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"Electricity Storage Services and Benefits"

Chapter 1

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Introduction to the Study Guide

The Study Guide for the present course consists of excerpts (primarily Chapter 1, "Electricity Storage Services and Benefits") from the "DOE/EPRI Electricity Storage Handbook in Collaboration with NRECA," February 2015.

The entire Handbook can be downloaded by clicking on this link, but the present course is based solely on the material in Chapter 1.

GLOSSARY

– A –	
AC	alternating current
ACE	area control error
AEP	American Electric Power
AFUDC	Allowance for Funds Used During Construction
AGC	automatic generation control
ARRA	American Recovery and Reinvestment Act of 2009
AS	ancillary service
– B –	
BPA	Bonneville Power Authority
– C –	
CAES	compressed air energy storage
CAISO	California Independent System Operator
Calculator	Lifecycle Analysis Calculator (EPRI)
CCGT	Combined-cycle gas turbine
CES	Community Energy Storage
CESA	California Energy Storage Alliance
CO2	carbon dioxide
CONE	cost of new entry
Co-op(s)	Rural electric cooperative(s)
CPUC	California Public Utility Commission
CT	combustion turbine
– D –	
DAS	Data Acquisition System
dc	direct current
DESS	Distributed Energy Storage System
DETL	Distributed Energy Technologies Laboratory
DOD	depth of discharge
DOE	U.S. Department of Energy
$/kW-month	dollars per kilowatt per month
DR	demand response
DSA	Dynamic Security Assessment
DSCR	Debt Service Coverage Ratio
– E –	
EES	Electric Energy Storage
EESAT	Electrical Energy Storage Applications and Technologies
EMC	electromagnetic compatibility
EPRI	Electric Power Research Institute
ERCOT	Electric Reliability Council of Texas
ESA	Electricity Storage Association

ESAL	Energy Storage Analysis Laboratory
ESCO	energy service company
ESCT	Energy Storage Computational Tool
ESIF	Energy Systems Integration Facility
ESPTL	Energy Storage Performance Test Laboratory
ESS	Energy Storage Systems or Electricity Storage Systems
ESTF	Energy Storage Test Facility
ESTP	Energy Storage Test Pad
ESVT	Energy Storage Valuation Tool
ETT	Electric Transmission Texas
EV	Electric Vehicle
– F –	
Fe-Cr	Iron-chromium
FERC	Federal Energy Regulatory Commission
– G –	
G & T	generation and transmission
GE	General Electric
GHG	greenhouse gas
GST	Grid Storage Technologies
GW	gigawatts
– H–	
H-APU	Hybrid Ancillary Power Unit
Handbook	Electricity Storage Handbook
HCEI	Hawaii Clean Energy Initiative
hr	hour
Hz	hertz
– I –	
IDC	Interest During Construction
ILZRO	International Lead Zinc Research Organization
IPP	Independent Power Producer
IR	infrared
ISO	Independent System Operator
ISO-NE	Independent System Operator – New England
IOU	Investor Owned Utility
– J –	
JCP&L	Jersey Central Power and Light Company
– K –	
KIUC	Kauai Island Utility Cooperative
kW	kilowatt
kWh	kilowatt hour

– L –	
LA	lead-acid
LCOE	levelized cost of energy
Li	lithium
LMP	locational marginal pricing
LSEs	load-serving entities
– M –	
MMBtu	one million Btu
Muni	municipal electric utility
MVAR	mega volt-ampere reactive
MW	megawatt
MWh	megawatt hour
– N –	
Na	sodium
Na_2S5	sodium pentasulfide
NaCl	salt
$NaAlCl_4$	sodium ion conductive salt
NaS	sodium sulfur
NAS™	registered trademark for NGK Insulators, Ltd. sodium sulfur batter
NEC	National Electrical Code
NEDO	New Energy Development Organization
NERC	North American Electric Reliability Council
NESC	National Electric Safety Code
NETL	National Energy Technology Laboratory
Ni	nickel
$NiCl_2$	nickel chloride
NIST	National Institute of Standards and Technology
NISTIR	National Institute of Standards and Technology Interagency Report
NiMH	nickel metal-hydride
NOx	nitrogen oxides
NPV	Net Present Value
NRECA	National Rural Electric Cooperative Association
NREL	National Renewable Energy Laboratory
NYISO	New York Independent System Operator
NYSERDA	New York State Energy and Development Authority
– O –	
O & M	Operations and Maintenance
OE (DOE)	Office of Electricity Delivery and Energy Reliability
OEM	original equipment manufacturer
OIR	
– P –	
PbO2	lead dioxide

PCS	power conversion system or power conditioning system
PCT	Patent Cooperation Treaty
PG&E	Pacific Gas and Electric
PEV	plug-in electric vehicle
PHEV	plug-in hybrid electric vehicle
PHES	pumped hydroelectric energy storage
PJM	PJM Interconnection, LLC
PNM	Public Service Company of New Mexico
PNNL	Pacific Northwest National Laboratory
PQ	power quality
PREPA	Puerto Rico Electric Power Authority
PSLF	Positive Sequence Load Flow
PUC	Public Utility Commission
PV	photovoltaic
Pb-acid	Lead Acid Battery
– Q –	
No “Q” terms	
– R –	
R&D	research and development
Redox	reduction and oxidation
RFI	Request for Information
RFP	Request for Proposals
RFQ	Request for Quote
RPS	Renewable Portfolio Standards
RTO	Regional Transmission Organization
– S –	
SCADA	Supervisory Control and Data Acquisition
SCE	Southern California Edison
SCR	Selective Catalytic Reduction
SDG&E	San Diego Gas and Electric
SGIP	Self-generating Incentive Program
SMD	Standard Market Design
SNL	Sandia National Laboratories
– T –	
T&D	transmission and distribution
TCOS	transmission cost of service
TEPCO	Tokyo Electric Power Company
TESA	Texas Energy Storage Alliance
TIEC	Texas Industrial Energy Consumers
TOU	time of use
TPC	total plant cost
TSP	Tehachapi Wind Energy Storage
TVA	Tennessee Valley Authority

