NREL
Transforming ENERGY

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

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Advanced Grid Research
OFFICE OF ELECTRICITY
US DEPARTMENT OF ENERGY

Contents

Energy Systems Integration Facility (ESIF)

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

Photo by 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

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.

Photo by NREL

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

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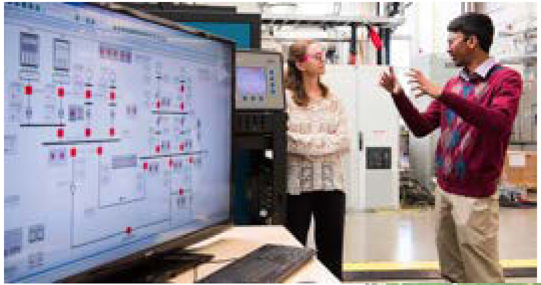
Controller- and Power-Hardware-in-the-Loop (CHIL/PHIL)

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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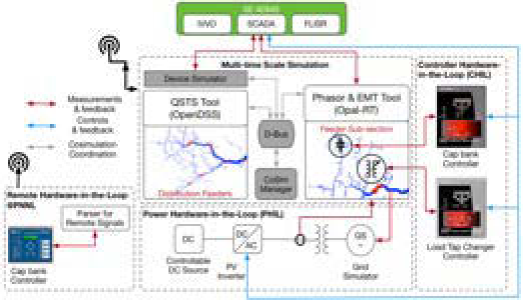
Microgrids



Cosimulation

Photo by NREL

Power System Studies

Controller- and Power-Hardware-in-the-loop (CHIL/PHIL)

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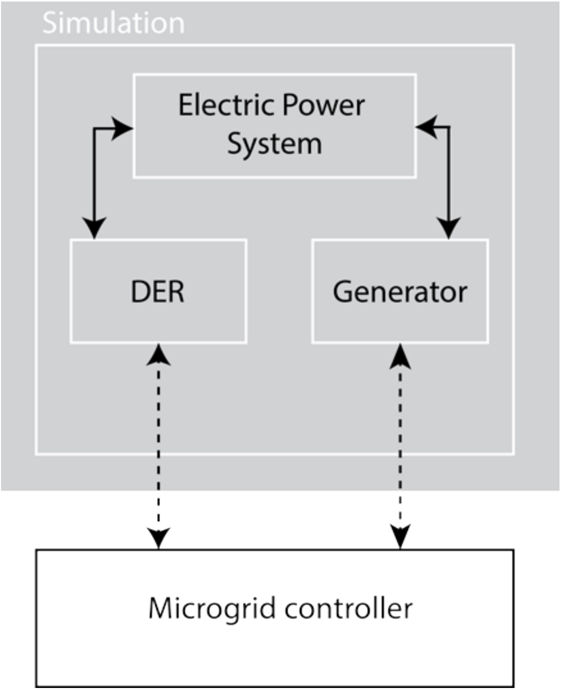

