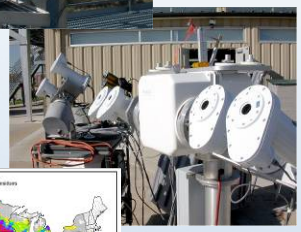
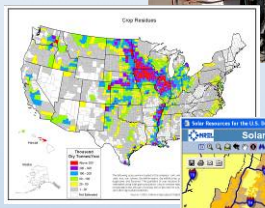
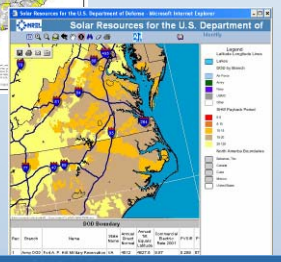











Distributed Energy Systems Integration

Ben Kroposki, PhD, PE
Group Manager
National Renewable Energy Laboratory

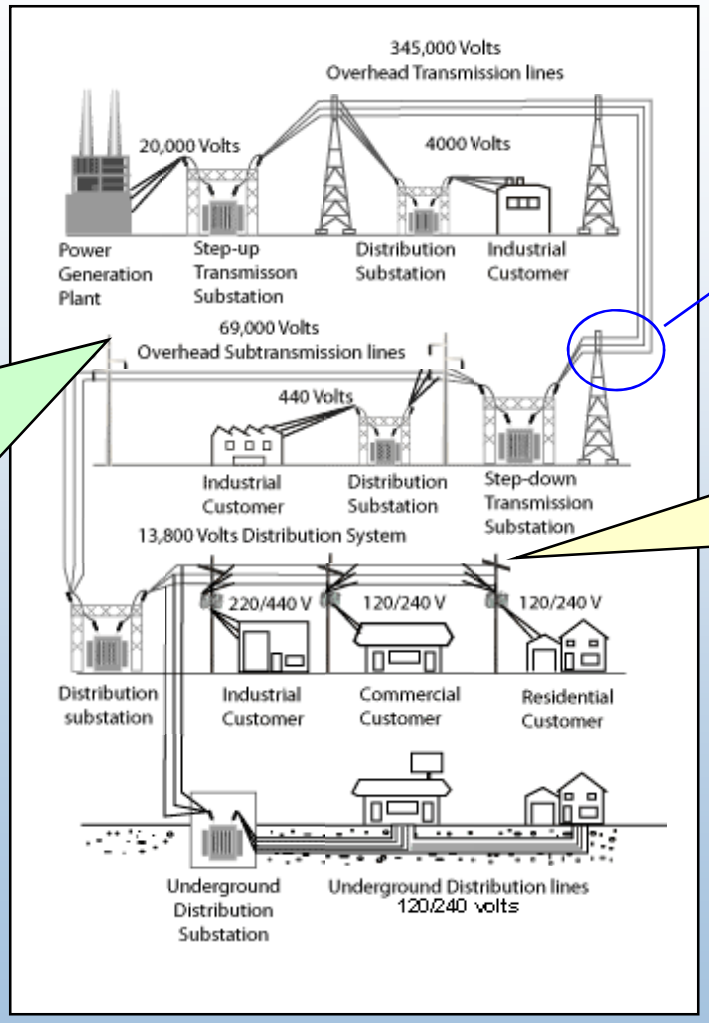
Distributed Energy Systems Integration

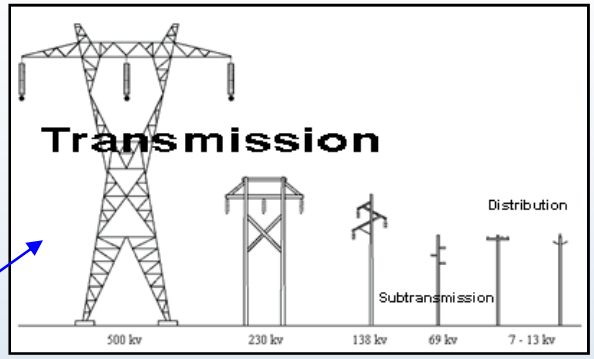
- **Systems Integration**
  - PV Grid Integration
  - Smart Grids
  - Electrical Modeling and Simulation
  - Codes and Standards Development
  - Interconnection Equipment Testing
  - Regulatory and Policy
  - Microgrids testing and standards
- **Advanced Power Electronics**
  - Advanced Functionality
  - Modular/Scaleable PE
- **Renewable Electrolysis**
  - Wind/PV to Hydrogen
  - Testing and Characterization of Electrolyzers

Renewable Systems Integration

Central Station

Large
wind farms, CSP
PV, biopower,
hydro, geothermal,
hydrokinetic,
interconnect at
transmission and
sub-transmission
levels

