Renewable Energy Interconnection and Storage - Technical Aspects

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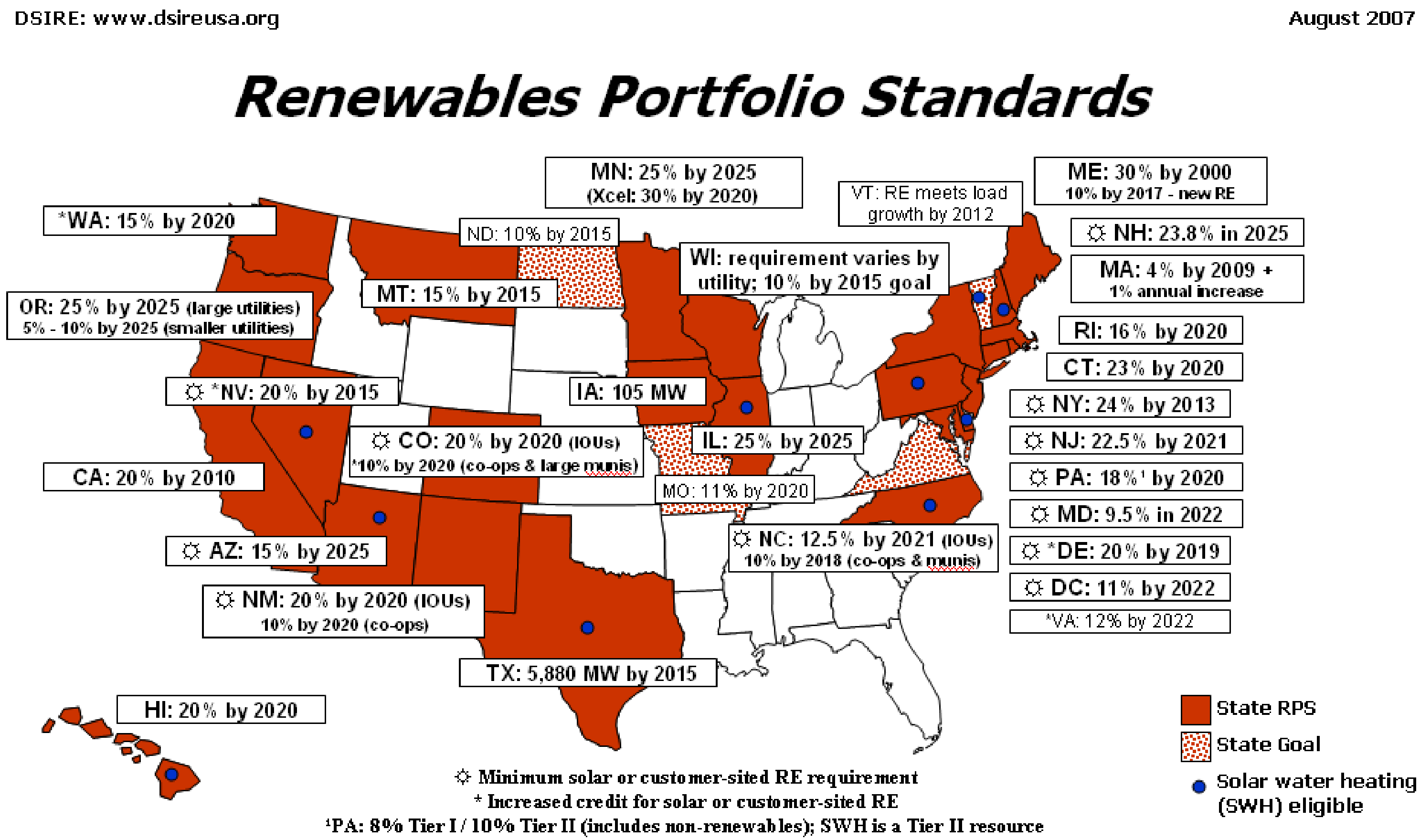
An Emerging Market:

