When It Comes to Battery Storage Systems, Co-ops Should Focus on a Primary Application

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What has changed?
In recent years, battery energy storage has become a realistic option for improving grid operation, including peak shaving and renewables integration, as well as mitigating, avoiding, or deferring infrastructure investments, such as upgrades to transmission and distribution (T&D) assets.

What is the impact on cooperatives?
Some cooperatives have begun operating one or more battery energy storage systems (BESS) to enhance operations. The battery energy storage industry is evolving, with new technologies promising improved performance and new operational characteristics, such as longer life, lower-cost, and improved safety. Cooperatives that want to explore the applicability of a BESS to an operational issue face the challenge of matching a technology to an application and justifying the business case — as well as evaluating the performance claims of battery manufacturers and vendors.

What do cooperatives need to know and/or what can they do?
Cooperatives are advised to identify the primary application for a BESS technology, such as peak shaving for demand-side management, renewables integration, or asset investment deferral and any secondary applications that may add value. Next, it is important to specify the requirements — including power rating, energy capacity, round-trip efficiency, cycling, and equipment life — of the technology. Finally, cooperatives should determine the value of the BESS for the chosen application, considering such factors as equipment installed cost, equipment operations and maintenance (O&M) cost, electricity prices and, where relevant, deferred equipment costs and payback time.

NRECA has developed several Use Cases that focus on a given application — distribution system demand-side management, commercial and industrial member demand-side management, solar photovoltaic (PV) smoothing, and distribution system optimization via substation storage, including T&D deferral. These cases offer guidance to cooperatives in matching a technology to an application and determining the value of that technology. They are available on cooperative.com in the Renewables and Distributed Generation section.
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INTRODUCTION

Large-scale battery systems hold great promise for all utilities. Through field tests and demonstration projects, a number of breakthroughs have recently been achieved, including longer life, improved reliability, and lower costs. In addition, the applications for these systems are widely varied, providing opportunity for a multitude of benefits to meet cooperatives’ needs.

The U.S. Department of Energy (DOE) has established a database that keeps track of the different energy storage technologies in the country, as well as abroad: (http://www.energystorageexchange.org/projects). This database tracks information on not only each type of energy storage technology, but its primary use for each installation.

Caveat emptor

The rapid evolution of the energy storage industry, however, makes it difficult for co-ops to assess the reliability of information on battery technologies provided by manufacturers and vendors. To assist co-ops in this effort, NRECA has identified five signs of a battery technology’s commercial maturity:

- Engineered package with AC system specifications
- Integrated controls software with standardized interfaces
- Marketing focus on specific applications
- Manufacturing capability
- Cost transparency

These five signs are discussed in Appendix B, Is a battery technology commercially mature?

ARRIVING AT A DECISION

The process of determining whether a battery storage system makes operational and economic sense entails several steps: identifying the application by defining the problem to be solved, finding the right technology for that application, and assessing the value of the technology.

Identifying an application

Battery storage systems can be used for a number of applications. Among them are:

- Capacity supply or deferral (peak shaving)
- Renewable capacity firming
- Responding to intermittency of renewable energy and the impact of climatic conditions on renewables delivery
- Transmission and distribution (T&D) upgrade deferral
- Energy time-shifting (arbitrage)
- Renewable energy time shift (storing renewable energy produced during low loads, e.g., at night and using the stored energy to shave peak demand when prices are high)
- Ease the impact of fast load ramps
- Mitigation of cycling damage to coal-fired plants when large-scale energy storage can be deployed.
- Black-start capability and provision of synchronous spinning reserves.
- Frequency regulation and other ancillary services

Although there is a range of applications for battery storage systems, co-ops should identify one primary need that a battery can address. “That initial application should be key and its value should drive decisions,” said Tom Lovas, an NRECA technical consultant. Although a battery technology may offer multiple benefits,
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co-ops should consider other value streams cautiously, he said. “Assume that you will get only a small percentage of the benefits from other applications.” And, using a battery for several applications may diminish its ability to meet the co-op’s primary need. “A battery tends to be specific to a given use,” said Lovas.

Once a cooperative has defined the key application for a battery system, it must identify the right technology for that application.

Matching application and technology
Research on energy storage systems has tried to identify the best technology for a given application. But, the ever-changing energy storage landscape can make it difficult to select the right technology. Promising technologies are coming forward, but many are still in the development stage, said Jeff Pratt, president of GreenPower EMC, the renewable energy supplier for 38 Georgia electric cooperatives. “There’s no clear technology winner.”

Rather than conducting research to determine which technologies would meet its need, a co-op should focus on the battery’s specifications. One approach is to spell out the qualifying requirements initially in a Request for Information (RFI) to screen BESS vendors and developers, and then prepare a Request for Proposals (RFP). In addition to eliciting information on technologies, the RFI and RFP should request information on the technologies’ value to the given application. “Co-ops need to have an idea of baseline economics,” said Lovas.

Depending on the application, specifications may include power rating, energy capacity, required footprint, round-trip efficiency, cycling, equipment life, and controls.

Assessing the value
The value of the battery storage system is core to building a business case for the investment. To determine the value, a co-op must conduct a discounted cash flow cost/benefit analysis. In general, the costs include the capital cost and operations and maintenance (O&M) costs. The benefits are the savings achieved by deploying the battery storage system.

Additional applications may result in other value streams, but as mentioned previously, a co-op should assume that it will realize only a small percentage of those benefits, and those benefits are perhaps achieved only over time. The value of the primary application should drive a co-op’s decision to invest in a battery energy storage system.

THE USE CASES: A HELPFUL TOOL
NRECA has developed a series of Use Cases of various energy storage aspects. The documents, which can be found at NRECA’s Energy Storage topic and Renewable and Distributed Generation pages on cooperative.com, provide descriptions and recommendations for applying energy storage to a given market scenario. The use cases are not case studies of a particular deployment of the technology. Rather, they provide guidance and offer insights on determining the value of energy storage for a given application.

To date, four use cases are available — one on distribution system demand-side management, also referred to as peak reduction or peak shaving; one on commercial demand-side management; one on photovoltaic (PV) smoothing; and, one on distribution system optimization via substation storage, including T&D deferral.