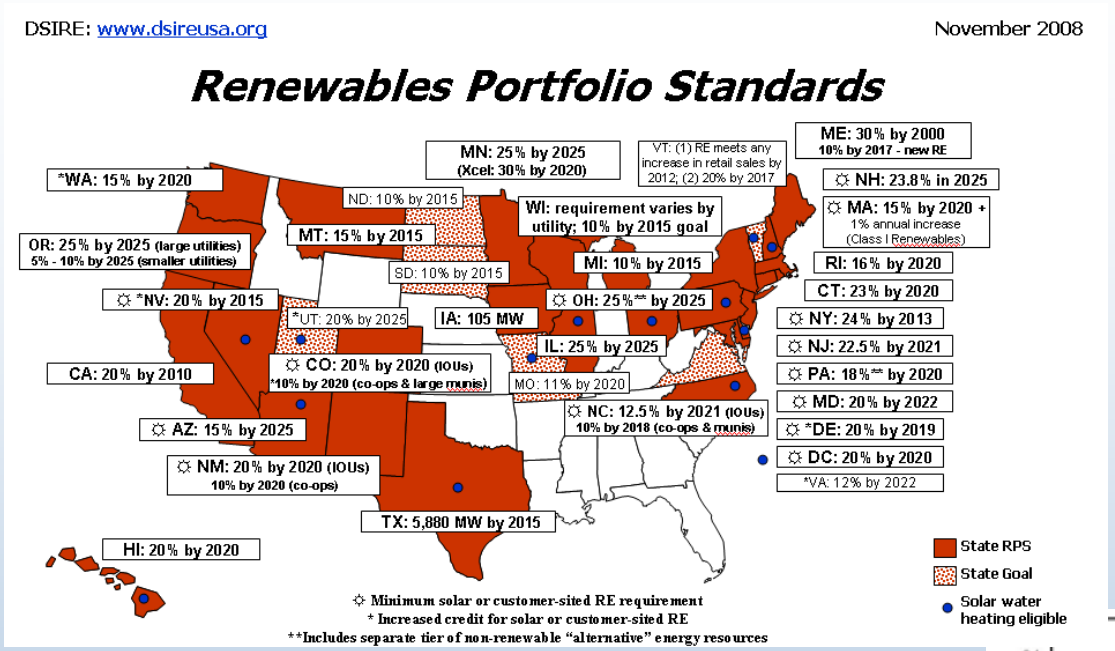




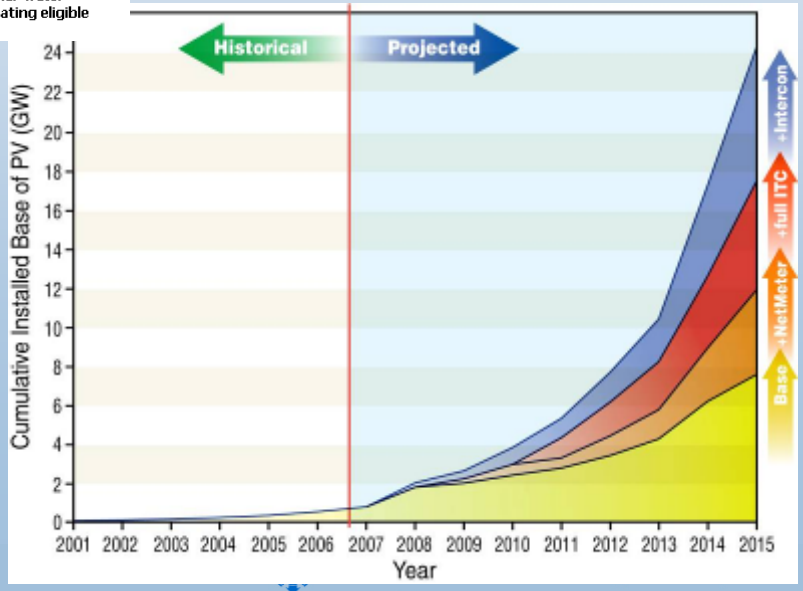
Distributed

PV, small
wind, fuel cells, V2G
interconnect at the
distribution level

Current Situation in U.S. for PV

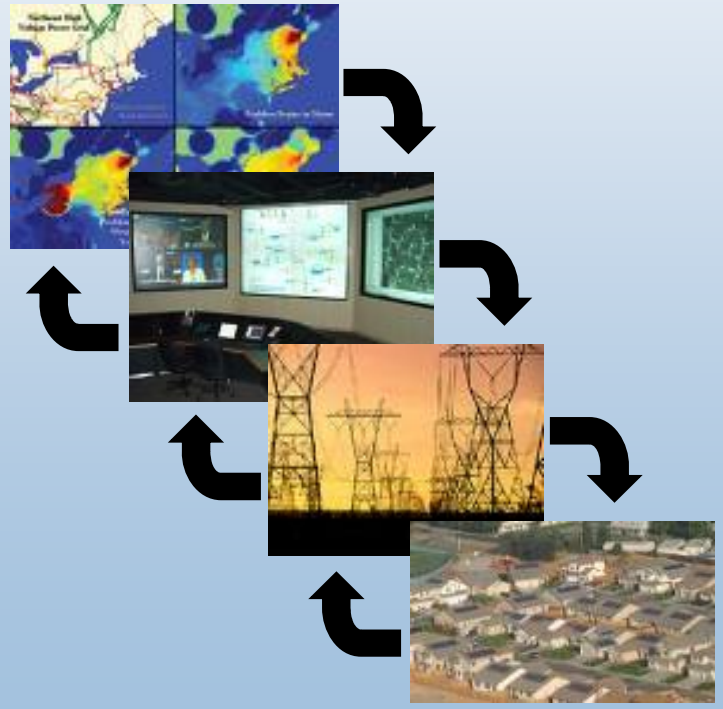


As PV market increases, industry has concerns about higher levels of penetration



Grid Integration Program Addressing High-Penetration PV Challenges

- **Issues Associated with High Penetration**
  - Affected by utilities' existing generation mix regulating capabilities, load characteristics, resource availability, and market structure
  - Additional systems costs may go up with increasing penetration due to variability and uncertainty



- **Solution Pathways**
  - Spatial diversity of the resource
  - Flexible conventional generation
  - Grid operations and control
  - Load management
  - Energy storage

Renewable System Interconnection (RSI) Study

(focus on distributed PV technology)

- Completed 14 reports available at:
  - http://www1.eere.energy.gov/solar/solar_america/rsi.html
- RSI Reports
  - Advanced PV System Designs and Technology Requirements
  - Test and Demonstration Program Definition to Support High PV Penetration
  - Advanced Grid Planning and Operations
  - Utility Models, Analysis and Simulation Tools
  - Development of Analysis Methodology for Evaluating the Impact of High Penetration PV
  - Distribution System Performance Analysis for High Penetration PV
  - Enhanced Reliability of PV Systems with Energy Storage and Controls
  - Transmission System Performance Analysis for High Penetration PV
  - Production Cost Modeling for High Levels of PV Penetration
  - Renewable System Interconnection Security Analysis
  - Solar Resource Assessment: Characterization and Forecasting to Support High PV Penetration
  - Value Analysis
  - PV Business Models
  - PV Market Penetration Scenarios