– U –	
UBG	Utility Battery Groups
UPS	uninterruptible power supply
– V–	
V	volts
VAR	reactive power and volt-ampere reactive
VLA	vented lead-acid
VPS	VRB Power Systems
VRLA	valve regulated lead-acid
W –	
WACC	weighted average cost of capital
WECC	Western Electric Coordinating Council
– X –	
No “X” terms	
– Y –	
No “Y” terms	
– Z –	
$ZnBr_2$	zinc bromine

ENERGY STORAGE 101

What is energy storage? Energy storage mediates between variable sources and variable loads. Without storage, energy generation must equal energy consumption. Energy storage works by moving energy through time. Energy generated at one time can be used at another time through storage. Electricity storage is one form of energy storage. Other forms of energy storage include oil in the Strategic Petroleum Reserve and in storage tanks, natural gas in underground storage reservoirs and pipelines, thermal energy in ice, and thermal mass/adobe.

Electricity storage is not new. In the 1780s, Galvani demonstrated "animal electricity" and in 1799 Volta invented the modern battery. In 1836, batteries were adopted in telegraph networks. In the 1880s, lead-acid batteries were the original solution for night-time load in the private New York City area direct current (dc) systems. The batteries were used to supply electricity to the load during high demand periods and to absorb excess electricity from generators during low demand periods for sale later. The first U.S. large-scale electricity storage system was 31 megawatts (MW) of pumped storage in 1929 at the Connecticut Light & Power Rocky River Plant. As of 2011, 2.2%[2] of electricity was stored world-wide, mostly in pumped storage.

In this Handbook, a complete electricity storage system (that can connect to the electric grid or operate in a stand-alone mode) comprises two major subcomponents: storage and the power conversion electronics. These subsystems are supplemented by other balance-of-plant components that include monitoring and control systems that are essential to maintain the health and safety of the entire system. These balance-of-plant components include the building or other physical enclosure, miscellaneous switchgear, and hardware to connect to the grid or the customer load. A schematic representation of a complete energy storage system is shown in Figure 1 with a generic storage device representing a dc storage source, such as a battery or flywheel.

In battery and flywheel storage systems, the power conversion system is a bidirectional device that allows the dc to flow to the load after it is converted to alternating current (ac) and allows ac to flow in the reverse direction after conversion to dc to charge the battery or flywheel. The monitoring and control subcomponents may not be a discrete box, as shown in Figure 1, but could be integrated within the power conversion system (PCS) itself.

[2] Source: *Annual Electric Generator Report,* 2011 EIA - Total Capacity 2009; U.S. Energy Information Administration, Form EIA-860, 2011.

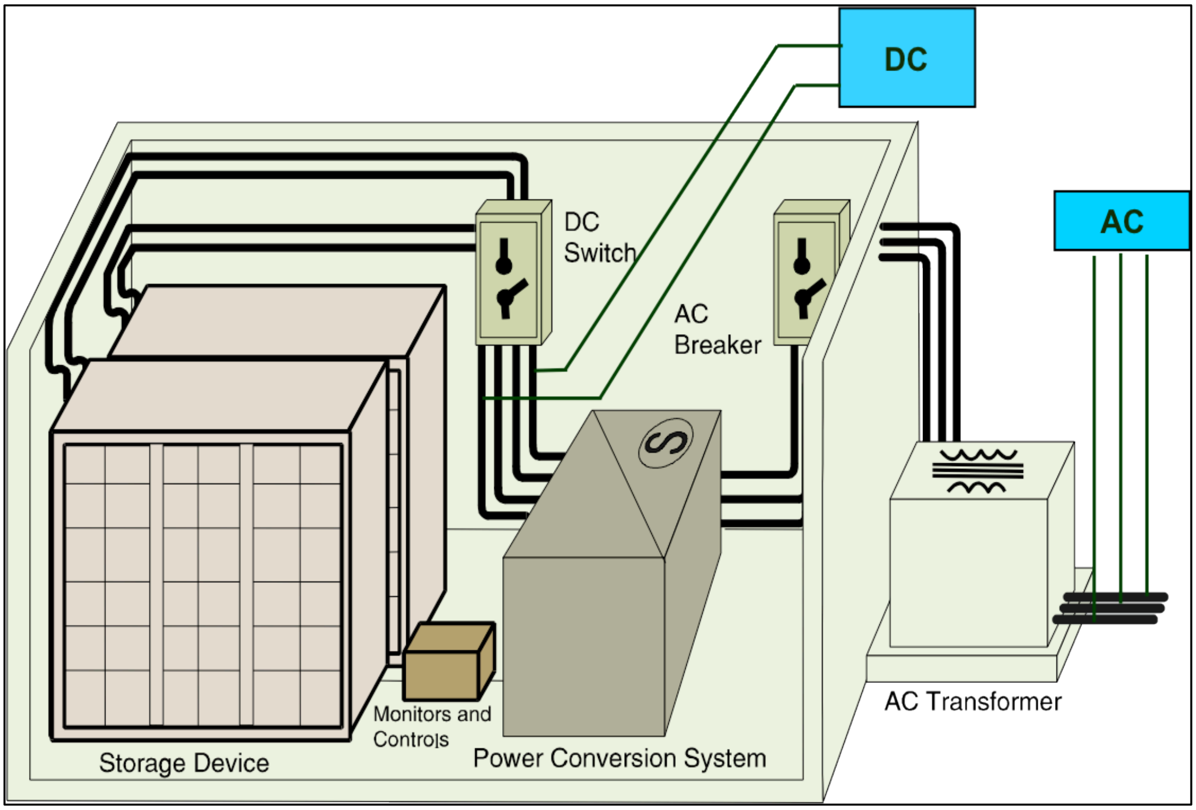

Figure 1. Schematic of a Battery Energy Storage System
(Source: Sandia National Laboratories)

