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

# First Workshop—June 2003

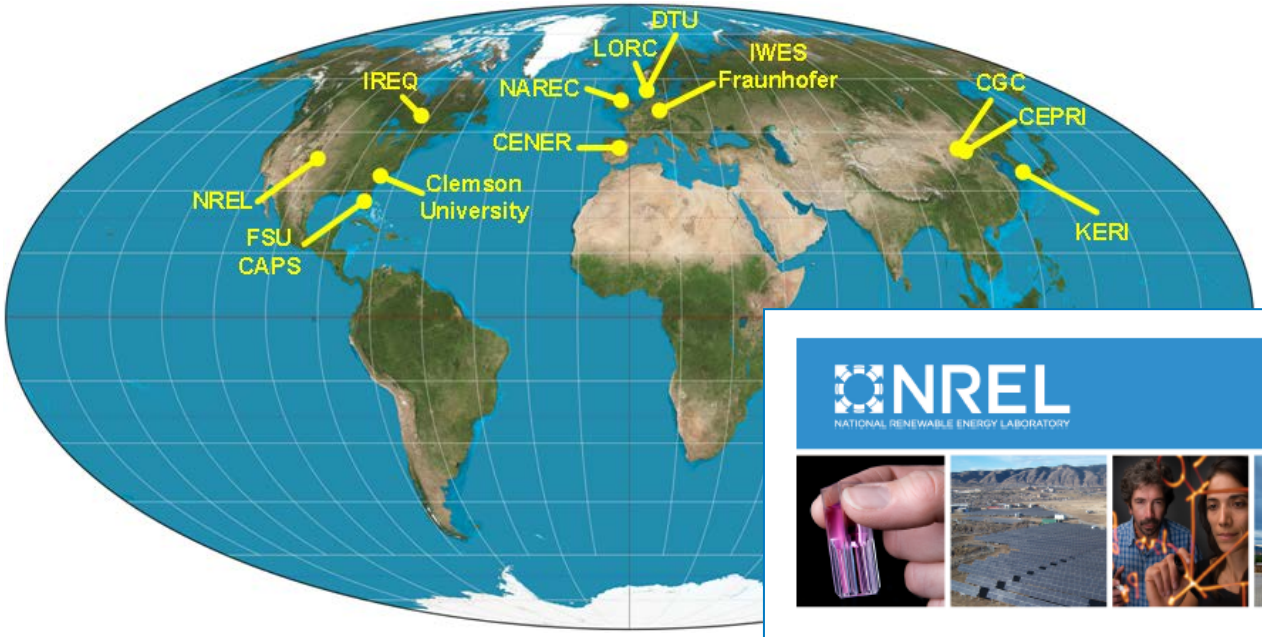



*Image from http://upload.wikimedia.org/wikipedia/commons/9/9e/Mollweide_projection_SW.jpg*


**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

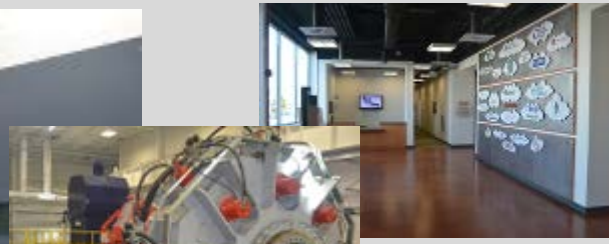
NREL

## 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

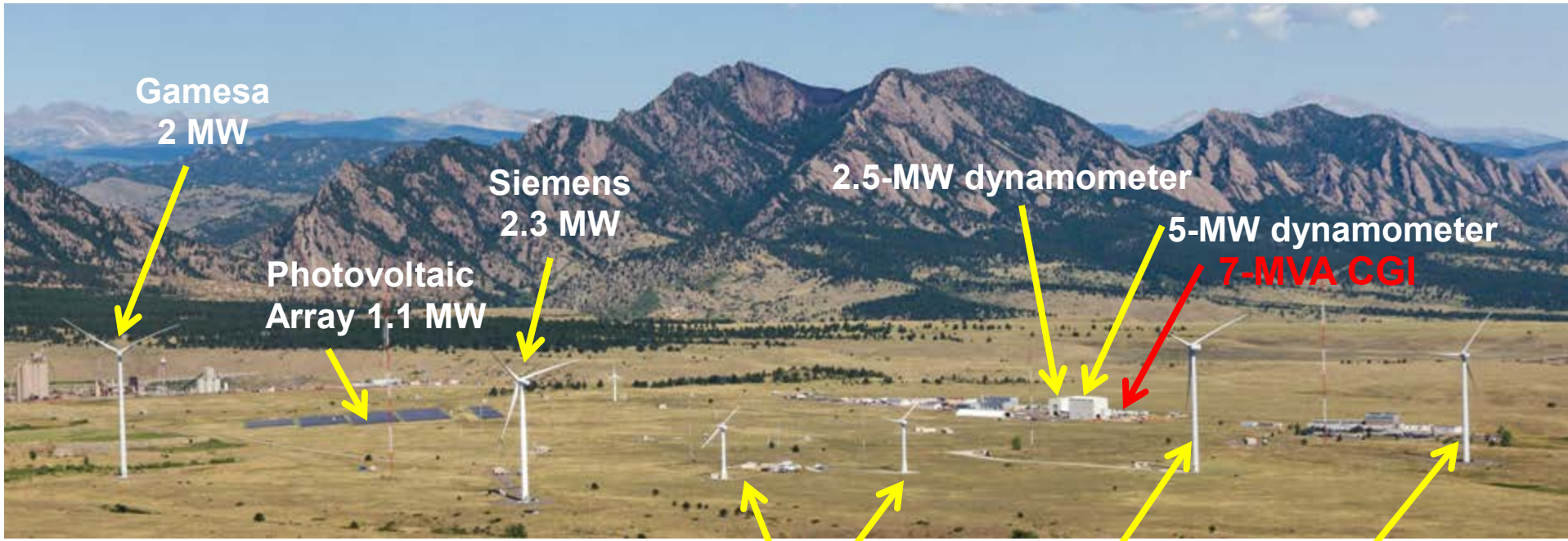



*Photo from Dave Simms, NREL*

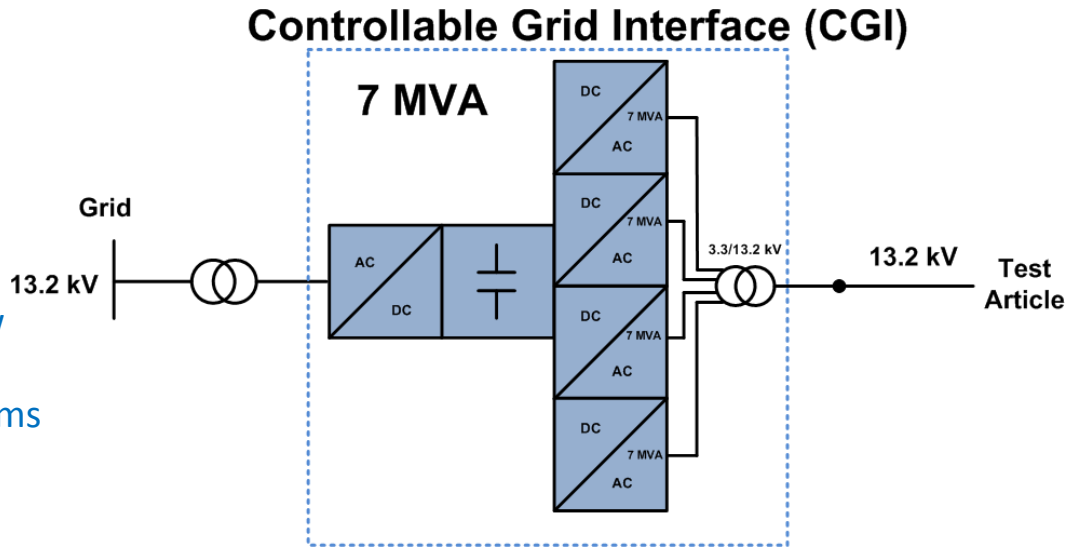
# CGI Main Technical Characteristics

**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

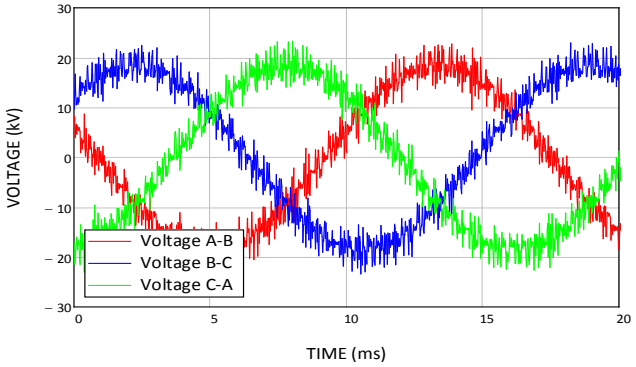
# NWTC's 7-MVA CGI

*Photo from Mark McDade, NREL*

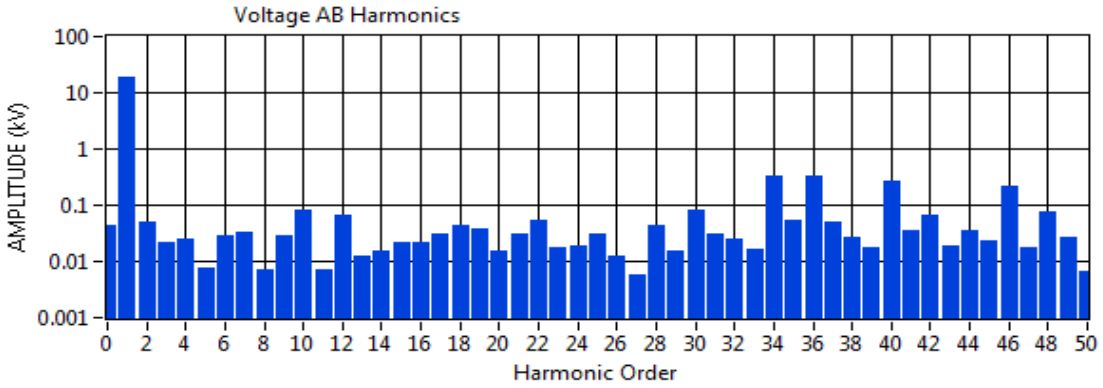
- Installed at NWTC test site—November 2012
- Commissioning and characterization testing—end of 2013
- Row 4/turbine bus connection—FY14
- Energy storage site connection—end of 2014

