NREL
NATIONAL RENEWABLE ENERGY LABORATORY

NREL's Controllable Grid Interface for Testing Renewable Energy Technologies

Second International Workshop on Grid Simulator Testing of Wind Turbine Drivetrains—

Clemson University, North Charleston, South Carolina

Vahan Gevorgian

September 17, 2014

NREL/PR-5D00-62998

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

First Workshop—June 2003

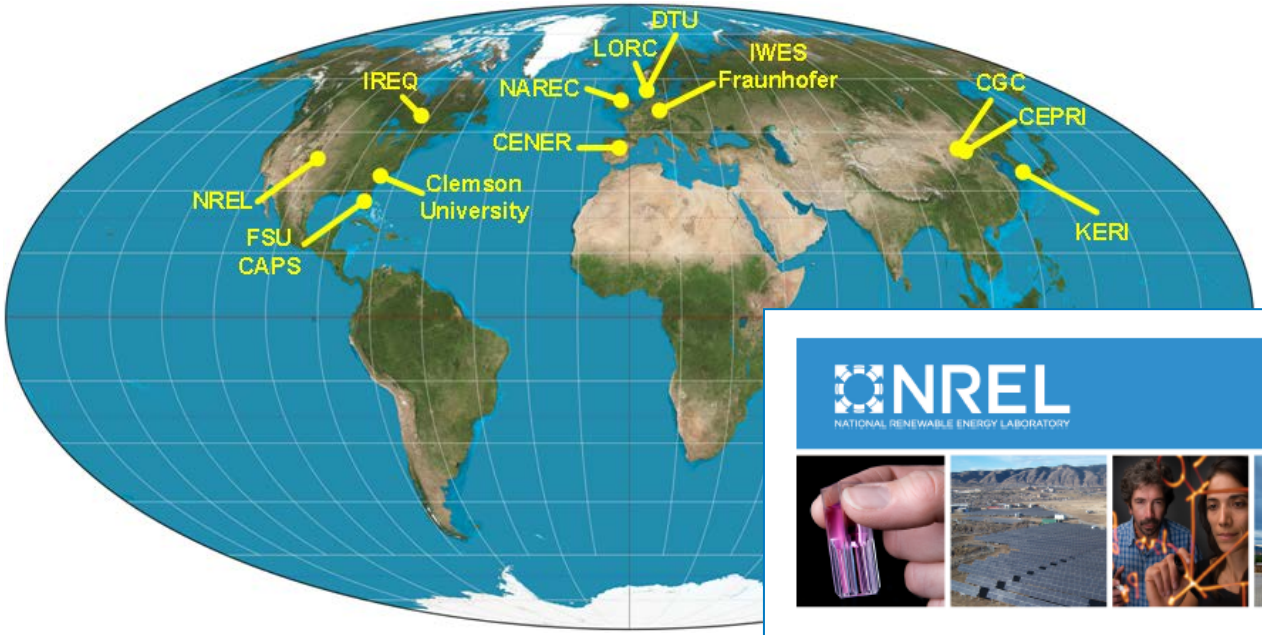


Image from http://upload.wikimedia.org/wikipedia/commons/9/9e/Mollweide_projection_SW.jpg

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

First International Workshop on Grid Simulator Testing of Wind Turbine Drivetrains: Workshop Proceedings

V. Gevorgian, H. Link, and M. McDade
National Renewable Energy Laboratory

A. Mander, J.C. Fox, and N. Rigas
Clemson University

Workshop report: http://www.nrel.gov/docs/fy14osti/60246.pdf
Workshop website: http://www.nrel.gov/electricity/transmission/grid_simulator_workshop.html

U.S. Multi-MW Facilities for Grid Integration Testing of Renewable Energy Technologies

Energy Systems Integration Facility (ESIF)

1+ MW

NREL

National Wind Technology Center (NWTC)

7 MVA

- U.S. Department of Energy Wind Program investment in world-class testing facilities
- Component, wind turbine, plant levels
- Key enabler for wind technology validation and commercialization
- Specific focus on testing ancillary service controls

Clemson University's SCE&G Energy Innovation Center and Duke Energy's eGRID Facility

15 MW

Photos from NREL and Clemson

NWTC Test Site

- Total of 11 MW of variable renewable generation currently at the NWTC test site
- Many small wind turbines (less than 100 kW) installed as well
- 2.5-MW and 5-MW dynamometers
- 7-MVA controllable grid interface (CGI) for grid-compliance testing
- Multi-megawatt energy storage testing capability under development

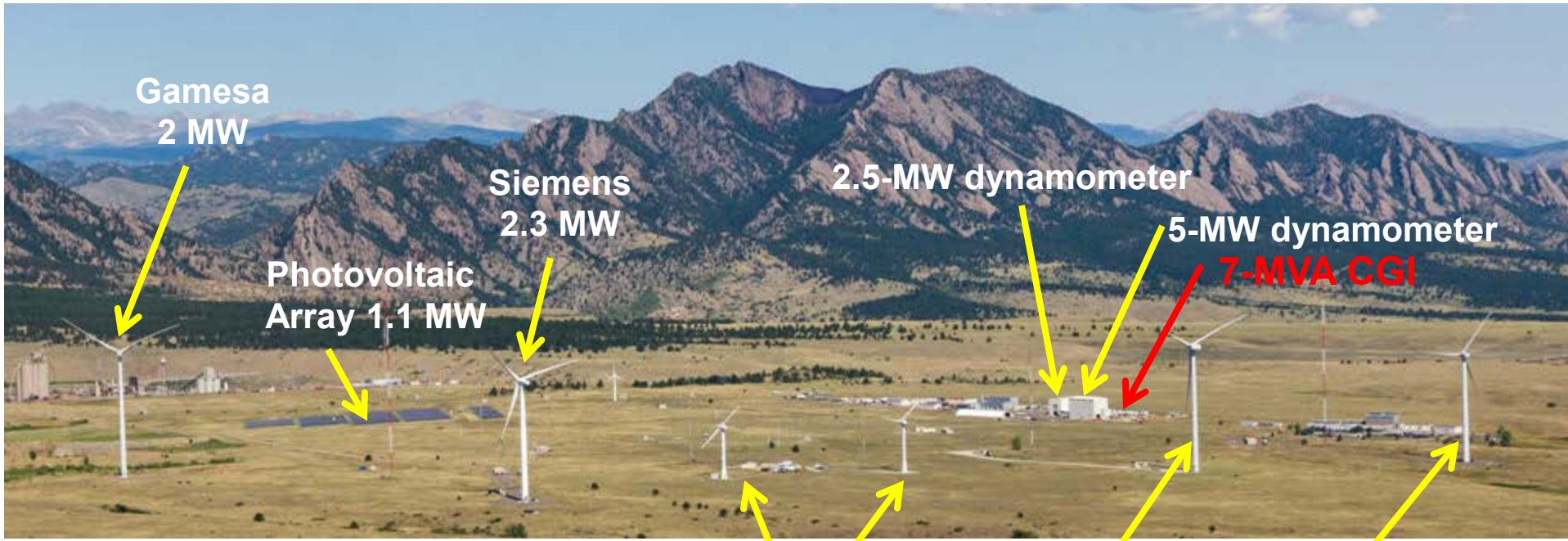


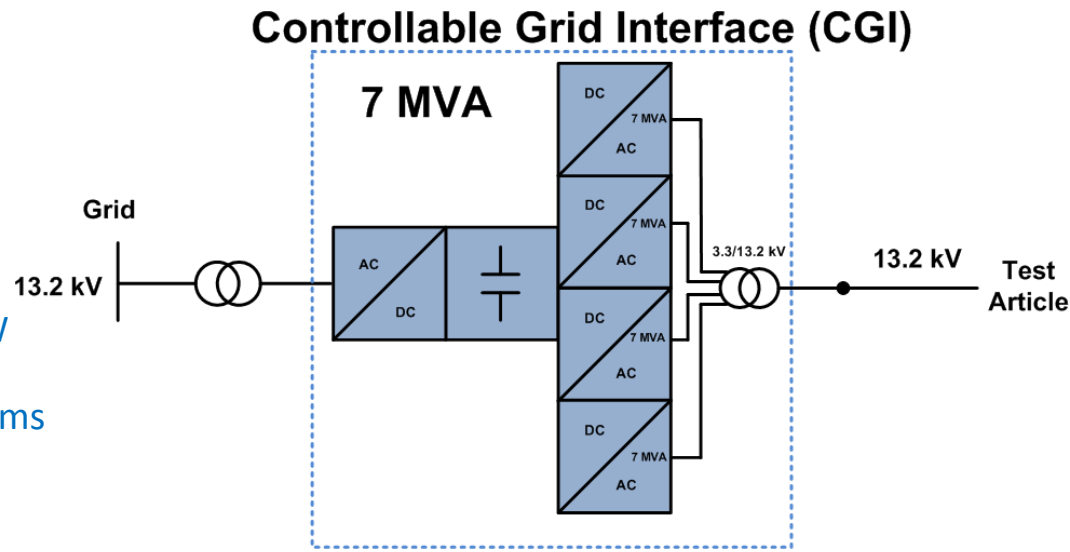
Photo from Dave Simms, NREL

Two Research Turbines 650 kW

Alstom 3 MW

GE 1.5 MW

CGI Main Technical Characteristics



Power rating
- 7-MVA continuous
- 39-MVA short-circuit capacity (for 2 s)

Possible test articles
- Types 1, 2, 3, and 4 wind turbines
- Capable of fault testing world's largest, 6.15-MW Type 3 wind turbine
- Photovoltaic (PV) inverters, energy storage systems
- Conventional generators
- Combinations of technologies

Voltage control (no load THD <5%)
- Balanced and unbalanced voltage fault conditions (ZVRT and 130% HVRT)—independent voltage control in each phase
- Long-term symmetrical voltage variations (+/- 10%) and voltage magnitude modulations (0 Hz to 10 Hz)—SSR
- Programmable impedance (strong and weak grids)
- Programmable distortions (lower harmonics 3, 5, 7)

Frequency control
- Fast output frequency control (+/- 3 Hz)
- 50-Hz/60-Hz operation
- Simulate frequency response of various power systems
- RTDS/HIL capable

Capabilities
- Balanced and unbalanced over and under voltage fault ride-through tests
- Frequency response tests
- Continuous operation under unbalanced voltage conditions
- Grid condition simulation (strong and weak)
- Reactive power, power factor, voltage control testing
- Protection system testing (over and under voltage and frequency limits)
- Islanding operation
- Sub-synchronous resonance conditions
- 50 Hz tests

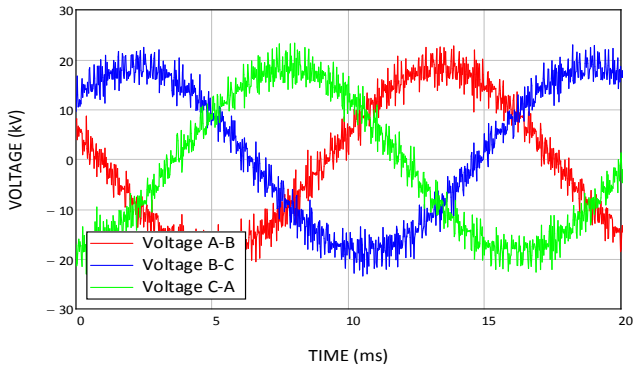
NWTC's 7-MVA CGI

Photo from Mark McDade, NREL

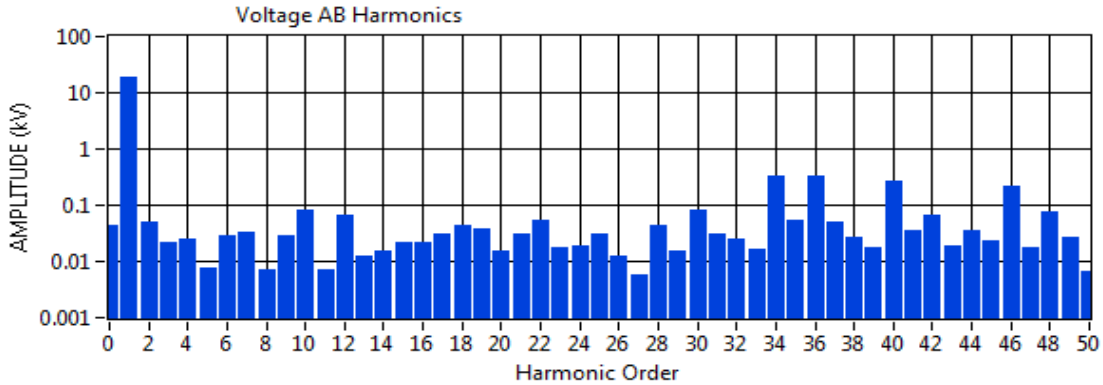
- Installed at NWTC test site—November 2012
- Commissioning and characterization testing—end of 2013
- Row 4/turbine bus connection—FY14
- Energy storage site connection—end of 2014

CGI Voltage Waveform

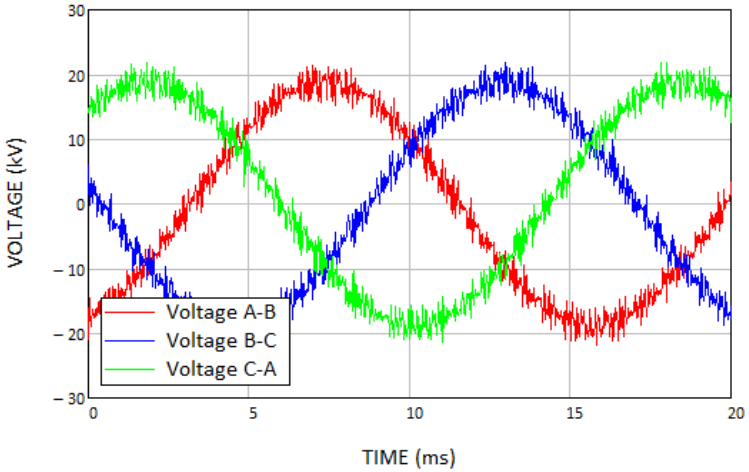
No-load L-to-L voltage



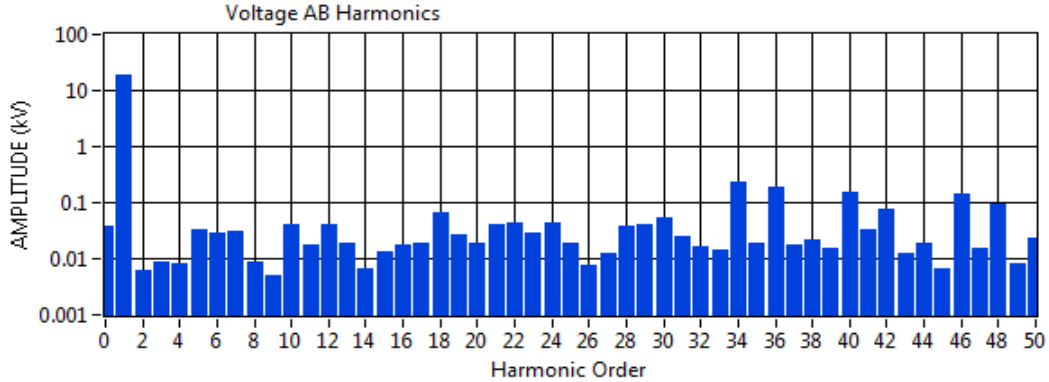
No-load voltage harmonics (THD=3.4%)



