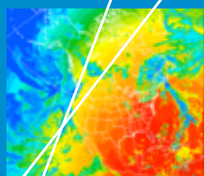
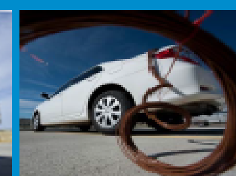
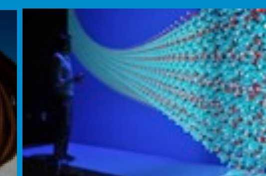
Power System Engineering Center (PSEC)



Ben Kroposki, PhD, PE, FIEEE

PSEC Director

March 2015

Background on NREL and Power Systems Engineering

NREL and PSEC

Energy Systems Integration

National Renewable Energy Laboratory (NREL)

Develops renewable energy and energy efficiency technologies and practices, advances related science and engineering, and transfers knowledge and innovations to address the nation's energy and environmental goals.

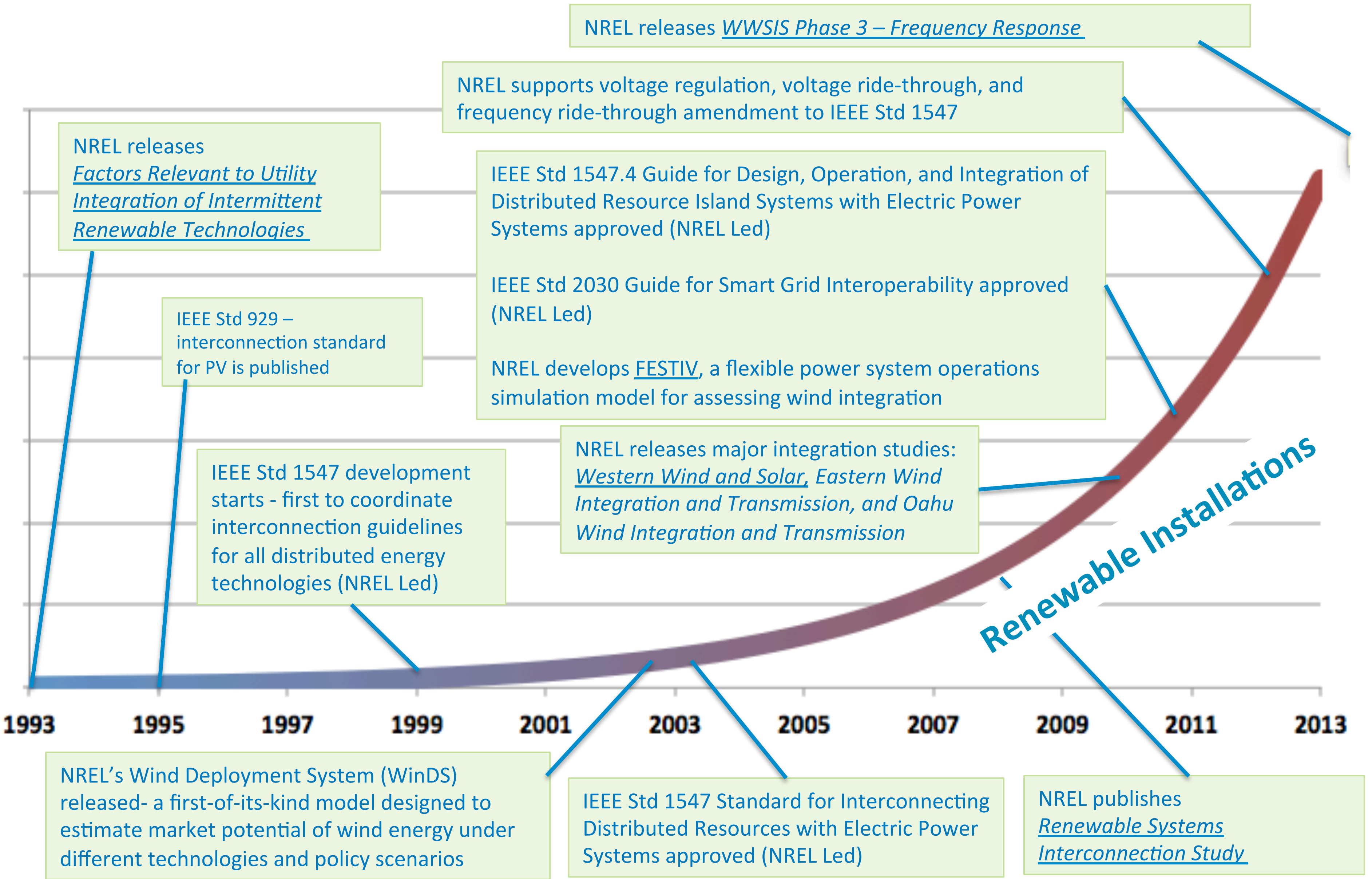
Power Systems Engineering Center (PSEC)

Addresses the design, planning and operational challenges of integrating clean energy technologies into electric grids through high-impact research and development in power systems engineering and resource assessment and forecasting.

PSEC is at the cutting-edge of integrating variable generation into power grids

Renewable Integration Timeline and Major NREL Involvement

Energy Systems Integration



NREL's PSEC Capabilities and Scope of Work

Energy Systems Integration

- **Distributed Energy Systems Integration**
  - Power electronics and interface design and testing
  - Distribution system and device data collection and visualization
  - Distributed power systems modeling
  - Microgrids and energy storage applications
  - Standards and codes development
  - Device and Integrated System Testing and Evaluation

- **Transmission Grid Integration**
  - Bulk system planning and operational tool development
  - Bulk system simulations and operations
  - Large generator and storage testing and modeling
  - Development of active power controls and frequency response
  - Energy markets design and analysis

- **Resource Assessment and Forecasting**
  - Solar resource measurement
  - Instrument calibration and characterization
  - Solar monitoring training
  - Standards development and information dissemination.

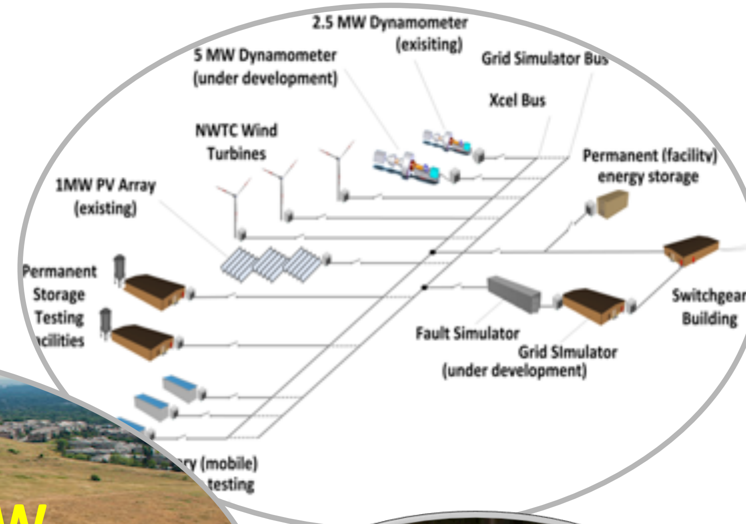
PSEC develops solutions to provide "end-to-end" capabilities from devices to markets

NREL's Energy Systems Integration Facilities

Energy Systems Integration

A unique national asset for energy systems integration R&D, testing, and analysis at various scales

NWTC – 2MW+



SRRL

DERTF
1kW-200kW

EV Chargers
NG and H2
Filling Stations

TTF

VTIF

RSF and NREL Campus

Energy Systems Integration Facility (ESIF)

Energy Systems Integration

http://www.nrel.gov/esif

NREL NATIONAL RENEWABLE ENERGY LABORATORY | ENERGY SYSTEMS INTEGRATION FACILITY

U.S. DEPARTMENT OF ENERGY

Unique Capabilities

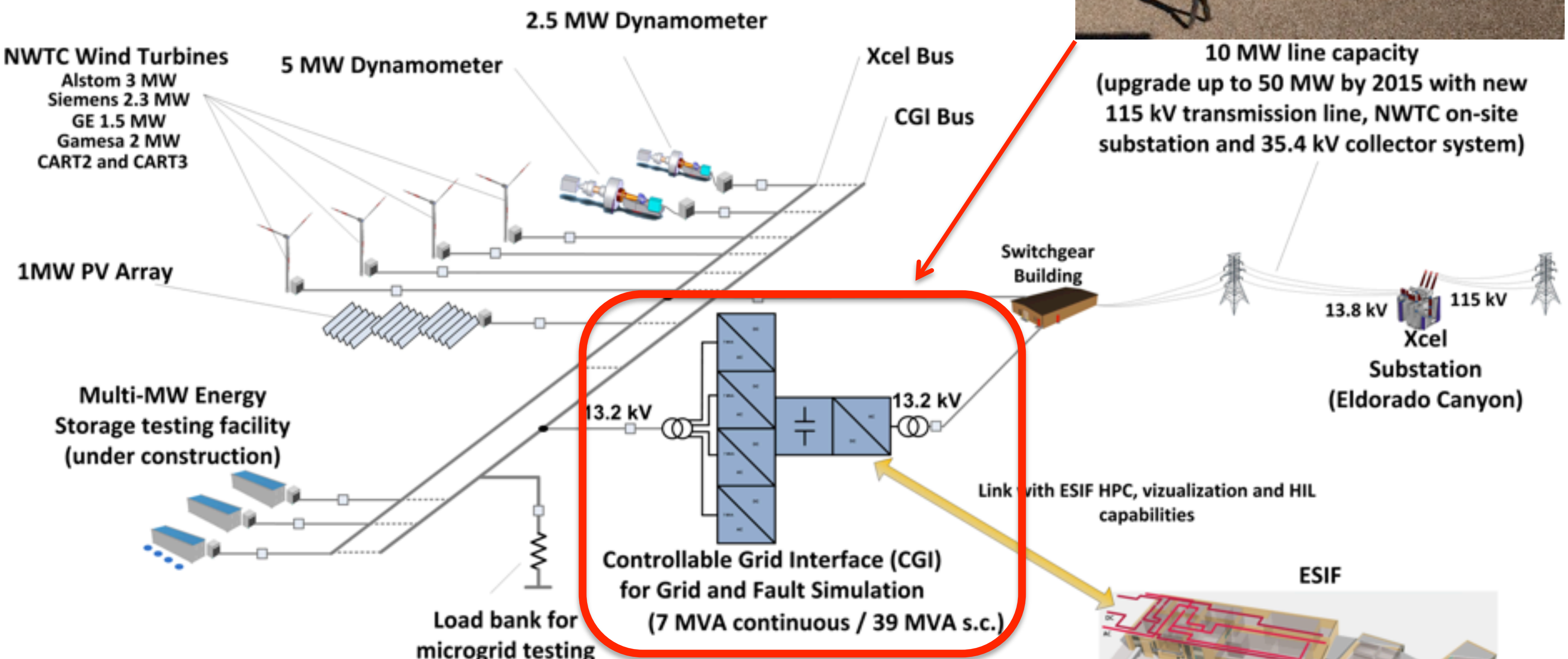
- Multiple parallel AC and DC experimental busses (MW power level) with grid simulation and loads
- Flexible interconnection points for electricity, thermal, and fuels
- Medium voltage (15kV) microgrid test bed
- Virtual utility operations center and visualization rooms
- Smart grid testing lab for advanced communications and control
- Interconnectivity to external field sites for data feeds and model validation
- Petascale HPC and data mgmt system in showcase energy efficient data center
- MW-scale Power hardware-in-the-loop (PHIL) simulation capability to test grid scenarios with high penetrations of clean energy technologies

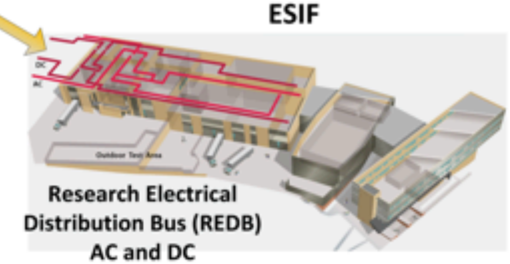
Shortening the time between innovation and practice

NREL – ESI at NWTC

Energy Systems Integration

- **Highly flexible and configurable controllable grid interface (CGI) for system level multi-MW testing/ demonstration platform**
- **Switchgear upgrade to connect field turbines and energy storage pads completed**





- **Grid connected testing**
- **Microgrids and off-grid system testing**
- **Combination of technologies / Advanced controls**