Preparing for Large-Scale Renewable Energy Interconnection

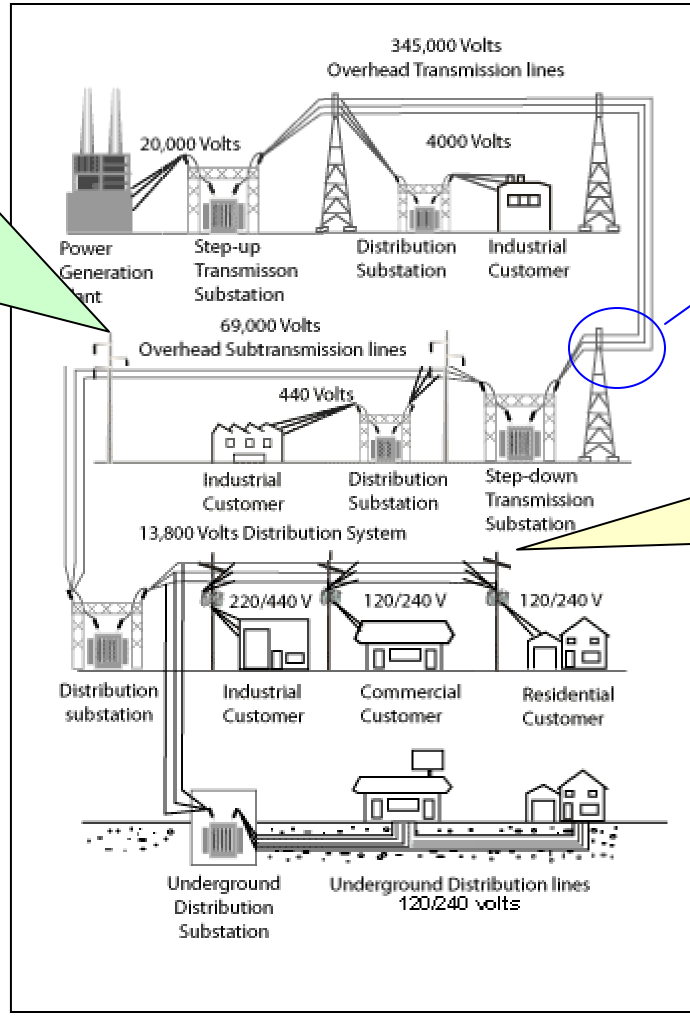
New Market Scenario: Climate change concerns, renewable portfolio standards, incentives, and accelerated cost reduction driving steep growth in U.S. renewable energy system installations.

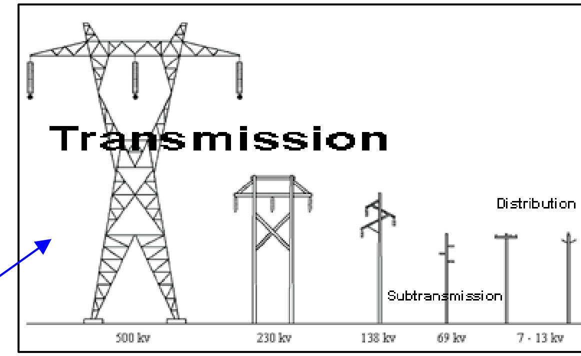


Where Renewable Energy Interconnects

Central Station

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





Distributed

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

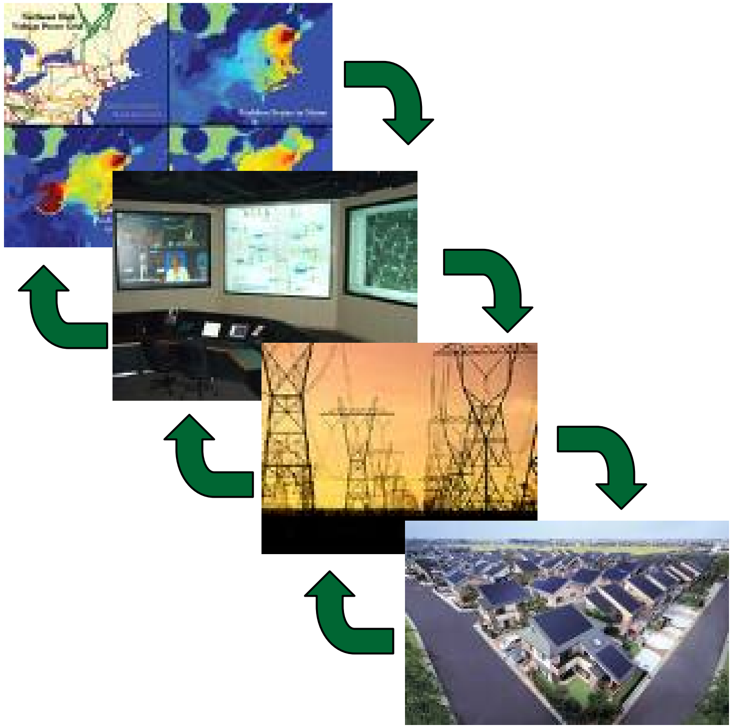
Performance Expectations at Various Connection Points in the Electric System

RE Connection Level	*Interconnection Rules*	*System Integration Concerns*	*Local and System Values*
Connection at End Use Low Voltage (LV)	**Local connection requirements…. e.g. IEEE 1547 and derivatives**	**Feeder- level issues such as power flows, protection, and voltage impacts… e.g. Issues related to high penetration levels**	**Power, heat, load control, quality and reliability**
Connection at Distribution (MV)			**Ancillary service support to utility T&D e.g. reserve capacity, demand response, deferral of expansions, etc.** **Variable energy resources displace fuel use and avoid emissions**
Connection at Transmission (HV)	**National Grid Codes** **-FERC 661-A** **-General Requirements for Interconnection (Utility document on file with FERC)**	**Understanding how to plan and operate the transmission grid and other generation resources based on RE operating characteristics**	

