NREL
NATIONAL RENEWABLE ENERGY LABORATORY

SESSION 3: Grid Integration Studies for Planning Secure and Reliable System Operations with Expected Shares of Variable Renewables

Presenter: Eduard Muljadi
National Renewable Energy Laboratory
15013 Denver West Parkway, Golden CO 80401

Workshop on Integrating Renewables into Power Systems in Central America

Part B: October 28, 2016: Planning the Secure and Reliable Operation of the Grid in Central America with High Shares of Variable Renewable Energy Resources

Panama City, Panama

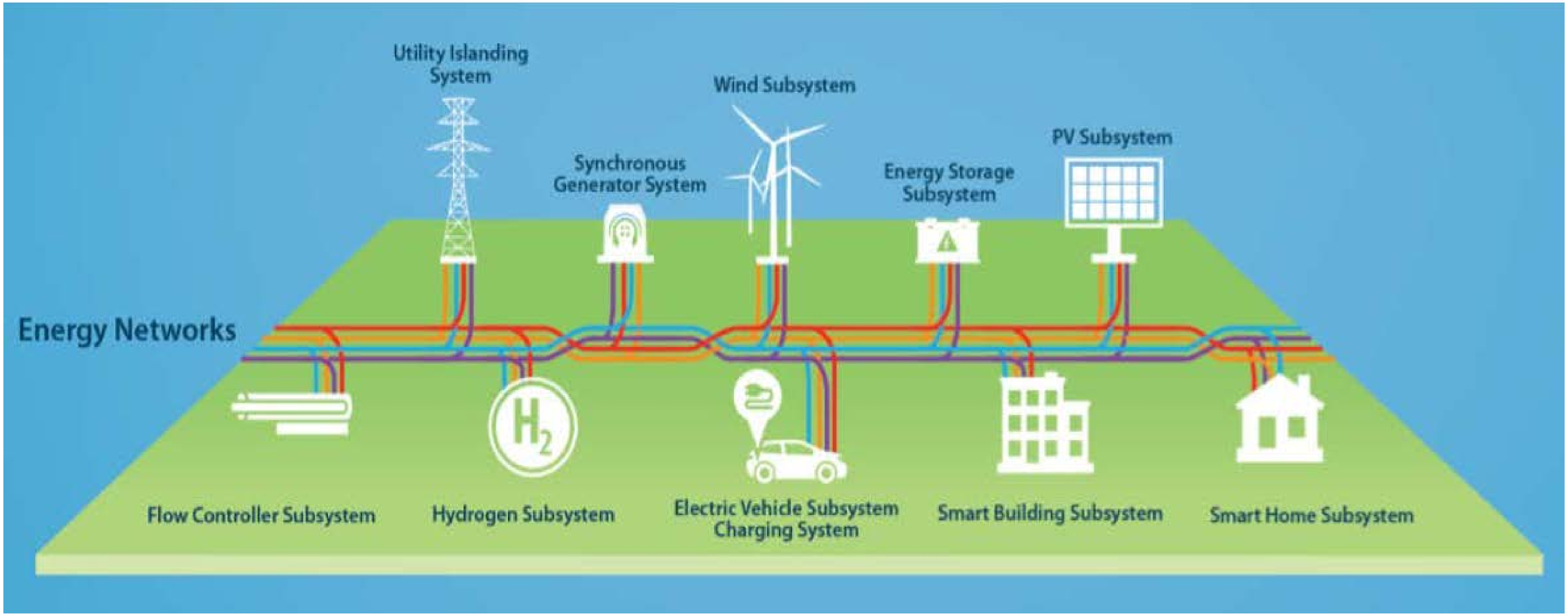
NREL/PR-5D00-67356

Energy Systems Integration

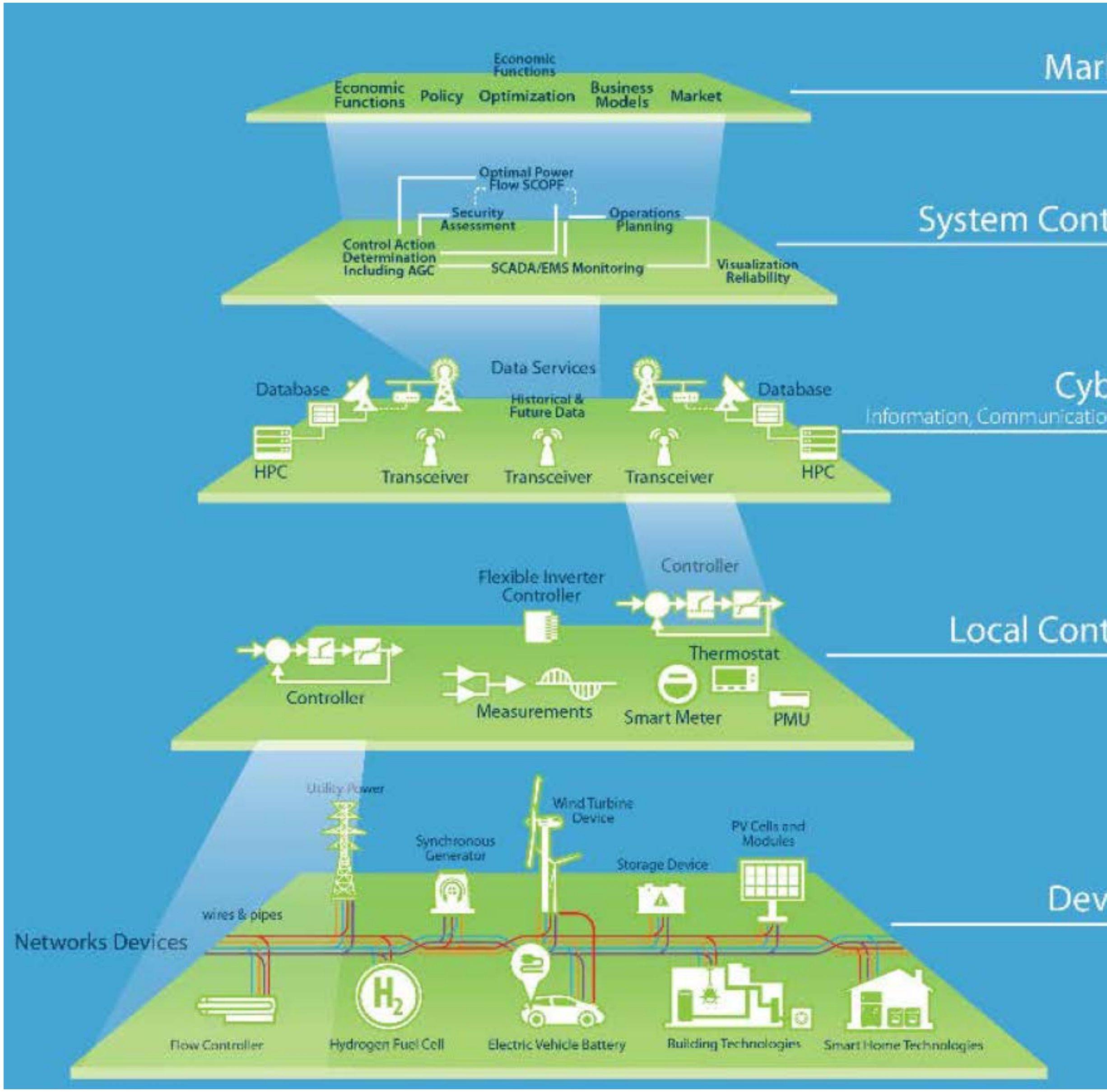
Energy System Integration

- of Renewable Energy Sources
- of Energy Efficiency

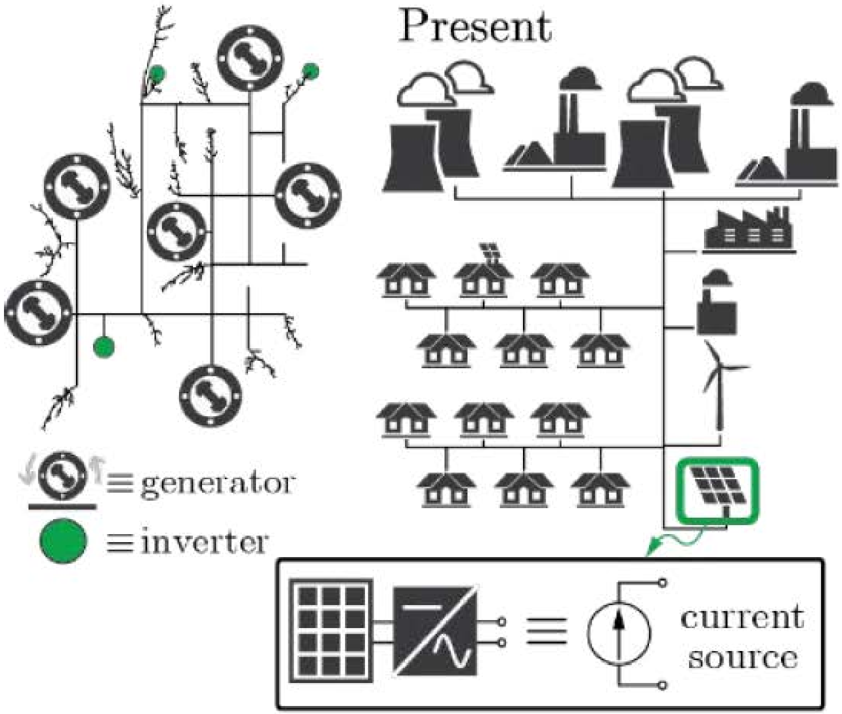
- across energy carriers
- across spatial scales
- across functional layers