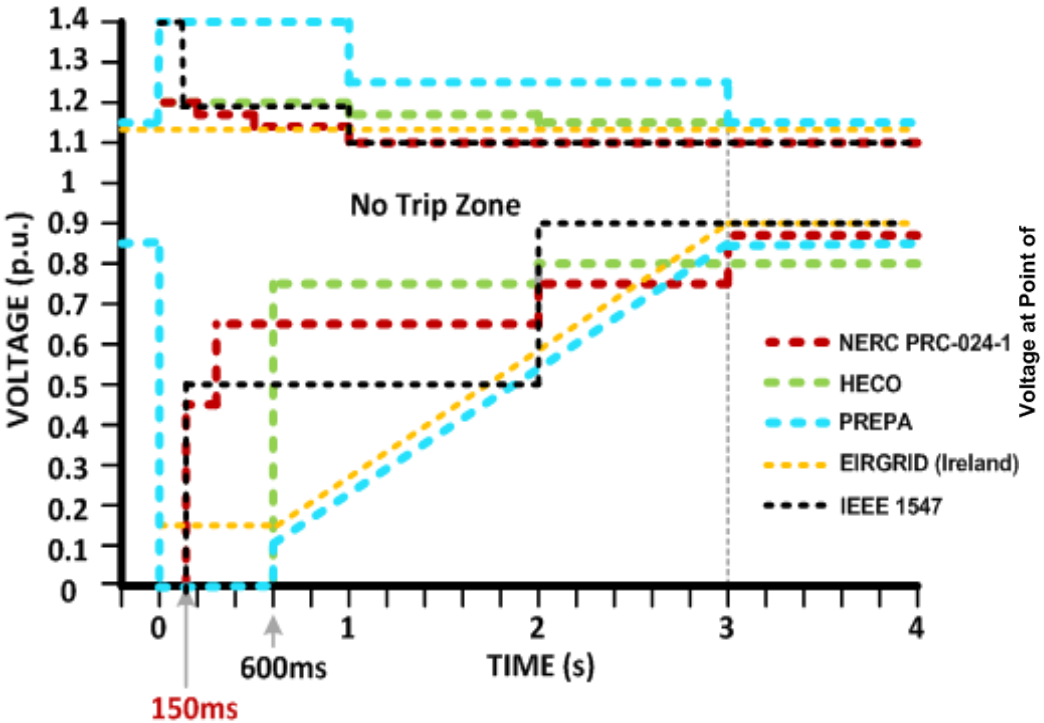
L-to-L voltage under 2.75-MW load



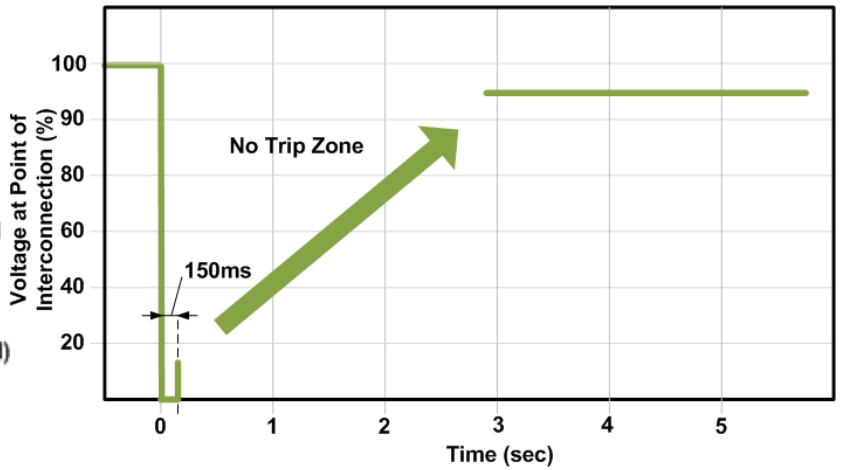
Voltage harmonics under 2.75-MW load (THD=2.5%)



Testing to All Interconnection Requirements and Grid Codes



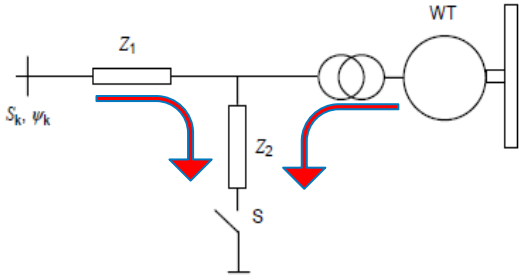
FERC LVRT requirements (Order 661-A)



IEC 61400-21 LVRT Testing Matrix

Fault Type	Voltage drop (fraction of nominal L-to-L voltage)	Fault Duration (ms)
Three-phase, balanced	0.9	500
Three-phase, balanced	0.5	500
Three-phase, balanced	0.2	200
Two Line-to-Line (L-L), unbalanced	0.9	500
Two Line-to-Line, unbalanced	0.5	500
Two Line-to-Line, unbalanced	0.2	200

IEC recommended fault emulator



GE 2.75-MW Installed in NREL Dynamometer

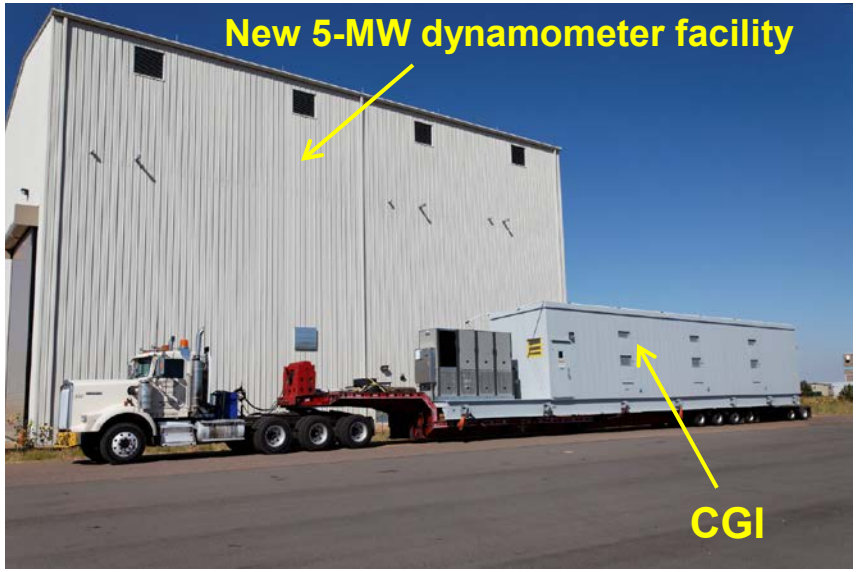
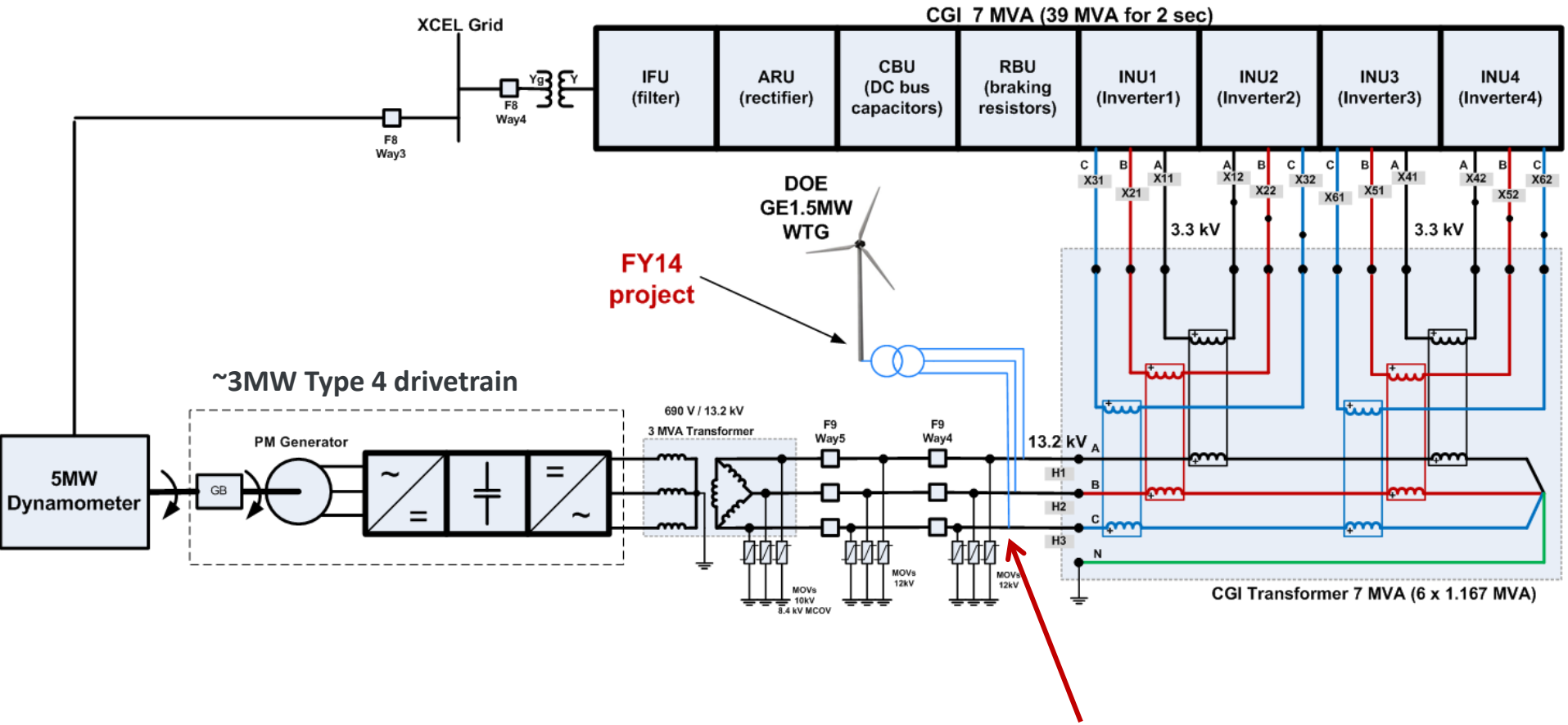


