DOE/OE Transmission Reliability Program

Continuous Data-Driven Model Development

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Project Motivation

"integrating large number of DERs with different dynamics into distribution level makes it practically impossible to find dynamic equivalents for distribution interconnections using traditional methods" [1]

"There is an imminent need for modeling distributed generation (e.g. solar, micro-turbines, fuel-cells etc.)."[2] … *and loads.*

Need for high fidelity dynamic models of DERs, microgrids, loads, and inter-connected system.

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[1] A. Ishchenko, J. Myrzik, and W. Kling, "Dynamic equivalencing of distribution networks with dispersed generation using hankel norm approximation," *Generation, Transmission & Distribution, IET*, vol. 1, no. 5, pp. 818–825, 2007.
[2] Allen, Eric, D. N. Kosterev, and Pouyan Pourbeik. "Validation of power system models." *Power and Energy Society General Meeting, 2010 IEEE*. IEEE, 2010.

Motivation: Grid Modernization

Cross-cuts: Smart Grid, Buildings, Vehicles, Transformative Manufacturing, IoT

Critical needs

- Sensing/Measurements
- Control
- Multi-level coordination
- Optimization
- Modeling/Simulation
- Cybersecurity
- Architecture
- Communications
- Two-way power flow

TODAY's GRID, AND TOMORROW's.

Today's Grid	Smart Grid
Consumers are uninformed and non-participative with power system	Informed, involved, and active consumers; demand response and distributed energy resources
Dominated by central generation; many obstacles exist for distributed energy resources interconnection	Many distributed energy resources with plug-and-play convenience; focus on renewables
Limited wholesale markets, not well integrated; limited opportunities for consumers	Mature, well-integrated wholesale markets, growth of new electricity markets for consumers
Focus on outages; slow response to power quality issues	Power quality is a priority with a variety of quality/price options; rapid resolution of issues
Little integration of operational data with asset management; business-process silos	Greatly expanded data acquisition of grid parameters; focus on prevention, minimizing impact to consumers
Responds to prevent further damage; focus is on protecting assets following fault	Automatically detects and responds to problems; focus on prevention, minimizing impact to consumer
Vulnerable to malicious acts of terror and natural disasters	Resilient to attack and natural disasters with rapid restoration capabilities