In addition to defining the application, the use cases provide information on battery specifications — including energy capacity, power rating, round-trip efficiency, cycling, equipment life, and controls — and technology options for the given application. Each of the use cases also discusses the value of the energy storage
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A battery energy storage system (BESS) can supply power to reduce the electric distribution system demand at any given time.

The value of a BESS for DSM is the savings in demand charges obtainable from the installation and operation of the system.

technology, including inputs to determining that value, as well as guidance on performing the cost/benefit analysis.

**Distribution Electric Cooperative Demand-side Management**

Distribution electric cooperatives pay a demand charge to their energy suppliers, as well as an energy charge. Normally, the demand charge is based on the peak power (kW) usage that is coincident with the peak period of the generation and transmission (G&T) electric cooperative. The peak period ranges from 15 minutes to an hour. Many distribution electric cooperatives will pay $10 to $20 per kW-month for the entire year, or a rate that varies with the season, reflecting the effect of load on the cost of acquiring or providing power during those times. A key consideration is that such demand-side programs serve a supply function for the G&T. As a result, recognition must be made of the integrated nature of planning and operating on behalf of the entire G&T membership when evaluating storage as a DSM measure.

This use case evaluates the use of energy storage for shaving distribution system monthly coincident peak demands with the G&Ts as part of a distribution electric cooperative demand-side management program in cooperation with the G&Ts.

A battery energy storage system (BESS) can supply power to reduce the electric distribution system demand at any given time. The maximum amount of the peak that can be reduced is the power rating of the BESS, determined by the size of the power converter/inverter, and the minimum amount of energy required is the rated power times the length of the peak period. Although the BESS would officially be used to eliminate the 15 minutes to 1 hour of peak load requirement in a month, the system would typically require 2 to 4 hours of operation to ensure that the hourly peak for the month is reduced.

The minimum discharge of the system would be one time per month, if adequate anticipatory data is available and system operators can discharge the battery over the 2 to 4 hour time period of the G&T peak. In that instance, the system would only discharge 12 cycles per year to offset the peak demand. In a real application, however, the BESS would likely operate multiple times per month in order to accomplish a reduction in the coincident peak of the G&T.

**BESS Specifications**

The specifications of a BESS used for demand-side management include:

- Power rating (measured in megawatts of AC load)
- Energy capacity (expressed in hours)
- Required footprint (expressed in square feet)
- Round-trip efficiency (expressed as a percentage; higher efficiencies decrease operating costs)
- Cycling (the discharge/recharge cycle)
- Equipment life (should be a minimum of 10 years)
- Controls (metering system for load following)

**Technologies for demand-side management**

This application, which requires medium duration energy capacities, would be appropriate for flow batteries, some lithium ion battery technologies and advanced lead-carbon, aqueous-ion and various sodium technologies, and zinc hybrid cathode technology.

**Determining the value**

The value of a battery storage system for distribution and G&T cooperative demand side management is the savings in demand charges obtainable from the installation and operation of the system. This is determined by comparing the life-cycle costs and the life-cycle benefits.
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There are three costs entailed in operating this type of battery storage system:

1) the capital cost of the equipment, which can be amortized over the life of the equipment;
2) the maintenance cost of operating this type of system (quarterly or semi-annual maintenance visits, replacement/refurbishment of components); and
3) the cost of recharging the battery after a discharge.

Although the primary benefit is reduction in power (kW) demand charges, there is a secondary benefit in that the system will reduce energy consumption during the peak load hours when the battery is discharged, which is offset by the energy consumed during the off-peak hours to recharge the battery after use. The amount of energy that the battery will require to recharge is always greater than the energy delivered. However, if the cooperative is subject to a time-of-use energy rate, the cost to recharge the battery could be less than the value of the energy supplied during discharge. The benefits of the battery storage system for this application are the savings in peak demand charges and the net cost of energy.

Inputs to the value determination include:

- Equipment installed cost
- Equipment operating and maintenance cost
- Financial variables, e.g., interest rate, terms of loan, tax incentives
- Electricity prices (for both discharging and charging the system)
- Demand charges

Performing the analysis

Guidance on conducting the cost/benefit and net present value calculations — as well as identifying additional benefits and determining the cost of alternative technologies — is provided in the full text of the use case: Energy Storage Use Case: Distribution Electric Cooperative Demand Side Management.

Summary

Battery energy storage could be an economic way to reduce demand charges for a distribution cooperative and capacity charges for a G&T. The value of a battery system depends on specific details of the wholesale rate structure of the cooperative’s power supplier, the peak demands of the cooperative, and the characteristics of the battery system to effectively shave the peaks and the need for future capacity.

Commercial Demand-Side Management

Commercial electric accounts often have a demand charge, as well as an energy charge and facilities charge. The demand charge is based on the peak power (kW) usage at some point during each month, and is independent of the total amount of energy that the member uses. The demand may be based on maximum delivery over a 15-minute period or a 1-hour period. It may apply over the entire month, or only during “on-peak” periods. The demand charge may also apply only to work days and may vary by season. The amount that co-ops charge varies widely. A quick online survey of co-op commercial rates showed demand charges ranging from just over $3.00/kW to nearly $15.00/kW.

A battery energy storage system (BESS) can supply power and energy to meet the commercial load and reduce the peak demand at any given time.
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Machine-learning algorithms, are being developed to address this issue, but since many peaks are weather-related, there will rarely be an accurate forecast for the peak period.

NRECA is developing an Open Modeling Framework (OMF)\(^1\) intended for dynamic power system engineering analysis. “There aren’t a lot of packages that do this type of analysis,” said David Pinney, analytics program manager in the Business and Technology Strategies department. One such package is GridLAB-D developed by the Pacific Northwest National Laboratory. “We wanted to take GridLAB-D and other software packages and wrap them into a single interface. OMF brings a collaborative approach to the issues of dynamic power flow and cost/benefit analysis for emerging technology,” he said.