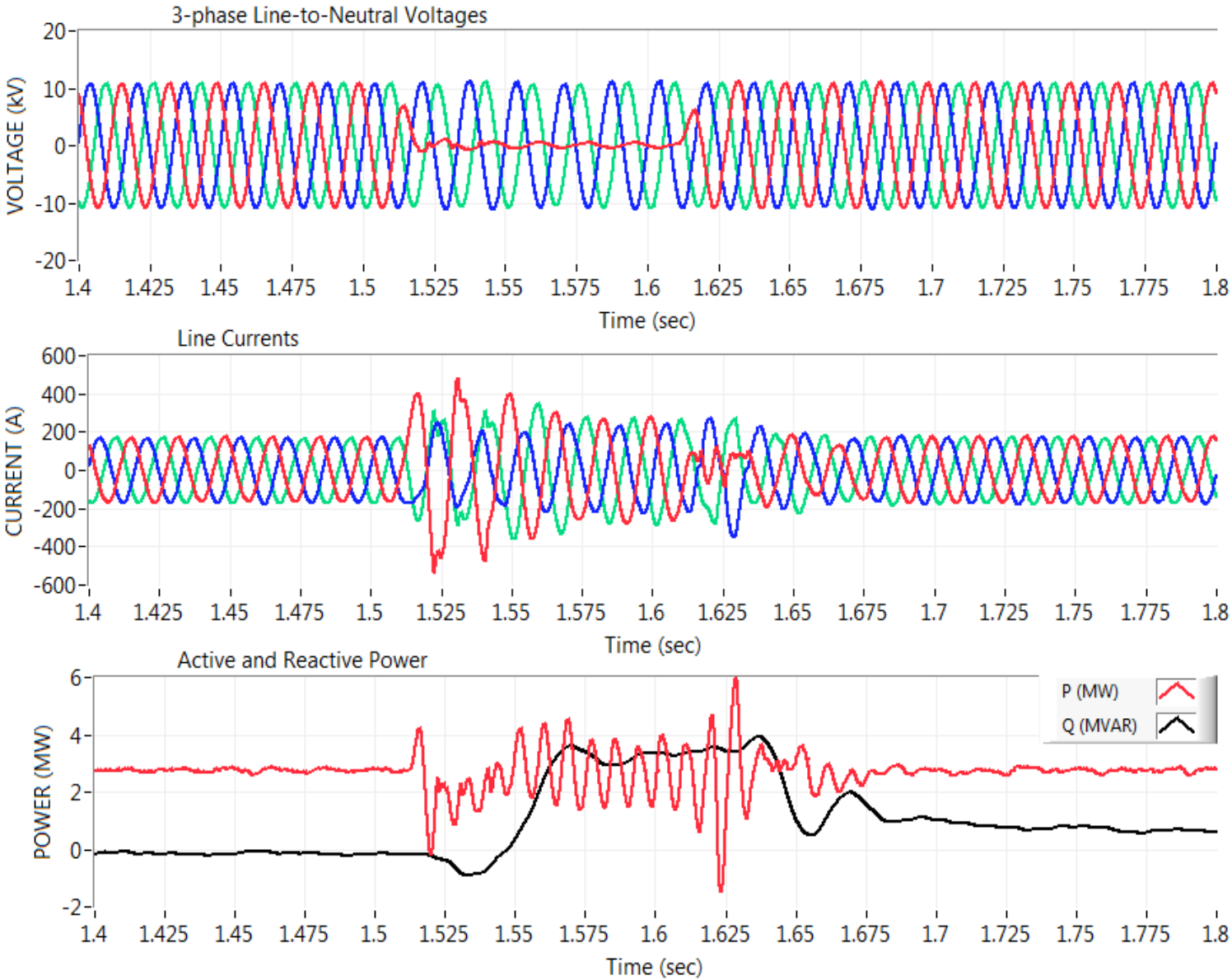
Photo from NREL

Type 4 ~3-MW Turbine Operation with CGI

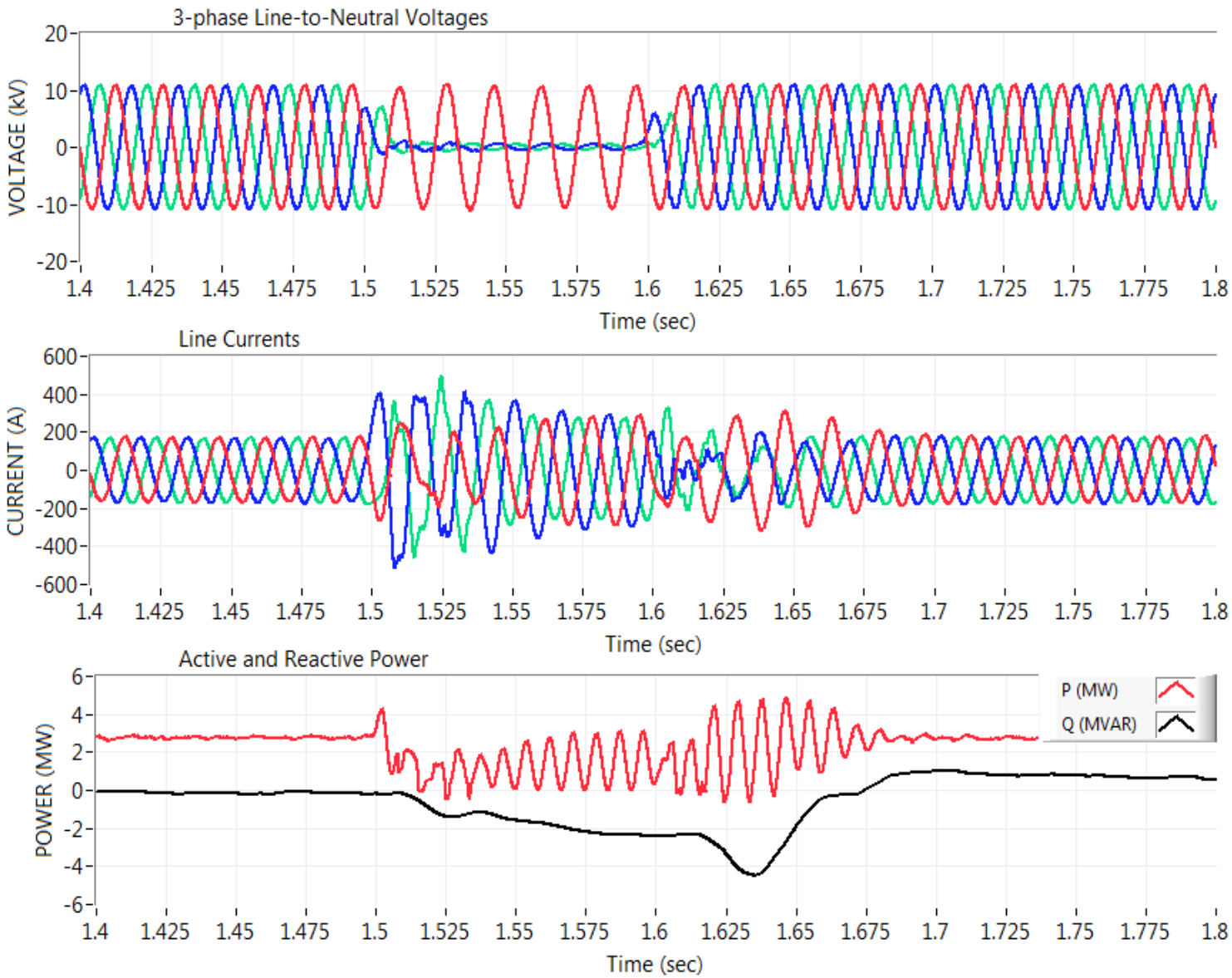


Voltage amplitude, frequency, phase angle, and harmonic content are controlled on CGI terminals

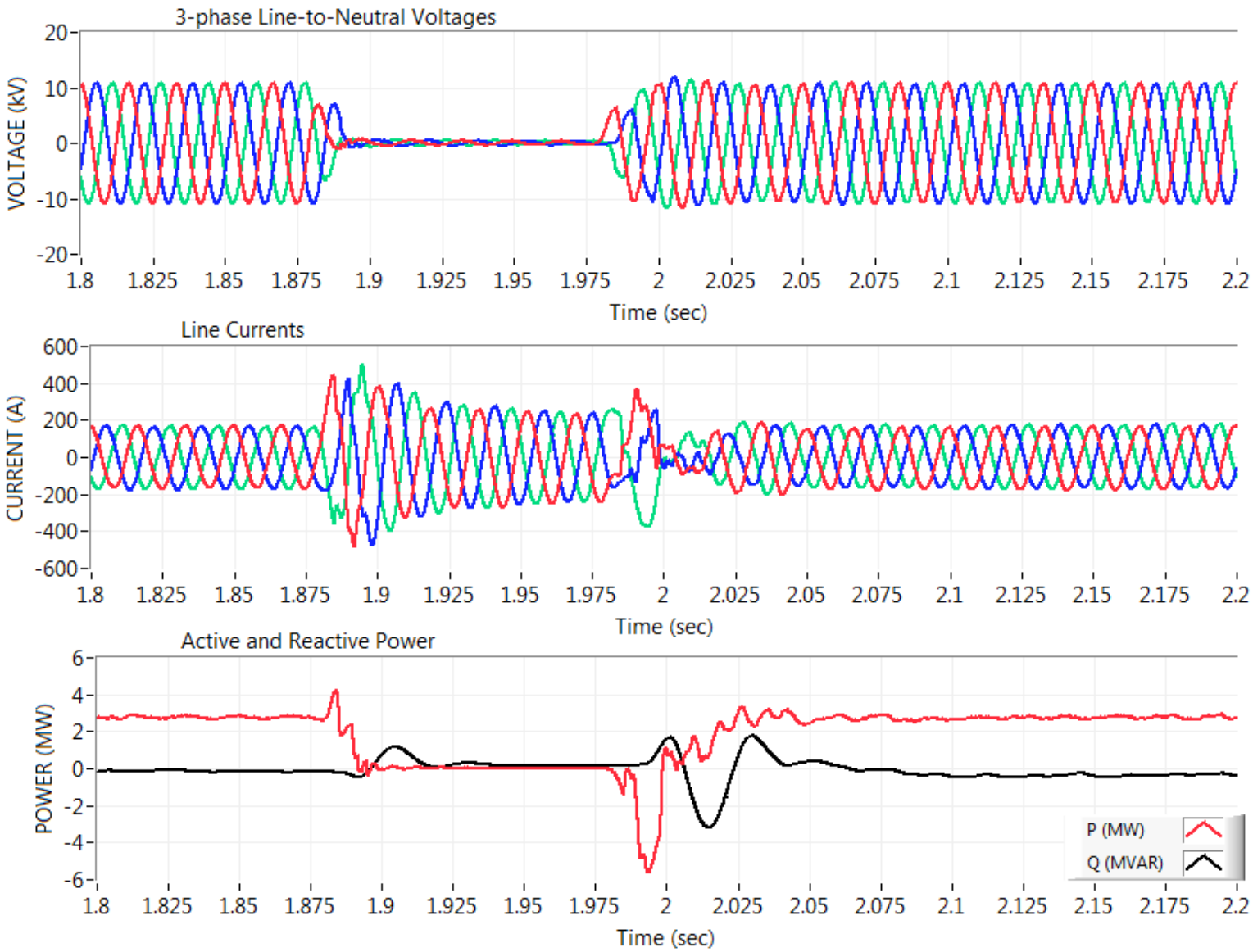
Example Test Result: Single-Phase Fault Emulated on MV Terminals of 2.75-MW Wind Turbine



