Distributed Energy Resources (DER)

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Distribution Systems and Planning Training for Midwest Public Utility Commissions
January 16-17, 2018
Introduction – What is a Distributed Energy Resource (DER)

A DER is a resource sited close to customers that can provide all or some of their immediate electric and power needs and can also be used by the system to either reduce demand (such as energy efficiency) or provide supply to satisfy the energy, capacity, or ancillary service needs of the distribution grid. The resources, if providing electricity or thermal energy, are small in scale, connected to the distribution system, and close to load. Examples of different types of DER include solar photovoltaic (PV), wind, combined heat and power (CHP), energy storage, demand response (DR), electric vehicles (EVs), microgrids, and energy efficiency (EE).*

* Diesel-fired backup generators may also fit in this definition. Whether a jurisdiction allows diesel-fired backup generation to count as a DER should be determined by the jurisdiction. For purposes of the NARUC Manual, the definition generally does not include diesel-fired backup generation (most diesel DG do not tied to the grid, but serve as a microgrid source).

* IEEE 1547 Standard specifically omits DR and other “loads” as part of the DER definition. It focuses on sources of generation tied to distribution systems.

* NARUC Design Manual (https://www.naruc.org/rate-design/):
DER action is coming…
from NERC and FERC

► “NERC and the industry [must] understand DER functionality and develop a set of guidelines to assist in modeling and assessments such that owners/operators of the [bulk power system] can evaluate and model DER in the electric system.”

– NERC DER Task Force, February 2017

► FERC is working on rules for market participation of electric storage and aggregated DER, reforming generator interconnection procedures & agreements, and further evolution of PURPA.

Source: Tom Stanton, NRRI
Where do DER Connect?

**Transmission Connected Generation**

Large wind farms, CSP, utility-scale PV, biopower, hydro, geothermal, interconnect at transmission level

**Electric Power System**

**Distribution Connected Generation (DER)**

Photovoltaic systems, small wind, storage & fuel cells interconnect at the distribution level – Behind the Substation

Photos: NREL PIX Library
Examples of DERs
Photovoltaic System (PV) - DER

- Converts DC from PV modules to alternating current (AC) to match the utility grid
- Implements Maximum Power Point Tracking (MPPT)

DER Characteristics:
- Provides energy from the sun
- Only produces energy when sun is shining (cold is better)
- Non-dispatchable, and may export to grid if greater than load
Grid Tie and Stand-Alone PV/Battery

DER Characteristics:

► Most PV today is “Grid Tie” and cheaper (no batteries required)
► Early PV and remote locations are stand-alone systems with batteries, load limits
Wind Generators
Squirrel-cage Induction Generator

- Type 1 squirrel cage induction generator shown (robust and low-cost)
- Distributed wind generation are now less common
- There have been major changes in wind technologies over past 20 years
- Most wind machines installed today are large (Type IV), and not tied to distribution grid

DER Characteristics:
- Provides energy from wind
- Only produces when wind blows, so variable
- Non-dispatchable, so may export if load is low
Battery Electric Storage Systems (BESS)

- Lead-Acid Battery
- NiMH Battery
- Li-Ion Batteries
  - LMO
  - LFP
  - LNMC
  - LTO
  - Li-S
- Redox Flow Battery
- Sodium Sulfur Battery

Estimated installed battery capacity

Source: IEEE P&E September/October 2017
Battery Electric Storage Systems (BESS)

DER Characteristics:
- Can be both a load and a DER source
- Can provide backup power during emergencies
- High cost per unit of storage energy today
- Promising technologies to help stabilize the grid, reduce demand
- Potential to eliminate backfeed, which would negate the need for NEM metering/policies!
Smart Buildings with Active EMS

DER Characteristics:
- Provides control of load using Demand Response (DR)
- DR and Energy Efficiency (EE) are factors
- Active Energy Management Systems (EMS) are critical to create “smart buildings” that respond to requests, utility signals
Electric Vehicles (EV or V2G)

DER Characteristics:
► Today they are loads, but V2G is a promising technology
► Can use clean energy when grid is underutilized (night)
► PV can be used to charge when people are at work….
► V2G are effectively BESS