OMF can be programmed to simulate the dispatch of a battery using a specific algorithm into a specific load profile based on real or simulated data. OMF offers three models that are targeted specifically at calculating the benefits of energy storage:

- **Shaving demand peaks**
- **Deferring capital investments**
- **Arbitrage** (buying low, selling high)

**BESS specifications**

The specifications of a BESS used for commercial demand management include:

- Power rating
- Energy capacity
- Required footprint
- Round-trip efficiency
- Cycling
- Controls

**Technologies for demand management**

Because this application requires medium duration energy capacities (of 2 to 3 hours, perhaps more), it would be appropriate for flow batteries, some lithium ion battery technologies, and advanced lead-carbon, aqueous-ion, and various sodium technologies, and zinc hybrid cathode technology.

**Determining the value**

The value of a BESS for commercial demand management is the savings in demand charges obtainable from the battery’s installation and operation. The savings are determined by comparing the life-cycle costs and the life-cycle benefits. Operating a battery storage system for this application entails three costs:

1) the capital cost of the equipment, which can be amortized over its life
2) the maintenance cost of operating this type of system (e.g., quarterly or semi-annual maintenance visits, replacement/refurbishment of components)
3) the cost of recharging the battery after a discharge

Although the primary benefit is reduction in peak demand charges, there is a secondary benefit: The system will reduce the facility’s energy consumption during discharges, which is offset by the need to recharge the battery after use. The amount of energy that the battery will require to recharge is the discharge energy divided by the efficiency of the battery. The energy used to recharge the battery is always greater than the energy delivered. However, if the facility is also on a time-of-use energy rate, the cost to recharge the battery could be less than the value of the energy supplied during discharge.

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\(^1\) For more information on OMF, please see NRECA’s related report, *Cost-Benefit Analysis of Demand Response Programs Incorporated in Open Modeling Framework*; and for questions, please contact David Pinney, lead of NRECA’s Analytics work group, at David.Pinney@nreca.coop.
An important consideration in commercial demand-side management using storage is the relationship among the commercial customer, the distribution cooperative, and the supplying G&T. That relationship can affect the overall economics owing to wholesale and retail energy charge differences, effect on distribution system net peak demand, and other factors that impact the distribution cooperative cost and payment structure. Implementation of storage behind the commercial meter, while potentially independently deployed, should consider those related impacts.

Inputs to the value determination include:

- Equipment installed cost
- Equipment operating and maintenance cost
- Financial variables
- Electricity prices
- Demand charges
- Wholesale power impacts

**Performing the analysis**

Guidance on conducting the cost/benefit and net present value calculations — as well as identifying additional benefits and determining the cost of alternative technologies — is provided in full text of the use case, *Energy Storage Use Case: Commercial Demand Side Management*.

**Summary**

Battery energy storage could be an economic way to reduce demand charges for a commercial customer, depending on the details of the commercial facility’s load profile and rate structure. Several companies — Stem, for example — are looking at ways of monetizing such savings through leasing programs and shared savings programs. A progressive cooperative could offer this option to commercial accounts as a service, and perhaps in coordination with the cooperative’s power supplier.

**Photovoltaic (PV) smoothing**

Energy from a photovoltaic (PV) system is inherently variable, as the sun can be blocked by clouds. If the clouds are moving rapidly in an otherwise clear sky, the change in the PV system’s output can vary dramatically over a short period of time, both when the cloud cover progresses over the array and when the array is no longer blocked by clouds. PV system output can ramp up very quickly or it can drop suddenly, due to cloud cover or as evening approaches, and the system’s output drops to zero over the course of several hours.

Variability in a PV system’s output can cause rapid fluctuations in grid voltage, potentially creating such problems as consumer voltage excursions outside the acceptable voltage range or excessive cycling of voltage control devices (e.g., capacitors, voltage regulators, load tap changers).

**BESS specifications**

The specifications of a BESS used for PV smoothing include:

- Energy capacity (useable capacity should be 25-33 percent of power rating)
- Power rating
- Required footprint
- Round-trip efficiency
- Cycling
- Equipment life
- Controls

**Technologies for PV smoothing**

The most critical requirement for this application is the extremely frequent cycling of the battery. For this reason, a non-battery technology — a flywheel — would be a reasonable technical choice. Alternatively, manufacturers of some of the newer lithium technologies claim the batteries can reach or exceed 100,000 discharge cycles, especially if the cycles are limited in
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depth-of-discharge. Lead-carbon batteries, which are also used in partial state-of-charge operation for frequency regulation, would be appropriate for a PV smoothing application.

Finally, this function could easily be incorporated in a longer-term battery, such as one used for demand management or energy time-shifting, although consideration should be made of the consequences of simultaneous applications, and the primary requirement for the longer-term battery. The ramp-control would be supplied by varying the power level of the charge or discharge process.

**Determining the value**

The value of an energy storage system for PV smoothing would be the benefits gained compared with the costs of the system over the operating period. The system costs include the installed cost of the system, the operations and maintenance costs, and the replacement/refurbishment of components. The benefits would be the reduction in impacts associated with the PV array’s variable output like shortened life and costs for earlier replacement of capacitors, voltage regulators, and load tap changers. For more information, please see NRECA’s related *TechSurveillance* articles on: *Variability and Uncertainty in Renewables’ Generation*.

However, the benefits of implementing ramping control are difficult to quantify. If there is a formal requirement for limited ramping, the cost of the energy storage system needs to be included in the overall cost of the PV system. For example, the California Independent System Operator (CAISO) has a ramping market, which serves to shift energy supply or demand within minutes, and was created as a part of CAISO’s Flexible Ramping Product. For more information, please see:

- **California ISO: Flexible Ramping Product** (CAISO website)

If there is no formal requirement, but rather a perception of a problem, then a tool such as the Open Modeling Framework could help quantify the effects of a PV system on a specific distribution system, so that the benefits of mitigation using energy storage could be evaluated.

Inputs to the value determination include:

- Equipment installed cost
- Equipment operations and maintenance cost
- Electricity prices
- Cost of associated voltage regulation equipment

**Performing the analysis**

Although the benefits of PV smoothing are difficult to quantify, some measure of the benefit must be identified and considered when evaluating the use of an energy storage system to help address intermittency. The benefit would then be the avoided cost of the associated alternative voltage regulation equipment or the damage to the existing voltage regulation equipment on the distribution system.

