Title: World's Largest Iron-Chromium Flow Battery Powered by CompactRIO

National Instruments (NI) products used: CompactRIO, LabVIEW **Category:** Energy

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The Challenge: To develop a safe, reliable electrochemical process control system capable of maximizing the efficiency of a grid-scale Iron-Chromium (Fe-Cr) flow battery.

The Solution: By building on the rugged CompactRIO platform, a LabVIEW control system was developed that incorporated a custom scripting engine that enabled engineers to test various strategies for optimal energy storage and delivery.

Introduction
Energy storage systems can play a key role in the development of reliable solar, wind, and run-of-river based power. This can be critical in remote areas that rely solely on such intermittent energy sources. Energy storage can also provide cost savings by buying and storing low-cost power from the grid at night and selling it back during peak demand.

Enervault Flow Battery Installation

Flow batteries are an emerging answer to the energy storage puzzle. By pumping electrolyte continually through a battery from storage tanks, a flow battery enables energy storage to scale linearly with tank size. The number of cells and cell area of the battery can likewise be scaled to the peak power requirements of the system. During the technology development stage, various vendors' control solutions were considered. NI LabVIEW's fast prototyping and its ability to seamlessly run high-speed DAQ and third party MODBUS devices on ruggedized real-time controllers made it an obvious choice. Several small scale systems were first tested in Enervault's laboratory to prove out the flexibility and rapid development advantage gained by using LabVIEW and CompactRIO.

Developing the Solution
Enervault Corporation and their engineering partners hired Canadian NI Alliance company LightWave Computing Ltd to develop a LabVIEW based control system to integrate the various components in their first field test of their megawatt-hour scale flow battery system. LightWave Computing's previous experience developing flow battery and fuel cell control systems made them a

natural fit for Enervault's project. Deployed in a remote area in California's Central Valley, the system consists of four large Fe-Cr electrolyte tanks, a Fe-Cr flow battery with 6480 cells, and a photo-voltaic solar array. The flow battery can sustain 250kW charge and discharge rates.

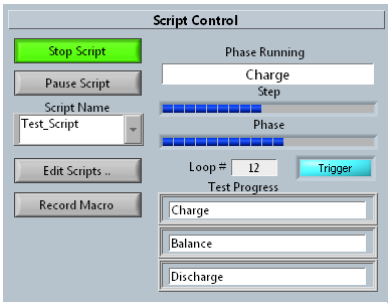
The control system was comprised of an 8 slot cRIO-9118 master controller, four daisy-chained 8 slot NI-9144 Ethercat Chassis, and a Windows HMI. This NI LabVIEW system was tasked with the control and measurement of the following subsystems:

- Measurement and logging of 3240 cell voltage pairs
- Real-time control of a 250kW power inverter, power analyzer and AC electronic load
- Control of electrolyte fluid pressures, temperatures and flow rates
- Control of the deterministic fault monitoring and protection systems
- Management of electrochemistry rebalancing system and fuel cell stack
- Logging of all data to local and remote databases

The CompactRIO deterministic real-time system handled all control functions, including interlocks and safety logic designed to protect against faults caused by computer or mechanical failure. The availability of the FPGA on the CompactRIO allowed us to pre-filter critical signals for noise. The FPGA also enabled us to create pulse-stream frequency to analog algorithms on 32 flow meters, obviating the need for dedicated converters and saving considerably on hardware and installation costs.

Flow battery systems must contend with the loss of efficiency due to the power used by pumps and other control devices not required in a conventional battery storage system. A key goal in proving the superiority of this system over competing storage technologies was to maximize the round-trip efficiency of the system. By iterating through various test strategies, solutions emerged for optimizing the efficiency of the system.

To test these strategies, the HMI was developed with a sophisticated scripting engine that allows for nested loops and branching based on various system parameters. The scripting engine features a drag-and-drop interface that allows users to manipulate and save automated trials to validate different charge and discharge strategies. Once scripts are developed and debugged, operators can run the scripted test trials unattended. To help engineers develop scripts, the user can also record a macro of a previous test and incorporate this as a phase of a larger test protocol. This macro can then be edited and have various events trigger other phases to execute as required.