Photos: NREL Pix
Micro-Grids

DER Characteristics:

► May combine one or more of the other DER technologies
► Often used as backup for critical reliability needs
► May stand-alone or be grid-tied
► Controls in infancy today
Providing Power & Energy to the Grid (and other functions & support)
Power (MW) vs. Energy (MWh)

Reference: California ISO (www.caiso.com/outlook)
DER Supporting Power and Energy Needs

Example Daily Power Demand

- **Peak power**
- **Surplus power** (Ideal)
- **Average power**

**DER Generation**
- Less Valuable to Grid
- More Valuable to Grid

**Power demand**
- MW

**Hours of day**
- Midnight
- Noon
- 24

**DER Generation**
- More Valuable to Grid
- Less Valuable to Grid
Examples of Load, Generation, Storage, etc.
Examples of Load and PV
Examples of Load and PV

Grid-Tied PV systems exporting power
Examples of Load, PV & Batteries

No exported power
By charging batteries
Penetration and Other Common Terms

► Capacity Penetration = total nameplate capacity of all distributed resources on the feeder (or line section) divided by peak annual load on feeder (traditional)
  □ Normally calculated as capacity of installed PV generation/peak non coincident feeder load
  □ Other ways it is calculated is as a function of the minimum non coincident day time load

► Energy Penetration = Total energy produced by all DERs on a feeder or utility territory divided by total energy consumed on a feeder or utility territory

► Other issues which may be linked to DER
  □ EV (vehicle to grid, V2G)
  □ Demand Response (DR)
  □ Energy Efficiency (EE)
Utility Concerns Regarding DER Impacts on Distribution & Operations
Question: How much DER can a Feeder Host?
Answer: It Depends....

There are many variables......

- Grid Hosting Capacity (GHC) depends on location, but is the maximum size DER that can be installed anywhere on a circuit without electrical upgrades/changes. So a feeder can have a GHC, but a “Locational GHC” is more specific.

- The absolute maximum limit will depend on the thermal limits of the conductors, circuit breakers, fuses, switches, and traditional electric design criteria.

- The GHC can be changed once updates are completed or smart inverters deployed, and varies.
Factors Determining Hosting Potential

- Size of each PV/DER system
- Location of each DER system
- Impedance of feeder
- Voltage level of distribution system
- Size & impedance of substation transformer
- Location of capacitor banks
- Line regulation configuration
- Presence of other DG, Loads
- Advanced inverter deployment

Graphic: Michael Coddington, NREL
## Utility Concerns on High PV Penetration

<table>
<thead>
<tr>
<th>Identified Issues</th>
<th>Relative Priority</th>
<th>Identified Issues</th>
<th>Relative Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage Control</td>
<td>High</td>
<td>Equipment Specs</td>
<td>High</td>
</tr>
<tr>
<td>Protection</td>
<td>High</td>
<td>Interconnection Handbook</td>
<td>Medium</td>
</tr>
<tr>
<td>System Operations</td>
<td>High</td>
<td>Rule 21 and WDAT</td>
<td>Medium</td>
</tr>
<tr>
<td>Power Quality</td>
<td>High</td>
<td>IEEE 1547/ UL 1741</td>
<td>Medium</td>
</tr>
<tr>
<td>Monitoring and Control</td>
<td>Medium</td>
<td>Application Review</td>
<td>High</td>
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<tr>
<td>Feeder Loading Criteria</td>
<td>High</td>
<td>Clarification of Responsibilities</td>
<td>High</td>
</tr>
<tr>
<td>Transmission Impact</td>
<td>Medium</td>
<td>Integration with Tariffs</td>
<td>Medium</td>
</tr>
<tr>
<td>Feeder Design</td>
<td>Medium</td>
<td>Coordination with Other Initiatives</td>
<td>Medium</td>
</tr>
<tr>
<td>Planning Models</td>
<td>Medium</td>
<td>Source: Russ Neal, SCE</td>
<td></td>
</tr>
</tbody>
</table>
Significant Grid Impact Concerns

- Voltage Regulation
- Protection coordination (fuses, circuit breakers, relays)
- Reverse power flow
- Increased duty of line regulation equipment
- Unintentional islanding
- Secondary network reliability
- Variability due to clouds
- Capacitor switching
- System **Inertia** for stability MUST be maintained

Based on interviews with 21 US electric utilities – 2013 – NREL & EPRI (report available)
Common Challenges
Distribution System Voltage Profile – Large PV

Graphic: Michael Coddington, NREL
Distribution System Voltage Profile – Large PV with localized load (near PV)

Graphic: Michael Coddington, NREL
What Needs to be Mitigated?