The system’s operating costs are the sum of the O&M costs (including refurbishment and replacement of components), the value of energy delivered when discharging the battery, and the cost of energy used to charge the battery. If the costs are below the avoided cost of the alternative, the investment may be worthwhile.

For a more detailed examination, a net present value, or “discounted cash flow,” analysis of the cost of owning and operating the energy storage system could be conducted. If the system is financed, the loan payments and other financing aspects, including any tax incentives or other unique financial instruments, must be included in the cash flow. The net present value cost would be compared with
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the discounted cash flow of the costs of adding, replacing, or upgrading the avoided or displaced regulating equipment.

For the full text of this use case, please see: Energy Storage Use Case: PV Smoothing.

Summary
PV smoothing with an energy storage system may be a worthwhile investment to address intermittency and ensure continuity of a feeder voltage profile. The location and characteristic delivery of power from the PV system, and local system voltage requirements, will be factors in considering this application.

Real-time smoothing of PV arrays using energy storage offers two possible benefits:

1) compliance with a mandated ramping limit, and
2) avoiding the acquisition of additional voltage regulation equipment or early deterioration of the equipment because of PV system impacts.

In the first case, compliance is a part of the project’s cost. In the second case, the costs of limiting voltage excursions due to excessive ramping would be compared to the costs of adding or upgrading voltage regulation equipment or replacing this equipment more often.

Distribution system optimization via substation storage
The concept of distribution system optimization (DSO) — and DSO functionality — relates to the effective use of cooperative assets to ensure the availability and reliability of power delivery. Energy storage, by its nature, has the potential to provide a number of useful contributions to system optimization, particularly if strategically located in dynamic operating environments. Such environments include locations where transmission and distribution (T&D) equipment is stressed by load demands from rapid growth in electricity use that would require an expensive upgrade to the T&D system, e.g., addition of a second transformer bank, a second line to a radial system, an increase in power rating to an existing line, and increasing penetration of distributed generation resources.

The advantages of using substation energy storage to accommodate the variety of changes experienced in today’s distribution systems are multiple. At the outset, substation storage may defer equipment upgrades and extend the life of existing equipment. Over time, the flexibility afforded through controls modifications of the energy storage system may provide adaptability to meet evolving operational requirements.

The logical first step in considering substation storage is to take credit for reduced system peak load resulting in reduced charges for new capacity for a G&T or reductions in demand charges for a distribution electric cooperative as the peak load. Next is to evaluate the deferral of T&D equipment (as the peak load for the T&D equipment is most likely coincident with the peak load for the G&T or within an hour or two of the peak load for the G&T), primarily involving short- to medium-term deferral of T&D upgrades.

BESS specifications
The specifications of a BESS used for substation system optimization include:

- Power rating
- Energy capacity
- Required footprint
- Round-trip efficiency
- Cycling
- Equipment life
- Controls

Technologies for substation system optimization
Because the T&D asset deferral and life extension application requires medium duration energy capacities (3 to 4 hours), appropriate
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Technologies include flow batteries, lithium technologies, and advanced lead-carbon, aqueous-ion and various sodium technologies, and zinc hybrid cathode technology. The downstream applications will generally be of medium duration (2 to 4 hours) energy capacity. Fast duration applications, such as PV smoothing or frequency regulation, can also be handled by the longer duration batteries. At present, substations system optimization is not an application suited for short-duration flywheels, which are more suited to rapid response requirements.

**Determining the value**
The substations storage system, when properly specified, will provide identifiable benefits for:

- Capital expenditure deferral
- Renewables integration
- Frequency regulation, which could be bid into a frequency regulation market
- Ability to maintain service if separation from grid occurs
- Congestion relief
- Reduced system losses
- Improved power quality.

The value of a substations battery for distribution system optimization is twofold: an initial value and a longer-term value. The initial benefits arise from the avoided cost of equipment deferred, and the longer-term value arises from either deployment to alternative sites or from the provision of additional services at the initial location or subsequent locations.

**Summary**
Substation battery storage can be an effective contributor to distribution system optimization. Effective asset deployment is a fundamental consideration for DSO functionality, and storage may provide a cost-effective means to defer or avoid investment in new T&D equipment or extend the life of existing T&D equipment. Deferral values may be derived from system planning studies on upgrade requirements and incremental T&D additions that can be avoided by means of an installed battery storage system.

However, storage devices can provide capabilities beyond the deferral application. By judicious assessment of long-term trends in system requirements, the installation of a battery based on initial deferral values can generate a stream of benefits beyond that initial term. Applying the evaluation techniques of deferral benefit based on T&D costs, storage could be supported economically and become available to provide a wide range of additional energy services, including optimal use of utility assets, either at the initial installation location, or alternative sites. A mobile battery installation may be justifiable to maximize the value achieved from the battery investment.

**NEXT STEP FOR CO-OPS**
The NRECA use cases provide fundamental methodologies that should be taken into consideration by co-ops assessing the role of a battery storage system. “But there’s no cookie-cutter approach,” said Lovas. Every battery application is different. And, he added, each battery type is unique in terms of both its input and output requirements, “How the components are assembled and how a battery is recharged are very specific to the need that the battery must meet.”
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APPENDIX A: BATTERY TYPES

Broadly speaking, electro-chemical batteries are divided into two types: solid state and flow.

In solid-state batteries, both the electrolyte and the electrode are solid. In a flow battery, two chemical components are dissolved in liquids contained within the system and separated by a membrane, providing chargeability. Flow batteries are classified as redox (reduction-oxidation) hybrid and membrane-less. Examples of redox flow batteries include iron-chromium and vanadium redox, while zinc-bromine and zinc-chlorine are examples of hybrid batteries and hydrogen-bromine laminar is an example of a membrane-less battery.

In solid state batteries, energy is stored as the electrode material; while in flow batteries, it is stored as electrolyte in flow cells.

SOLID STATE BATTERIES

Lead-acid
In the conventional lead-acid battery, the positive electrode is composed of lead-dioxide, while the negative electrode is composed of metallic lead. The electrolyte is a sulfuric acid solution approximately 37 percent sulfuric acid by weight.