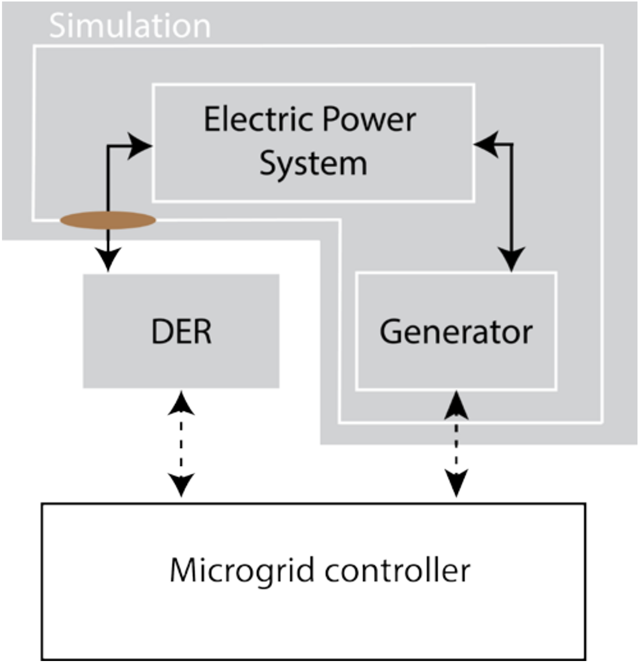

Team Information

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- Computational Science Center
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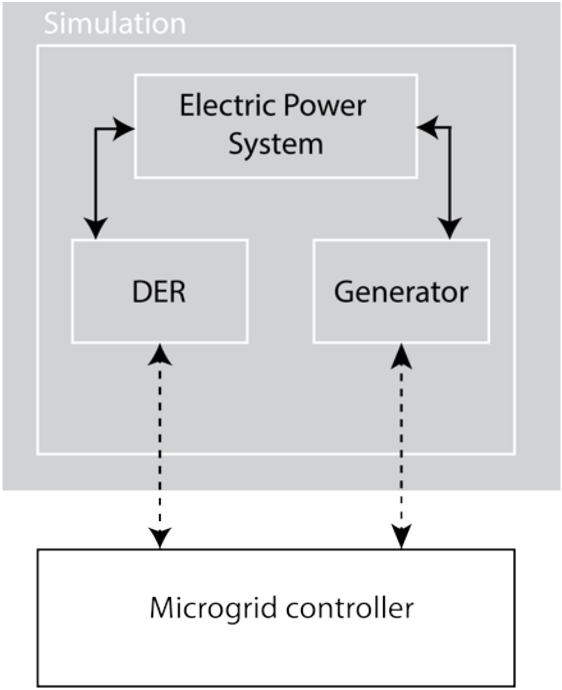
  - Nick Wunder
  - Courtney Pailing
  - Kristi Potter
  - Matthew Eash
  - Kristin Munch

Hardware-in-the-Loop Requirements

Controller Hardware-in-the-Loop Requirements

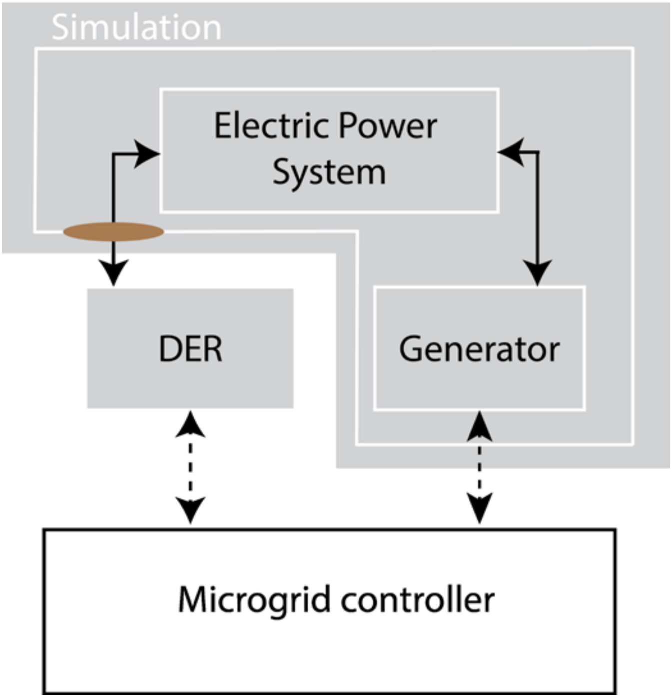
- RMS-type measurements
- Power electronics controller applications might need higher frequency
- Update rates to power system controllers are slow (ADMS test bed, microgrid controller)
- Can run for longer period without supervision
- Data storage requirements might exceed limits based on experiment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



Maitra, Arindam, Annabelle Pratt, Tanguy Hubert, Dean Wang, Kumaraguru Prabakar, Rachna Handa, Murali Baggu, and Mark McGranaghan. "Microgrid controllers: expanding their role and evaluating their performance." *IEEE Power and Energy Magazine* 15, no. 4 (2017): 41-49.