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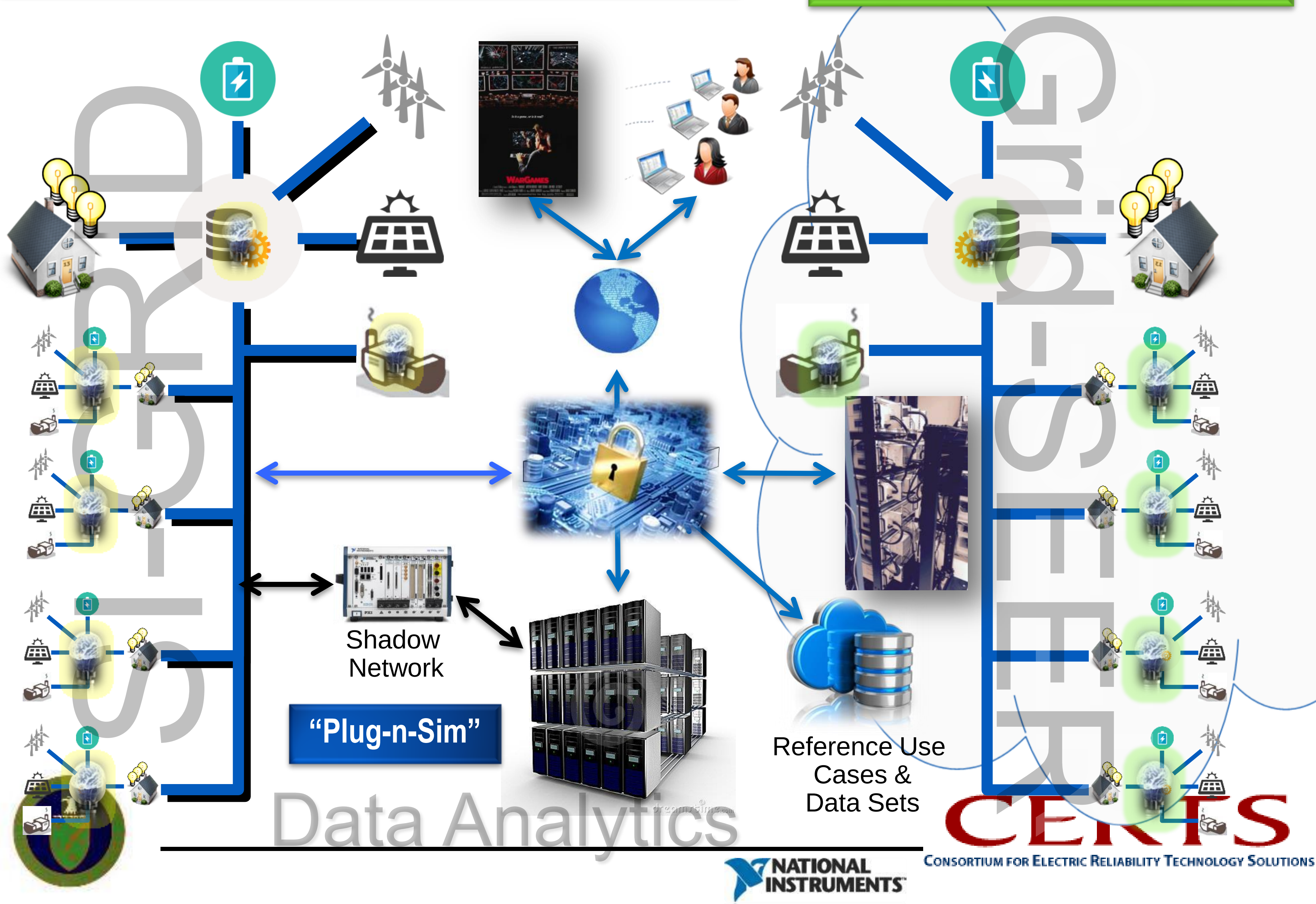
Vision: a grid modernization research platform



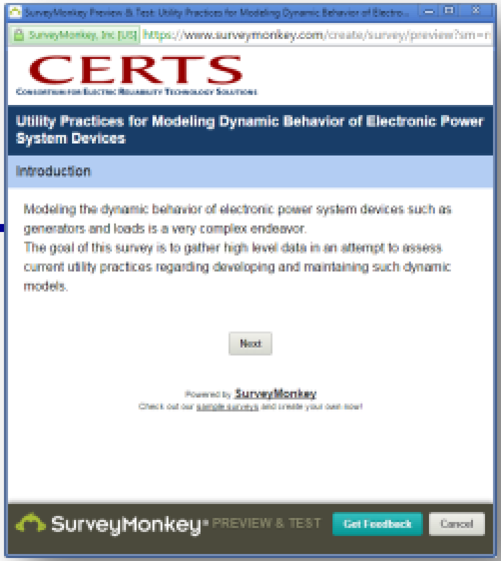
Project Objective and FY15 Tasks

Objective: Develop a learning system to generate models that adequately represent the dynamic behavior of generators, loads, and storage devices connected to the electric grid (for use in real-time power system simulations).

