Power Electronics: Roles in Renewable Energy Generation – Challenges and Opportunities

Panel Session: Challenges/Issues for Smart Grid

Presenter: Eduard Muljadi
National Renewable Energy Laboratory

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Outline

- Background
- Renewable energy
- Grid integration
- Power electronics control
- Hardware/software
- Testing
- Storage
- Environment

Background

- Applications
  - mW or MW level
  - Isolated or grid connected
- Variability of the source
  - Temporal (second, hour, day, week, season)
  - Spatial (continental, local, plant)
- Large-area coverage—diversity
  - Resource
  - Electrical characteristics
- Operation
  - Normal/abnormal
  - Balanced/unbalanced

Renewable Energy

Renewable Energy

Solar Photovoltaic (PV)

Image from Sun Power Corp., 23816

PV Plant (5~50 MW)

Rooftop PV (1~30 kW)

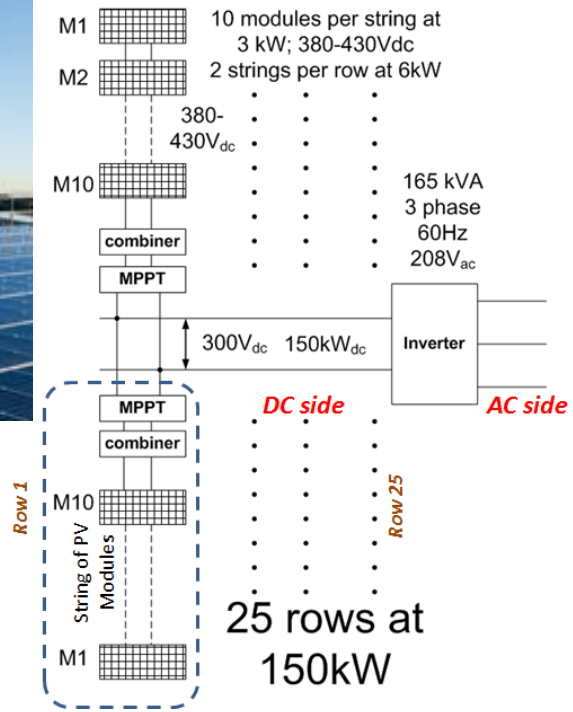
Image from DOE FEMP, 27638

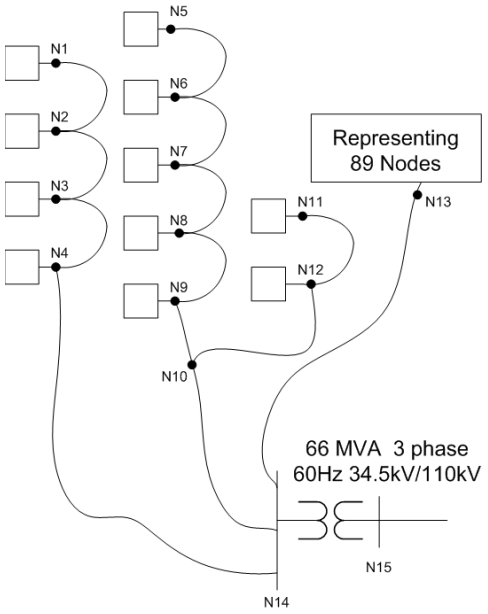
Image by Dennis Schroeder, NREL 22192

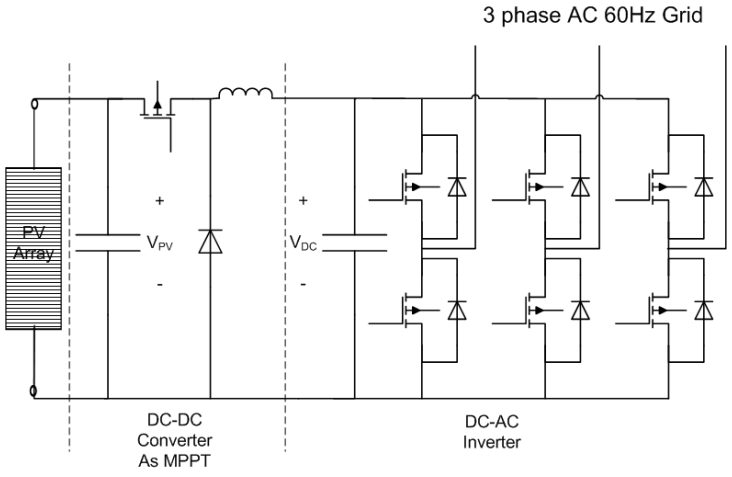
Mobile 9-kW PV system
Bechler Meadows Ranger Station
Yellowstone National Park

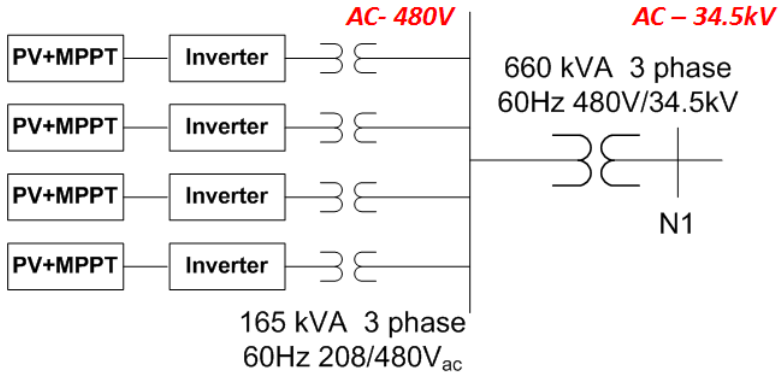
Renewable Energy

Image by Dennis Schroeder, NREL 27806



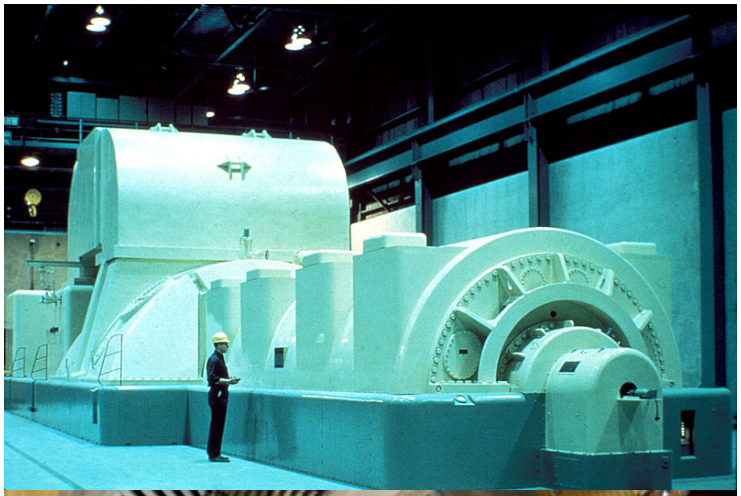






Conventional Power Plant vs. Renewable Energy Power Plant

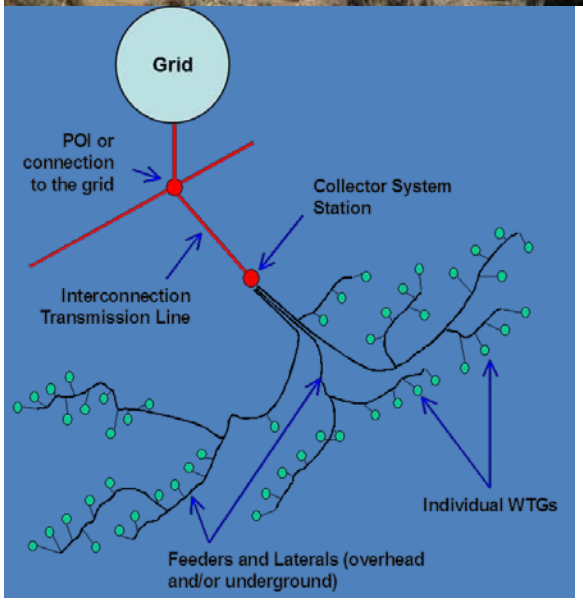
U.S. NRC image of a modern steam turbine generator.
Image from Wikipedia



