Open-Source Framework for Data Storage and Visualization of Real-Time Experiments

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The ESIF is a national user facility located in Golden, Colorado, on the campus of the National Renewable Energy Laboratory (NREL).

http://www.nrel.gov/esif
Research Electrical Distribution Bus (REDB) Technical Specification

**AC**
- Rated 600Vac 3ϕ, 2ϕ, or 1ϕ
- 5-wire design: L1, L2, L3, ground, neutral with selectable ground bonding location
- 16.67 Hz to 400 Hz
- 250A and 1600A installed
- 250A and 2500A planned (future)
- Experiment connection via mobile or fixed equipment CB/Fuse
- Connects PSIL, SPL, ESL, GSE, LBE, LVOTA, MVOTA, ESIL.

**DC**
- Rated ±500Vdc or 1000Vdc
- 4-wire design: positive, negative, common, and ground
- Any pole may be tied to ground at selectable location
- 250A and 1600A installed
- 250A and 2500A planned (future)
- Experiment connection via mobile or fixed equipment CB/Fuse
- Connects PSIL, SPL, ESL, PVE, LVOTA, MVOTA, ESIL.
Grid Simulator 2 x 1 MW

Architecture
12 Ametek RS-90 units connected in sets of 3 to make 4 quads. Configure any combination of quads.

PV Simulator 1.5 MW

Architecture
6 Magna-Power MTD 1000-250 units configurable in series or parallel up to 1500 ADC or 4000 VDC.

Key ratings
• 1.5 MW
NREL’s megawatt-scale controller- and power-hardware-in-the-loop (CHIL/PHIL) capability allows researchers and manufacturers to test energy technologies at full power in real-time grid simulations to safely evaluate performance and reliability.
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Hardware-in-the-Loop Requirements
Controller Hardware-in-the-Loop Requirements

- RMS-type measurements
- Power electronics controller applications might need higher frequency
- Update rates to power system controllers are slow (ADMS test bed, microgrid controller)
- Can run for longer period without supervision
- Data storage requirements might exceed limits based on experiment run time and number of variables that need to be stored.

• Requires mostly 60 Hz information of voltage and current with harmonic content
• Need to be run with supervision
• Running 1-MW PHIL for an hour will result in 1-MWh electricity charge (less for back to back) plus demand charges.

Combined Data Requirements

- Capability to run longer experiments impacts the data storage (for both CHIL and PHIL)
- CHIL requires RMS data with long-term data storage of large number of data points (For power electronics CHIL, this may change.)
- PHIL requires 1 kHz to 5 kHz (or more) data storage with fewer number of data points
- Storing this in csv is even more expensive—six times more because the floating data point is stored as string.
- For the above example, it would be 8.64 Kilobytes.
Experimental Setup #1

Experimental Setup #2

Other Utility Management Systems
- Microgrid Controller
- DERMS Controller
- Transmission EMS

Vendor ADMS
- IVVO
- SCADA
- FLISR

Multi-timescale Simulation
- QSTS Tool (OpenDSS)
- Phasor & EMT Tool (Opal-RT)

CHIL
- Protection Relays
- Asset Controllers
- Voltage Controllers

Remote HIL
- Interface
- Models
- Controller

PHIL
- Controllable DC Source
- PV/BESS Inverter
- Grid Simulator
Data Challenges
Generic Data Challenges

• Streaming real-time data outside the real-time simulator
• Data storage
  – Data format (csv vs Hex encoded)
  – Restreaming (publisher-subscriber vs client-server)
  – Post-processing and offline analysis (Matplotlib vs Plotly)
• Real-time analysis and visualization.
HIL-Related Data Requirements and Challenges

- Impacts of data storage on the real-time computation
- Plots (limited by update frequency and the window length, number of plots)
- For example, visualizing RMS voltage (3), current (3), and power (6) in all the three phases in a 30-node system requires 360 floating data points 1.4 kilobytes. Storing this in csv is even more expensive.
- There is a requirement to separate data processing from real-time computation.
- This is crucial especially for PHIL with longer experimentation time and larger networks.
Combined Requirements

• Capability to store
  – Larger data sets
  – Both high-frequency and low-frequency data
• Separate data processing from real-time computation
• One solution for both data storage and visualization.
Open-Source Ethernet-Based Solutions
Architecture of Ethernet-Based Solution
Implementation of Ethernet-Based Solution

- Power Hardware Under Test
- Controller Hardware Under Test
- Digital Real Time Simulator 1
  - Raw socket
  - Interface Application for Data Relaying
  - ØMQ publisher
- ØMQ Server
  - Interface application for data relaying
- ØMQ Subscriber 1: Logging
- ØMQ Subscriber 2: Visualization
- ØMQ Subscriber 3: Analysis
- Remote location
- Remote ØMQ Subscriber 1: User Defined
Visualization

- **Conditioner**
  - Objective: Resample from 5 kHz to visualization-ready 60 Hz
  - Open-source Qt/C++ library
- Can run as service to feed low-performance web apps or integrated into custom desktop apps.
Updated Control Center with Real-Time Visualization

Photo by NREL
Updated Control Center with Real-Time Visualization

Photo by NREL
Open-Source Links

RTS Data Viz Application: [https://github.com/NREL/rts-vis-app](https://github.com/NREL/rts-vis-app)
- **Conditioner**: A tool to resample high-rate data from the relay for low-rate visualization
- **Chart**: An example tool to plot the data from the relay; includes a specialized copy of the conditioner.

RTS Data Application: [https://github.com/NREL/rts-data](https://github.com/NREL/rts-data)
- Stream DRTS data as it is generated to a message broker for other downstream applications—data archiving tools or real time visualizations
- Accepts UDP data from the DRTS and relay these data, using TCP, to a server hosting a message broker.
Summary

- Data storage and real-time visualization of CHIL/PHIL experiments can be of great value.
- Data storage capability provided through the application here will enable better insight into the models being simulated and the experiments being performed in real time.
- The real-time visualization application developed is crucial for running PHIL experiments where identifying an issue in the simulation as soon as possible will save a lot of time and effort in terms of maintenance.
- The two applications developed have been successfully used in multiple projects.
- More than 300 gigabytes of data were stored using this capability.
Future Work

• Still challenges with visualizing high-frequency signals in real time.
• Move the visualization from control room to the 3D visualization room at ESIF.
• Heat maps for voltage profiles.
• Visualization with augmented reality.
Thank you

www.nrel.gov

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