Mitigating potentially negative grid impacts

- Voltage support / ANCI C84.1
- Protection coordination
- Reverse power flow (e.g. secondary networks)
- Unintentional Island conditions
- Flicker effects from cloud variability
- Capacitor or voltage regulator switching

Mitigation may be a technical solution, program limit, approved approach, etc. The goal is to avoid any problems.
Mitigation Strategy “Toolbox”

<table>
<thead>
<tr>
<th>Mitigation Strategy Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protection Coordination Mods $</td>
</tr>
<tr>
<td>Upgraded Line Sections $--$$</td>
</tr>
<tr>
<td>Voltage Regulation Devices $--$</td>
</tr>
<tr>
<td>Direct Transfer Trip $$$</td>
</tr>
<tr>
<td>Communication &amp; Control $--$$</td>
</tr>
<tr>
<td>Advanced Inverters $</td>
</tr>
<tr>
<td>Power Factor Controls $</td>
</tr>
<tr>
<td>Grounding Transformers $--$</td>
</tr>
<tr>
<td>Capacitor Control Modifications $--$</td>
</tr>
<tr>
<td>Volt / VAR Controls $--$$</td>
</tr>
<tr>
<td>Upgrade Transformer or Secondary conductors $</td>
</tr>
</tbody>
</table>

$--$$--$$ $$ Denotes ranges of cost for option

From NREL/EPRI “21 Utility Survey on Interconnection”
Technical Limitations that Impact DER Behavior (and Mitigation Strategies)
Can DER Bring Value to the Grid?

Yes, in some cases, absolutely! There are MANY reports and methods to help you understand potential values. Examples include:

- Deferral of distribution upgrades, substation upgrades, transmission upgrades
- Reduced line losses
- Reduction of emissions near population centers
- Backup power during emergencies
- Time-of-use bill management
- Demand charge reduction
- Energy arbitrage
- Voltage support
- Frequency support
- Increased PV self-consumption (using BESS)
- Spinning/non-spinning reserves
- Black start support
- Etc.
Understanding Intermittency
California Duck Curve

The Duck Curve – California Net Load March 31

Source: CAISO
Hawaii – the Nessie Curve

“Meet Nessie”

Typical Hawaii load profile – Evening Peaking

“What’s Our New State?”

Courtesy of Dora Nakafuji, HECO
Distribution feeder peaks are often not coincident...dependent on feeder type
Variability Analysis in Hawaii – smoothing with dispersed generation

https://www.nrel.gov/docs/fy13osti/54494.pdf
Tracking PV site behavior

- **Additional things detected**
  - Topology Change Detection & Variability Impact Analysis
  - Team Developed State of the PV report
  - Daily/weekly report on MwH generated, backfeed hours, max voltage variability, and transients/anomalies

- Load switched onto Mt. View Substation

- MT. View L1 Mag
- Tequesquite L1 Mag
- MT. View C1 Mag
- Tequesquite C1 Mag
Questions on intermittency – it depends

► What happens to load profiles when you combine solar PV with storage? How does storage help you ride out solar PV’s intermittency?
  □ Depends on the controls

► How can you use storage to reduce a customer’s demand and demand charges?
  □ Depends on the controls

► What kind of capabilities come with storage products — e.g., fast ramping, island-able?
  □ Depends on the product, state and the controls
Generators on distribution circuits locally elevate voltage profile while injecting power.

