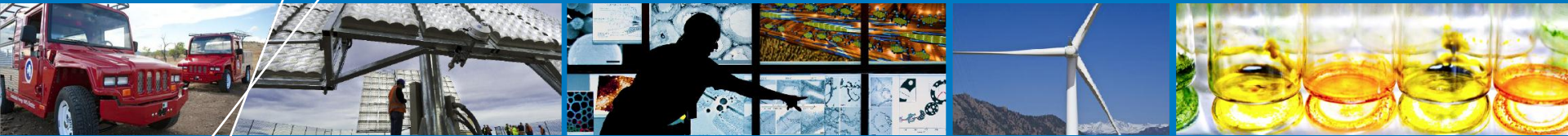# National Wind Technology Center Controllable Grid Interface
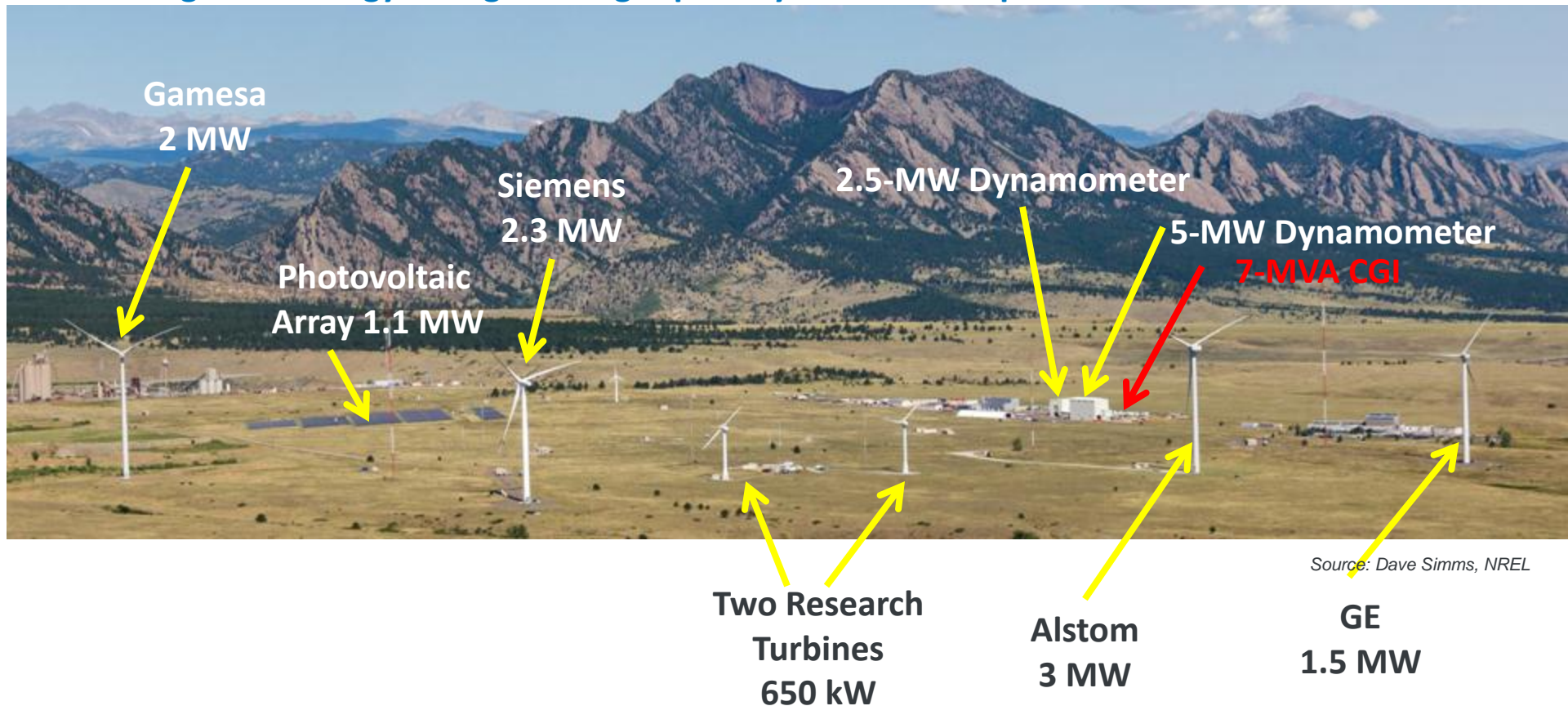
Vahan Gevorgian

June 13, 2013

NWTC Test Site

- **Total of 11 MW of variable renewable generation currently at the National Wind Technology Center (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**