CAES involves high-pressure air stored in underground caverns or above-ground storage vessels (e.g., high-pressure pipes or tanks). In pumped hydroelectric energy storage (PHES), energy is stored by pumping water to an upper reservoir at a higher elevation than the system's lower reservoir.

CHAPTER 1. ELECTRICITY STORAGE SERVICES AND BENEFITS

Operational changes to the grid, caused by restructuring of the electric utility industry and electricity storage technology advancements, have created an opportunity for storage systems to provide unique services to the evolving grid. Regulatory changes in T&D grid operations, for instance, impact the implementation of electricity storage into the grid as well as other services that storage provides. Although electricity storage systems provide services similar to those of other generation devices, their benefits vary and are thoroughly discussed in this chapter.

Until the mid-1980s, energy storage was used only to time-shift from coal off-peak to replace natural gas on-peak so that the coal units remained at their optimal output as system load varied. These large energy storage facilities stored excess electricity production during periods of low energy demand and price and discharged it during peak load times to reduce the cycling or curtailment of the coal load units. This practice not only allowed the time-shifting of energy but also reduced the need for peaking capacity that would otherwise be provided by combustion turbines. The operational and monetary benefits of this strategy justified the construction of many pumped hydro storage facilities. From the 1920s to the mid-1980s, more than 22 gigawatts (GW) of pumped hydro plants were built in the United States. After this period, the growth in pumped hydro capacity stalled due to environmental opposition[3] and the changing operational needs of the electric grid, triggered by the deregulation and restructuring of the electric utility industry.

By the mid-1980s, the push was stronger to develop battery and other storage technologies to provide services to the electric grid. However, these technologies could not match the ability of pumped hydro to provide large storage capacities. In the late 1980s, researchers at DOE/SNL and at EPRI were identifying other operational needs of the electric grid that could be met in shorter storage durations of 1 to 6 hours rather than the 8 to 10+ hours that pumped hydro provided.

Two SNL reports[4,5] in the early 1990s identified and described 13 services that these emerging storage technologies could provide. A more recent report, Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide[6] expanded the range of the grid services and provided significantly more detail on 17 services as well as guidance on estimating the benefits accrued by these services.[7] Other works have also documented use cases and services

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[3] From the 2003 Handbook: ‘‘The addition of pumped hydro facilities is very limited, due to the scarcity of further cost-effective and environmentally acceptable sites in the U.S.’’ *EPRI-DOE Handbook of Energy Storage for Transmission and Distribution Applications*, L. D. Mears, H. L. Gotschall - Technology Insights; T. Key, H. Kamath - EPRI PEAC Corporation; EPRI ID 1001834, EPRI, Palo Alto, CA, and the U.S. Department of Energy, Washington, DC, 2003.

[4] *Battery Energy Storage: A Preliminary Assessment of National Benefits (The Gateway Benefits Study)*, Abbas Ali Akhil; Hank W Zaininger; Jonathan Hurwitch; Joseph Badin, SAND93- 3900, Albuquerque, NM, December 1993.

[5] *Battery Energy Storage for Utility Applications: Phase I Opportunities Analysis*, Butler, Paul Charles, SAND94-2605, Albuquerque, NM, October 1994.

[6] *Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide*, Eyer, James M. – distributed Utility Associates, Inc., Garth Corey – Ktech Corporation, SAND2010-0815, Albuquerque, NM and Livermore, CA, February 2010.

[7] An application, or grid service, is a use whereas a benefit connotes a value. A benefit is generally quantified in terms of the monetary or financial value.

that storage provides to the grid. Most notably, EPRI's Smart Grid Resource Center Use Case Repository contains over 130 documents that discuss various aspects of storage.[8] Similarly, California Independent System Operator (CAISO) also describes eight scenarios supplemented by activity diagrams to demonstrate the use of storage for grid operations and control.[9]

This Handbook combines that knowledge base and includes the description and service-specific technical detail of 18 services and applications in five umbrella groups, as listed in Table 1.

Table 1. Electric Grid Energy Storage Services Presented in This Handbook

Bulk Energy Services	
	Electric Energy Time-Shift (Arbitrage)
	Electric Supply Capacity
Ancillary Services	
	Regulation
	Spinning, Non-Spinning and Supplemental Reserves
	Voltage Support
	Black Start
	Other Related Uses
Transmission Infrastructure Services	
	Transmission Upgrade Deferral
	Transmission Congestion Relief
Distribution Infrastructure Services	
	Distribution Upgrade Deferral
	Voltage Support
Customer Energy Management Services	
	Power Quality
	Power Reliability
	Retail Electric Energy Time-Shift
	Demand Charge Management

1.1 Bulk Energy Services

1.1.1 Electric Energy Time-shift (Arbitrage)

Electric energy time-shift involves purchasing inexpensive electric energy, available during periods when prices or system marginal costs are low, to charge the storage system so that the stored energy can be used or sold at a later time when the price or costs are high. Alternatively, storage can provide similar time-shift duty by storing excess energy production, which would otherwise be curtailed, from renewable sources such as wind or photovoltaic (PV). The functional operation of the storage system is similar in both cases, and they are treated interchangeably in this discussion.

