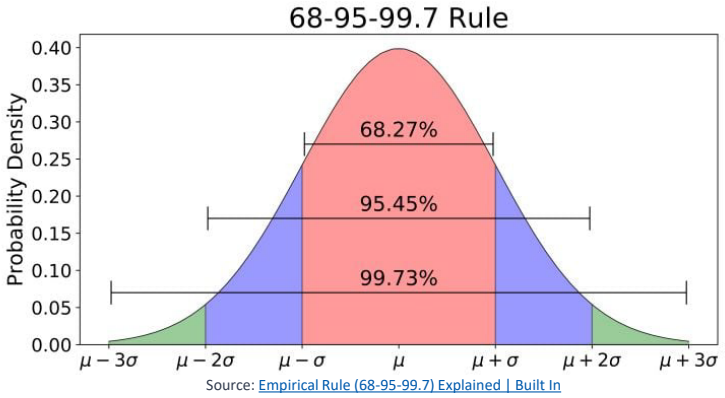
> Quality:

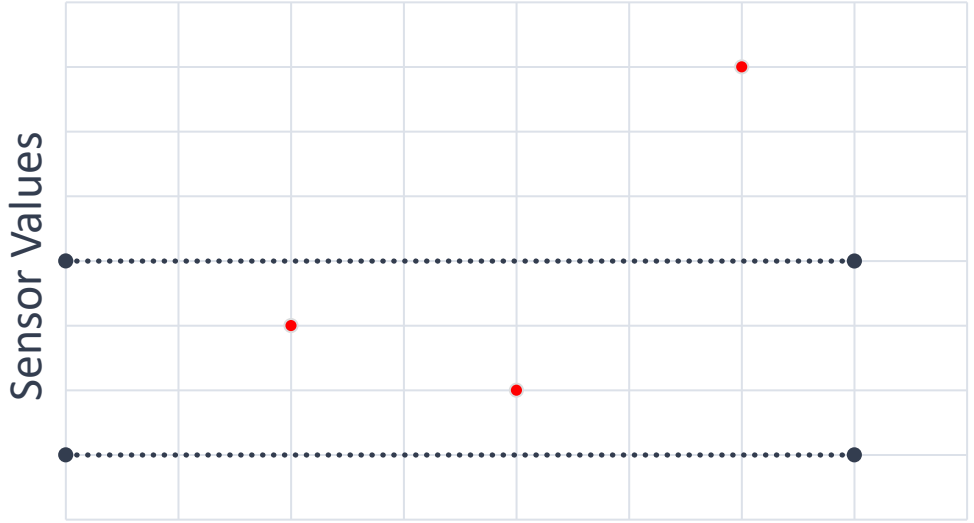
- 0 – Good
- 1 – Out of Expected Range or 95% Uncertainty Bounds at location
- 2 – Fault, bad signal
- 3 – Fault/Missing, no signal