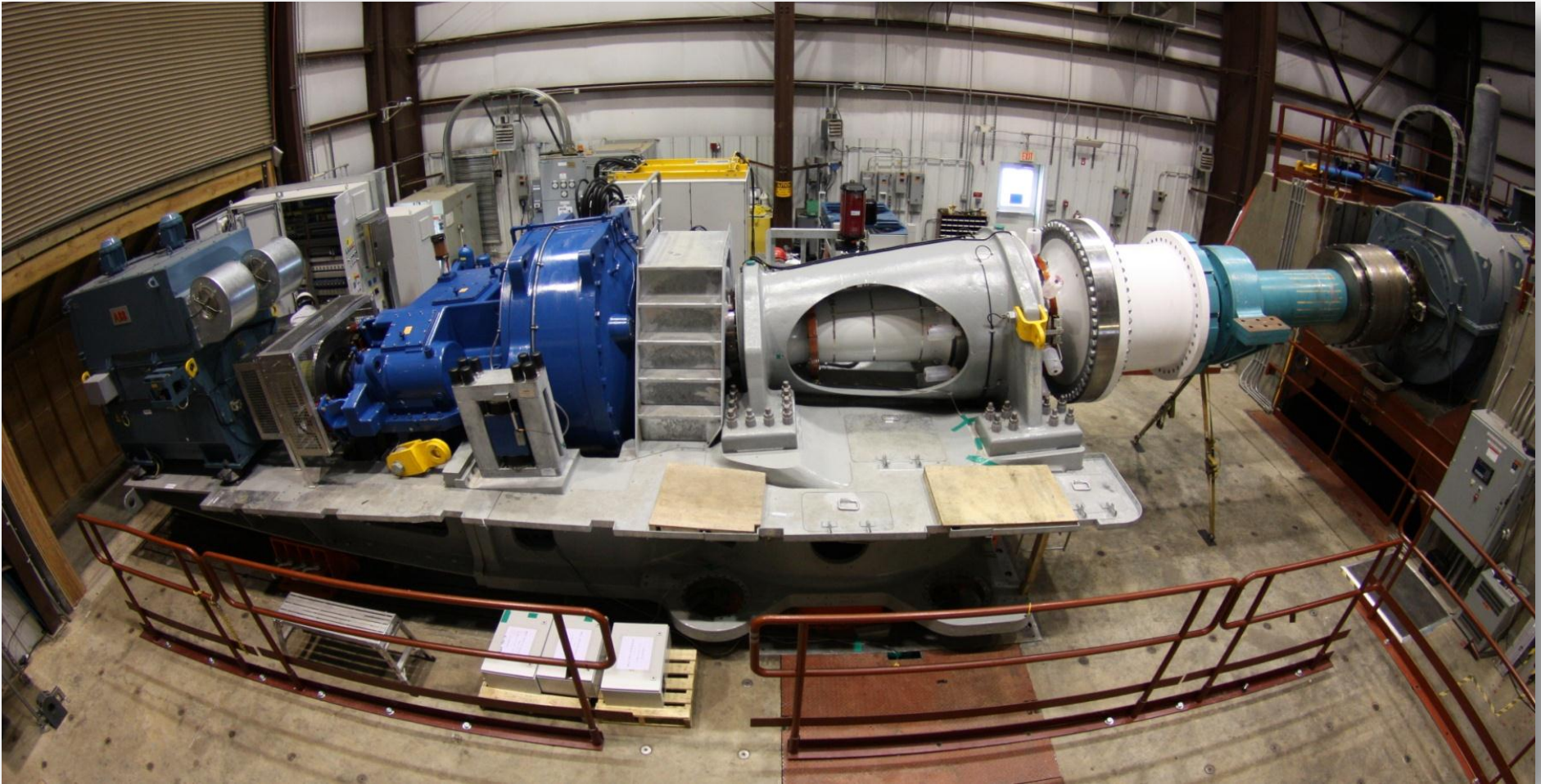Gamesa 2 MW · Photovoltaic Array 1.1 MW · Siemens 2.3 MW · 2.5-MW Dynamometer · 5-MW Dynamometer · 7-MVA CGI · Two Research Turbines 650 kW · Alstom 3 MW · GE 1.5 MW

Source: Dave Simms, NREL

2.5-MW Dynamometer Facility

Photo by

New 5-MW Dynamometer

Drive Motor

Gearbox

Non-Torque Loading System

High-Speed Shaft

Low-Speed Shaft

Adaptor Flange

Auxiliary Hydraulic Equipment

Test Article Bed Plates
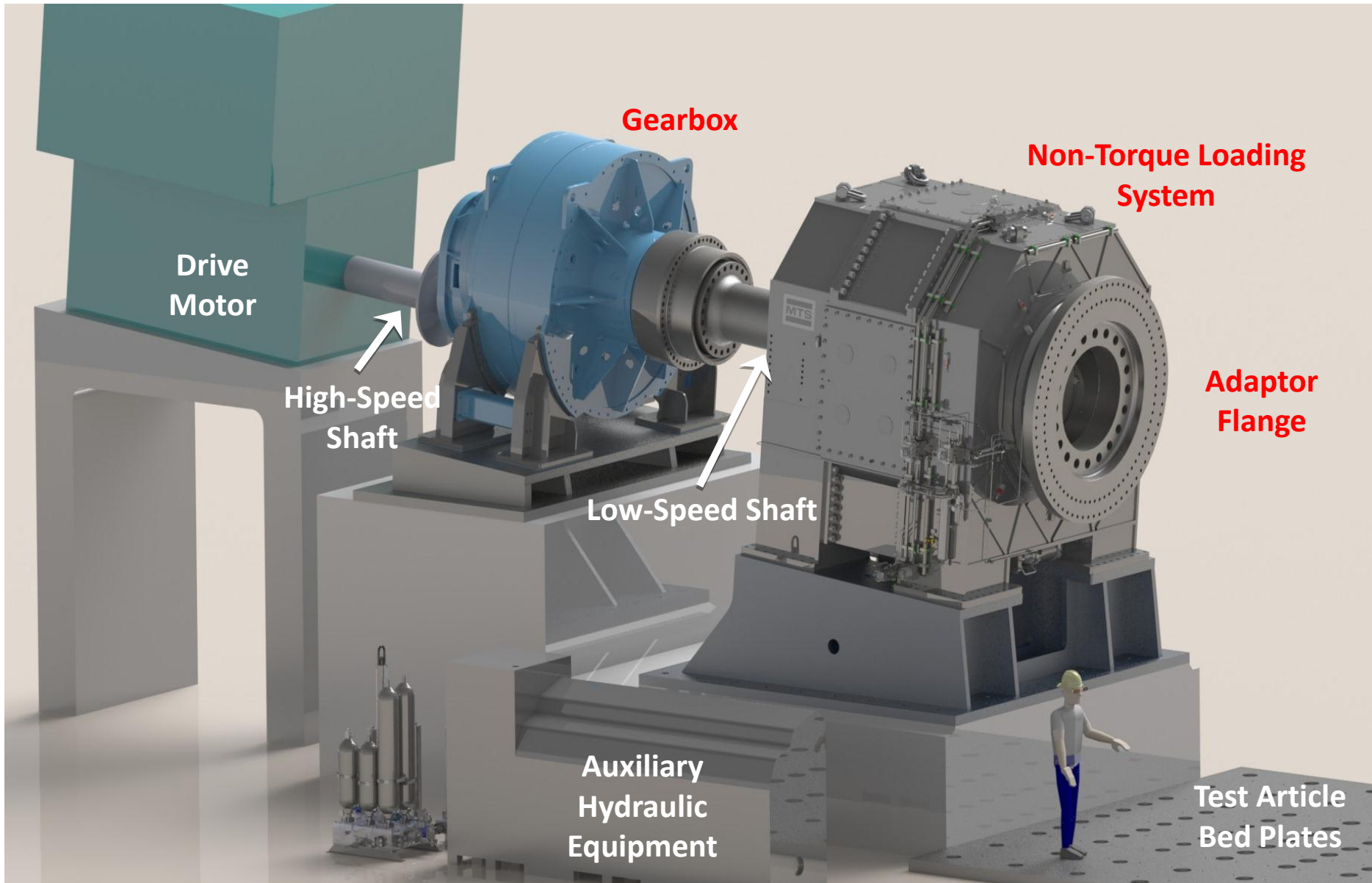
CGI Facility Status