# CGI Voltage Waveform

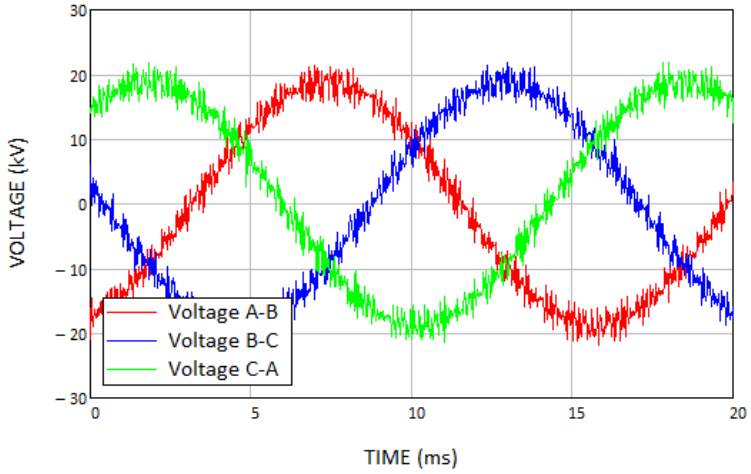
## No-load L-to-L voltage



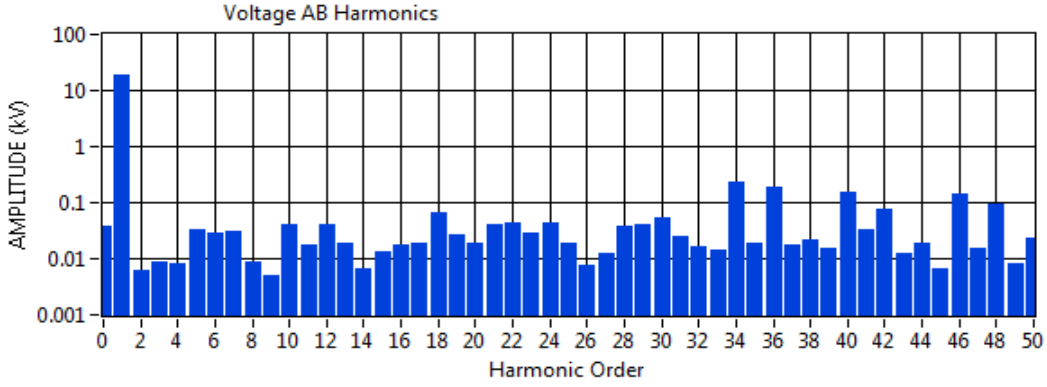

## No-load voltage harmonics (THD=3.4%)



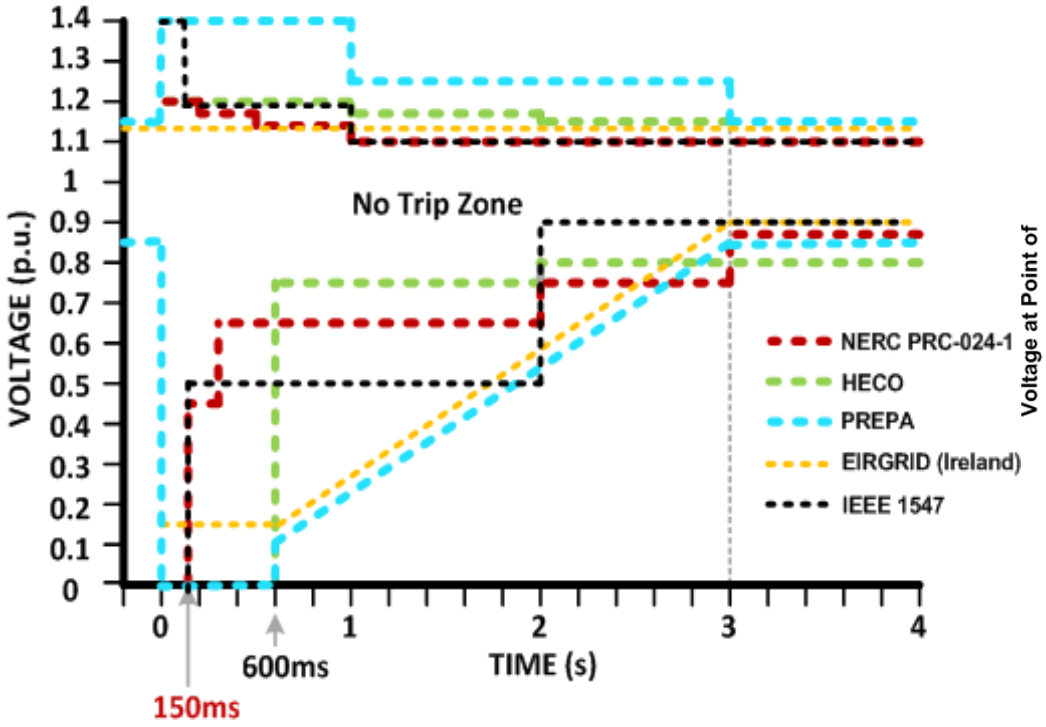

## L-to-L voltage under 2.75-MW load



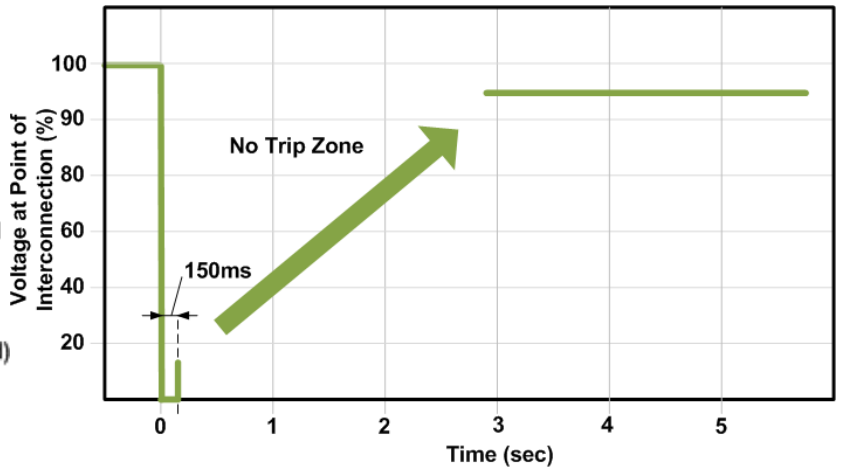

## Voltage harmonics under 2.75-MW load (THD=2.5%)



# Testing to All Interconnection Requirements and Grid Codes



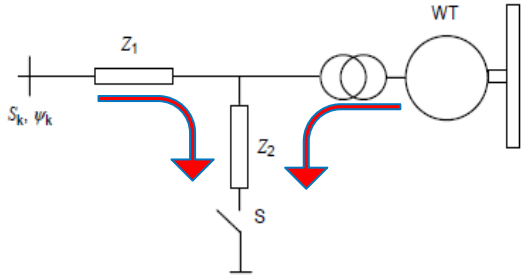

## FERC LVRT requirements (Order 661-A)




## 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 Dynanometer

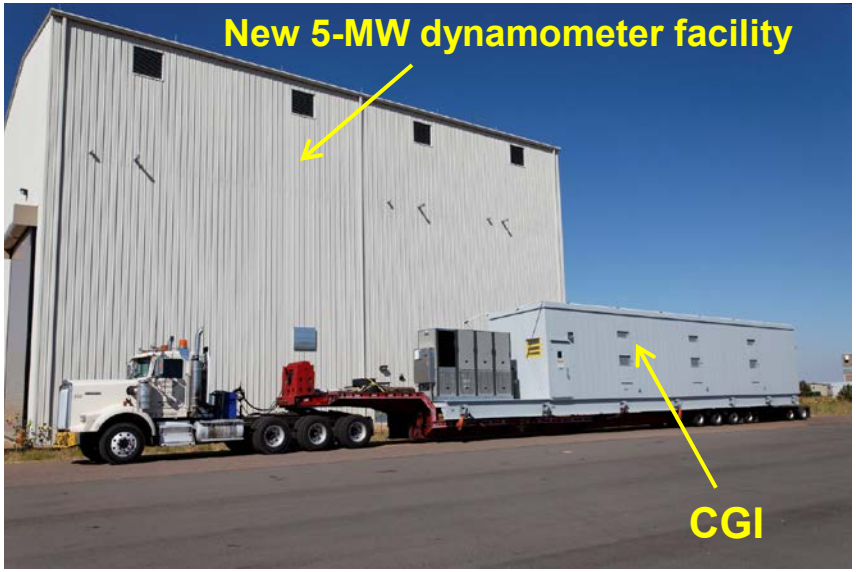
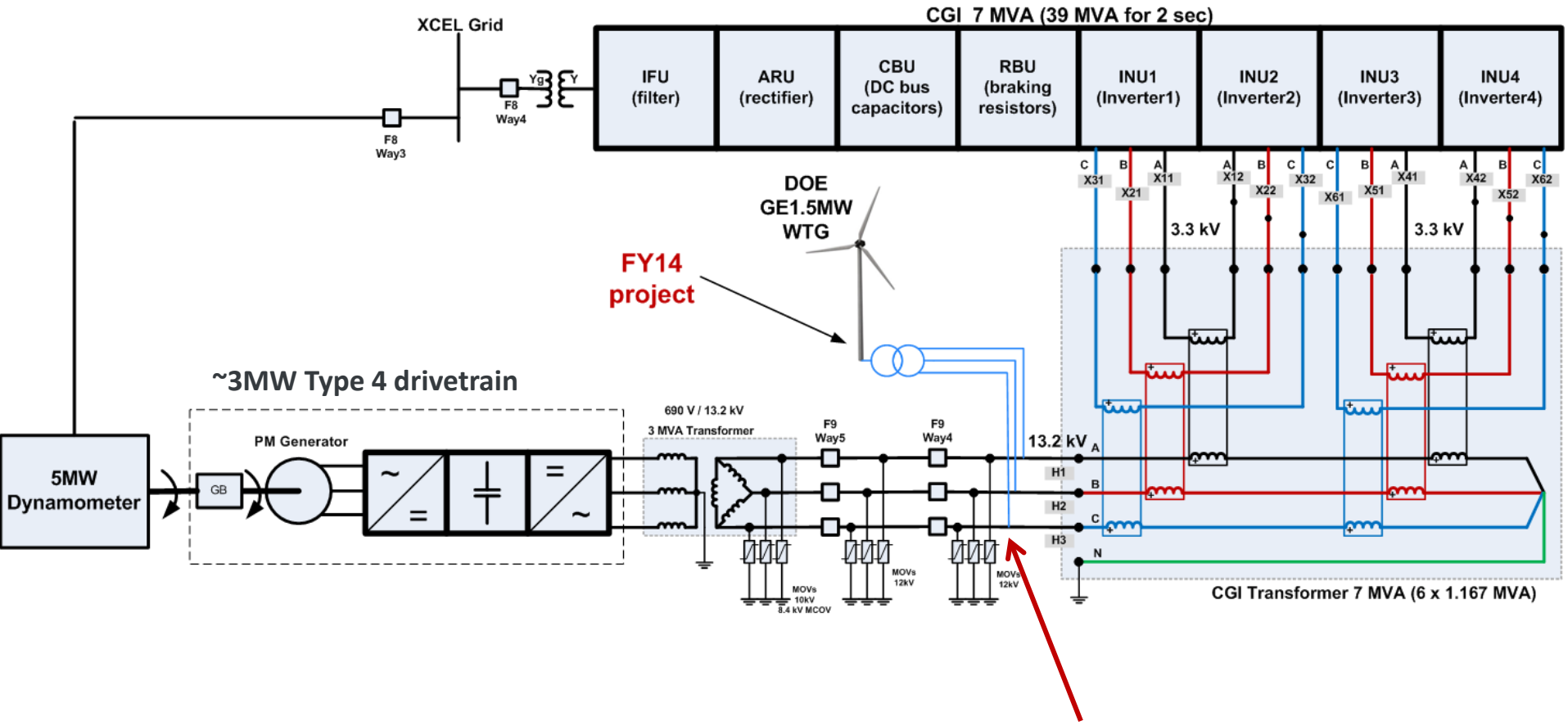