Two advanced versions of lead-acid storage technologies have been developed: advanced lead-carbon and advanced lead-acid.

Advanced lead-carbon. In this battery type, the conventional lead-acid battery is improved by incorporating carbon in one or both electrodes.

Advanced lead-acid. These batteries focus on such technology enhancements as carbon-doped cathodes, granular silica electrolyte retention systems, higher density positive active materials and silica-based electrolytes.

Lead-carbon
This battery uses a standard lead type battery positive electrode and a supercapacitor carbon negative electrode.

Lithium-ion
In this battery, lithium ions move from the negative electrode to the positive electrode during discharge and back when charging. The battery uses an intercalated lithium compound as the electrode material.

Metal-air
This type of battery uses an anode made from pure metal — such as zinc, aluminum, magnesium or lithium — and an external cathode of ambient air, typically with an aqueous electrolyte.

The lithium-air battery uses oxidation of lithium at the anode and reduction of oxygen at the cathode to include a current flow. The Zinc-air battery, which is not rechargeable, is powered by oxidizing zinc with oxygen from the air.

Continued
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Zinc hybrid cathode
This technology employs inexpensive, widely available materials, e.g. zinc, carbon, plastic, within a robust, scalable design to achieve long life and extremely low cost.

Nickel-cadmium (Ni-Cd)
This battery uses electrodes made of nickel oxide hydroxide and metallic cadmium, and an alkaline electrolyte of potassium hydroxide.

Sodium-sulfur (NaS)
In this battery, the negative electrode is made of liquid sodium, while a solid ceramic material of beta-aluminum—a type of aluminum oxide—serves as the electrolyte. The positive electrode is made from molten sulfur.

Sodium-nickel-chloride (NaNiCl2)
In this battery, salt (NaCl) and nickel (Ni) are transformed into nickel-chloride (NiCl) and molten sodium (Na) during charging. The chemical reactions are reversed during discharge. The electrodes are separated by a ceramic wall (electrolyte) that is conductive for sodium ions but an isolator for electrons.

FLOW BATTERIES
Aqueous metal ion
This type of battery uses a water-based electrolyte and various types of ions — lithium, sodium, zinc — to carry the charge. One product — the aqueous hybrid ion battery — uses sodium, lithium and hydrogen ions.

Iron-chromium redox (ICB)
This battery consists of two tanks that store electrolytes containing iron and chromium. During discharge, the electrolytes are pumped through an electrochemical reaction cell. To store energy, the process is reversed.

Vanadium redox (VRB)
This battery has two chambers — a positive chamber and a negative chamber — separated by an ion-exchange membrane. The two chambers are circulated with electrolytes containing active species of vanadium in different valence states.

Zinc-bromine (ZnBr) hybrid
This battery consists of a zinc negative electrode and a bromine positive electrode separated by a microporous separator. An aqueous solution of zinc bromide is circulated through the two compartments of the cell from two separate reservoirs.

Zinc-chloride (ZnCl) hybrid
This battery is similar to the zinc-bromine battery, but uses an aqueous solution of zinc chloride.
APPENDIX B: IS A BATTERY TECHNOLOGY COMMERCIALLY MATURE?

To assist cooperatives in assessing the reliability of information on battery technologies, NRECA has identified five signs of a battery technology’s commercial maturity:

A fully engineered package. A commercially-mature BESS will be available “off the shelf” and deployable upon delivery. The system developer will identify all necessary components, allowing for installation and interconnection without additional design work by the installer or the cooperative. Laboratory testing and post-production quality assurance will verify the operability of all components. The complete package will have passed field tests. Complete documentation and references of successful installations are available.

Integrated controls software with standardized interfaces. Control software is the heart of BESS functionality, and no system is complete without fully-tested software included in the engineered package. Custom interfaces should not be required for interconnection with a cooperative’s SCADA and ancillary communications systems. Details on communications protocols and control software features will be provided upon request and available for review while the system is under consideration by the cooperative.

Marketing focus on specific applications. Energy storage, in general, can provide for multiple services on a co-op’s electrical system; a commercially mature BESS technology will have characteristic features that are particularly attuned for one or more specific uses. A technology that provides maximum capacity for short durations and rapid recharging will be more suited for peak shaving, for example, than a technology that provides stored energy over a longer period. A battery technology marketed toward the application best suited for that system provides validation of successful performance.

Manufacturing capability. Consistent, standardized manufacturing is a hallmark of commercial maturity, including the identification of manufacturing facilities that are open to visitation; in continuous production of components or complete systems; and capable of meeting scheduled deliveries. Until recently, BESS have been “one of a kind,” and that is part of what is changing. When reviewing manufacturing capacity, some experts put a higher value on a maker’s ability to ramp up to larger volumes quickly as a sign of commercial maturity. Others are looking for facilities that are reasonably scalable, and not “one-of-a-kind,” or even the “second of a kind.” Consistency in product, however, is required.

Cost transparency. A commercially mature BESS technology will have known costs, both in terms of acquisition and routine operation. Vendors will provide, upon request, firm costs, performance guarantees, ongoing operational support of known levels, and budgetary impacts. Vendors will make public information on those costs and expected changes over time. Be wary of any company that is not willing to provide a solid cost quote that includes all the parts. An established price is evidence that the company has a business plan with a “finalized” product design, as well as supply chain and manufacturing costs for an estimated market penetration.
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APPENDIX C: NRECA ENERGY STORAGE RESOURCES

NRECA has created a Lexicon that provides a common vocabulary for talking about electrical energy storage systems. It is focused on grid-connected systems, but many of the terms also apply to off-grid systems.

The Lexicon, which covers technical terms, types of energy storage systems, specifications, business terms and applications, is available in Appendix D of this report, and on cooperative.com at Energy Storage Lexicon.

Growth in battery storage — a series of technologies that will address various uses and needs — is expected by industry watchers. But, battery storage is not the only storage option. A broader mix of storage resources — organized around the term “community storage” — is also gaining currency. Community storage refers to programs that aggregate distributed energy storage resources, including batteries as well as water heaters and electric vehicles, to improve the operational efficiency of electric energy services to consumers. More than 40 organizations, including over a dozen cooperatives, are engaged in the Community Storage Initiative.