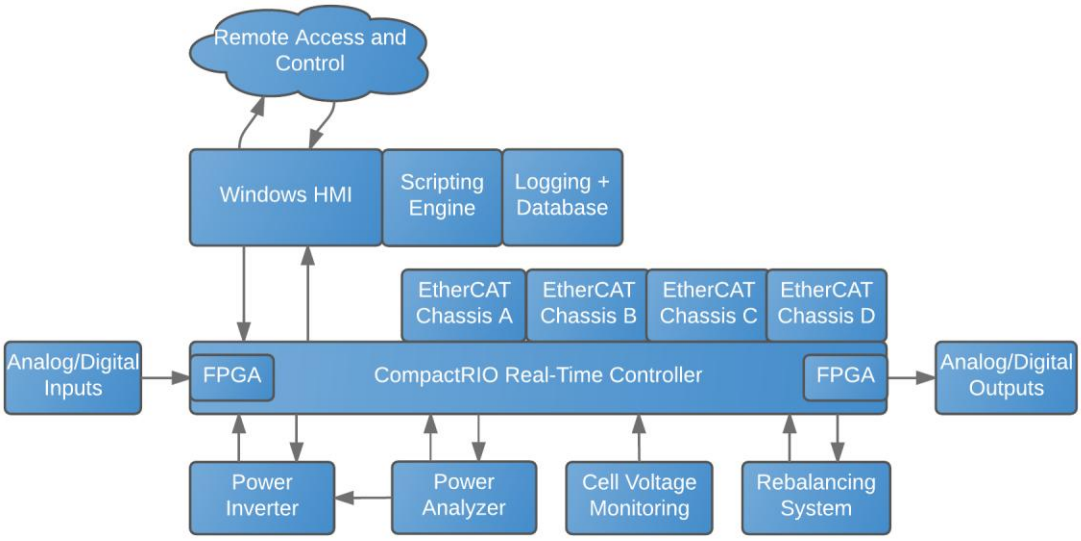


Run-Time Scripting Control

The battery consists of nine 720 cell cascades with multiple RS-485 based cell voltage monitoring nodes per cascade. The system measures each cell voltage pair, passing this data via the CompactRIO to provide important metrics of the total battery performance. This data also enables early intervention and automated recovery if the cascades are not providing equal power due to the condition of a particular cascade.

Battery charge and discharge inevitably leads to small side reactions that over time will degrade the battery performance. In a Fe-Cr battery, small volumes of hydrogen are released in these side reactions which the system routes to a small fuel cell stack allowing the capture of this waste energy. To determine the state of the electrolyte, four sensors are continuously drawing small samples into a test chamber for analysis. This information is made available to the scripting engine to schedule a chemistry balancing if required at the end of a charge or discharge cycle.

The core communication strategy employs a LabVIEW queued message handler to pass data between the critical real-time processes and the various MODBUS instrumentation devices. The system also made use of the NI Simple TCP/IP Messaging Library (STM) to collect and transmit messages as required back and forth from the host to the CompactRIO. The STM structure made it easy for the CompactRIO to connect to the HMI and provide an orderly system startup and shutdown mechanism. Remote access to the system was provided through a cellular network.



Flow Battery Control Architecture

Given the tight production targets and ambitious performance goals, it was important to have the ability to simulate the real-world environment of the system before the physical plant was completed in order to get a head-start on software commissioning. LabVIEW's ability to use conditional compilation allowed us to easily test our scripting language and fault logic of the real-time code running in simulation on a Windows platform. Furthermore, this allowed us to test upgrades to the system in Windows prior to the upgrade being pushed out to the CompactRIO real-time system. This process enabled us to commission and upgrade the system with minimal delay and debugging effort.

Conclusion

The flexibility of LabVIEW and CompactRIO cut our development time in half and allowed us to beat our testing and production goals. Being able to run LabVIEW as a single coding platform from HMI through to the Real-Time and FPGA turned out to be a unique benefit that provided us with an easy method to run system simulations. The extensive LabVIEW code libraries and NI community support made it possible to quickly build our scripting engine to the customer's specifications. Using LabVIEW enabled us to integrate a disparate cluster of instrumentation into our system; in some cases leveraging pre-built instrument drivers copied directly from the NI website.

The ability to store renewable energy efficiently using advanced flow battery technologies better positions us to reduce our reliance on carbon-based energy sources resulting in a positive impact on our environment. National Instruments role in launching the world’s largest Fe-Cr flow battery project helps pave the way for still other creative solutions to help reduce global warming.

Additional Information

Dedication video for Enervault Flow Battery Installation: https://youtu.be/b-DUWoH5ILE

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