Concerns with Integrating Renewables

- **Penetration**
  - Affected by utilities' existing generation mix regulating capabilities, load characteristics, resource availability, and correlations between system load and resources
  - Additional systems costs imposed by variability and uncertainty may go up with increasing penetration
  - Costs are moderate – up to 20-30% Penetration – and depend on balancing authority and market structure
- **Infrastructure Capacity**
  - Lack of transmission capacity from stranded renewable resource locations
- **Variable and Uncertain Generation**

  Solved by
  - spatial diversity of the resource
  - flexible conventional generation
  - grid operations and control areas
  - limited curtailment for extreme events
  - load management
  - and at high penetrations possibly storage
- **Technical Concerns**
  - Real but solvable



RE Interconnection – Technical Concerns

Wind and Large Solar (Bulk System Connected Generation)

- Steady state and transient stability analysis
- Load/Generation Coincidence (Peak Load and Variability of Source)
- Regulation Requirements
- Integration with Automatic Generation Control (AGC)
- Incorporation of renewable resource forecasting
- Examine current operating practice and new concepts to enable high penetration;
  - frequency responsive (create regulating reserves)
  - demand side coordination

Distributed Solar and Small Wind (Distributed Generation)

Issues listed above, plus

- Voltage and VAR Regulation
- Power Quality (Harmonics, Flicker, DC Injection)
- Unintentional Islanding
- Protection design and coordination (short circuit, recloser, etc.)
- Equipment grounding
- Load and generation imbalance
- Generation interaction with controllable loads (DSM)
- Storage and storage controls

- **Most technical concerns at the bulk level have been solved with modern wind turbines and grid codes**
- **Technical concerns at the distribution level have been identified, but small RE have not been fully integrated into planning and operations**

- **Interconnection concerns are real and solvable:**
  - **e.g., specific to: equipment, design, location, application, etc.**

Interconnection Technologies

Distributed Energy Resources

Fuel Cell

PV

Microturbine

Wind

Energy Storage

Generator

Interconnection Technologies

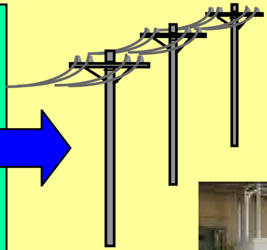
Power Electronics-Inverter

Switchgear, Relays, & Controls

Functions

- •Power Conversion
- •Power Conditioning (PQ)
- •Protection
- •Source and Load Control
- •Ancillary Services
- •Communications
- •Metering

Electric Power Systems



Utility Grid

Micro Grids

Loads

Historical and Current DOE Integration Activities Regarding Large Wind Integration Studies

- A large amount of research has looked into the technical concerns regarding integration of wind farms into the electrical grid.
- Several studies have examined 20-30% penetration
- For large, diverse electric balancing areas, existing regulation and load following resources and/or markets are adequate and associated costs are low
- Moderate cost increases may be needed to account for variability and uncertainty of wind resource (3-4% low to 7-10% high)
  - Largely dependent on local utility market design and resource constraints
- State of the art forecasting can reduce costs
  - majority of the value can be obtained with current state-of-the-art forecasting
  - additional incremental returns from increasingly accurate forecasts
- Realistic studies are data intensive and require sophisticated modeling of wind resource and power system operations

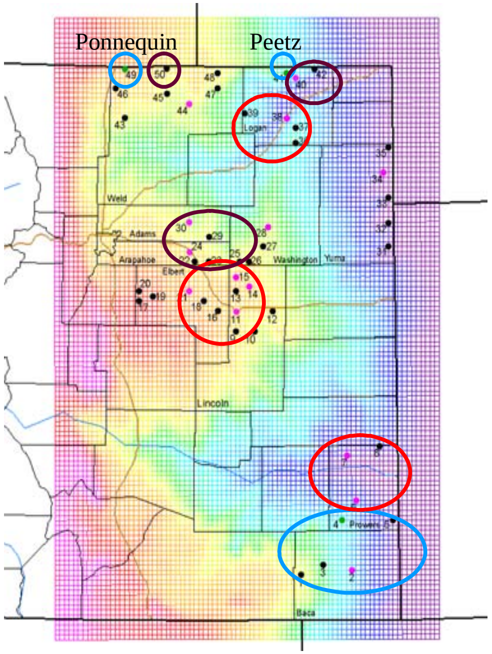
Large Wind Integration Study References

- **California Intermittency Analysis –** The Intermittency Analysis Project conducted a series of scenario based studies to examine the statewide system impacts of higher levels of intermittent renewables on the California electricity and transmission infrastructure.
  - http://www.energy.ca.gov/pier/notices/
- **Minnesota State 20% Wind Integration Study –** Wind Integration Study of the impacts on reliability and costs associated with increasing wind capacity to 20% of Minnesota retail electric energy sales by the year 2020.
  - http://www.puc.state.mn.us/docs/index.htm
- **Northwest Wind Integration Action Plan –** The region's utility, regulatory, consumer, and environmental organizations worked together to address several major questions surrounding the growth of wind energy.
  - http://www.nwcouncil.org/energy/Wind/Default.asp
- **New York ISO and NYSERDA -** A joint study to produce empirical information that will assist the NYISO in evaluating the reliability implications of increased wind generation.
  - http://www.nyserda.org/publications/wind_integration_report.pdf
- **MISO 20-25% wind study –** Begins in 2008
- **Western Wind Integration Study –** Started in '07 – End results in '09