http://www.energy.siemens.com/hq/en/

Generator Sgen 4,000-W (Siemens)
1,300–2,235 MVA

Image from David Hicks, NREL 18454



Wind Turbine Generator
1–6 MW

Plant Diversity

Concentrating Solar Power Plant

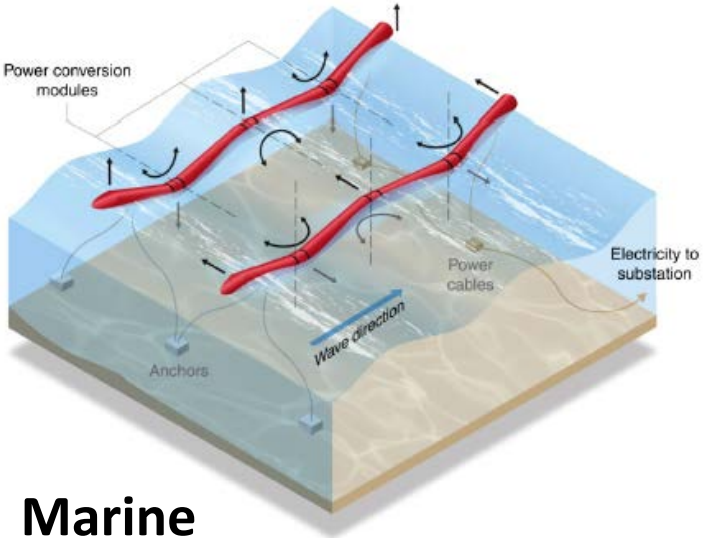
Image from Bill Timmerman, 08989

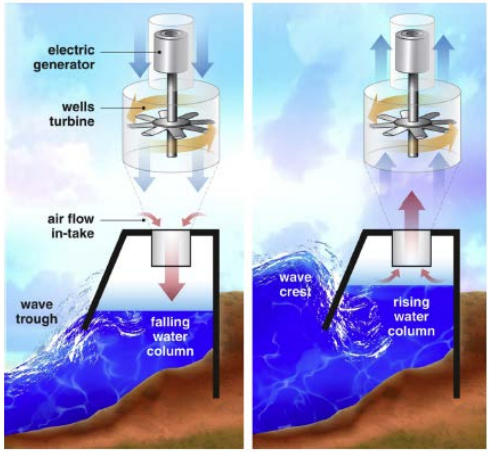
Image from David Hicks, NREL 18557

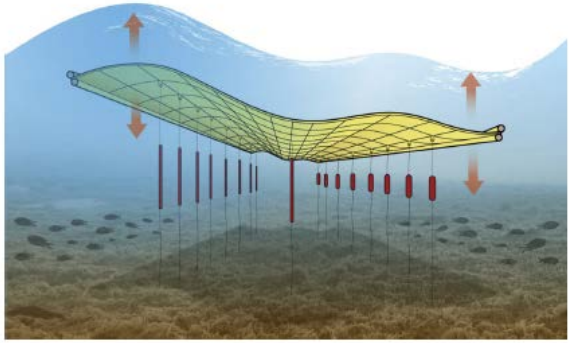
Image from Greg Glatzmaier, NREL 19807

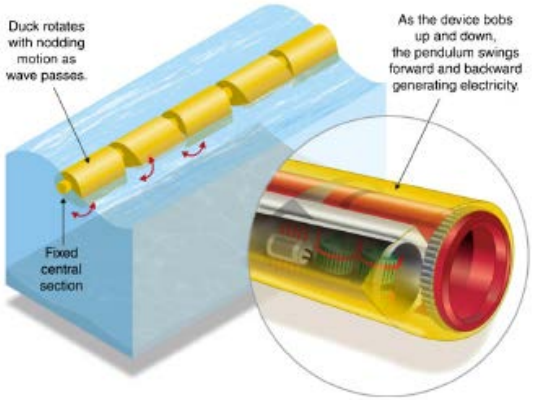
Image from David Hicks, NREL 19881

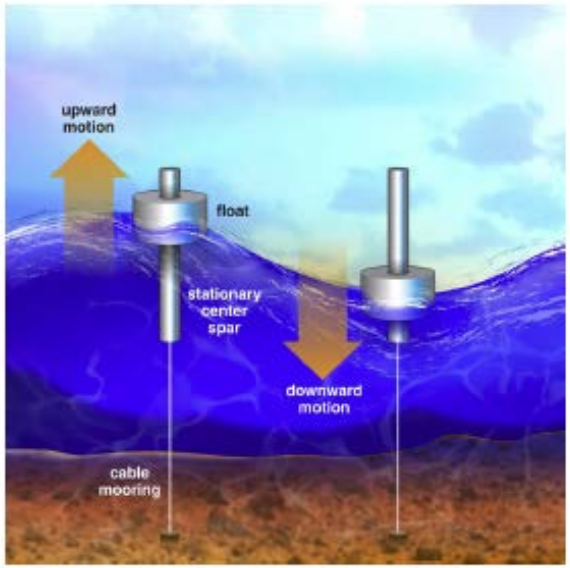