[8] EPRI Smartgrid Resource Center: Use Case Repository, http://smartgrid.epri.com/Repository/Search.aspx?search=storage, last accessed May 9, 2013.

[9] "*IS-1 ISO Uses Energy Storage for Grid Operations and Control*," Ver 2.1, California ISO, Folsom, CA, November 2010, http://www.caiso.com/285f/285fb7964ea00.pdf, last accessed May 9, 2013.

Technical Considerations

Storage System Size Range: 1 – 500 MW
Target Discharge Duration Range: <1 hour
Minimum Cycles/Year: 250 +

Storage used for time-shifting energy from PV or smaller wind farms would be in the lower end of the system storage size and duration ranges shown above, whereas storage for arbitrage in large utility applications or in conjunction with larger wind farms or groups of wind and/or PV plants would fall in the upper end of these ranges.

Both storage variable operating cost (non-energy-related) and storage efficiency are especially important for this service. Electric energy time-shift involves many possible transactions with economic merit based on the difference between the cost to purchase, store, and discharge energy (discharge cost) and the benefit derived when the energy is discharged.

Any increase in variable operating cost or reduction of efficiency reduces the number of transactions for which the benefit exceeds the cost. That number of transactions is quite sensitive to the discharge cost, so a modest increase may reduce the number of viable transactions considerably. Two performance characteristics that have a significant impact on storage variable operating cost are round-trip efficiency of the storage system and the rate at which storage performance declines as it is used.

In addition, seasonal and diurnal electricity storage can be considered as a bulk service. It can be very useful for wind or PV if there are significant seasonal and diurnal differences.

1.1.2 Electric Supply Capacity

Depending on the circumstances in a given electric supply system, energy storage could be used to defer and/or to reduce the need to buy new central station generation capacity and/or purchasing capacity in the wholesale electricity marketplace.

The marketplace for electric supply capacity is evolving. In some cases, generation capacity cost is included in wholesale energy prices (as an allocated cost per unit of energy). In other cases, market mechanisms may allow for capacity-related payments.

Technical Considerations

Storage System Size Range: 1 – 500 MW
Target Discharge Duration Range: 2 – 6 hours
Minimum Cycles/Year: 5 – 100

The operating profile for storage used as supply capacity (characterized by annual hours of operation, frequency of operation, and duration of operation for each use) is location-specific. Consequently, it is challenging to make generalizations about storage discharge duration for this service. Another key criterion affecting discharge duration for this service is the way that generation capacity is priced. For example, if capacity is priced per hour, then storage plant duration is flexible. If prices require that the capacity resource be available for a specified duration for each occurrence (e.g., five hours), or require operation during an entire time period (e.g., 12:00 p.m. to 5:00 p.m.), then the storage plant discharge duration must accommodate those requirements.

The two plots in Figure 2 illustrate the capacity constraint and how storage acts to compensate the deficit. The upper plot shows the three weekdays when there is need for peaking capacity. The lower plot shows storage discharge to meet load during those three periods and also shows that the storage is charged starting just before midnight and ending late at night during the times when system load is lower.

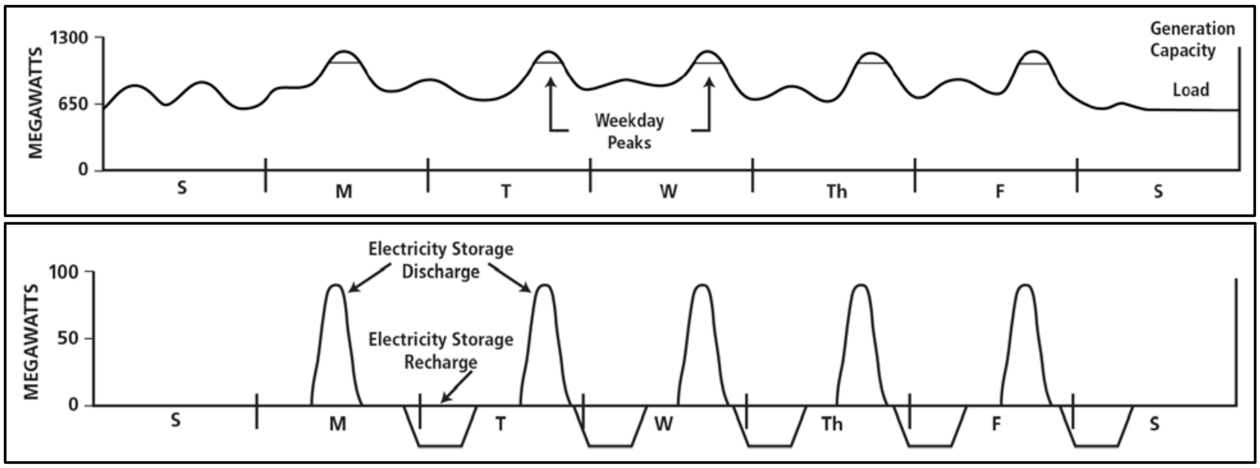

Figure 2. Storage for Electric Supply Capacity

1.2 Ancillary Services

1.2.1 Regulation

Regulation is one of the ancillary services for which storage is especially well-suited. Regulation involves managing interchange flows with other control areas to match closely the scheduled interchange flows and momentary variations in demand within the control area. The primary reasons for including regulation in the power system are to maintain the grid frequency and to comply with the North American Electric Reliability Council's (NERC's) Real Power Balancing Control Performance (BAL001) and Disturbance Control Performance (BAL002) Standards.