PV Grid Integration

Working with SMUD and Xcel Energy to evaluate PV grid impacts

Currently installing data acquisition and monitoring on distribution feeder at the Anatolia Subdevelopment in Rancho Cordova, CA

Smart Grid

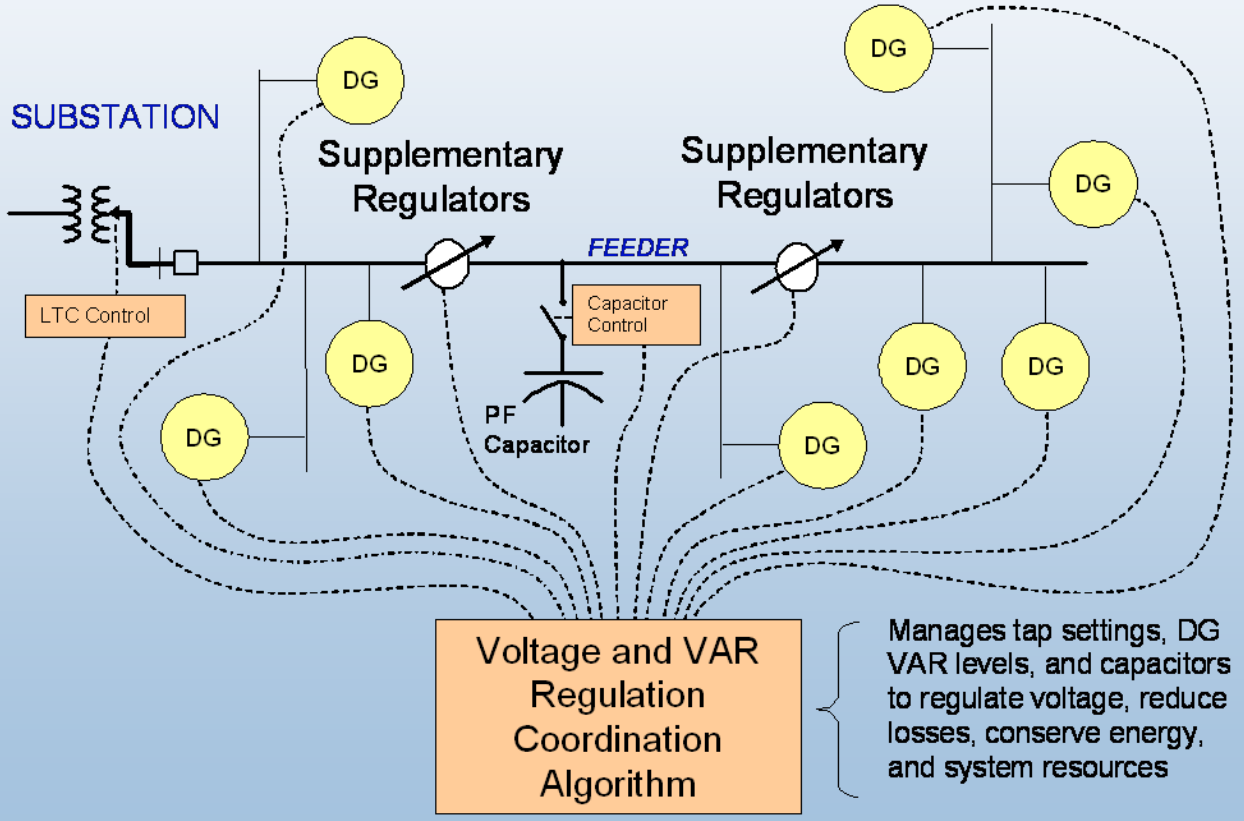
- Considerable effort is going into developing a strategy to modernize the US grid, turning it into a “smart grid.”