Marine Hydrokinetic

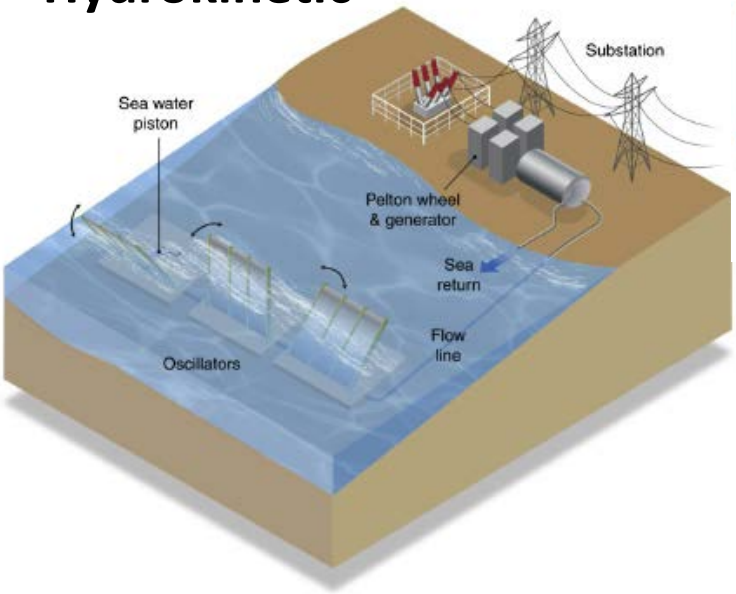


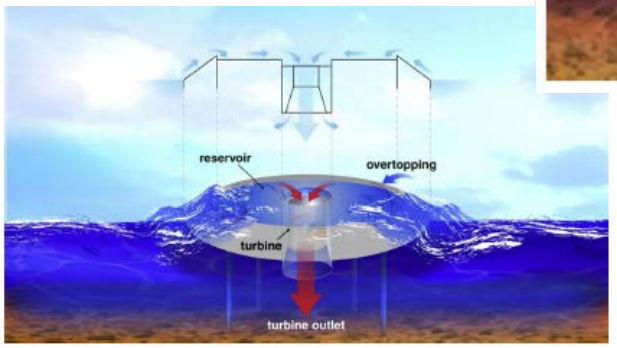








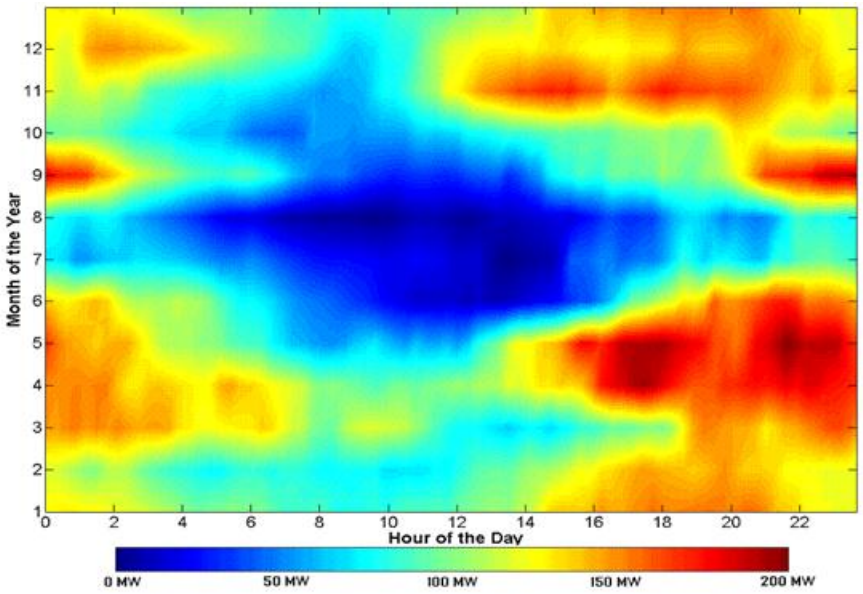




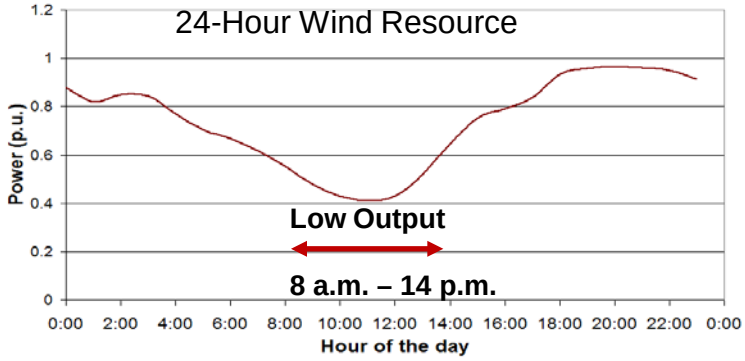
Reference: Li, Y.; Yu, Y.H. (2012). “Synthesis of Numerical Methods for Modeling Wave Energy Converter-Point Absorbers.” Preprint. NREL/JA-5000-52115.

Wind Resource—Midwest

Spring Peaking

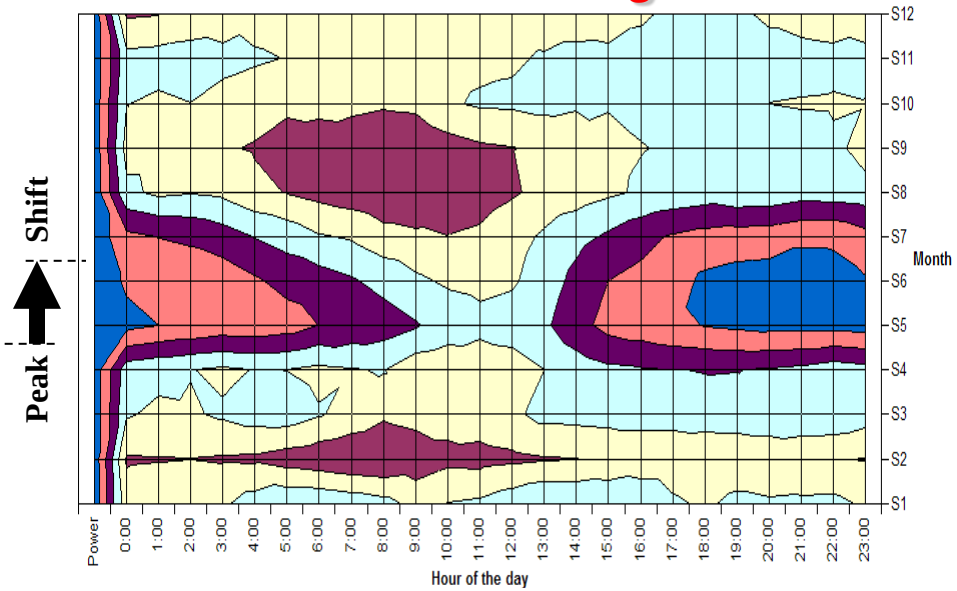


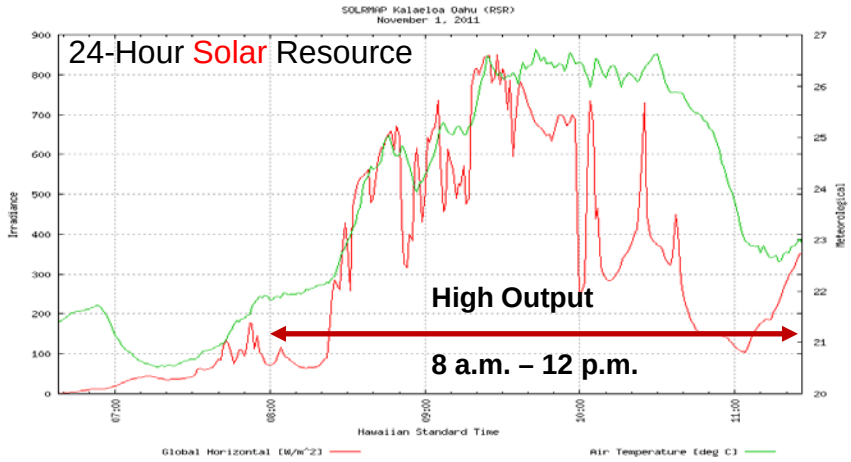
Typical Wind Power Output
Hourly Average
Summer 2006 - Southern California