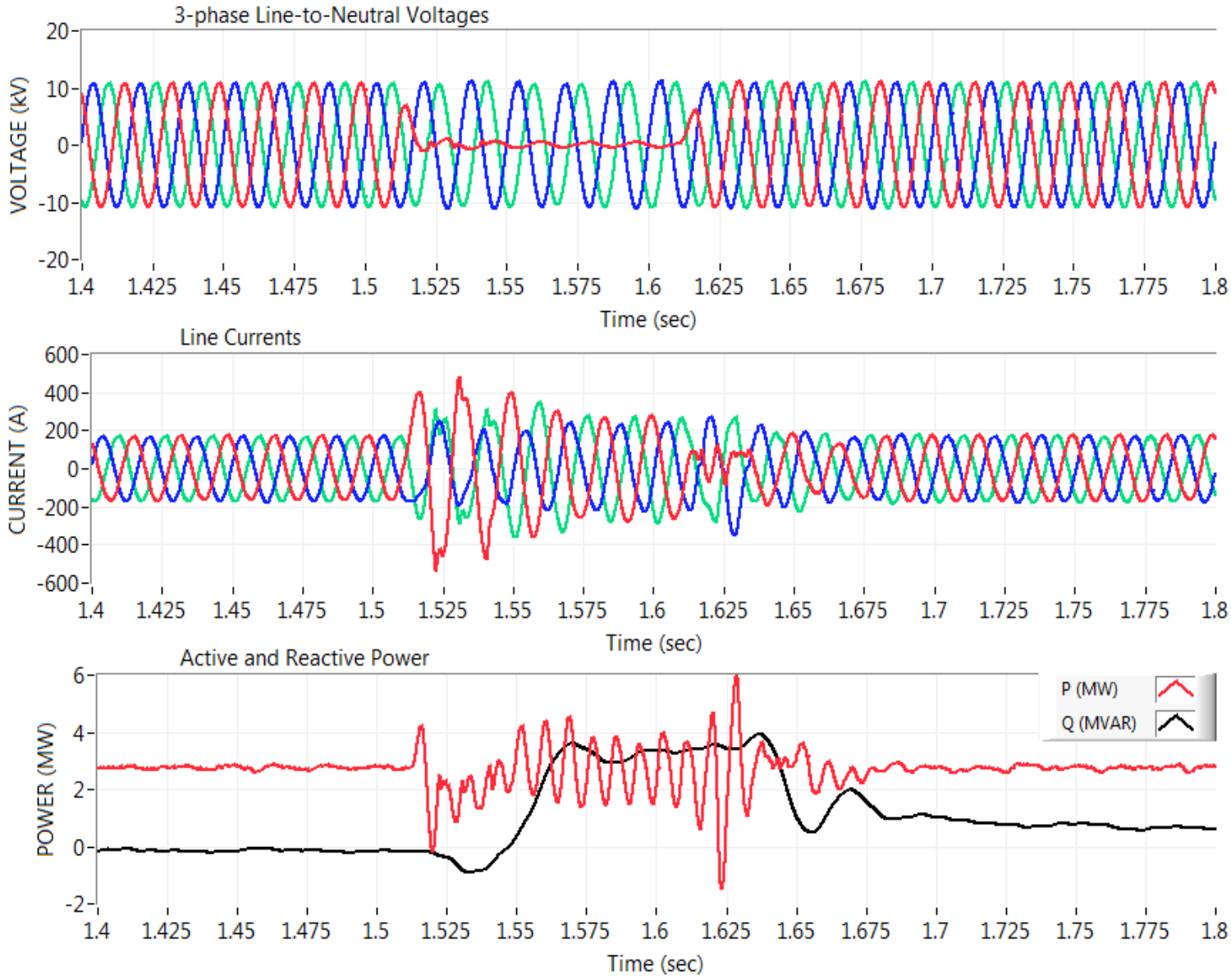
*Photo from NREL*

# Type 4 ~3-MW Turbine Operation with CGI

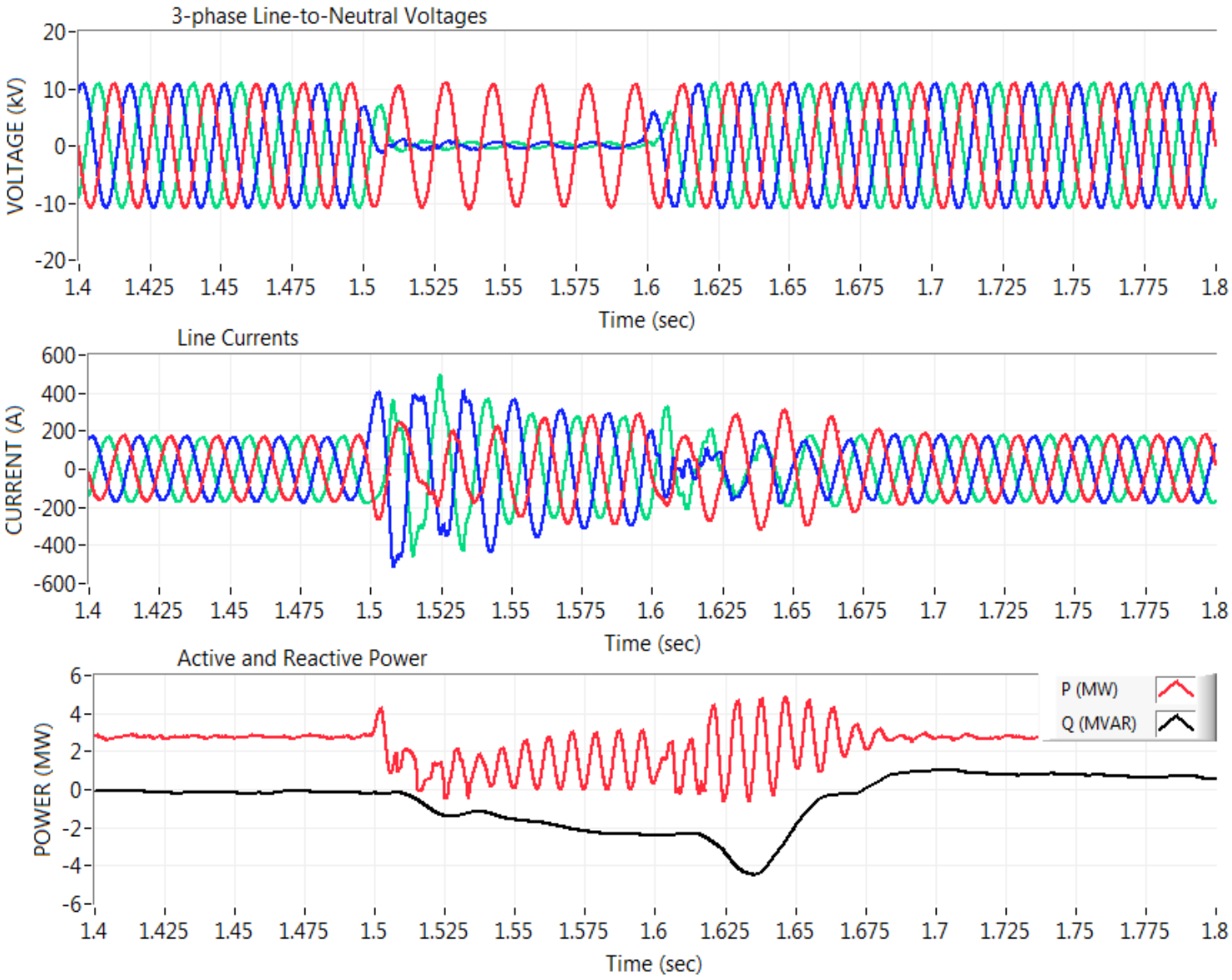



**Voltage amplitude, frequency, phase angle, and harmonic content are controlled on CGI terminals**

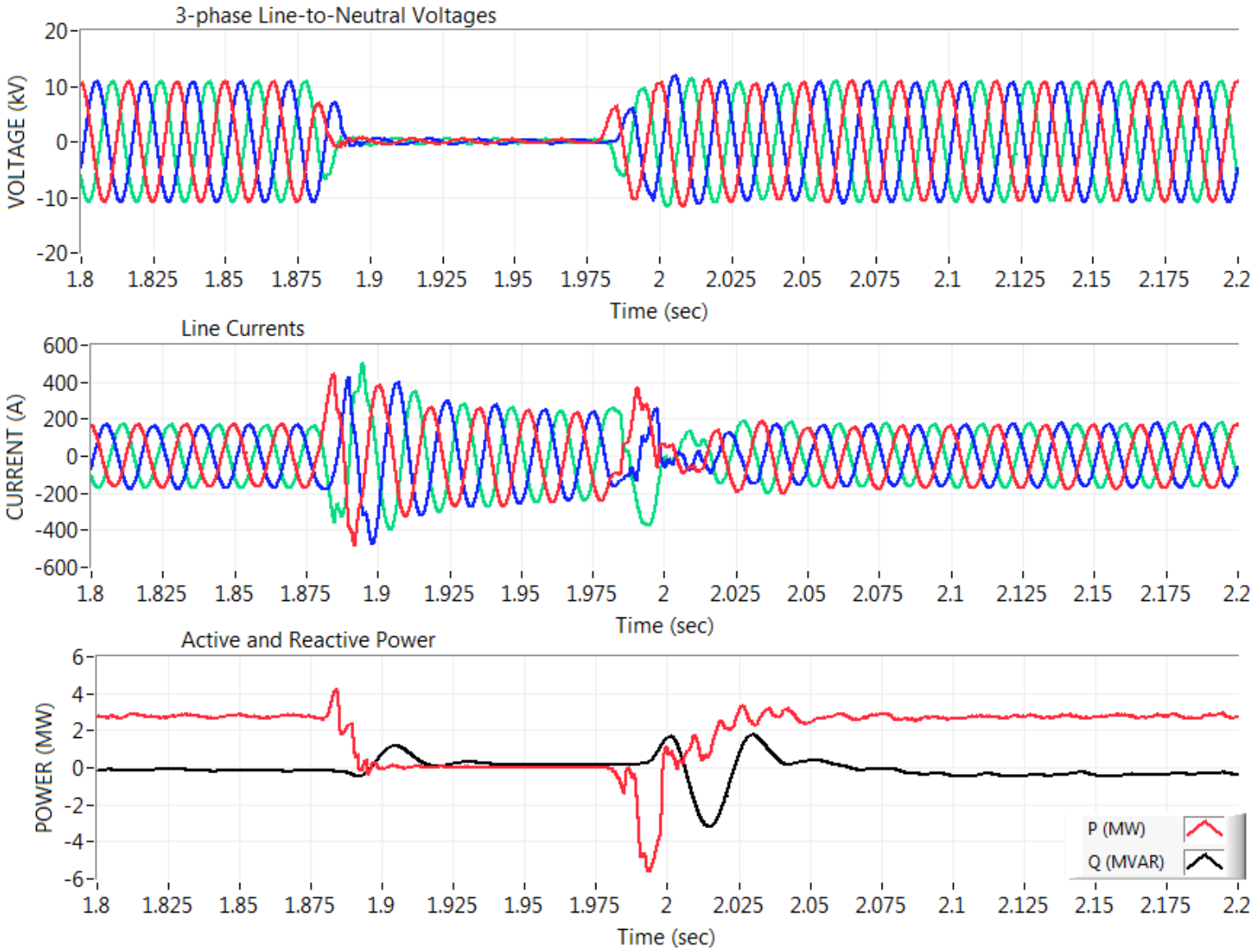
# Example Test Result: Single-Phase Fault Emulated on MV Terminals of 2.75-MW Wind Turbine