Project tasks:

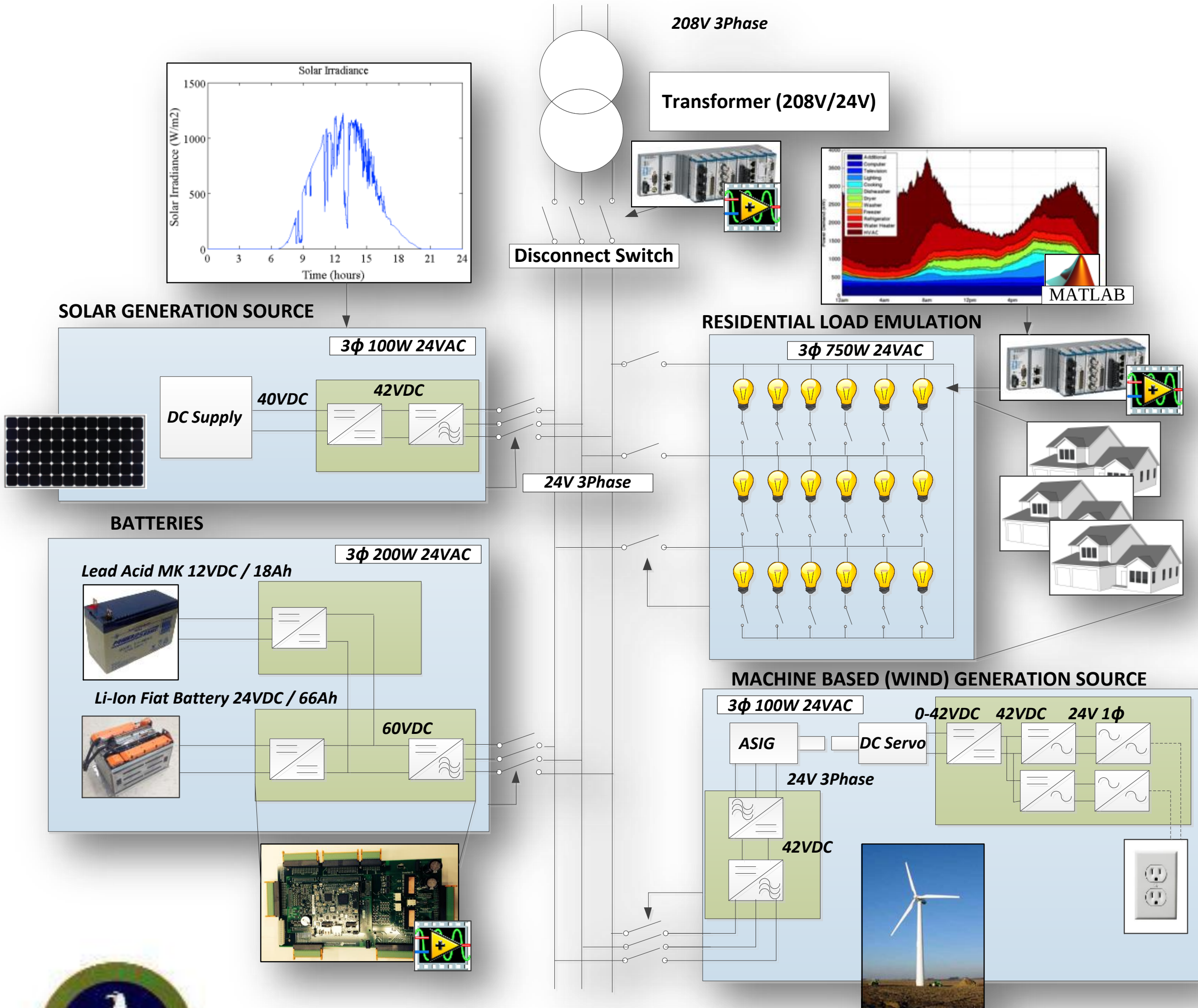
- Develop machine models;
  - Synchronous generators
  - **Induction machines**
  - **Inverter-based motor controls**
  - **Inverters for PV**
  - Inverters for wind turbines
  - **Inverters for energy storage** (Lithium-ion, **Lead Acid**)
- Characterize steady state and dynamic parameters for selected equipment (through measurements)
- **Perform real-time machine simulations**
- **Develop a system to learn "model" parameters from empirical data**
- Compare results from rotating and electronically-coupled machines to the actual behavior of those machines
- Outreach to socialize concept, solicit guidance on prioritization, **recruit a host/partner for field deployment and evaluation**