Wind Resource—West Coast

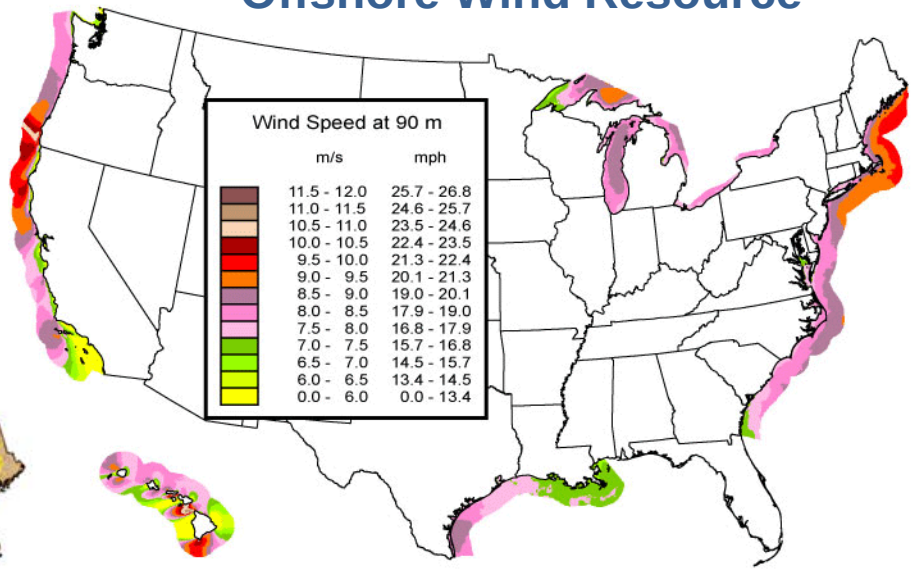
Summer Peaking



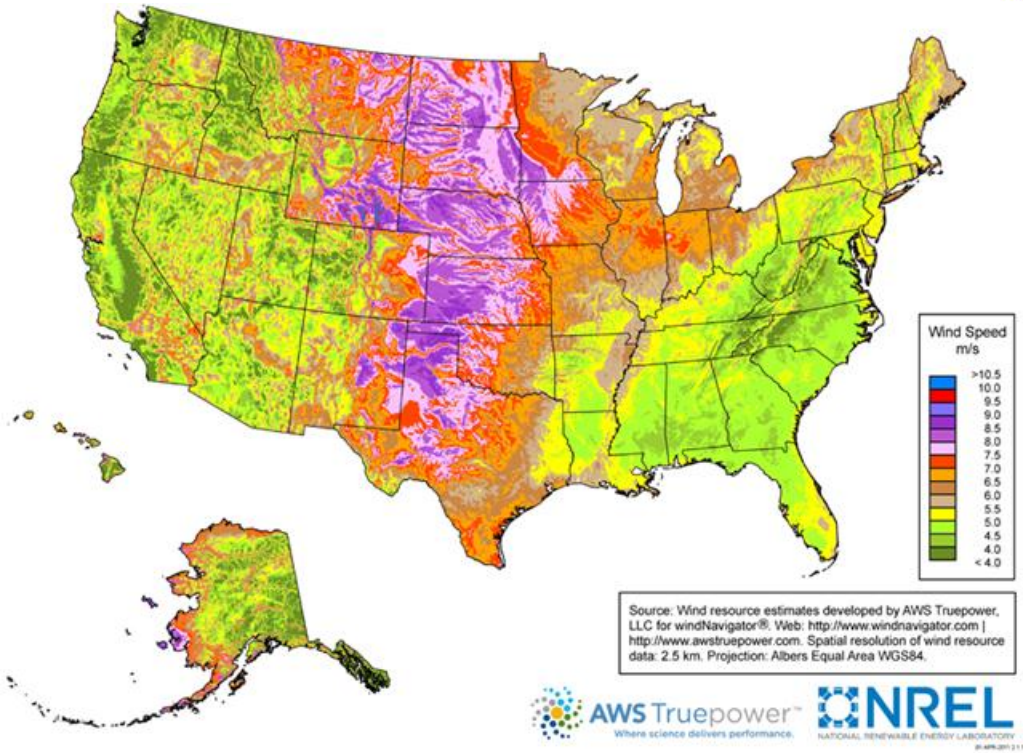


Resources

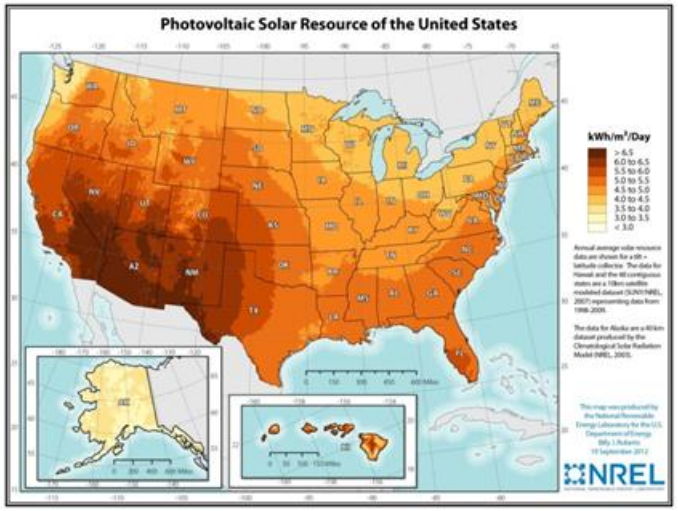
Offshore Wind Resource



U.S. Wind Resource



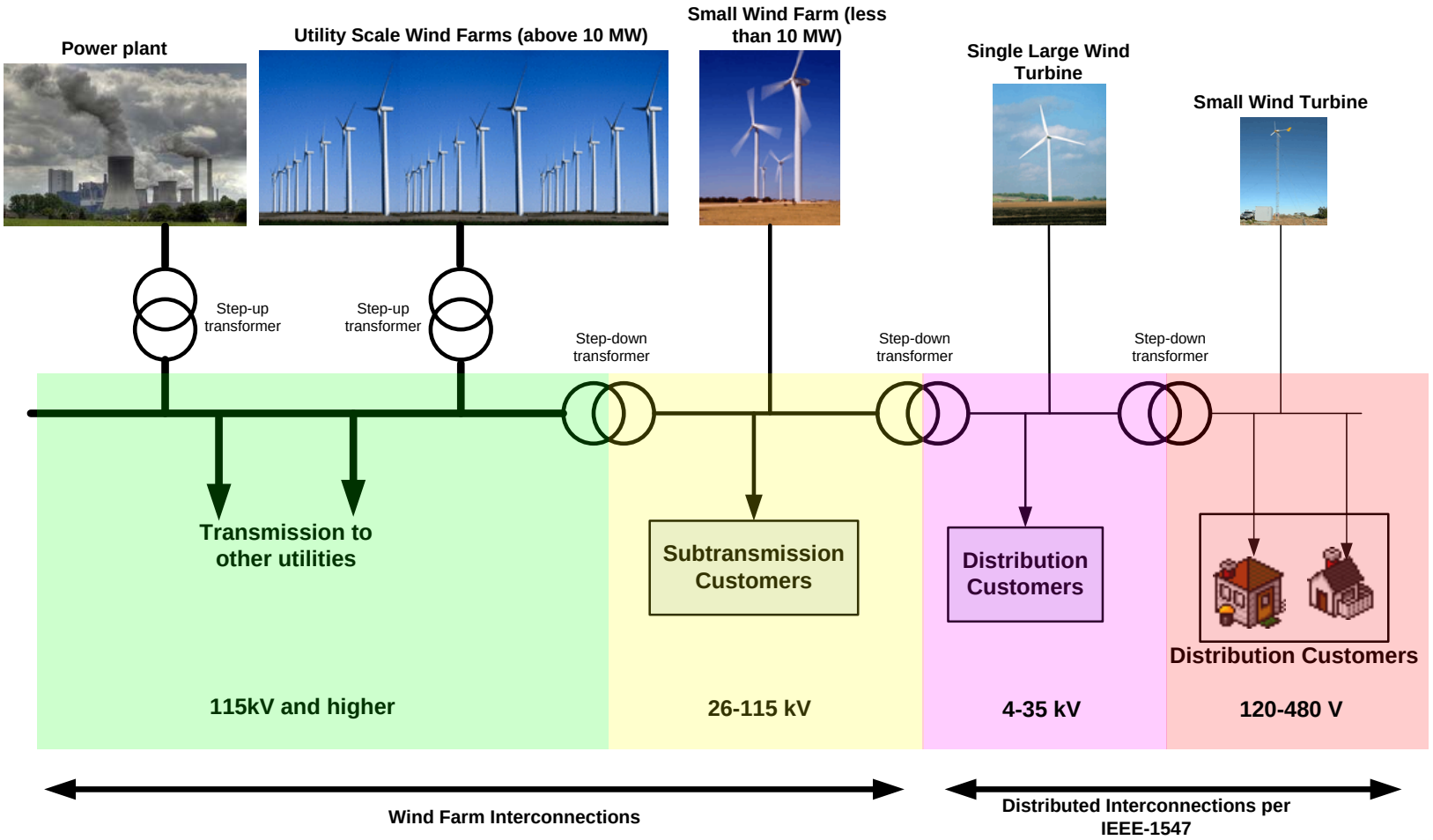
Solar Resource



Integration

- Grid integration
  - Interconnection
  - Operation
  - Standards—grid codes
  - Ancillary services
    - Inertial response, frequency and governor response, reserves