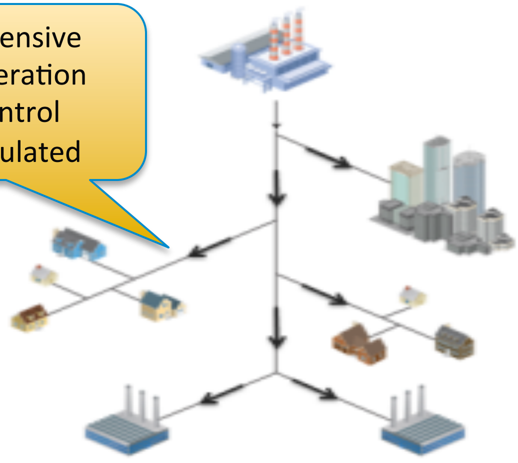
The Future Grid

Evolution of the Grid

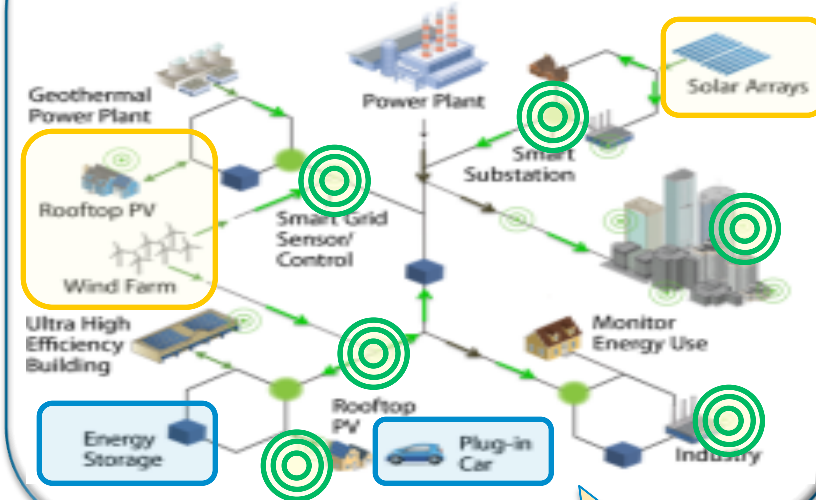
Energy Systems Integration

Current Power System

- Carbon Intensive
- Large Generation
- Central Control
- Highly Regulated



Future Power Systems



DRIVERS
- Increased variable gen
- More bi-directional flow at dist level
- Increased number of smart - active devices
- Evolving institutional environment

New Challenges to a Modern Grid

- New energy technologies and services
- Increasing penetration of variable renewables in grid
- New communications and controls (e.g. Smart Grids)
- Electrification of transportation
- Integrating distributed energy storage
- Need to increase system flexibility
- Need to capitalize on interactions between electricity/thermal/fuel systems

35% Wind by 2050

Energy Systems Integration

http://energy.gov/windvision

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Report: Wind power could be 35% of supply by 2050

David Jackson, USA TODAY *10:10 a.m. EDT March 12, 2015*

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(Photo: Matt Young, AP)

WASHINGTON — The Obama administration is setting higher goals for wind power, saying it could supply 35% of the nation's electricity by the year 2050.

Wind power currently generates 4.5% of electricity, but that number is expected to more than double to 10% by 2020, says a report obtained by USA TODAY that will be released Thursday b[y] the U.S. Department of Energy.

27% Solar by 2050

Energy Systems Integration

http://energy.gov/eere/sunshot/sunshot-vision-study

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Office of Energy Efficiency & Renewable Energy

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Home » About » SunShot Vision Study

SUNSHOT VISION STUDY

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  - Key Activities
  - History
  - Leadership
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The *SunShot Vision Study* provides an in-depth assessment of the potential for solar technologies to meet a significant share of electricity demand in the United States during the next several decades. The DOE study explores a future in which the cost of solar technologies decreases by about 75% between 2010 and 2020 in line with the **SunShot Initiative's cost targets**.

With a focus on photovoltaics (PV) and concentrating solar power (CSP), the *SunShot Vision Study* examines the potential pathways, barriers, and implications of achieving the SunShot Initiative price reduction targets and resulting market penetration levels.

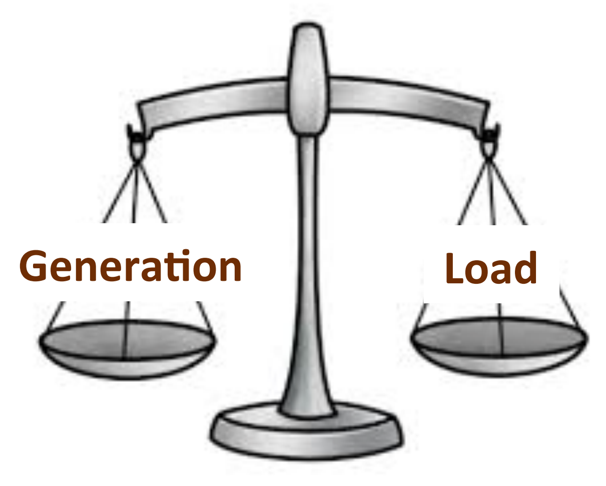
METHODOLOGY

The study used two models developed by the National Renewable Energy Laboratory to evaluate a SunShot scenario and a reference scenario. Key findings of the study include the following:

Driver - Increased Variable Generation

Energy Systems Integration

Rapid increase in variable generation makes balancing generation and load much more difficult increasing system operational uncertainty. Wind and solar technologies may also impact the stability of the grid due to the reduction in systems inertia and interconnection standards that don't support system stability.



Generation-Load Balance

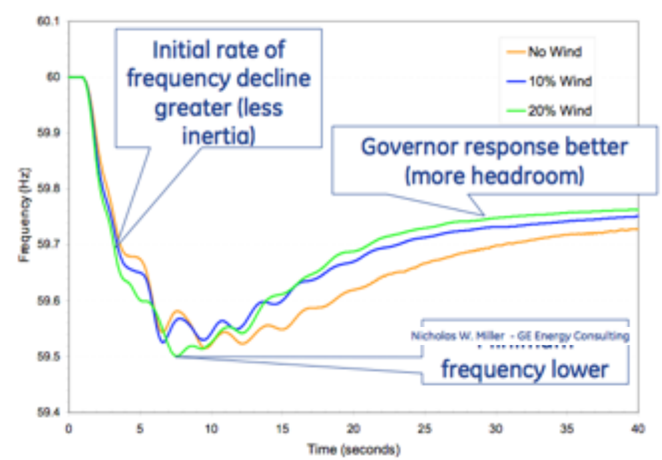
- Generation no longer follows load and gen/load coincidence is a bigger factor
- Increased system operational uncertainty
- Increased need for better resource forecasting
- Increase need for many forms of system flexibility

Steady-state Operations

- Updates to regulation requirements and reserves
- Integration with Automatic Generation Control (AGC)
- Coordination with demand side management

Transient and Dynamic Stability

- Reduced system inertia with high penetrations of wind and solar
- Interconnection codes and standards need to support system stability
- Improvements in RE interfaces critical



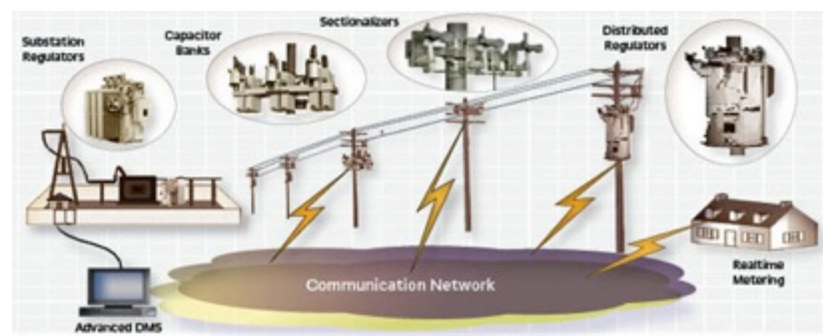
Driver – More bi-directional flow at dist level

Energy Systems Integration

The increase of distributed generation and storage is resulting in greater two-way power flow on the distribution system and back to the transmission system.

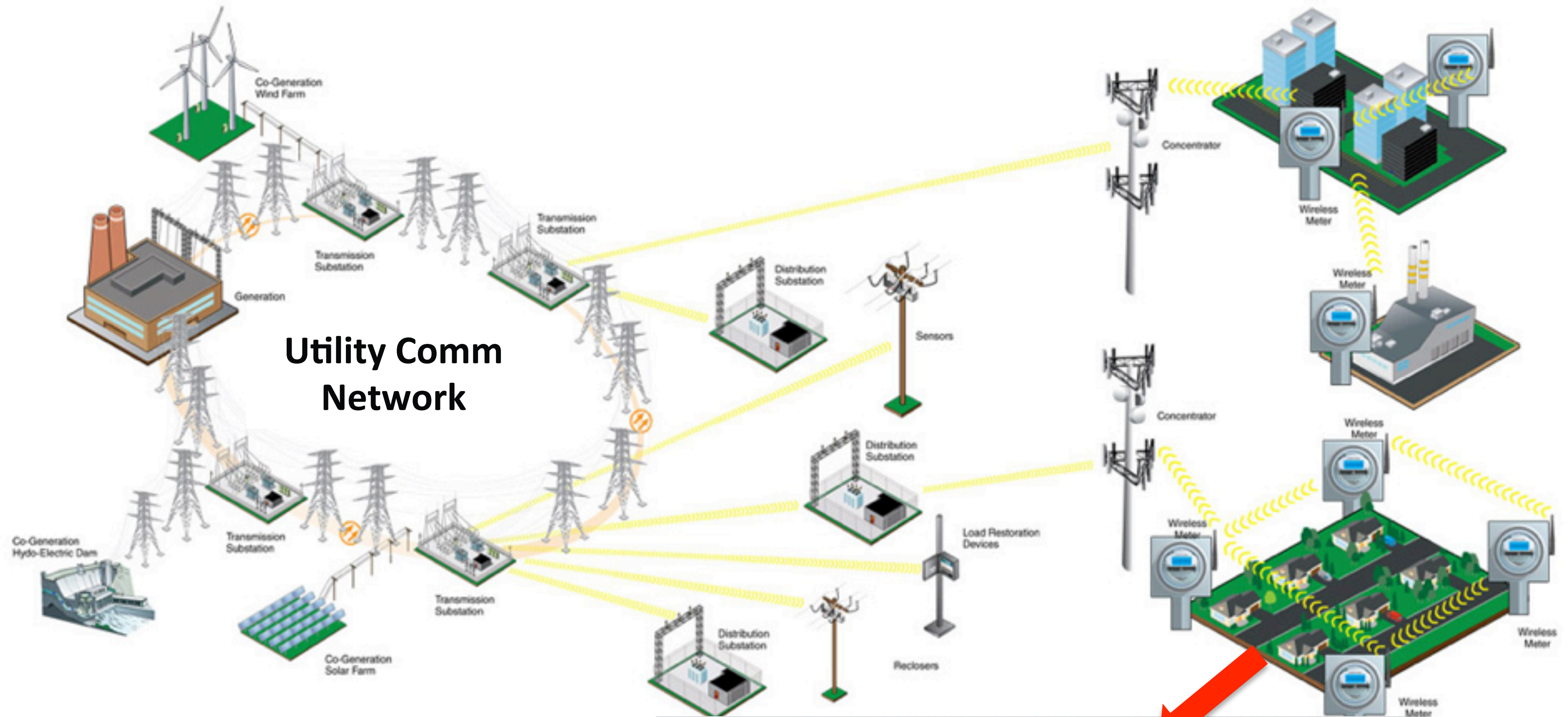
Distributed Generation and Storage

- Voltage and reactive power (volt/var) regulation
- Equipment grounding and transient over-voltage protection
- Protection design and coordination (short circuit contributions, recloser and fuse coordination, etc.)
- Microgrids and unintentional islanding protection
- Power Quality (Harmonics, Flicker, DC Injection)
- Interactions with local energy storage and loads