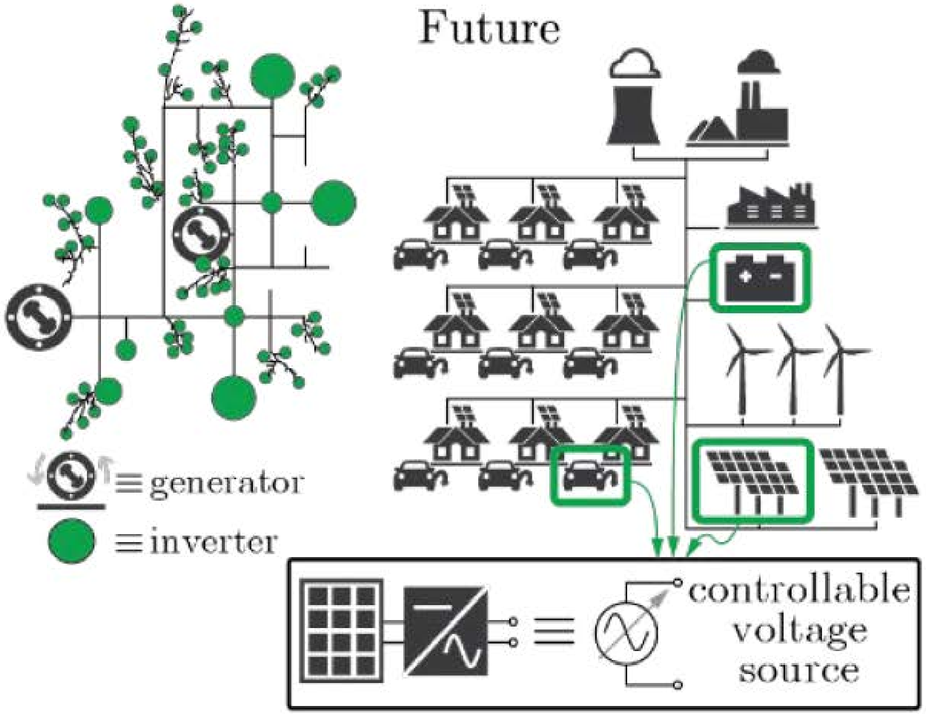
Functional Layers



Evolution of the Grid

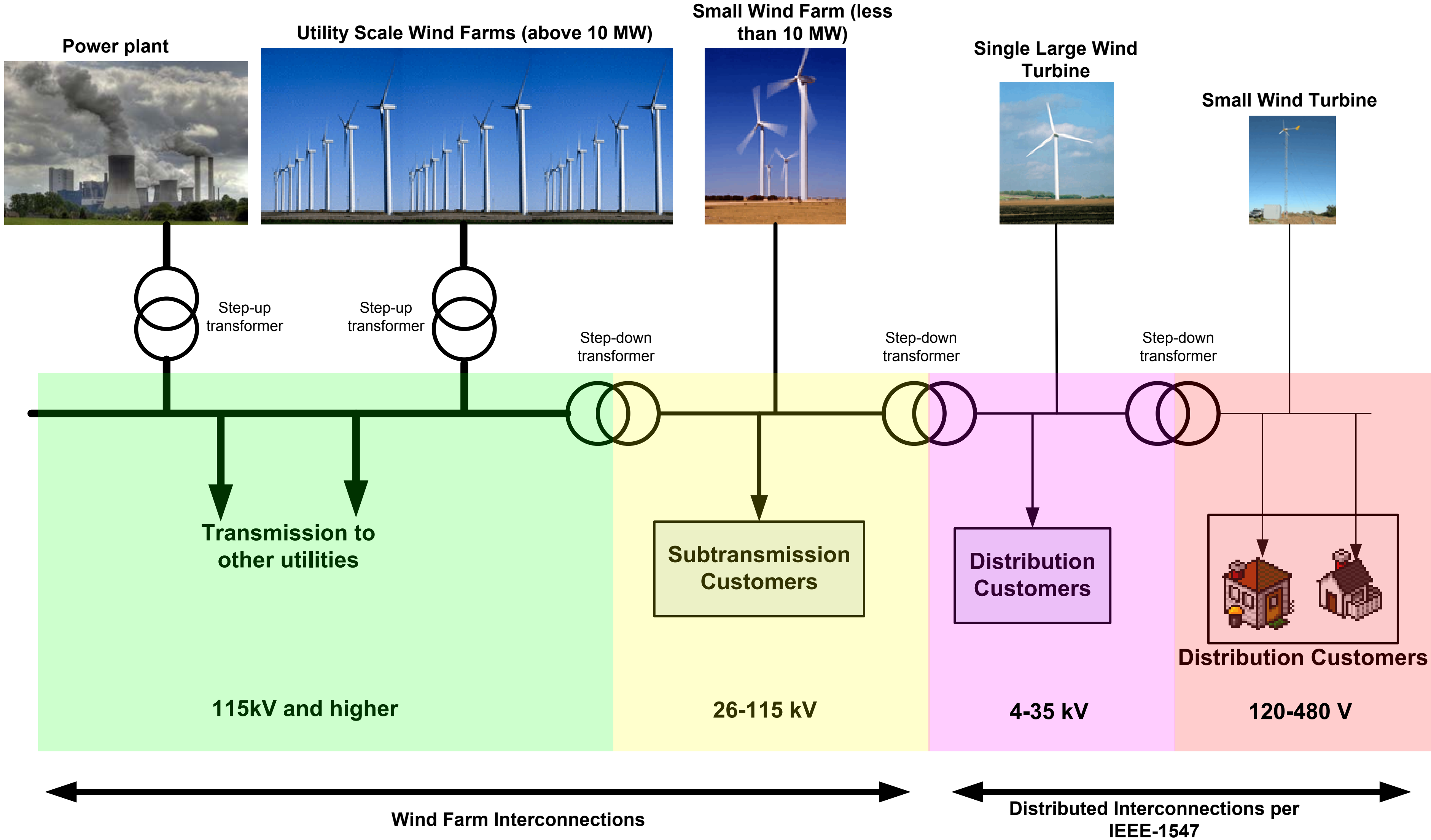


From grid-following controls

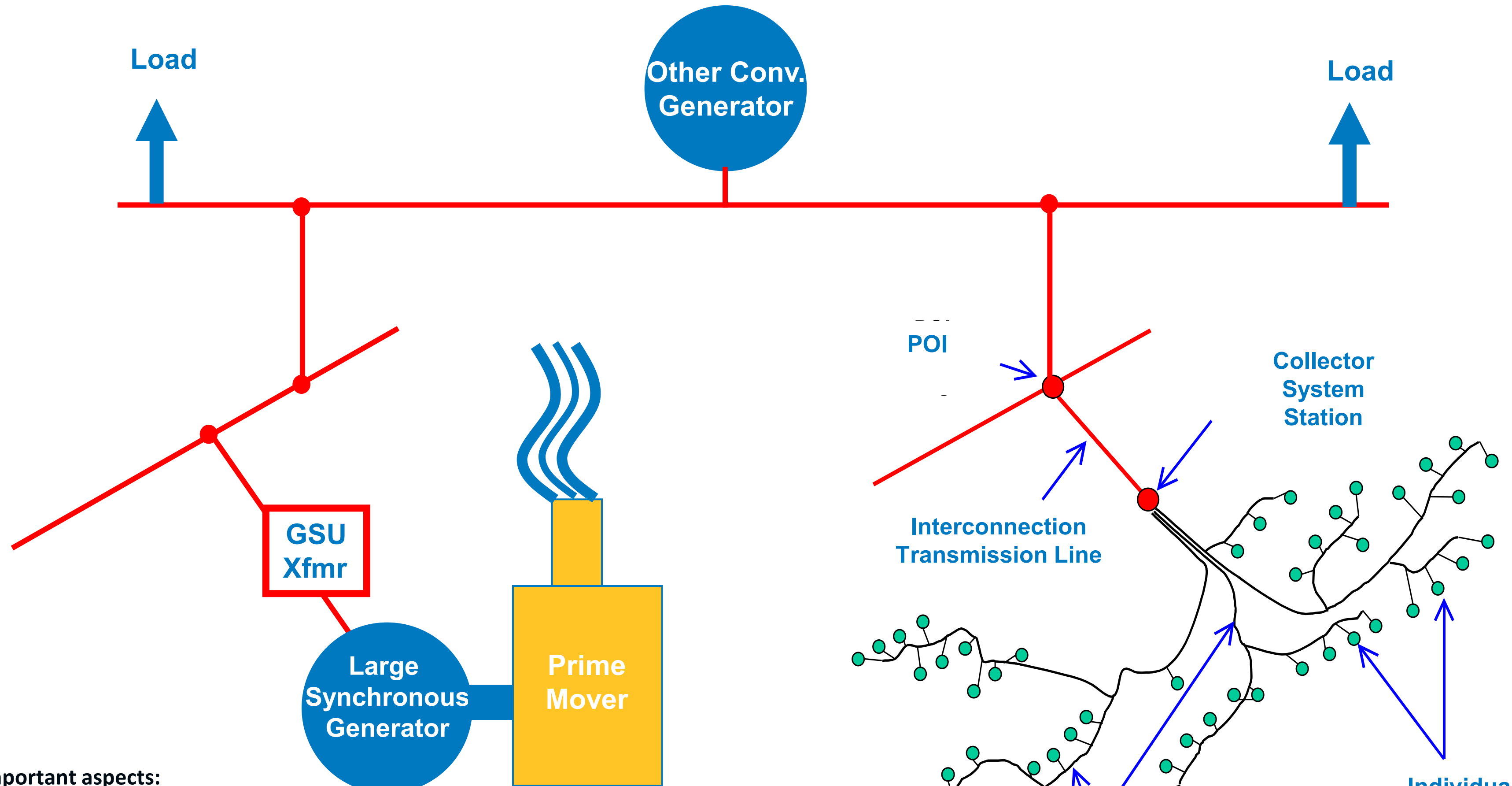


To next-generation grid-forming controls

Renewable Integration



Conventional vs. Renewable Power Plant



<u>Important aspects:</u>

- Collector system optimization
- Reactive power management
- Voltage regulation at the point of interconnection (POI) and each turbine
- AC vs. DC; OH vs. UG; offshore vs. land-based collector systems
- Predictive maintenance
- Wind power plant model vs. wind turbine generator (WTG) model.

Planning and Operational Issues

POWER SYSTEM OPERATIONS

- Operational strategy modeling
- Operating reserve requirements
- Operations of emerging resources (e.g. DR, storage)
- Integration Studies

ELECTRICITY MARKET DESIGN

- Flexibility market designs
- Revenue sufficiency
- Ancillary service market designs, primary frequency response market

POWER SYSTEM PLANNING

- ELCC, LOLP, with renewables
- Generation and transmission expansion
- Policy issues
- Flexibility needs of the future

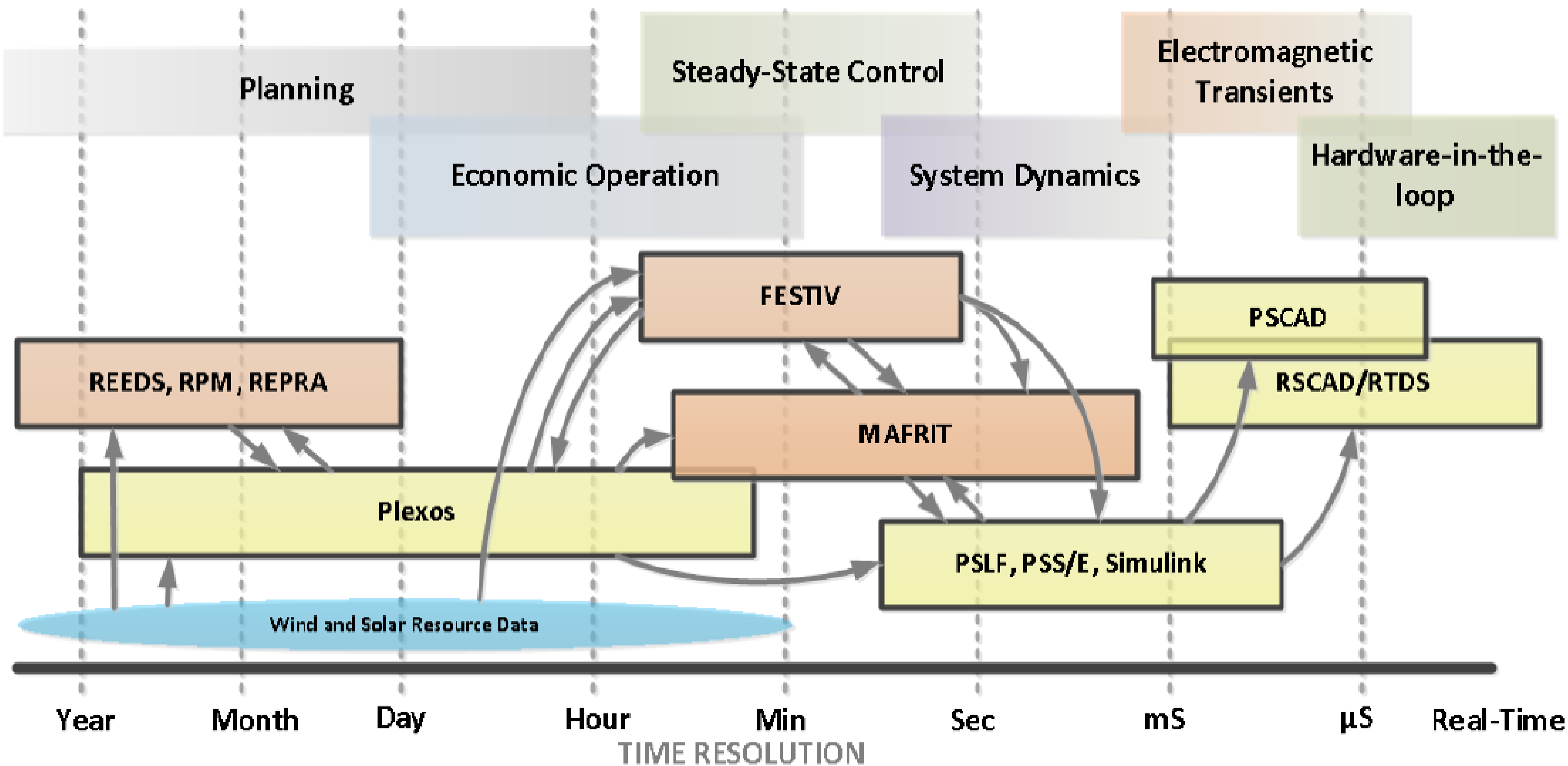
GENERATOR MODELING

- Generic wind and solar models
- Three phase and positive sequence
- Validation using PMUs
- New frequency, voltage, damping controls

OPERATIONAL FORECASTING

- Error characteristics of wind, solar, load forecasts
- Economic and reliability metrics of forecasts
- Probabilistic forecasts

Broad Spectrum of Time Resolution



Resource Adequacy **Economic Dispatch** **Stability—Reliability**

Forecasting

	Type of Forecast	Time Horizon	Key Applications	Methods
Generation	Intra-hour	5-60 min	Regulation, real-time dispatch market clearing	Statistical, persistence.
	Short term	1-6 hours ahead	Scheduling, load-following, congestion management	Blend of statistical and NWP models
	Medium term	Day(s) ahead	Scheduling, reserve requirement, market trading, congestion management	Mainly NWP with corrections for systematic biases
	Long term	Week(s), Seasonal, 1 year or more ahead	Resource planning, contingency analysis, maintenance planning, operation management	Climatological forecasts, NWP
Decision support	Ramp forecasting	Continuous	Situational awareness, Curtailment	NWP and statistical
	Load forecasting	Day ahead, hour-ahead, intra-hour	Congestion management, demand side management	Statistical

