Workshop Agenda

- ***Day 1***
  - *Badging and breakfast – 8:00 a.m.-8:45 a.m.*
  - *Morning sessions – 8:45 a.m.-12:00 p.m.*
  - *Lunch – 12:00 p.m.-1:00 p.m.*
  - *Afternoon session – 1:00 p.m.-5:00 p.m.*
  - *Group dinner in Boulder area (7 p.m.) – please let us know if you are coming*
- ***Day 2***
  - *Arrival and breakfast – 8:00 a.m.-8:45 a.m.*
  - *Morning sessions – 8:45 a.m.-12:00 p.m.*
  - *Lunch – 12:00 p.m.-1:00 p.m.*
  - *National Wind Technology Center tour – 1:00 p.m.-3:00 p.m.*
  - *Adjourn – 3:00 p.m.*

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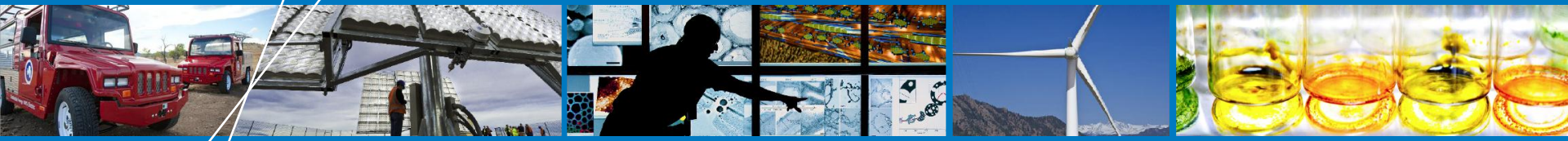
Overview of Workshop Goals



First International Workshop for Grid Simulator Testing of Wind Turbine Drivetrains

National Renewable Energy Laboratory, National Wind Technology Center

June 13, 2013

First Workshop on Grid Simulator Testing of Wind Power

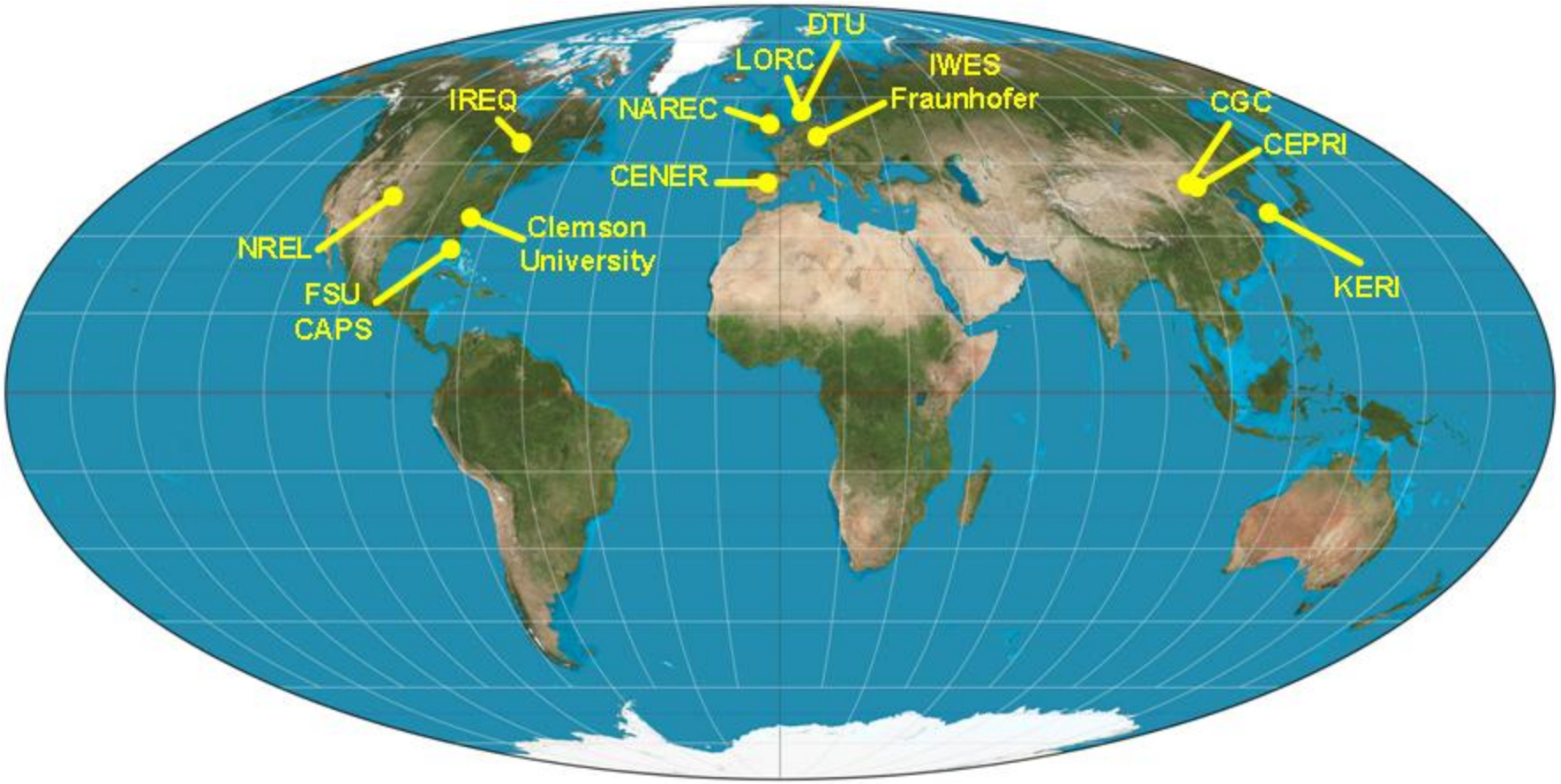
NREL NATIONAL RENEWABLE ENERGY LABORATORY — Leading clean energy innovation — U.S. DEPARTMENT OF ENERGY