- **Installed at NWTC test site in November 2012**
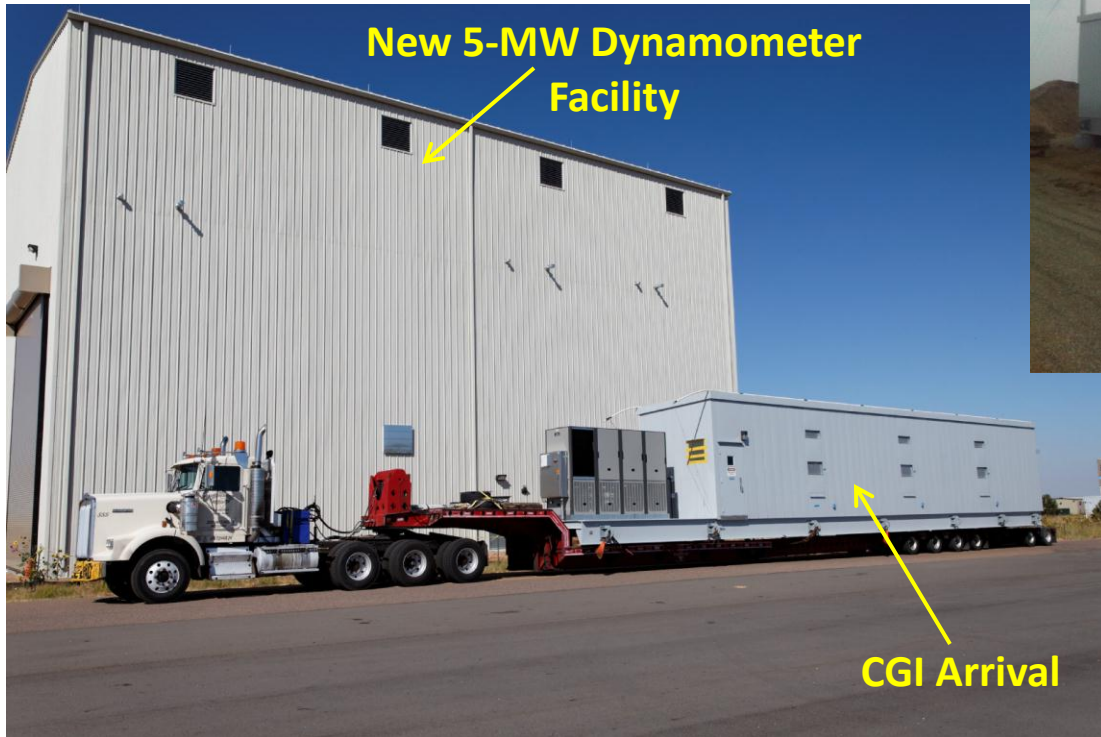- **Commissioning and initial testing is scheduled from April 2013 to September 2013**

New 5-MW Dynamometer Facility

CGI Arrival

Photo by Mark McDade, NREL

CGI Installed on Foundation

Photo by Mark McDade, NREL

CGI Main Technical Characteristics

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

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 (LVRT, 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
- Real Time Digital Simulator/hardware-in-the-loop (HIL) capable

Controllable Grid Interface (CGI)
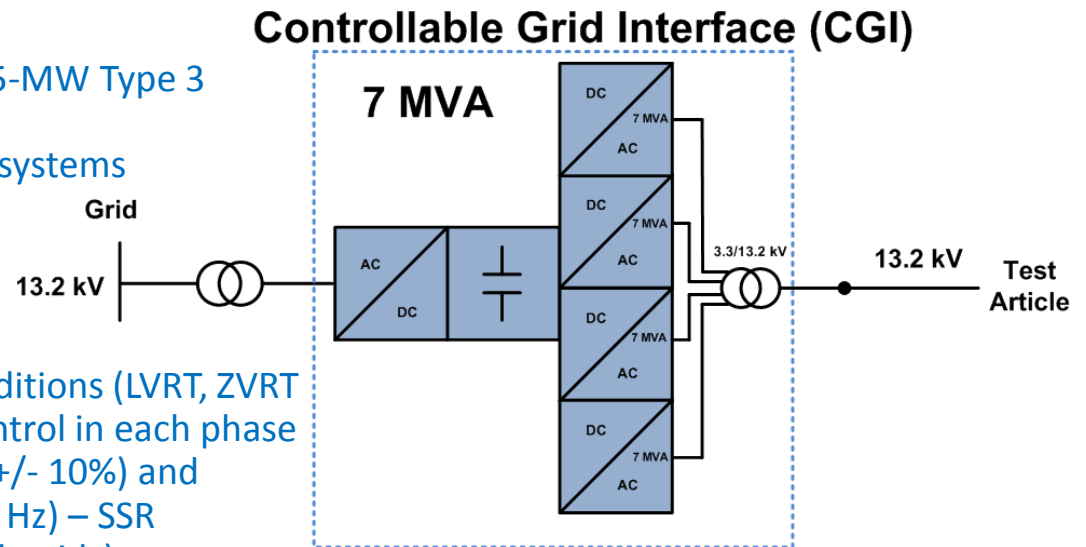
Power electronic grid simulator based on three-level VSC VFD technology (ABB ACS 6000 module – same hardware used in NWTC 5-MW dynamometer)