Interconnection



Image's from NREL's TGIG presentation archives

Power Electronics Control

- Generator level
- Plant level
- Transmission level

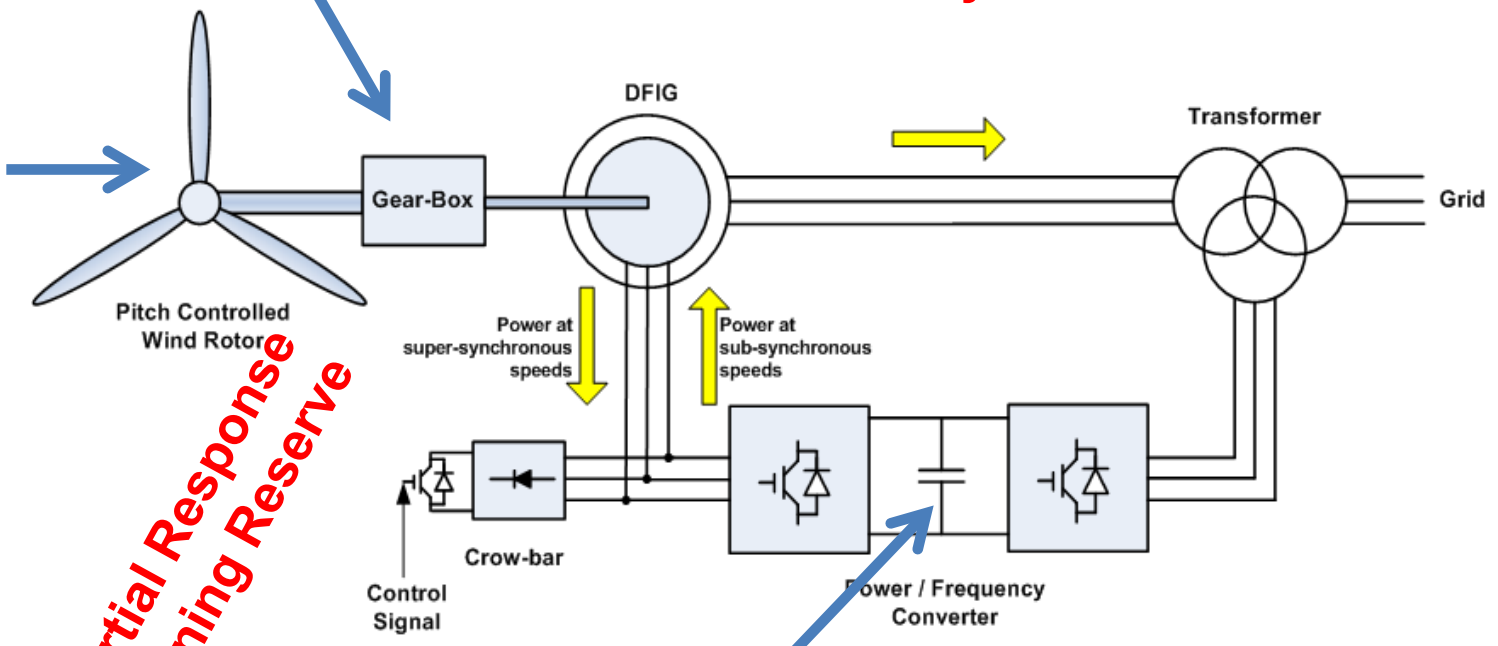
Control

Load Control
Gearbox Preservation

Provide Active Damping to Power System Network

Maximize Energy Capture

Inertial Response
Spinning Reserve

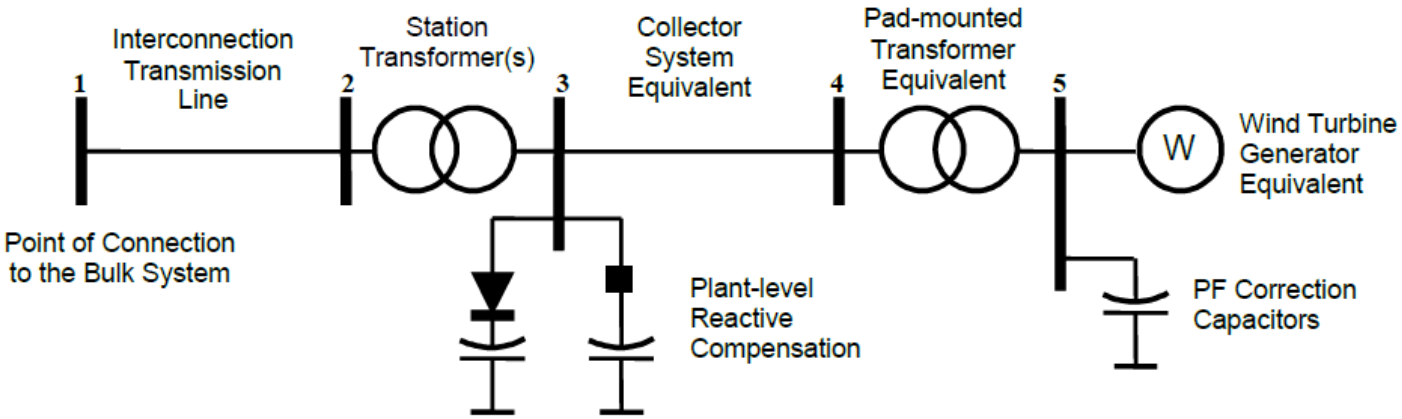


Power Quality
Real and Reactive Power Control

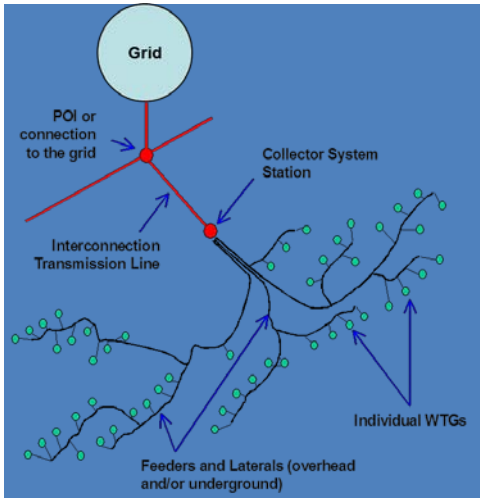
Short-/Long-Term DC
Distributed Storage

At the Generator Level

Control—Generator/Plant

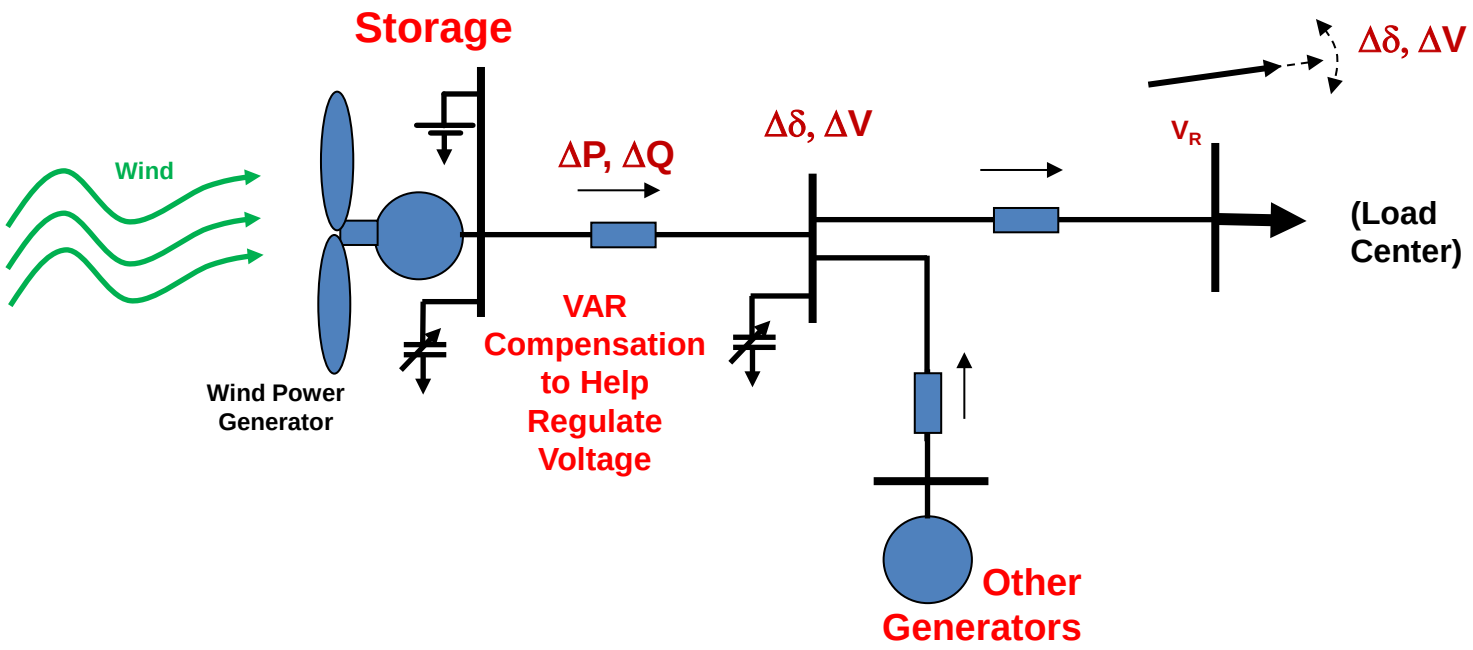


- Many (hundreds) of wind turbines (1 MW to 5 MW each)
- Prime mover: wind (wind turbine)—renewable (free, natural, pollution free)
- Controllability: curtailment
- Predictability: wind variability based on wind forecasting, influenced more by nature (wind) than humans, based on maximizing energy production (unscheduled operation)
- Located at wind resource; may be far from the load center
- Generator: four different types (fixed-speed, variable-slip, variable-speed, full-converter)—nonsynchronous generation
- Types 3 and 4: variable-speed with flux-oriented controller via power converter. Rotor does not need to rotate synchronously.