Their changing operating status increases the range of voltage variation along the circuit (e.g., if suddenly tripping off-line), with potential consequences:

- may exceed voltage regulation capability on the circuit
- may cause voltage flicker during lag time before regulator or load tap changer operation, possibly exceeding acceptable level (5%)
- may cause excessive wear on voltage regulators or load tap changers due to frequent operation

**Prevention:**

- Careful analysis of voltage profiles and regulation capability
Coordination and control

Coordination Issues

• DG may drive voltage out of range
• DG may wear out legacy equipment “hunting” the voltage
• inverted voltage profile may confuse controls
• voltage status may become even less transparent to operators
DRP’s, ICA, and Case Studies
Hosting Capacity and Integrated Analyses

► What is it?
► Why is it different to interconnection?
► Many states making concerted efforts to undertake hosting capacity and integrated resource assessment - examples
Definition:
- Hosting Capacity is the amount of DER that can be accommodated without adversely impacting power quality or reliability under current configurations and without requiring infrastructure upgrades.

Hosting Capacity is
- Location dependent
- Feeder-specific
- Time-varying

Hosting capacity considers DER interconnection without allowing
- Voltage/flicker violations
- Protection mis-operation
- Thermal overloads
- Decreased safety/reliability/power quality

Hosting capacity evaluations require precise models of entire distribution system

A feeder’s hosting capacity is not a single value, but a range of values
### Key Components of an Effective Hosting Capacity Method:

- **Granular**
  - Capture unique feeder-specific responses

- **Repeatable**
  - As distribution system changes

- **Scalable**
  - System-wide assessment

- **Transparent**
  - Clear and open methods of analysis

- **Proven**
  - Validated techniques

- **Available**
  - Using existing planning tools and readily available data

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Feeder Hosting Capacity:
amount of installed PV
(in kW or % of load)
where adverse effects can be ruled out with relative confidence

Problem:
Highly site specific,
requires lots of modeling
but want to have quick, easy rules of thumb

Imperfect Solution:
Apply “Screen” criterion or criteria,
e.g. PV installed capacity < 15% of max feeder load
if YES, then OK
if NO, then perform a detailed, time consuming impact study

New Methodology to Determine Locational DER Capacity

New methodology was required to be developed to calculate DER Integration Capacity

- PG&E was instructed to develop a new methodology to help determine locational DER capacities that would not require significant upgrades to interconnect
- Methodology considers important criteria and aspects considered in detailed engineering reviews during interconnection
- Result is capacity values that estimate when significant impacts are not expected and detailed review is not necessary

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Establish Granularity

- Determine Level of Granularity (e.g., Substation, Feeder, Line Section)

Model and Extract Data

- Model Circuits (e.g., Weekly Circuit Model Update from GIS Maps)
- Extract Capability of Planning Tools (e.g., Load Profiles, Circuit Modeling)
- Extract Dynamic Circuit Data (e.g., Load Profiles, Thévenin Impedance)

Evaluate Criteria

- Evaluate Criteria (e.g., Thermal, Voltage, Protection, Safety)
- Publish ICA results (e.g., PG&E RAM Map)

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Speed

- Detailed Interconnection Studies
- Integration Capacity Analysis
- Fast Track Screens

Accuracy

From PG&E DRP webinar
Proactive Approach: Awareness to “See & Inform & Act”
Hotspots & Impacts

New LVM

Locational Value Maps showing high penetration distribution areas

“Look for Leading Indicators of change”

Credit: Dora Nakafuji HECO
Hawaii – Enhancing models for mapping of accurate hosting capacity

Upgraded Models to Account for PV as Generation NOT as Negative Load

- Enables more accurate modeling of DG resources for planning
- Consistent distribution system model expedites modeling and analysis process
- Allows for “what-if” analysis to stay ahead of system change and minimize risks of stranded assets

Recommended Representation of PV for a Transmission Analysis

Source: HECO Hi-PV Study, CSI RD&D 3 Presentation, BEW Engineering
Energy Storage Systems Overview

- Terms for size and costs
- Utility regulatory environment
- Ownership models
- State responses
- Valuation principles and taxonomy
- Additional resources
Storage Terms for Size

- Size is commonly expressed as MW/MWh
- MW – the maximum amount of power that an energy storage system can discharge
- MWh – the maximum amount of energy that a system can discharge from full charge
Storage Terms for Costs

- Costs can be expressed as $/kWh or $/kWh/cycle
- Most new developments are lithium-ion, with flow batteries contributing 5% of new market growth in 2017 [source: GTM Energy Storage Monitor]
- OE Energy Storage Program goal: $150/kWh
Energy Storage Ownership Models