Grid Codes

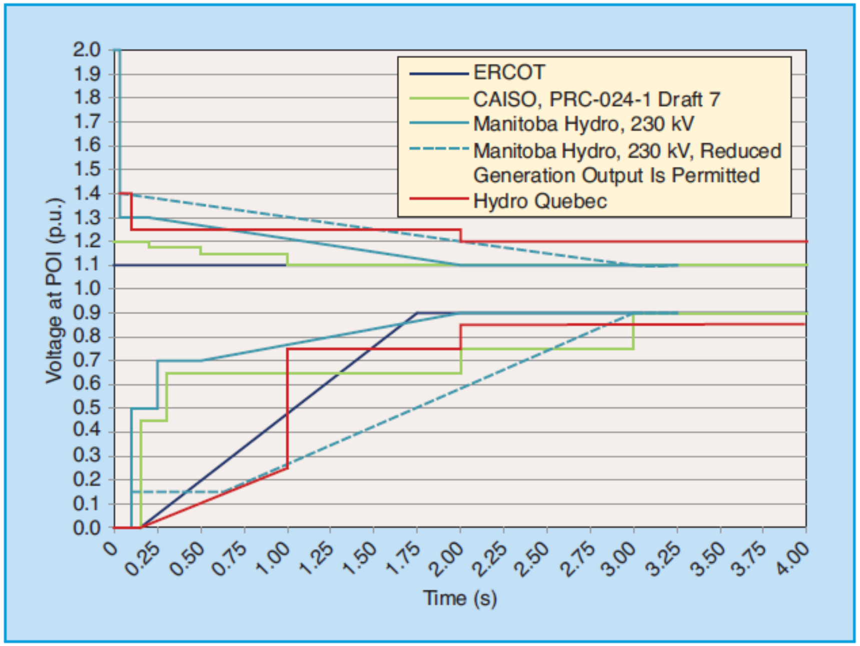


figure 1. Low and high fault ride-through. The requirements in PRC-024-1 are severity-cumulative duration curves, while other requirements are voltage-versus-time envelopes.

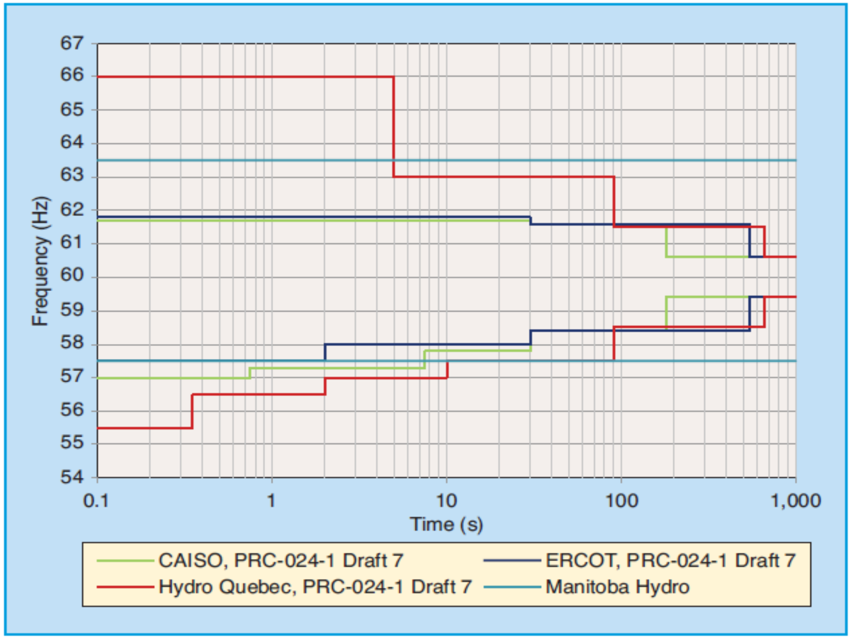


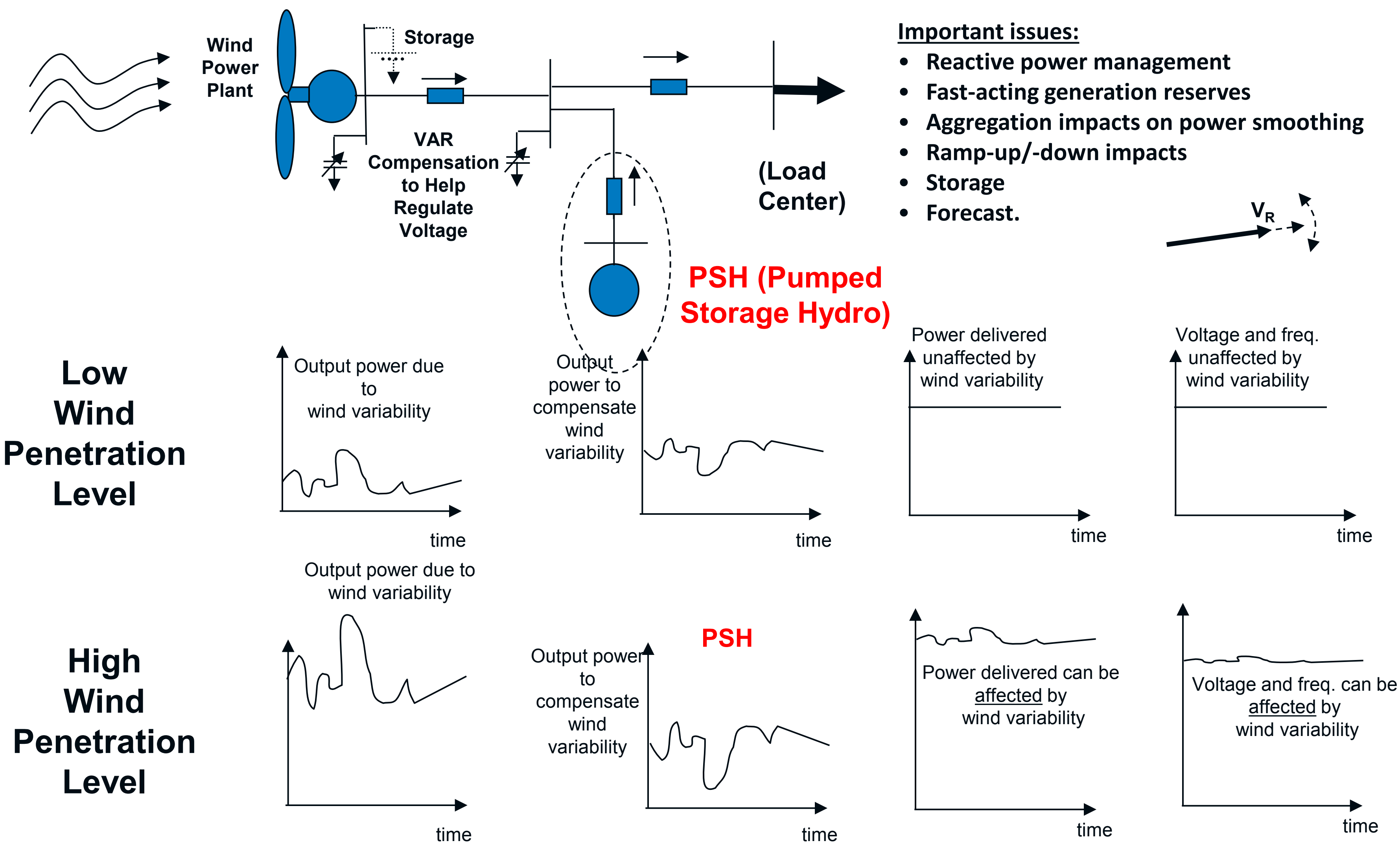
figure 2. Frequency range requirements.