Power Hardware-in-the-Loop Requirements

- 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.



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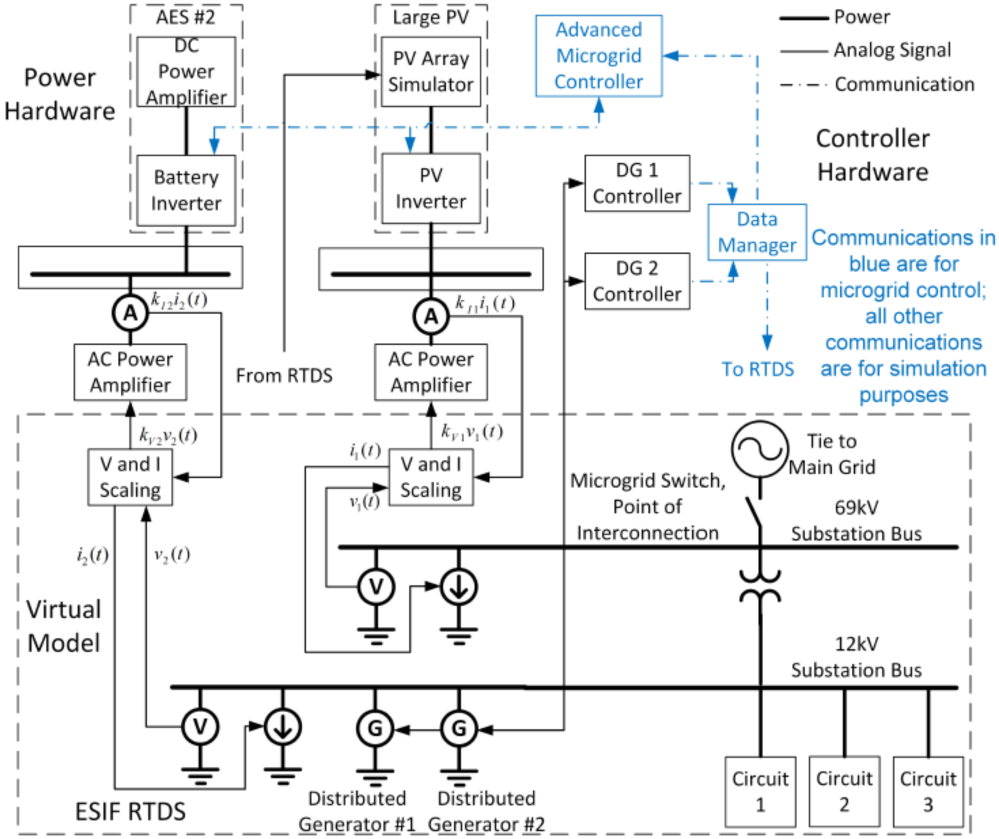
Combined Data Requirements