Regulation is used to reconcile momentary differences caused by fluctuations in generation and loads. Regulation is used for damping of that difference. Consider the example shown in Figure 3. The load demand line in Figure 3 shows numerous fluctuations depicting the imbalance between generation and load without regulation. The thicker line in the plot shows a smoother system response after damping of those fluctuations with regulation.

Generating units that are online and ready to increase or decrease power as needed are used for regulation and their output is increased when there is a momentary shortfall of generation to provide up regulation. Conversely, regulation resources' output is reduced to provide down regulation when there is a momentary excess of generation.

An important consideration in this case is that large thermal base-load generation units in regulation incur significant wear and tear when they provide variable power needed for regulation duty.

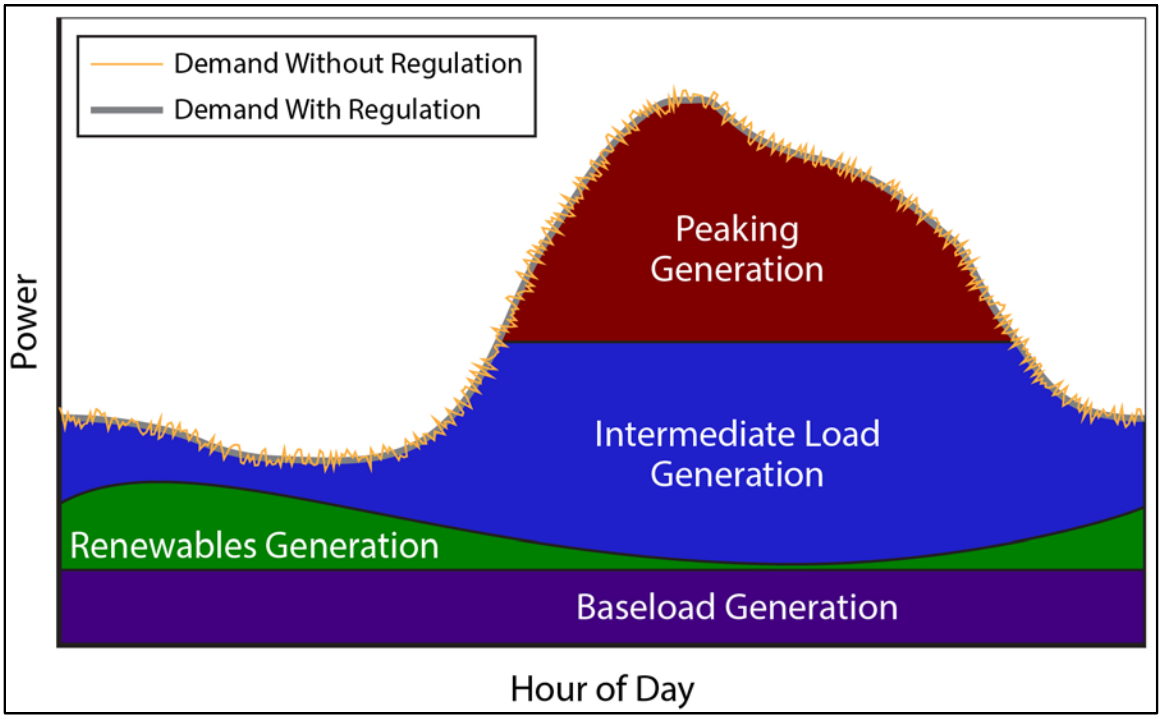

Figure 3. System Load Without and With Regulation
(Source: Sandia National Laboratories)

Two possible operational modes for 1 MW of storage used for regulation and three possible operational modes for generation used for regulation are shown in Figure 4. The leftmost plot shows how less-efficient storage could be used for regulation. In that case, increased storage discharge is used to provide up regulation and reduced discharge is used to provide down regulation. In essence, one-half of the storage's capacity is used for up regulation and the other half of the storage capacity is used for down regulation (similar to the rightmost plot, which shows how 1 MW of generation is often used for regulation service). Next, consider the second plot, which shows how 1 MW of efficient storage can be used to provide 2 MW of regulation – 1 MW up and 1 MW down – using discharging and charging, respectively.

When storage provides down regulation by charging, it absorbs energy from the grid; the storage operator must pay for that energy. That is notable – especially for storage with lower efficiency – because the cost for that energy may exceed the value of the regulation service.

Technical Considerations

Storage System Size Range: 10 – 40 MW
Target Discharge Duration Range: 15 minutes to 60 minutes
Minimum Cycles/Year: 250 – 10,000

The rapid-response characteristic (i.e., fast ramp rate) of most storage systems makes it valuable as a regulation resource. Storage used for regulation should have access to and be able to respond to the area control error (ACE) signal or an automatic generation control (AGC) signal if one is available from the Balancing Authority in which the storage system is located, as opposed to conventional plants, which generally follow an AGC signal. The equivalent benefit of regulation from storage with a fast ramp rate (e.g., flywheels, capacitors, and some battery types) is on the order of two times that of regulation provided by conventional generation,[10] due to the fact that it can follow the signal more accurately and thus reduce the total wear and tear on other generation.