Driver - Increased number of active devices

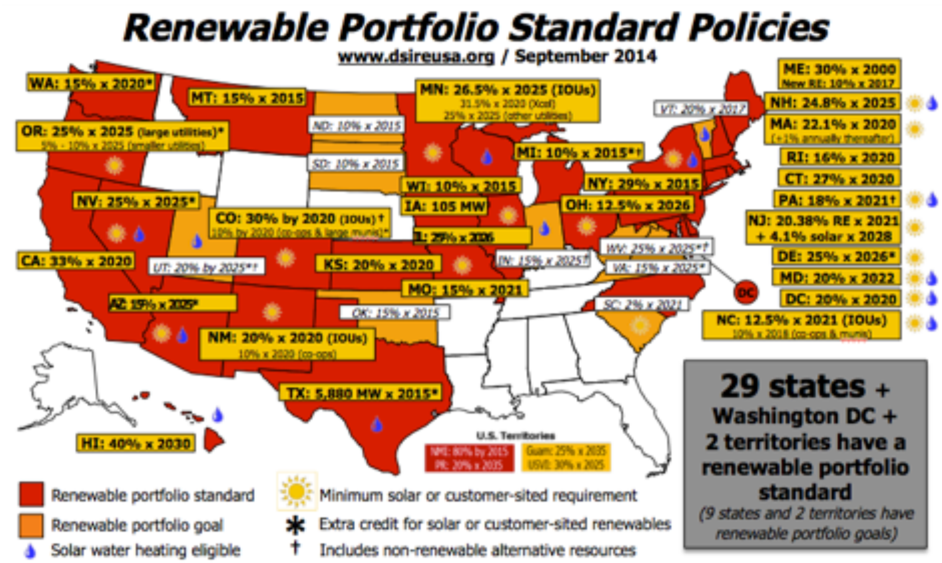
Energy Systems Integration

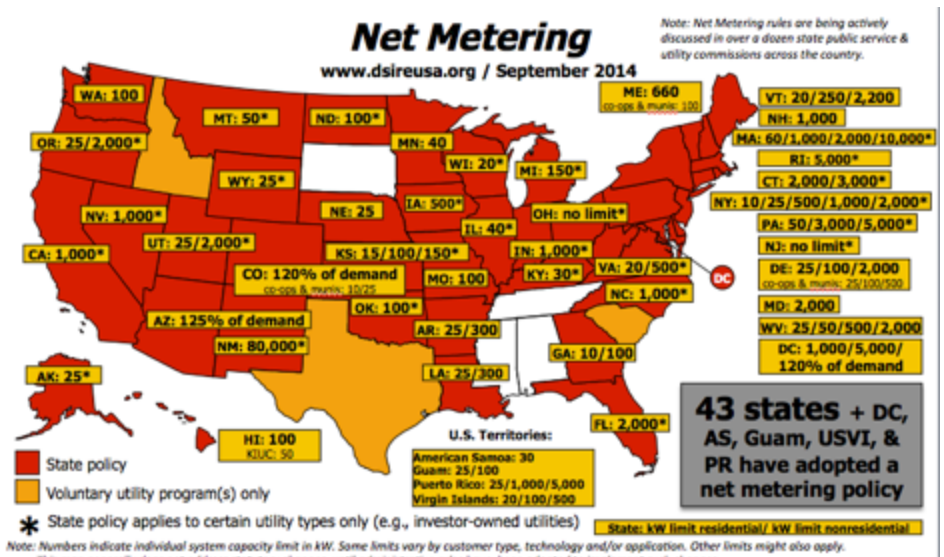


Consumers are more interested in installing and owning distributed energy resources and installing more sophisticated, connected active loads and devices. These active devices can provide value to the grid by providing new energy products and services.

Driver – Evolving Institutional Environment

Energy Systems Integration





Renewable and energy efficiency portfolio standards, distributed generation, and new energy products and services are challenging the existing business model for the grid.

- **Interconnection Standards**
- **Market Mechanisms**
- **Renewable Portfolio Standards**
- **Net Metering Requirements**
- **Permitting and Siting**
- **Tax Incentives**
- **Rebate Programs**
- **Business Models**

Future Grid Challenges and Solutions

Energy Systems Integration

Emerging Technologies

Renewable Energy

Sustainable Transportation

Energy Efficiency

Physical Scales

Bulk System

Distribution

Customer

Drivers

More Variable Generation

Greater two-way power flow

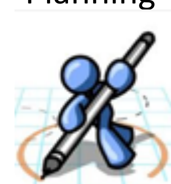
Increasing numbers of active devices

Evolving Institutional Environment

Solutions

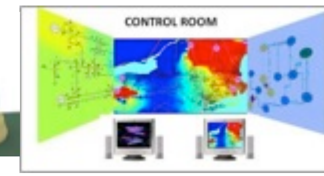
Markets and Business Models

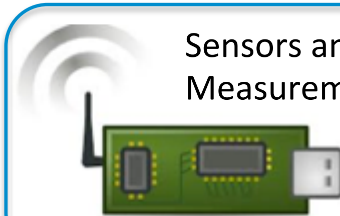
Design and Planning



Forecasting

Controls and Power Flow





Sensors and Measurements

Interoperability

Interconnection

Characterization

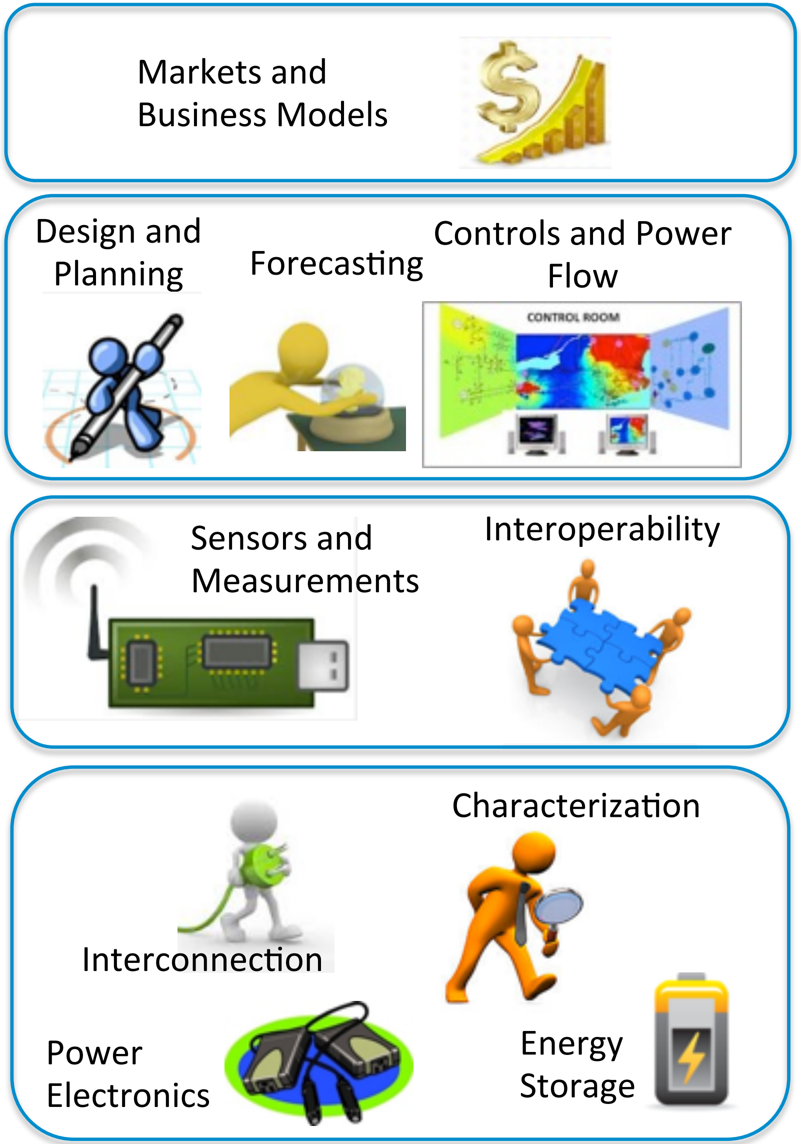
Power Electronics

Energy Storage

Recent Research on Power Systems at NREL

PSEC – Providing Solutions

Energy Systems Integration



Markets

- Understanding the impacts of Market Design
- Analysis of markets for flexibility and other ancillary services

Planning, Operations, and Forecasting

- Bulk-System Planning and Operations
- Distribution System Planning and Operations
- Solar, Wind, and Load Forecasting

Sensing and Measurements

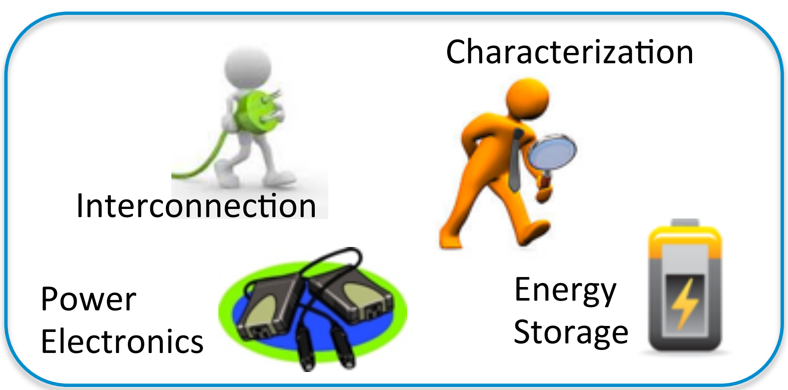
- Grid sensing – PMUs, DMUs
- Solar Radiation Measurements and Sensors
- Interoperability between devices

Grid device development and integrated system testing

- PV inverters, Wind Inverters, EV inverters development and testing
- Energy storage systems (battery+inverter)
- Interconnection Standards
- Ancillary Service Characterization

PSEC – Providing Solutions

Energy Systems Integration



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Smart Inverters : NREL, SolarCity and HECO

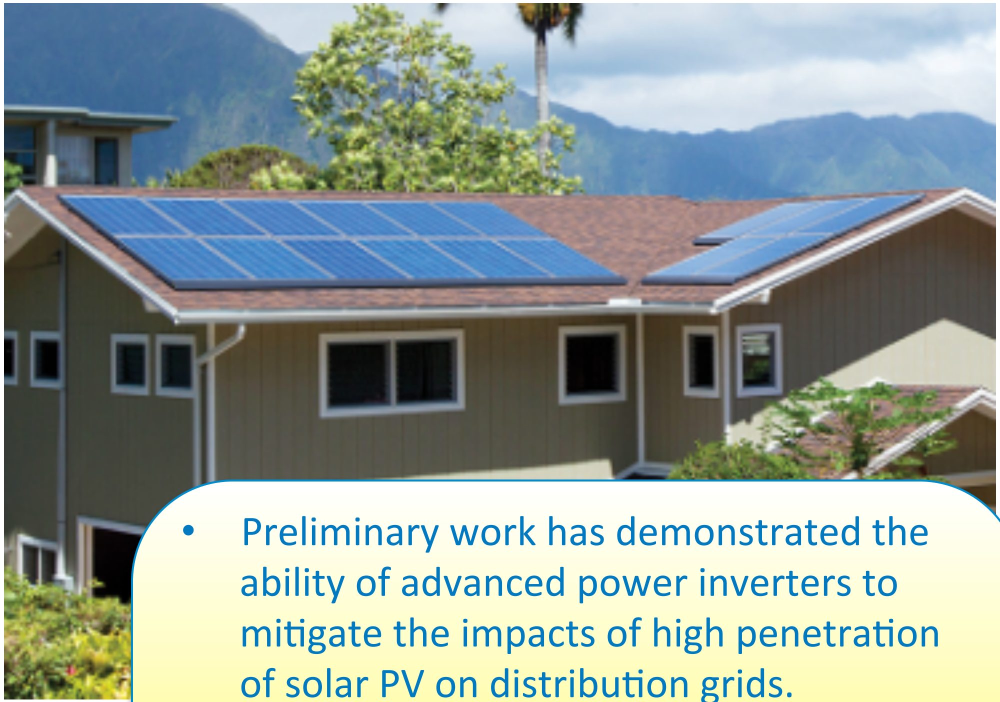
Energy Systems Integration

TECHNOLOGY ADDRESSED

Interconnection challenges when connecting distributed PV into the electrical distribution grid such as in Hawaii (HECO).

IMPACT

Hawaii is moving towards 50% renewable energy and this project will work to improve the safety, reliability and stability of the electric power systems that include high levels of distributed PV.

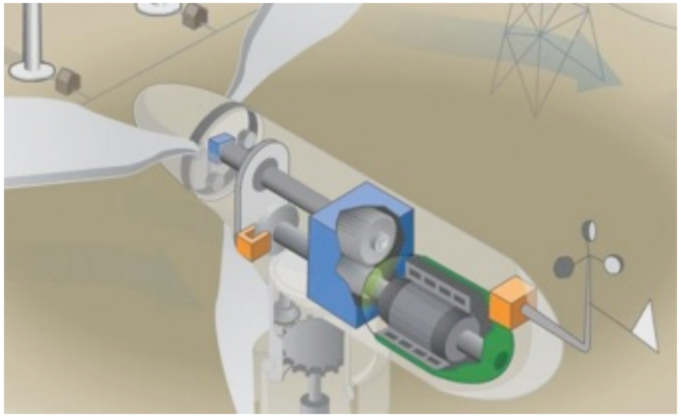


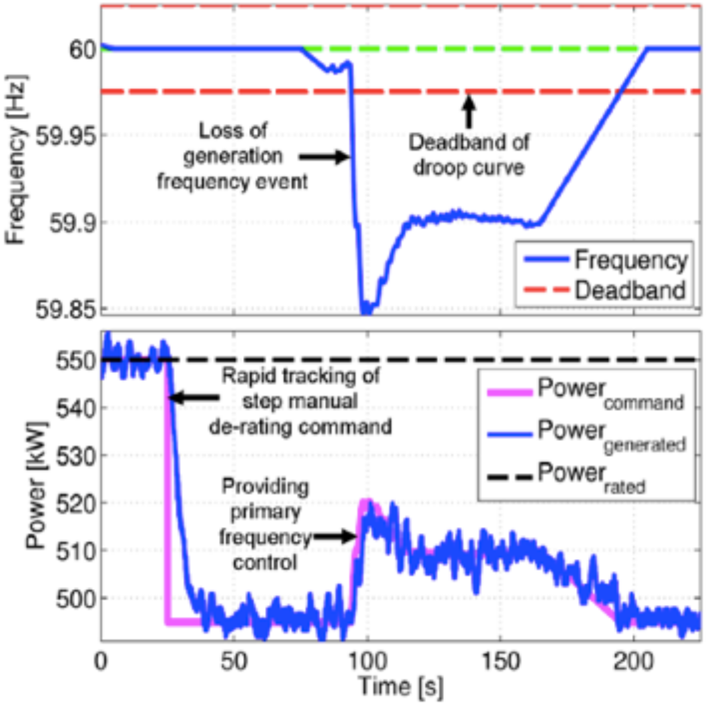
- Preliminary work has demonstrated the ability of advanced power inverters to mitigate the impacts of high penetration of solar PV on distribution grids.
- As a result, HECO has now indicated it will expedite the installations of solar PV systems on circuits with over 120% of daytime minimum load if the PV systems are installed with advanced inverters that meet stricter requirements.