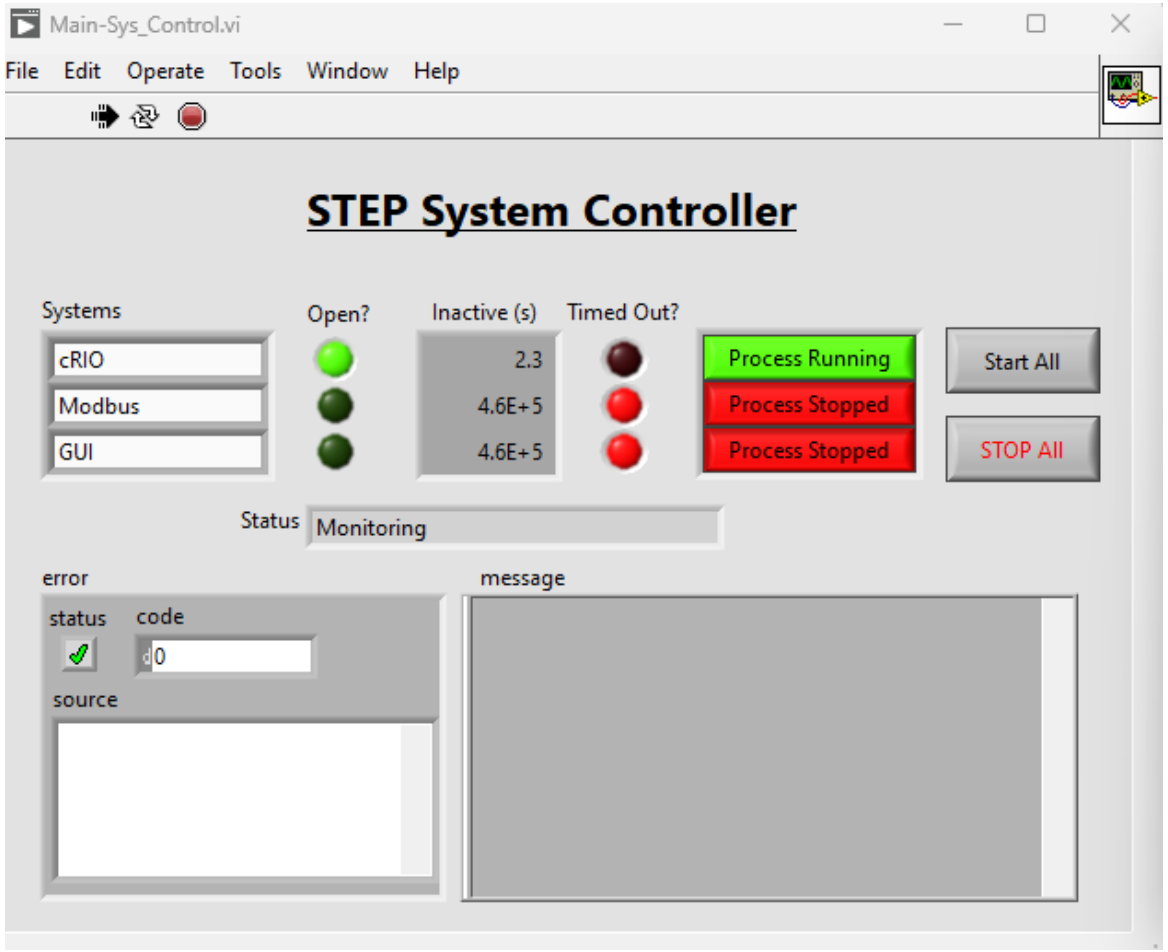
Sensor voting logic excludes sensors that deviate too far from the average

- More than two standard deviations from average and that point is removed
- Sensors in fault are excluded from averages
- Quality is carried through calculation to calculated value





A watchdog program pings running interface software and restarts them if any issues