More information about community storage and the associated initiative is available on cooperative.com in the Energy Efficiency area.

Other resources include:

• “Dispatchable” Solar Power — a new approach to the combination of solar power and battery energy storage (cooperative.com login)
• Energy Storage Toolkit — resources to help cooperatives assess and implement electrical energy storage systems (cooperative.com login)
Appendix D: Electrical Energy Storage – A Lexicon

Electrical energy storage is an increasingly important topic in discussions about the future of the grid. The following provides a common vocabulary for talking about electrical energy storage systems. It is focused on grid-connected systems, but many of the terms also apply to off-grid systems.

TECHNICAL TERMS

- **Battery**
  An electrochemical energy storage device which is usually DC. This is one part of an energy storage system.

- **Battery Cell**
  This is the smallest individual electrical component of a battery. It may be a separate physical device (such as an “18650” cell commonly used with lithium batteries), or it may be part of a larger package, yet electrically isolated (a 12V lead acid car battery actually has six two-volt cells connected via bus bars).

- **Battery Management System**
  This is a system which manages and monitors the battery to ensure even charging and discharging. This may be part of a system controller or may be a separate subsystem controller.

- **Charge Rate**
  The ratio of the charge power to the energy capacity of an energy storage system.
  For example, a 2 MWh system being recharged at 400 kW would have a charge rate of 0.2C (or C/5), while the same battery being charged at 8 MW would have a charge rate of 4C.
  There are often limits as to how fast a system can be charged / discharged.

- **Depth of Discharge**
  This is the inverse of Battery State-of-Charge (BSOC), and is usually abbreviated as DOD. This is usually used to describe battery cycling characteristics.

- **Discharge Rate**
  The ratio of the discharge power to the energy capacity of an energy storage system.
  For example, a 2 MWh system being discharged at 500 kW would have a discharge rate of 0.25C (or C/4) while the same system being discharged at 4 MW would have a discharge rate of 2C.
  There are often limits as to how fast a battery can be discharged. These limits can be a function of the battery (e.g., plate thickness in solid state batteries, membrane size in a redox flow battery), or it may be a limitation of the power interface (e.g., inverter or motor generator rating).

Continued
• **Energy**
   The capacity of a physical system to perform work.
   Electrical energy is measured in Joules (J) or more commonly watt-hour (Wh), kilowatt-hour (kWh), or megawatt-hour (MWh). A 5 kW generator running for 12 hours per day would produce 60 kWh/day.

• **Energy Storage System (ESS)**
   In this context, this is typically used to describe the entire system, including the energy storage device (battery or other) along with any motor/generators, power electronics, control electronics, and packaging.

• **Islanding**
   Islanding occurs when a system continues to generate power and export it, even after the failure of the main electric grid.
   There are two types of islanding – unintentional and intentional.
   - **Unintentional Islanding**
     This would happen if a system were to somehow continue to export power into the grid after the main grid had failed. This is a serious safety problem and would be dangerous both to the crews working to repair the lines and to other consumers sharing that line. Fortunately, all interconnected energy storage systems are subject to IEEE 1547, which requires that distributed generation systems (including energy storage systems which can act as generators) disconnect from the grid in the event of grid failure. Assuming that the equipment is listed to UL-1741 (which incorporates IEEE 1547) or otherwise certified to IEEE 1547 standards, this should prevent unintentional islanding.
   - **Intentional Islanding**
     This is a special case where the system disconnects from the electric grid as per UL-1741, but still continues to power a set of loads behind the system disconnect. To do this, the inverter has to switch from “grid interactive mode” to “load following mode”. The system would continue to monitor the grid and reconnect when the grid is available and stable per IEEE 1547.

• **Power**
   The rate at which work is done upon an object.
   Electrical power is the rate at which electrical energy is transferred by an electric circuit. Electric power is measured as Joules per second (J/s), or more commonly watt (W), kilowatt (kW) or megawatt (MW).

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APPENDIX D: ELECTRICAL ENERGY STORAGE – A LEXICON (CONT.)

• Power Subsystem
  This is the device that converts the energy storage in the battery (or other device) into AC power for interaction with the grid.
  Most modern energy storage systems use solid state power electronics (inverters), while some compressed air and other systems use rotating motor-generators. All interactive power electronics should meet IEEE 1547 and applicable UL and NEC standards.

• State-of-Charge
  Typically abbreviated as SOC or BSOC (battery SOC). The amount of capacity remaining in a battery.
  A fully charged battery is 100% SOC; a fully discharged battery is zero percent SOC. Note that some technologies have different capacities available depending on discharge rate, so it may be a little difficult to completely describe the SOC at any given time.

TYPES OF ENERGY STORAGE SYSTEMS

• Electrical
  Category includes capacitors (often described as “super” or “Ultra” capacitors) and Superconducting Magnetic Energy Storage (SMES).

• Electro-chemical flow
  Battery that uses pumped electrolyte to transfer energy, typically involving a membrane.
  There are two primary types of flow batteries generally available — the “redox” battery, where the electrolyte is pumped through a membrane, and the Zinc Bromide battery, where zinc is plated from the electrolyte onto a membrane.
  Theoretically the energy capacity is determined by the volume of electrolyte and the “power rating” is determined by the size of the membrane and some other factors. These batteries have moving parts (pumps) and “plumbing” which introduces failure mechanisms which are not present in solid state batteries. Redox batteries are very similar in concept to hydrogen fuel cells.

• Electro-chemical solid state
  Category includes lead acid, lead-carbon, nickel-metal-hydride, various lithium technologies, sodium nickel chloride, and “liquid metal” batteries, among others.
  Typically, there is an electrolyte that interacts with an “electrode” with no moving parts or pumps. (The liquid metal battery uses layers of molten metals and complex salts, but there are still no moving parts.)

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Appendix D: Electrical Energy Storage – A Lexicon (Cont.)

- **Electro-mechanical**
  Category covers rotating energy storage (flywheels) and compressed air energy storage (CAES), as well as pumped-hydro and other gravity-based storage systems. These systems rely on mechanical processes, rather than electrochemical interactions, to store energy, and can thus have nearly infinite cycle life, provided proper maintenance is done on components.