Grid code:

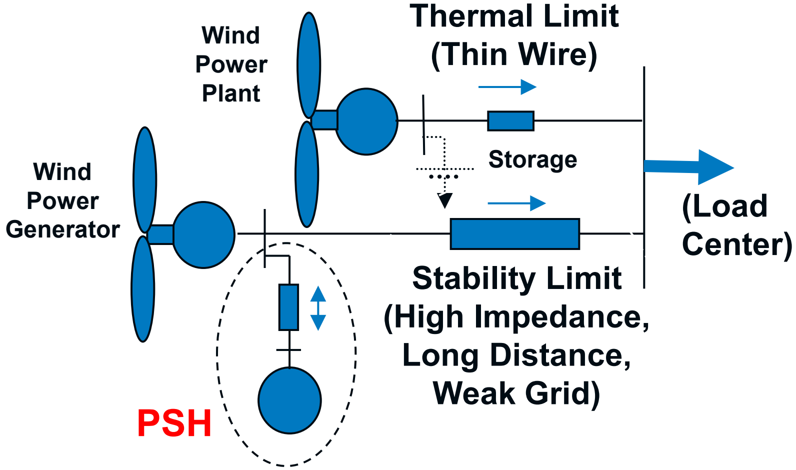
- **Voltage and frequency range requirement**
- **Reactive power capability at the generator or plant level**
- **Requirement for system communication and data acquisition**
- **Requirement for supervisory control and coordinated system protection**
- **Depends on the regional reliability organization and/or local utilities.**

Challenges—Output Variability

Important issues:
- **Reactive power management**
- **Fast-acting generation reserves**
- **Aggregation impacts on power smoothing**
- **Ramp-up/-down impacts**
- **Storage**
- **Forecast.**



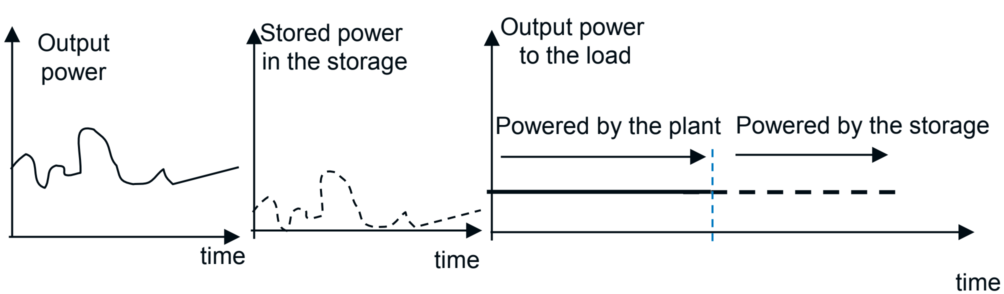
Challenges—Transmission Constraints



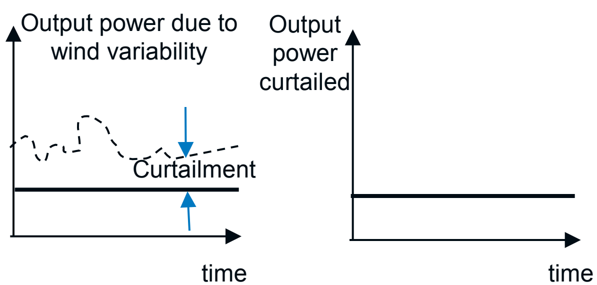
Important issues:

- Short-term storage—stability improvement
- Long-term storage—economic/peak-shaving
- Large-scale transmission optimized planning
- High-voltage power electronics (FACTS devices)
- Smart grid, demand-side management, deferrable load, controllable load resources, plug-in hybrid electric vehicles
- Forecast.

Storage (Energy Time Shifter)



No Storage, Curtailment (Energy Wasted)



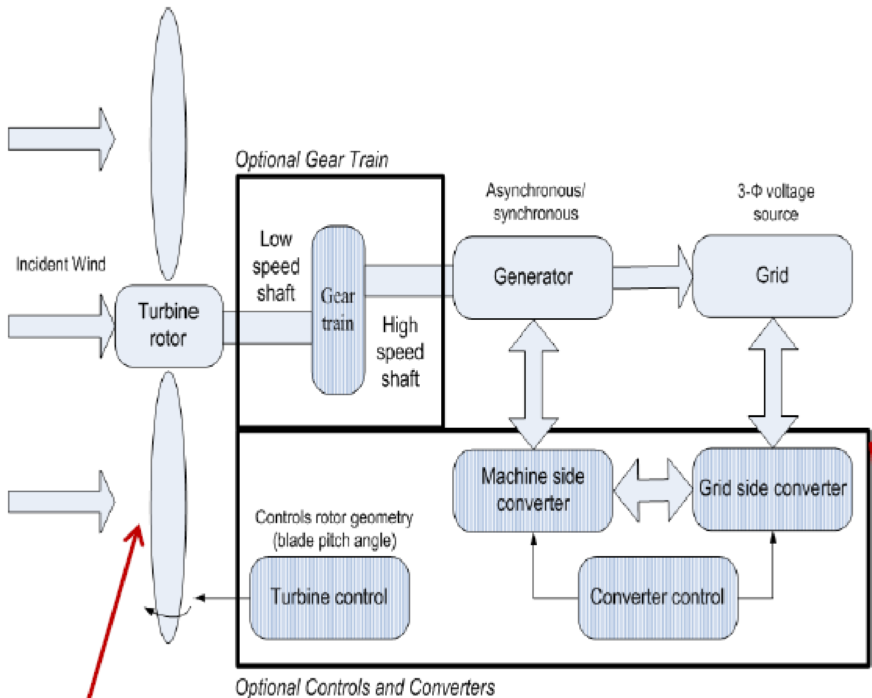
Load Flow Modeling

- Engineering, not economic model
- Common models: PSLF, PSSE, and PowerWorld
- Bus-level detail
- Analyze multiple post-contingency events
- Steady-state contingency for n-1 event (thermal and voltage analysis, static voltage stability, transfer limits)
- Example uses include secure islanding, reactive power adequacy
- Transient analysis for frequency and voltage effect (and not chronological; rather, snapshot in time)
- Dynamic contingency.

Dynamic Modeling

- It is important to determine the power system survival after a disturbance. The post-transient dynamic condition must be a stable operation.
- Power system disturbances may include faults, unbalance, voltage/frequency dips, oscillations, and they may be short-term or persistent.
- Resource disturbances may include a sudden change of output power (forecast error, ramping rates of wind power plants, temporary cloud shading on photovoltaic [PV] plant).
- A correct/up-to-date representation of the model of the generator, system network, control/protection, or sequence of events is required.
- The collective behavior of the plant (hundreds of wind turbines or PV inverters) is more important than that of a single generator.

Wind Turbine Dynamic Model



Optional controls:
- Type 1: None
- Type 2: Machine-side converter + R_{ext}
- Type 3: Both converters on rotor circuit + blade pitch control (allows additional user input: Reactive power demand)
- Type 4: Both converters on stator circuit + blade pitch control (also allows reactive power demand)

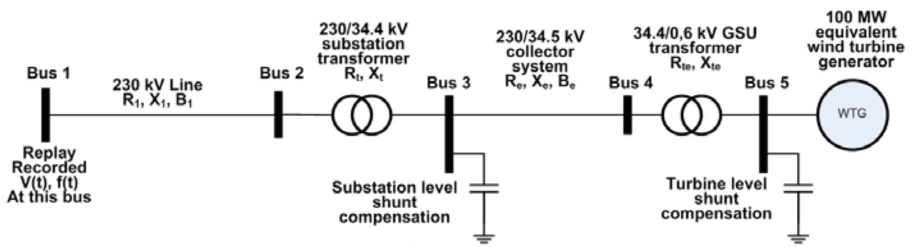
Wind speed, user input:
A) Constant, or can be
B) Waveform: Mean value + ramp + gust + noise, or
C) Random samples from distribution

Model framework

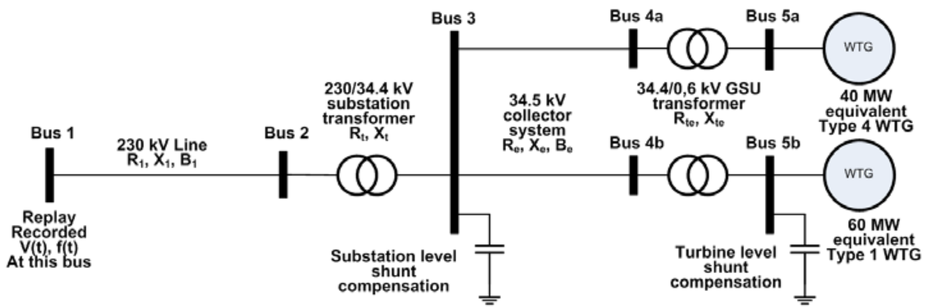
- Develop models for electromechanical devices, power electronic converters and controls for RE generators
- Uses of models: Fault response, frequency response, stability assessments, power quality & harmonics studies among others
- Platforms: PSLF, PSS/E, PSCAD, RTDS/RSCAD, Cyme, MATLAB/Simulink
- Usage of PMU data for validation and simulation
- Work with WECC REMTF on standard models
- Collaboration with EPRI, WECC, Sandia, BPA, others
- Develop individual generator models and aggregate plant level models
  - 4 WTG types
  - PV
  - Pumped Storage Hydro (FY14 onwards)

