Integration, Management and Control of Distributed Energy Resources

Patrick Dalton, ICF
Rois Langner, NREL

Integrated Distribution System Planning Training for Midwest/MISO Region
October 13-15, 2020
Integration, Management and Control of Supply-Side DERs

Patrick Dalton, ICF
Key Takeaways

- DER integration considerations vary by technology type and use case
- Grid planners and modelers review a standard set of physical and control impacts
- Operational, planning, and market integration needs are evolving
- DER controls can be autonomous (e.g., inverter), centralized (e.g., Advanced Distribution Management System or Distributed Energy Resource Management System), or a combination
  - Use cases drive the type of control needed
- Interoperability is key for remote control and management
Brief Overview of DER Technologies
DER Integration Considerations Vary by Technology

Rotating Machine

- Mechanically coupled response
- Higher fault current levels
- Well-characterized fault current response
- Able to sustain islands (voltage source)
- Limited reactive power capabilities

Inverter-Based

- Software defined response
- Lower fault current levels
- Wide range of fault current responses
- Not able to sustain islands (current source)
- Full range of reactive power capabilities

Source: rotating machine image from https://electricallive.com/2015/03/salient-pole-synchronous-motor.html
Inverters Are a Growing, Flexible Interface

- Converts direct current to alternating current
- Act as a “current source” that follows system voltage
- Software-defined advanced functions (i.e., Smart Inverters)

Rotating Machines Continue to Be Deployed

- Generator’s physical rotation is directly related to grid frequency
  - “inertial response”
  - Higher fault currents

- Physical limitations for contributing to grid voltage management

- Example:
  - Synchronous: Hydro
  - Induction (doubly-fed): Wind

https://www.theengineeringknowledge.com/introduction-to-synchronous-motor/
Battery Energy Storage Adds Another Control Layer

- Inverter based with battery management system (BMS)
- IEEE P1547.9 – Draft Guide on Energy Storage DER is underway
Solar PV Is Driving Inverter-Based Generation Growth in the United States

United States Distributed Generation Capacity by Fuel Type (MW), 2018
EIA, EIA Form-861

Note: categorization is approximated based on fuel types. Some cross-over between power conversion technologies exist for certain fuel types.
DER Integration Considerations
A Progression for Integrating DER

- Voltage limits
- Thermal constraints
- Control compatibility
- Protection

- Situational awareness
- “Hidden Load”
- Remote control
- Bulk system reliability (e.g., ride-through)

- Non-wires alternatives
- Market services

Lower Complexity

Higher Complexity Increasing Monitoring and Control Needs
DER Reverse Power Impacts Feeder Voltage

Reverse Power Flow from Generator Can Lead to High Voltage
DER Controls to Mitigate High Voltage

Two ways DER can reduce voltage:

1. Consume Reactive Power (vars)

2. Reduce Active Power Injection (Watts)
Situational Awareness Needs

- Monitoring and estimation of DER output and system conditions
  - Data also informs planning models

- Balance of direct monitoring and estimation
  - Tools for estimating load hidden by behind the meter increasingly important

Example of feeder switching

Reverse power flow
Potential for thermal and/or voltage issues
DER Management and Control
### IEEE 1547-2018 Standard Control Capabilities

**Voltage and Reactive Power Control**

- Constant Power Factor
- Constant Reactive Power
- Voltage – Reactive Power (Volt-Var)
- Active Power – Reactive (Watt-Var)*

* Required for Category A only (i.e., rotating machines)

**Voltage and Active Power Control**

- Voltage – Real Power (Volt-Watt)*

* Default mode is unity power factor (Constant Power Factor)
* Reactive power modes are mutually exclusive (i.e. one-at-a-time)
* Volt-Watt can be stacked on reactive power functions
Volt-Var Mode Senses and Reacts to Grid Voltage

Voltage-Reactive Power Mode (Volt-Var)

- Reactive power absorption or injection is changed based on voltage
  - Absorbing Vars $\rightarrow$ Lowers voltage
  - Injecting Vars $\rightarrow$ Raises voltage
Example of Volt-Var Response