- **Electro-thermal**
  Category refers to reversible electric storage systems which store energy using heat.
  An example of this is Isentropic Systems in the UK, which uses a piston powered heat pump to heat (500°C) and cool (-160°C) argon gas. This gas is circulated through beds of gravel to store the heat/cold. When electricity is needed, the system is reversed and the stored heat/cold is used to drive the heat pump to produce electricity. Other proposed systems use CO2 as the working gas.

- **Thermal**
  Category is distinguished from electro-thermal in that it is one way. Electrical energy is converted into either heat (as in a water heater) or cold (as in ice storage), and then the thermal energy is used directly without reconverting to electricity. This creates what Amory Lovins famously called “Nega-watts” – using the thermal energy directly means that you will not have to use the equivalent amount of electrical energy.
  Some modern solar thermal systems store thermal energy in molten salts, which are then used to create steam to drive generators. This is one-way electrical energy storage in the opposite direction.
  One form of thermal energy storage varies the hourly use of electricity to produce hot water or heat in the home, and is the simplest and lowest-cost form of energy storage. Electricity can be used to produce hot water from 11 PM to 7 AM when electricity prices are cheap. During the off peak time while the hot water is being produced, the electricity used can be varied to provide valuable spinning reserve and frequency regulation service to the grid. The stored hot water is then used during the morning peak hours or during the daily peaks when needed.
  Thermal energy storage can also be used to heat up ceramic bricks at night with the heat released during the daytime during peak periods of electricity use.

- **Other**
  There are other methods which can potentially serve as energy storage – creating and storing hydrogen or ammonia using excess electricity, and then using that fuel to power either a generator or a mechanical device (automobile or tractor, for example).
  Another method called Liquid Air Energy Storage (LAES) uses excess electricity to cool and liquefy air or nitrogen which is stored in an insulated tank at low pressure. The process is reversed by pressurizing the liquid air and then allowing it to evaporate and expand, creating a high pressure gas which is heated and then used to drive a turbine/generator.

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APPENDIX D: ELECTRICAL ENERGY STORAGE – A LEXICON (CONT.)

SPECIFICATIONS

There are seven primary specifications associated with energy storage:

- **Cost — specified in dollars ($)**
  
  It is important to note whether the specified cost is for the entire system (including storage subsystem, power and control electronics, housing and interconnection transformer), or just for the energy storage subsystem / battery.

  It is also important to note whether the cost is ex-factory (not including shipping) or shipped and installed.

  There are four types of costs typically used to describe energy storage systems:

  - **Capital Cost** — the simple initial cost of the system.
  
  - **Cost per kW (MW)** — the cost of the system divided by the output power rating of the system. Must specify as $/kW-AC (preferred) or $/kW-DC.
  
  - **Cost per kWh (MWh)** — the cost of the system divided by the amount of energy storage. Must specify as $/kWh-AC (preferred) or $/kWh-DC. Also must specify whether this is based on the useable storage capacity versus the rated storage capacity, if different.
  
  - **Cost per kWh Throughput** — the cost of the system divided by the product of the useable capacity of the system and the cycle life of the system:
    
    \[
    \text{kWh\_throughput} = \frac{\text{Cost}}{(\text{useful\_kWh} \times \#\_cycles)}
    \]

    This is not very useful since it assumes that the battery will be used to 100% of its technical capacity, which is not usually achieved in actual applications.

- **Cycle Life**
  
  This is the number of times an energy storage system can be discharged and recharged before end-of-life.

  Cycle life may vary with depth of discharge (DOD) and/or discharge rate. It is usually specified as a number of cycles to a certain depth-of-discharge (e.g. 5,000 cycles to 80% DOD), or even as a table or graph. A sample is provided in Figure 1.

  Cycle life may also vary based on the charge rate.

FIGURE 1: Sample Cycle Life vs. Depth-of-Discharge Graph

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APPENDIX D: ELECTRICAL ENERGY STORAGE – A LEXICON (CONT.)

• **Energy Capacity**

  This is the amount of energy which can be stored in the device for delivery to a load and is described in kilowatt-hour (kWh) or megawatt-hour (MWh).

  It is important here to note the difference between direct current (DC) and alternating current (AC) ratings, and between the “rated capacity” and the “useable capacity.” Many energy storage devices (especially those called “batteries”) are rated in DC, while an energy storage “system” — which interacts with the electric grid — is rated in AC. So, it is important to note which one is being discussed by specifying “kWh-DC” or “kWh-AC”.

  It is also important to note whether this is the “nameplate rating” or the “useable capacity.” Some technologies (e.g. lead-acid and lithium) have a theoretical rating based on 100% discharge. However, using this capacity repeatedly would cause physical damage to the battery, so manufacturers recommend using only some percentage (e.g., 50% or 80%) of the nameplate rating. There are other energy storage systems, especially flow batteries, that can do 100% depth of discharge (DOD) without physical damage to the battery.

• **Power Rating**

  This is the amount of power which can be delivered from the energy storage system, and is measured in kilowatts (kW) or megawatts (MW).

  This must also be specified as DC (if discussing the battery alone) or AC (if discussing an energy storage system).

  This rating is a function of the battery itself and of the power electronics (inverter), which are used to convert the battery energy into AC power. The most common specification is for continuous power, but different devices may also be rated for short-term or “surge” power. The power rating is usually the same for both discharge and recharge, but it can be different in special circumstances, especially when discussing the battery alone.

• **Round-Trip Efficiency**

  This is the ratio of the amount of energy which can be discharged from the energy storage system to the amount of energy it takes to recharge to the initial state. It is usually abbreviated as RTE, which must be specified as DC (if discussing the battery alone) or AC (if discussing an energy storage system).

  \[ \text{ACRTE} = \text{DCRTE} \times \text{inverter efficiency} \times \text{charger efficiency} \]

  Round-trip efficiency may vary based on charge/discharge rate.

  Note that all energy storage systems have a round-trip efficiency of less than 100%.

  Actual DCRTE can be between 65% and 95%, depending on the battery technology.

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APPENDIX D: ELECTRICAL ENERGY STORAGE – A LEXICON (CONT.)