Dynamic Model Validation—Wind Power Plant

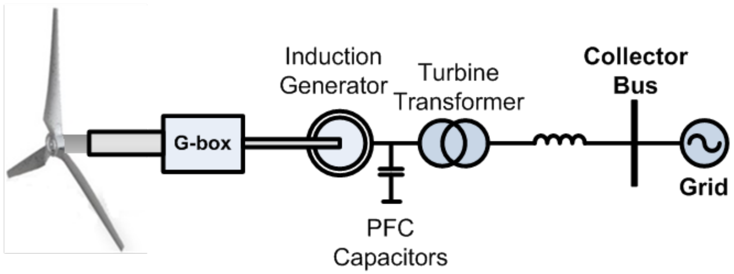
Wind Power Plant Representation



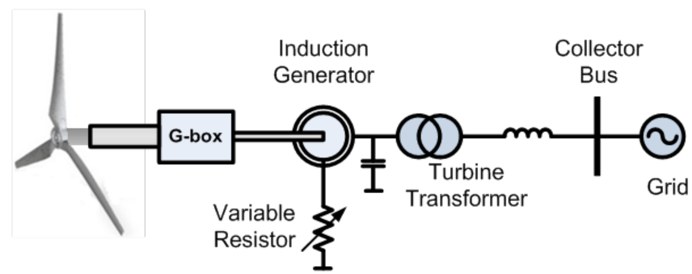
Single-turbine representation



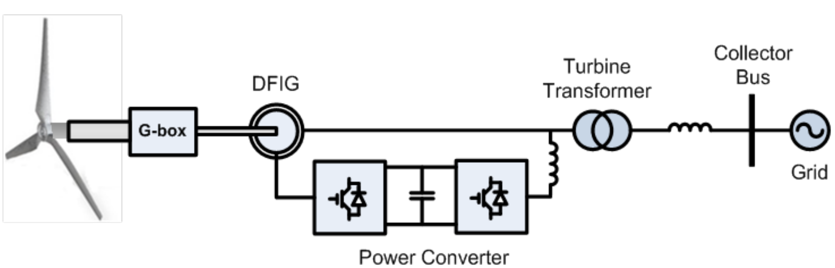
Multiple-turbine representation



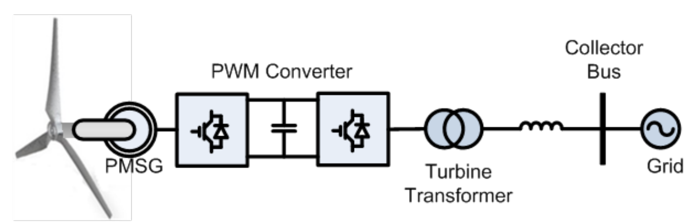
Type 1 Fixed Speed Induction Generator



Type 2 Variable Slip Induction Generator



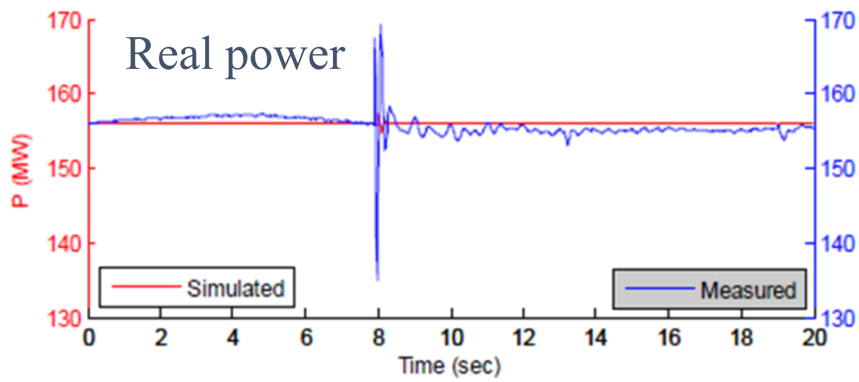
Type 3 Doubly Fed Induction Generator (DFIG)
(Variable Speed WTG)

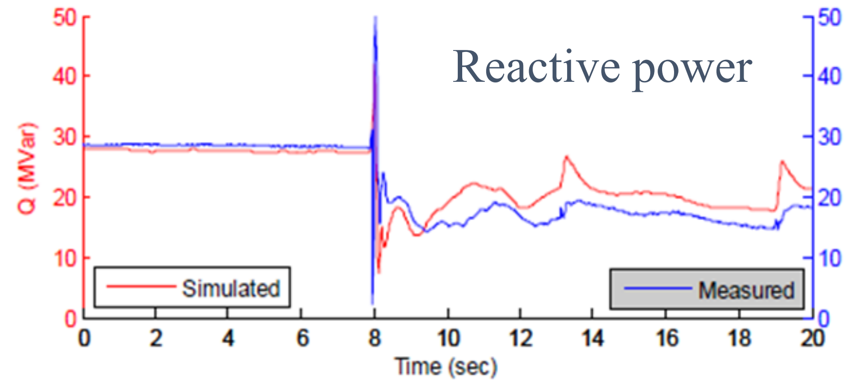


Type 4 Full Power Conversion
(Variable Speed WTG)

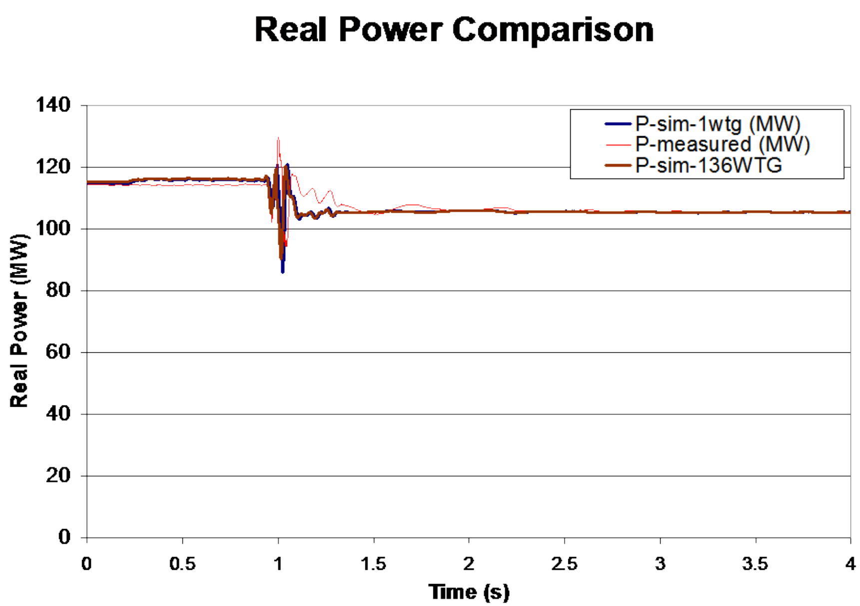
Dynamic Model Validation—Wind Power Plant

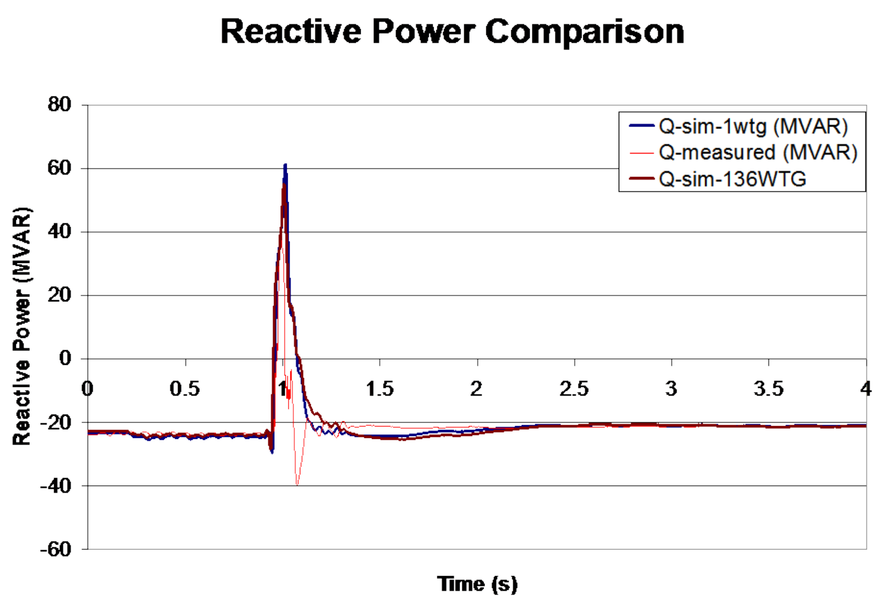
A Wind Power Plant in the Northwest United States