CLEMSON UNIVERSITY WIND TURBINE DRIVETRAIN TESTING FACILITY

- Cohosted by the National Renewable Energy Laboratory and Clemson University
- Ongoing collaboration in developing dynamometer and grid simulator capabilities
- U.S. Department of Energy (DOE)-funded activity
- Stakeholders from the industry have been engaged in the planning process
- Primary objective of this workshop is to bring together other labs worldwide to exchange experience and learn from each other

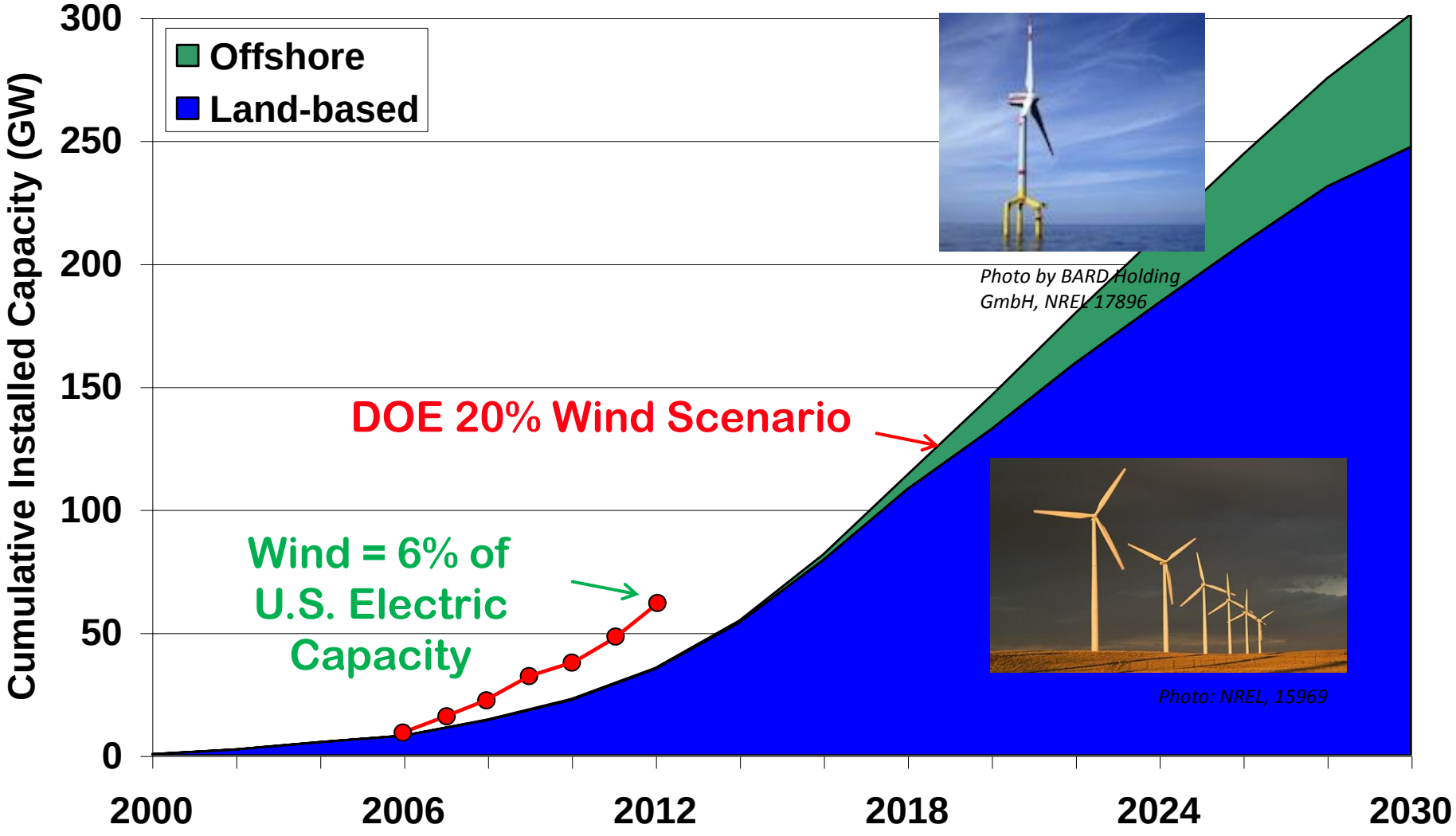
Grid Simulator Testing

Global trend, hot topic in many countries …



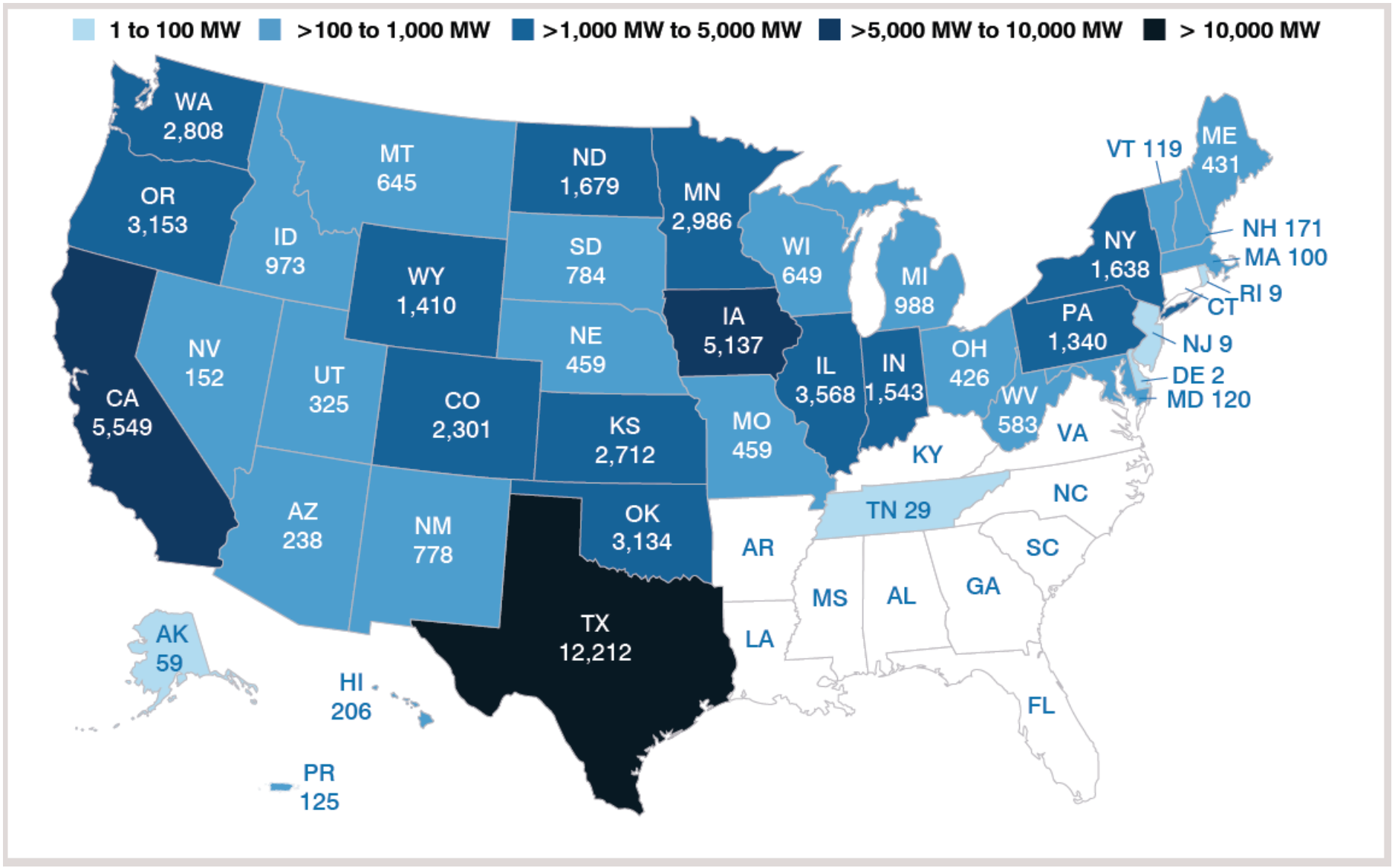
Source:: http://upload.wikimedia.org/wikipedia/commons/9/9e/Mollweide_projection_SW.jpg