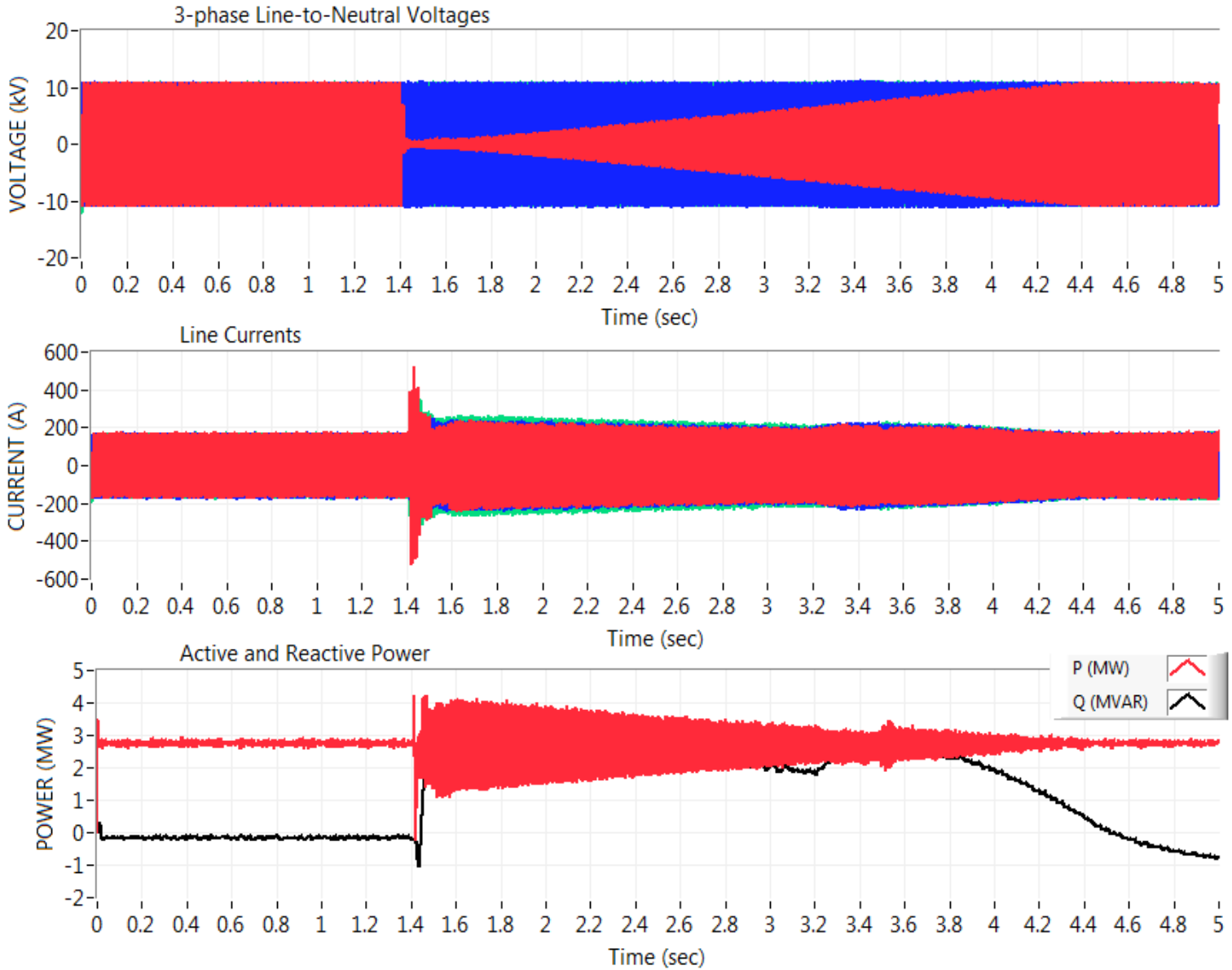
Two-Phase Fault



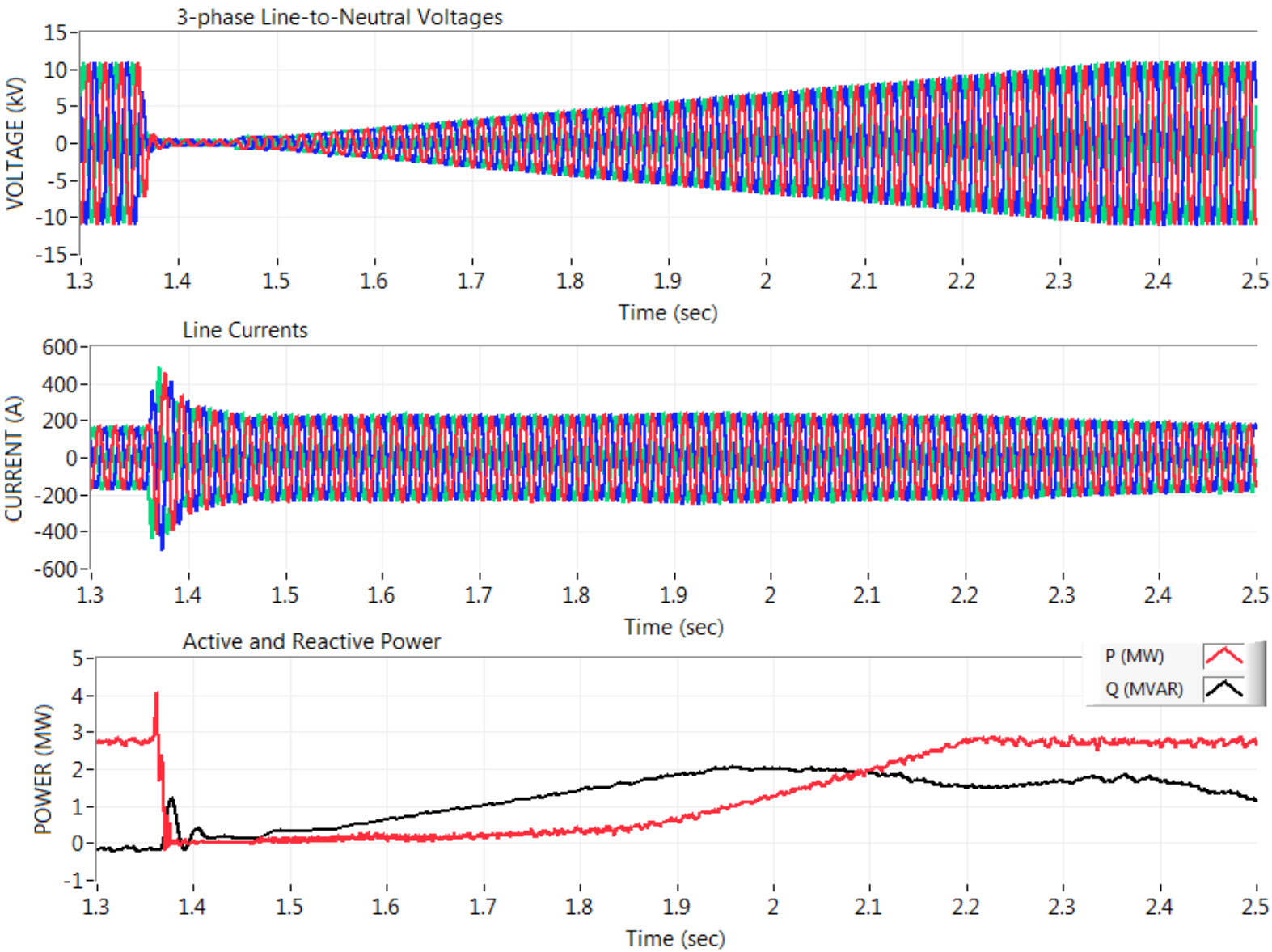
Three-Phase Fault



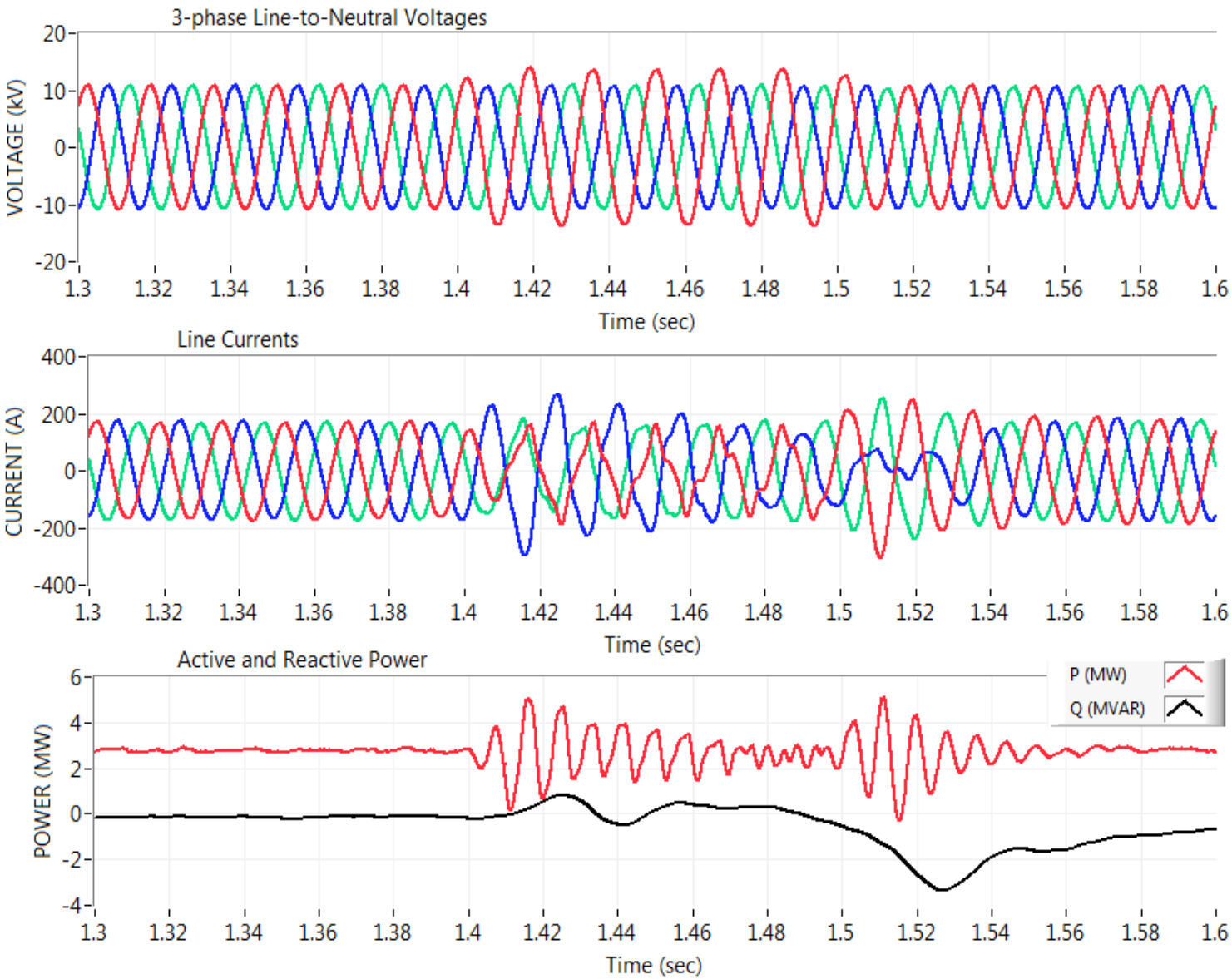
Single-Phase Fault—Slow Recovery



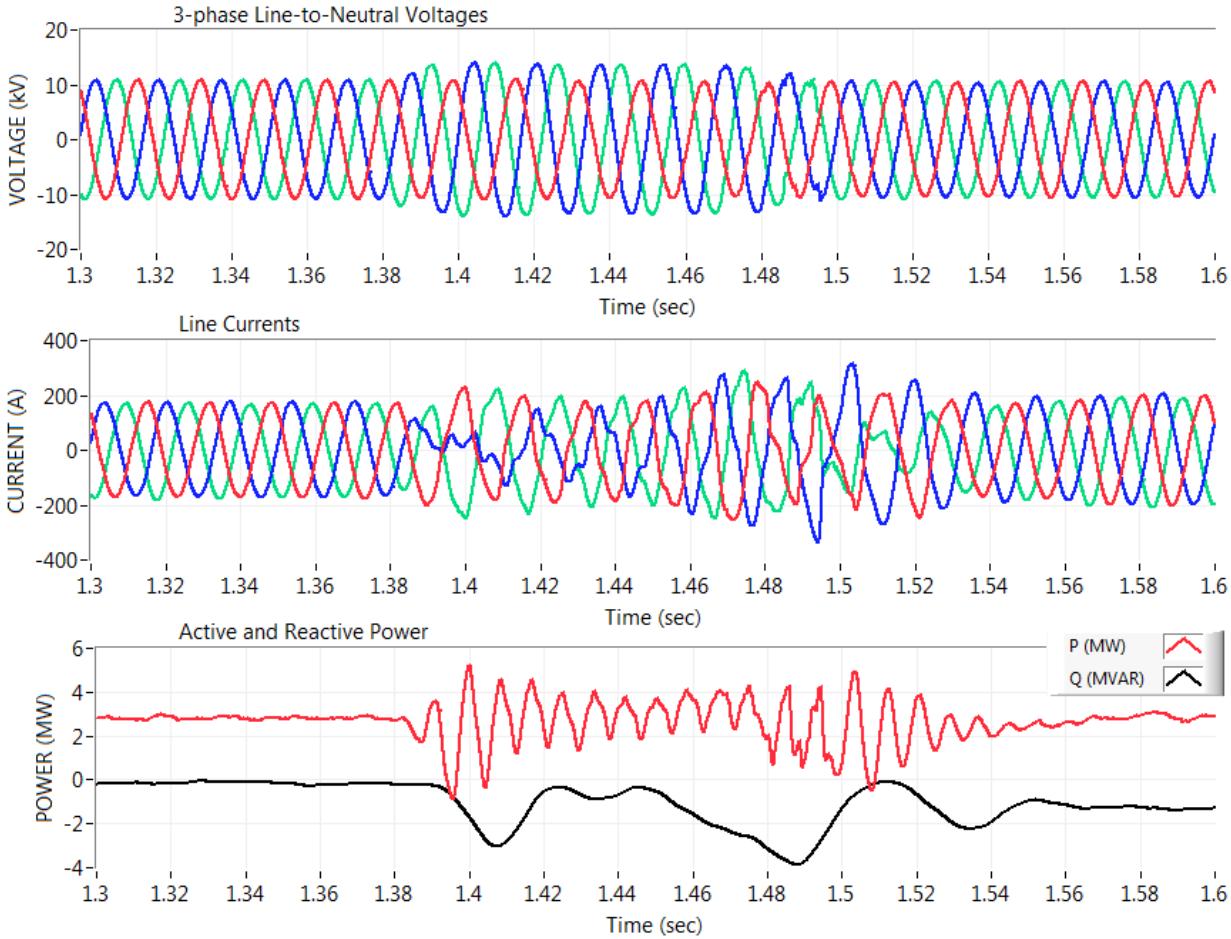
Three-Phase Fault—Slow Recovery



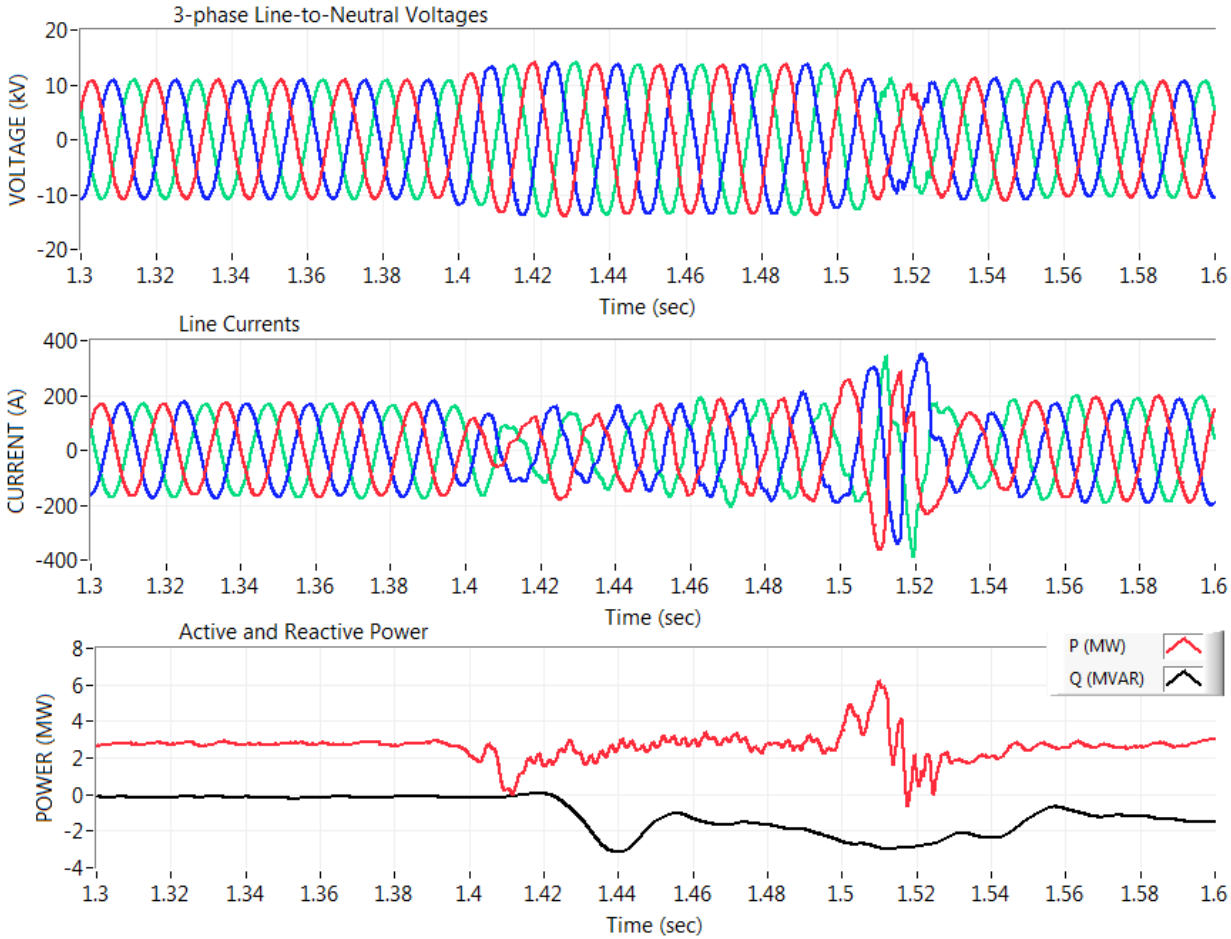
Single Phase—130% Overvoltage



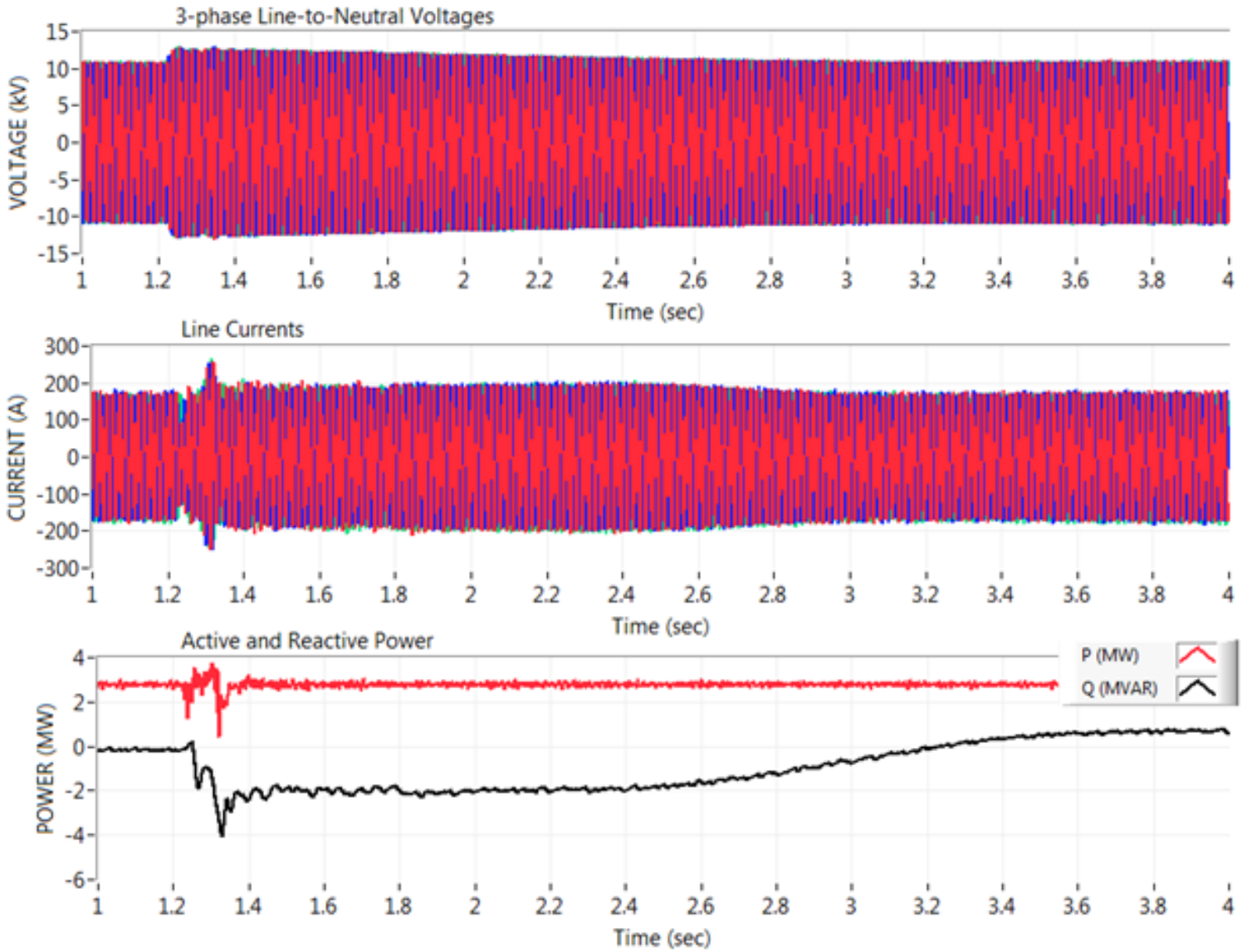
