THE INTEGRATED GRID
REALIZING THE FULL VALUE OF CENTRAL AND DISTRIBUTED ENERGY RESOURCES

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The Electric Power System
Looking Forward
Distributed Energy Resources

**Photovoltaics**

**Fuel Cells**

**Micro-generation**

**Storage**

**Plug-In Electric Vehicles**

- Photo courtesy of NREL

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**Distributed Energy Resources**

- Photovoltaics
- Fuel Cells
- Micro-generation
- Storage
- Plug-In Electric Vehicles

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The Grid Provides Transactional Value
Grid Delivers Balancing Resource
Solar resource calendar for August 2012 shows irradiance profiles in NJ

Blue area: measured irradiance
Orange line: calculated clear sky irradiance
Grid Provides Reliability Service

System Average Interruption Duration Index (SAIDI)
Without Major Events

Minutes

Average Grid Reliability

- 99.97% excluding major events
- Equivalent reliability services from local generation will require onsite redundancy
The Grid Provides Startup Power

Measured HVAC Startup Power vs. PV Output Comparison

Difference provided by grid connection

PV Array

Real Power (kW)

Time (s)
Grid Connectivity Reduces Harmonic Impact
Cost of Grid Connectivity for Local Resources

Average Residential Usage 982 kWh/month
Average Residential Bill $110/month

Energy ($59/month)
Capacity ($51/month)

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Cost Projection for Off-Grid Local Energy Resource

Oversized PV Array | Additional Electronics | Multi-day Storage
---|---|---
Backup Generation | Controlled Load | 

Monthly Cost to Provide Grid Services from Local Resources:

- Projected Cost in 2020: $165-$262
- Monthly Cost: $228-$361

1 Does not include additional cost of energy from local resources

Photo courtesy of NREL
Lack of Visibility, Control, Frequency Support Challenges Grid Reliability at Higher Penetration Level of Local Resources
The Integrated Approach

Local Resources are Also Part of Grid Operation and Planning

Bulk Power System

Distribution System

Market Operator

System Operator

Distribution Management System

Community LEN¹

Campus LEN

Building LEN

¹LEN: Local Energy Network

Master Controller

Master Controller

Master Controller
Understanding System Impacts of DER

Energy, Capacity & Ancillary

Central Generation

Generation Capacity & Ancillary Service

Frequency Support

Transmission

Voltage & Frequency Stability

Loss Reduction

Sub-transmission

Increasing Re-dispatch Transmission Constraint

T&D Avoided Capacity

Substation

Reverse Power Flow Reactive Power Balance

Loss Reduction

Distribution

Prevalent voltage, Capacity & Protection Issues

Voltage Support

Customer

Localized Voltage & Capacity in Long Circuits

Increasing Penetration Level

Increasing Penetration Level
Sample High-Level Results

Each feeder has

- a unique hosting capacity
- a unique “range” that can be accommodated
- unique constraint that limits hosting capacity

MW of Consumer PV
Hosting Capacity – Sample Results
Overvoltage Results Shown for Feeder J1

Overvoltage Results

2500 cases shown
Each point = highest primary voltage

ANSI voltage limit

Total PV: 1173 kW
Voltage violation

Minimum Hosting Capacity
Maximum Hosting Capacity

2500 cases shown
Each point = highest primary voltage

No observable violations regardless of size/location
Possible violations based upon size/location
Observable violations occur regardless of size/location

Total PV: 540 kW
Bulk System Impacts of Distributed PV

Impact on Frequency:
- Reduction in system inertia due to change in generation mix
- PV drop out due to large voltage disturbance (as per IEEE 1547)

Impact on Voltages:
- Delay in voltage recovery
- Degradation of load power factor
- Change in Active/Reactive Power Margins
CAISO Net Load – 2012 Through 2020

Typical March day – significant change starting in 2015

Potential over-generation

Source: California ISO
The “Duck” Curve is for Real

Not Just Resource Adequacy but the Adequacy of Resource of the Right Type

Increased requirement for downward ramping capability in the morning

Need lower minimum generation levels to avoid over-generation

Source: ENEL – Measured Data from Southern Italy and CAISO analysis
Example: The Right Interconnection Rules

![Graph showing grid frequency in Germany over time with different interconnection rules.](image)

- **Source:** T. K. Vrana (2011)

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Germany: Higher Penetration of Local Generation Necessitates an Integrated Approach

**Installed Capacity (2013)**

- **Solar**: 1.4%
- **Wind**: 22.7%
- **Other**:
  - 25.5%
  - 8.2%
  - 20.6%
  - 9.9%

**Interconnection Rules**
- Grid frequency support

**Grid Infrastructure Upgrade**
- ~$27.5B-$42.5B upgrade

**Two Way Communication**
- Enabled by Advanced Distribution Management

~63GW of Installed Wind and PV – mostly connected to LV and MV grid

Recent Changes in Germany to Address Concern of Grid Reliability

Source: Fraunhofer Institute, Germany
DER Interconnection Requirements

Future Interconnection Standards Should Consider

- Voltage Support
- Frequency Support
- Fault Ride-Through
- DER/DSO Communication

EPRI working on recommended technical guidelines for voltage and frequency ride through capability for DG based on new IEEE 1547a
What is Included in Benefit/Cost Framework

**Utility Operations**
- (people and how they do their jobs: non-fuel O&M, non-production assets, safety)

**System Operations**
- (the power system and its efficiency: losses, combustion, dispatch optimization, emissions)

**Utility Assets**
- (production assets required: GT&D)

**Reliability & Power Quality**
- (frequency and duration of customer interruptions, harmonics, sags/swells, voltage violations)

**Customer**
- (equipment & other direct customer costs)

**Society**
- (jobs, security, environmental and other economic costs and benefits)

Included EPRI’s Methodology based on Power System Analysis and Economics

Not in scope of EPRI’s Methodology
Building Upon Prior Efforts

Many have contributed to specific aspects of the framework
Need comprehensive approach: connecting all puzzle pieces
Foundation of An Integrated Grid

1. Grid Modernization

2. Communication Standards and Interconnection Rules

3. Integrated Planning and Operations

4. Informed Policy and Regulation
Action Plan

Global Collaboration to Establish the Science, Engineering and Economics

Inform Stakeholders on Key Concept & Challenges

Benefit/Cost Framework for Different Designs

Data, Information and Tools

Global Demonstrations

Global Collaboration to Establish the Science, Engineering and Economics

Electricity
Safe
Reliable
Environmentally Responsible
Affordable

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