U.S. Wind Generation



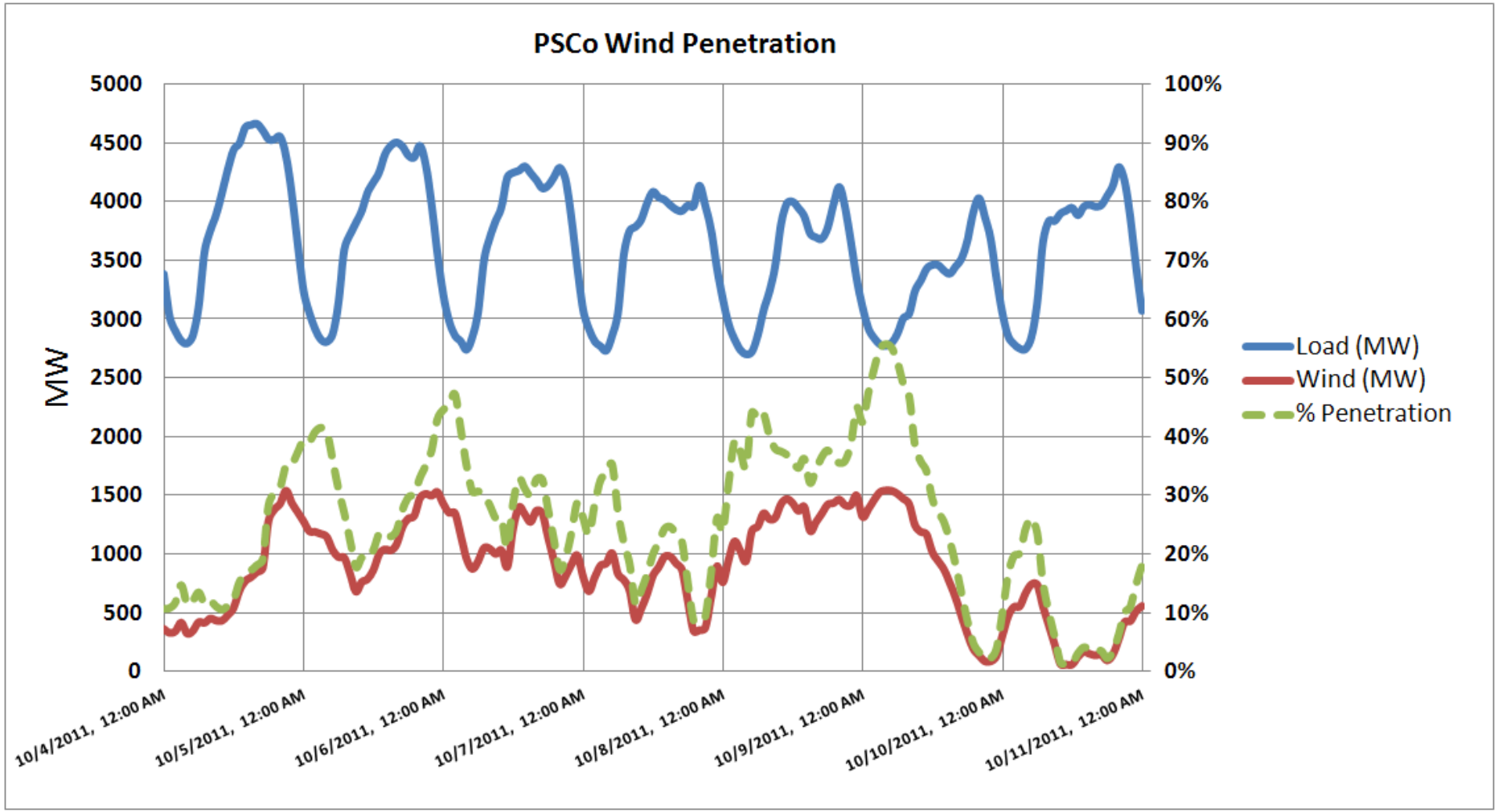
Source: AWEA 2012 Market Report

U.S. Wind Power by State



Source: AWEA 2012 Market Report

56% Penetration in Public Service Company of Colorado



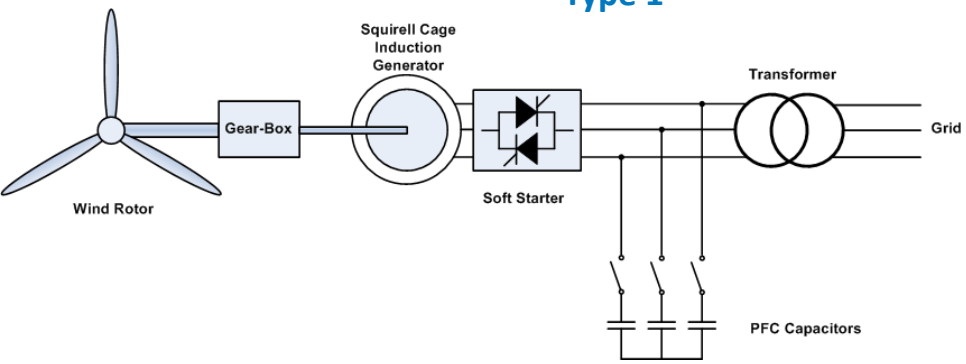
Impacts on Testing

- **Large-scale integration of wind energy will present new challenges for testing community**
- **Evolving grid codes and interconnection requirements (often utility specific)**
- **Existing wind turbine testing practices "in isolation" from other parts of power system need improvements**
  - Interaction with other wind turbines in the plant
  - Interactions between grid and power plants
  - Impacts on power system reliability
- **Ancillary services by wind (various forms of active and reactive power control)**
- **New generation of testing methods and equipment**
- **Hardware-in-the-loop (HIL) testing**
- **Specifics of offshore operation (AC and DC)**
- **Grid simulator testing can become a useful tool for the industry**

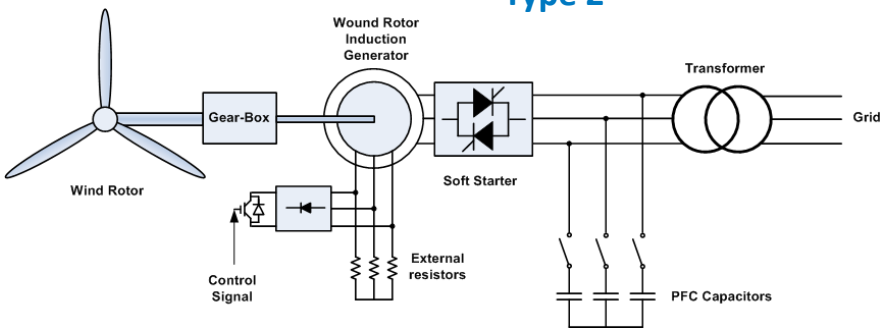
Evolution of Wind Turbine Electrical Topologies