- A smart grid has the following characteristics:
  - self-healing
  - active participation by consumers in demand response (including DG)
  - operating resiliently against physical/ cyber attack
  - high power quality
  - accommodating all generation and storage options (including DG)
  - enabling new applications (including DG)
  - operating efficiently.

- The most important aspect of the modern grid is that it is currently envisioned that it will seamlessly integrate many types of generation and storage systems with a simplified interconnection process analogous to “plug and play.”

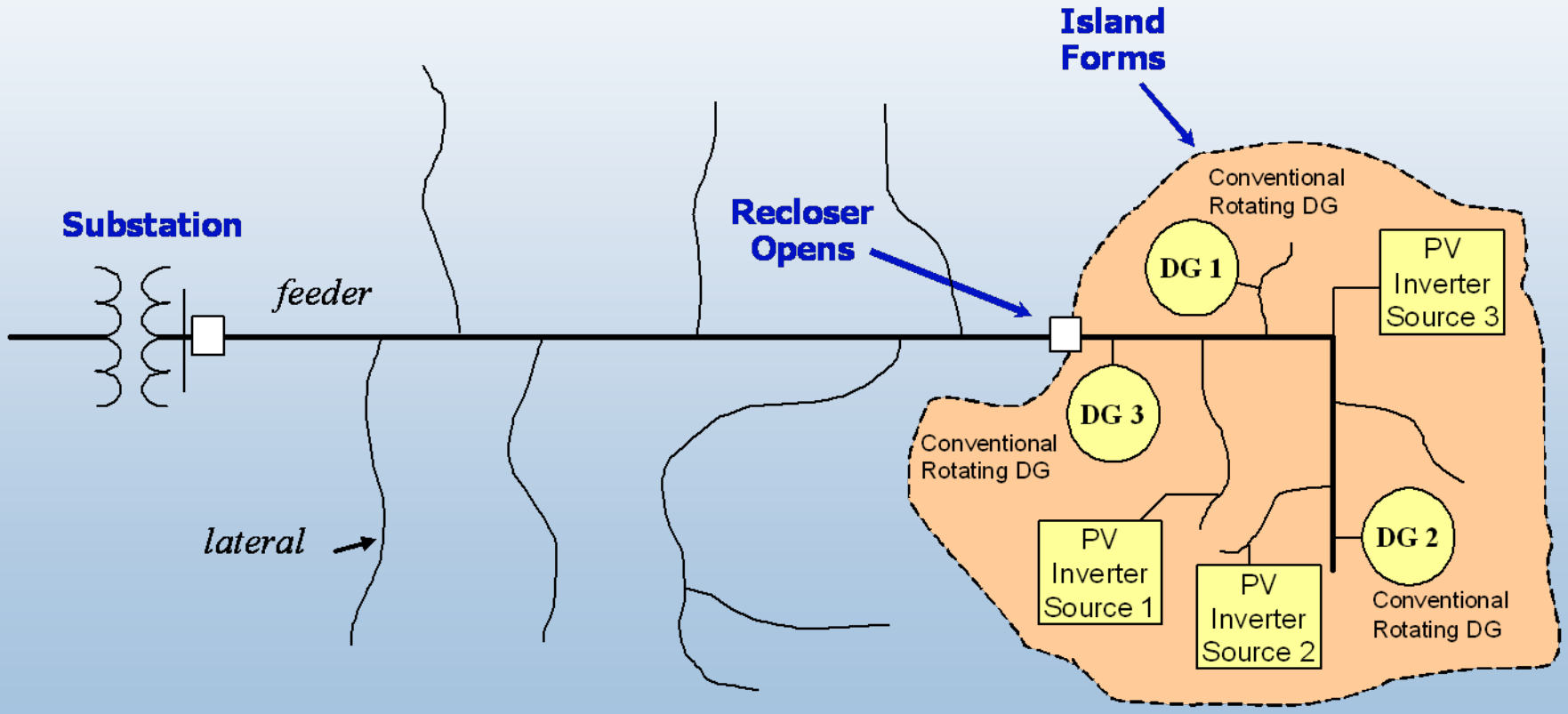
Smart Grid – Advanced operations

DG needs to actively participate in grid functions like voltage regulation



Smart Grid – Advanced operations

DG needs to integrate with other DG and Energy Storage to form Microgrids



Distributed Energy Interconnection

Distributed Energy Resources


Fuel Cell


PV


Microturbine


Wind


Energy Storage


PHEV - V2G


Generator

Interconnection Technologies

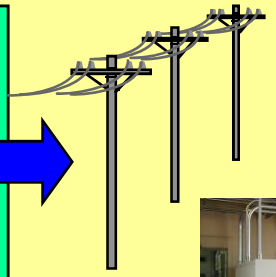

Inverter


Switchgear, Relays, & Controls

Functions

- Power Conversion
- Power Conditioning
- Power Quality
- Protection
- DER and Load Control
- Ancillary Services
- Communications
- Metering

Electric Power Systems


Utility System


Microgrids

Loads

Local Loads

