An Integrated Grid Path for Solar

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Changing Landscape: An Integrated Grid is a Better Grid

- Combined Heat & Power
- Demand Response
- Energy Management
- Rooftop Solar
- Electric Vehicles
- Energy Storage
- Two Way Power
US, March 2016 Electricity Report
History of U.S. Net Generation (billion kWh)

Total (All Sectors), Major Sources, 1949–2015

From EIA Database
Noting History… PV Module Price Trajectory

This illustrates how the historical average module selling price has declined by about 20% with each doubling of sales over several decades...
Noting History… Cell Efficiency Trajectory

Efficiency Data Points from NREL
Solar PV, a key driver of change

**US Future?**
302 GW PV by 2030

**Germany Now – Power Demand for one week in May 2015**
60 GW

DOE “SunShot” Vision Study,
Released February 2012

Is the grid ready for PV?
US Solar compared to Germany Solar

- Fastest growing generation technology, ~200 GW worldwide
- U.S. total capacity ~25 GW at beginning of 2016

(Solar Resource Availability: NREL, PV Capacity Additions: SEPA)
GLOBAL HORIZONTAL IRRADIATION

Solar PV Radiation at Latitude Tilt

- Germany 2015 >40 GW, ~3.2 kWh/m²/day
- U.S. 2015 >20 GW, ~5 kWh/m²/day

(Solar Resource Availability: NREL, PV Capacity Additions: SEPA, total solar radiation latitude tilt)

- Fastest growing of all renewable technologies
- ~180 GW installed worldwide, Germany leads with ~38 GW
- U.S. total capacity ~18 GW at beginning of 2015

Solar PV the poster child of grid edge assets
Solar Potential by country assuming residential PV Costs

Source: Bloomberg New Energy Finance
# Interconnection Challenge: Solar output variability

Calendar based on irradiance, 1-min averages at 30° fixed tilt, Knoxville

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Single-Module Ramp Events on 1-MW Site in TN
Measured 1-sec output from a 224-W module with micro-inverter

Single-Module PV System Power Production Profile

AC Power (kW)

Local Date & Time (Eastern)

-0.18kW in 24 sec (3.3% per sec)
+0.18kW in 9 sec (9.1% per sec)
PV variable output on distribution feeder
Circuit map showing locations of pole-mount systems in Rome, GA
Spatial- and time-based PV-feeder demo

Search: “Youtube Epri Pv Penetration”
Potential Grid Issues with PV Variability

Voltage Control
- Overvoltage
- Voltage variations

Equipment Operation
- Feeder regulators,
- Load tap changers
- Switched capacitor banks

Demand/Energy
- “Masking” peak demand
- Unbalancing supply and demand

System Protection
- Relay desensitization, networks
- Breaker reduction of reach
- Unintentional islanding

Power Quality
- Harmonic generation
- Flicker worries
Example: Overvoltage related hosting capacity

Total PV: 1173 kW

Minimum Hosting Capacity
Maximum Hosting Capacity

Maximum Feeder Voltages (pu)

Increasing penetration (kW)

No observable violations regardless of size/location

Possible violations based upon size/location

Observable violations occur regardless of size/location

2500 cases shown
Each point = highest primary voltage

Total PV: 540 kW
Individual feeder PV “Hosting Capacity” is important

Baseline – No PV
PV Penetration 1
PV Penetration 2
PV Penetration 3
Beyond…

Process is repeated 100’s of times to capture many possible scenarios

Increase Penetration Levels Until Violations Occur
- voltage
- protection
- power quality
- thermal
Mapping Feeder Hosting Sample Chattanooga, TN, USA

System Hosting Capacity
(~ 300 distribution feeders)

Substation-level Hosting Capacity

Feeder-level Hosting Capacity

*hosting capacity
- 0.0-1.4 MW
- 1.4-2.9 MW
- 2.9-4.3 MW
- 4.3-5.7 MW
- 5.7-7.1 MW
- 7.1-8.6 MW
- 8.6-10.0 MW
- 10.0-11.4 MW

*Initial analysis results from TVA/EPB study, results not finalized
Inverter – Role in PV Plants

PV inverter converts DC energy from solar modules into AC energy and interface the PV system with electricity grid

Traditional Inverter
- 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
Planning with DER - Mitigation

Analytics
- Screening
- Hosting Capacity
- Reliability
- DER/Grid Modeling

Tools
- Advancing commercial tools
- Open-source (OpenDSS)

Mitigation
- Smart inverters
- Grid-side enhancements

Training
- Engineering Guidelines
- Planning with DG

Improved Integration with

24 Hour Simulation
- Often least-cost solution
- Increased hosting capacity

Primary Voltage
- Baseline – No PV
- 20% PV
- 20% PV with smart inverter
Advanced Inverters Have Significant Upside

Distribution Feeder Hosting Capacity: What Matters When Planning for DER?

EPRI White Paper summarizing ~ 5 years of research on the Integration of DER.

Search “EPRI and 3002004777”
Conclusions: Key Takeaways

- Variable PV works better with the grid
- We need to leverage our existing grid, cultivate “hosting capacity”
- Grid upgrades and reinforcements increase hosting, see PVGrid
- Future DG to provide grid support with Smart Inverters
- An integrated grid approach will help to transform the power system

Integrated
The Whole is Greater than the Sum of its Parts

Transforming the Power System will be a Journey not a Destination
Questions?

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The Integrated Grid Online Community
http://integratedgrid.epri.com