Grid Integration of Distributed Generation and Storage

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National Harbor, MD
Variable solar and wind generation

A US Future of 302 GW PV by 2030?

Generation in Germany Week - April 14-20, 2014

DOE “SunShot” Vision Study, Released February 2012

Is the grid ready?
Steps for Integrating DG?

- Understanding PV Plant Performance
- Determine Feeder Hosting Capabilities
- Develop Fast-Track Screening
- Deploy Inverter-Grid Support

Current Research Activities
EPRI SolarTAC Testing

Normalized I-V Curves

Seasonal Performance Factors for SolarTAC

Weighted Average Module Temperature (°C) for Suntech
Seasonal PV Daily Output Profile

Shows max, min, median, and middle 50% range for a Georgia Site

- **Winter (Jan-Mar)**: 0.68 span
- **Spring (Apr-Jun)**: 0.18 span
- **Summer (Jul-Sep)**: 0.3 span
- **Fall (Oct-Dec)**: 0.58 span

Normalized Power vs. Hour of Day
Solar Resource Calendar – 1MW<sub>AC</sub> Output Power

December 2011: Tennessee 1MW PV System Power

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<tr>
<th>Sun</th>
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Calendar profiles are 1-minute averages derived from 1-sec data
Categories for Daily Variability Conditions

Sandia’s variability index (VI) and clearness index (CI) to classify days

- **VI > 10**: High
- **2 ≤ VI < 5**: Mild
- **5 ≤ VI < 10**: Moderate
- **VI < 2**: Overcast
- **CI ≥ 0.5**: Clear
- **CI ≤ 0.5**: Overcast

- **Clear Sky POA Irradiance**
- **Measured POA Irradiance**

*Image showing the variability index and clearness index categories with corresponding graphs.*
Geographical and Seasonal PV Variability

Variability Conditions: NM

Variability Conditions: NJ

Variability Conditions: AZ

Variability Conditions: TN
EPRI High-resolution PV Monitoring

Concentrated areas include Southeast, Atlantic Coast, and California

Site Locations, September 2013

Clusters
PV Plants

Installed
Recent Install
Planned
Example of Variability on a Feeder in Rome, GA

1 km² grid

= DPV Site

Substation

© Google – Map data © Google
Monitoring PV Output Variability

Monitoring solar variability and power quality events throughout the feeder

Using the high resolution data for modeling analysis
Applying Measured PV Data to Feeder Model

Solar Data
• Collect high-res 1 sec solar data to use in model simulations

Feeder Modeling
• Develop feeder models with input from utilities
Analysis Approach

Uniqueness from other research efforts
- Large sample of feeders/characteristics considered
- 1000’s of potential deployments (size/location) analyzed
- Range in hosting capacity reported for each issue

Details on analysis method:
*Stochastic Analysis to Determine Feeder Hosting Capacity for Distributed Solar PV.*
Sample Analysis – Spatial & Time Based

3D Visualization of PV Measurement

Feeder Voltage Profile

PV Production Time Series

Regulator/Capacitor Operations
Smart Inverter is a Key Integration Technology

**Traditional Inverter Functionality**
- Matching PV output with grid voltage and frequency
- Providing safety by providing unintentional islanding protection
- Disconnect from grid based on over/under voltage/frequency

**Smart Inverter Functionality**
- Voltage Support
- Frequency Support
- Fault Ride Through (FRT)
- Communication with grid
What is a Smart-Grid Ready Inverter?

Link to distributed PV and Storage Systems that become Beneficial distribution system assets.

- Improving Efficiency
- Reliability
- Improving Power Quality
- Deferred Costs
- Asset Life
- Enabling Higher Penetration of Renewables
- Improving Power Quality
- Asset Life
- Deferred Costs
- Improving Efficiency

DMS
DER Management
DERMS
Communication Level
Hosting Capacity with Inverter Support Function

**PV at Unity Power Factor**
- Minimum Hosting Capacity
- Maximum Hosting Capacity

2500 cases shown
Each point = highest primary voltage

**PV with Volt/var Control**
- Minimum Hosting Capacity
- Max Hosting Capacity

ANSI voltage limit

Increasing penetration (kW)

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No observable violations regardless of PV size/location
Possible violations based upon PV size/location
Observable violations occur regardless of size/location
Hosting Impact of Smart Inverter Functions and Set Points

All penetrations in this region are acceptable, regardless of location

Some penetrations in this region are acceptable, site specific

No penetrations in this region are acceptable, regardless of location
Understanding Potential Benefits of Storage

**Power Supply**
- Energy and load shifting
- Regulating services
- Contingency reserve

**Power Delivery**
- Asset utilization
- Investment deferral
- Power quality and reliability

**End Use**
- Photovoltaic Energy Shifting
- Demand Peak Reduction
The Energy Storage Value Concept

For Illustration Only

Costs of Storage

Benefits of Storage

Balance of Plant
Power Electronics
Battery Cost

Photovoltaic Peak Shift
Demand Peak Reduction
Regulation Services
Voltage Support
Inertia Support
Power Quality and Reliability
T&D Upgrade Deferral