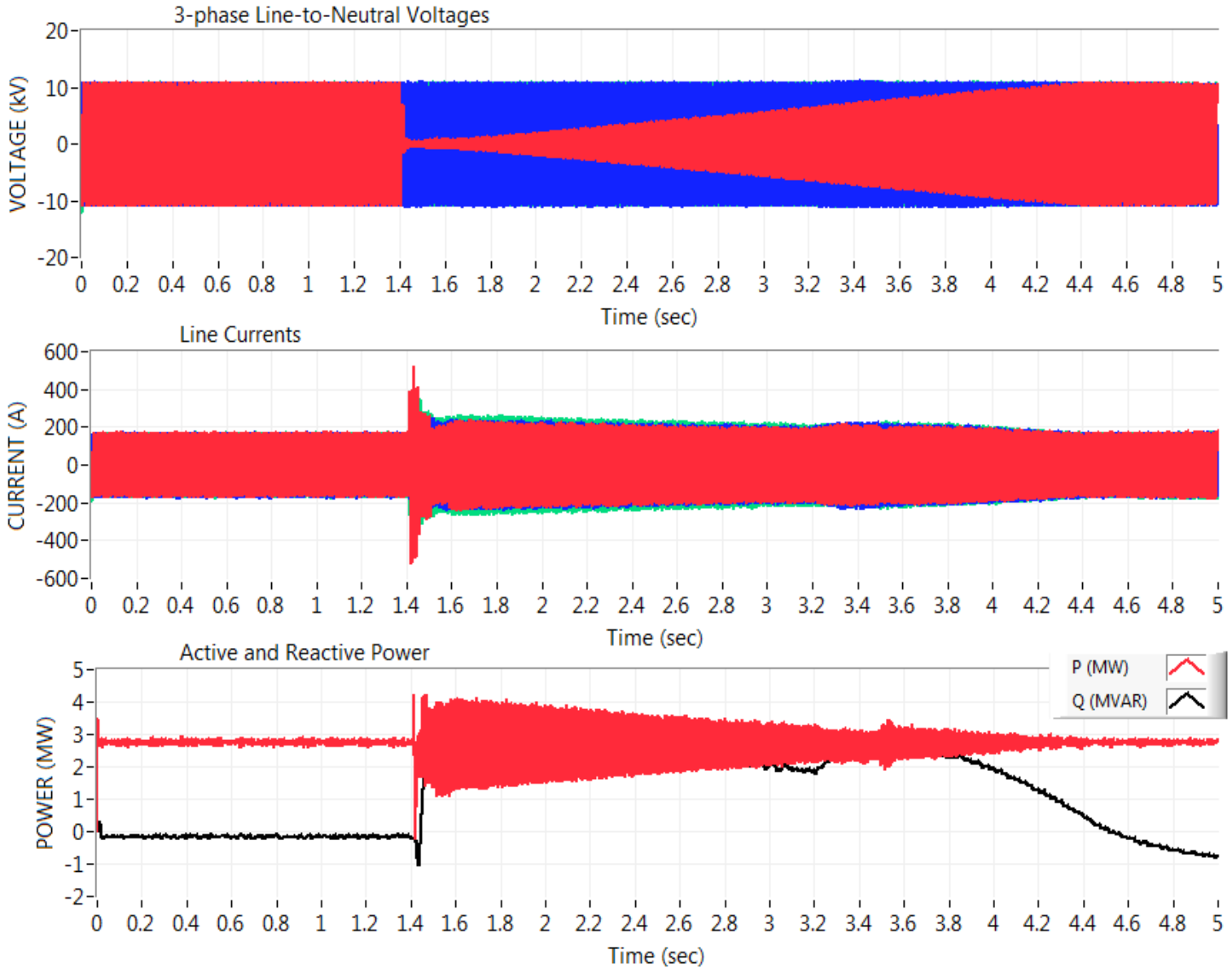
# Two-Phase Fault



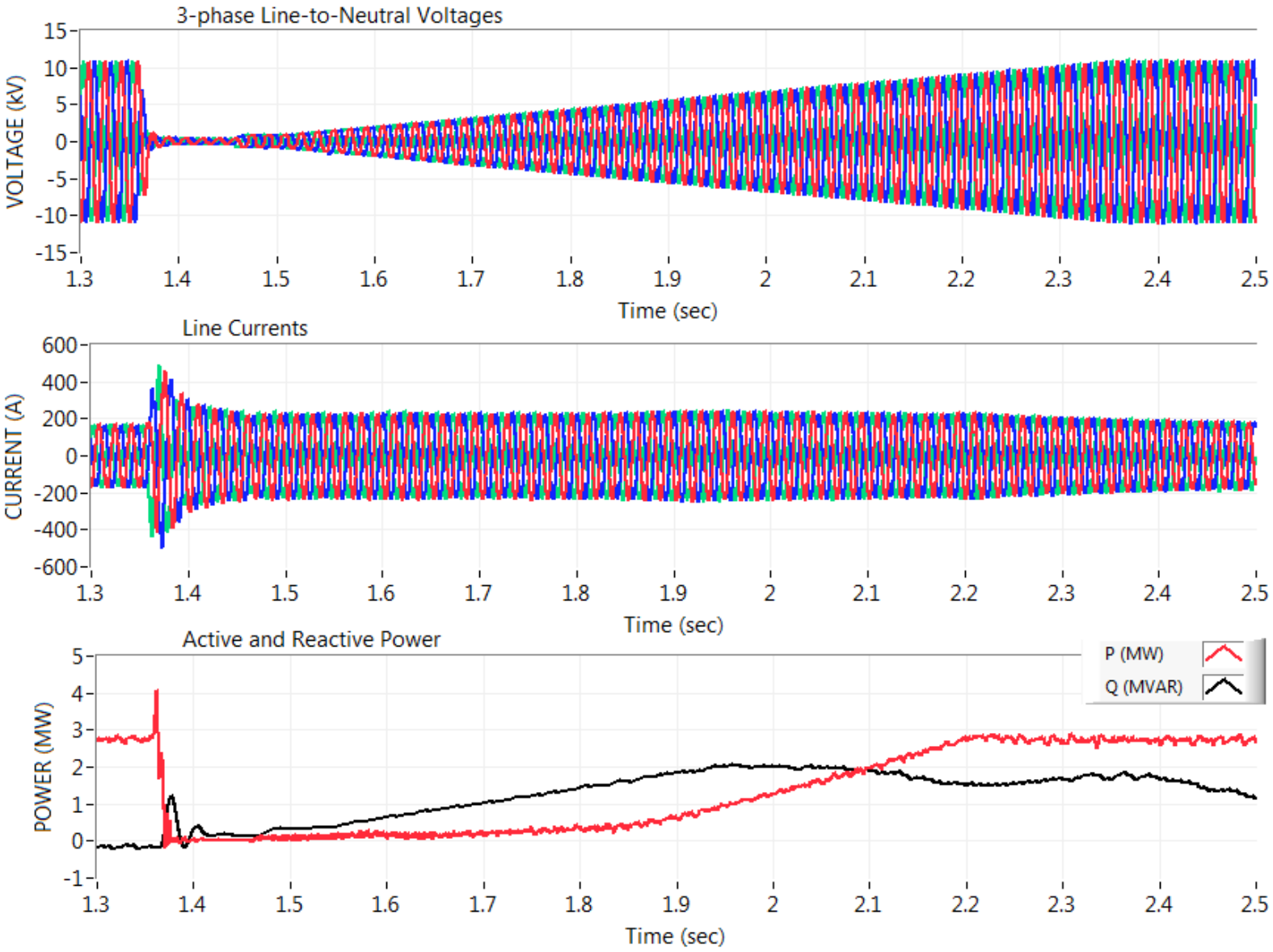
# Three-Phase Fault



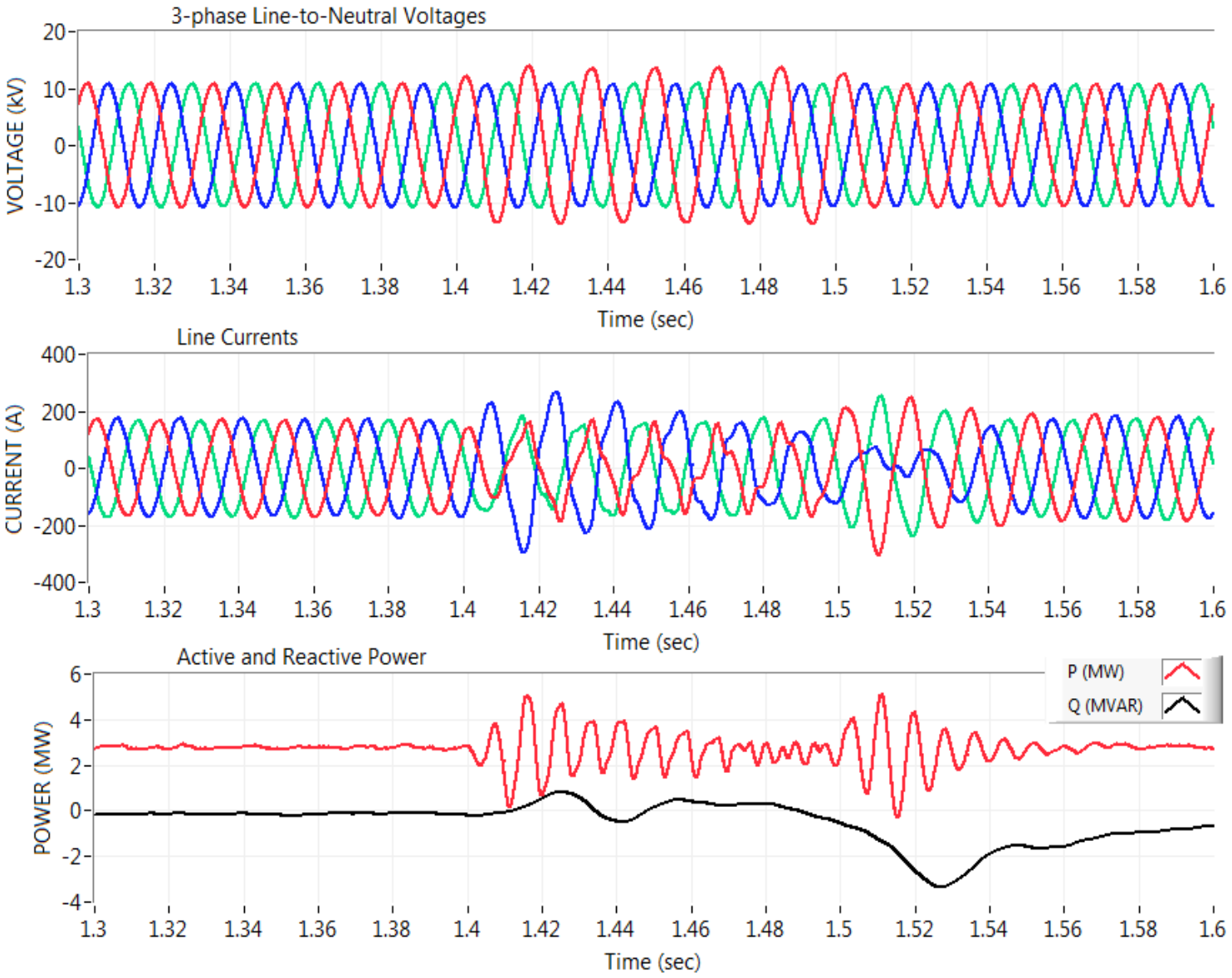
# Single-Phase Fault—Slow Recovery



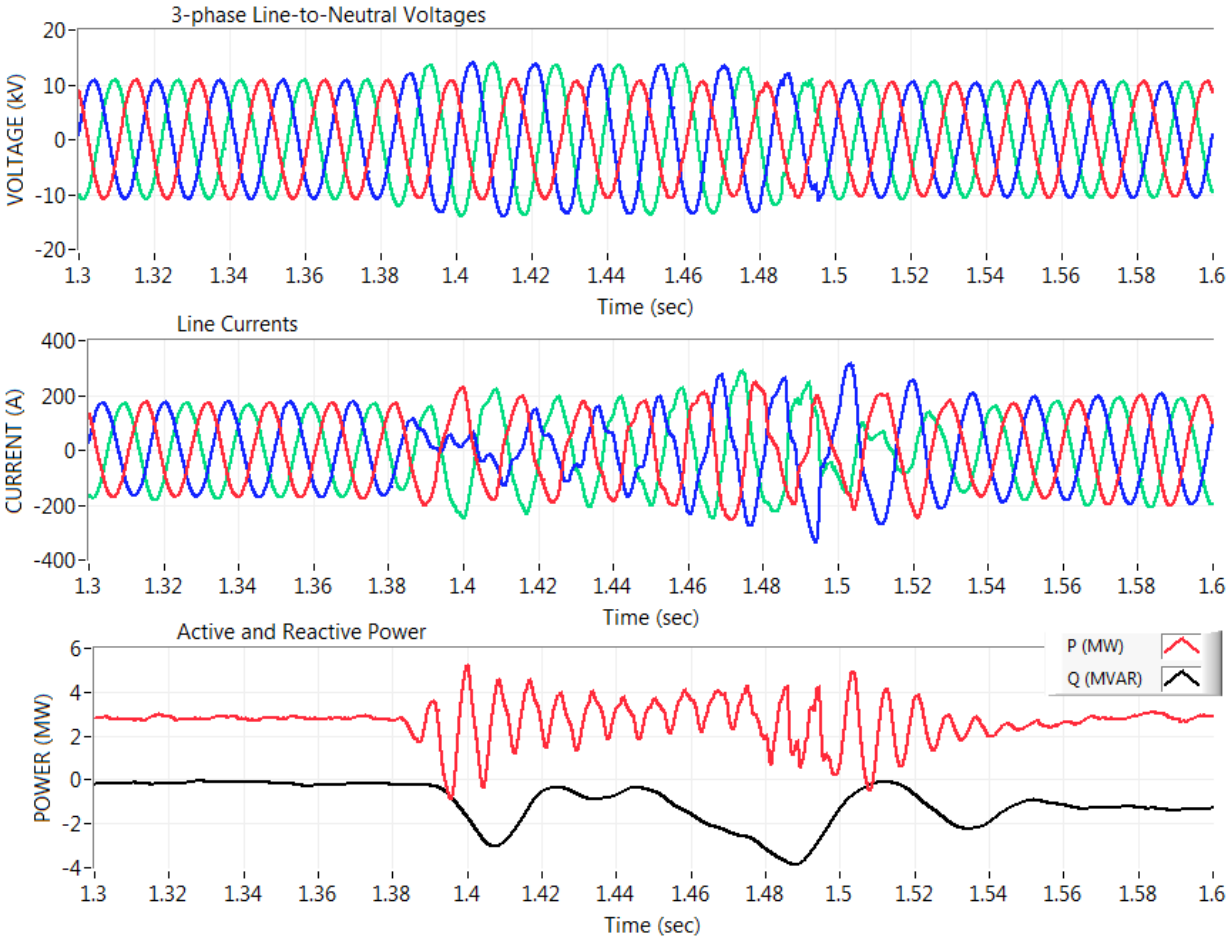
# Three-Phase Fault—Slow Recovery



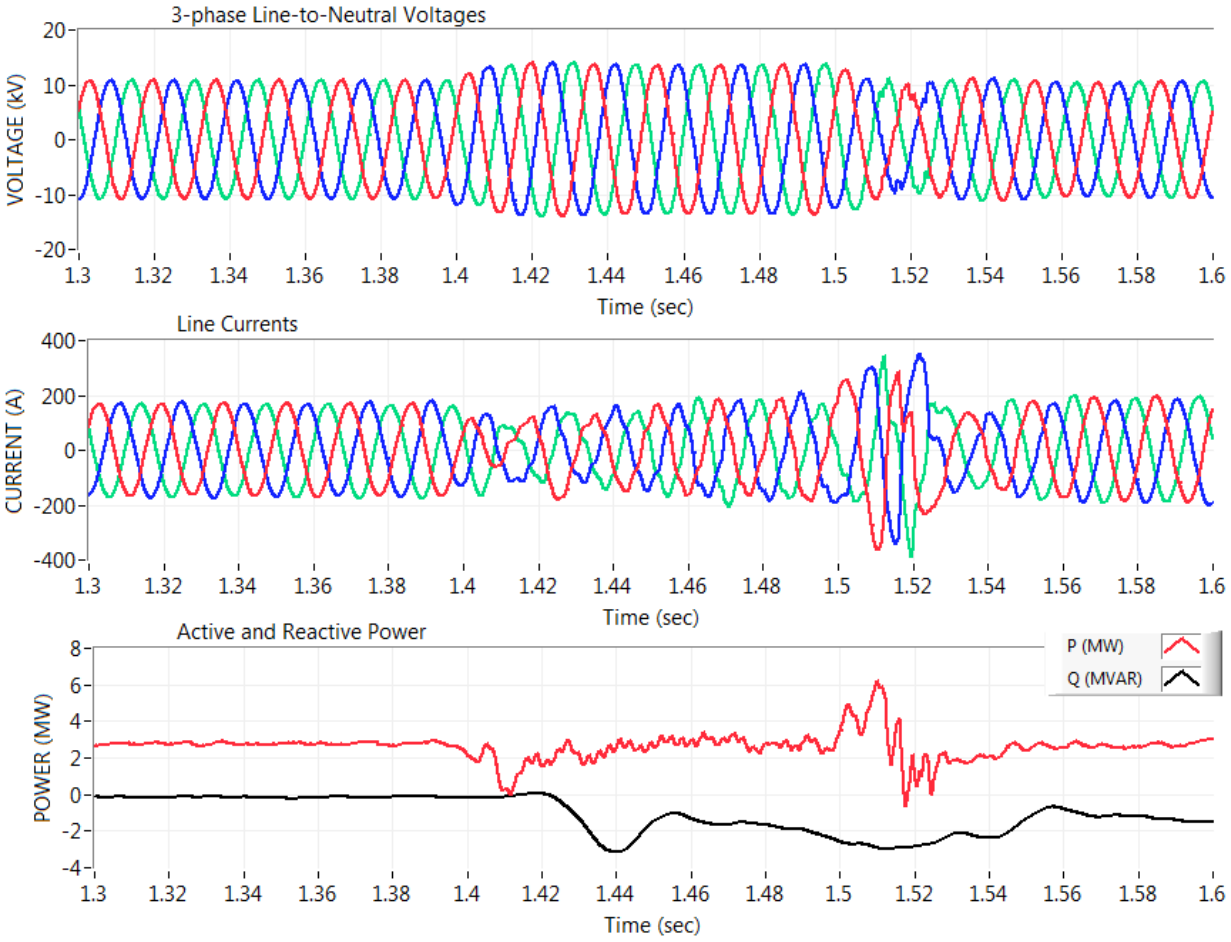
# Single Phase—130% Overvoltage



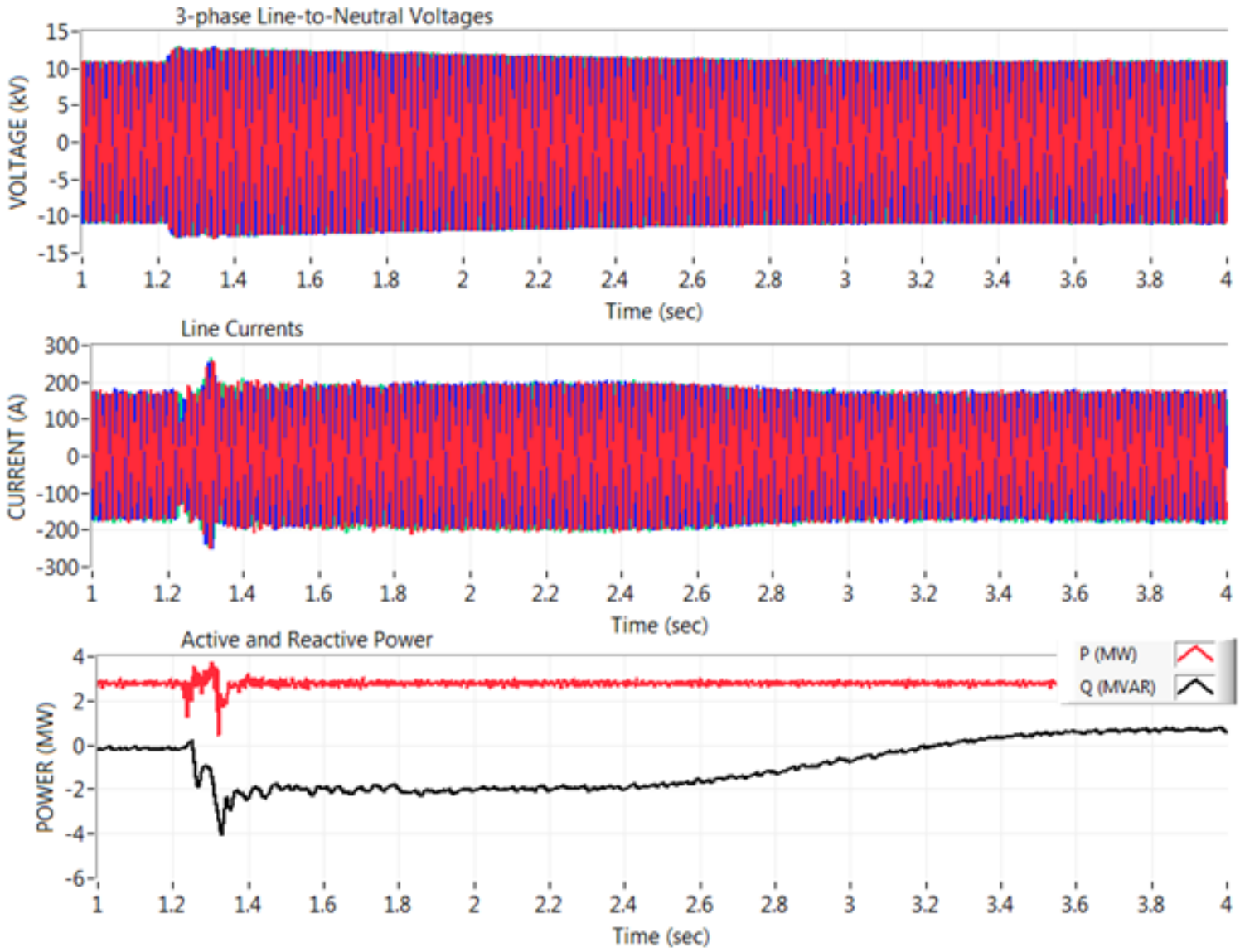