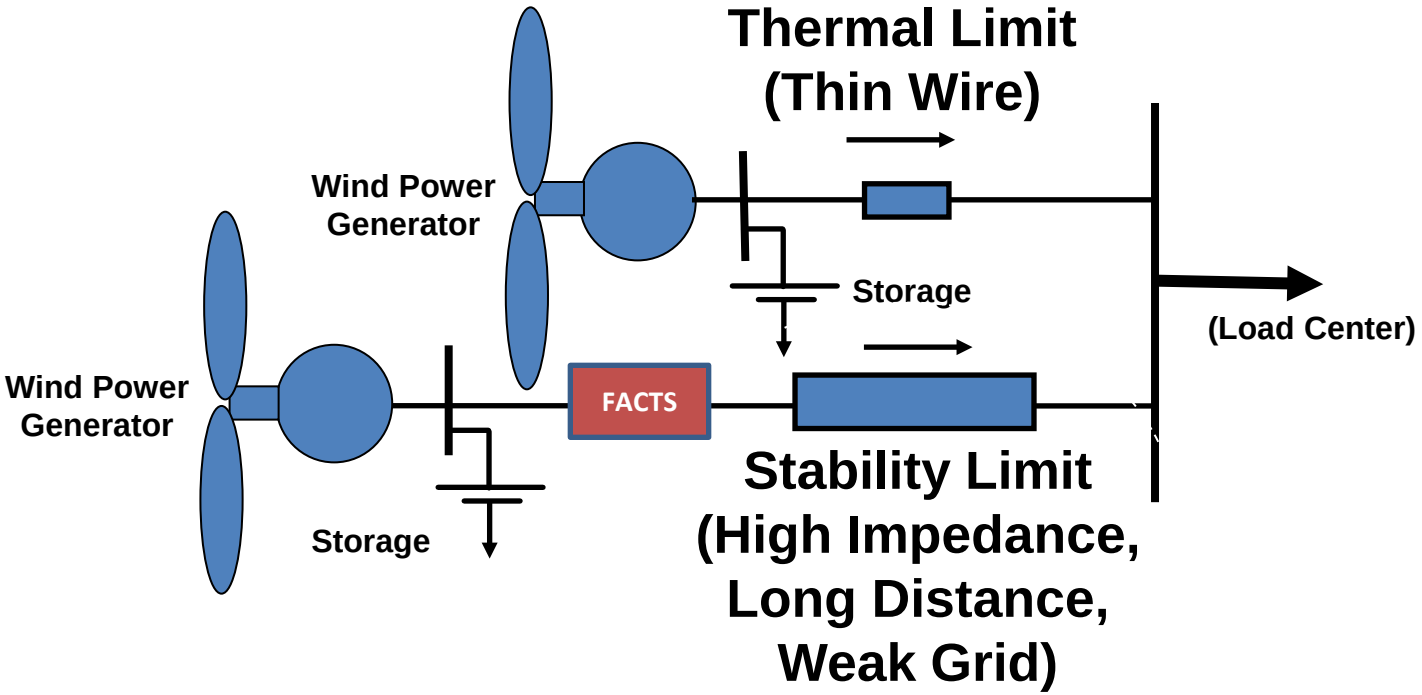
At the Plant Level

Variability



At the Transmission Level

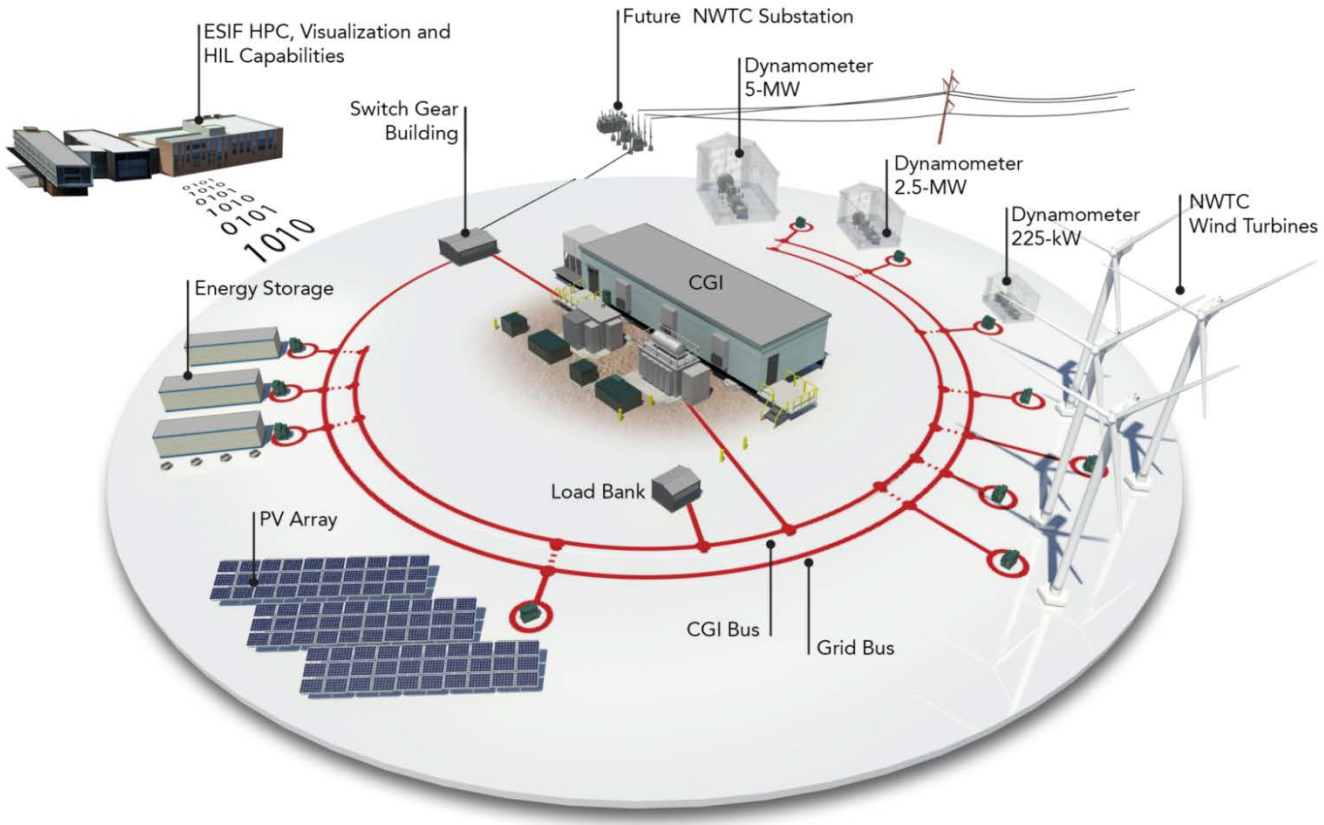
Transmission Constraints



At the Transmission Level

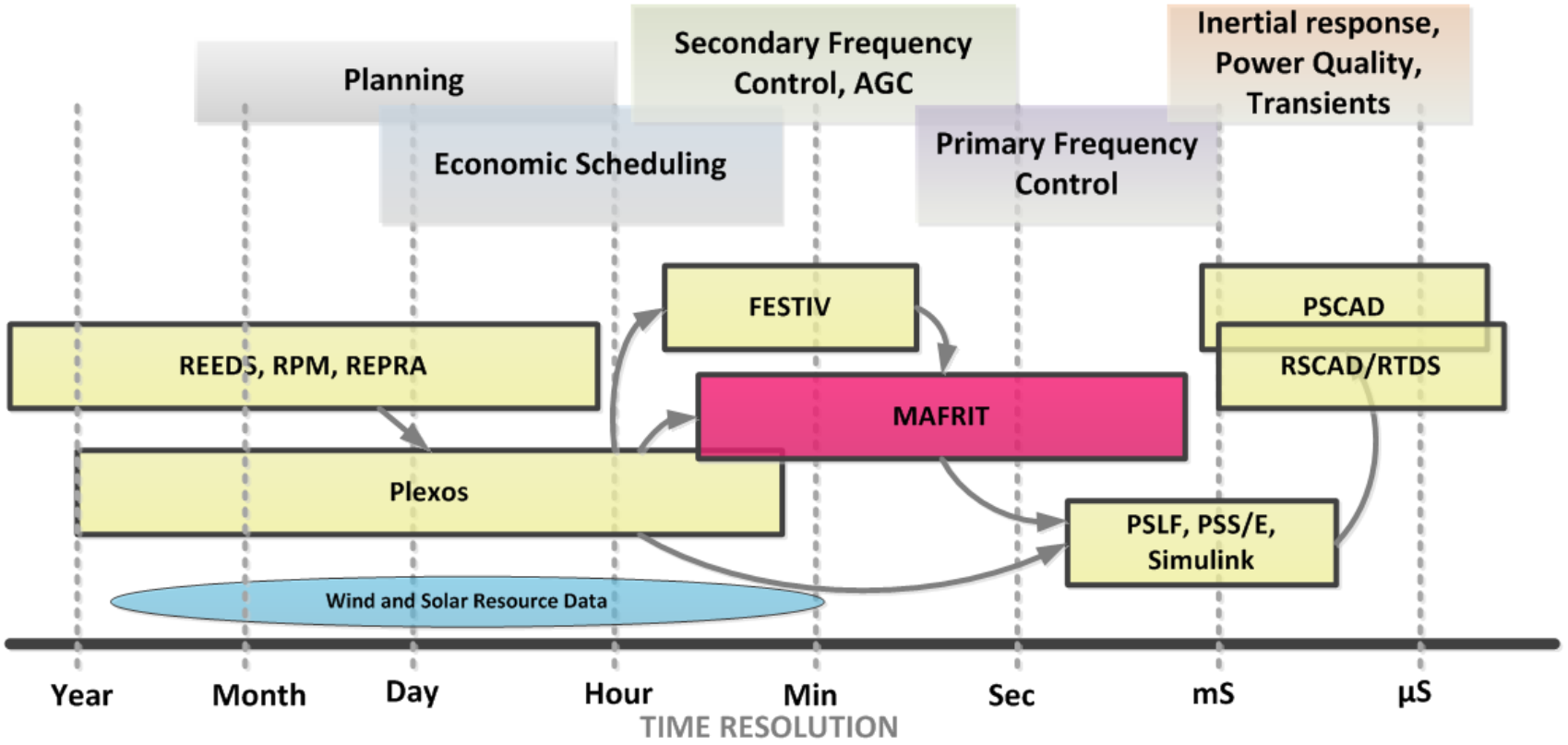
Hardware

Hardware Testing



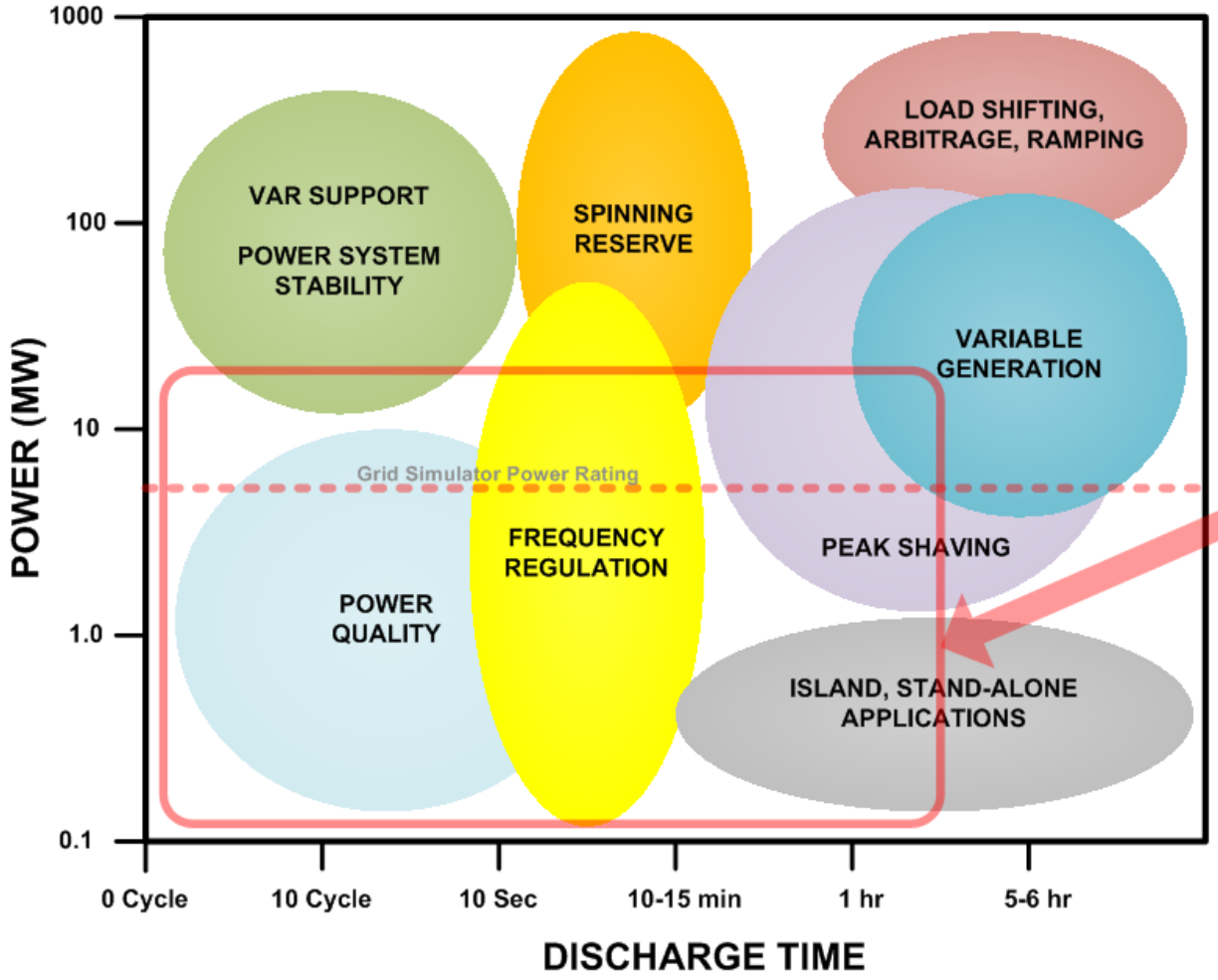
Software

Power Electronics— Bridging Different Time Domains



Storage

Energy Storage



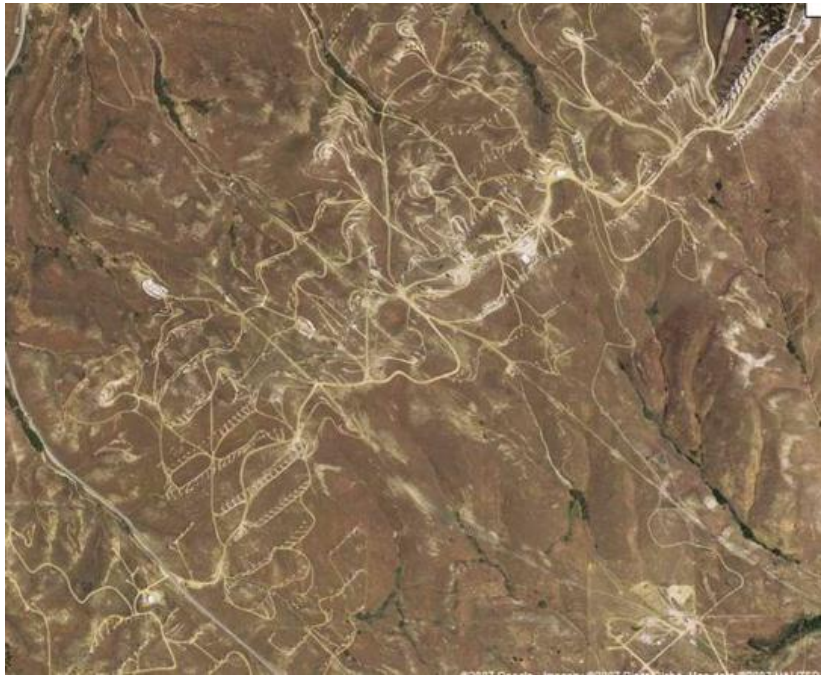
NREL's unique niche in energy storage testing area