Constant Speed

Type 1

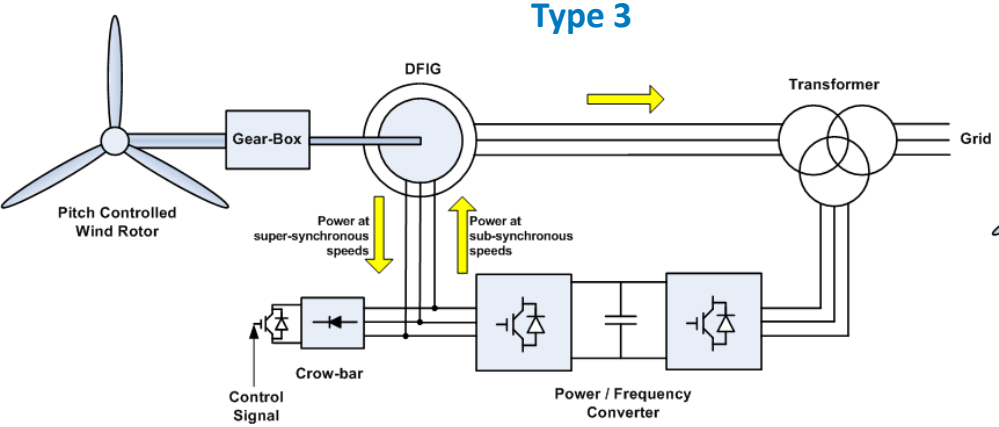


Type 2

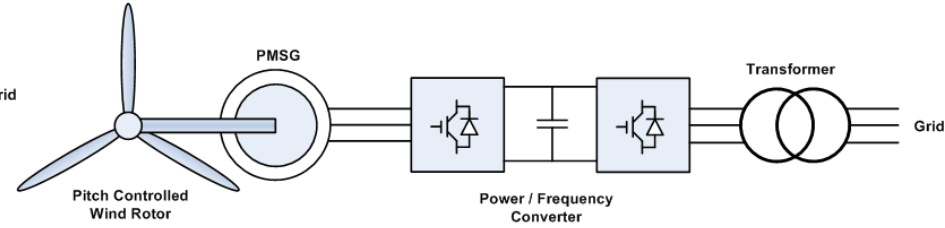


Variable Speed

Type 3

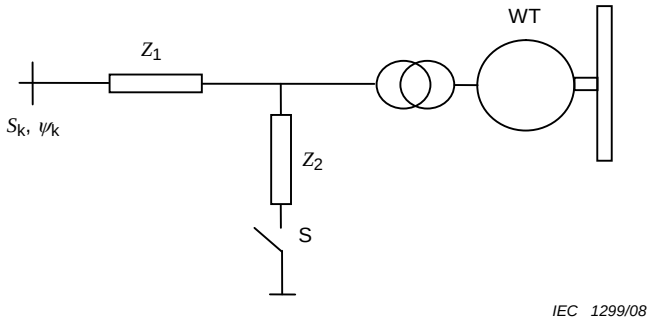


Type 4



IEC 61400-21 Power Quality Testing Standard

- Field testing standard (not applied to dynamometer testing)
- Provides unified methodology to grid compliance testing
- Early years: Reactive power, Flicker, Harmonics
- Ed. 2: Low-voltage ride-through (LVRT), active/reactive power set point control
- Ed. 3: Some additions are expected:
  - High-voltage ride-through (HVRT)
  - Inertia
  - Voltage control