Two Phase—130% Overvoltage



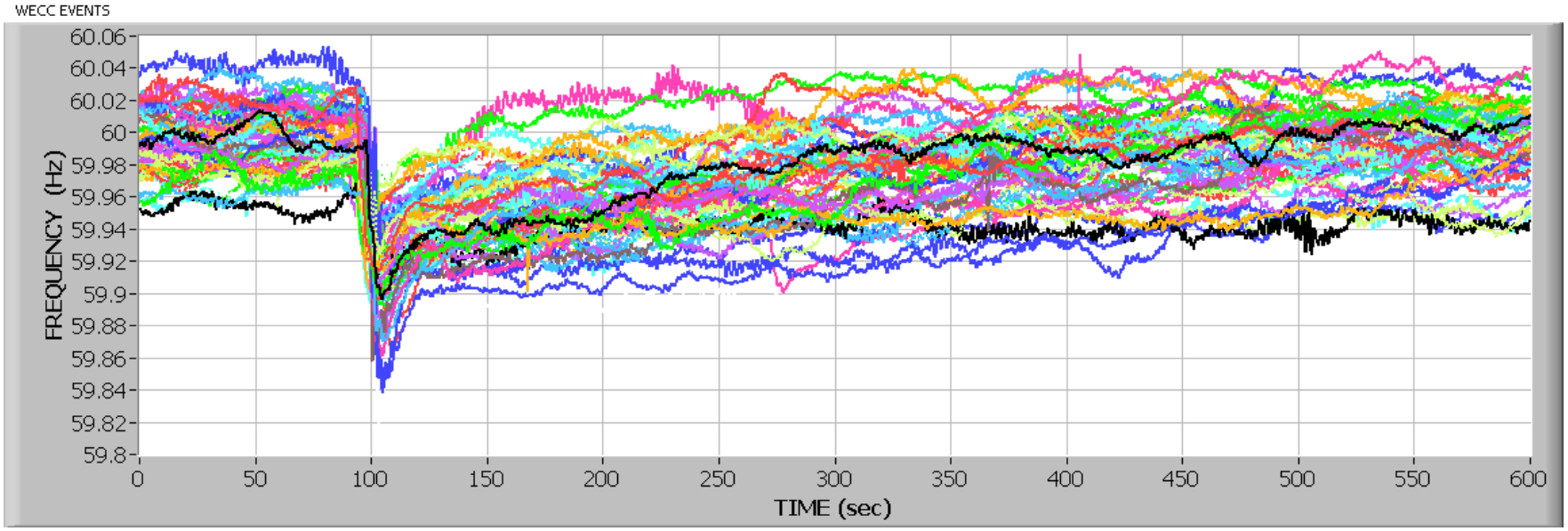
Three Phase—130% Overvoltage

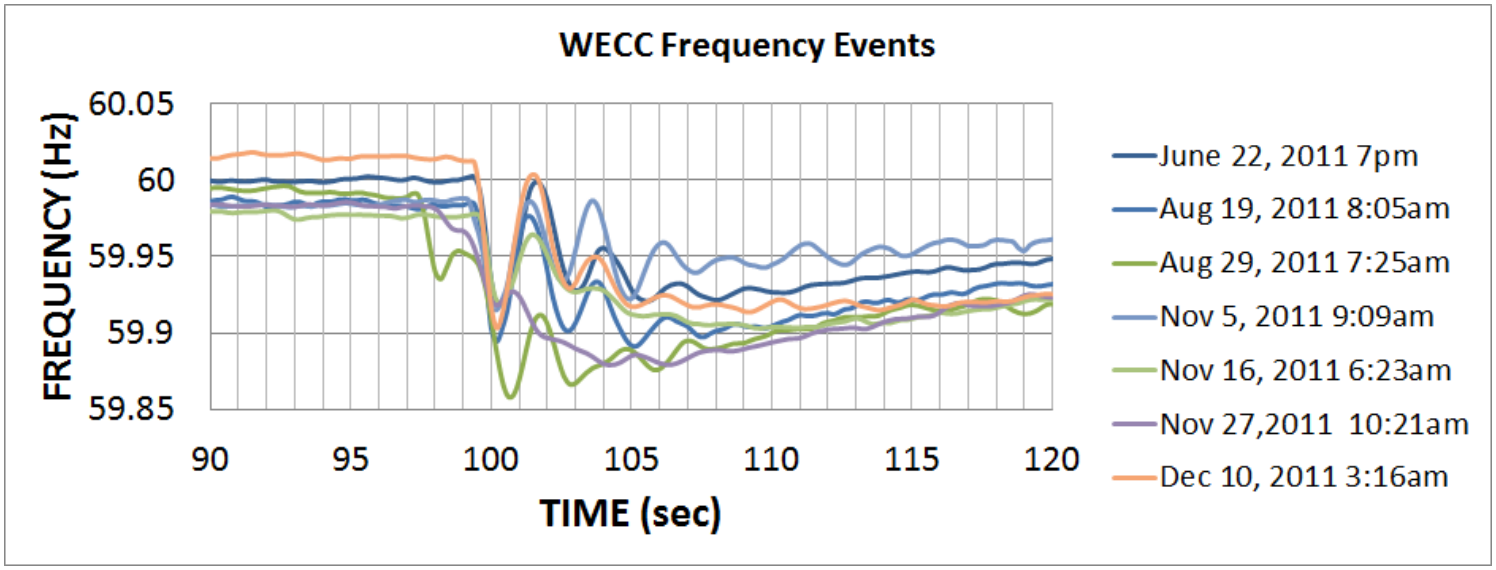


Three Phase Overvoltage—Slow Recovery

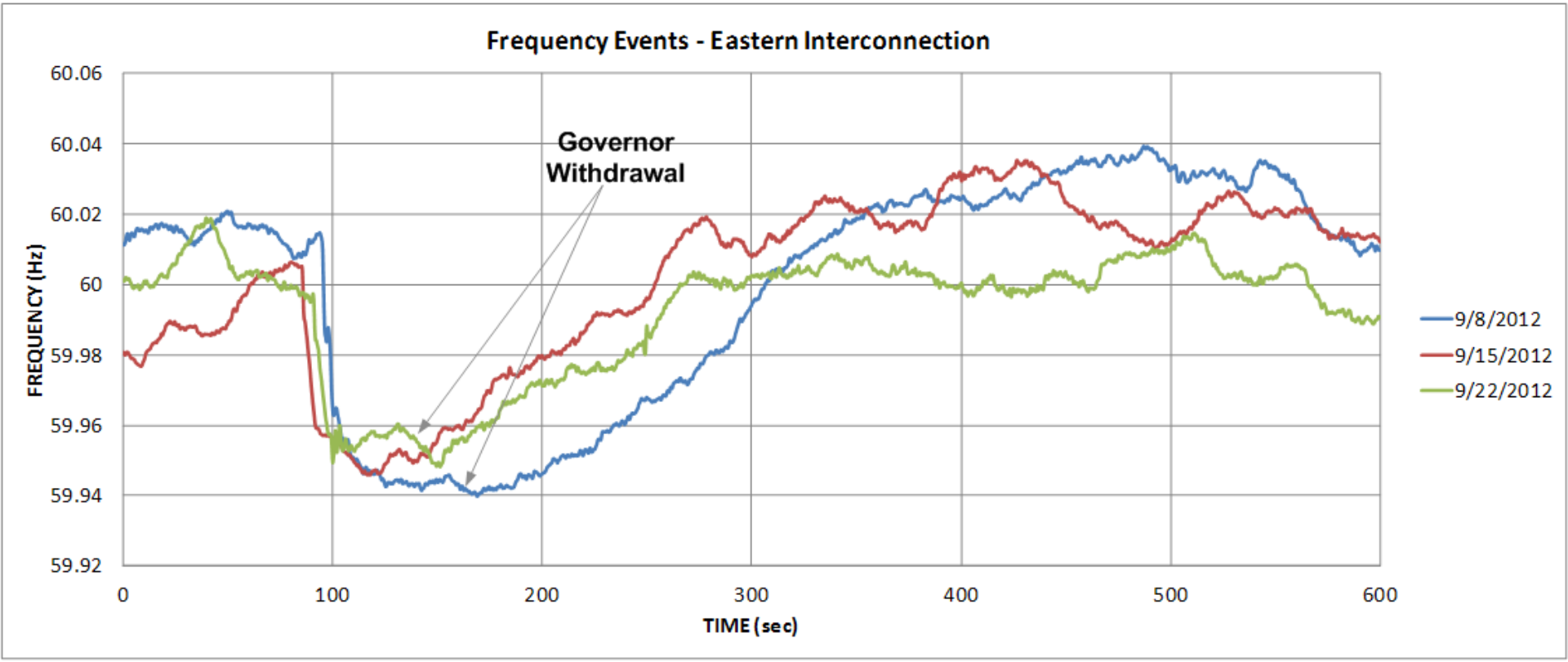


Frequency Events in the Western Interconnection

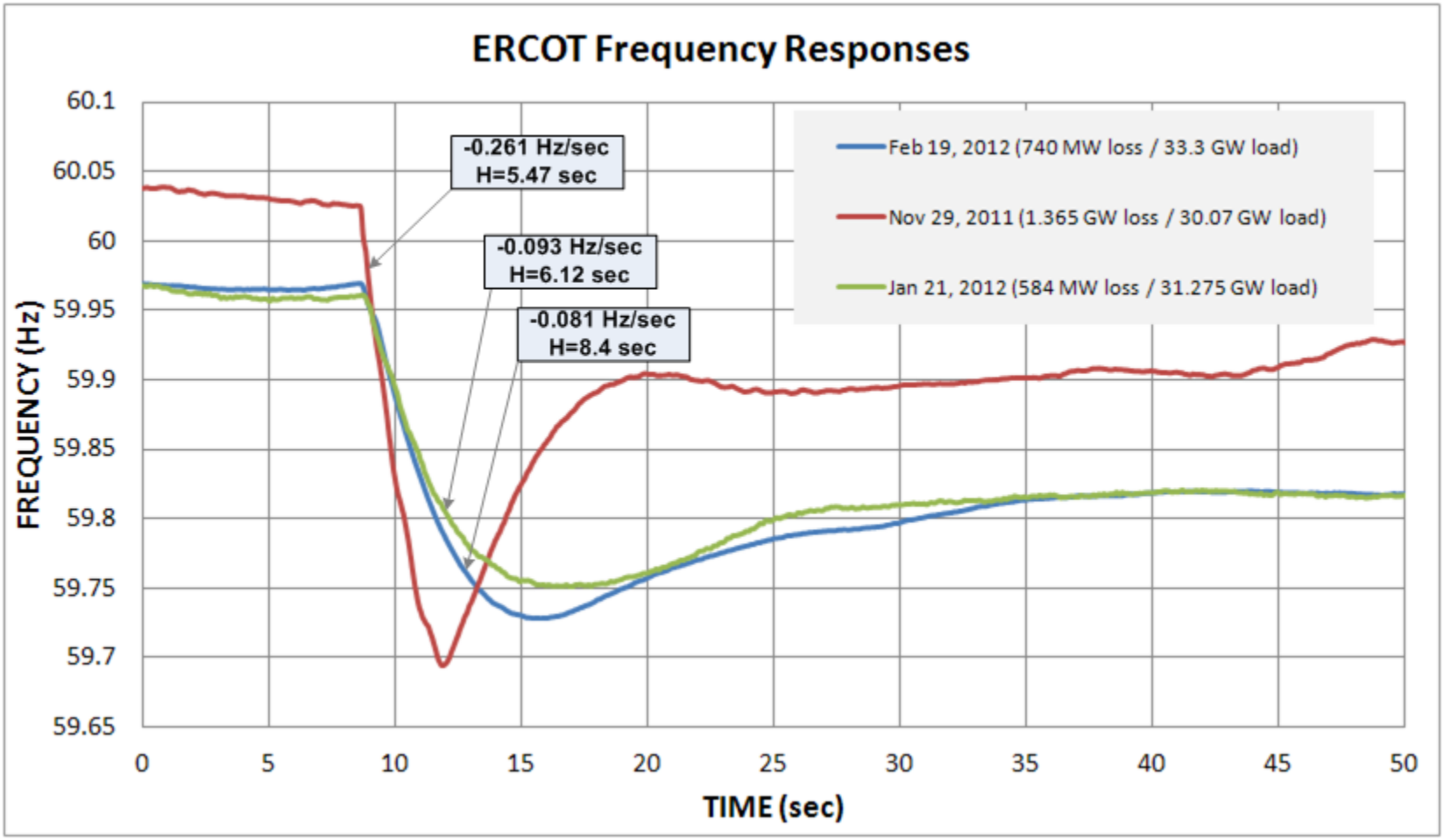




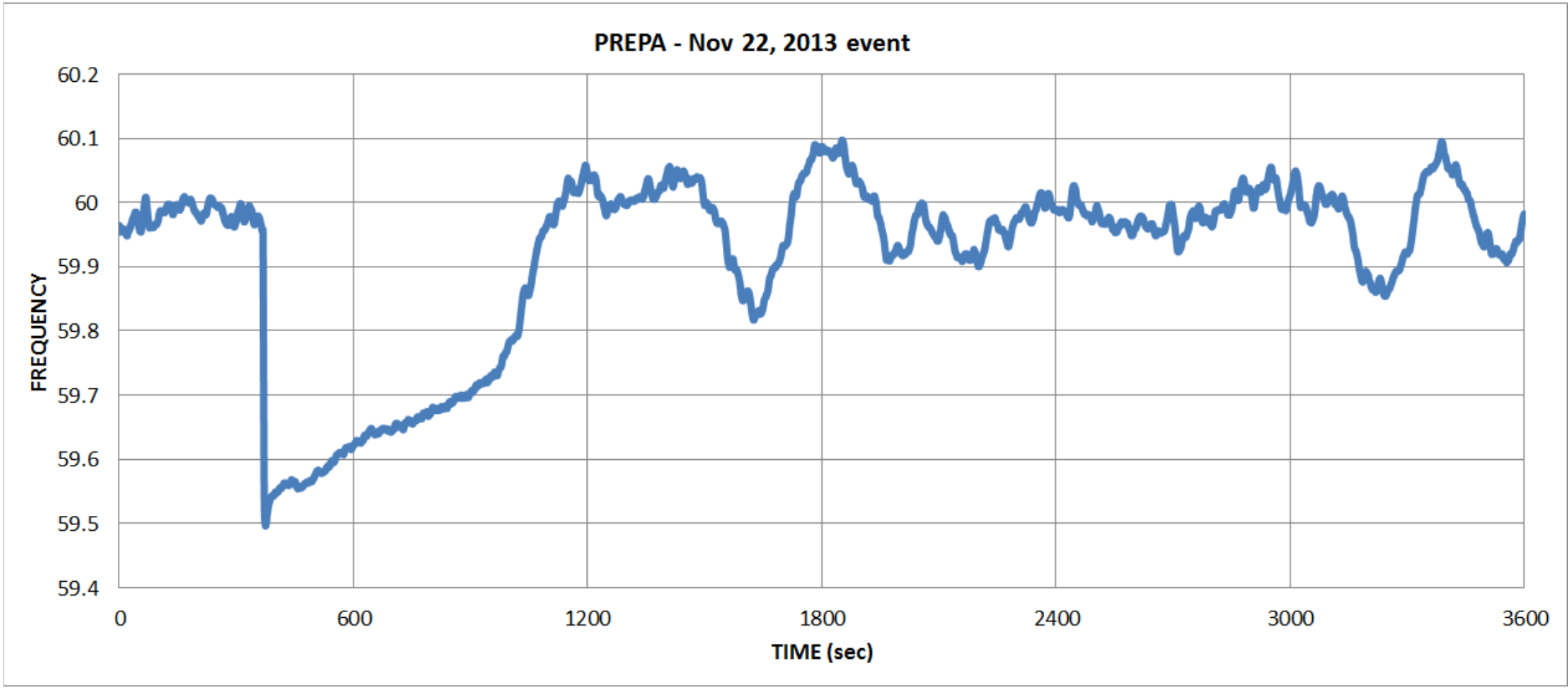
Frequency Events in the Eastern Interconnection