Major Accomplishments

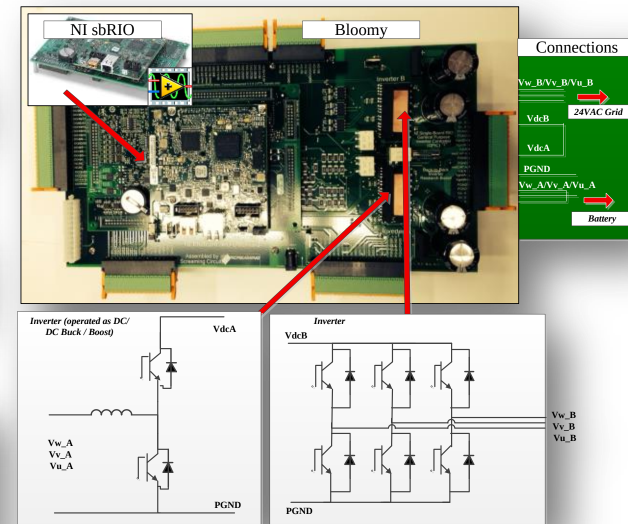


- Developed a 3-phase low-voltage microgrid
  - Mix of DER assets – *leveraged*
  - Using it to develop and validate this approach for both device and systems level models
- Developed *real-time device models* of DER assets
- Developed the on-line learning framework for inverter based machines (DE/CGLS)
- Developed an online survey (Survey Monkey) to identify utility needs (deficiencies in the current systems) and timing of modeling work

SI-GRID: Software-defined Intelligent Grid Research Integration and Development platform



Real-time co-simulation model and learning engine runs in the controller FPGA



DC-DC boost converter and DC/AC inverter implemented on a NI-GPIC (general purpose inverter control)