Solutions to Variable and Uncertain Generation

- Spatial diversity of the resource
- Flexible conventional generation
- Grid operations and control areas
- Load management
- Limited curtailment for extreme events
- And at high penetrations possibly storage

Wind Diversity in Colorado

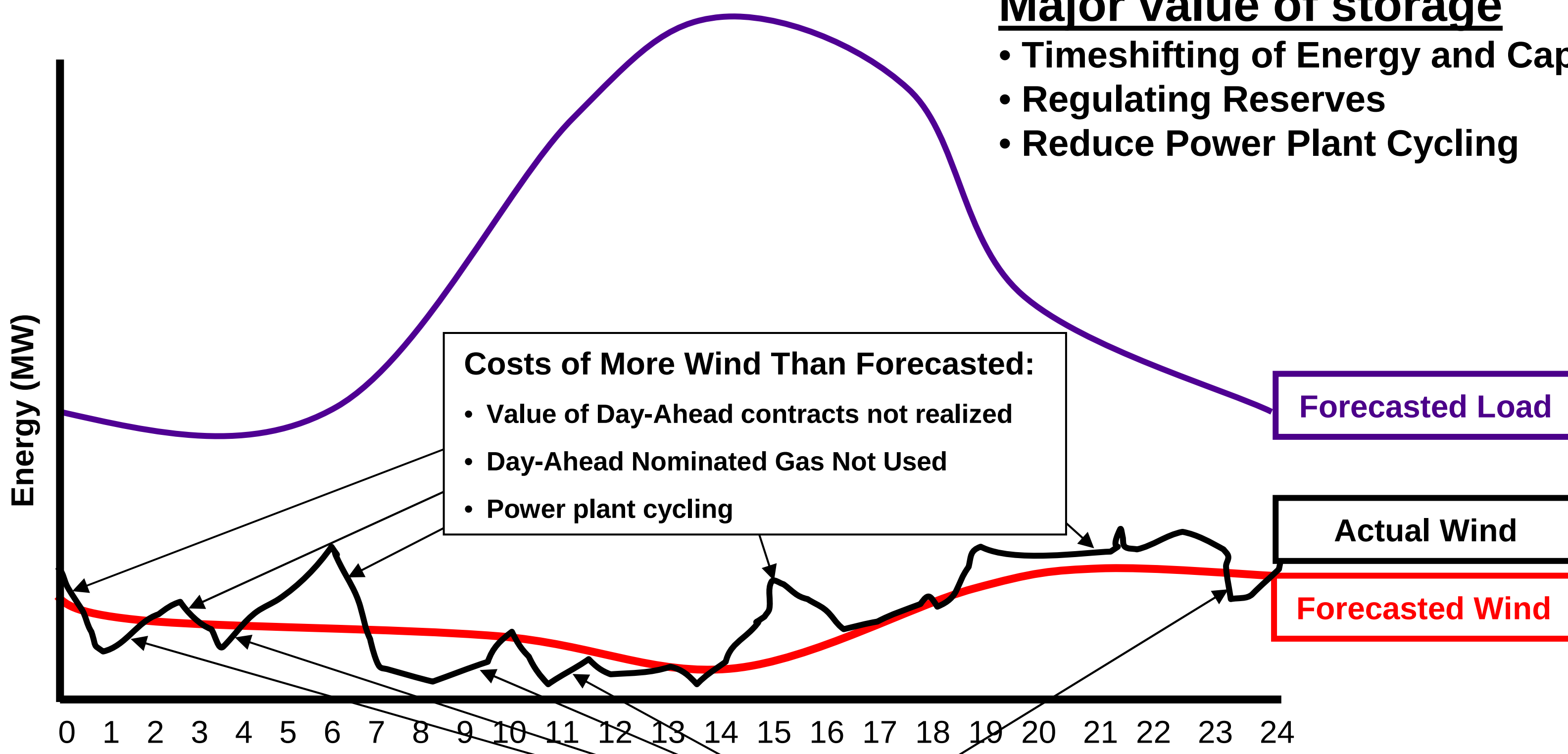


Pumped Hydro Facility

Energy Storage to Address RE Generation

Major value of storage

- Timeshifting of Energy and Capacity
- Regulating Reserves
- Reduce Power Plant Cycling



Costs of Less Wind Than Forecasted:

- Spot market electric purchases
- Greater peaker "wear & tear" costs due to more starts/stops than assumed in Retail rate design
- Potential depletion of gas system pressure due to higher than expected peaker starts/usage
- Power Plant Cycling