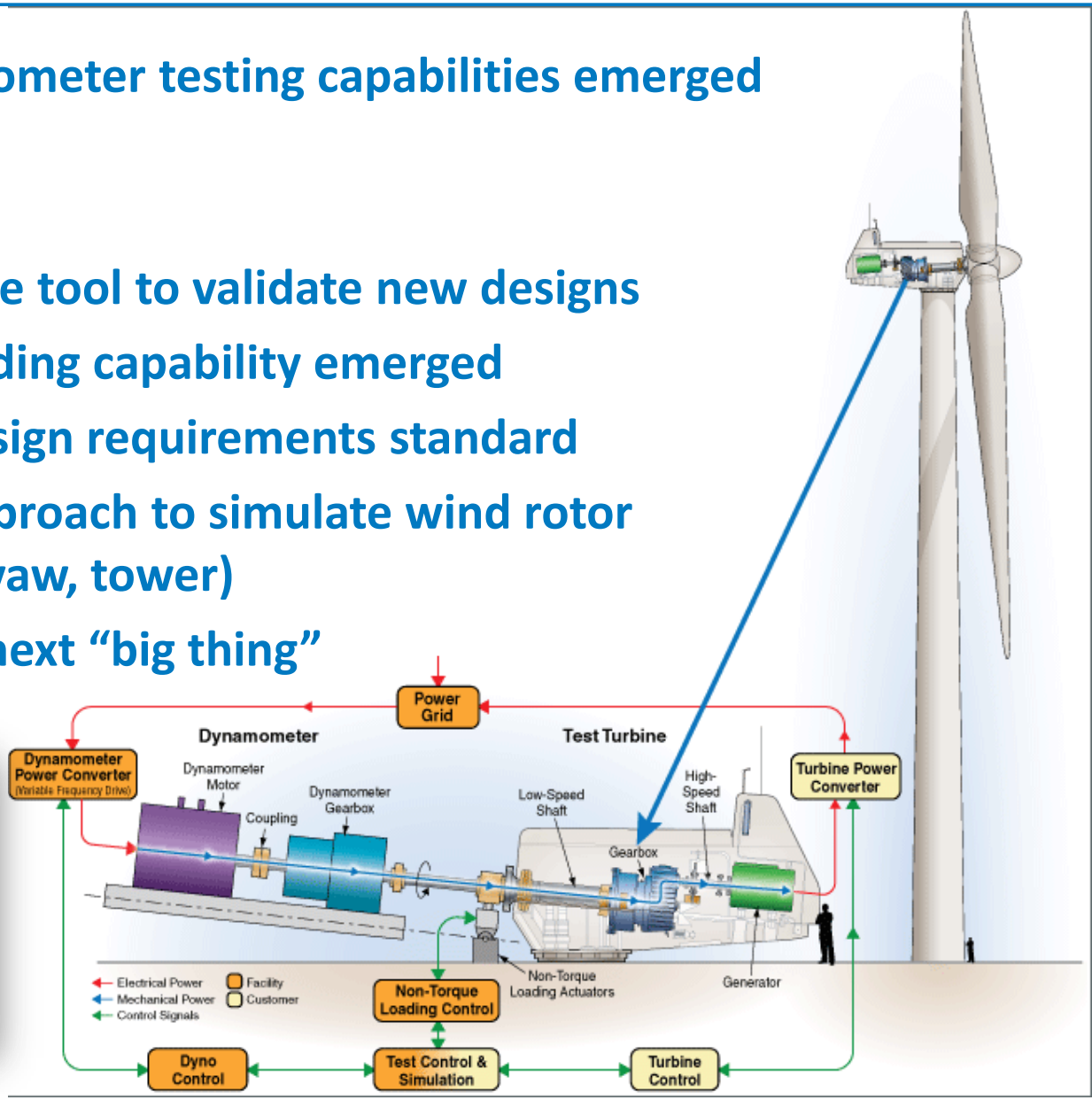


- Two separate pieces of equipment needed for LVRT and HVRT tests
- Frequency response testing can be conducted only by feeding a frequency signal into turbine controller

History of Wind Turbine Dynamometer Testing

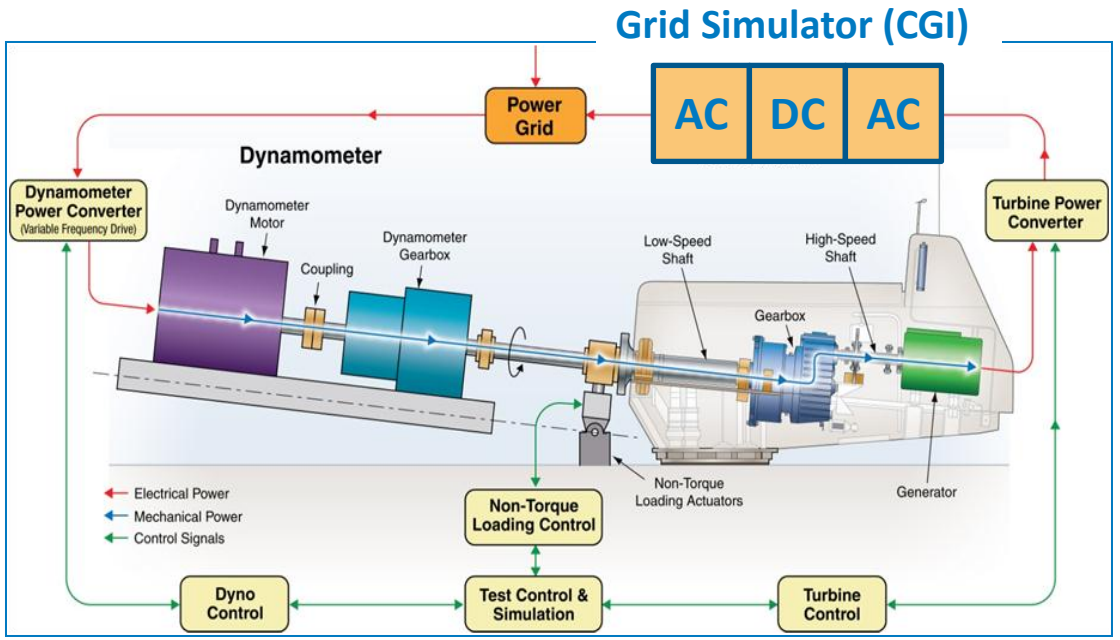
- Megawatt-scale dynamometer testing capabilities emerged around mid-1990s
- HALT/reliability testing
- Proven to be an effective tool to validate new designs
- Need in non-torque loading capability emerged
- IEC 61400-4 gearbox design requirements standard
- "Model-in-the loop" approach to simulate wind rotor dynamics (rotor, pitch, yaw, tower)
- Electrical testing is the next "big thing"