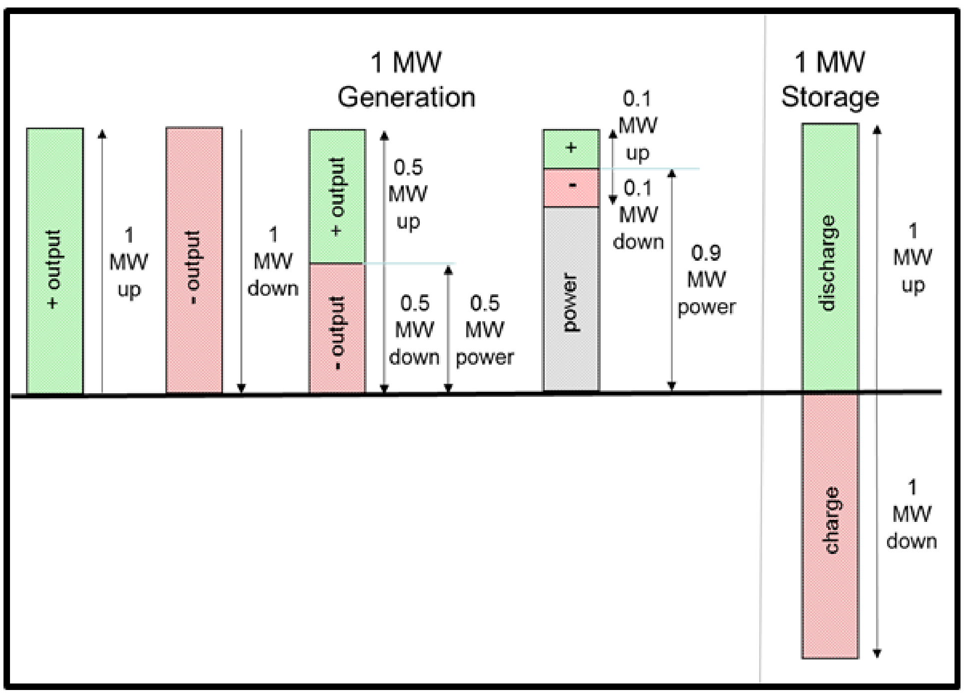

Figure 4. Storage and Generation Operation for Regulation
(Source: E&I Consulting)

Figure 5 shows two plots to illustrate the storage response for a regulation requirement. The upper plot is an exaggerated illustration of the generation variance in response to fluctuating loads. The lower plot shows storage either discharging or charging to inject or absorb the generation as needed to eliminate the need for cycling of the generation units.

[10] "*Assessing the Value of Regulation Resources Based on Their Time Response Characteristics*," Y.V. Makarov, S. Lu, J. Ma, T.B. Nguyen, PNNL-17632, Pacific Northwest National Laboratory, Richland, WA, June 2008.

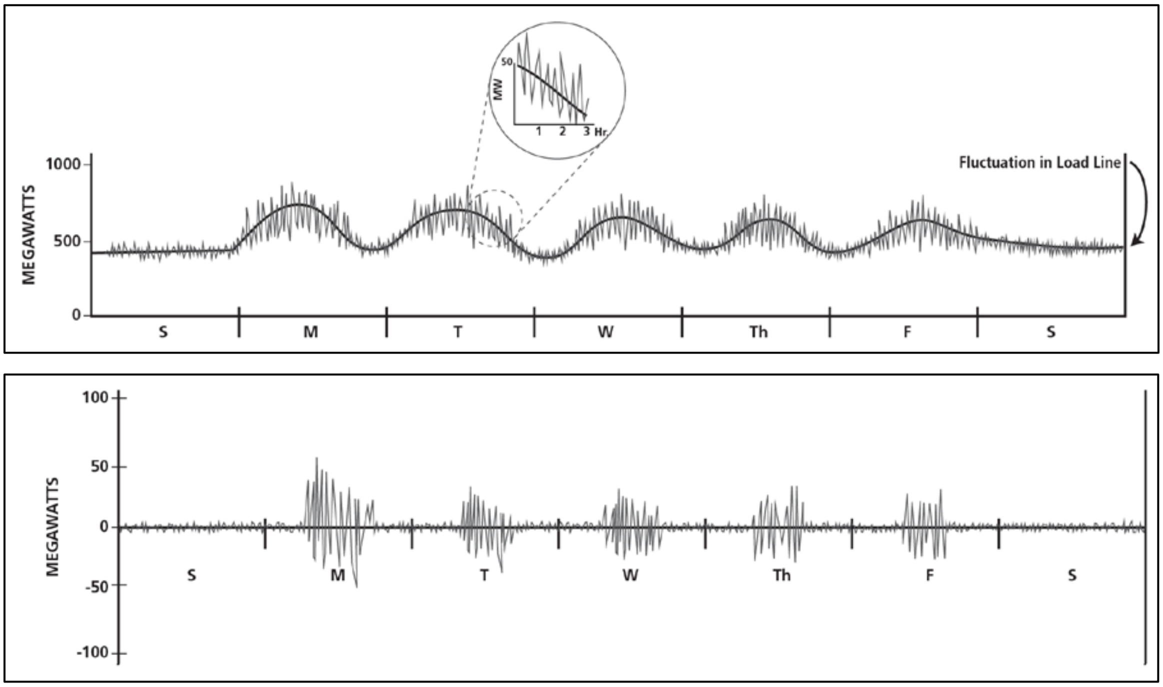

Figure 5. Storage for Regulation

1.2.2 Spinning, Non-Spinning, and Supplemental Reserves

Operation of an electric grid requires reserve capacity that can be called upon when some portion of the normal electric supply resources become unavailable unexpectedly.