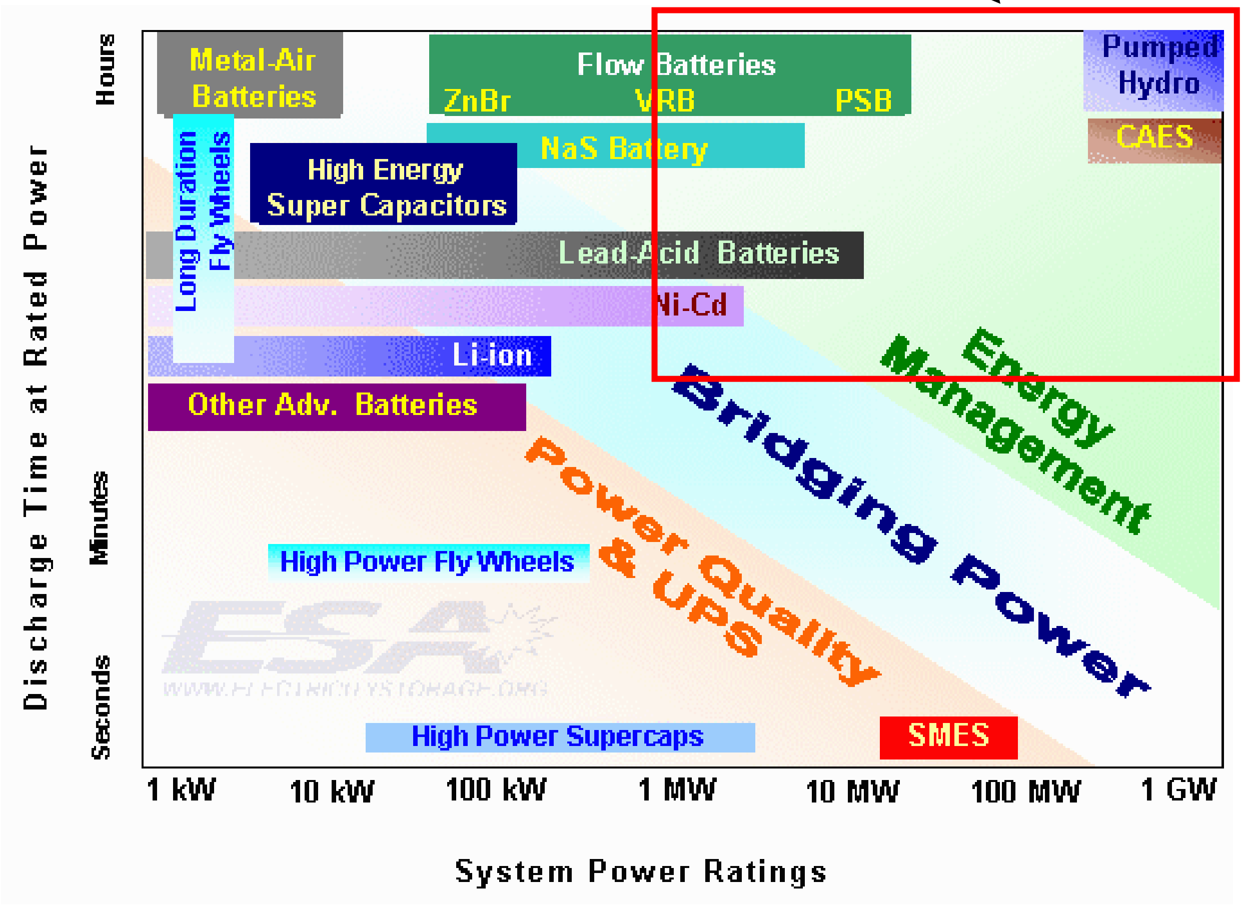
Note: At the utility scale, energy storage only needs to cover relatively small fluctuations

Energy Storage Options

- Pumped Hydro
- CAES
- Batteries (Lead Acid, NaS, VRB, Lithium ion, etc.)
- Super Caps
- Flywheels

- Hydrogen
- PHEV/V2G
- Thermal Storage
- Natural Gas

Utility needs for Integration with Renewables



Notes: no storage need found yet in wind studies looking at up to 20-30%.
most storage is not economically feasible currently or in the near term

Historical and Current DOE Integration Activities Regarding Distributed Energy Interconnection

- DOE EERE Office of Power Technologies initiated the Distributed Power Program in 1999 to look at integration and interoperability of distributed generation and renewable energy technologies into the electric power system through interconnection standards development in response to the deregulation movement at that time. This effort grew into a major program and was highly regarded in addressing the electric grid and renewable energy integration needs.

- With the formation of the DOE OE (formerly OETD) in the 2002 time frame the integration effort was re-located to the R&D area of OE within the systems integration and transformation area, and is currently funded regarding interconnection standards development (i.e. IEEE, IEA, and IEC), interconnection technology development, interoperability of the T&D system and the impacts on the grid and solutions to minimize these impacts to allow greater renewable and DG technology applications for interconnection and operability at the point of common coupling to the grid, both at the distribution and transmission connection points.

- The current effort by DOE EERE is to identify the path forward to high distributed penetration renewable energy scenarios. This effort is maximizing efforts of the past and providing potential solutions for renewable technology acceptance for grid planning and operation.