Active Power Control from Variable Gen

Energy Systems Integration

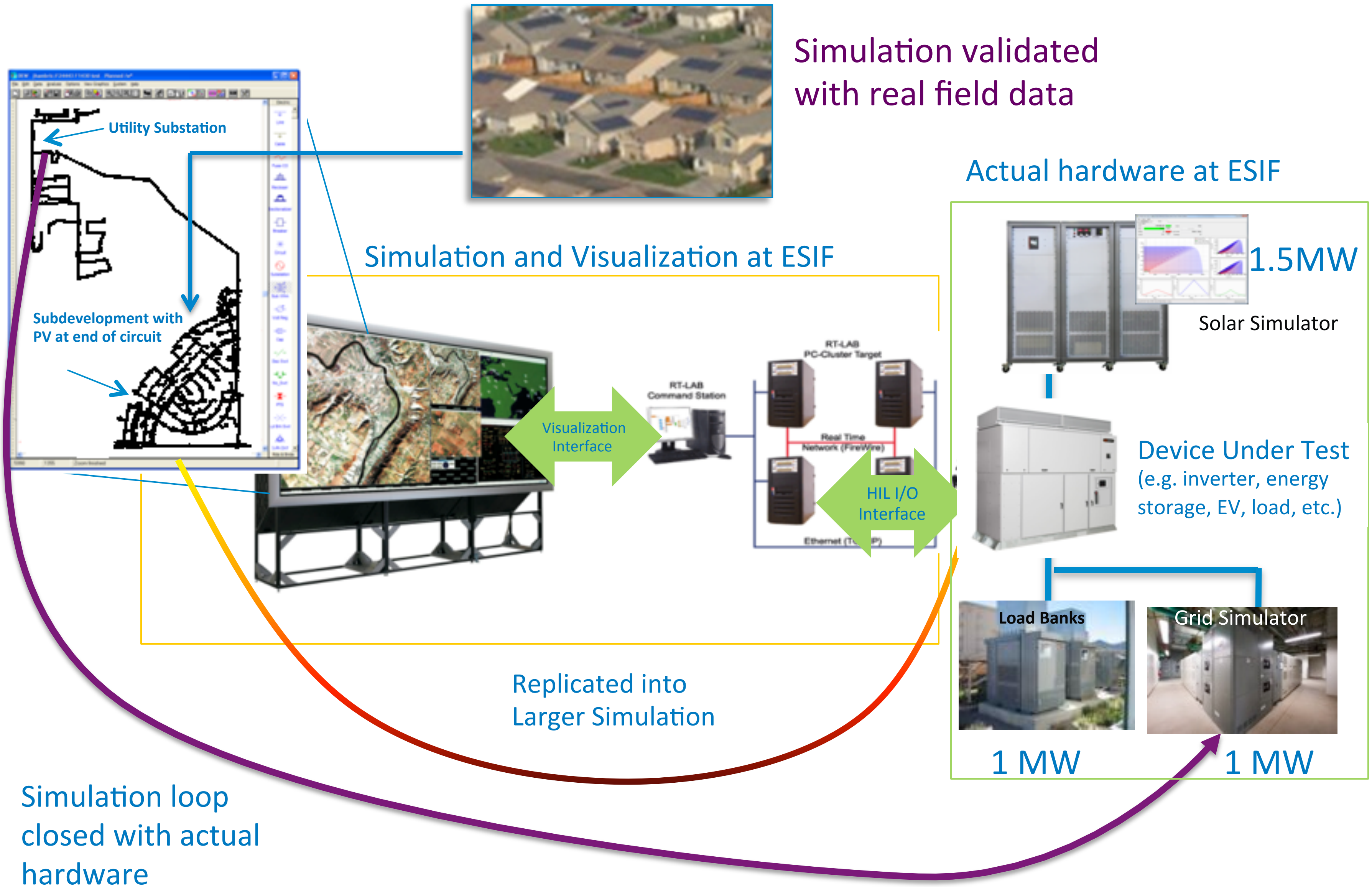
- **Understanding how Variable Generation (Wind and Solar) can provide primary and secondary reserves.**
- **Inertial control, Primary Frequency Control (PFC), and Automatic Generation Control (AGC) from Wind and Solar is feasible with negligible impacts on loading**





Power Hardware-in-the-Loop: Connecting Experiments to Simulations

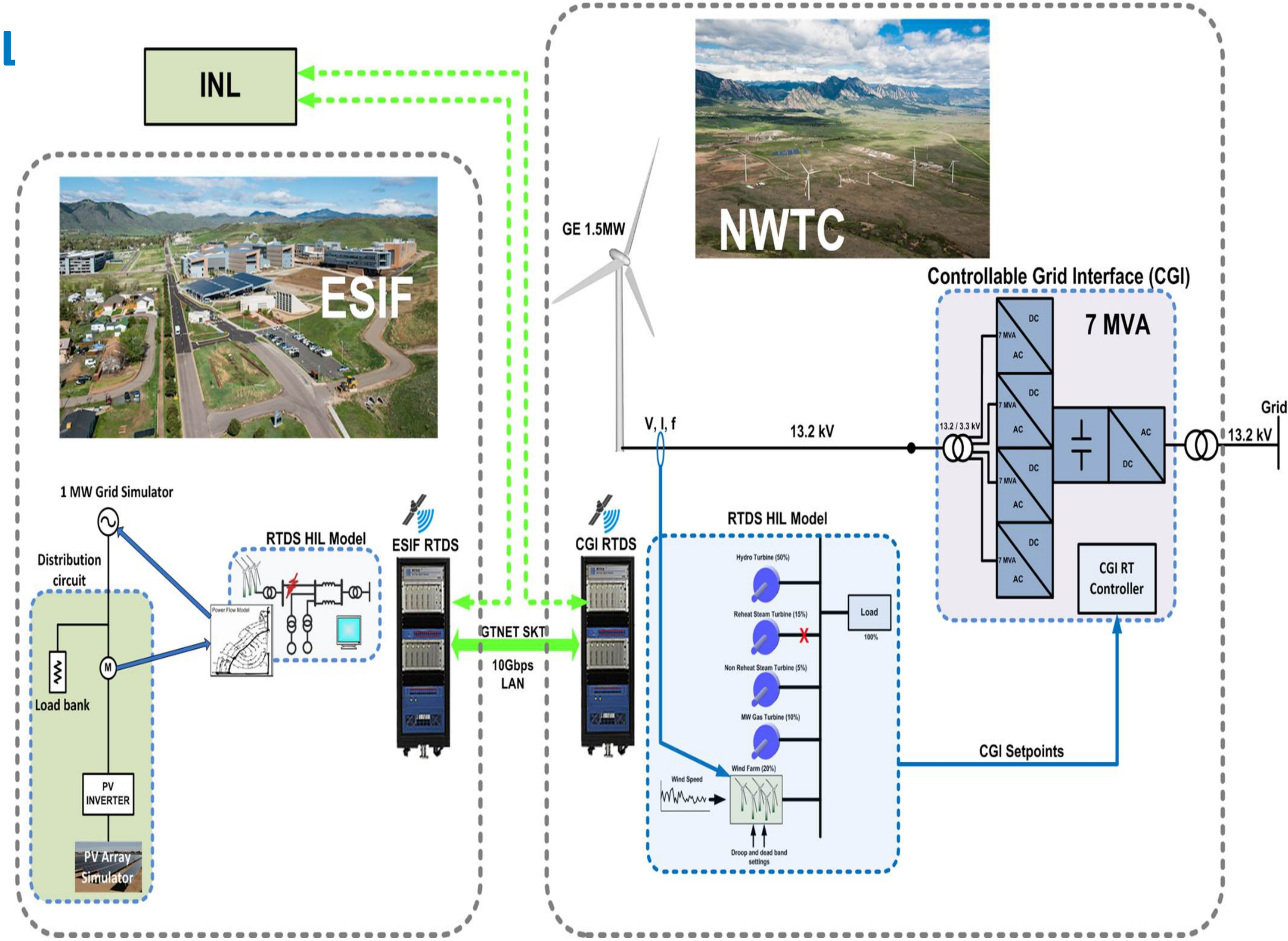
Energy Systems Integration



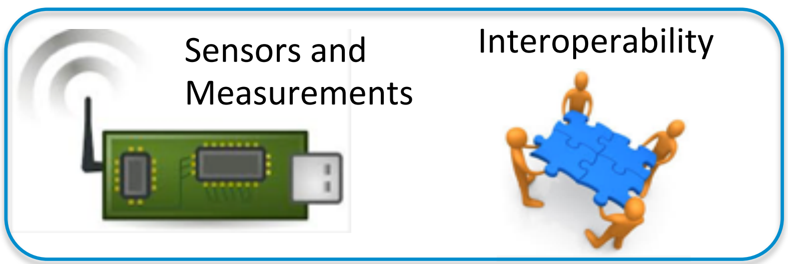
Recent PHIL R&D

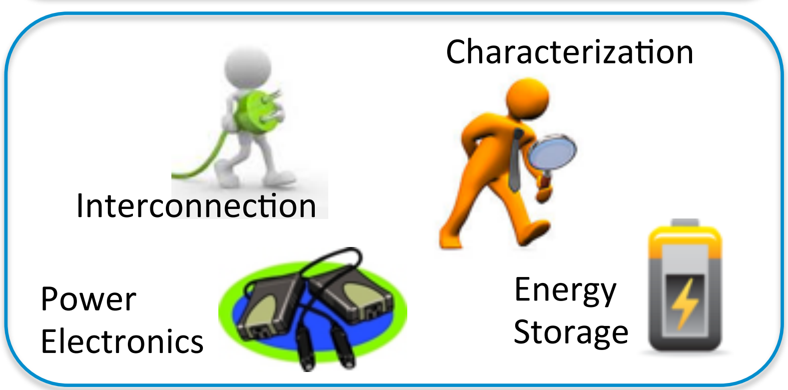
Inter-Lab PHIL

- PNNL
- INL
- CSIRO
- NWTC



PSEC – Providing Solutions





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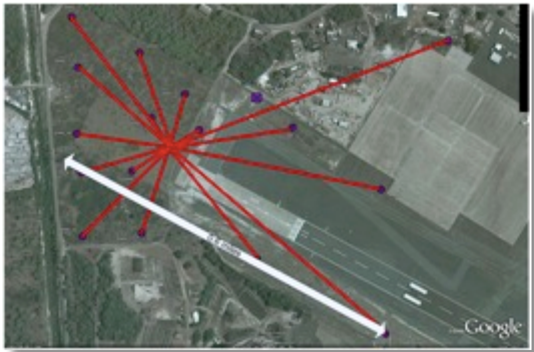
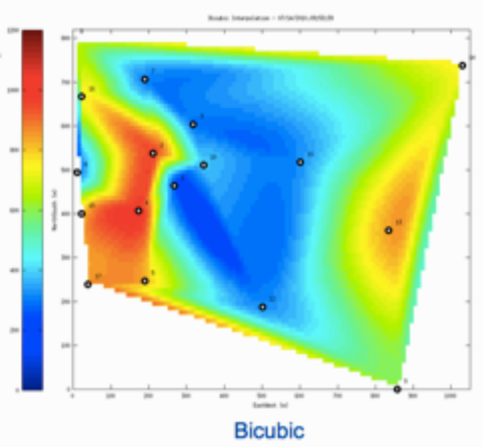
- Energy Service Characterization

Solar Resource and Power Variability

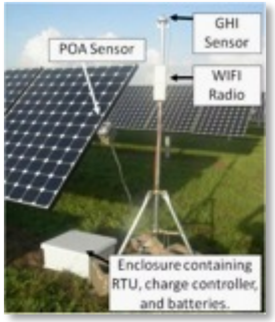
Measurement Networks:
Sub-km with 1-sec data