Load Simulators

IEEE 1547 Series Standards

1547-2003 Standard for Interconnecting Distributed Resources with Electric Power Systems

1547.1-2005 Conformance Test Procedures for Equipment Interconnecting DR with EPS

Current Projects

1547.2 Application Guide for IEEE 1547 Standard for Interconnecting DR with EPS

1547.3 Guide for Monitoring, Information Exchange and Control of DR

P1547.4 Guide for Design, Operation, and Integration of DR Island Systems with EPS

P1547.5 Guidelines for Interconnection of Electric Power Sources Greater Than 10 MVA to the Power Transmission Grid

P1547.6 Recommended Practice for Interconnecting DR With EPS Distribution Secondary Networks

Future Projects

- DG Specifications and Performance
- Guide for Interconnection System Certification
- Guide for Grid/DG Impacts Determination
- Guide for DR Power Electronics

Microgrids

Urban distribution networks

http://grouper.ieee.org/groups/scc21/index.html

DE Interconnection System Testing

3 AC Buses

Microturbines

Wind Turbines

Utility Grid

PHEV/V2G

Inverters

3 DC Buses

NREL DER Test Facility

Advancing Renewable, Distributed Energy, and Hydrogen Technologies

DC Bus – Allows up to **10** DC device (Battery, PV) connections

AC Bus (3Phase, 480V, 400A rated) – Allows up to **15** AC device (inverters, microturbine, generators) connections