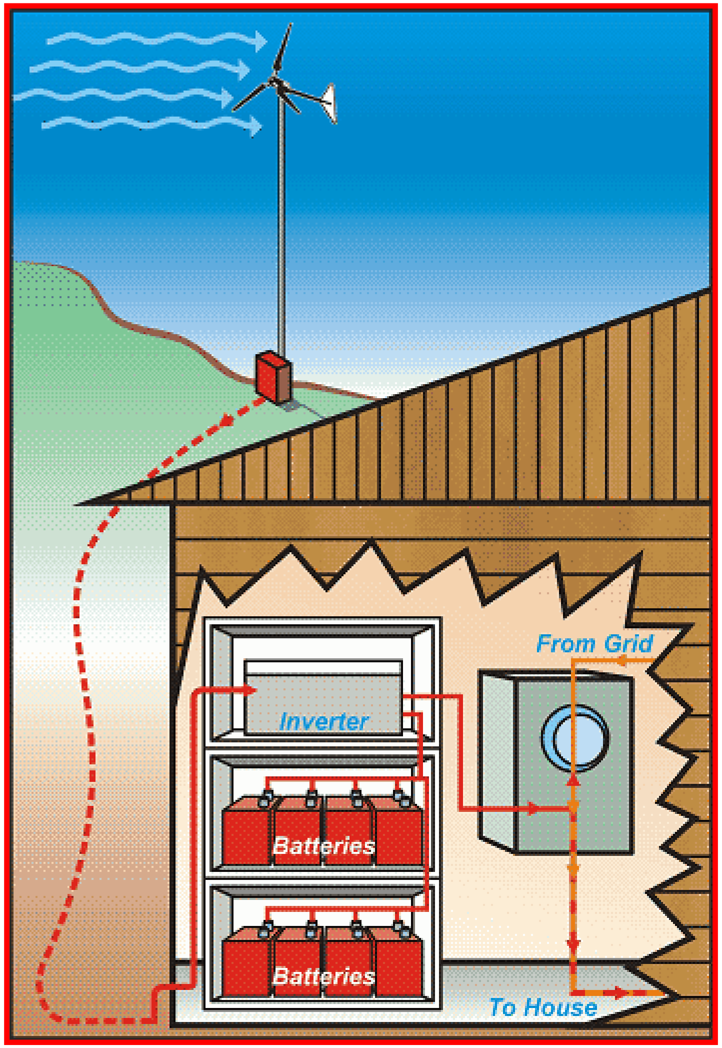
Distributed Renewable System Interconnection Studies

- DOE is completing a report on Distributed Renewables (focused on PV)
  - Target audience: DOE and external stakeholders (utilities, system integrators, regulators, trade organizations, etc)
  - Draft reports – Mid October 2007

- Renewable Systems Interconnection Reports
  - Advanced Grid Planning and Operations Study
  - Utility Simulation and Modeling Study
  - High Penetration Distributed PV Studies
  - Resource Assessment Study
  - Distributed PV Systems Design & Tech Requirements
  - Test & Demonstration Program Definition
  - Production Cost Modeling Study
  - PV Value Analysis Study
  - Business Model Development Study
  - Market Penetration Study

Connecting to the Utility for Distributed Renewables

- Individuals contact utility before connecting to its lines and obtain an "interconnection agreement."
- Often, a simple, standard agreement is available for small renewable energy systems.
- **EPACT 2005** offers interconnection
  - Requires utilities to consider interconnection service to its customers (on-site generation connected to distribution facilities)
  - Interconnection services shall be offered based upon IEEE 1547
  - Agreements and procedures shall be established, promoting current best practices of interconnection, including practices stipulated in state regulatory model codes



DOE Interconnection Best Practices: http://www1.eere.energy.gov/solar/pdfs/doe_interconnection_best_practices.pdf

IEEE 1547 Series of Standards

Approved Standards

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

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

Integrated with UL 1741 for equipment certification

Current Projects

P1547.2 Application Guide for IEEE 1547 Standard for Interconnecting DR with EPS

P1547.3 Guide for Monitoring, Information Exchange and Control of DR

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

Microgrids

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

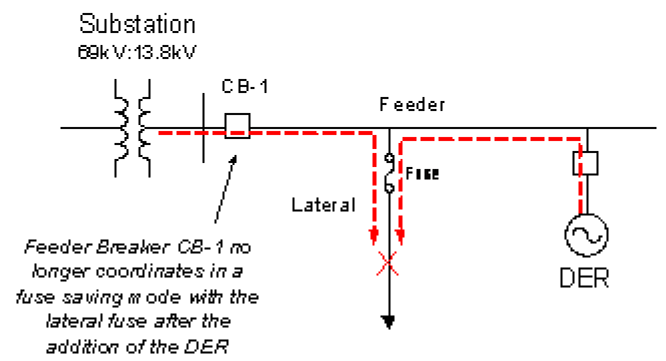
Urban distribution networks

DOE has had a major role in supporting the development of these standards

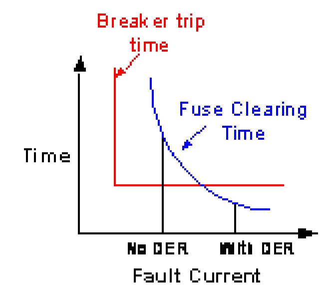
http://grouper.ieee.org/groups/scc21/index.html

Short-circuit current coordination

DR can provided a variety of levels of short circuit current. There has to be a sufficient level of short circuit current available within the separated Local Electric Power System (EPS) and Distributed Resource (DR) system to clear short circuit faults.