- **DeSoto, Florida**
  SCADA-Compatible Wireless Solar Measurement System
  17 Stations over extended area (300MW) to be installed FY11-12
  17 Stations on PV site FY11-12



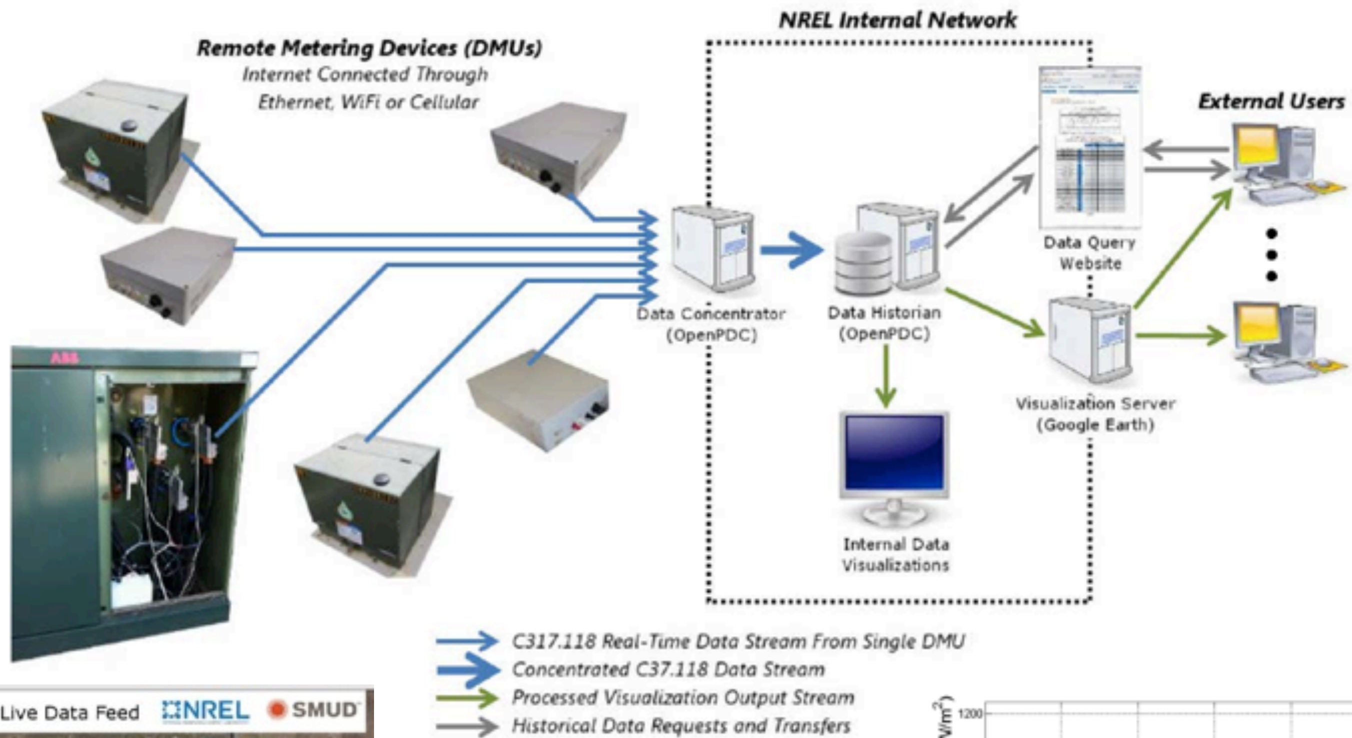


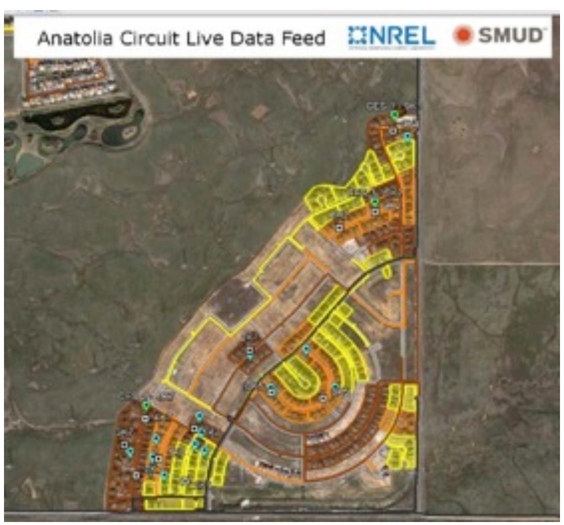
- **Hawaii**
  <u>Publicly available:</u>
  Oahu: 3 areas – 25 stations (installed June 2009 – March 2010)
  Lanai: 4 stations - July 2009

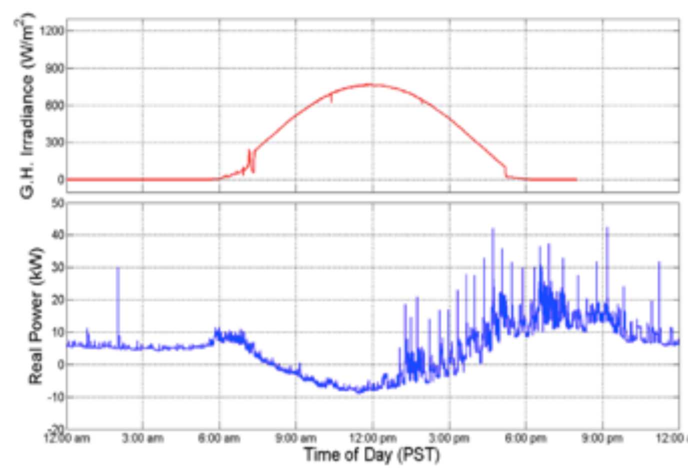


- **NREL Campus**
  4 Stations operating since March 2009

DMUs for Renewable Integration

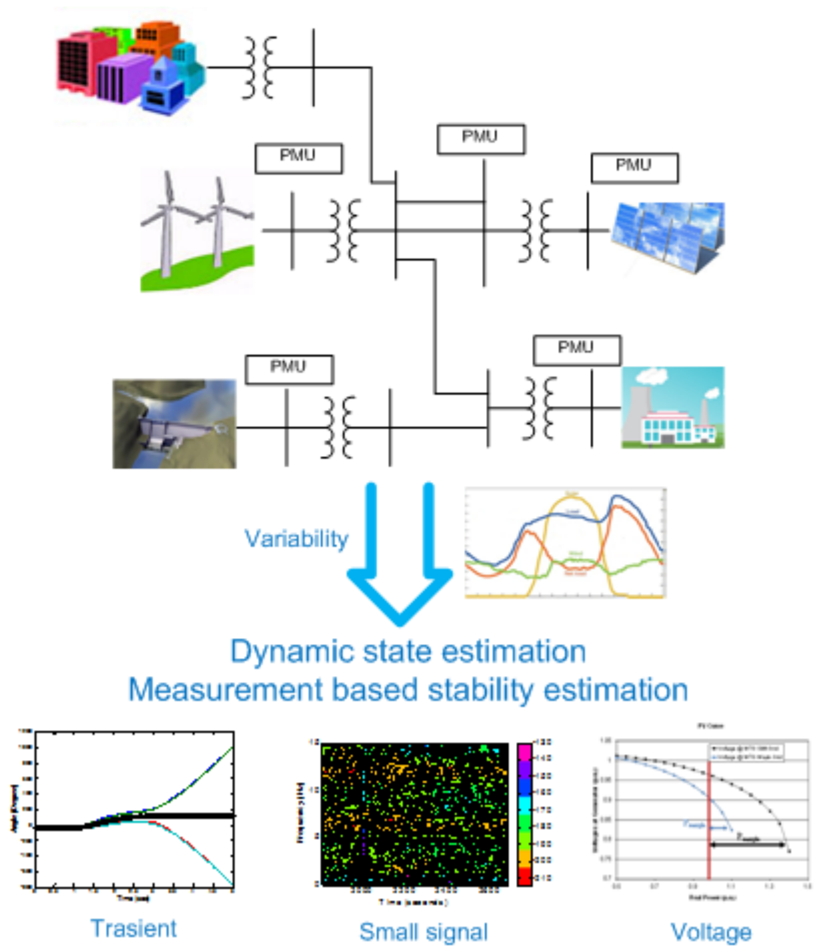






PMUs for Renewable Integration

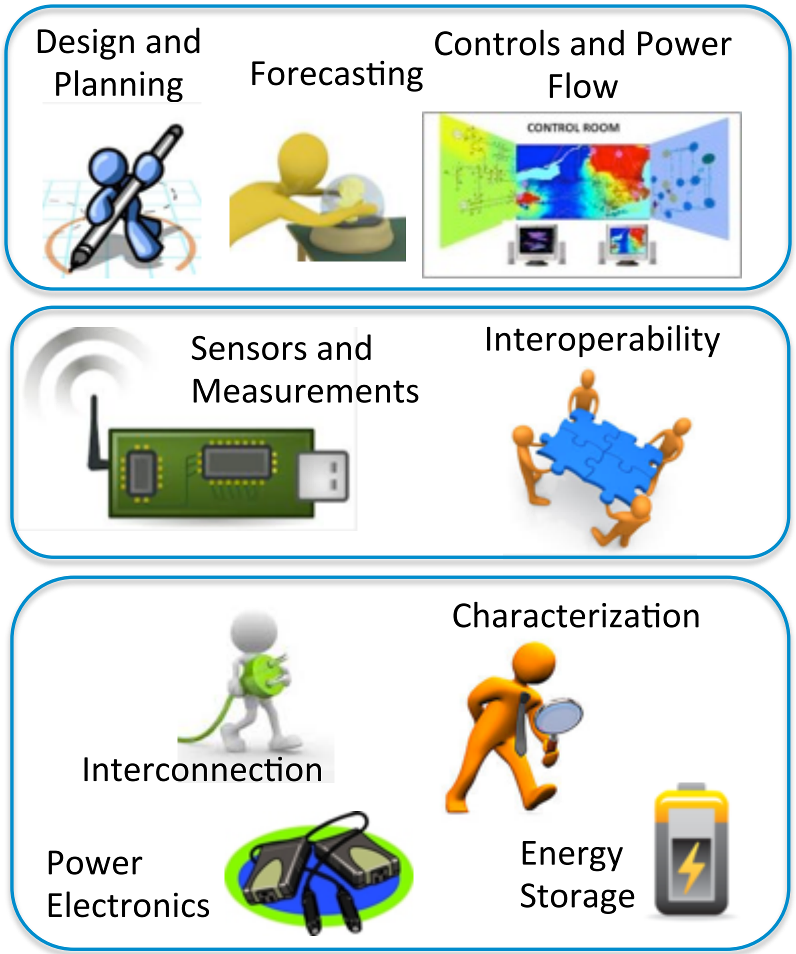
- **PMU provides millisecond level scan of the power system that can be used for**
  - Dynamic state estimation
    - Quasi-steady state estimation
    - Trajectory prediction
  - Measurement-based stability estimation
    - Transient stability
    - Small signal stability
    - Voltage stability
    - Frequency stability
  - Flexible and fast acting control of power system



- **Investigating PMU-based control algorithms to improve the operation of renewable energy from the perspectives of WAMPAC (Wide Area Monitoring Protection and control) utilizing availability of power electronics**

PSEC – Providing Solutions

Energy Systems Integration



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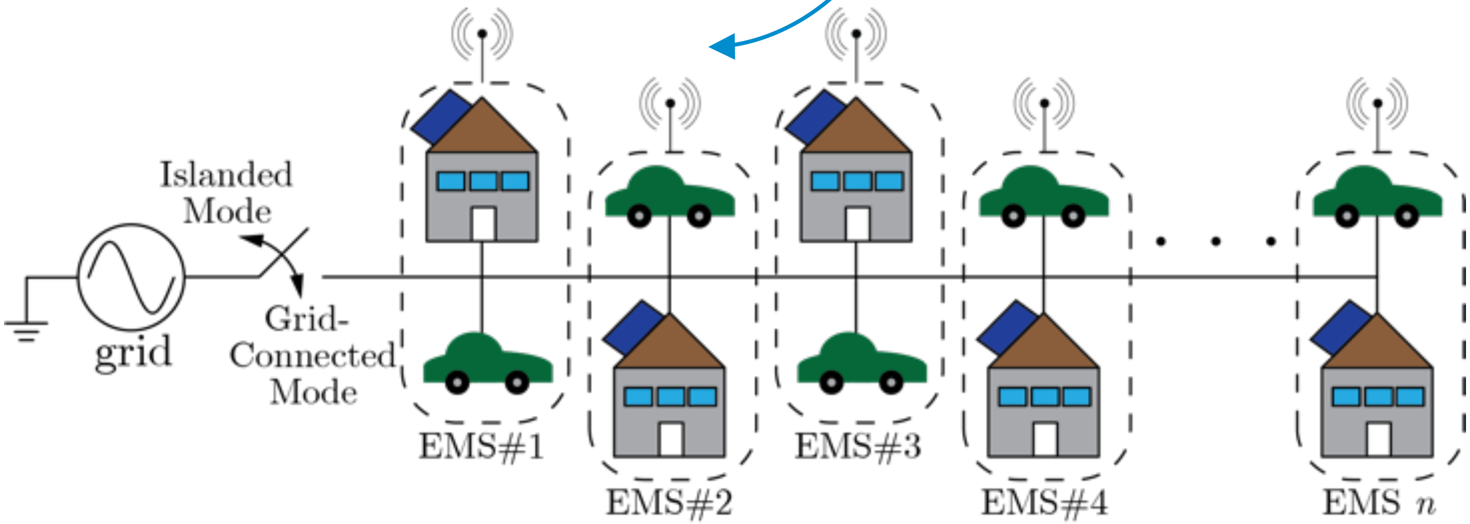
- Interconnection Standards
- Energy Service Characterization