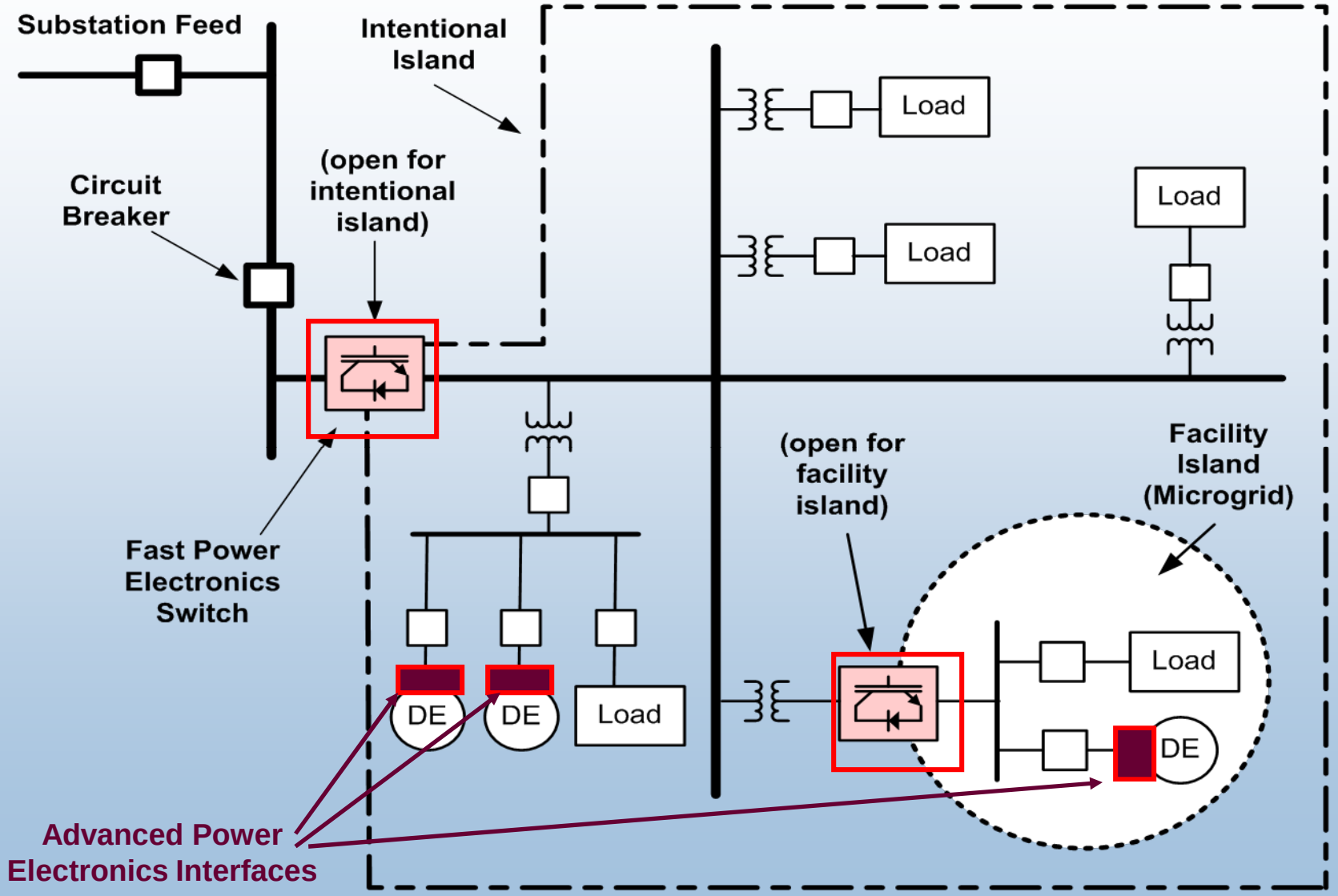
Switch Panel – Computer controlled. Allows tester to easily configure systems. Ability to run 3 independent systems simultaneously.

NREL DER Test Facility

Example Projects – IEEE 1547.1 and UL 1741 Testing

- NREL also conducts testing for the development and validation of test procedures. This activity includes working with IEEE and UL.
- The tests that can be conducted included validation of tests from IEEE P1547.1 *"Standard for Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems".*
  - over/under voltage and frequency
  - loss of synchronism
  - limits for DC injection
  - Harmonics
  - surge capability
  - islanding
  - response to faults