Photo by: Rob Wallen, NREL 17398



Grid Simulators for Dynamometer Testing

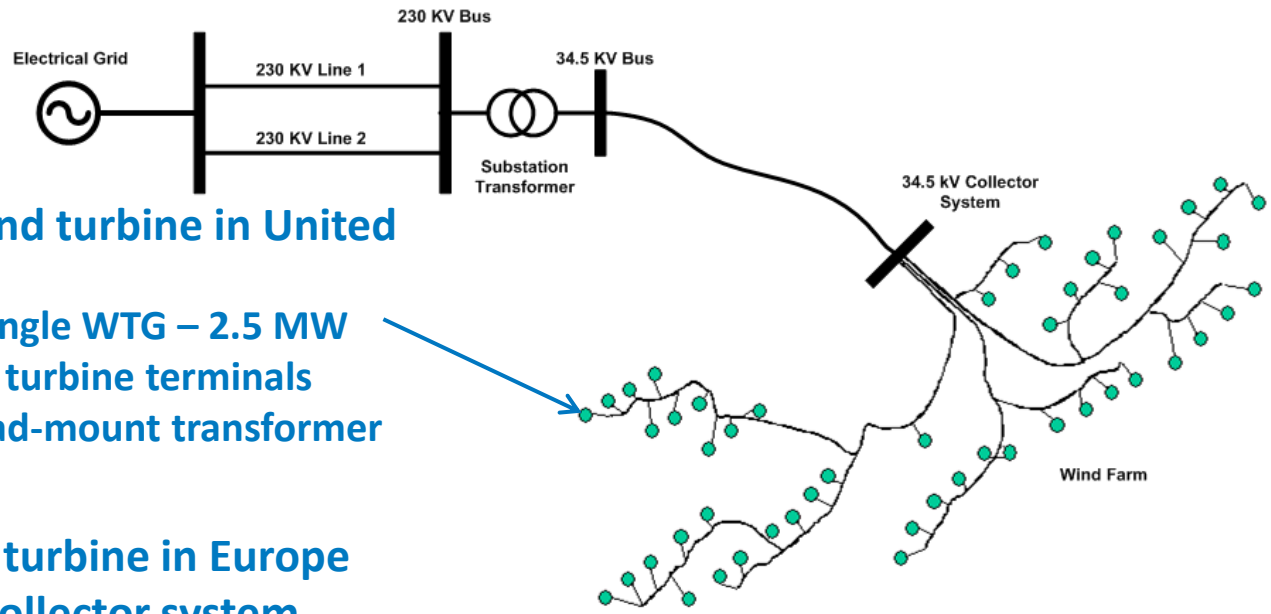
- **Dyno. environment**
  - Weaker grids
  - No disturbance to utilities is tolerated
  - Power electronics seem to be the best solution



- **Advantages of power electronics solution**
  - Fast, flexible control (HIL)
  - Control of voltage (LVRT/HVRT, low-frequency modulations) and frequency
  - 50-Hz/60-Hz operation
  - Recreation of field events

- **Disadvantages of power electronics solution**
  - Possible harmonic interactions (topology dependent)
  - Sequence capabilities (topology dependent)

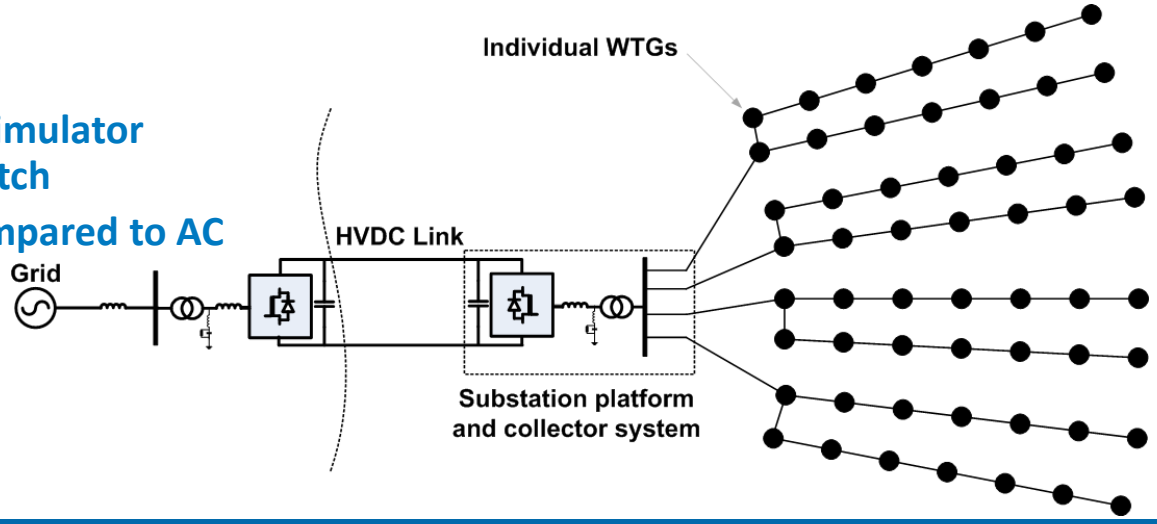
Realistic Simulation of Wind Farm Conditions