# Two Phase—130% Overvoltage



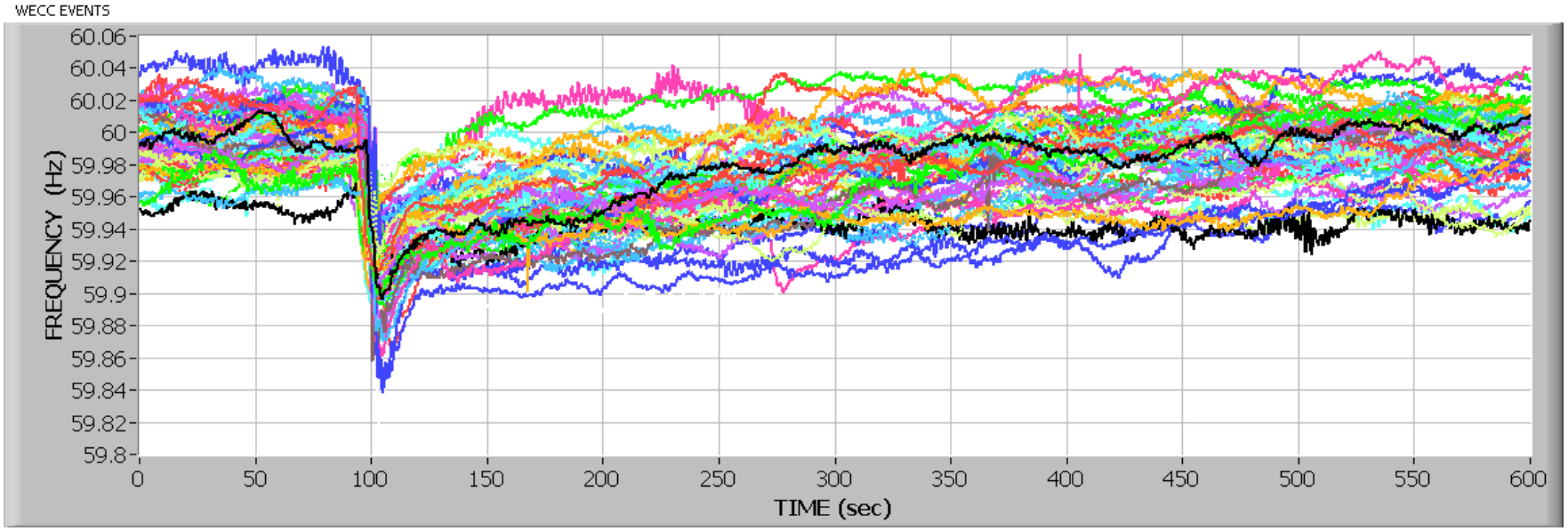
# Three Phase—130% Overvoltage

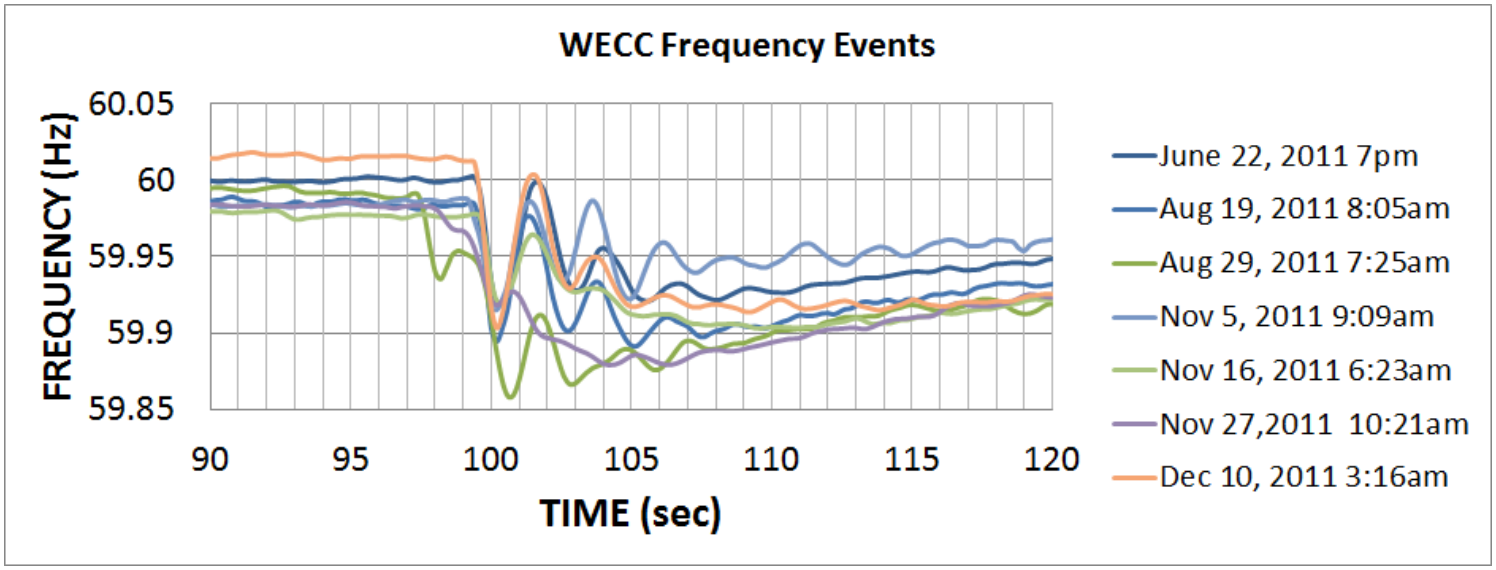


# Three Phase Overvoltage—Slow Recovery

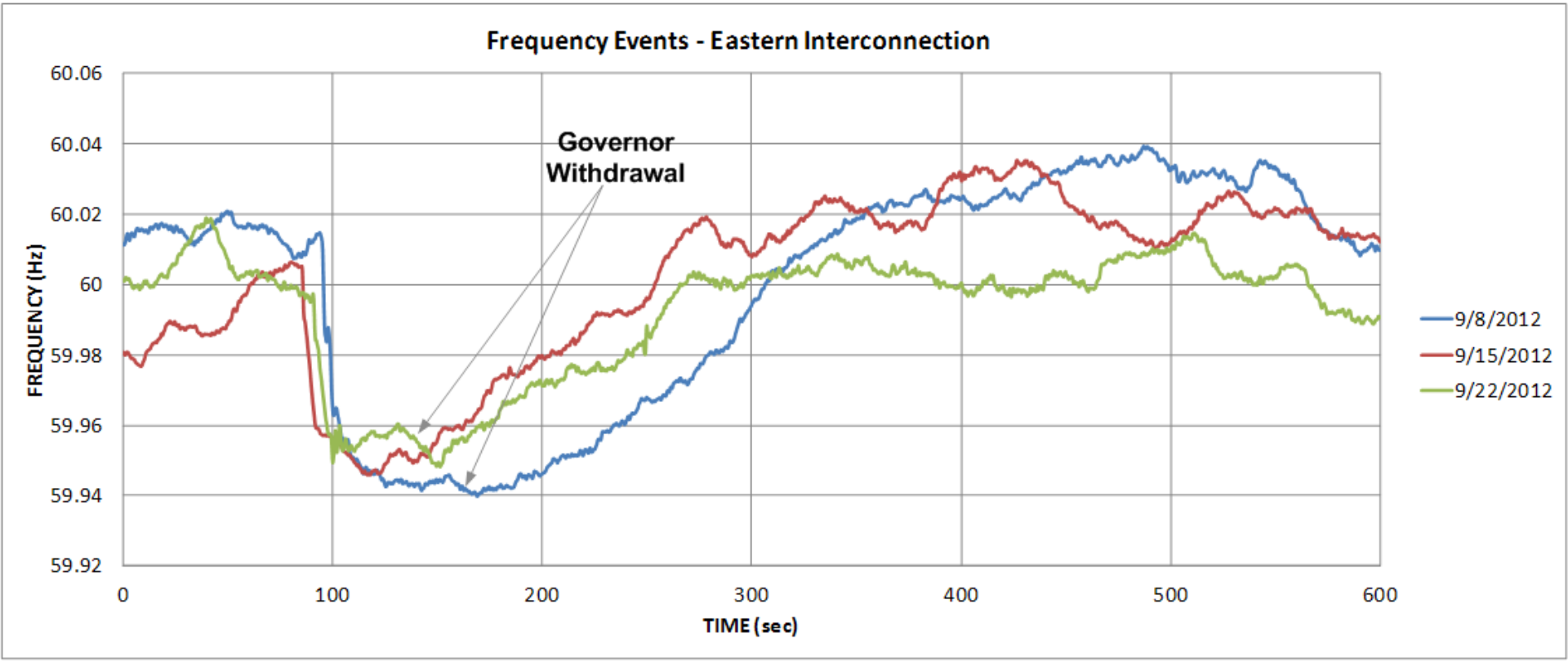


# Frequency Events in the Western Interconnection

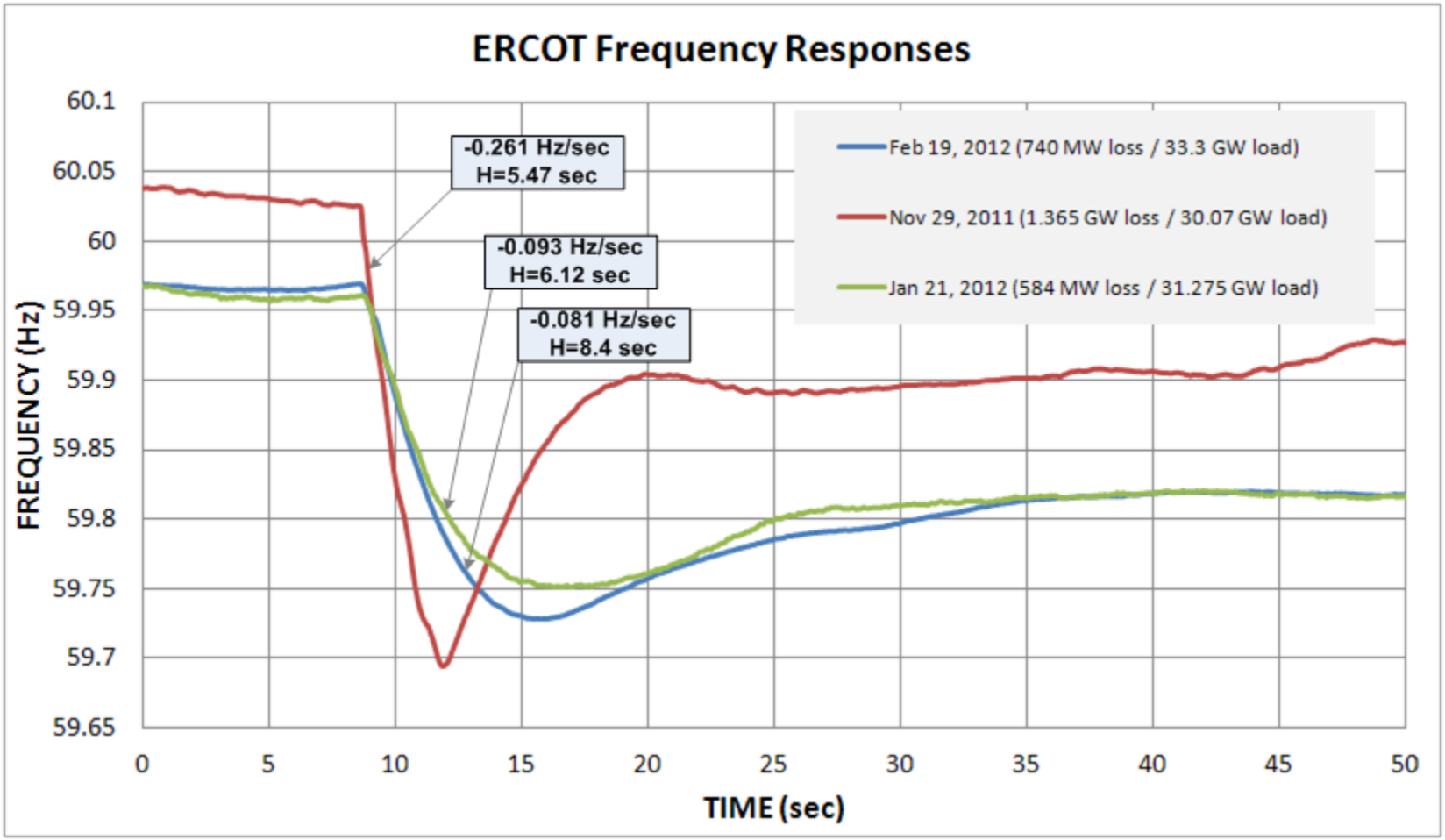