CGI Design Allows Testing for All Fault Ride-Through Requirements
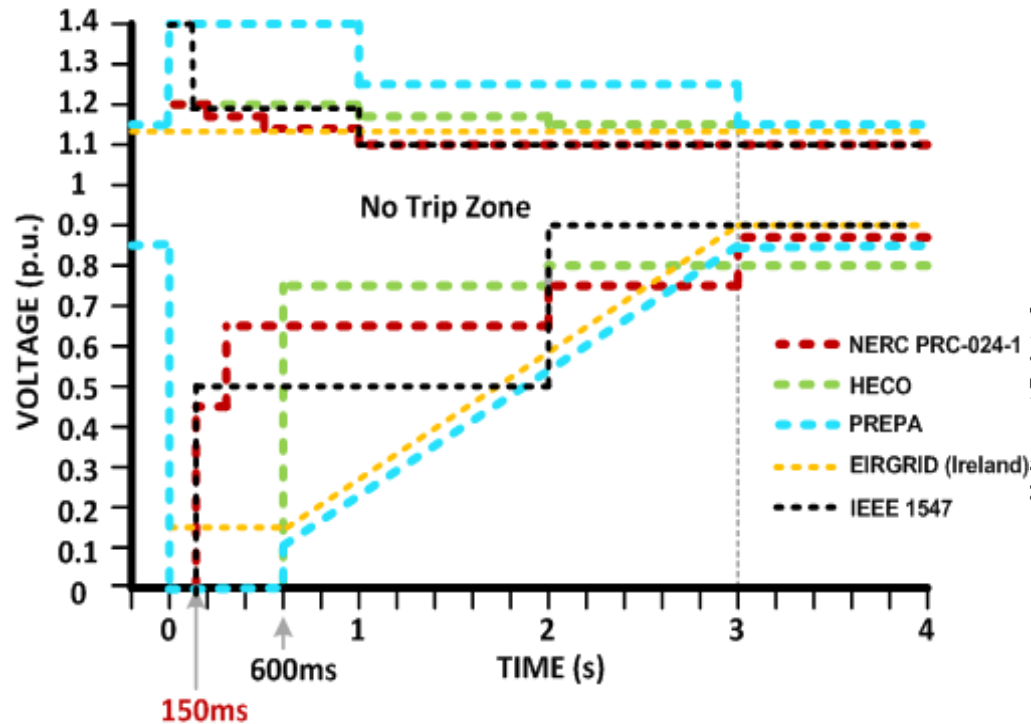
Federal Energy Regulatory Commission Low-Voltage Ride-Through Requirements (Order 661-A)

Legend:
- NERC PRC-024-1
- HECO
- PREPA
- EIRGRID (Ireland)
- IEEE 1547
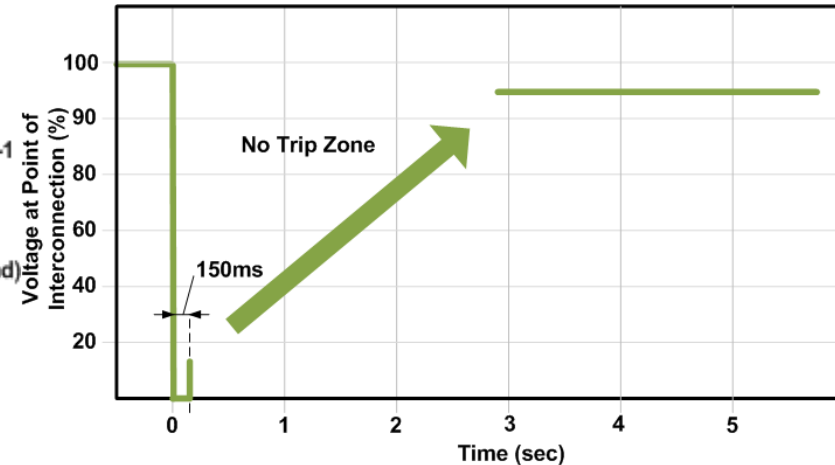
IEC Low-Voltage Ride-Through Testing