- **Typical land-based wind turbine in United States:**
  - Average size of single WTG – 2.5 MW
  - 690 VAC on wind turbine terminals
  - 690-V/34.5-KV pad-mount transformer

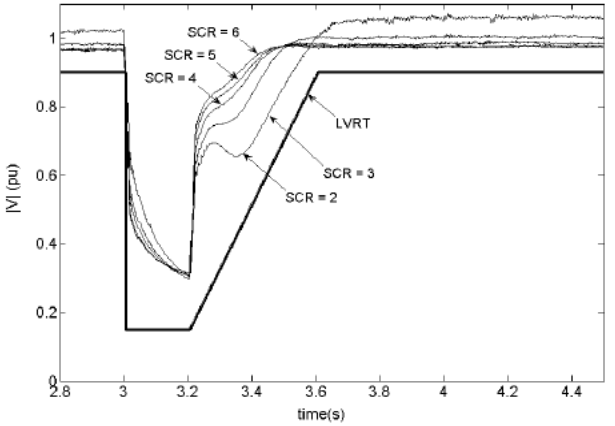
- **Typical offshore wind turbine in Europe is connected to 33-kV collector system**

- **Offshore HVDC**
  - Power electronic grid simulator seems to be a good match
  - Different operation compared to AC
  - Harmonic interactions

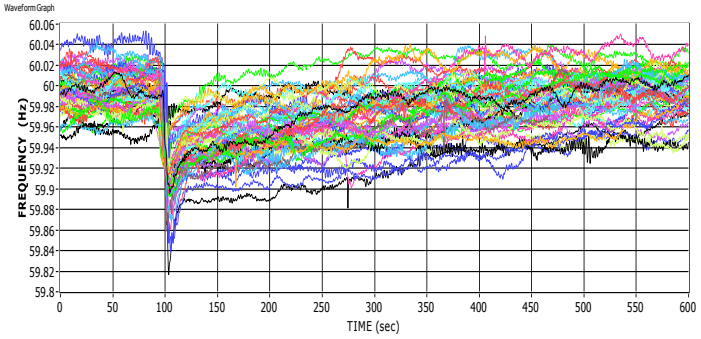


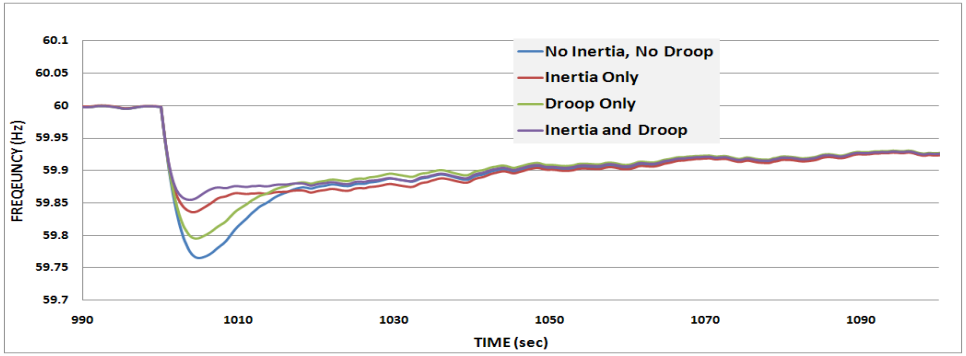
Benefits of Grid Simulator Testing

- Many electrical testing scenarios can be conducted in safe, controlled environment
- Provides testing capabilities platform beyond present gird compliance standards
- Can be used as a platform for new standards development and validation
- Platform for dynamic model validation
- HIL capability to test controls of a single wind turbine as part of a large wind power plant (onshore and offshore)
- Value and capabilities beyond needs of the wind industry



Source: IEEE





Goals for Workshop

- **Establish collaboration between testing labs worldwide to identify testing needs and capability gaps**
- **Establish a framework for sharing testing experience, test protocols and procedures, etc.**
- **Explore needs in having unified testing methods**
- **Further dialogue with wind O&Ms and plant operators to identify and meet their testing needs**
- **Next steps:**
  - Future workshops
  - Engaging larger stakeholder groups (utilities and independent system operators)
  - Going beyond wind (photovoltaic inverters, energy storage testing, MHK, etc.)
- **Success requires your active participation and discussion**

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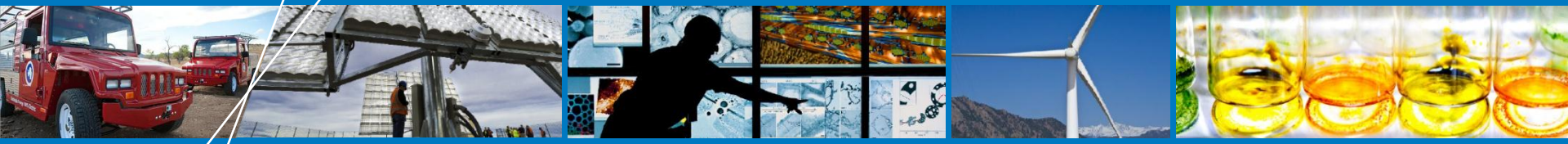

Thank you.

Questions?