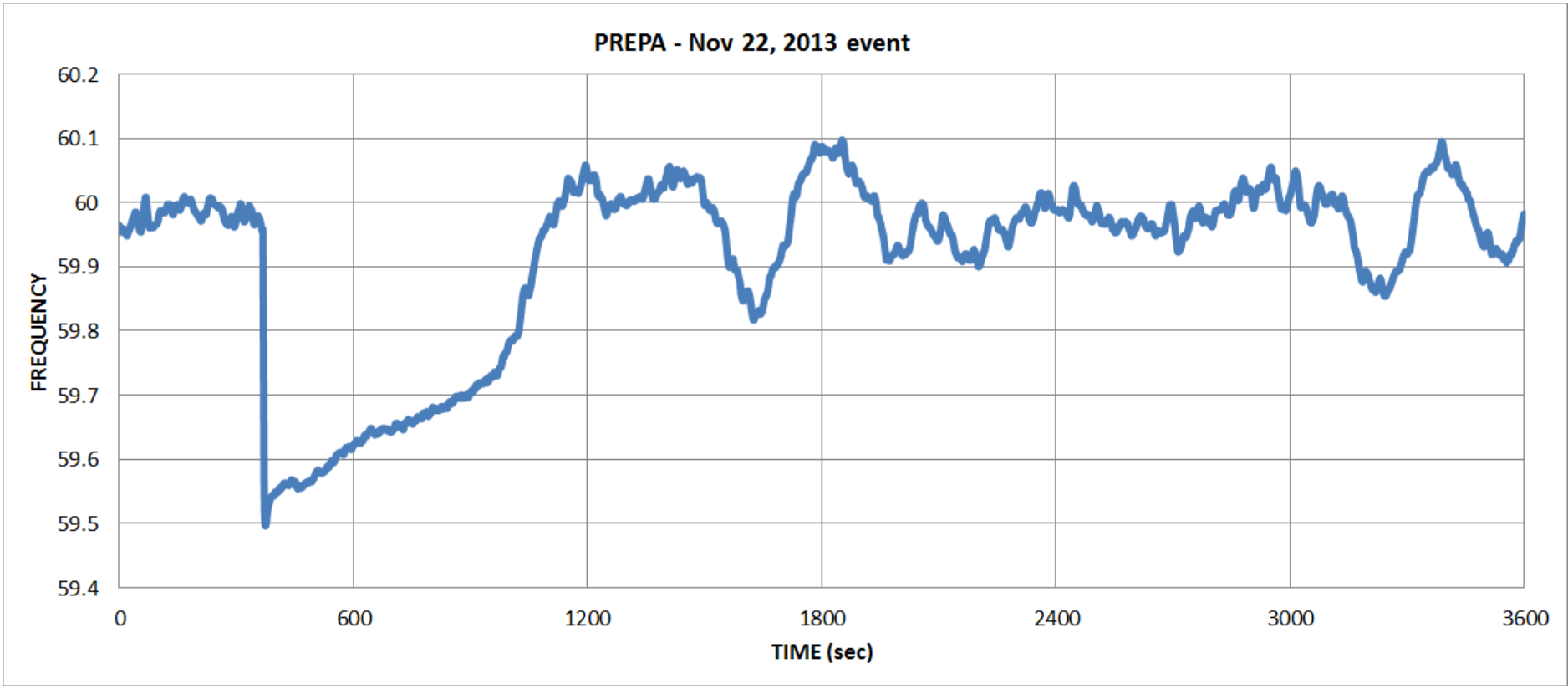
# Frequency Events in the Eastern Interconnection



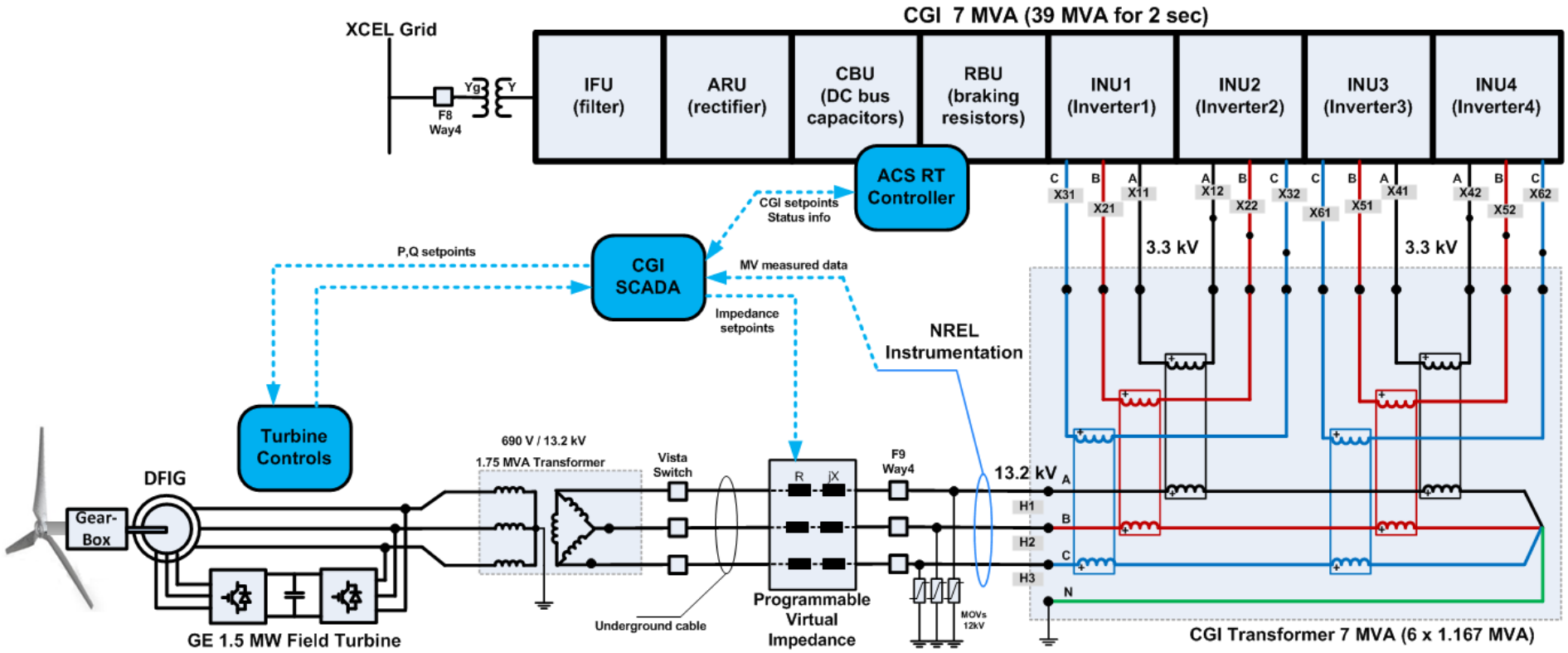
# Frequency Events in the Electric Reliability Council of Texas (ERCOT)



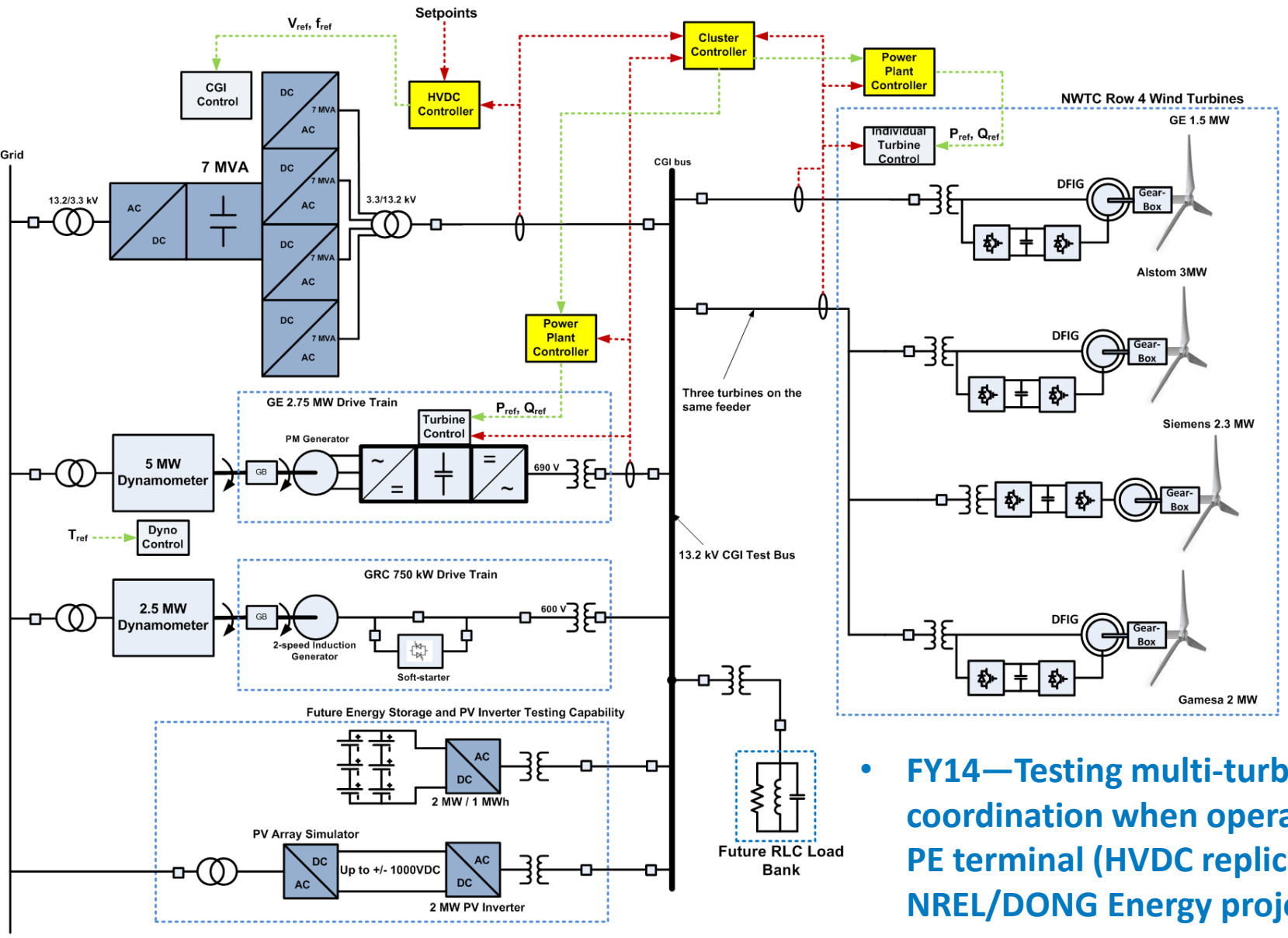
# Frequency Response of an Island Power System



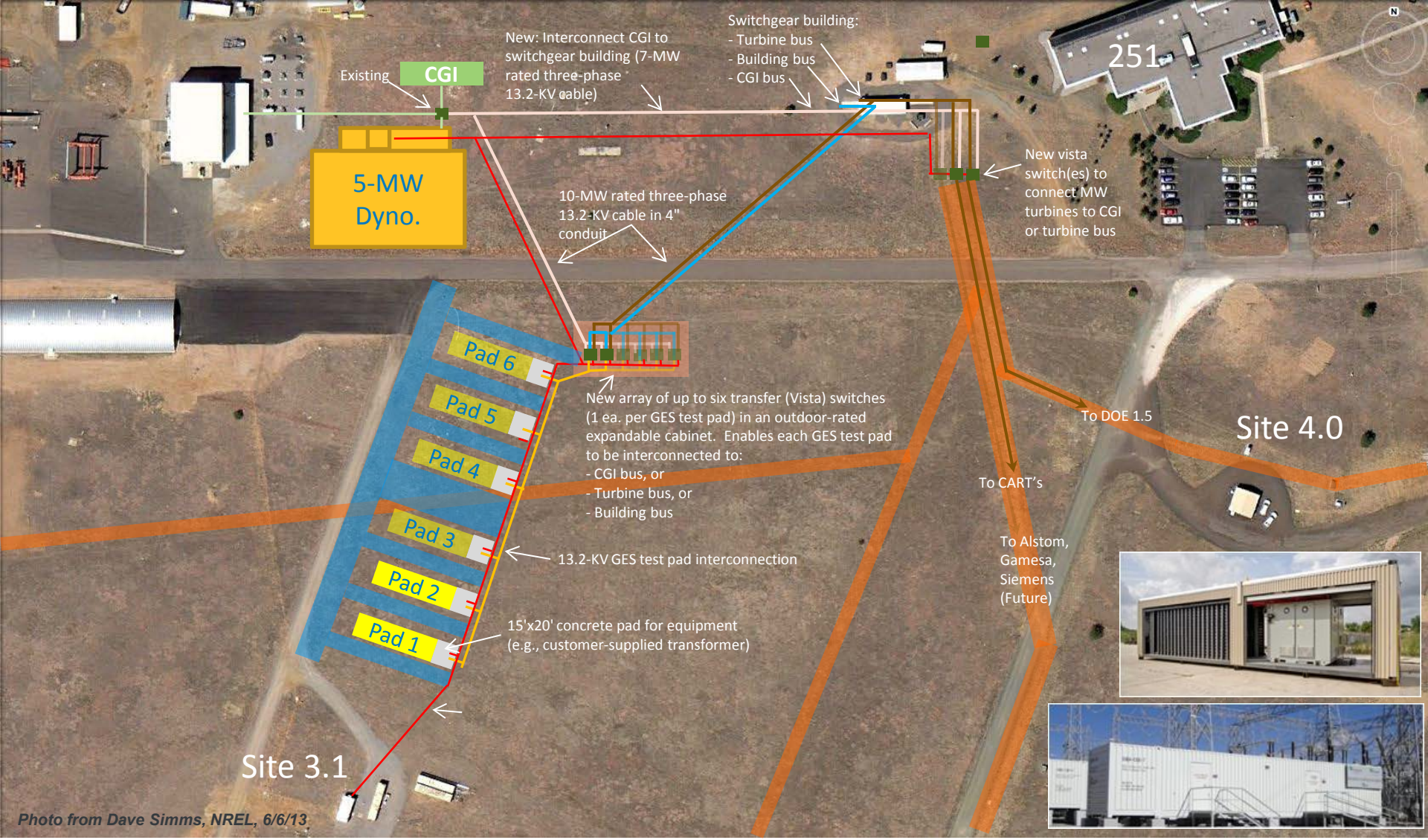
# GE 1.5-MW Field Turbine/CGI Interconnection