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

Recreation of Frequency Events

Eastern Interconnection
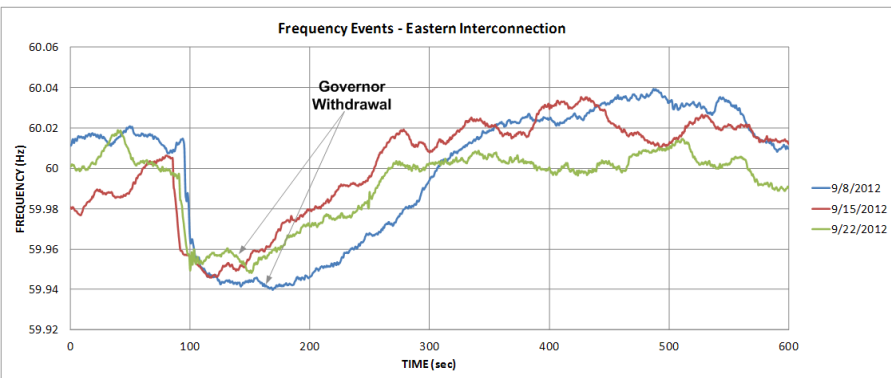
Western Interconnection
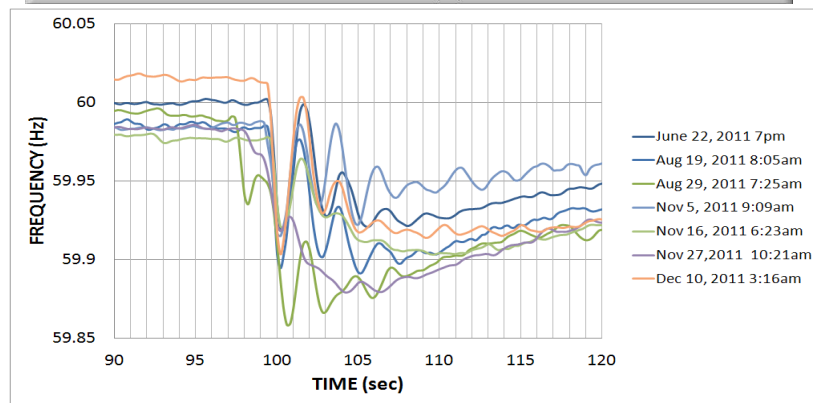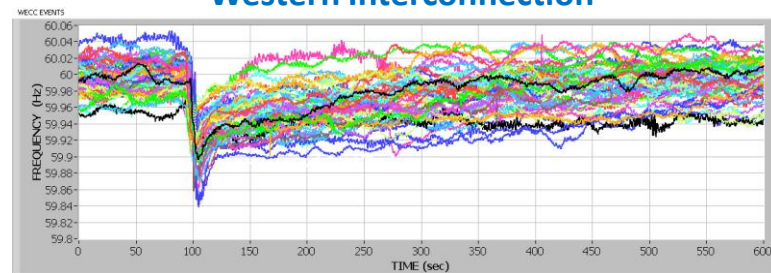
Electric Reliability Council of Texas
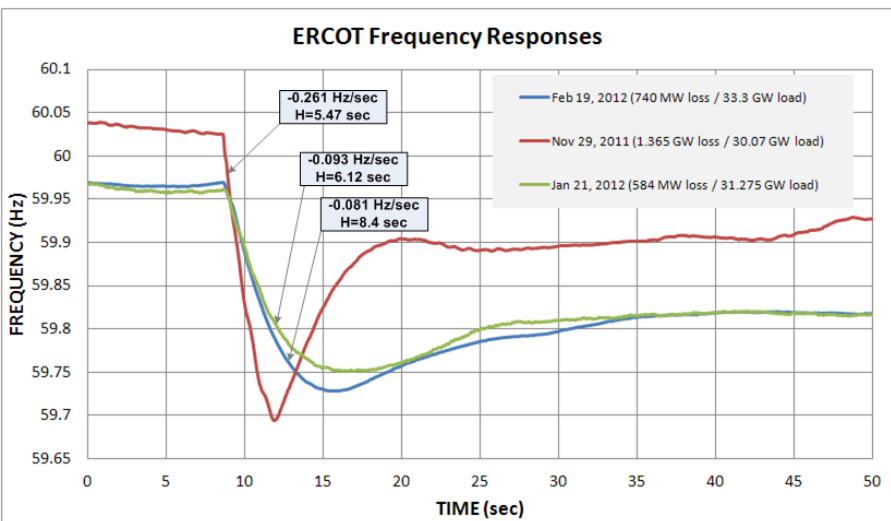
Island System
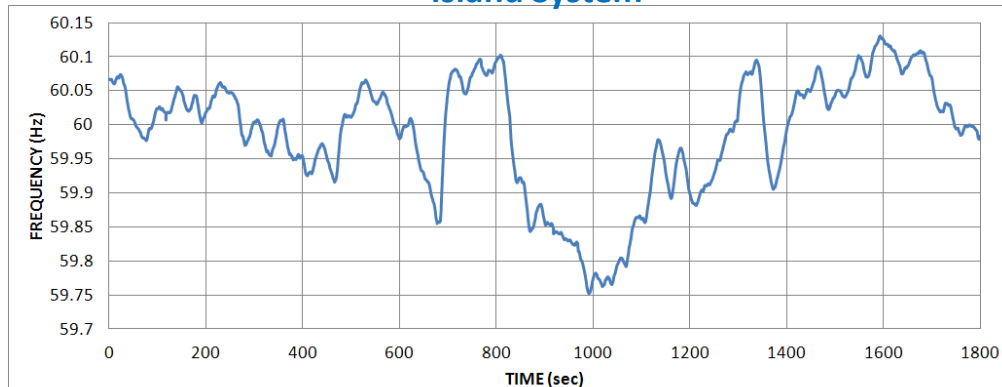
Testing Wind Power to Provide Frequency Response

CGI is a useful tool for testing wind, PV, and storage to provide inertial and primary frequency response.

Example of Island Grid HIL Testing
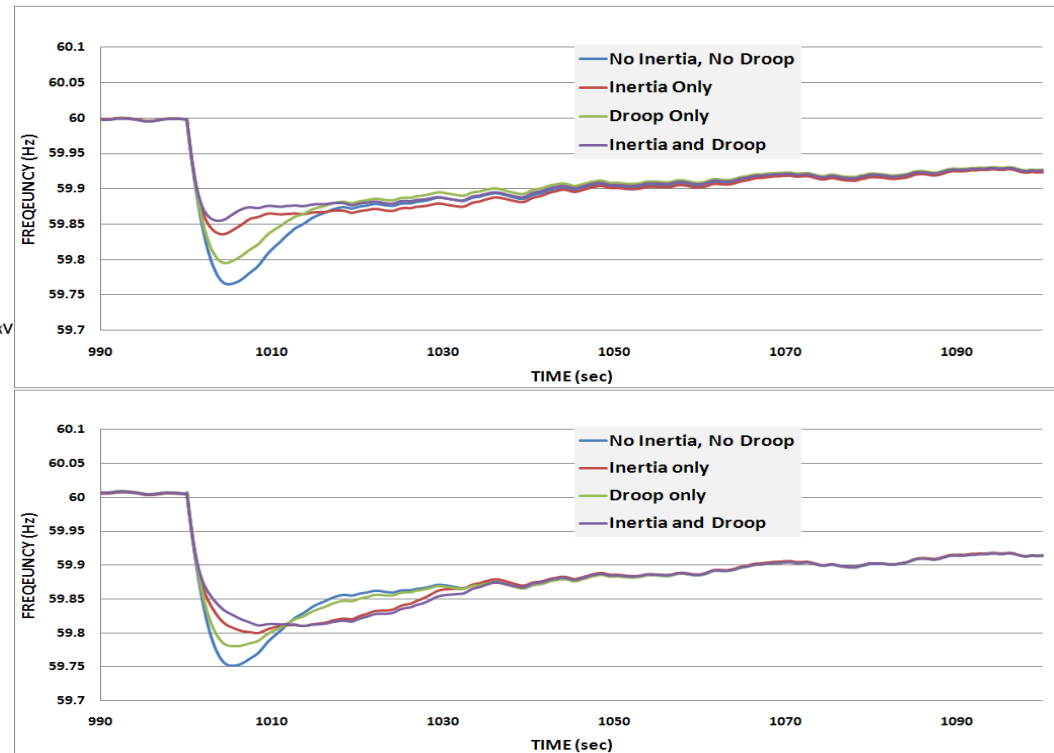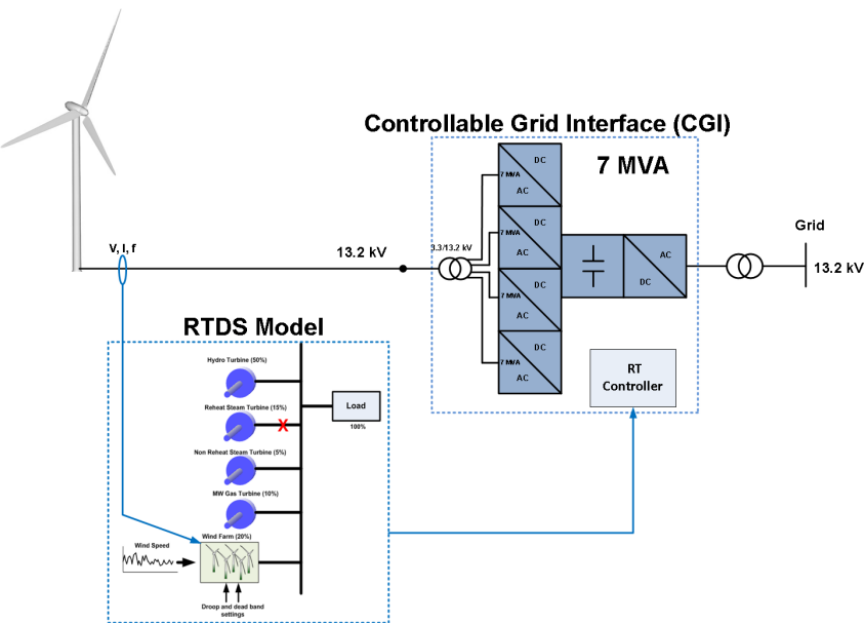
CGI for Wind Turbine, Energy Storage, and PV Inverter Testing