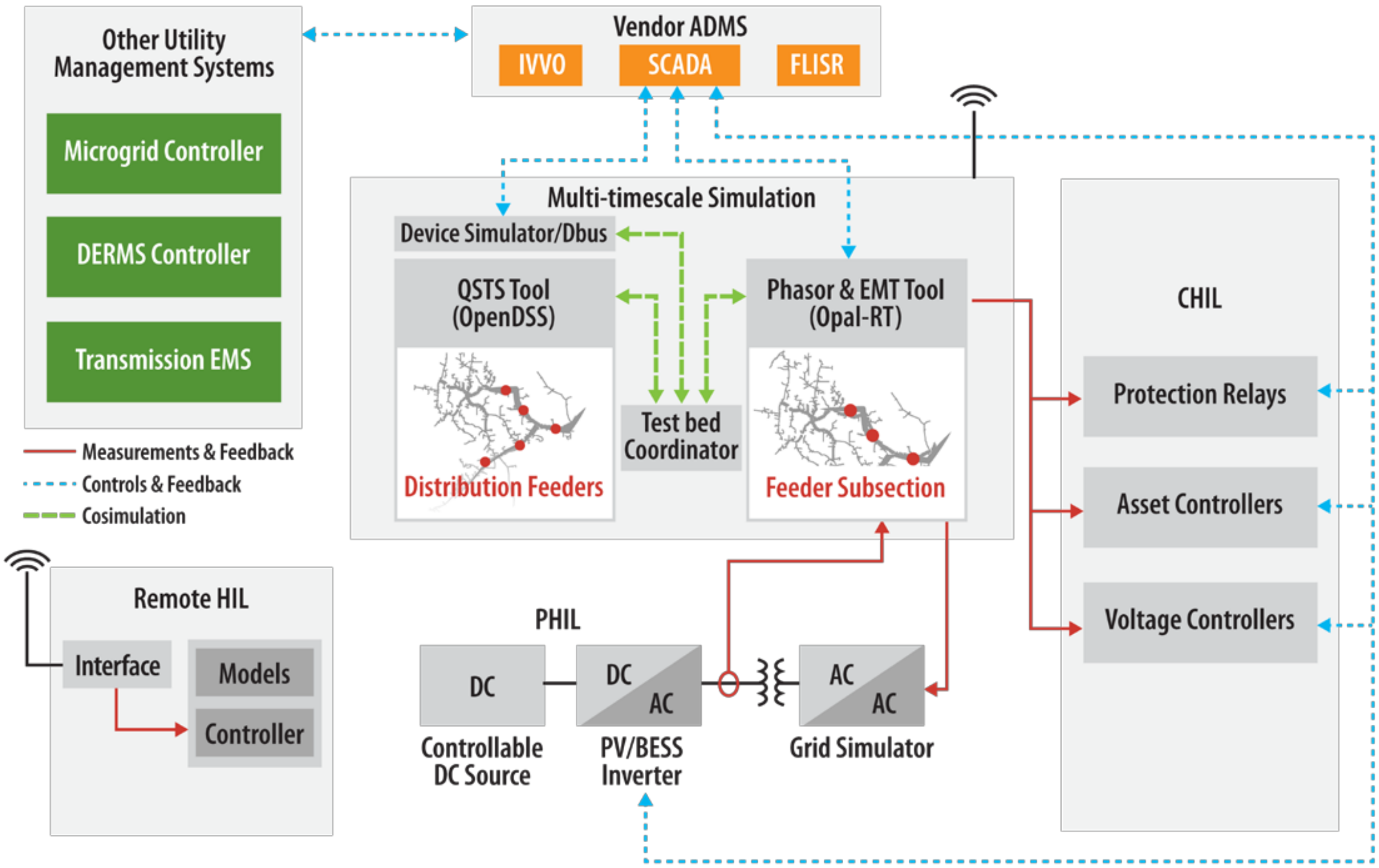
- Capability to run longer experiments impacts the data storage (for both CHIL and PHIL)
- CHIL requires RMS data with long-term data storage of large number of data points (For power electronics CHIL, this may change.)
- PHIL requires 1 kHz to 5 kHz (or more) data storage with fewer number of data points
- 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



K. Prabakar, A. Pratt, J. Fossum, J. Wang, B. Miller, M. Symko-Davies, M. U. Usman, and T. Bialek, "Site-Specific Evaluation of Microgrid Controller Using Controller and Power-Hardware-in-the-Loop," *IECON 2019 - 45th Annual Conference of the IEEE Industrial Electronics Society*, Lisbon, Portugal, 2019, pp. 6463-6468.