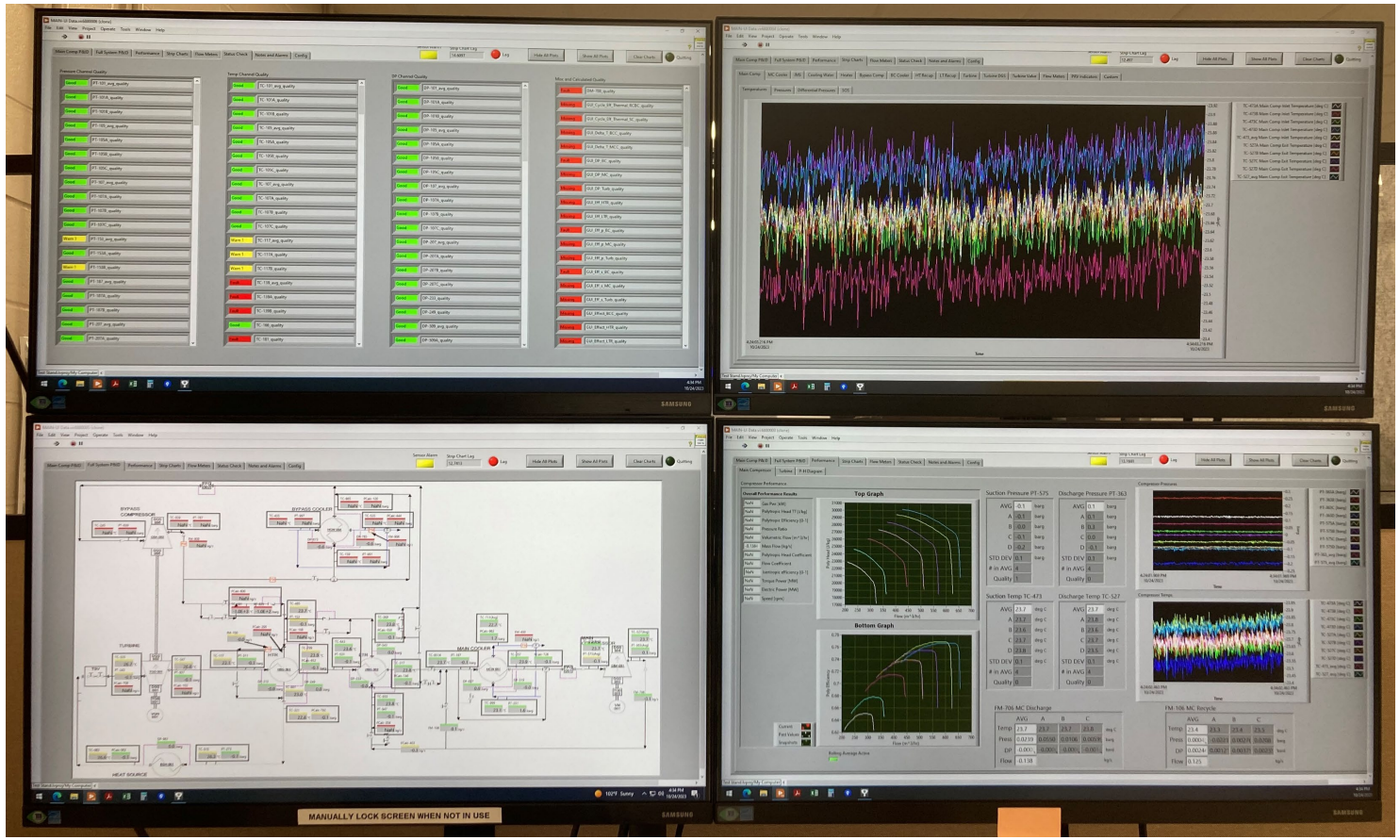


Configuration of the DAQ for new or modified sensors is simple

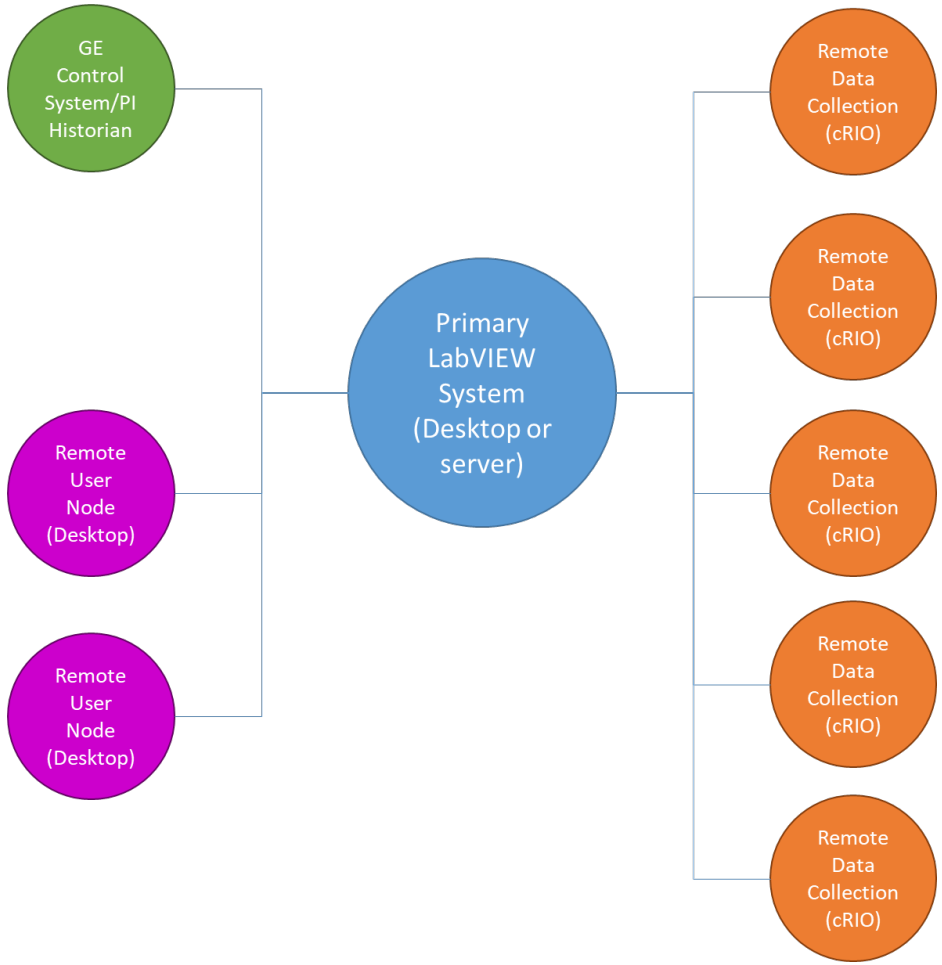
Spreadsheet format allows for quick changes and troubleshooting.

Channels												
Tag	Description	Rate	DAQ Type	Data Type	Scale	Offset	Units	Channel	Warn_min	Warn_max	Fault_min	Fault_max
DP-101A	Turbine DGS IS Vent Differential Pressure (0.5" OM)	25	Current	Float	2506.875	-10.0275	mbard	192.168.1.11/Mod1/ai0	-0.60165	38.1045	-1.2033	40.11
DP-101B	Turbine DGS IS Vent Differential Pressure (0.5" OM)	25	Current	Float	2506.875	-10.0275	mbard	192.168.1.11/Mod1/ai1	-0.60165	38.1045	-1.2033	40.11
DP-105A	Turbine DGS IS Supply Differential Pressure (OM)	25	Current	Float	3885	-15.54	mbard	192.168.1.11/Mod1/ai2	-0.9324	46.62	-1.8648	62.16
DP-105B	Turbine DGS IS Supply Differential Pressure (OM)	25	Current	Float	3885	-15.54	mbard	192.168.1.11/Mod1/ai3	-0.9324	46.62	-1.8648	62.16