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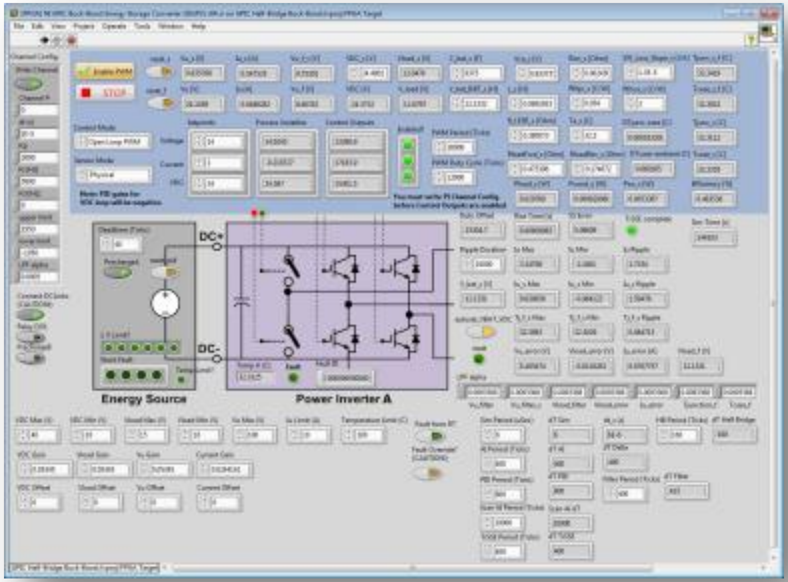
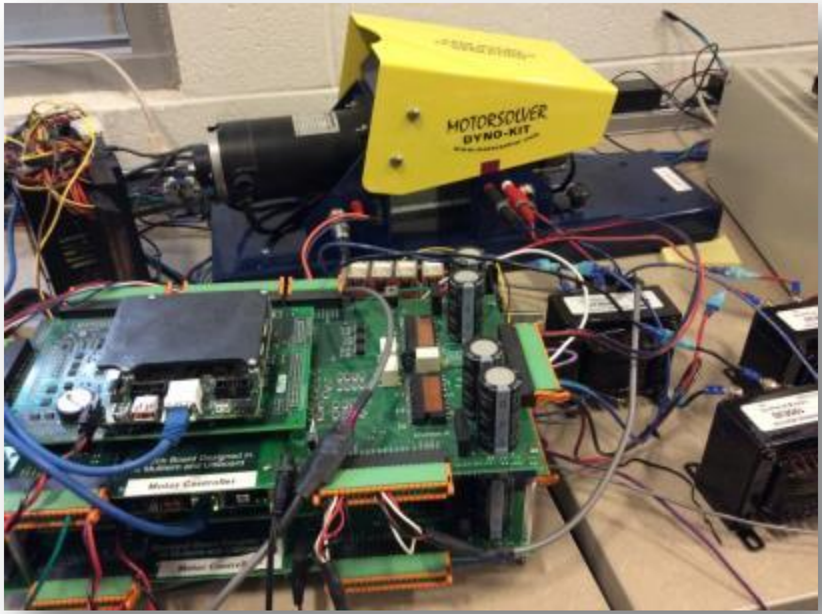
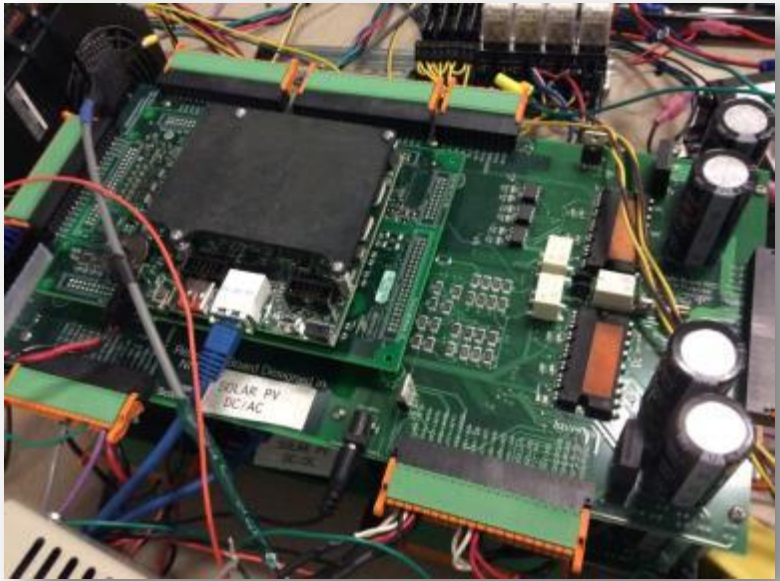
Motor Drive Setup

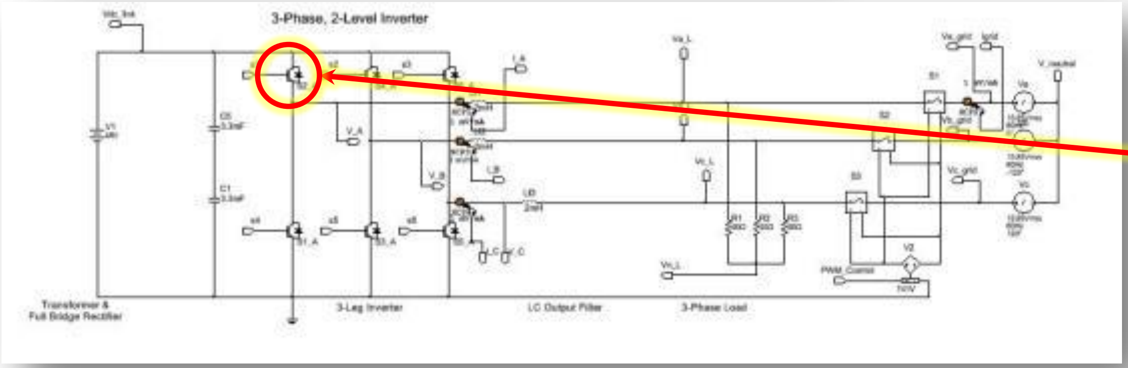
FPGA Front Panel During Run-Time - Physical IO and HIL Model Running in GPIC FPGA