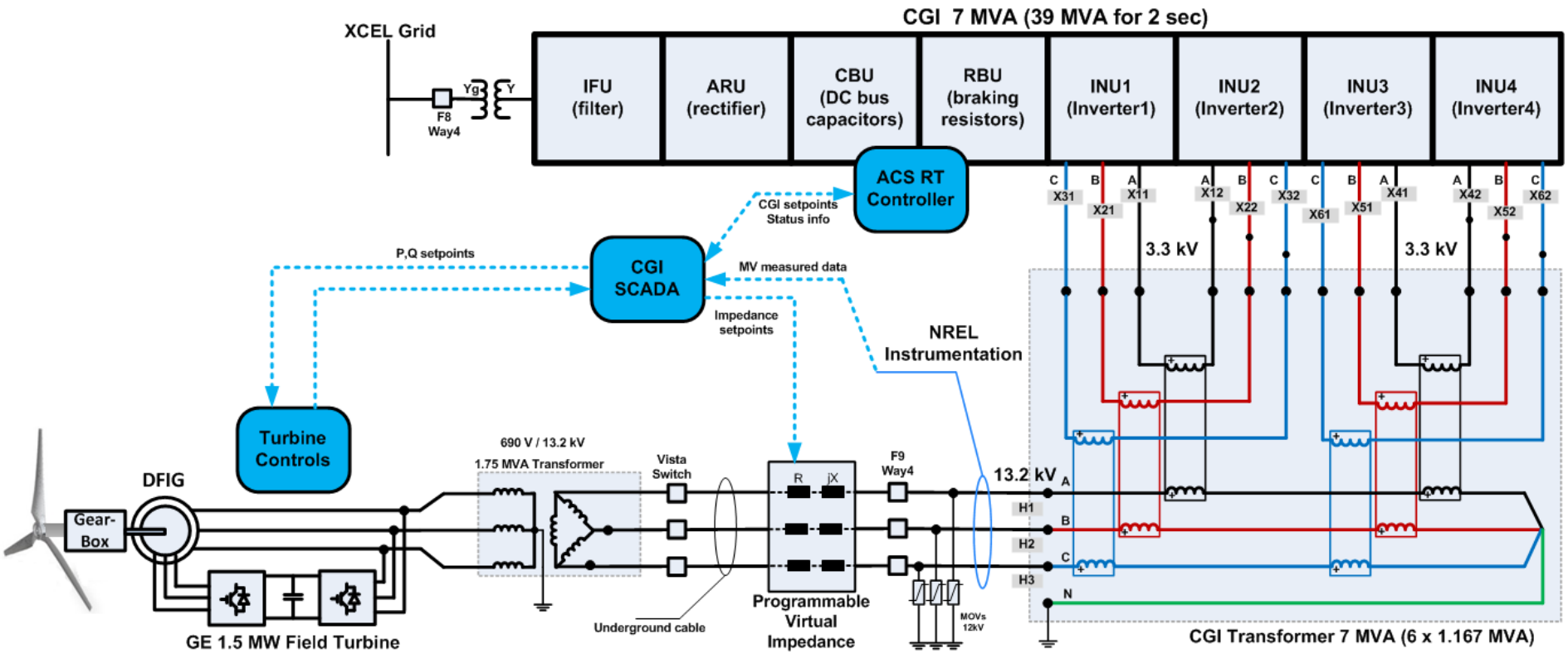
Frequency Events in the Electric Reliability Council of Texas (ERCOT)



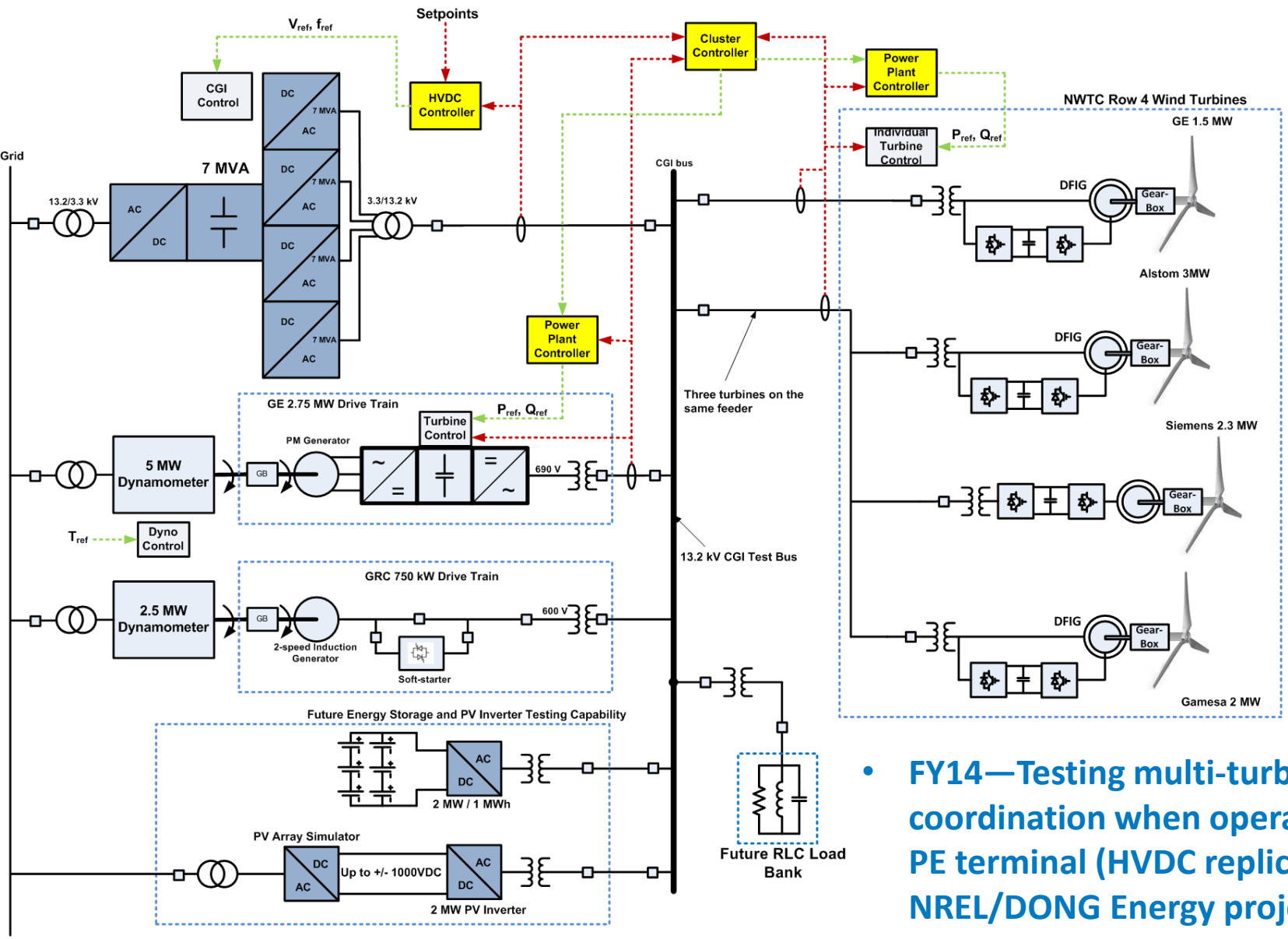
Frequency Response of an Island Power System



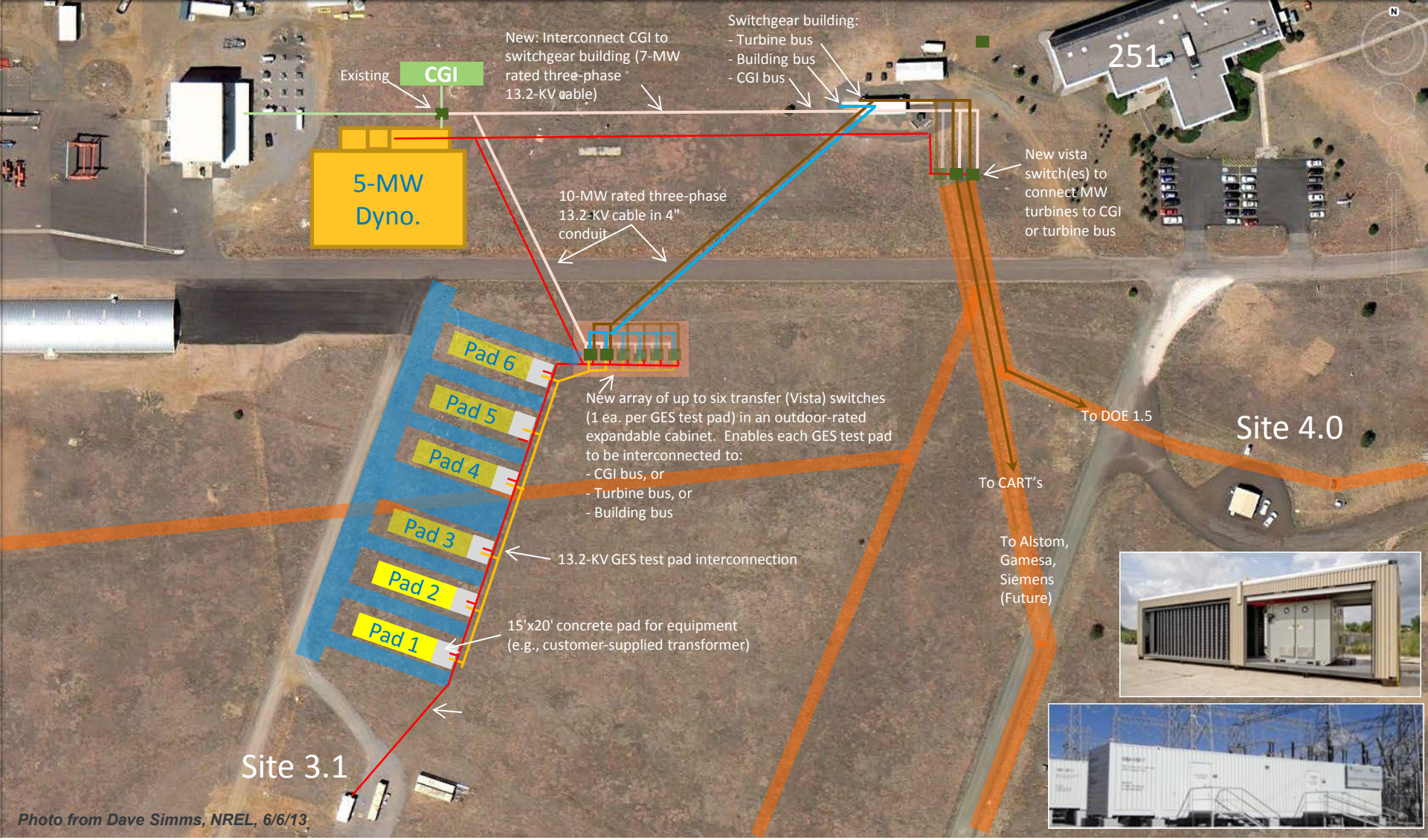
GE 1.5-MW Field Turbine/CGI Interconnection



FY14/15 Multi-Turbine Testing Project



- **FY14—Testing multi-turbine controls coordination when operating with PE terminal (HVDC replica), NREL/DONG Energy project**