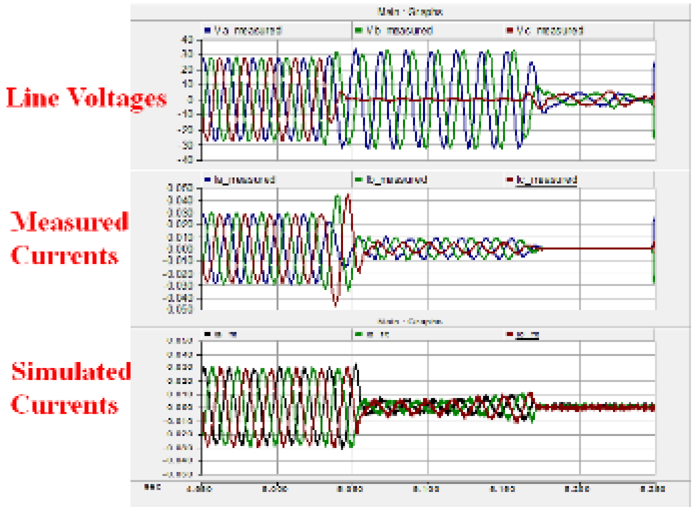
A Wind Power Plant in the Midwest United States



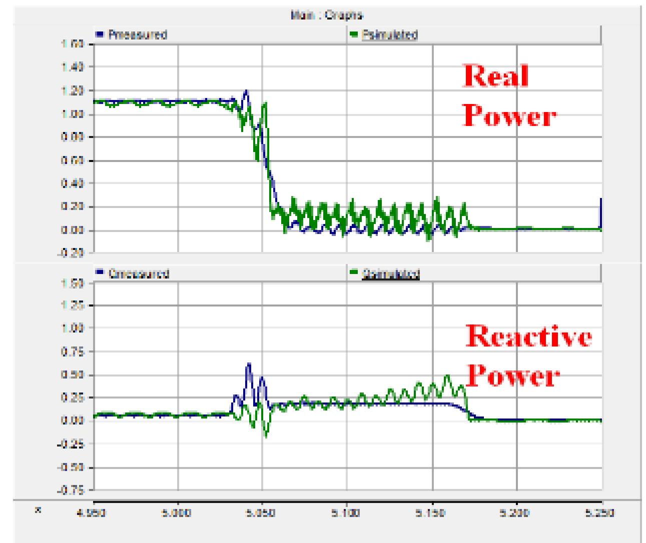


Dynamic Model Validation—Photovoltaic Power Plant

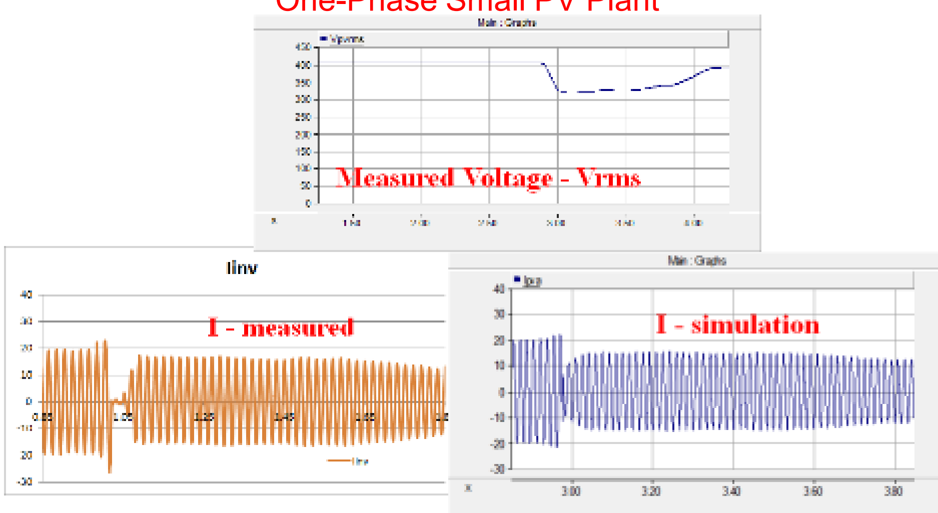
Transient Solar Model Development
Three-Phase Large PV Plant



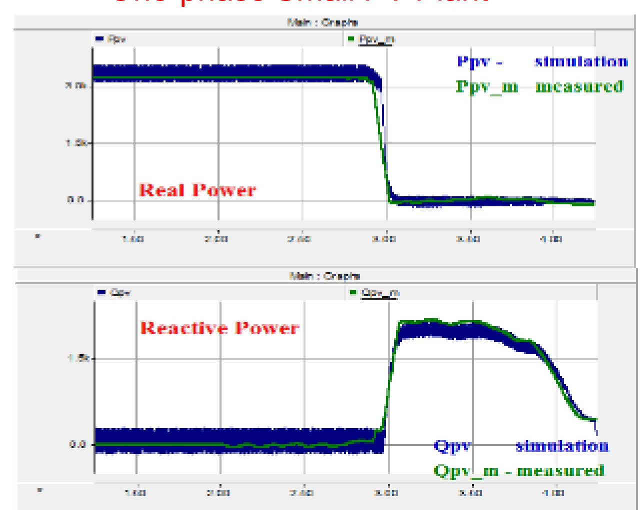
Transient Solar Model Development
Three-Phase Large PV Plant



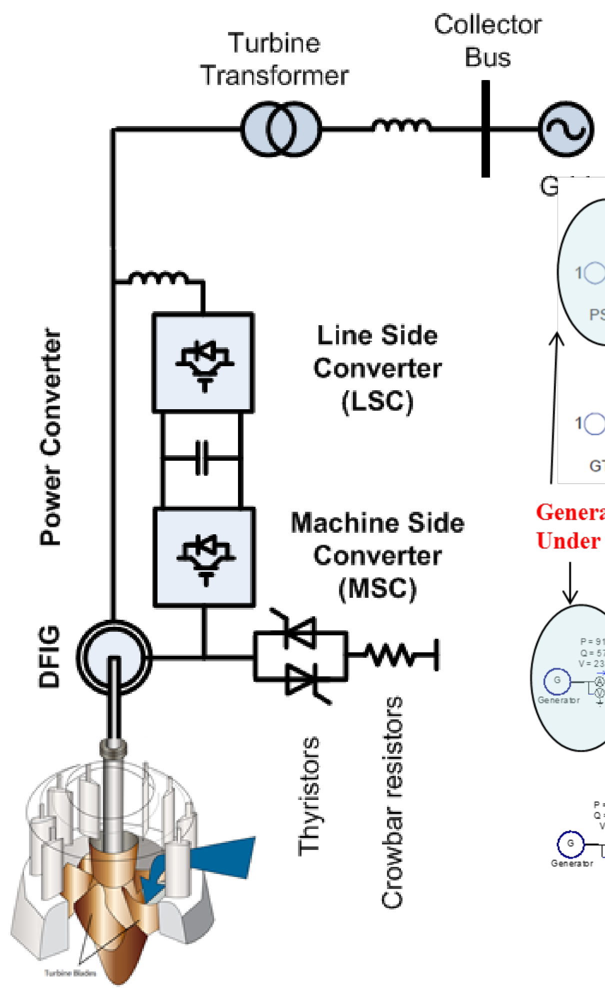
Transient Solar Model Development
One-Phase Small PV Plant



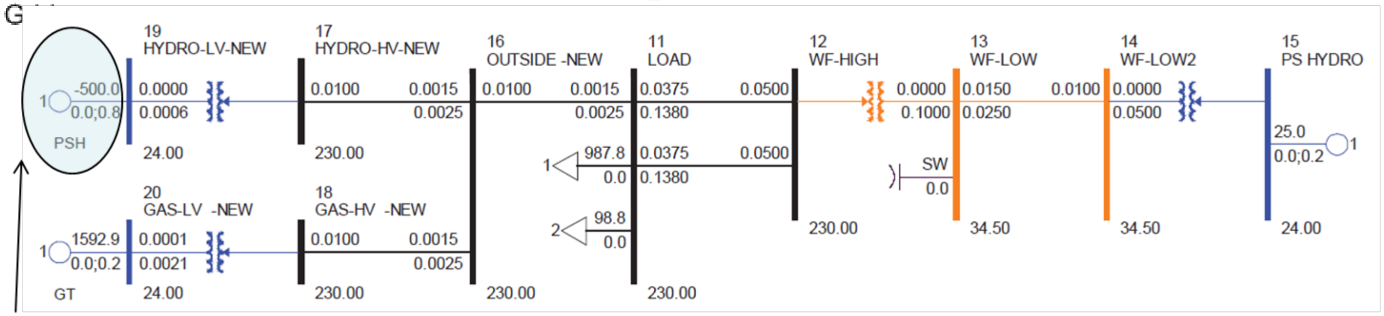
Transient Solar Model Development
One-phase Small PV Plant