The separated Local EPS and DR system has to provide enough fault current to operate the protective devices in the system including circuit breakers, fuses, and fault protection relays.



Recloser coordination

Automatic circuit reclosers also may be deployed in the feeder circuit to clear faults and quickly restore service on the feeder. Reclosers reenergize the circuit automatically immediately after a trip resulting from a feeder fault. The response of the DR unit must be coordinated with the reclosing strategy of the isolations within the Area EPS. Coordination is required to prevent possible damage to Area EPS equipment and to equipment connected to the Area EPS other than the DR.

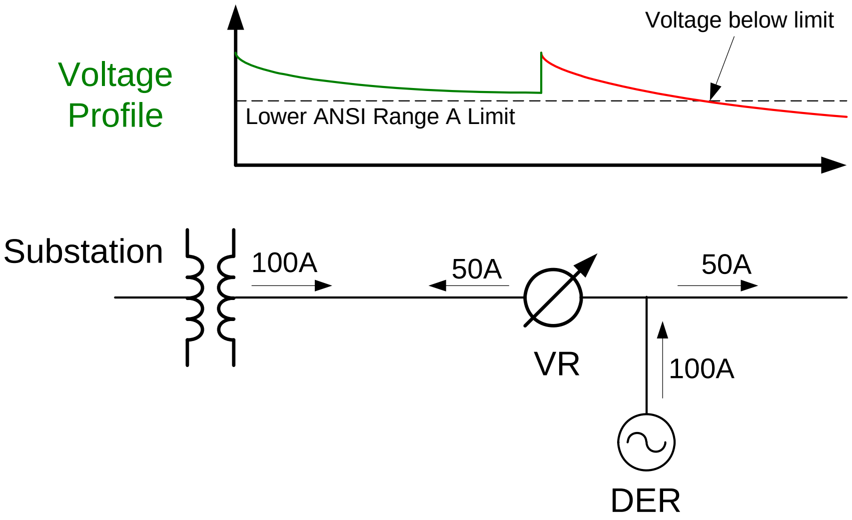
Distribution Interconnection – Technical Concerns

Voltage Regulation

Primary objective of voltage regulation is to provide each customer connected to the utility with voltage that conforms to the design limitations of the customer's utilization equipment.

Voltage supplied to each customer at the PCC is an important measure of service quality. Satisfactory voltage level is required to operate lights, equipment and appliances properly.

Injecting power from a DR device into the power system will offset load current thus reducing the voltage drop on the utility. The DR device may inject leading reactive power (capacitive) into the power system or draw lagging reactive power (inductive) from the power system thus affecting the voltage drop on the utility.



Grounding

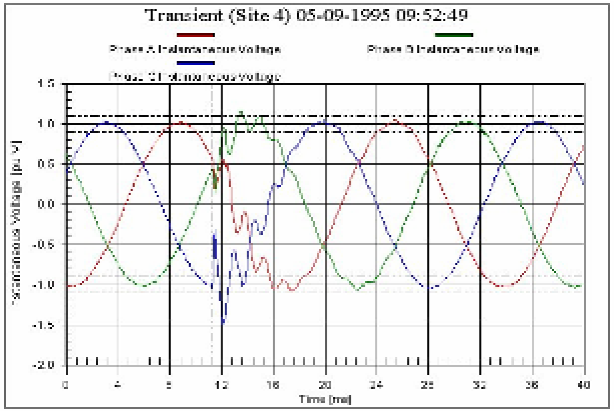
Depending on how the DR is constructed within the Local EPS there could be potential grounding conflicts setup in the installation. If the point of interconnection for the DR occurs within a building inside of a service entrance then this issue is more likely to be of concern. Under normal conditions the DR generator is a grounded source since it receives a ground reference from the grounding of the electrical service at the service entrance to the building as required by building codes. Those codes require also that the service is grounded only once at the service entrance to the building and thus a local grounding of the DR generator elsewhere in the building premises would be prohibited. Then when the abnormal conditions do occur and the DR separates from the grid and the grounded service, suddenly the DR generator loses its independent ground reference.