Experimental Setup #2



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

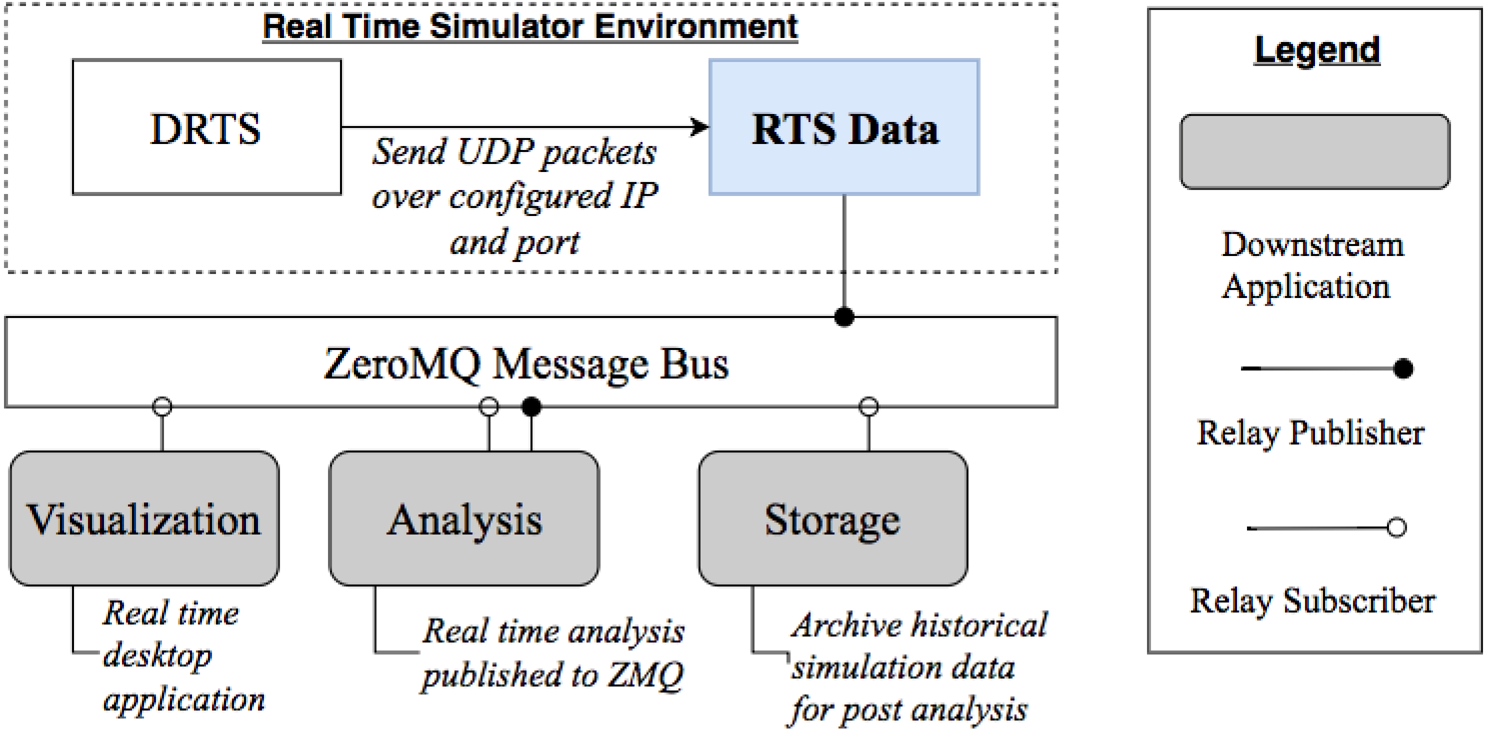
- Impacts of data storage on the real-time computation
- Plots (limited by update frequency and the window length, number of plots)
- For example, visualizing RMS voltage (3), current (3), and power (6) in all the three phases in a 30-node system requires 360 floating data points 1.4 kilobytes. Storing 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