Developing Decentralized Controls

Energy Systems Integration

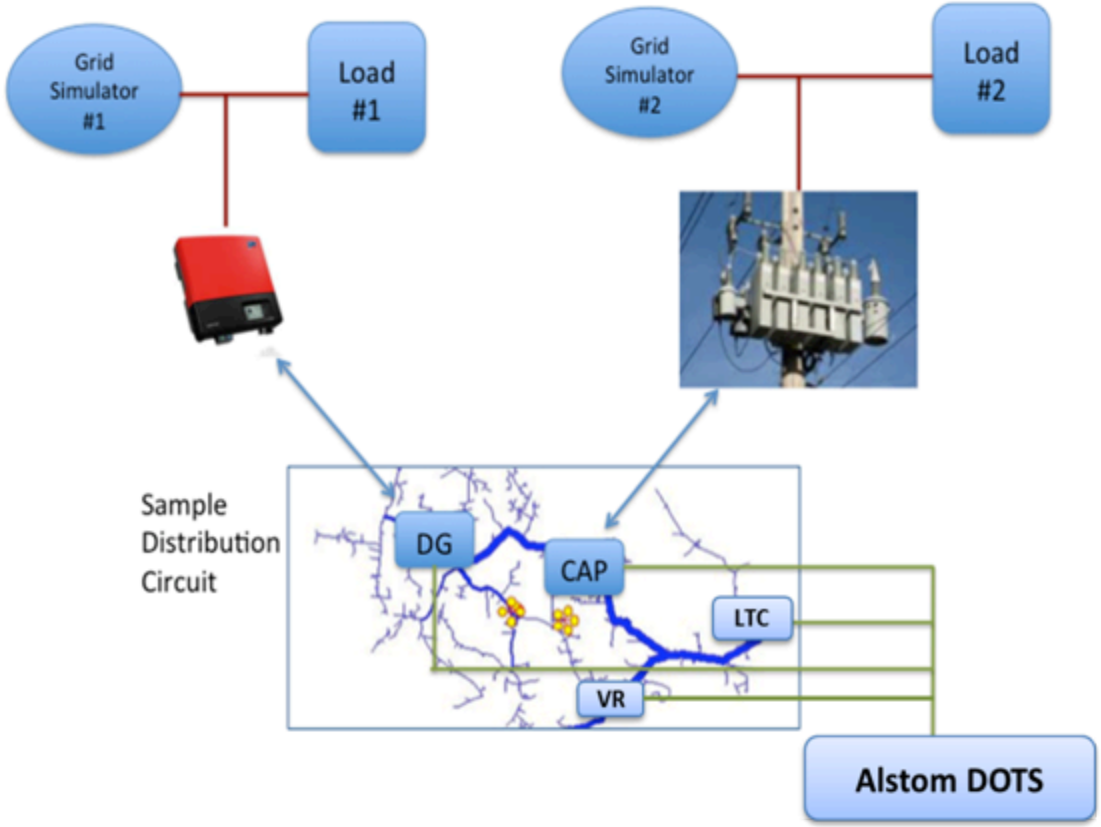
- Leverage neighbor-neighbor communication
- Flocking, consensus techniques, leading to formal agreement protocols
- Demonstrating operations of high penetrations of PV, EC, DR



ADMS with Utility Partners/Vendors

Energy Systems Integration

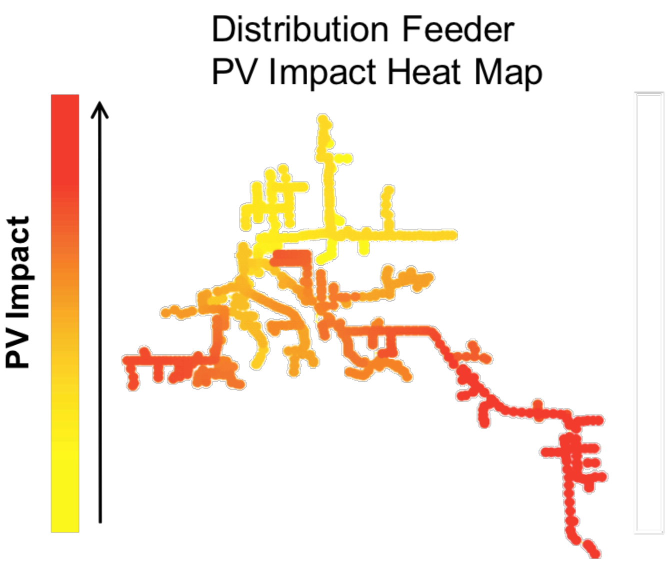
- Model large scale distribution systems using the HPC to replicate parts of a utility service territory and connect to a **Advanced Distribution Management Systems (ADMS)**
- Integrating distribution system hardware in ESIF using real devices to multiple nodes in computer simulation using power hardware in the loop co-simulation
- Advanced visualization capability at ESIF to simulate a mock utility distribution system operator's control room.

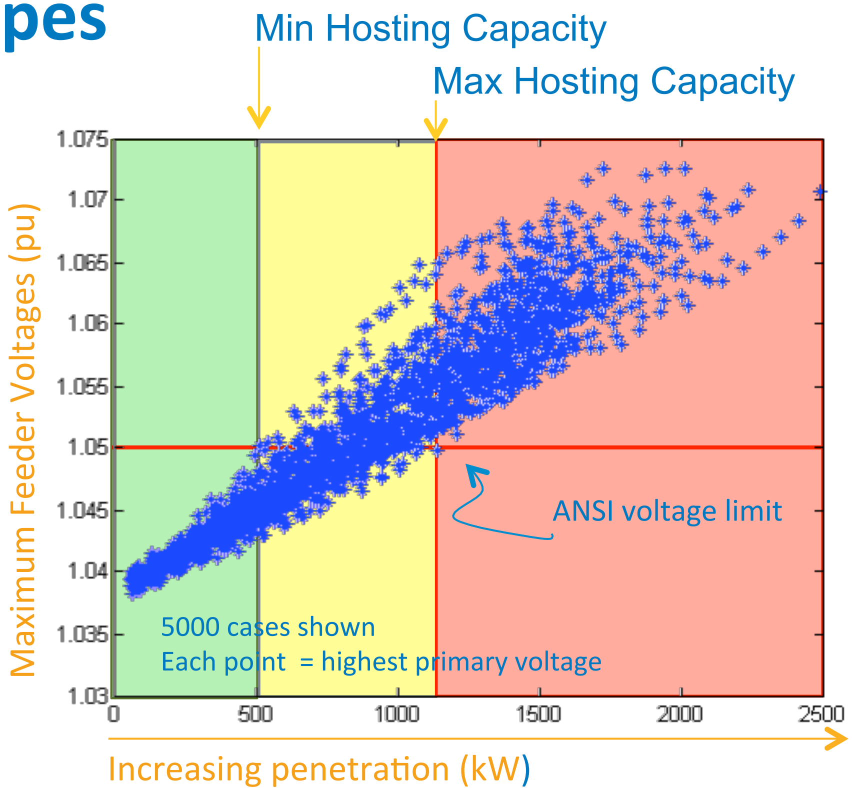


PHIL Co-Simulation setup with Alstom DMS

Energy Systems Integration

- **Use of clustering technique for creating taxonomy of feeder types**
- **Application of hosting capacity analysis to representative feeder types**