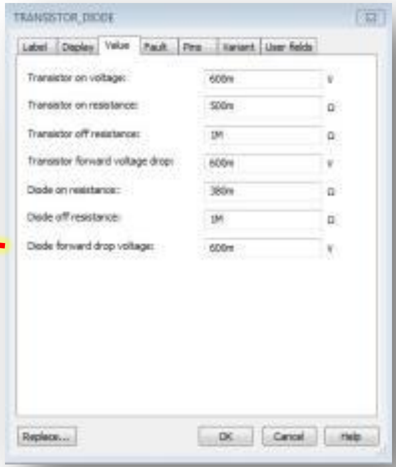




PV Inverter (MPPT)







IGBT model parameters: NI Multisim 3-Phase Back-to-Back Inverter Model

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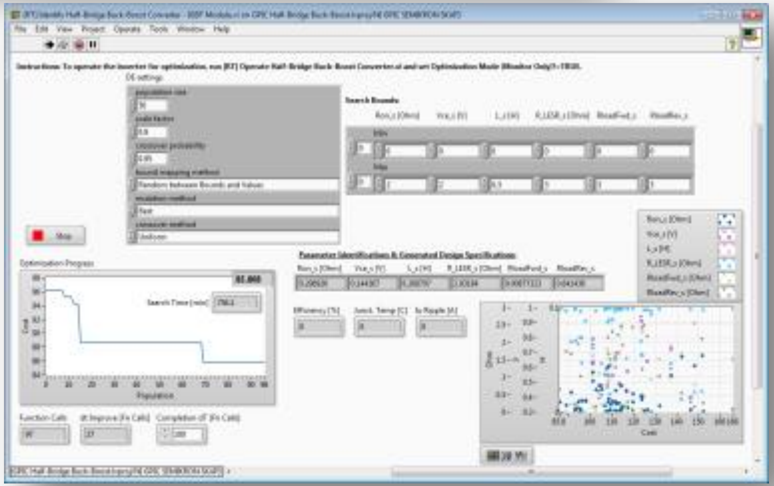
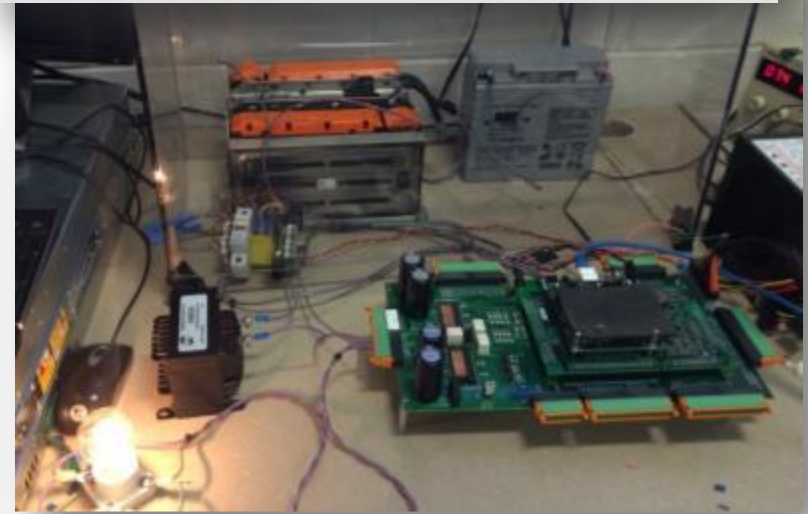
Energy Storage Setup

Physical and FPGA-simulated waveforms – use DE optimizer on (Vce, Ron, L, R_LESR, RloadFwd, RloadRev)