• **Size**

  Dimensions and weight of the device.

  It is important to note whether the specified size is for the entire system (including storage subsystem, power and control electronics, housing and interconnection transformer) or just for the energy storage subsystem/battery.

• **System Life**

  This is the number of years that the system is expected to operate within specified parameters. For example, some systems may be specified to operate for 5 or 10 years and then be replaced / recycled, while others may be specified to operate for 25 years, assuming certain maintenance and component replacements along the way.

  Inverters and pumps/motor drives and flow-battery membranes are examples of components that may need refurbishing and/or replacement over the life of the system.

  There are also other specifications which may be described on a datasheet, including:

• **Degradation**

  Some energy storage systems (especially electrochemical) will experience a reduction in capacity over their life. Such systems are often rated using terminology such as “5,000 cycles to 80% final capacity.”

  Note — this is the reason why people are looking at selling used electric vehicle (EV) batteries for home energy storage after they have outlived their specified life in the vehicle.

• **Hazardous Waste Category**

  Many batteries contain hazardous materials, and the battery specification should list these materials, typically in a “Material Safety Data Sheet” or MSDS.

• **Included Recycling**

  Some energy storage manufacturers are starting to offer recycling at the end of system life, either as part of the initial cost or as an added service. Lead acid batteries have a recycling infrastructure in place.

• **Interconnection Voltage**

  This is the AC voltage at which the system will interconnect with the grid.

  Residential systems will interconnect at 120/240 single phase, commercial systems at 480 3-phase, substation-sized systems at distribution voltage (15 kW class), and large grid support systems at higher voltage.

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APPENDIX D: ELECTRICAL ENERGY STORAGE – A LEXICON (CONT.)

• **Response Time**
  This is the time it takes the system to respond to either a ramping signal (e.g., “change from 50% discharge to 100% discharge”) or to a reversal in direction of power flow (e.g., “change from current discharge rate to full recharge”). This is usually specified either in milliseconds (ms) or cycles (1 cycle = 1/60th of a second in the United States).

• **Self-Discharge**
  This is the rate at which an energy system will lose capacity if left unconnected to a charging source.

  It is important to note that some technologies (lead acid, lithium, flow batteries) are suitable for standby use (long periods of inactivity followed by use), while others (sodium nickel chloride, liquid metal batteries) are designed to be used continuously, since their “losses” help provide the heating for the high temperature elements of the battery.

• **Standby/Tare Loads**
  The “tare load” is the amount of energy used by the energy storage system to maintain itself at a specific state when it is not being used. This could account for energy to keep the battery “topped up,” circulating pumps for flow batteries, climate control to keep the battery / system within a certain temperature range, or “background” power for control and power systems.

• **Temperature Range/Derating**
  A good specification will include an operating ambient temperature range and a “storage” range. The temperature range may include derating (e.g., “100% up to 40 deg C, 2% per degree up to 55 deg C”) which is due to the effect of temperature both on the battery chemistry and on the ability to cool the power electronics.

BUSINESS TERMS

• **End-of-life**
  This is the condition which defines the end of the useful operation of the energy storage system. In electrochemical systems, this is typically expressed in percent of original capacity.

• **FMEA — Failure Modes and Effects Analysis**
  This is a formal study of a complex system to examine the effects of different types (modes) of failure on a system.

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APPENDIX D: ELECTRICAL ENERGY STORAGE – A LEXICON (CONT.)

• Reliability
  All physical systems are subject to failures at some point during their operational life. Reliability of a system is typically described with two numbers: MTBF and MTTR

  ▪ MTBF — Mean Time Before Failure
    This is the number of hours of operation expected before the system experiences a failure resulting in a loss of operating capacity. Note that a failure may cause complete shutdown of a system, or only degradation in system capabilities.

  ▪ MTTR — Mean Time To Repair
    This is the mean number of hours needed to repair a system in order to restore operation.

• Warranty
  A written guarantee, issued to the purchaser of an article by its manufacturer, promising to repair or replace it if necessary within a specified period of time.

  Note that a warranty period is not the same as the useful life of that product.

  Note also that a warranty may only pay for partial replacement if failure occurs before the warranty period. For example, if a battery fails 5 years into a 10-year warranty, the warranty might only pay for half of the original cost.

  A completely packaged system would typically have a single warranty, while a system which is engineered out of separate components may have multiple warranties (e.g., battery, power electronics, workmanship).

APPLICATIONS

This is a partial list of the most common applications. The full list and definitions are available in the NRECA Document “Financial Screening for Energy Storage” and in the DOE/Sandia Energy Handbook.

• Demand Side Management/Peak Reduction
  Use energy storage to reduce electricity demand during peak demand periods, recharging during low demand periods. May be implemented by the customer or the utility.

• Electric Service Reliability/Resilience
  Provide backup power during outages, including integration with distributed generation sources.

• Energy Arbitrage
  Purchase off-peak electricity at low prices for charging the storage plant, so that stored energy can be used or sold at a later time when the price of purchased electricity is high. This is sometimes referred to as Electric Energy Time–Shift.
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APPENDIX D: ELECTRICAL ENERGY STORAGE — A LEXICON (CONT.)

• **Fast Response Frequency Regulation**
  Manage the interchange flows between control areas, especially to support frequency regulation.
  FERC Order 755 promotes ES as an option for frequency regulation, allowing for a higher premium to be paid where there are markets for ancillary services for the rapid response of energy storage in maintaining system frequency.

• **Micro-grids**
  The use of dispatchable and non-dispatchable generators, often combined with energy storage, and intentional islanding, to produce energy for distribution to a local set of loads. Usually done for energy independence or economic optimization purposes.

• **Off-grid systems**
  Systems which are not connected to a utility grid.
  These range from solar-powered streetlights and mountaintop microwave repeaters to individual homes and even whole communities which are powered by local generation sources.

• **Renewables Firming**
  Use ES in tandem with intermittent wind or solar to provide a more constant power source.

• **Transmission/Distribution System Deferral**
  Defer and/or reduce the need to build new generation/distribution capacity or purchase generation capacity in the wholesale electricity marketplace. Distribution applications include deferral of transformer upgrades or line reconductoring.
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