Link with Energy Systems Integration Facility (ESIF) for advanced HIL testing

Large overcurrent capacity is needed for some wind turbine topologies and conventional generation low-voltage ride-through (LVRT) testing

ESIF HPC

Visualization

High Performance Model for Transmission and Distribution Operations

ESIF 1 MW Grid Simulator

Load bank

INVERTER

RTDS / HIL

Power Flow Model

CGI

DC 7 MVA AC

6.3 MVA

DC 7 MVA AC

AC DC

DC 7 MVA AC

DC 7 MVA AC

3.3/13.2 kV

CGI Controller

Grid 13.2 kV

Multiple inverters for short term overcurrent capacity (2 sec @ 39 MVA)

Voltage is controlled at this point (130% overvoltage is possible)

13.2 kV

RMS Current Ratings
Nominal @ 7 MVA continuous - 306 A
Short term @ 22.8 MVA for 10 sec - 1000A
Short term @ 39 MVA for 2 sec - 1725A

DFIG

Gear-Box

Type 3 Wind Turbine

13.2 kV

Voltage Dip

Test Generator Voltage Waveforms

Test Generator Current Waveforms

13.2 kV

AC DC

Energy Storage

Current Response of Type 3 WTG

Labels in figure:

Existing **CGI**

New: Interconnect CGI to switchgear building (7-MW rated three-phase 13.2-KV cable)

Switchgear building:
- Turbine bus
- Building bus
- CGI bus

251

New vista switch(es) to connect MW turbines to CGI or turbine bus

5-MW Dyno.

10-MW rated three-phase 13.2-KV cable in 4" conduit

Pad 6
Pad 5
Pad 4
Pad 3
Pad 2
Pad 1

New array of up to six transfer (Vista) switches (1 ea. per GES test pad) in an outdoor-rated expandable cabinet. Enables each GES test pad to be interconnected to:
- CGI bus, or
- Turbine bus, or
- Building bus

13.2-KV GES test pad interconnection

15'x20' concrete pad for equipment (e.g., customer-supplied transformer)

To DOE 1.5

Site 4.0

To CART's

To Alstom, Gamesa, Siemens (Future)