Environment

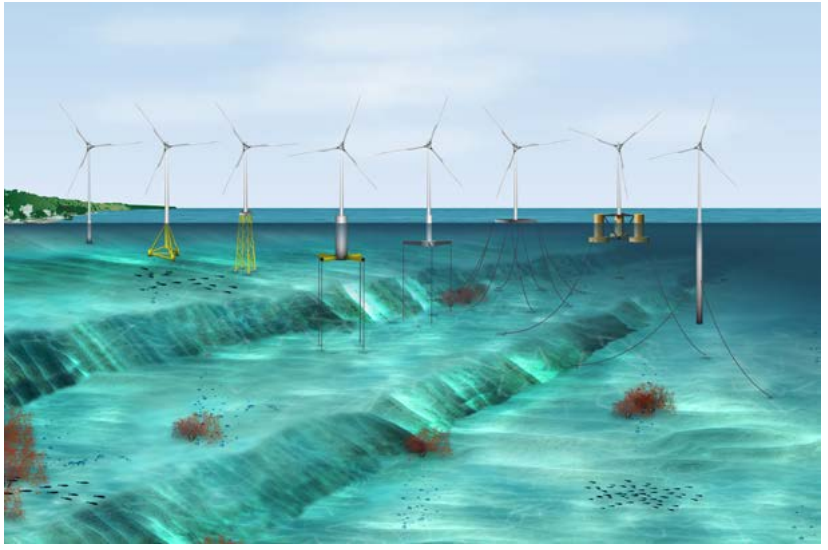
Lightning Protection

Reference: McNiff, B. (2002). *Wind Turbine Lightning Protection Project: 1999–2002.* NREL/SR-500-31115.

Image from Stephen Drouilhet, 05626



Google Map of a wind power plant, Tehachapi, CA



Reference: "NREL Software Aids Offshore Wind Turbine Designs." (2013). Fact Sheet. NREL/FS-6A42-60377.

Summary

- Cost reduction in the past 20 years
- Many and diverse opportunities for power electronics
  - Generation, transmission, and distribution
- Know the limitations
  - Thermal, magnetic, electric (voltage, current), etc.
- Know the applications
  - Environment: ocean, land-based, isolated, clusters
  - Opportunities to work in parallel: PV, wind, and concentrating solar power
- Leverage existing and future technologies
  - Other industries: drives, transportation, shipbuilding
  - Modern technologies: smart control, wireless, condition monitoring, cyber physical and security, synchrophasor, market driven.