# FY14/15 Multi-Turbine Testing Project




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

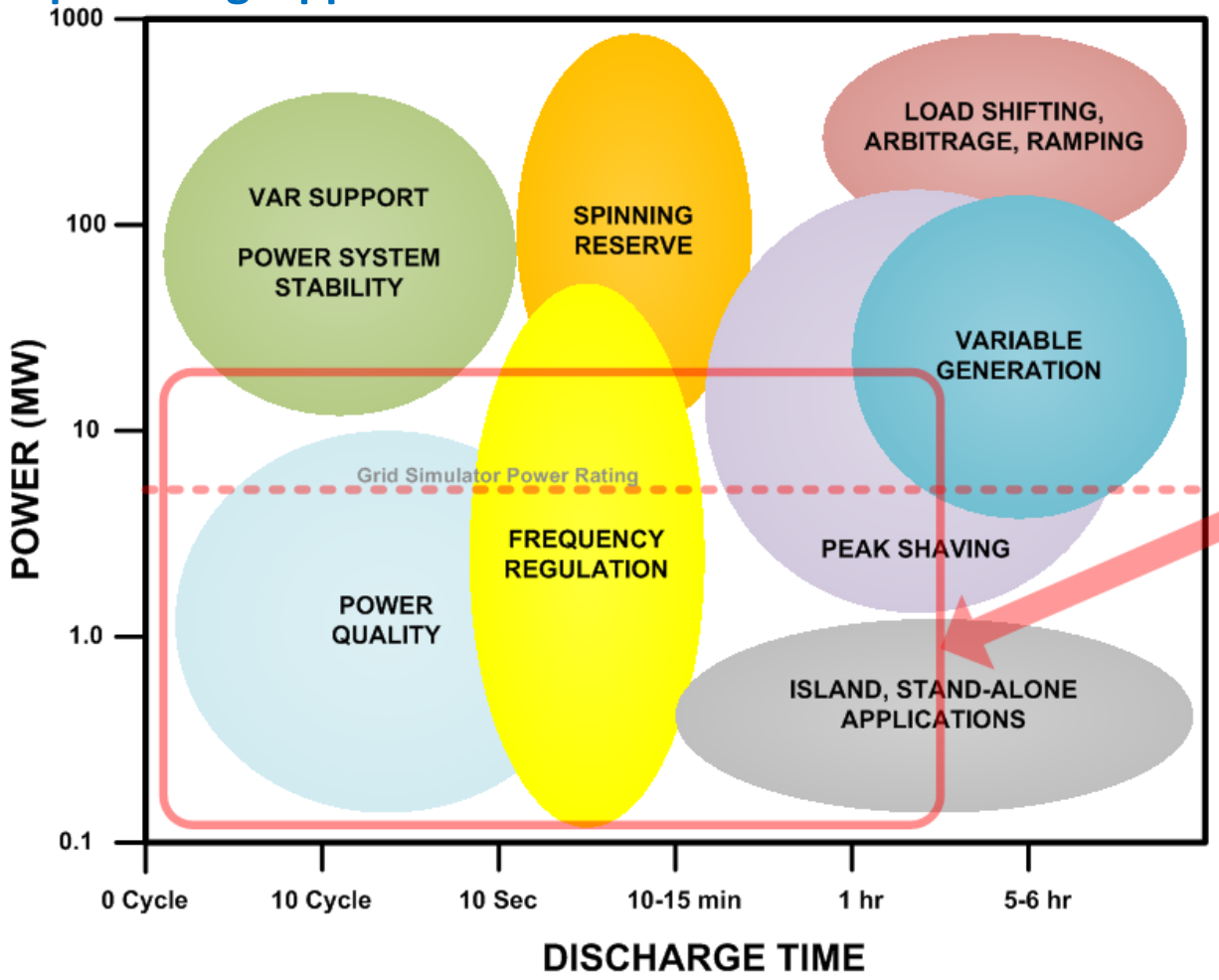



# Proposed Electrical and Facility Infrastructure for Grid Energy Storage (GES) Test Pads and Row 4 Turbine Interconnection to CGI

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

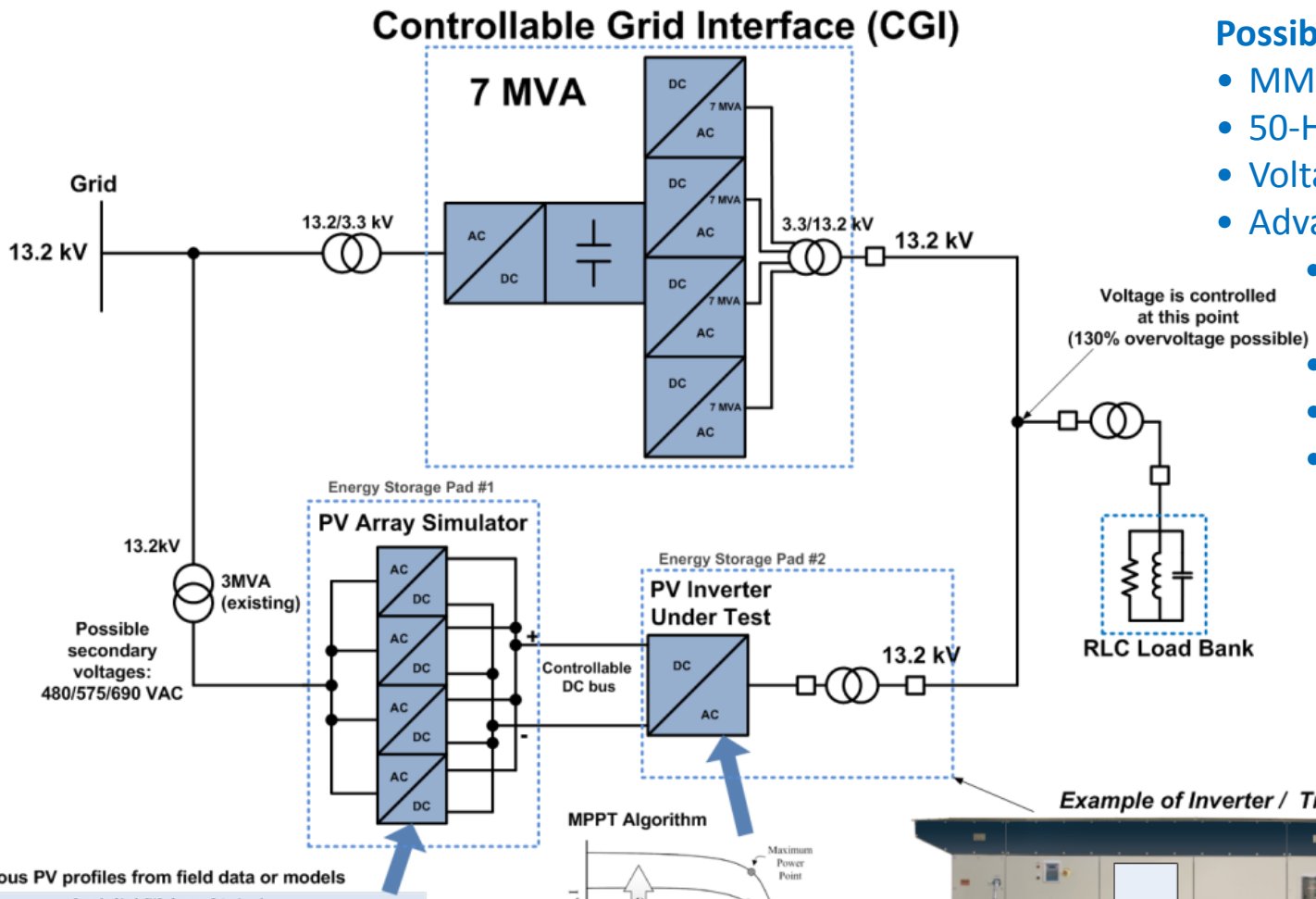
# Energy Storage Testing for Ancillary Services

- 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

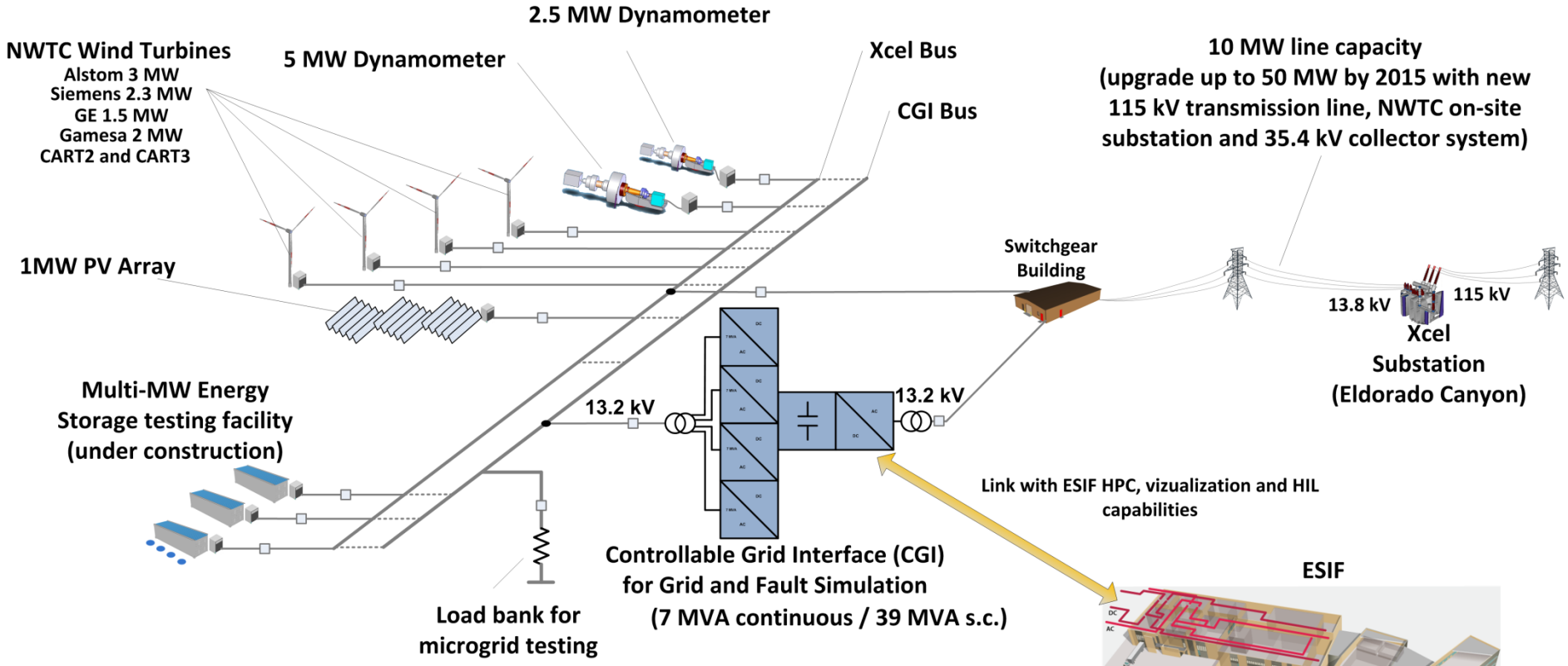



**Possible tests**

- 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

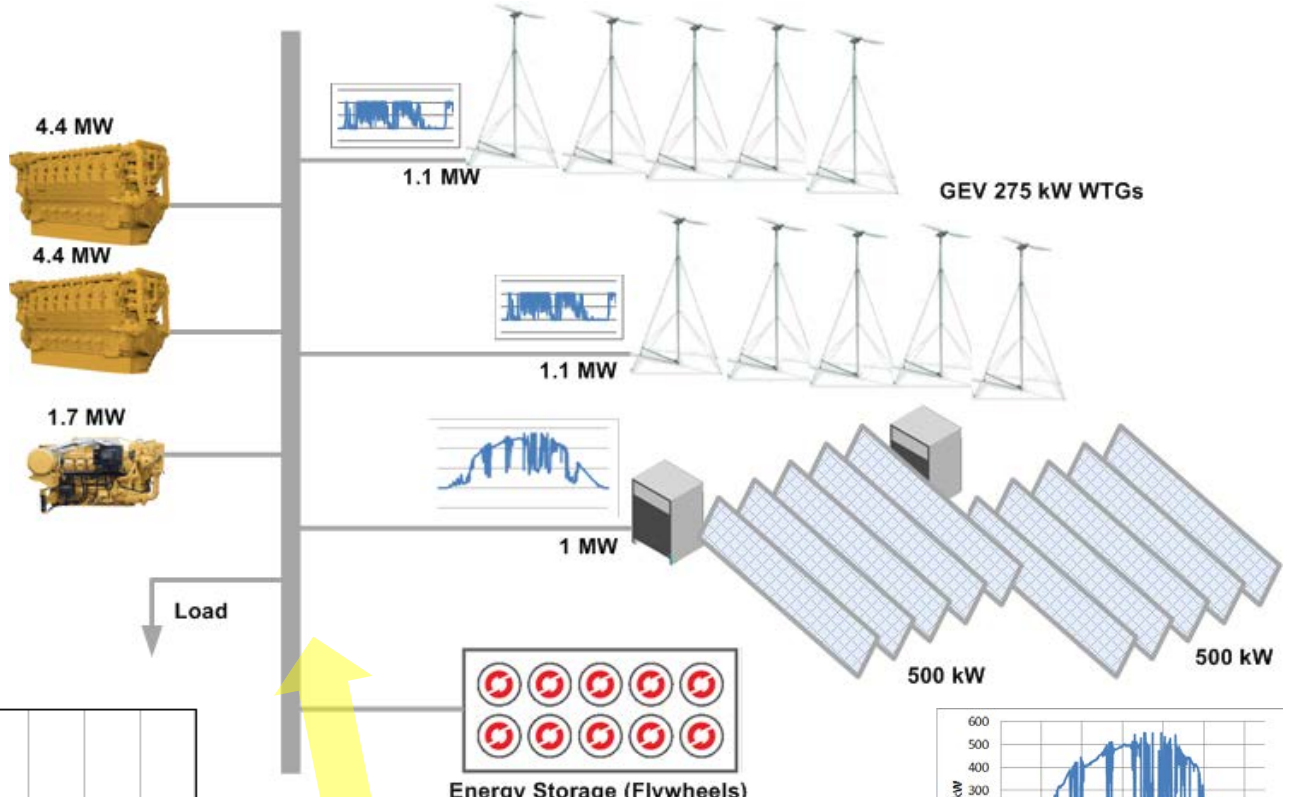
- Highly flexible and configurable system-level multi-MW testing/demonstration platform
- Most components in place and operational
- Energy storage testing facility to become on-line by the end of 2014