Site 3.1

Source: Dave Simms, NREL, 6/6/13

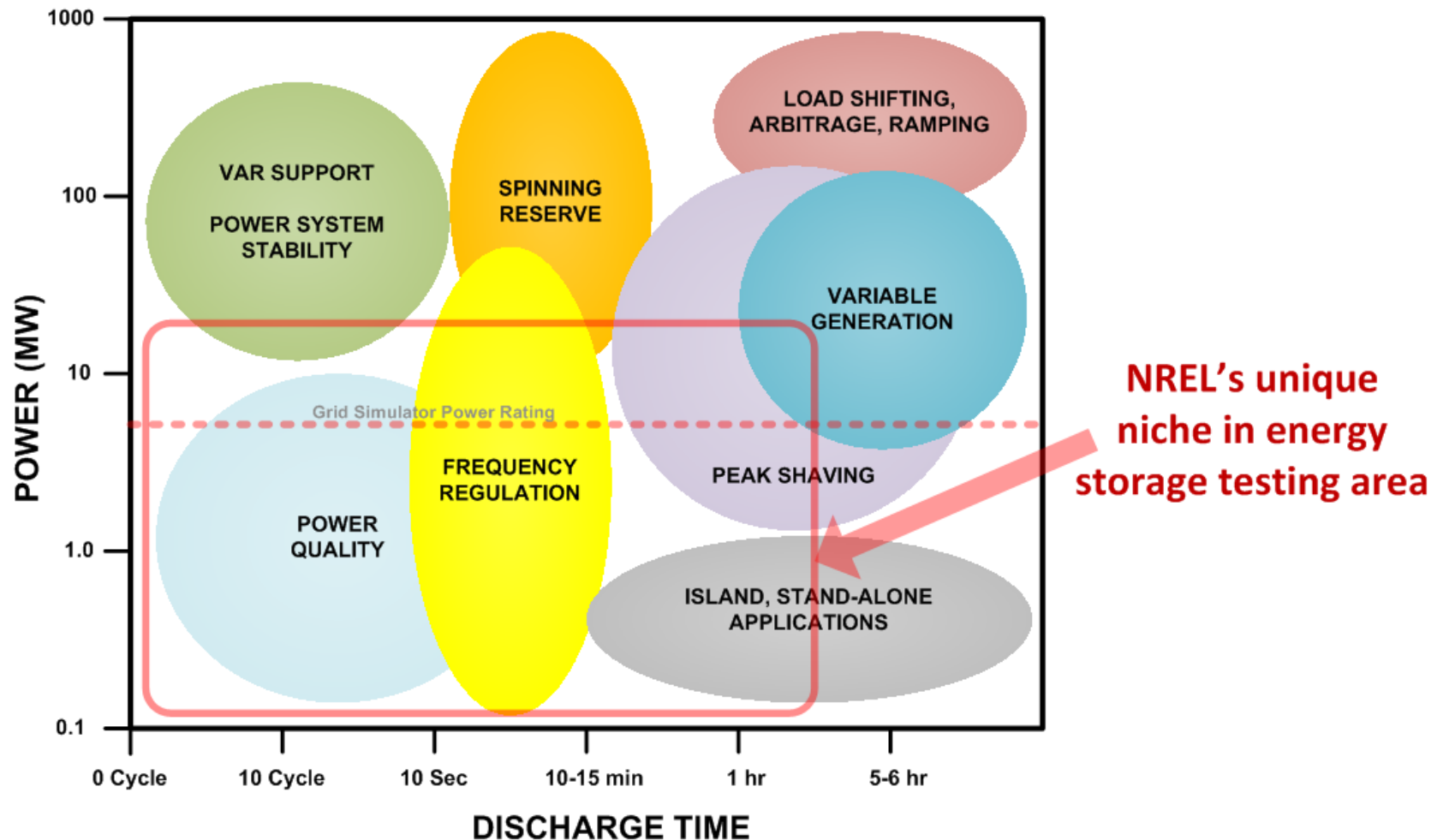## Proposed Electrical and Facility Infrastructure for Grid Energy Storage (GES) Test Pads and Row 4 Turbine Interconnection to CGI

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
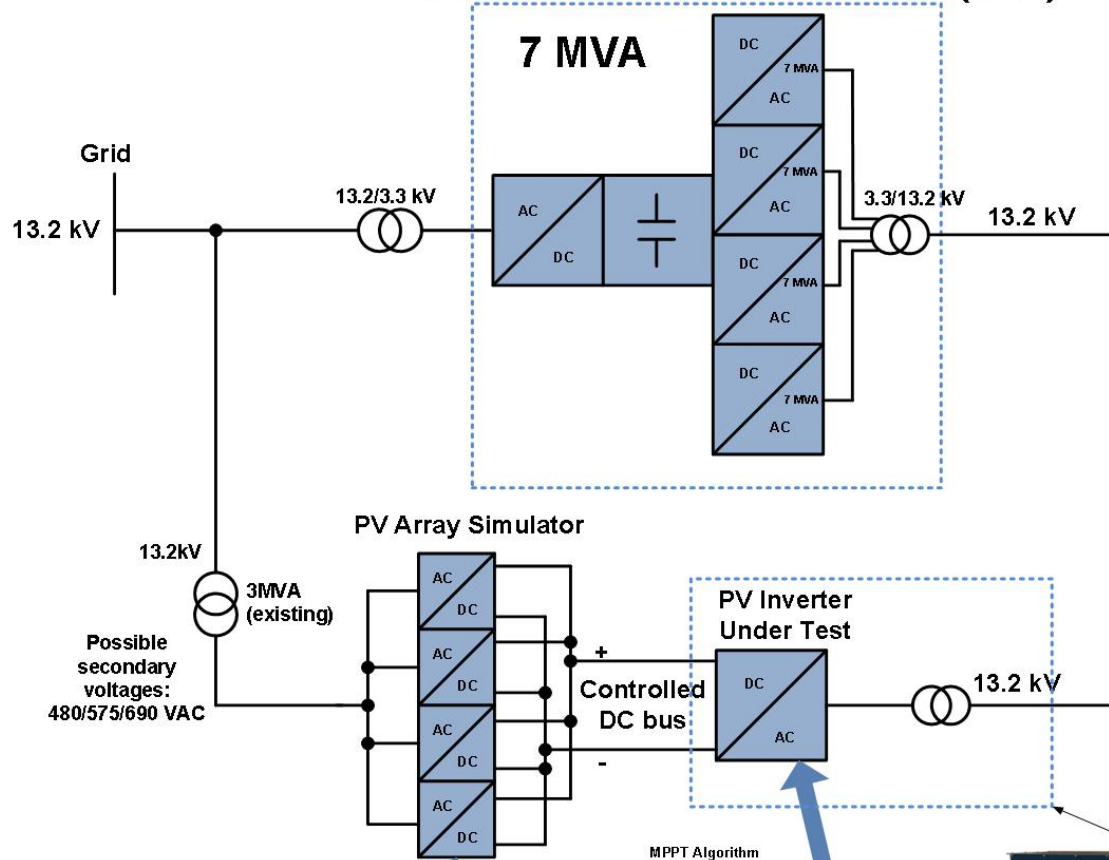
NWTC's Unique Role in Energy Storage Testing

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

PV Inverter Testing Concept Using NWTC CGI

Controllable Grid Interface (CGI)

7 MVA

Grid

13.2 kV

13.2/3.3 kV

3.3/13.2 kV

13.2 kV

DC / 7 MVA / AC

DC / 7 MVA / AC

AC / DC

DC / 7 MVA / AC

DC / 7 MVA / AC

13.2kV

3MVA (existing)

Possible secondary voltages: 480/575/690 VAC

PV Array Simulator

AC / DC

AC / DC

AC / DC

AC / DC

Controlled DC bus

+ −

PV Inverter Under Test

DC / AC

13.2 kV

Voltage is controlled at this point (130% overvoltage is possible)