**Feeder Load and Voltage at DER Over Time**

- **Loading (%)**
  - 100%
  - 20%
  - 0%
  - 1.03
  - 0.98

- **Voltage (p.u)**
  - 1.03
  - 0.98

- **Hour of day**
  - 3
  - 15
  - 24

**Volt-Var Operation**

- **Vars Injected (%)**
  - 44%

- **Voltage (p.u)**
  - 0.97
  - 0.99
  - 1.0
  - 1.05

- **Vars Absorbed (%)**
  - -44%
Volt-Watt Acts as a Soft Shutdown for High Voltages

**Voltage-Active Power Mode (Volt-Watt)**

- Power output reduced when voltage limit is reached
- Reduced power results in lower voltage

![Diagram showing the relationship between active power and voltage](chart.png)
Application of Volt-Watt

Per unit volages

Active Power (Generation)

\[ (P_1, V_1) \]

\[ (P_2, V_2) \]

\[ V_1 = 1.05 \text{ p.u.} \]

\[ V_2 = 1.07 \text{ pu} \]

\[ V_H \]

\[ P_2 \]

1.05 1.08

V = 1.07 pu

P = 250 kW
Stacking Smart Inverter Functions to Address Operational Needs

- **Reactive** power control functions for *normal (long term operating)* voltage conditions and **Real** power control for *contingency (unplanned emergency or temporarily maintenance)* voltage conditions

![Diagram showing voltage control functions]

- Abnormal Conditions: Cease to Energize
  - Contingency Voltage Conditions: Normal Voltage Conditions
    - Voltage (% of nominal):
      - 110%
      - 106%
      - 103%
    - **Real** Power Control: Volt-Watt
    - **Reactive** Power Control: Volt-Var
Bulk Power System Perspective DER

Distribution System Needs

- Short trip times
- Ride-through with momentary cessation
- Voltage rise concerns
- Islanding concerns
- Protection coordination
- Line worker safety

Bulk Power System Needs

- Long trip times
- Ride-through with constrained momentary cessation
- Reactive power demands
- Dynamic voltage support
- Frequency support

The need for transmission and distribution coordination is increasing.

► Continuous Operation: Normal production with all standard requirements applicable

► Mandatory Operation: required to maintain exchange of active and reactive power

► Momentary Cessation: remains connected and synchronized, but stops producing power
ISO/RTO Guidelines Modify Undervoltage Trip Settings

- MISO guidelines modified default undervoltage trip settings
- Developers and utilities will be responsible for implementing settings

Source: ICF
DER Interoperability Unlocking Monitoring, Control, and Management
Interoperability Scope of IEEE 1547-2018

- Monitoring, Control, and Information Exchange
- Information Models
- Protocols

Key:
- Green: In Scope
- Red: Out of Scope
**DER Monitoring and Control through a Standard Communications Interface**

<table>
<thead>
<tr>
<th>Nameplate (Read-Only)</th>
<th>Configuration (Read/Write)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Equipment Ratings</td>
<td>• Each rating in the Nameplate Information Table is configurable</td>
</tr>
<tr>
<td>• Performance Category</td>
<td>• Not intended for continuous dynamic adjustment</td>
</tr>
<tr>
<td>• Normal</td>
<td></td>
</tr>
<tr>
<td>• Abnormal</td>
<td></td>
</tr>
<tr>
<td>• Supported Control Modes</td>
<td></td>
</tr>
<tr>
<td>• Make, Model, Version</td>
<td></td>
</tr>
<tr>
<td><strong>Monitoring (Read-Only)</strong></td>
<td><strong>Management (Read/Write)</strong></td>
</tr>
<tr>
<td>• Active Power</td>
<td>• Control mode settings</td>
</tr>
<tr>
<td>• Reactive Power</td>
<td>• Voltage/frequency tripping</td>
</tr>
<tr>
<td>• Voltage</td>
<td>• Limit maximum active power</td>
</tr>
<tr>
<td>• Frequency</td>
<td></td>
</tr>
<tr>
<td>• Operational Status</td>
<td></td>
</tr>
<tr>
<td>• Connection Status</td>
<td></td>
</tr>
<tr>
<td>• Alarm Status</td>
<td></td>
</tr>
</tbody>
</table>
Use Cases for Interoperability