Customer Side Applications

Market Applications

Rate Based Applications
The Value of Storage Realities

For Illustration Only

Balance of Plant
Power Electronics
Battery Cost

Costs of Storage

Benefits of Storage

- Photovoltaic Peak Shift
- Demand Peak Reduction
- Regulation Services
- Voltage Support
- Inertia Support
- Power Quality and Reliability
- T&D Upgrade Deferral

Customer Side Applications
Market Applications
Rate Based Applications
Various Sources of Flexibility

- **Conventional Resources**
  - Peaking and cycling units

- **Emerging Resources**
  - Demand response
  - Energy storage
  - Plug-in electric vehicles

- **VG Power Management**
  - Control VG output

- **Institution/Market Flexibility**
  - Coordination among Balancing Authorities (BAs)
  - Shorter scheduling

- **More Transmission**
Smart Grid Ready Inverter: Objectives

1. **Make Inverter Ready and Demo in Field**
   - Develop, test, field demo at utility sites
   - Define and incorporate standard grid support functions (500 kVA level)*
   - Use feeder/PV modeling for scale up

2. **Revisit Feeder Level Anti-Islanding**
   Identify utility-controlled trip options
   - Conduct laboratory side-by-side tests

3. **Model DMS-DERMS Level Integration**
   - Characterize and model support functions
   - Evaluate voltage control strategies and coordination with traditional devices

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Success depends on utility engagement and site learning
Who are Project Partners?

- Hydro One
- DTE Energy
- National Grid
- Xcel Energy
- KCP&L
- Southern Co.
- AEP
- Pepco
- SDG&E

- DOE Project
- EPRI Cost Share

Logos:
- SOLECTRIA RENEWABLES
- DTE Energy
- nationalgrid
- Xcel Energy
- Spirae
- bplGLOBAL
- IEEE Power & Energy Society
Demonstration Sites

1.7MW (DC) PV
18 – 95kW Inverters
Cedarville, NJ

225kW(DC) PV
300kVA Inverters
Ann Arbor, MI

605kW (DC) PV
330kW & 250kW Inverters
Everett, MA

1MW (DC) PV
2 – 500kW Inverters
Haverhill, MA
1. Make Inverter Ready

- Utility resource or customer owned?
- Markets-drive or grid-code required?
- What functions and how to initiate them?
- Standards and testing? Settings
- Performance and reliability?
## Benefits Demonstrated at Different Sites

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<th>Site</th>
<th>Efficiency</th>
<th>Power Quality</th>
<th>Asset Life</th>
<th>Deferece of Capital Spending</th>
<th>Reliability</th>
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# Benefits Derived from Functions

<table>
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<th>Inverter Function</th>
<th>Efficiency</th>
<th>Power Quality</th>
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Testing at ESIF - NREL's Energy System Integration Facility

Volt-var Function
Deadband 2%, dQ/dV = 25, Sandia Lab voltage profile is used

Frequency - Watt Operation
Deadband = 0.2 Hz, dW/df = -44%/Hz, Sandia Lab Frequency Profile is sued
2. Revisit Anti-Islanding

- Enabling Voltage Sag Ride-Through
- Impacts on DER Hosting Capacity
- Need for feeder level anti-islanding solutions
- Update standards for anti-islanding
- Compare different methods in laboratory
Side by Side comparisons of different technologies

- Direct transfer trip (DTT) via radio, cell or wire
- Power line carrier communications (PLCC) low or high frequency
- Shorting switch
- Integration of DG into the utility SCADA
- Synchrophasor-based methods

- Research Prior Art
- Develop Functional Requirements
- Select Suitable Technology for Evaluation
- Evaluate Technologies in Lab and Field
Power-Line Carrier Signal for DER – Concept

- Substation Power Line Tone Generator
- DX3 Pulsar Transmitter
- Island Controller
- Grid
- Island
3. Model DMS-Level Integration

Define functional requirements for DMS-DERMS

Address gaps in feeder operational control

Managing grid control at the edge of the grid

New Types of DER autonomous or controllable

Coordinating with traditional voltage control devices
**DER Enterprise Integration**

- DER representation in system model
- Creation of groups and sharing of group definitions
- Monitoring of group status
- Dispatch of real and reactive power
- Forecasting of group capabilities

Diagram showing integration of MDMS, OMS, GIS, DMS, DERMS, and DER systems with sensors, switches, capacitors, regulators, solar, battery, and PEV.
Project Resources

https://solarhighpen.energy.gov/segis/electric-power-research-institute

Public Reports:
Integrating Smart Distributed Energy Resources with Distribution Management Systems, 1024360

Collaborative Initiative to Advance Enterprise Integration of DER, 1026789

Common Functions for Smart Inverters, Version 2, 1026809

Enterprise Integration Functions for Distributed Energy Resources: Phase 1, 3002001249
Conclusions

1. Smart inverter functions are defined and commercially available.
2. Demonstration in various system feeders, and geographic locations needed.
3. There are many lessons to learn and share.
4. Challenges: settings, anti-islanding and integration with utility DMS.

Thank you! tkey@epri.com