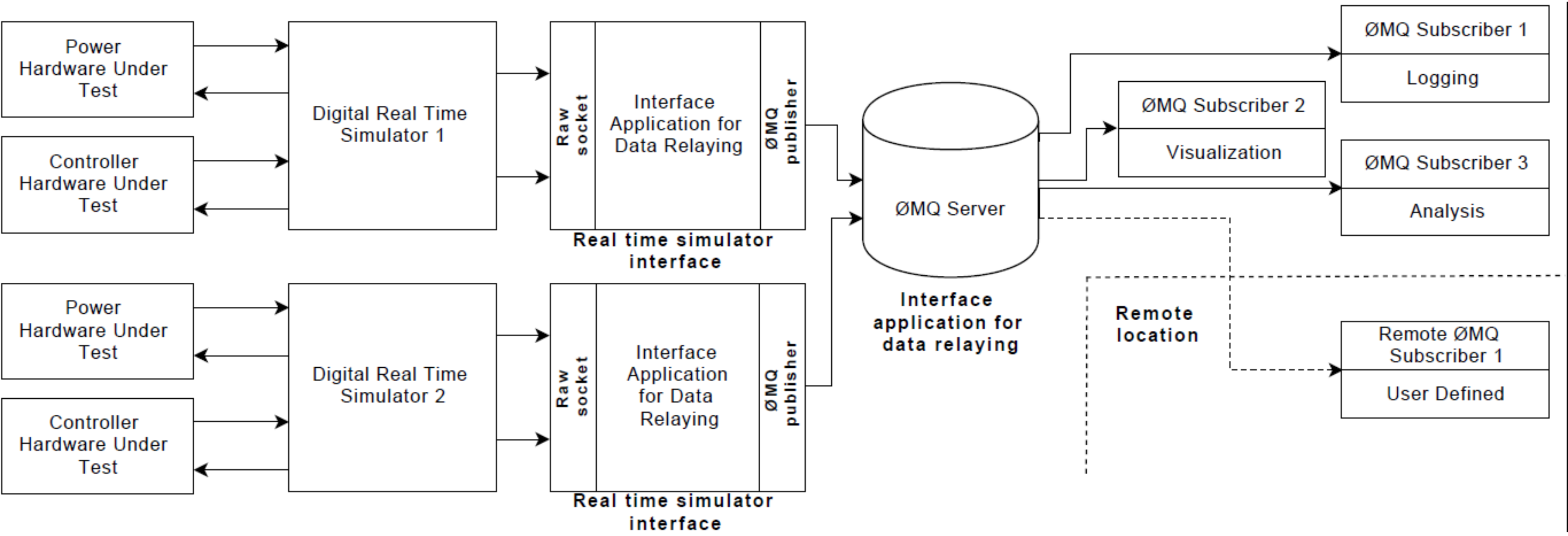
- Capability to store
  - Larger data sets
  - Both high-frequency and low-frequency data
- Separate data processing from real-time computation
- One solution for both data storage and visualization.