- Monitoring of near real-time status for Operations
- Remote settings changes for contingency or emergency situations
- Coordination with Advanced Distribution Management System (ADMS) applications and DERMS
- Supporting flexible interconnections
Accounting for DER in ADMS

- Situational awareness – “hidden load”
  - Balance of Estimated vs Measured

- Fault calculation impacts – FLISR
  - Reduced system fault current

- Voltage regulation – IVVO
  - Coordination with local voltage controls (e.g., inverter volt-var)
Potential Relationship of ADMS and DERMS

- **ADMS**
  - Monitor assets for situational awareness, reporting
  - Network Optimization
  - Control authority based on operational rules, reliability requirements
  - Sends SCADA information to DERMS

- **Distribution SCADA**
  - SCADA collects and sends data from relays, IED’s and RTU’s installed on the distribution network.

- **DERMS**
  - Prosumer Aggregation
  - Registration, Contracting, settlement
  - Economic optimization for market
  - Sends control messages to 3rd party aggregators or directly to DER’s

- **Aggregator**

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**Cyber security** is a growing consideration as DER is networked and relied upon for critical grid operations.

**Market and Distribution Non-Wires** likely to interact with aggregation platforms.

Source: Power Grid International
[https://www.power-grid.com/2019/02/05/a-look-towards-the-future-integrating-derms-and-adms/#gref](https://www.power-grid.com/2019/02/05/a-look-towards-the-future-integrating-derms-and-adms/#gref)
Key Takeaways

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- Interoperability is key for remote control and management
What DER-related grid constraints are most commonly leading to mitigations or system upgrades?

How and when will smart inverters be used as a mitigation?

What state-level or utility IEEE 1547-2018 implementation processes are needed to unlock the value of smart inverters?

How do planned or proposed grid modernization investments contribute to DER integration?

What steps can be taken today to plan for true interoperability between DER owners, utilities, and third-party aggregators?
Resources for More Information

https://www.nrel.gov/docs/fy19osti/72102.pdf

► NARUC, Adoption of IEEE 1547-2018 and Interconnection Procedures, 2020,
https://pubs.naruc.org/pub/7A52CAA7-155D-0A36-31F0-7455E3DBB548

► NREL, High-Penetration PV Integration Handbook for Distribution Engineers, 2016
https://www.nrel.gov/docs/fy16osti/63114.pdf

► NREL, Sequential Mitigation Solutions to Enable Distributed PV Grid Integration
https://www.nrel.gov/docs/fy19osti/70411.pdf

► NREL, New Approaches to Distributed PV Interconnection: Implementing Considerations for Addressing Emerging Issues
https://www.nrel.gov/docs/fy19osti/72038.pdf

► DOE, Revised IEEE 1547-2018 Standard Will Aid Solar Integration, 2019

► NERC, Reliability Guideline: Bulk Power System Reliability Perspectives on the Adoption of IEEE 1547-2018, 2020
Thank you!

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Buildings as a Grid Resource

Rois Langner
National Renewable Energy Laboratory (NREL)
Objectives

- Impact of buildings on the grid
- Buildings can be flexible in how they use energy
- Dynamic signals from utilities can be used to manage building loads
U.S. Energy Consumption

Estimated U.S. Energy Consumption in 2019: 100.2 Quads

Source: LLNL March, 2020. Data is based on DOE/EIA MER (2019). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in MWh-equivalent values by assuming a typical fossil fuel plant heat rate. The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 21% for the transportation sector and 85% for the industrial sector, which was updated in 2017 to reflect DOE’s analysis of manufacturing. Totals may not equal sum of components due to independent rounding. LLNL-NI-410527
Grid-Interactive Efficient Buildings (GEBs)

What are they?
GEBs are about enabling buildings to provide flexibility in energy use and grid operations.