Various PV profiles from field data or models

Example of 1-min PV Performance Data - 1 week

MPPT Algorithm

Array Current, I

Irradiance

Maximum Power Point

Terminal Voltage, V

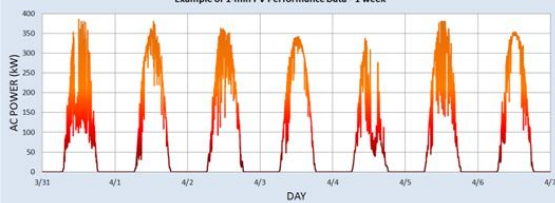*Example of Inverter / Transformer Integrated System*
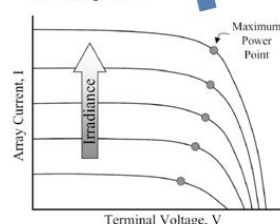
Possible tests
- MMPT algorithms
- 50-Hz/60-Hz operation
- Voltage fault tests
- Advanced testing
  - Operation with reserves
  - Frequency response
  - Voltage control
  - Testing with energy storage

NWTC Two-Bus Test Site Concept

Most components are already in place. Switchgear upgrade is underway.

2.5 MW Dynamometer (exisiting)

NWTC Wind Turbines
Alstom 3 MW
Siemens 2.3 MW
GE 1.5 MW
Gamesa 2 MW
CART2 and CART3

5 MW Dynamometer (exisiting)

Xcel Bus

CGI Bus

PV Inverter Testing with DC Simulator

10 MW line capacity (upgrade to 50 MW by 2014)

Xcel Substation

1MW PV Array (existing)

Permanent Storage Testing Facilities*

13.8 kV   115 kV

Switchgear Building

Link with ESIF HPC and HIL capabilities

Controllable Grid Interface (CGI) for Grid and Fault Simulation (7 MVA)

ESIF

Temporary (mobile) storage testing facilities (under development)

Future addition of load bank will enable full microgrid testing

Research Electrical Distribution Bus (REDB) AC and DC

*Permanent storage facility concept is under evaluation

NREL's ESIF

- **HIL 1-MW power electronic grid simulator**
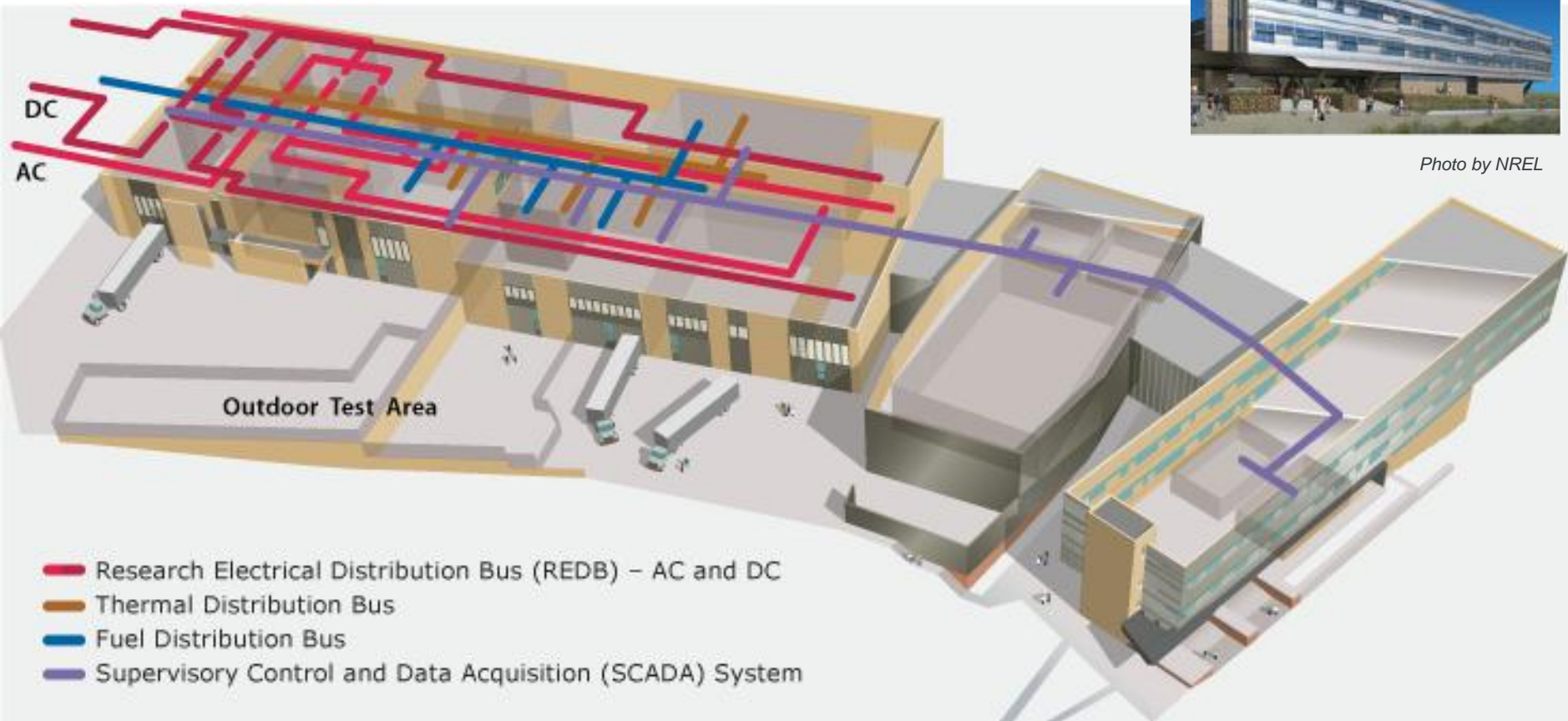- **High-performance computing data center**
- **Data analysis and visualization**

Photo by NREL

DC

AC

Outdoor Test Area

━━━ Research Electrical Distribution Bus (REDB) – AC and DC
━━━ Thermal Distribution Bus
━━━ Fuel Distribution Bus
━━━ Supervisory Control and Data Acquisition (SCADA) System