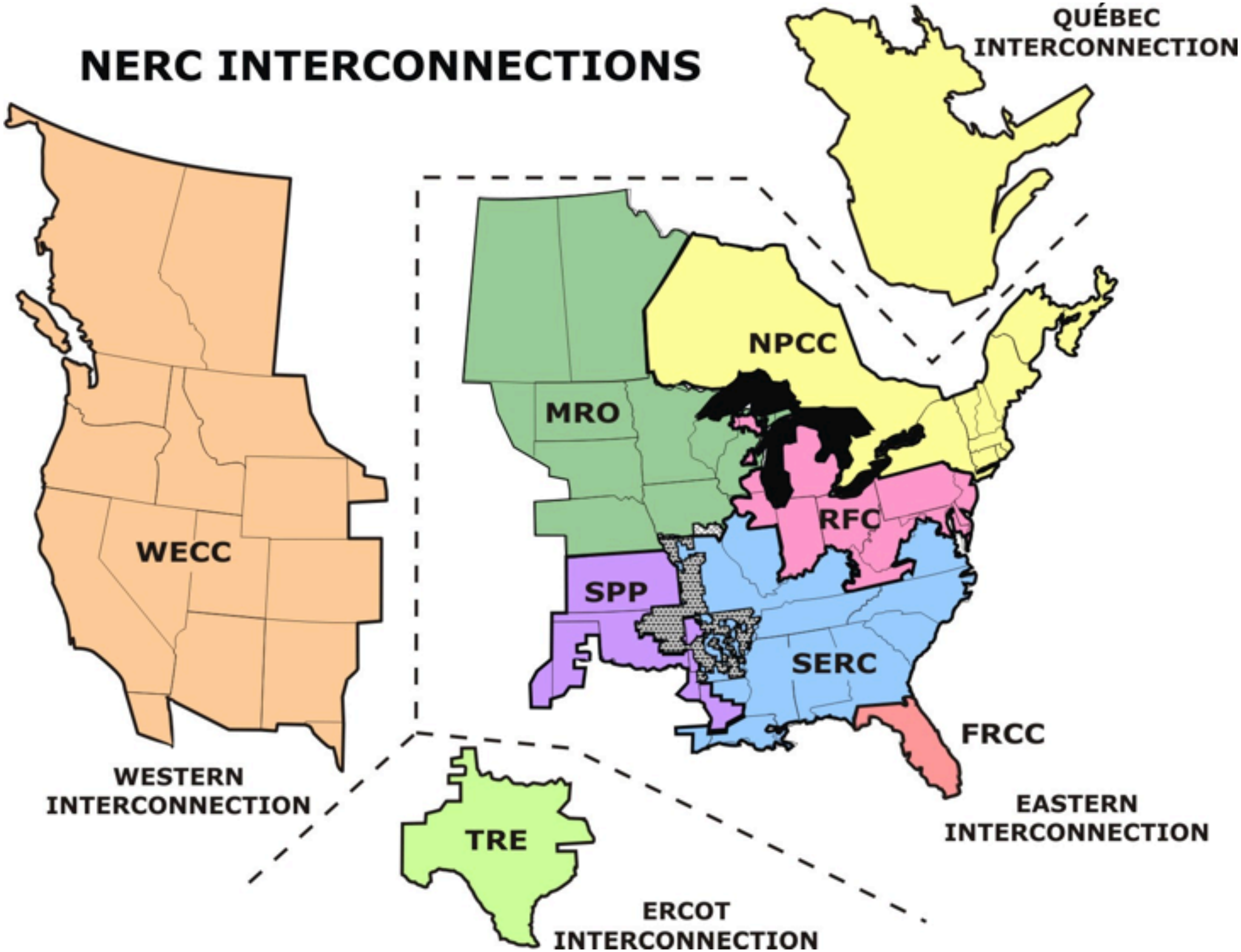




Source: http://calsolarresearch.ca.gov/Funded-Projects/solarforum.html

Bulk-Power Interconnections

Energy Systems Integration

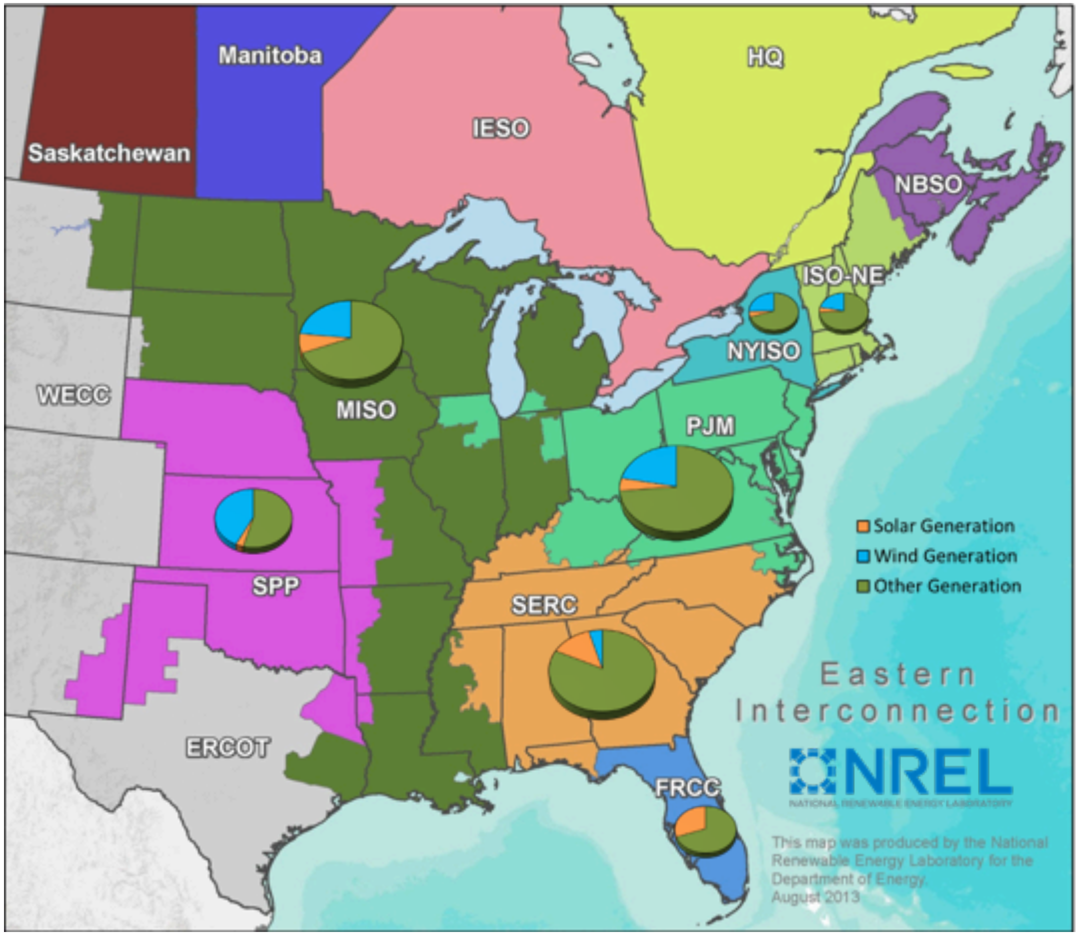


Eastern Renewable Generation Integration Study

Energy Systems Integration

- **Goals**
  - Operational impact of 30% wind and solar penetration on the Eastern Interconnection at a 5-minute resolution.
  - Efficacy of mitigation options in managing variability and uncertainty in the system.

- **Operational Areas of Interest**
  - Reserves
    - Types
    - Quantities
    - Sharing
  - Commitment and Dispatch
    - Day-ahead
    - 4-hour-ahead
    - Real-time
  - Inter-regional Transactions
    - 1-hour
    - 15-minute
    - 5-minute



This map shows the assumed structure of the Eastern Interconnection in the study year. The pie chart slices indicate the relative amount of solar, wind, and other generation in each region and the relative size of the pies indicates the amount of generation for the Regional 30% RE scenario.

Western Wind and Solar Integration Studies

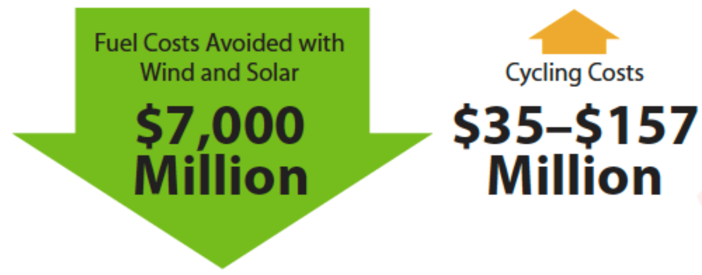
Phase 1: Can WECC handle 35% RE? Yes, with practice change

Phase 2: Cycling Cost and Emissions Impacts

	Emission Reduction Due to Renewables	Cycling Impact
CO_2	260–300 billion lbs 29%–34%	Negligible Impact
NO_x	170–230 million lbs 16%–22%	3–4 million lbs (reduction)
SO_2	80–140 million lbs 14%–24%	3–4 million lbs (increase)

Emissions impacts of cycling are relatively small

From a system perspective, cycling costs are relatively small



Note: Capital costs for wind and solar are not reflected.

- **Phase 3: Frequency Response and Grid Impact**

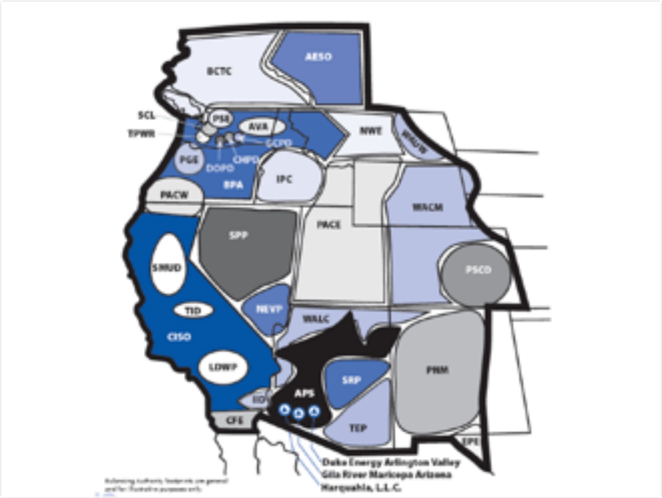
❖ **What happens to the transmission grid's frequency with high penetration of distributed generation at low load?**

❖ **What happens to the grid when remote transmission lines are highly-loaded to move wind long distances?**

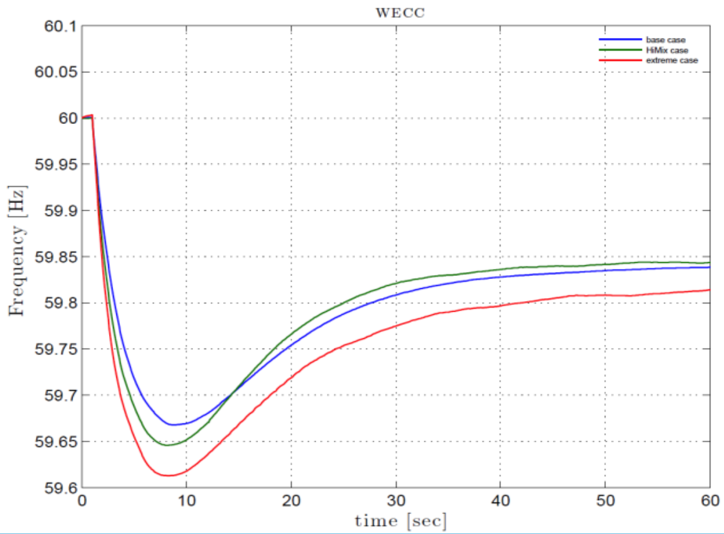
WWSIS- Phase 3 Key Questions

Energy Systems Integration

- **What is the impact of high penetration wind and solar on specific aspects of reliability of the Western Interconnection?**
  - **i.e. "will the system successfully serve customer loads for the first minute after a big disturbance"**
- **What mitigation means are effective in addressing any adverse impact?**



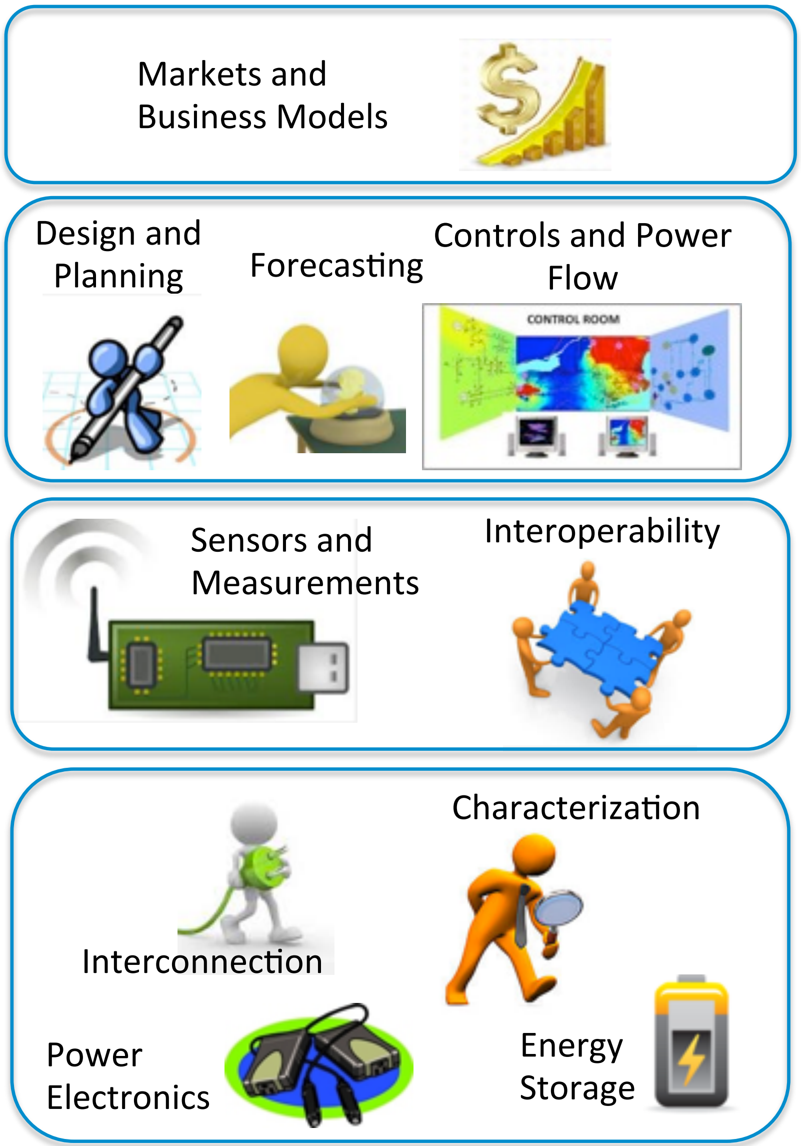
Disturbance: Trip 2 Palo Verde units (~2,750MW)



Interconnection frequency response > 840 MW/0.1Hz threshold in all cases.
No under-frequency load shedding (UFLS).

PSEC – Providing Solutions

Energy Systems Integration



Markets

- Understanding the impacts of Market Design
- Analysis of markets for flexibility and other ancillary services

Planning, Operations, and Forecasting

- Bulk-System Planning and Operations
- Distribution System Planning and Operations
- Solar, Wind, and Load Forecasting

Sensing and Measurements

- Grid sensing – PMUs, DMUs
- Solar Radiation Measurements and Sensors
- Interoperability between devices

Grid device development and integrated system testing

- PV inverters, Wind Inverters, EV inverters development and testing
- Energy storage systems (battery+inverter)
- Interconnection Standards
- Energy Service Characterization

Integrated T&D Grid Modeling System (IGMS)

Energy Systems Integration

Summary: A next-generation analysis framework for full-scale transmission and distribution modeling that supports millions of highly distributed energy resources.

Example Applications

- Analyze distributed PV support for grid operations
- Simulate smart grid storage, PV, and Demand response
- Simulate alternative market and service architectures
- Co-simulation with Hardware via PHIL
- Connect to Advanced DMS/EMS systems

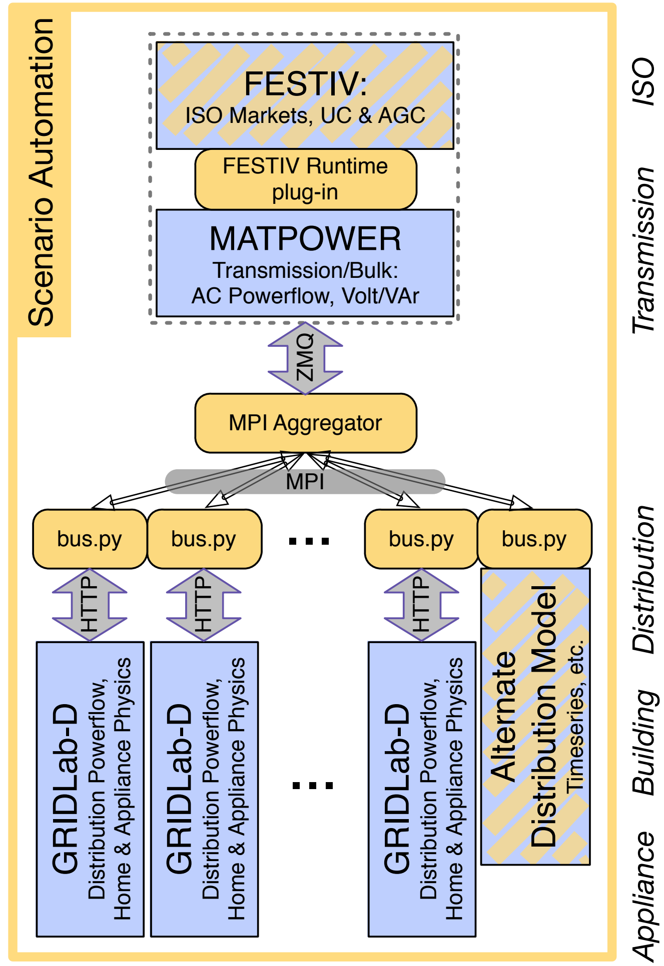
End-toEnd T&D Models

- detailed multi-period wholesale markets
- generator/reserve dispatch (AGC),
- AC Powerflow (bulk transmission)
- Full unbalanced 3-ph power flow for 100s to 1000s of distribution feeders
- Physics based end-use models of buildings and end-use loads.