► Utility-owned assets
  □ More likely to capture portfolio of benefits, rather than split benefits among entities
  □ But may be harder to ascertain time-step values for specific services

► Engaged customers
  □ Interested in load management, resiliency, full economic value of PV
  □ Green Mountain Power customer incentive model

► Third-party ownership
  □ Typically market-facing assets
  □ Challenges with PURPA, RPS, and traditional access points

► FERC
  □ Facilitating aggregation of storage
  □ Cost allocation principles
  □ Storage market participation models
Uncertainties for Energy Storage in Traditional Utility Regulation

- Technology innovation
  - Pilots and demonstrations vs commercial solutions
  - Continuous evolution of costs and lifespans
  - Multiple technology types with various performance characteristics
  - Risk management

- Traditional methods for resource planning do not effectively evaluate energy storage
  - Accurate resource characterization and cost attribution
  - System models do not evaluate sub-hourly benefits, locational benefits, distribution system benefits, and customer benefits
  - Equitable resource comparison

- Core infrastructure
State Responses: Establish Procurement Targets

- Primary form of storage program development: legislature will direct the state utility commission to establish utility procurement targets
  - By a date
  - Considering a range of potential benefits
  - If cost-effective
- In 2013, the California legislature directed the California PUC to establish targets for energy storage procurement. The result: 1.325 GW by 2020

<table>
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<th>2014</th>
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<th>2018</th>
<th>2020</th>
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<td>65</td>
<td>85</td>
<td>110</td>
<td>310</td>
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<tr>
<td>Distribution</td>
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<td>50</td>
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<td><strong>Subtotal PG&amp;E</strong></td>
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<td><strong>San Diego Gas &amp; Electric</strong></td>
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<td><strong>Subtotal SDG&amp;E</strong></td>
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<td><strong>Total - all 3 utilities</strong></td>
<td>200</td>
<td>270</td>
<td>365</td>
<td>490</td>
<td>1,325</td>
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</tbody>
</table>
State Responses: Increase Rigor of Planning Processes

- **Washington**
  - Commission policy statement
  - Directs utilities to improve quality of modeling and adopt a “net cost” approach in the interim

- **New Mexico**
  - New rules direct utilities to evaluate storage in IRPs

- **Other significant state actions:**
  - Study to inform target (Massachusetts)
  - Incentives / tax credits (Maryland)
  - “Storage-friendly” tariff (Arizona)
Storage Valuation Principles

► **Co-optimization:** the system may not fulfill multiple services simultaneously, and choosing one action may prevent the system from responding effectively to another opportunity (e.g. discharging for arbitrage may prevent the system from mitigating an outage)

► **Performance-informed:** asset conditions and performance vary by technology and design, and we are still learning how precisely systems respond to control communications and how intensively state of charge (SOC) affects efficiency

► **Discrete values:** benefits must not overlap to avoid double-counting, with a value developed from an avoided cost, revenue, or societal benefit

► **Timeframe for analysis:** analysis time horizon should be equal to the lifetime and life-cycle cost of the proposed set of assets

► **Location:** values should reflect local conditions and value streams should be location-, market-, region-, and utility-specific
Co-optimization

Energy price ($/MWh)

- Arbitrage only
- Arbitrage + Balancing
- Arbitrage + Balancing + T&D deferral
- Arbitrage + Balancing + T&D deferral + volt/var
## Value Taxonomy