Distribution Interconnection – Technical Concerns

Power Quality Issues:

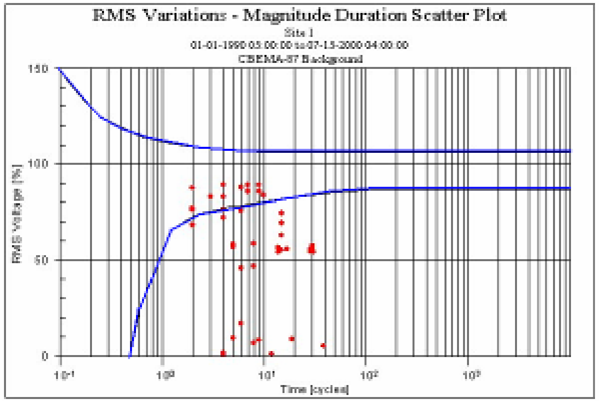
Harmonics

Harmonic currents cause transformers to overheat, in turn overheating neutral conductors. This overheating may cause erroneous tripping of circuit breakers and other equipment malfunctions. The voltage distortion created by nonlinear loads may create voltage distortion beyond the premise's wiring system, through the utility, to another user. DR should be designed to inject a minimal amount of harmonic distortion onto the grid.



DC Injection

DC injection produces a DC offset in the basic power system waveform. This offset increases the peak voltage of one-half of the power system waveform (and decreases the peak voltage in the other half of the waveform). The increased half-cycle voltage has the potential to increase saturation of magnetic components, such as cores of distribution transformers. DR should be designed to not inject DC current onto the grid.



Flicker

Flicker is a power quality issue that is predominately associated with noticeable changes in light output from incandescent lighting caused by minor changes in voltage levels. Flicker can exist in fluorescent lighting but requires somewhat larger voltage deviations. DR should not cause flicker.

Distribution Interconnection – Technical Concerns

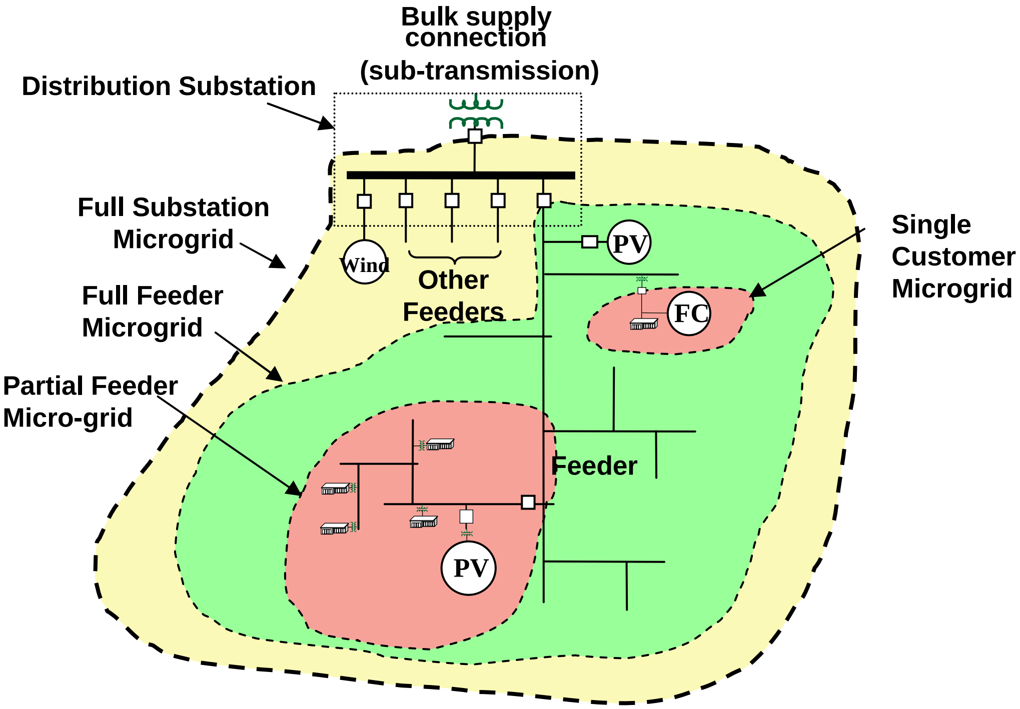
Intentional and Unintentional Islanding

Unintentional Islanding occurs when the distributed generator (or group of distributed generators) continues to energize a portion of the power system that has been separated from the rest of the Utility.

In most cases it is not desirable for a DG to island with any part of the utility on an unplanned basis; this can lead to safety and power quality problems that will affect the Area EPS and local loads.

During utility repair operations, such as dealing with downed conductors, DG islanding can expose utility workers to circuits that otherwise would be de-energized (and the workers believe to be de-energized).

1547 requires DR interconnection systems shall detect the island and cease to energize the Area EPS within two seconds of the formation of an island.



Intentional Island

(Covered in IEEE 1547.4)

- **Can improve customer reliability**
- **Improve power quality**
- **Used by utilities for maintenance**

Needs for Distributed Renewables

- Distributed renewable interconnection technologies with advanced functionality
- Integration of renewable energy with dispatchable load and storage
- Electric power systems technologies, controls, and operations that enable high penetration of distributed renewable energy systems
- Models for renewable energy systems that allow them to be included in the planning and analysis tools