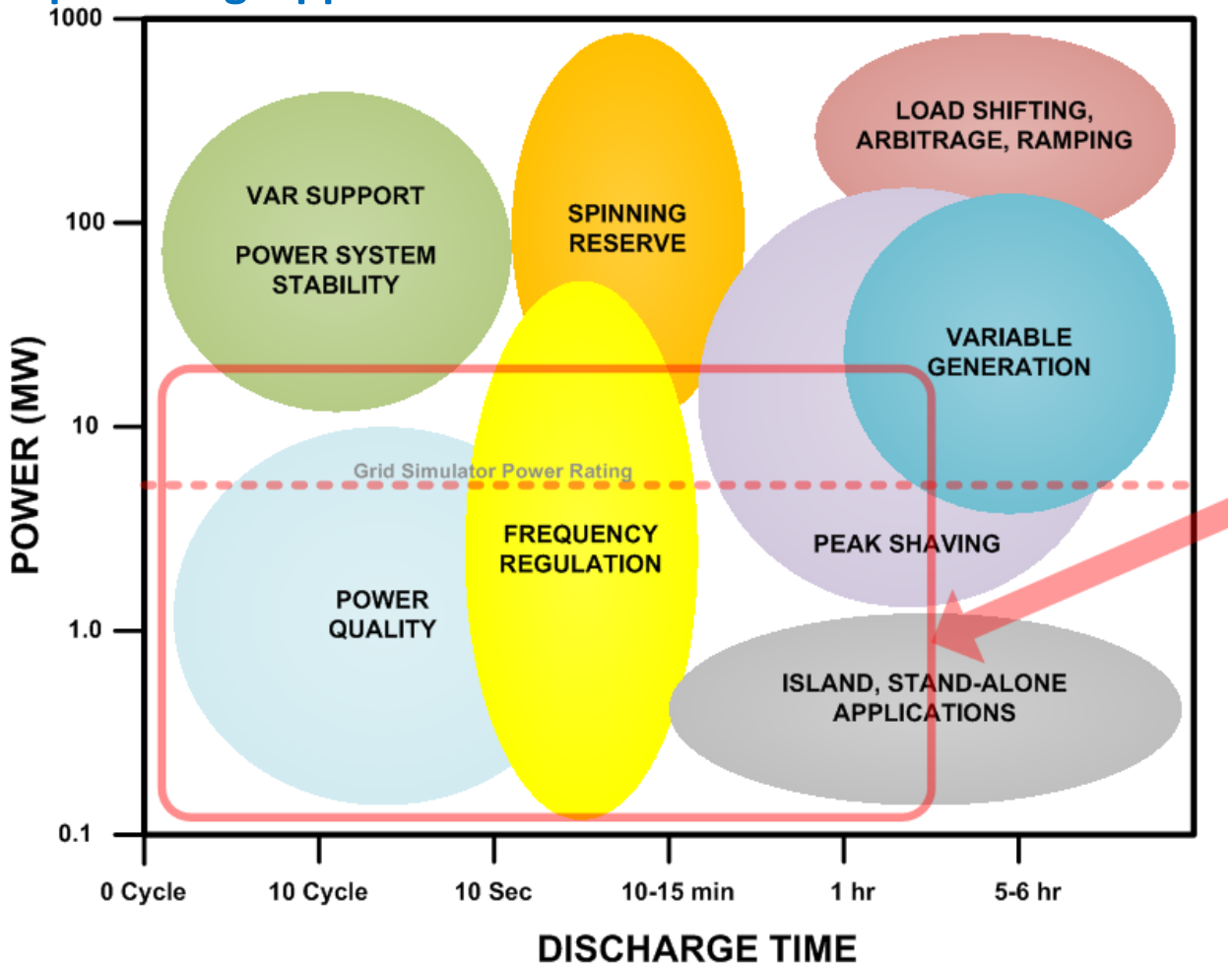


Proposed Electrical and Facility Infrastructure for Grid Energy Storage (GES) Test Pads and Row 4 Turbine Interconnection to CGI

Notes:
- Graphical infrastructure depiction only, not to scale—locations shown are approximate; final siting should be based on cost/ practical considerations
- GES test pads sized to house customer-supplied GES test articles (pictured) plus customer-supplied transformer and other equipment
- Translucent items depicted are optional depending on budget; plan and install as much as possible/practical anticipating future expansion
- The 5-MW Dyno. Control Room or the Site 3.1 Data Shed (partial N area) could serve as a client facility for GES test control/DAS/customer use

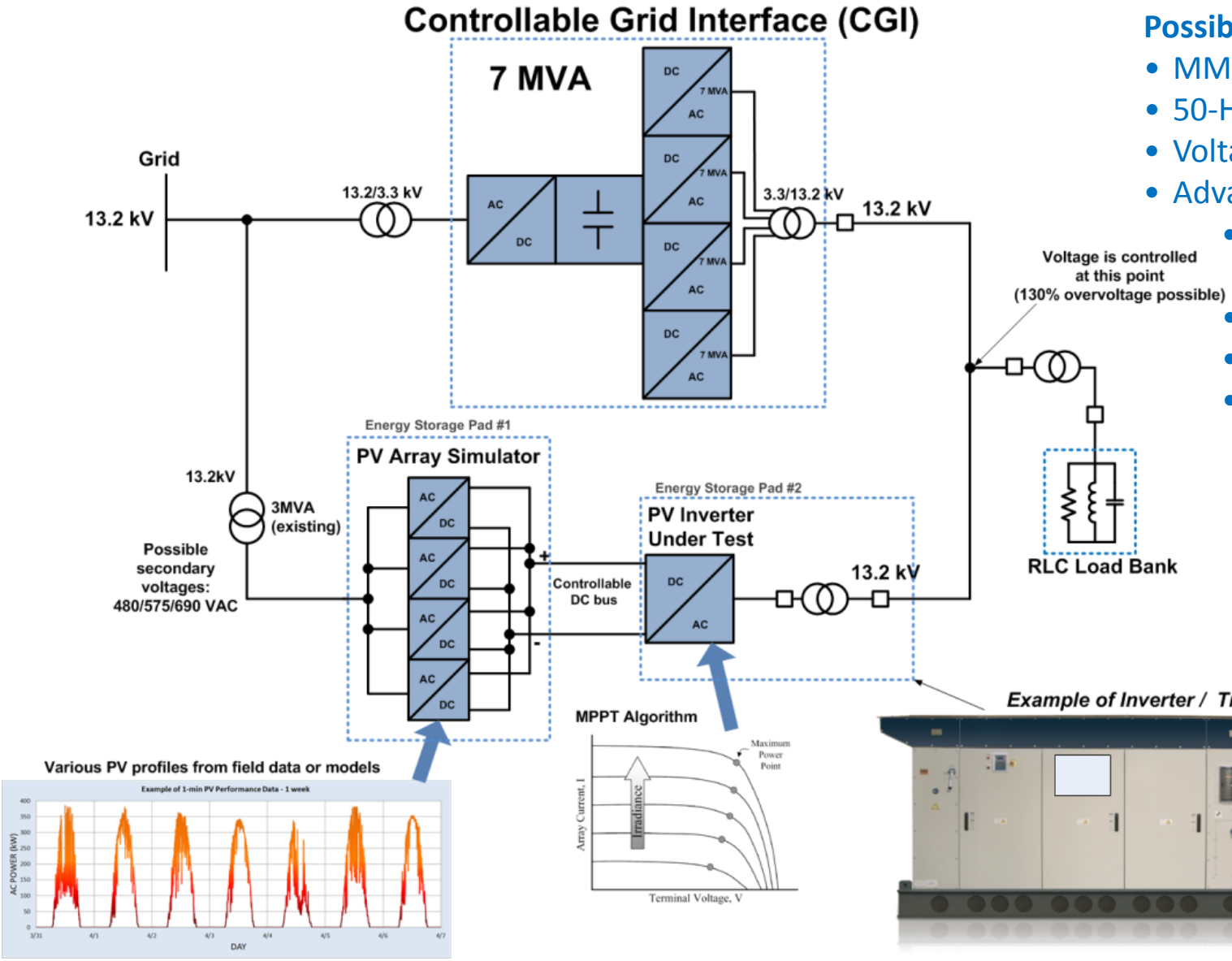
Energy Storage Testing for Ancillary Services

- CGI-connected tests for storage inverter LVRT testing and frequency response testing
- Utility-connected tests in parallel with real MW-scale wind and PV resource variability
- Ideal conditions to test energy storage for frequency regulation, variability smoothing, and ramp-limiting applications



Focused on these applications

PV Inverter Testing Concept Using NWTC CGI

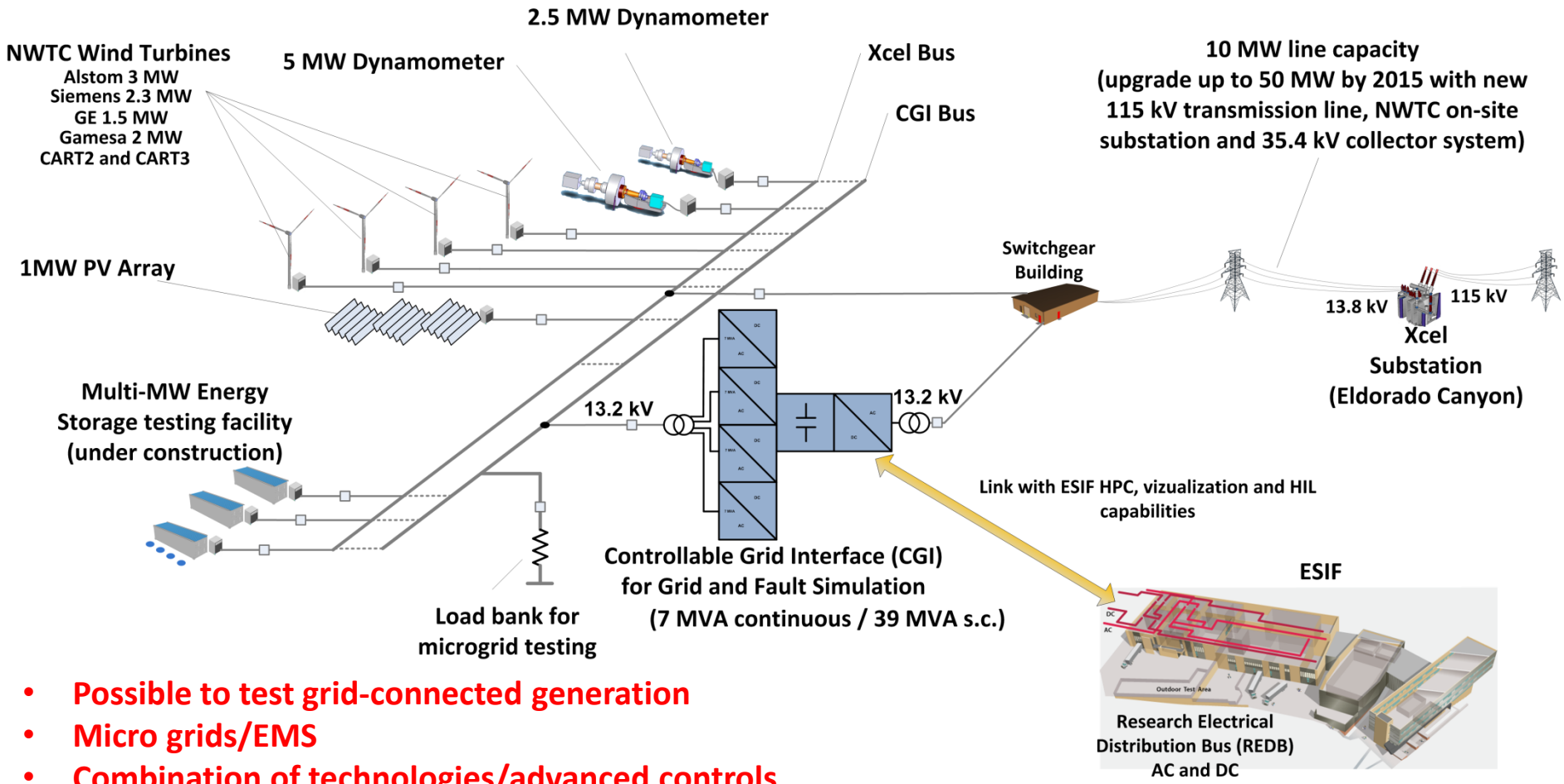


Possible tests

- MMPT algorithms
- 50-Hz/60-Hz operation
- Voltage fault tests
- Advanced testing
  - Operation with reserves
  - Frequency response
  - Voltage control
  - Testing with energy storage

NWTC Dual-Bus Test Setup

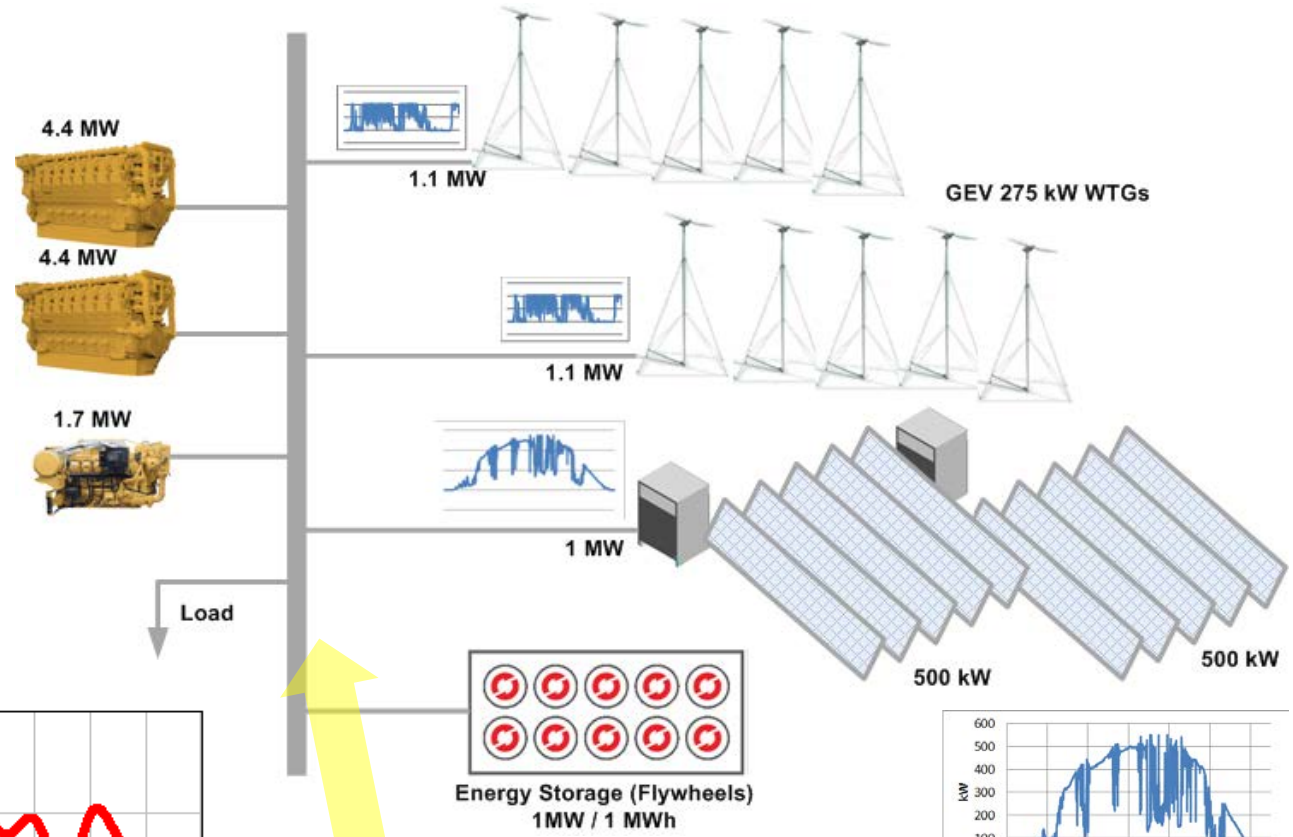
- Highly flexible and configurable system-level multi-MW testing/demonstration platform
- Most components in place and operational
- Energy storage testing facility to become on-line by the end of 2014