~75% of electricity generation is used in buildings.
Key Characteristics of GEBs

- **EFFICIENT**: Persistent low energy use minimizes demand on grid resources and infrastructure.
- **CONNECTED**: Two-way communication with flexible technologies, the grid, and occupants.
- **SMART**: Analytics supported by sensors and controls co-optimize efficiency, flexibility, and occupant preferences.
- **FLEXIBLE**: Flexible loads and distributed generation/storage can be used to reduce, shift, or modulate energy use.
How Can Buildings Provide Flexibility?
Demand Flexibility Provided by GEBs
Demand Flexibility Provided by GEBs

- **Efficiency**: Baseline, Efficiency
- **Efficiency + Generate**: Baseline, Efficiency, Solar PV, Generate
- **Efficiency + Generate + Shed/Shift**: Baseline, Efficiency, Solar PV, Generate, Shed/Shift
Potential Benefits of Flexible Building Loads

- Energy affordability
- Improved reliability & resiliency
- Reduced grid congestion
- Enhanced services
- Environmental benefits
- Customer choice
# Residential GEB Measures

<table>
<thead>
<tr>
<th>GEB Measure</th>
<th>GEB Control Capability</th>
<th>Load Shed</th>
<th>Load Shift</th>
<th>Demand Response</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Smart thermostats</strong></td>
<td>Modify temperature setpoints, and pre-heat or pre-cool during off-peak hours</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>Smart appliances (washers/dryers/dishwashers)</strong></td>
<td>Shift operation to off-peak hours</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>Electric lighting</strong></td>
<td>Turn-off or dim lighting during peak-hours, based on occupancy needs</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><strong>Water heating/thermal storage</strong></td>
<td>Leverage thermal mass of the water tank to pre-heat water during off-peak times</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td><strong>Electric vehicles &amp; chargers</strong></td>
<td>EV charging can be shifted to off-peak times, or when times when renewable energy sources are abundant</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>Battery storage</strong></td>
<td>Utilize battery storage to shed and shift load</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>Solar PV</strong></td>
<td>Utilize on-site generation to offset peak load</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
# Commercial GEB Measures

<table>
<thead>
<tr>
<th>GEB Measure</th>
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<th>Load Shed</th>
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<th>Demand Response</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LED fixture with full control</strong></td>
<td>Dim lights for load shed capability</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><strong>Automatic window shade devices</strong></td>
<td>Control for west, south, and east-facing facades to shed solar heat gain during the day</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><strong>Staging of electric resistance heating</strong></td>
<td>Stage operation for load shed capability</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><strong>Zone space temperature setback</strong></td>
<td>Program setbacks during defined peak demand periods for load shed capability</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><strong>Thermal energy storage</strong></td>
<td>Leverage building thermal mass or water storage to shift heating and cooling loads</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td><strong>Staging of AHU fans</strong></td>
<td>Stage operation for load shed capability</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><strong>Static pressure reset for demand response</strong></td>
<td>Static reset for load shed capability</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><strong>Laptop battery charger staging</strong></td>
<td>Stage battery-based plug-in equipment for load shed capability</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><strong>Solar PV</strong></td>
<td>Utilize on-site generation to offset peak load</td>
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<td>Utilize battery storage to shed and shift load</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
• Can leverage existing equipment
• Technologies may, or may not, be “smart”
• Building managers can control individual equipment, or leverage software solutions to optimize multiple end-use systems
• Flexibility can be provided though:
  • Continuous demand management
  • Response to specific Demand Response (DR) events
• Dynamic signals can and should be leveraged where possible
<table>
<thead>
<tr>
<th>Characterizing GEB Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Name/Vendor</strong></td>
</tr>
<tr>
<td><strong>Functionality</strong></td>
</tr>
<tr>
<td><strong>Targeted end-uses</strong></td>
</tr>
<tr>
<td><strong>Demand flexibility modes supported</strong></td>
</tr>
<tr>
<td><strong>1- or -2-way communication with utility</strong></td>
</tr>
<tr>
<td><strong>Communication protocol</strong></td>
</tr>
<tr>
<td><strong>Behavior on connectivity loss</strong></td>
</tr>
<tr>
<td><strong>Grid-interactive control</strong></td>
</tr>
<tr>
<td><strong>Response time</strong></td>
</tr>
<tr>
<td><strong>Duration of response</strong></td>
</tr>
<tr>
<td><strong>Lifetime &amp; maintenance issues</strong></td>
</tr>
<tr>
<td><strong>Impact on building services</strong></td>
</tr>
<tr>
<td><strong>Energy penalty</strong></td>
</tr>
<tr>
<td><strong>Data points integrated</strong></td>
</tr>
<tr>
<td><strong>Technology capabilities</strong></td>
</tr>
<tr>
<td><strong>IT cybersecurity</strong></td>
</tr>
</tbody>
</table>
GEB Software Solutions