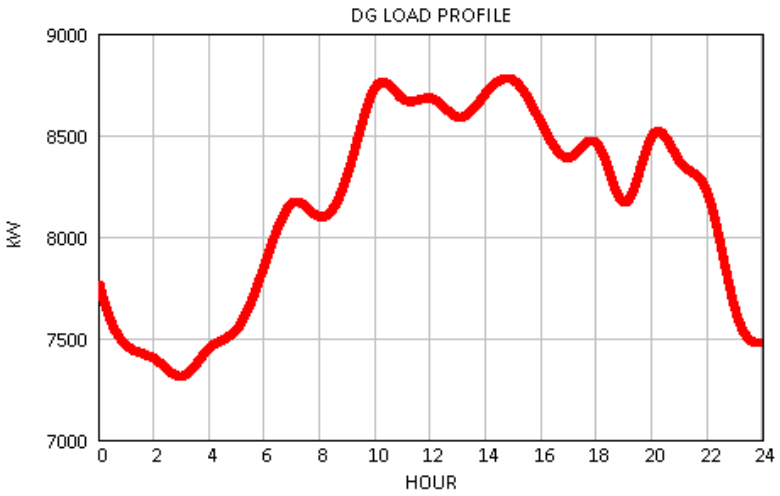



- Possible to test grid-connected generation
- Micro grids/EMS
- Combination of technologies/advanced controls

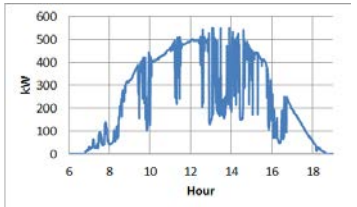
# Diego Garcia Wind/PV Integration Study—30% Case

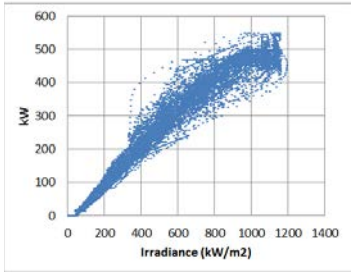
- Evaluate impacts of wind and PV on distributed generation grid reliability
- Estimate the size of energy storage
- Control strategies



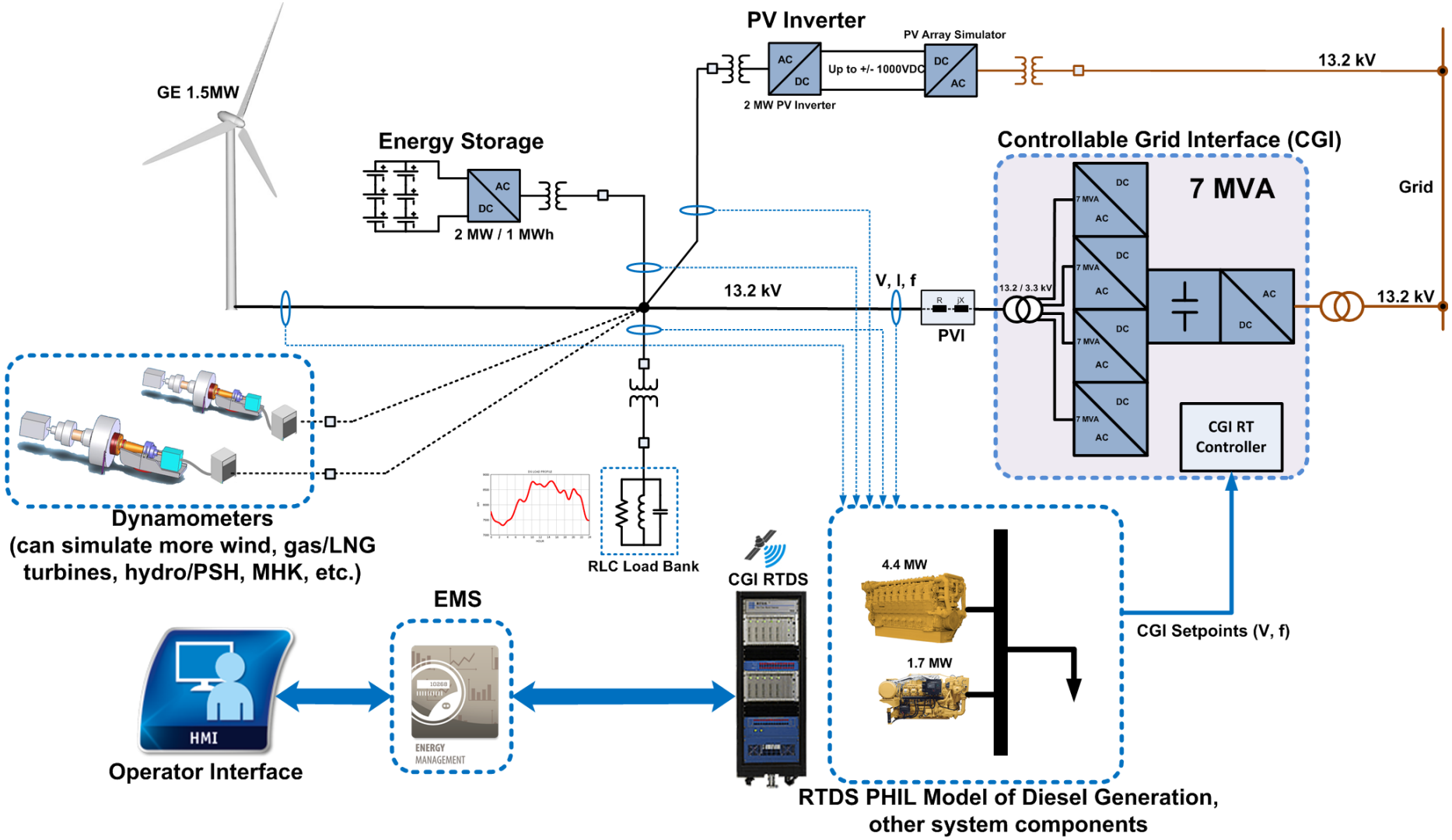




**A system like this can be replicated at the NWTC in full scale for CGI testing. (See next slide.)**

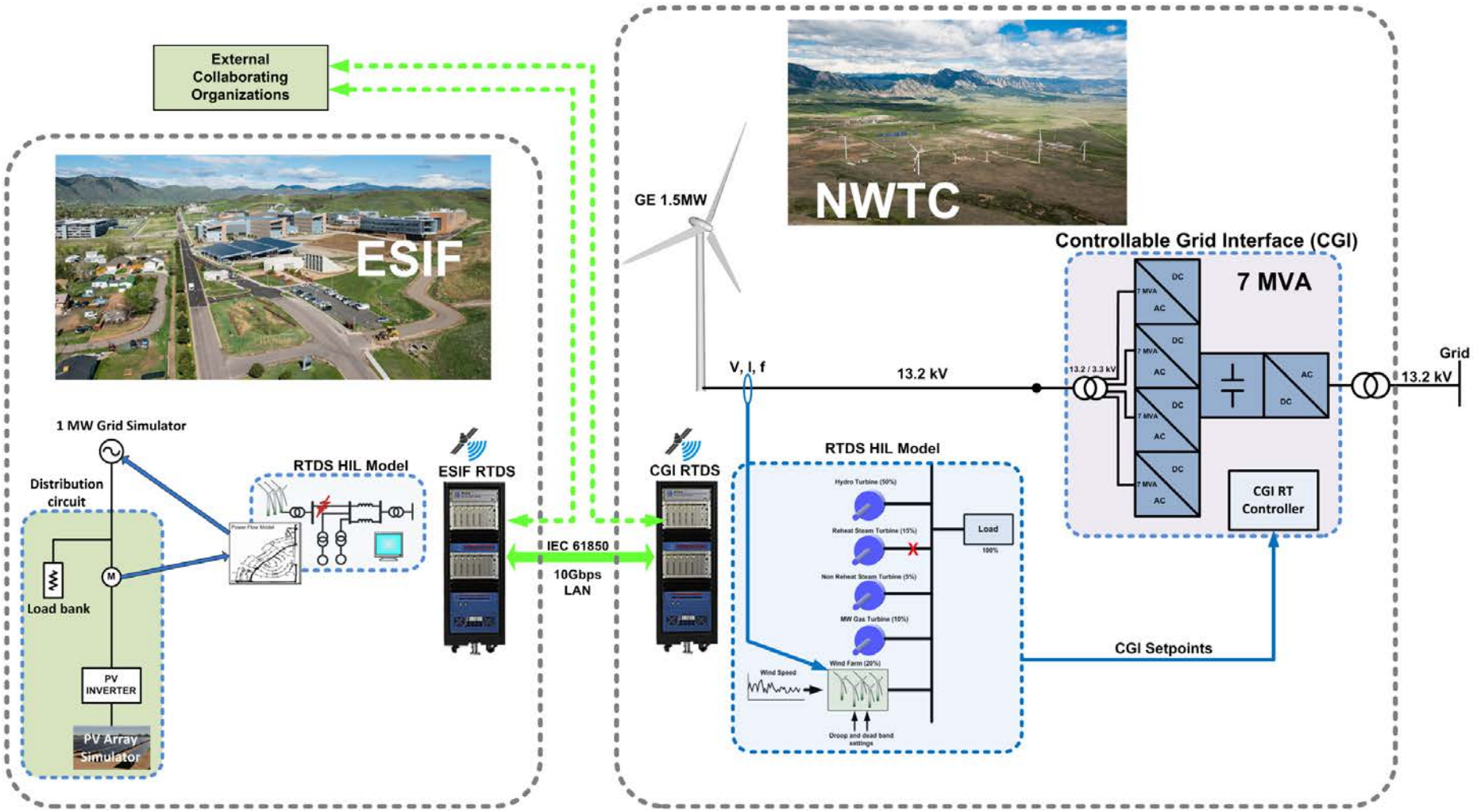


# NWTC CGI for Microgrid Testing

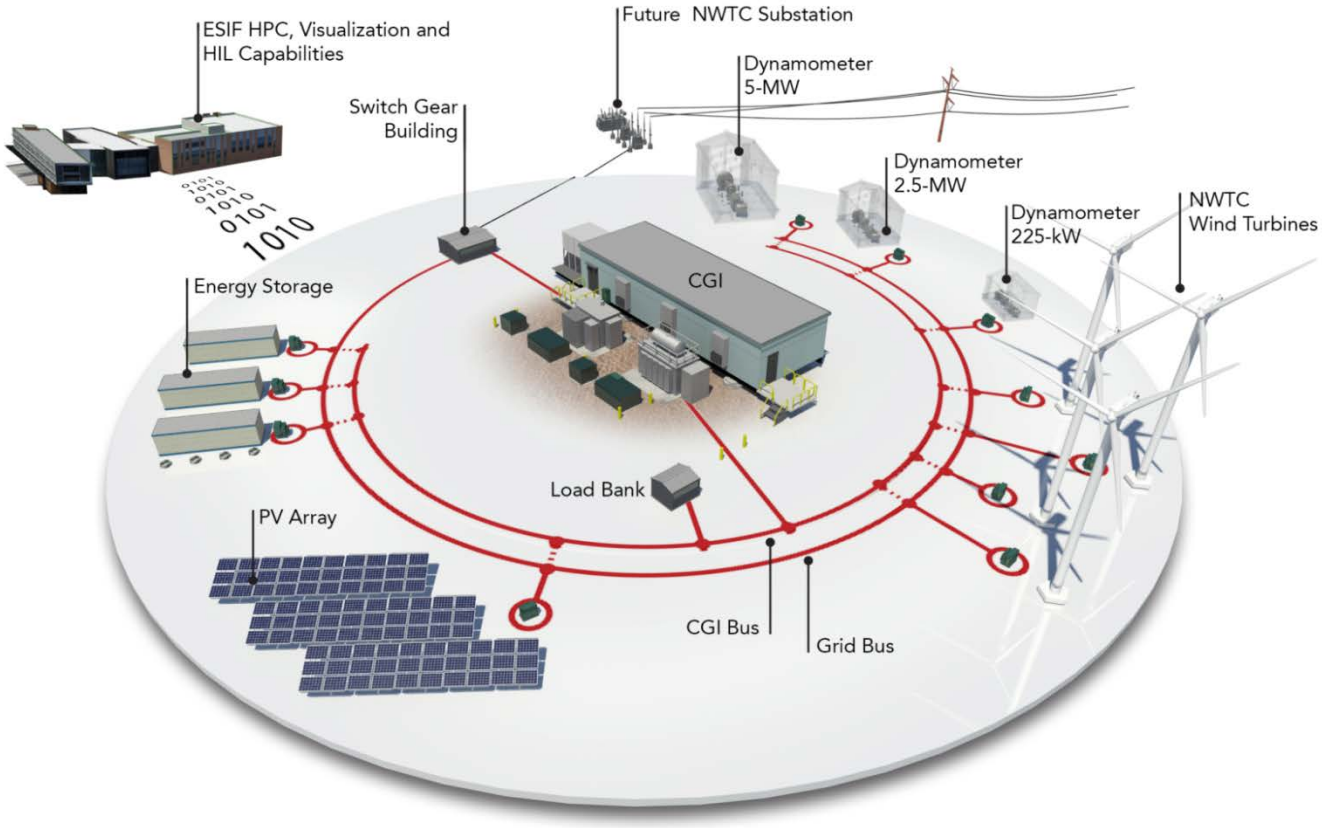


# NWTC/ESIF Real-Time Interconnection



# 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



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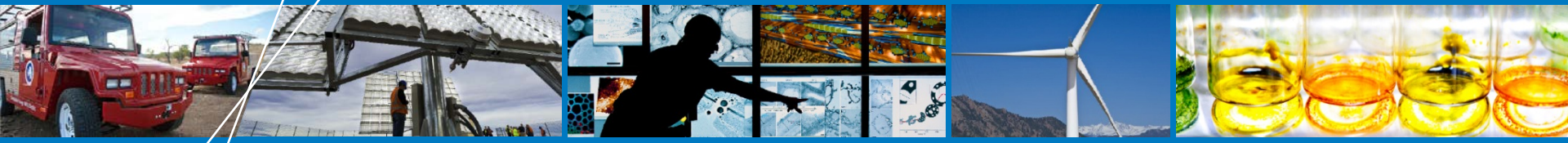

# Thank you.

# Questions?