<table>
<thead>
<tr>
<th>Category</th>
<th>Service</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bulk Energy</strong></td>
<td>Capacity or Resource Adequacy</td>
<td>The asset is dispatched during peak demand events to supply energy and shave peak energy demand. The asset reduces the need for new peaking power plants and other peaking resources.</td>
</tr>
<tr>
<td></td>
<td>Energy arbitrage</td>
<td>Trading in the wholesale energy markets by buying energy during off-peak low-price periods and selling it during peak high-price periods.</td>
</tr>
<tr>
<td><strong>Ancillary Services</strong></td>
<td>Regulation</td>
<td>An operator responds to an area control error in order to provide a corrective response to all or a segment portion of a control area.</td>
</tr>
<tr>
<td></td>
<td>Load Following</td>
<td>Regulation of the power output of an asset within a prescribed area in response to changes in system frequency, tie line loading, or the relation of these to each other, so as to maintain the scheduled system frequency and/or established interchange with other areas within predetermined limits.</td>
</tr>
<tr>
<td></td>
<td>Spin/Non-spin Reserve</td>
<td>Spinning reserve represents capacity that is online and capable of synchronizing to the grid within 10 minutes. Non-spin reserve is offline generation capable of being brought onto the grid and synchronized to it within 30 minutes.</td>
</tr>
<tr>
<td></td>
<td>Frequency Response</td>
<td>The asset provided energy in order to maintain frequency stability when it deviates outside the set limit, thereby keeping generation and load balanced within the system.</td>
</tr>
<tr>
<td></td>
<td>Flexible Ramping</td>
<td>Ramping capability provided in real-time, financially binding in five-minute intervals in CAISO, to meet the forecasted net load to cover upwards and downwards forecast error uncertainty.</td>
</tr>
<tr>
<td></td>
<td>Voltage Support</td>
<td>Voltage support consists of providing reactive power onto the grid in order to maintain a desired voltage level.</td>
</tr>
<tr>
<td></td>
<td>Black Start Service</td>
<td>Black start service is the ability of a generating unit to start without an outside electrical supply. Black start service is necessary to help ensure the reliable restoration of the grid following a blackout.</td>
</tr>
</tbody>
</table>

Modified from Akhil et al, *DOE/EPRI Energy Storage Handbook*
## Value Taxonomy (cont.)

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<thead>
<tr>
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<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transmission Services</strong></td>
<td>Transmission Congestion Relief</td>
<td>Use of an asset to store energy when the transmission system is uncongested and provide relief during hours of high congestion.</td>
</tr>
<tr>
<td></td>
<td>Transmission Upgrade Deferral</td>
<td>Use of an asset to reduce loading on a specific portion of the transmission system, thus delaying the need to upgrade the transmission system to accommodate load growth or regulate voltage.</td>
</tr>
<tr>
<td><strong>Distribution Services</strong></td>
<td>Distribution Upgrade Deferral</td>
<td>Use of an asset to reduce loading, voltage, or some other parameter on a specific portion of the distribution system, thus delaying or eliminating the need to upgrade the distribution system to accommodate load growth or regulate voltage.</td>
</tr>
<tr>
<td></td>
<td>Volt-VAR Control</td>
<td>Volt-ampere reactive (VAR) is a unit used to measure reactive power in an AC electric power transmission and distribution system. VAR control manages the reactive power, usually attempting to get a power factor near unity.</td>
</tr>
<tr>
<td></td>
<td>Outage management</td>
<td>Use of an asset to reduce the frequency and duration of outages (avoided lost sales, avoided penalties).</td>
</tr>
<tr>
<td></td>
<td>Conservation Voltage Reduction</td>
<td>Use of an asset to reduce energy consumption by reducing feeder voltage.</td>
</tr>
<tr>
<td><strong>Customer Energy-Management Services</strong></td>
<td>Power Reliability</td>
<td>Power reliability refers to the use of an asset to reduce or eliminate power outages to customers.</td>
</tr>
<tr>
<td></td>
<td>Time-of-Use Charge Reduction</td>
<td>Reducing customer charges for electric energy when the price is specific to the time (season, day of week, time-of-day) when the energy is purchased.</td>
</tr>
<tr>
<td></td>
<td>Demand Charge Reduction</td>
<td>Use of an asset to reduce the maximum power draw by electric load in order to avoid peak demand charges.</td>
</tr>
<tr>
<td></td>
<td>Demand Response</td>
<td>Demand response provides an opportunity for consumers to reduce or shift their electricity usage during peak periods in response to financial incentives.</td>
</tr>
</tbody>
</table>

Modified from Akhil et al, *DOE/EPRI Energy Storage Handbook*
Additional Resources


► DOE/EPRI Energy Storage Handbook

► DOE Global Energy Storage Database
http://www.energystorageexchange.org/
Overview of Energy Storage Systems