• Connects to building automation systems (BAS) or home energy management systems (HEMS)
• Can control multiple building end-use systems
• May offer 1- or 2-way communication with the grid
• Provide analytics for flexible control
• Trend load data
• Should capture dynamic signals:
  • Weather
  • TOU utility rates
  • Carbon emissions
The End Goal

- More flexible, and optimized performance
- Reduced peak demand, and lower demand charges
- Responsive to building and grid needs
GSA Proving Ground
DOE High Impact Technology Catalyst

2019 Request for Information:
- GEB solutions that cost-effectively provide building load flexibility
- Load flexibility modes (at least 3):
  - Energy efficiency
  - Load shed
  - Load shift
  - Modulation
- Integrate multiple building systems, beyond HVAC & lighting
- Aggregate data and dynamically manage and coordinate loads
GPG/HIT Catalyst Field Studies

5 Selected GEB Solutions

4 Laboratories to Lead M&V:
- NREL, LBNL, PNNL, ORNL

Federal (GSA) & Non-Federal Buildings
Key Objectives for GEB M&V

- Key objectives for evaluating GEB solutions:
  - Capability to enable energy efficiency & load flexibility – continuously & in response to DR events
  - Costs
  - Building owner and utility benefits
  - Integration and building service impact

- Highly complex solutions
  - Control of multiple building systems
  - Multiple load flexibility modes
  - Climate zone implications
  - Differences in building operational mission

Important to coordinate language, metrics, and M&V approach to enable as much consistency as possible across projects
## Metrics

<table>
<thead>
<tr>
<th>Quantitative Objectives for Demand Flexibility</th>
<th>Metrics - developed by LBNL, LLNL, and NREL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy Efficiency Savings (from GEB solution)</strong></td>
<td>Energy savings: kWh/year and % savings</td>
</tr>
<tr>
<td></td>
<td>Energy intensity savings: kWh/ft²/year</td>
</tr>
<tr>
<td><strong>Continuous Demand Management</strong></td>
<td>Monthly peak demand reduction: kW and %</td>
</tr>
<tr>
<td></td>
<td>Summer and winter average peak kW reduction</td>
</tr>
<tr>
<td><strong>Peak Load Shed</strong></td>
<td>Demonstrated load shed based on a utility signal:</td>
</tr>
<tr>
<td></td>
<td>• Demand shed per event: Average kW reduction (for shed) over a specified time window</td>
</tr>
<tr>
<td></td>
<td>• Average % demand reduction</td>
</tr>
<tr>
<td></td>
<td>• Demand shed intensity: W/ft²</td>
</tr>
<tr>
<td><strong>Load Shift</strong></td>
<td>Average demand increase or decrease over shift days during the summer and winter: kW, W/ft², %</td>
</tr>
<tr>
<td></td>
<td>Net building consumption change in 24 hours over shift days during the summer and winter: %</td>
</tr>
<tr>
<td><strong>Carbon Reduction</strong></td>
<td>CO₂/ft²/year</td>
</tr>
</tbody>
</table>
Resources for More Information

- Published report series establishing demand flexibility framework, evaluating technologies and assessing value and performance.
  - DOE’s “GEB-site”: https://www.energy.gov/eere/buildings/grid-interactive-efficient-buildings
- Performance Assessments of Demand Flexibility from GEBs (LBNL): https://emp.lbl.gov/publications/performance-assessments-demand
Thank you!

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