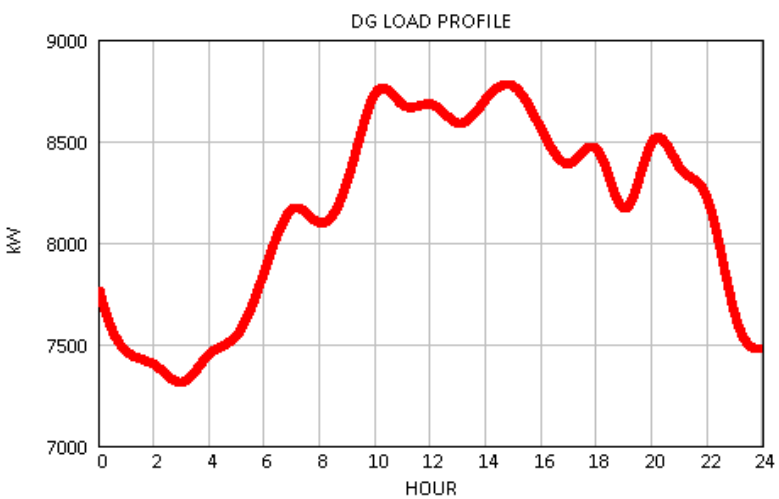


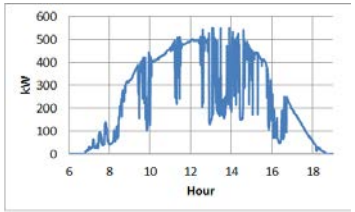
- Possible to test grid-connected generation
- Micro grids/EMS
- Combination of technologies/advanced controls

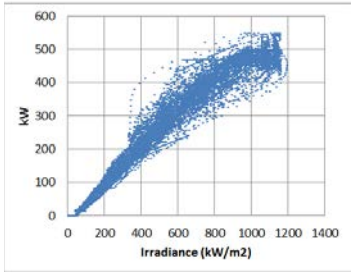
Diego Garcia Wind/PV Integration Study—30% Case

- Evaluate impacts of wind and PV on distributed generation grid reliability
- Estimate the size of energy storage
- Control strategies



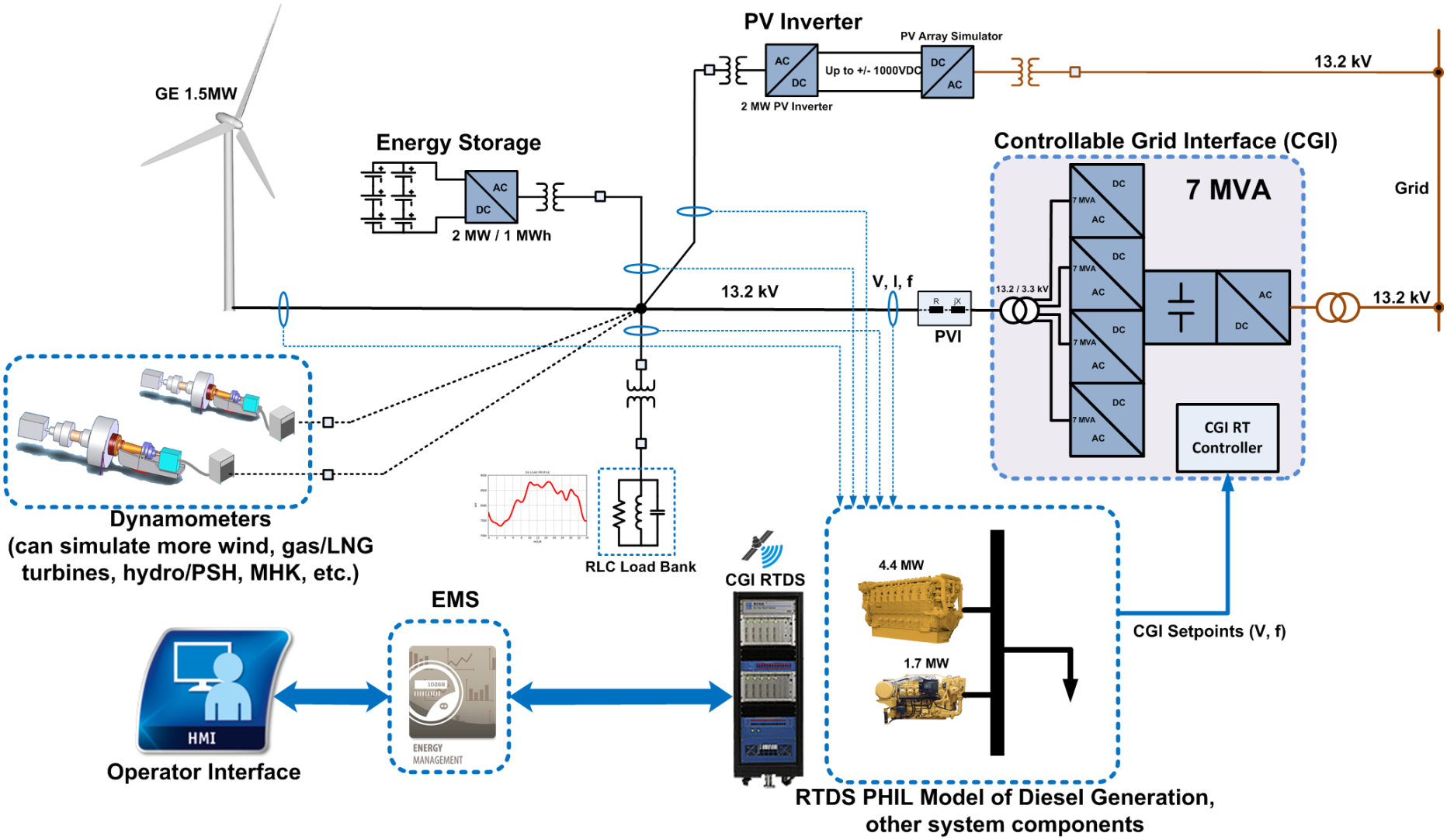




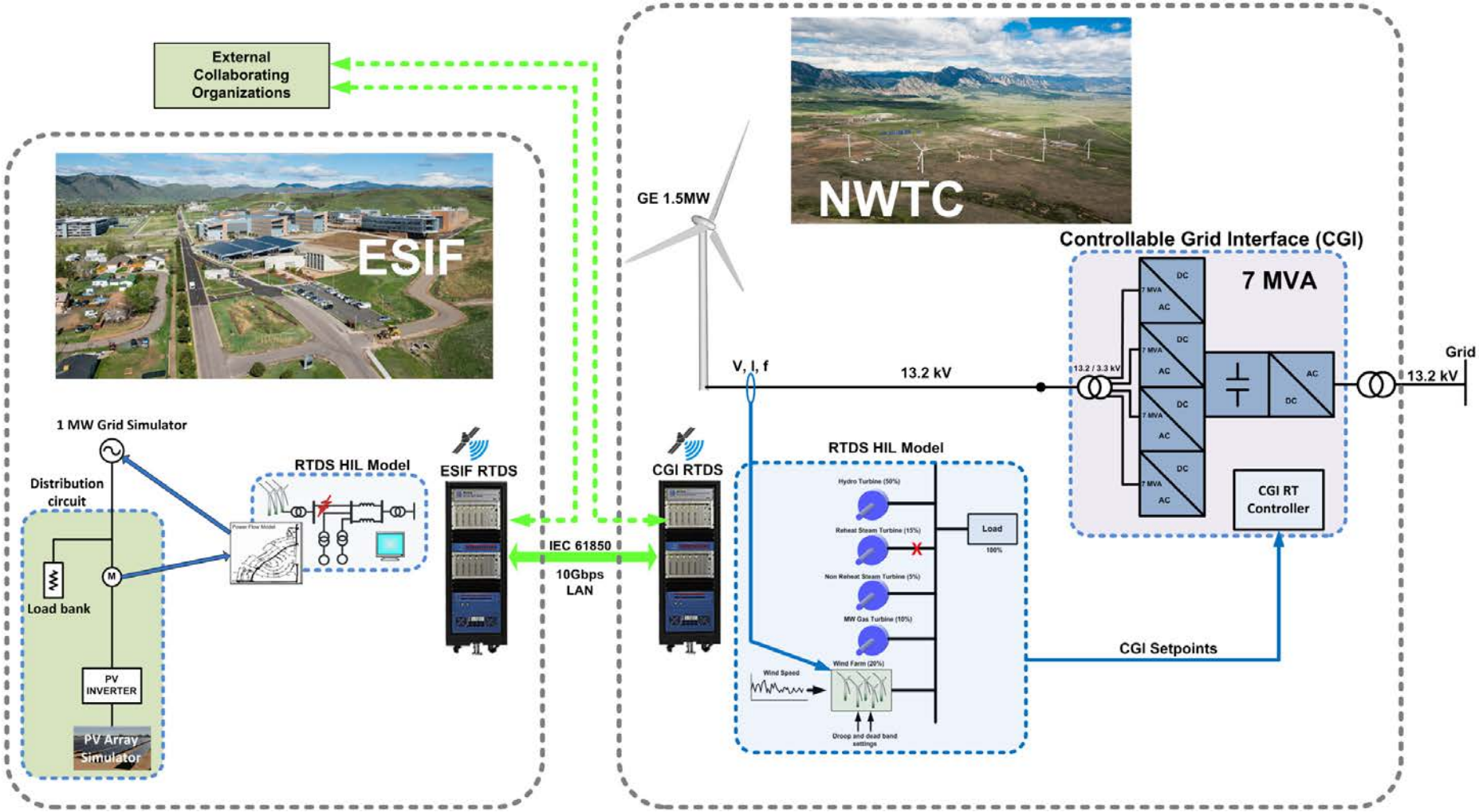


A system like this can be replicated at the NWTC in full scale for CGI testing. (See next slide.)

NWTC CGI for Microgrid Testing

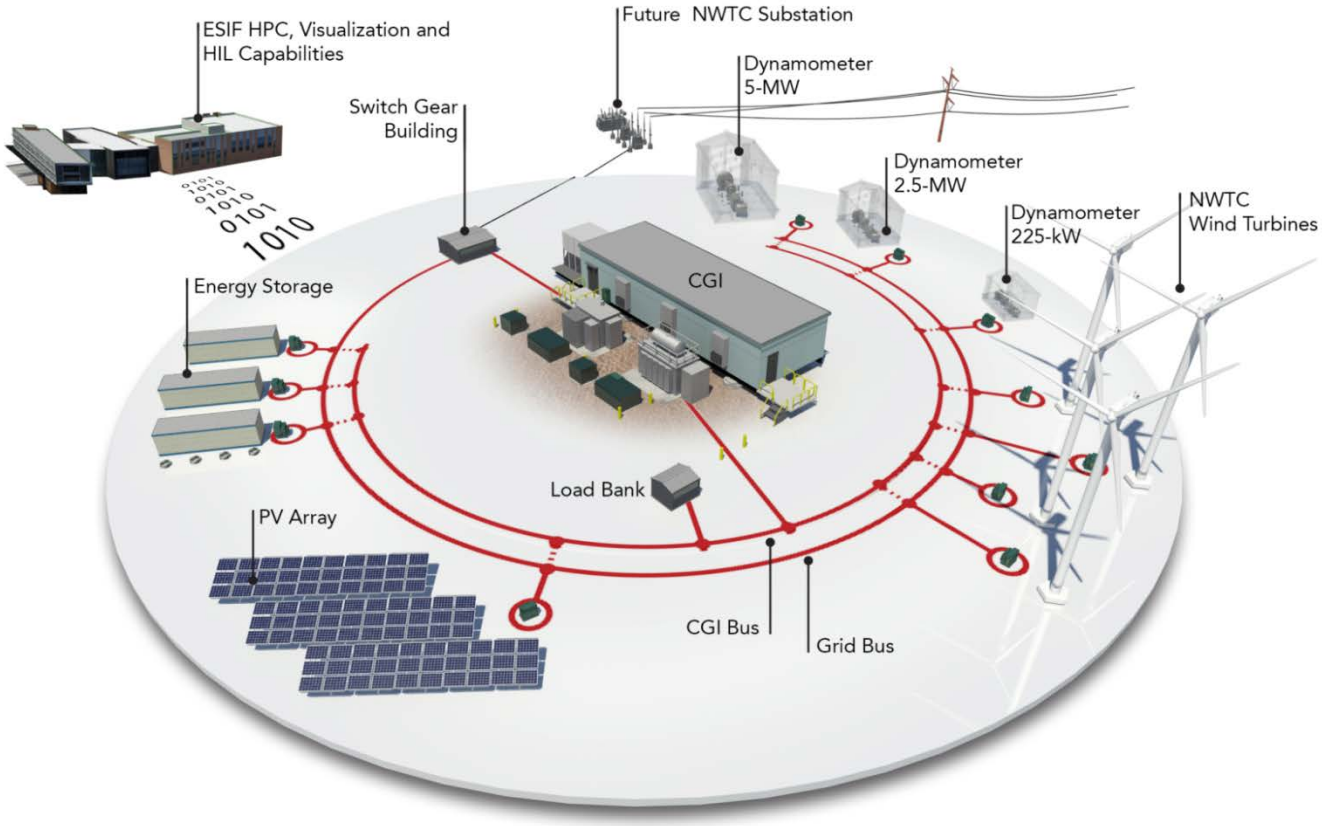


NWTC/ESIF Real-Time Interconnection

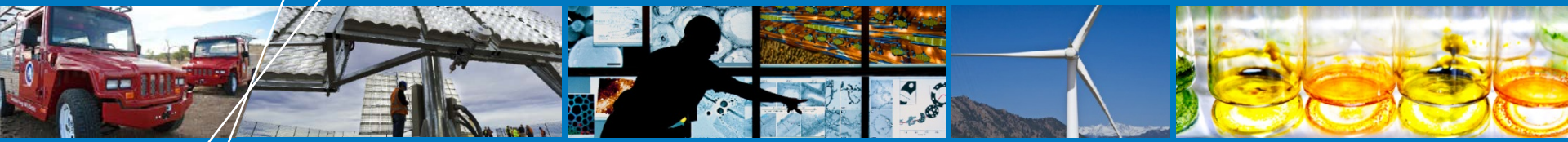


CGI Value Proposition

- Cross-technology grid-compliance and ancillary services testing at multi-MW level under controlled MV grid conditions
- Tool for renewable energy industry to test for compliance with national and international electrical standards, grid codes, and interconnection requirements
- Tool for advanced controls testing and validation
- Helps increase reliability and reduce integration cost of renewables generation



NREL
NATIONAL RENEWABLE ENERGY LABORATORY



Thank you.

Questions?