Open-Source Ethernet-Based Solutions

Architecture of Ethernet-Based Solution

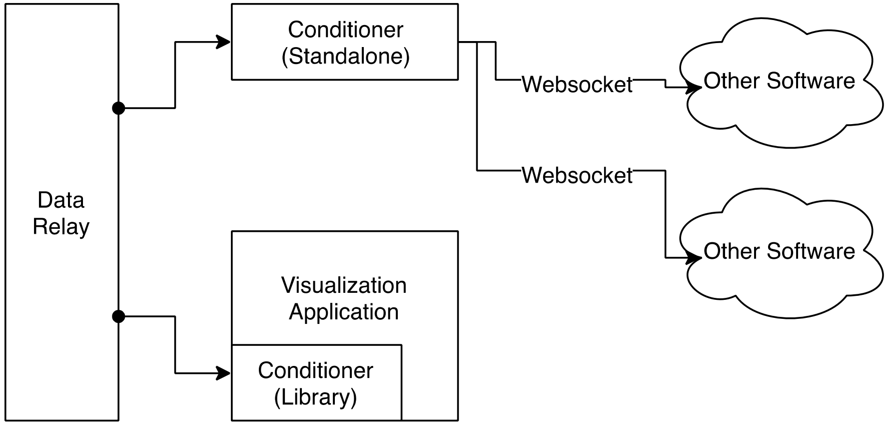


Implementation of Ethernet-Based Solution

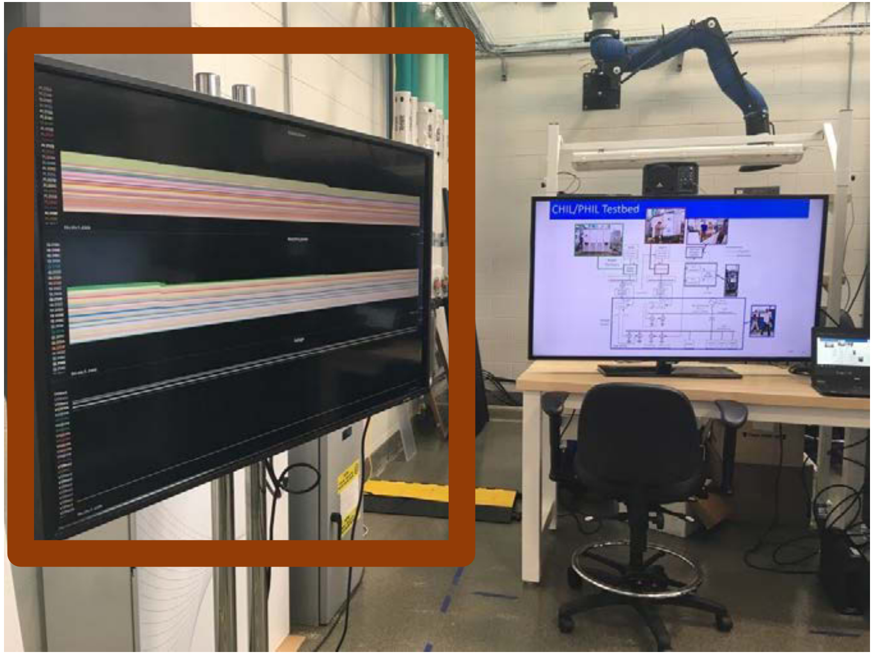


Visualization

- 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



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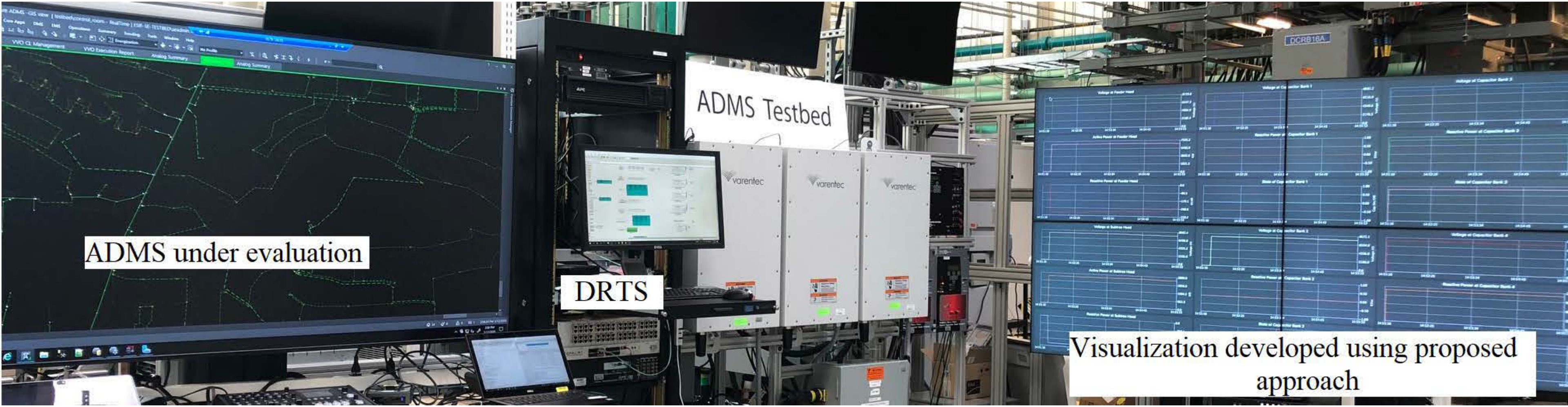
Updated Control Center with Real-Time Visualization



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Open-Source Links

RTS Data Viz Application: 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

- 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.

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Thank you

www.nrel.gov

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