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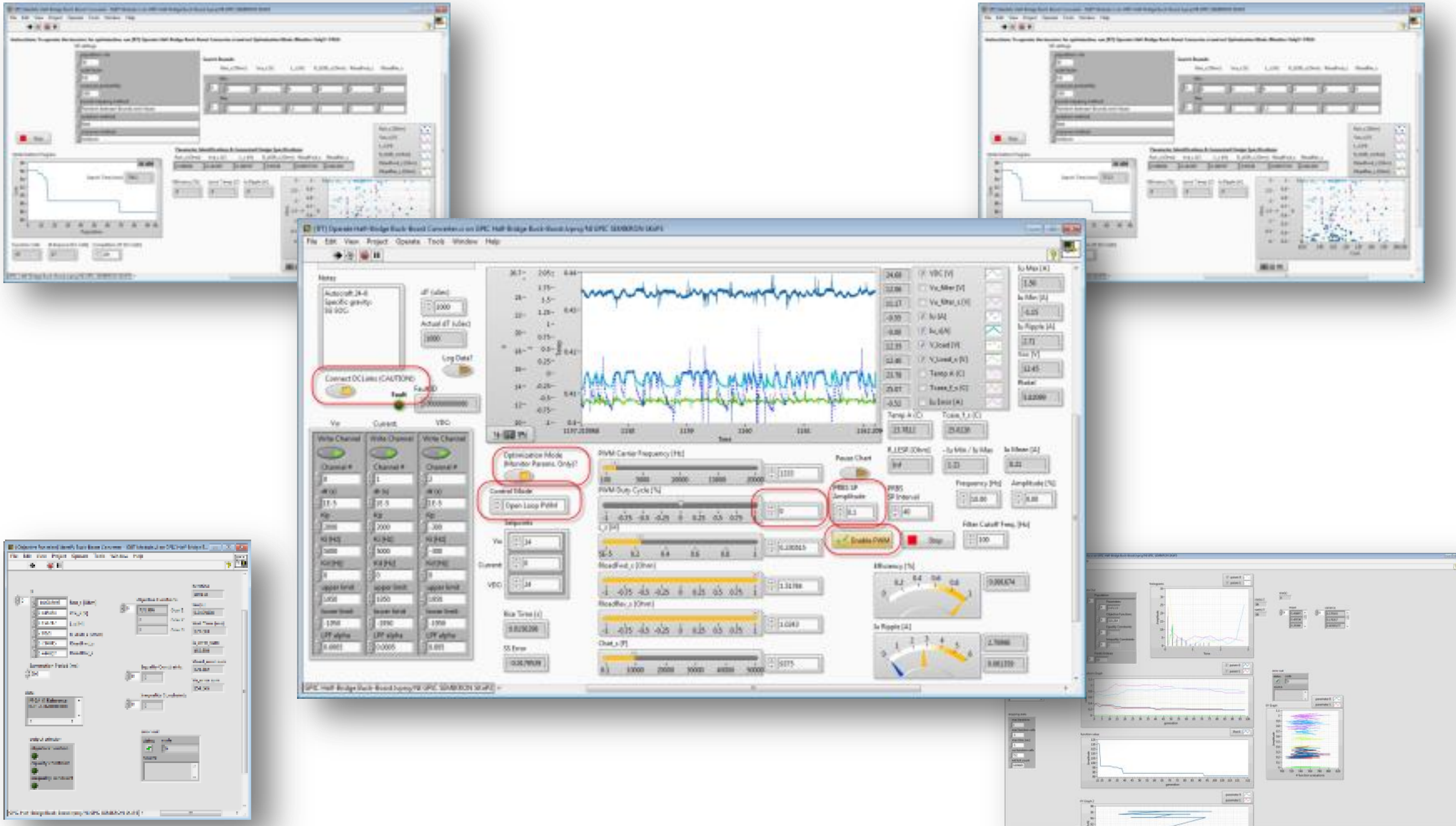
Online Learning System Screen Shots