Dynamic Model Validation—Pumped Storage Hydro

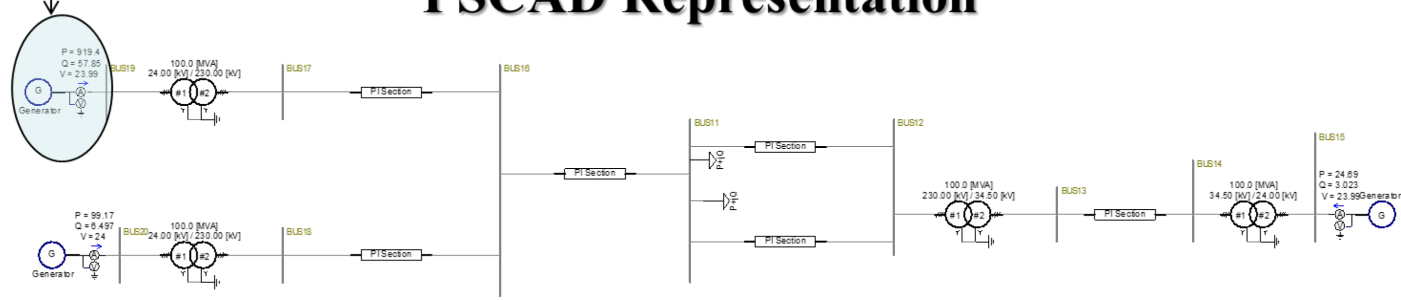


PSSE Representation

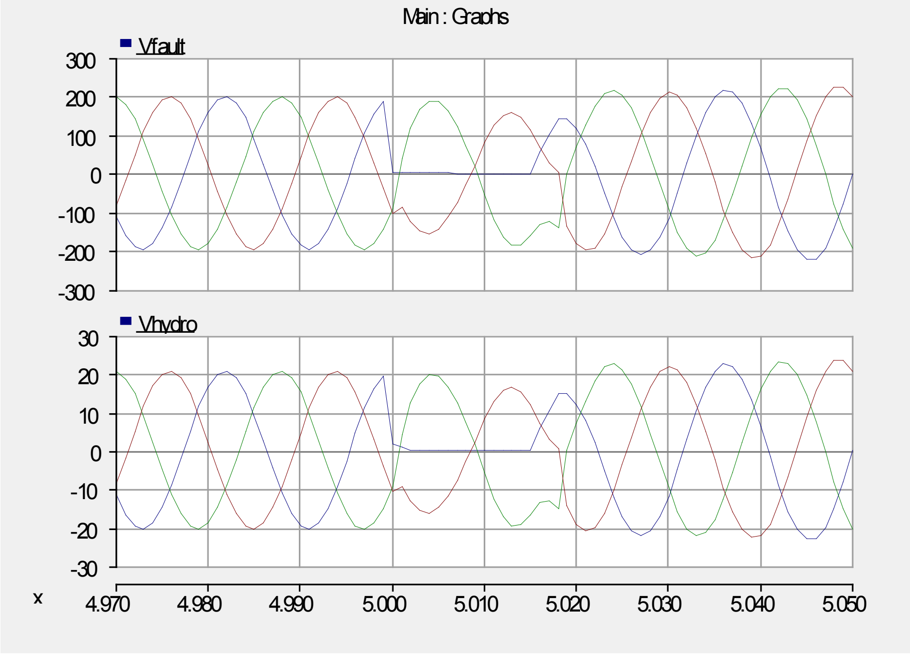


Generator Under Test

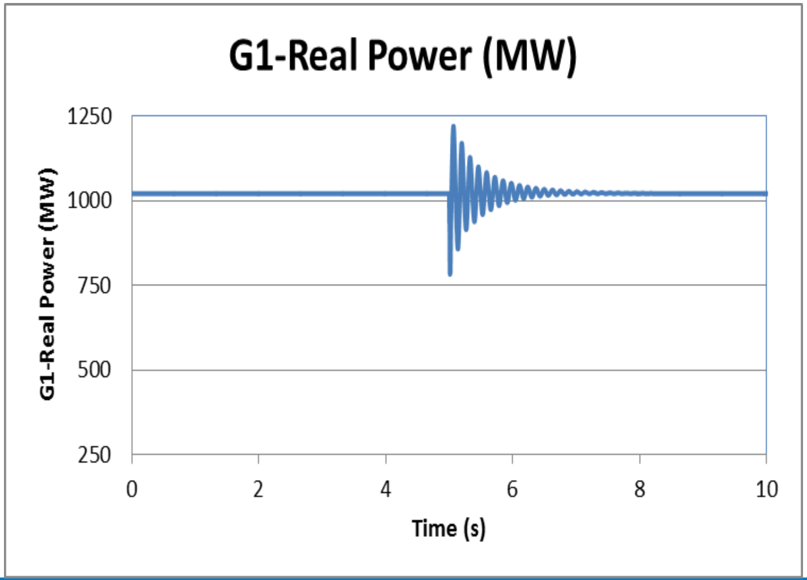
PSCAD Representation

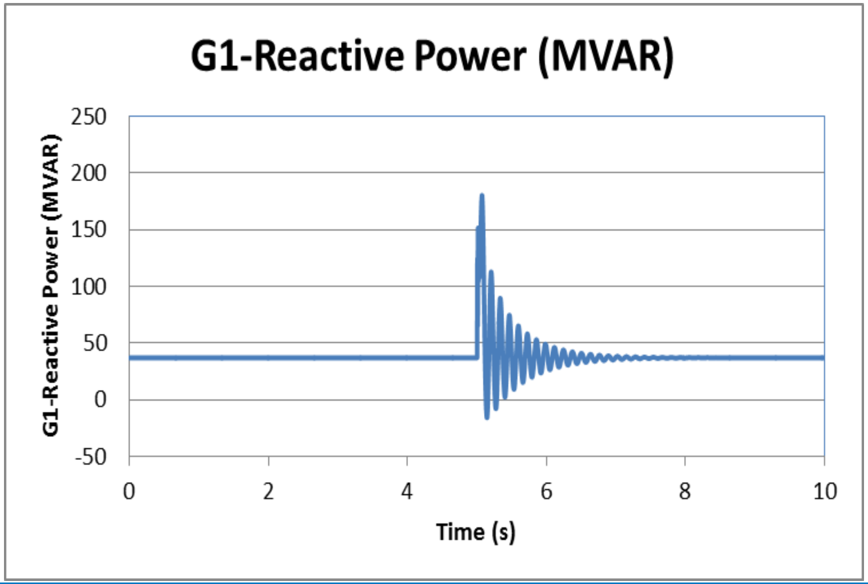


Dynamic Model Validation—Pumped Storage Hydro



Single-Line-to-Ground *Fault*





Summary

- Energy systems integration consists of renewable and efficiency aspects. It includes energy carriers, spatial scales, and functional layers.
- The integration of variable and renewable energy resources into the grid should be considered from many different angles and across different time resolutions.
- The grid of the future has different characteristics from those of the conventional grid in several way (e.g., bidirectional power flow; many inverter-based generators; less susceptible to frequency/voltage deviations; high penetrations of variable and renewable energy resources; the presence of long-/short-term energy storage and FACTS devices; market and technically driven; coexistence of AC and DC systems; wide-area-based coordination in monitoring, control, and protection).
- Power systems of the future will be more dynamic and require a shorter cycle of system planning, operation, and market design as technology moves at a rapid pace.
- Grid codes are expected to be revised at the national, regional, and local levels to reflect the continuing changes in the system network and existing technologies.

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- V. Gevorgian et al. Forthcoming. “Controllable Grid Interface for Testing Ancillary Service Controls and Fault Performance of Utility-Scale Wind Power Generation.” Paper to be presented at the 15th Wind and Solar Integration Workshop, Vienna, Austria, November 15–17, 2016.

- V. Gevorgian et al. Forthcoming. “Demonstration of Active Power Controls by Utility-Scale PV Power Plant in an Island Grid.” Paper to be presented at the 15th Wind and Solar Integration Workshop, Vienna, Austria, November 15–17, 2016.

- Additional publications can be found at www.nrel.gov/publications.

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