Microgrids – Improving Grid Reliability

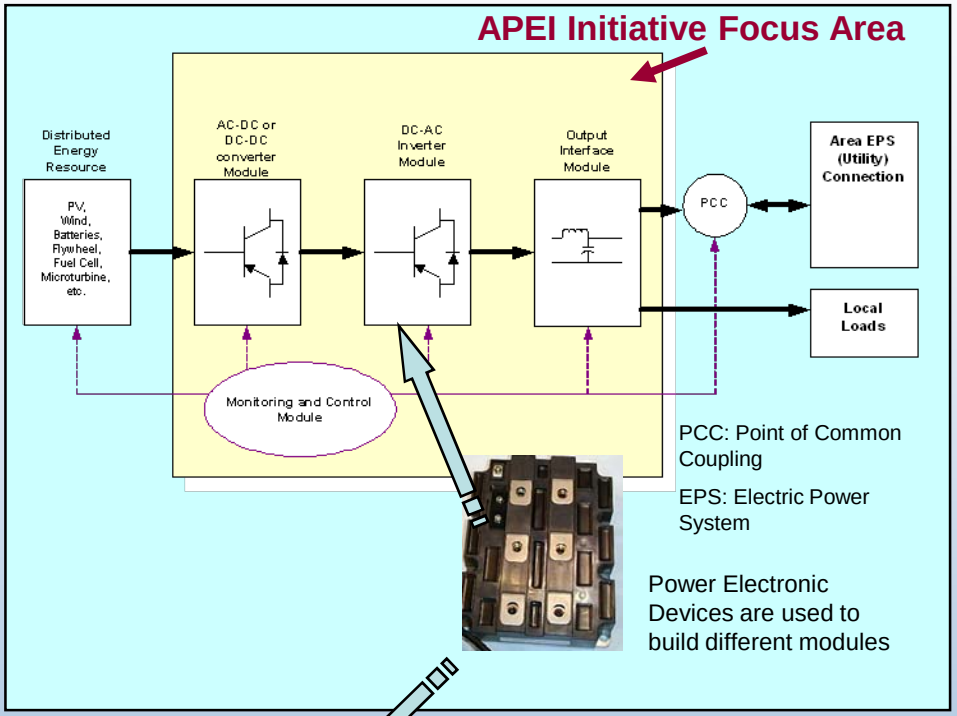


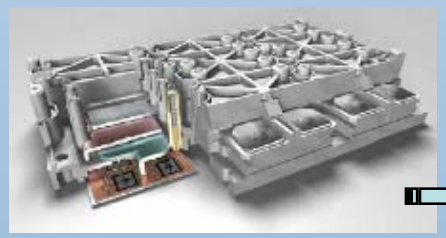
NREL DER Test Facility

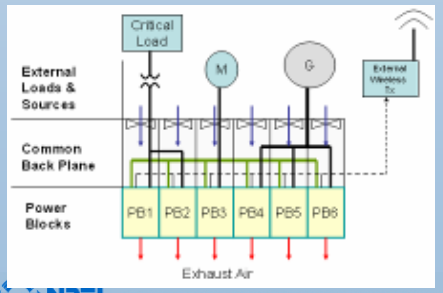
Example Projects – Advanced Power Electronics Development

Advanced Power Electronics Interface (APEI) Initiative Objectives

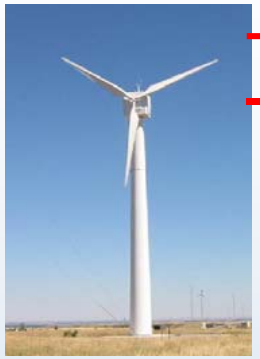
- The APEI Initiative is a coordinated plan to develop a standardized, highly integrated, **modularized power electronic interconnection technologies** that will come as close as possible to “plug-and-play” for distributed energy resource (DER) platforms.
- The goal of the APEI Initiative is to develop power electronics technology that improves and accelerates the use of DER systems.
- Reduce costs for DER and interconnections by developing standardized, high production volume, power electronic modules.







Wind2H2 Project



100kW Wind Turbine

Excess AC Power

DC BUS

Utility Grid

DC-DC Converter

DC-DC Converter

ASCO Transfer Switch

Proton Energy (PEM) 5kW Electrolyzer

Proton Energy (PEM) 5kW Electrolyzer

Teledyne (Alkaline) 50kW Electrolyzer

AC Power

Hydrogen IC Engine/ Genset 60kW

AC Power

Hydrogen Fuel Cell 5kW

10kW Wind Turbine

AC-DC Converter

Hydrogen Output

10kW PV

DC-DC Converters

Hydrogen Compression 150psi - 3,500psi

Hydrogen Storage 85kg

(Future) H2 Filling Station