DP-105C	Turbine DGS IS Supply Differential Pressure (OM)	25	Current	Float	3885	-15.54	mbard	192.168.1.11/Mod1/ai4	-0.9324	46.62	-1.8648	62.16
DP-207A	Turbine DGS OS Supply Differential Pressure (OM)	25	Current	Float	3885	-15.54	mbard	192.168.1.11/Mod1/ai5	-0.9324	46.62	-1.8648	62.16
DP-207B	Turbine DGS OS Supply Differential Pressure (OM)	25	Current	Float	3885	-15.54	mbard	192.168.1.11/Mod1/ai6	-0.9324	46.62	-1.8648	62.16
DP-207C	Turbine DGS OS Supply Differential Pressure (OM)	25	Current	Float	3885	-15.54	mbard	192.168.1.11/Mod1/ai7	-0.9324	46.62	-1.8648	62.16
DP-409	IMS BC Return Differential Pressure (2" OM)	25	Current	Float	155	-0.62	bard	192.168.1.11/Mod1/ai8	-0.0372	1.86	-0.0744	2.48

A separate GUI software package allows live viewing of DAQ data on multiple screens



The Primary hosts a Modbus server for passing data to the DCS for historian archival storage



The Primary hosts a time reference server for synchronization between DCS and DAQ systems

The DCS and DAQ systems together meet the unique needs of the STEP Demo plant