Modular, scalable, parallel architecture

- Co-simulation of existing open-source modeling tools
  - Novel, highly scalable MPI-based framework
- Optimized for HPC use: full utility/ISO scale simulations
- Could be expanded to support additional layers:
  - Communications simulation
  - Agent behavior
  - Distribution markets

Integrated Grid Modeling System

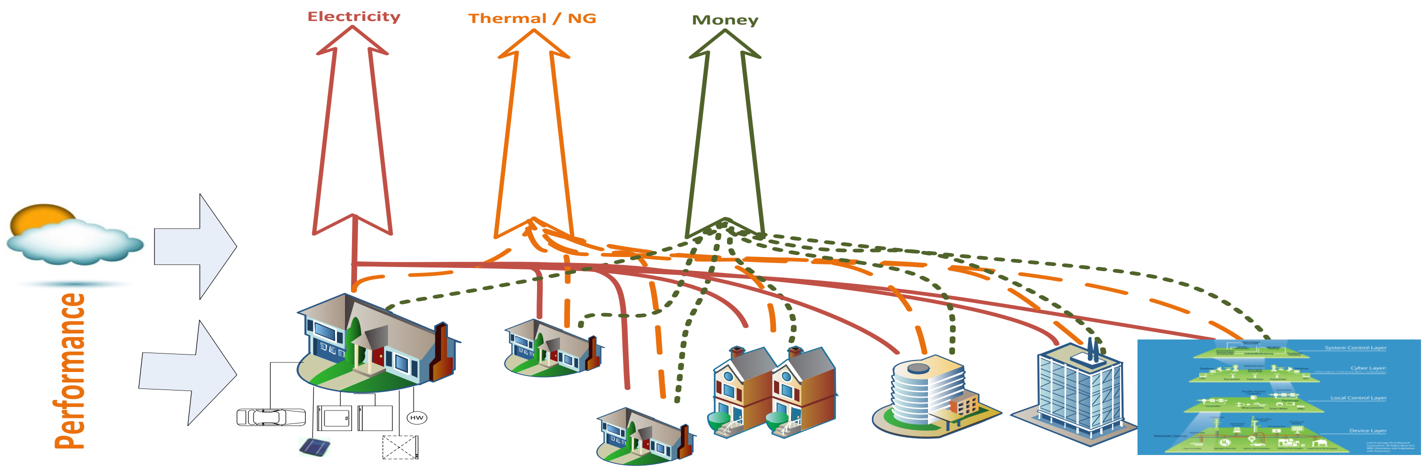


Integrated Energy System Model (IESM)

Energy Systems Integration

Summary: The IESM simulates performance of technologies within multiple buildings under various retail market structures to:

- Identify barriers to integration benefits
- Inform regulatory and technology decisions
- Provide market layer input to market-to-device HIL testing
- Time: 1-second to 5-minutes Resolution over months
- Space: Distribution feeder including loads (focus on residential homes)



Inputs:

- Feeder topography
- Residential specifications (both static and operational)
- Meteorological time series,
- Control systems
- Acceptable elasticity

Outputs:

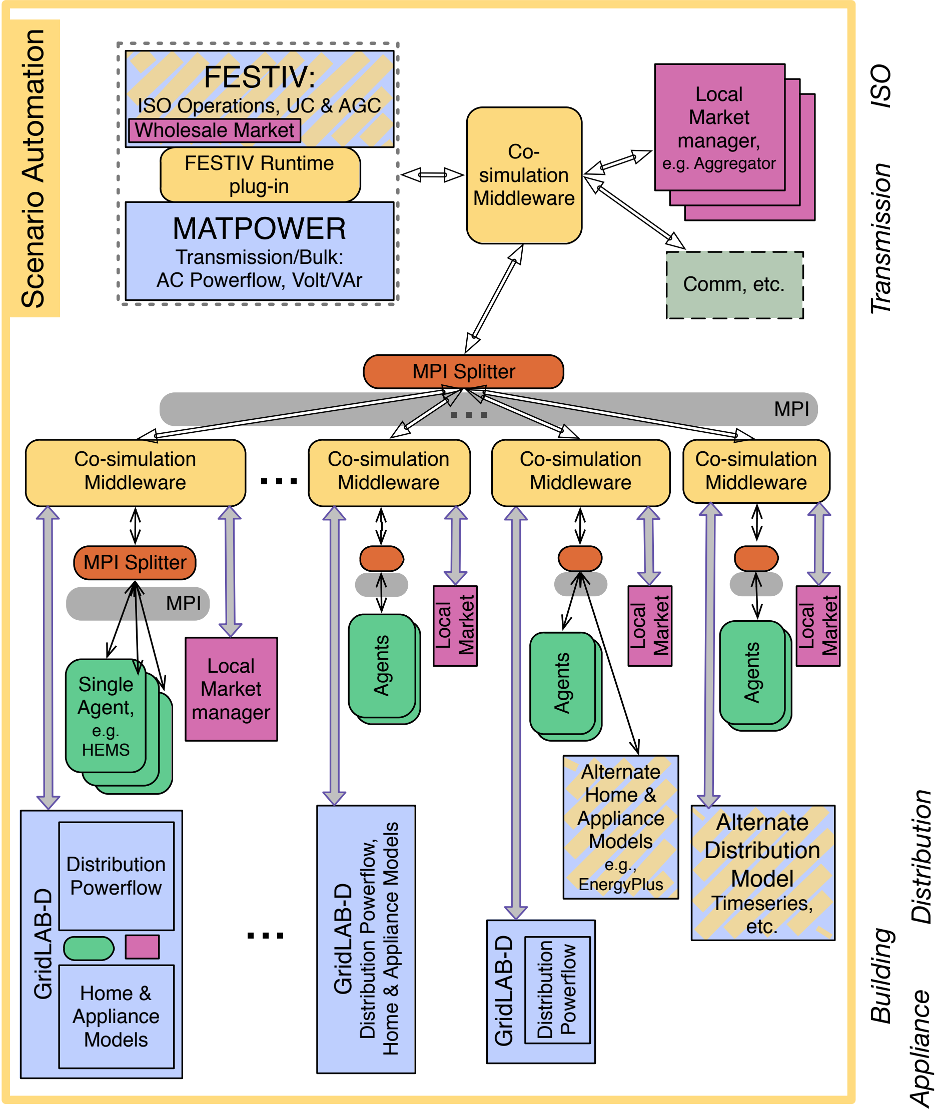
- Impacts on residential expenses and comfort
- Impacts on feeder operations

Creating Models from ISO to Appliance

Energy Systems Integration

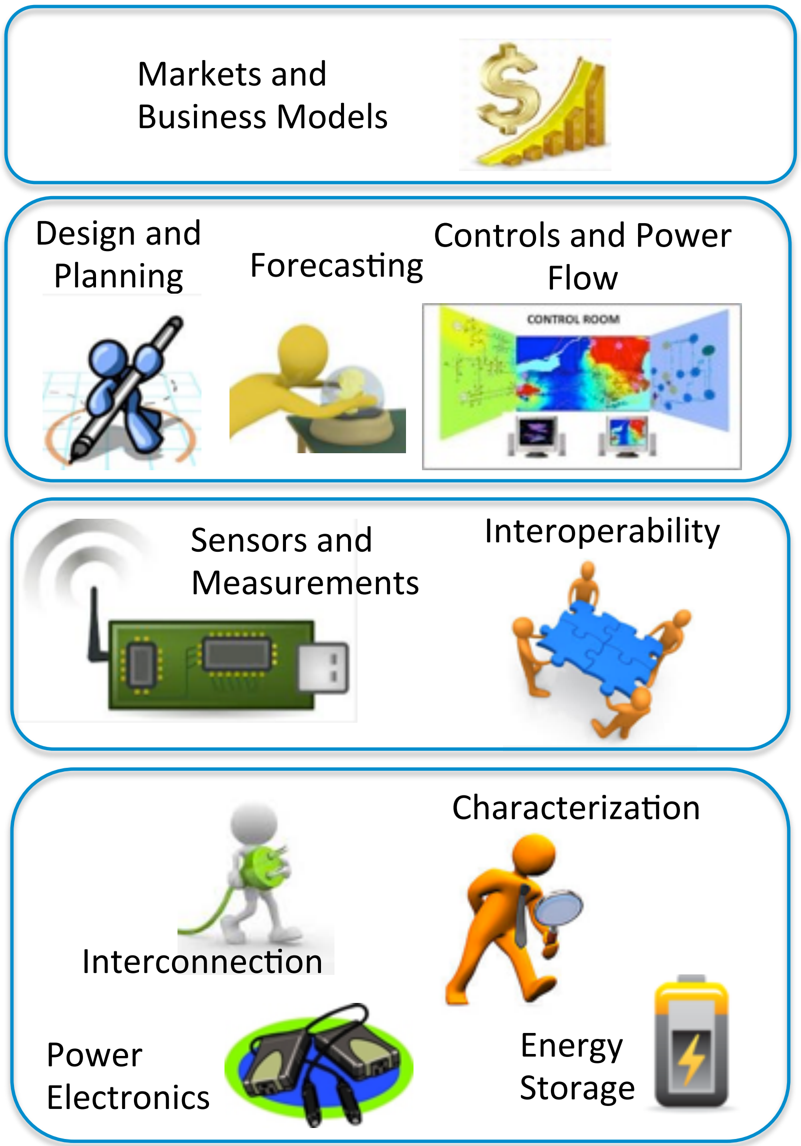
- **Integrated Modeling**
  - IGMS: Bulk + many Dist systems
  - IESM: Dist systems + many HEMS

- **Vision:**
  - ISO <-> Smart Appliance
  - Wholesale + Retail Market Interactions
  - Shared Hierarchical, Scalable Co-simulation
  - End-to-end techno-Economic models for power systems



Developing End-to-End Solutions

Energy Systems Integration



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IEEE Power & Energy Magazine

Energy Systems Integration

- Maximizing the Benefits and Minimizing the Impacts of DERs in an Integrated Grid
- Verifying That Smart Grid Power Converters Are Truly Smart
- Protection, Controls, and Testing for High Penetrations of PV Inverters on Distribution Systems
- The Impact of Distributed Solar on Germany's Energy Transition
- Measuring and Mitigating Solar PV Impacts in Southern California Using Power Factors Other than One
- The Solar Energy Challenge in Chile

March-April 2015

NREL Is Hiring!

Energy Systems Integration

http://www.nrel.gov/careers/find-job.html

Your search criteria: (5D00 - Power Systems Engineering)

	Posting Title	Requisition Number	Location	Center Office Number	Date updated
	Internship (Summer) - Solar Forecasting	4239BR	Golden, CO	5D00 - Power Systems Engineering	11-Mar-2015
	Internship (Summer)-Power Systems Operations	4240BR	Golden, CO	5D00 - Power Systems Engineering	11-Mar-2015
	Internship (Summer) - Power Systems Operations	4250BR	Golden, CO	5D00 - Power Systems Engineering	11-Mar-2015
	Internship (Summer) - Power Systems Operations	4251BR	Golden, CO	5D00 - Power Systems Engineering	11-Mar-2015
	Engineer III - Applied Distributed Energy Systems	4248BR	Golden, CO	5D00 - Power Systems Engineering	09-Mar-2015
	Engineer III - Applied Distributed Energy Systems	4119BR	Golden, CO	5D00 - Power Systems Engineering	03-Mar-2015
	Internship (Year Round) - Integration of wind and solar power	4218BR	Golden, CO	5D00 - Power Systems Engineering	23-Feb-2015
	Transmission Planning Engineer	4112BR	Golden, CO	5D00 - Power Systems Engineering	24-Dec-2014
	Post Doctoral Researcher - Distributed Energy Systems	4083BR	Golden, CO	5D00 - Power Systems Engineering	21-Nov-2014

Thank You

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