Generally, reserves are at least as large as the single largest resource (e.g., the single largest generation unit) serving the system and reserve capacity is equivalent to 15% to 20% of the normal electric supply capacity. NERC and FERC define reserves differently based on different operating conditions. For simplicity, this Handbook discusses three generic types of reserve to illustrate the role of storage in this service:

Spinning Reserve[11] **(Synchronized) –** Generation capacity that is online but unloaded and that can respond within 10 minutes to compensate for generation or transmission outages. ‘Frequency- responsive’ spinning reserve responds within 10 seconds to maintain system frequency. Spinning reserves are the first type used when a shortfall occurs.

[11] Spinning reserve is defined in the NERC Glossary as “Unloaded generation that is synchronized and ready to serve additional demand.”

Non-Spinning Reserve[12] **(Non-synchronized) –** Generation capacity that may be offline or that comprises a block of curtailable and/or interruptible loads and that can be available within 10 minutes.

Supplemental Reserve – Generation that can pick up load within one hour. Its role is, essentially, a backup for spinning and non-spinning reserves. Backup supply may also be used as backup for commercial energy sales. Unlike spinning reserve capacity, supplemental reserve capacity is not synchronized with grid frequency. Supplemental reserves are used after all spinning reserves are online.

Importantly for storage, generation resources used as reserve capacity must be online and operational (i.e., at part load). Unlike generation, in almost all circumstances, storage used for reserve capacity does not discharge at all; it just has to be ready and available to discharge when needed.

Technical Considerations

Storage System Size Range: 10 – 100 MW
Target Discharge Duration Range: 15 minutes – 1 hour
Minimum Cycles/Year: 20 – 50

Reserve capacity resources must receive and respond to appropriate control signals. Figure 6 shows how storage responds to spinning reserve requirements. The upper plot shows a loss of generation and the lower plot shows the immediate response with a 30-minute discharge to provide the reserve capacity until other generation is brought online.

[12] Non-spinning reserve is not uniformly the same in different reliabiity regions. It generally consists of generation resources that are offline, but could be brought online within 10 to 30 minutes and could also include loads that can be interrupted in that time window.

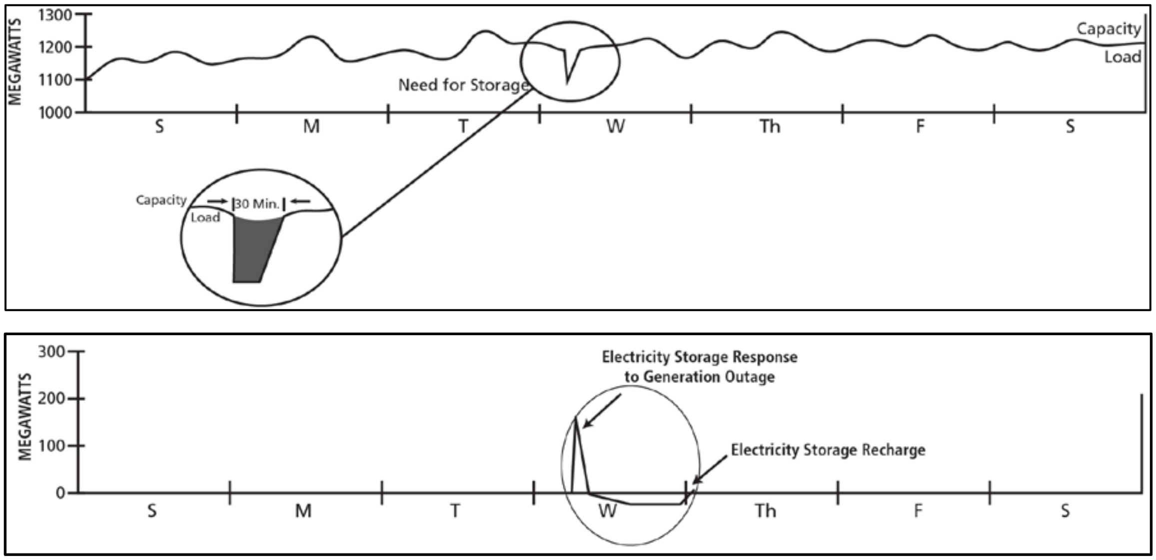

Figure 6. Storage for Reserve Capacity

1.2.3 Voltage Support

A requirement for electric grid operators is to maintain voltage within specified limits. In most cases, this requires management of reactance, which is caused by grid-connected equipment that generates, transmits, or uses electricity and often has or exhibits characteristics like those of inductors and capacitors in an electric circuit. To manage reactance at the grid level, system operators need voltage support resources to offset reactive effects so that the transmission system can be operated in a stable manner.

Normally, designated power plants are used to generate reactive power (VAR) to offset reactance in the grid. These power plants could be displaced by strategically placed energy storage within the grid at central locations or taking the distributed approach and placing multiple VAR-support storage systems near large loads.

Technical Considerations

Storage System Size Range: 1 – 10 mega volt-ampere reactive (MVAR)
Target Discharge Duration Range: Not Applicable
Minimum Cycles/Year: Not Applicable

The PCS of the storage systems used for voltage support must be capable of operating at a non-unity power factor, to source and sink reactive power or volt-ampere reactive (VARs). This capability is available in all PCSs used in today's storage systems. Real power is not needed from the battery in this mode of operation and thus discharge duration and minimum cycles per year are not relevant in this case.

The nominal time needed for voltage support is assumed to be 30 minutes — time for the grid system to stabilize and, if necessary, to begin orderly load shedding to match available generation. Figure 7 shows three discharges of storage: with active injection of real power and VARs, with absorbing power to balance voltage while providing VARs, and providing VARs only without real power injection or absorption as needed by the grid.