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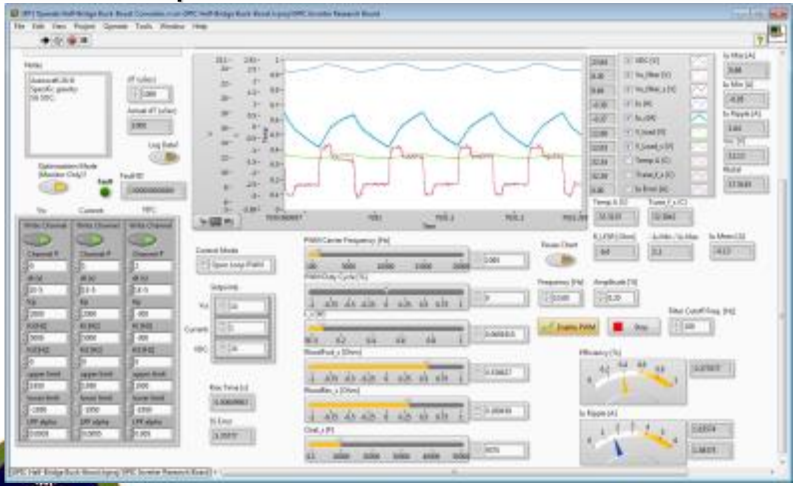
Online Learning System Results

Hand tuned parameters before global optimization

Physical and FPGA-simulated waveforms after global optimization of (Vce, Ron, L, R_LESR, R_BATCharge, R_BATDischarge)

Validation of parameter ID



Test	Description	mean(|X1 error|)	mean(|X1 error|*evaluations)
1	No local optimization	0.568	238.5408
2	Optimize only the best	0.5631	483.66
3	Sequentially Optimize the N Best (N=5)	0.3358	248.2386
4	Optimize one random population member	0.5612	475.4459
5	Locally optimize every population member	0.007	52.7633
6	Sequentially Optimize the N Best (N=10)	0.2383	176.3019
7	Sequentially Optimize the N Best (N=15)	0.1935	143.4965
8	Sequentially Optimize the N Best (N=20)	0.1995	147.9021
9	Locally optimize best 5 population members	0.2908	649.2309
10	Locally optimize worst 5 population members	0.568	471.6775
11	Locally optimize random 5 population membe	0.5351	1386.9866

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Milestones

- Report documenting survey questions on utility needs (deficiencies in the current system) (March 2015)
- Technical paper documenting the data-driven learning framework (D2LF) for synchronous generator, induction machine, and inverter on SI-GRID (May 2015)
- Report documenting the engagement of selected utilities (June 2015)
- Report documenting participation in NI Week’s power and energy track (Sept 2015)
- Technical report describing the approach and results of the learning system algorithms on SI-GRID (Sept 2015)
- Report documenting a plan to obtain utility vetting of newly developed model derivation and validation processes (Sept 2015)

Looking Forward (FY15)

- Solicit utility participants for SurveyMonkey
- Report on SurveyMonkey results
- Complete technical paper documenting the D2LF
- Present a paper at NI Week on the D2LF
- Complete D2LF & validate models and approach against operating SI-GRID (Document in a report)
- Identify a willing utility and develop a plan to vet the D2LF

Risk Factors

- Learning engine for the D2LF doesn't work
- Co-simulation models are too complex to run in real-time in the current FPGAs
- Dynamics of the inverter based DERs on SI-GRID are too complex and fast to develop accurate models
- Measurements are too noisy/inaccurate to develop accurate models on SI-GRID
- Relevance of approach for transmission systems

Future work FY16

- Create versions of the D2LF to
  - Develop models of existing devices while they are operating
    - Portable system with appropriate I/O
  - Explore interfacing with existing modeling tools/simulators (e.g., EMTP-RV, ATP, … RTDS, OpalRT, …)
- Vet approach with utility partner(s)
- Transition D2LF to industry
  - Integrate into NI's LabVIEW Electrical Power Suite
  - Publish as open framework with SI-GRID as a reference implementation
- Integrate D2LF and Grid-SEER to create a data-driven plug-and-sim modeling and simulation framework

Questions