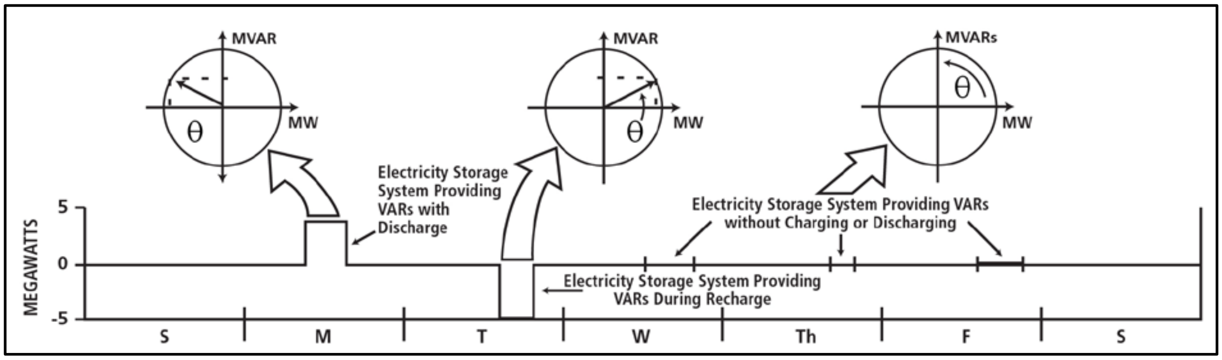

Figure 7. Storage for Voltage Support Service

1.2.4 Black Start

Storage systems provide an active reserve of power and energy within the grid and can be used to energize transmission and distribution lines and provide station power to bring power plants on line after a catastrophic failure of the grid. Golden Valley Electric Association uses the battery system in Fairbanks for this service when there is an outage of the transmission intertie with Anchorage. The operation of the battery is illustrated in Figure 8, which shows its discharge to provide charging current to two transmission paths as needed, as well as start-up power to two diesel power plants that serve Fairbanks until the intertie is restored.

Storage can provide similar startup power to larger power plants, if the storage system is suitably sited and there is a clear transmission path to the power plant from the storage system's location.

Technical Considerations

Storage System Size Range: 5 – 50 MW
Target Discharge Duration Range: 15 minutes – 1 hour
Minimum Cycles/Year: 10 – 20

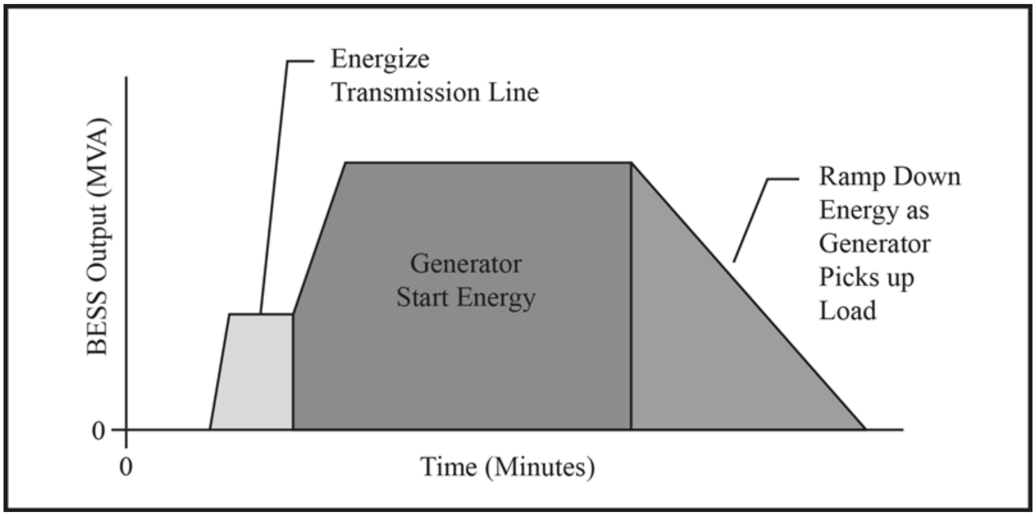

Figure 8. Black Start Service by Storage
(Courtesy: Golden Valley Electric Association)

1.2.5 Other Related Uses

1.2.5.1 Load Following/Ramping Support for Renewables

Electricity storage is eminently suitable for damping the variability of wind and PV systems and is being widely used in this application. Technically, the operating requirements for a storage system in this application are the same as those needed for a storage system to respond to a rapidly or randomly fluctuating load profile. Most renewable applications with a need for storage will specify a maximum expected up- and down-ramp rate in MW/minute and the time duration of the ramp. This design guidance for the storage system is applicable for load following and renewable ramp support; this Handbook therefore treats them as the same application.

Load following is characterized by power output that generally changes as frequently as every several minutes. The output changes in response to the changing balance between electric supply and load within a specific region or area. Output variation is a response to changes in system frequency, timeline loading, or the relation of these to each other that occurs as needed to maintain the scheduled system frequency and/or established interchange with other areas within predetermined limits.

Conventional generation-based load following resources' output *increases* to follow demand up as system load increases. Conversely, load following resources' output *decreases* to follow demand down as system load decreases. Typically, the amount of load following needed in the up direction (load following up) increases each day as load increases during the morning. In the evening, the amount of load following needed in the down direction (load following down) increases as aggregate load on the grid drops. A simple depiction of load following is shown in Figure 9.

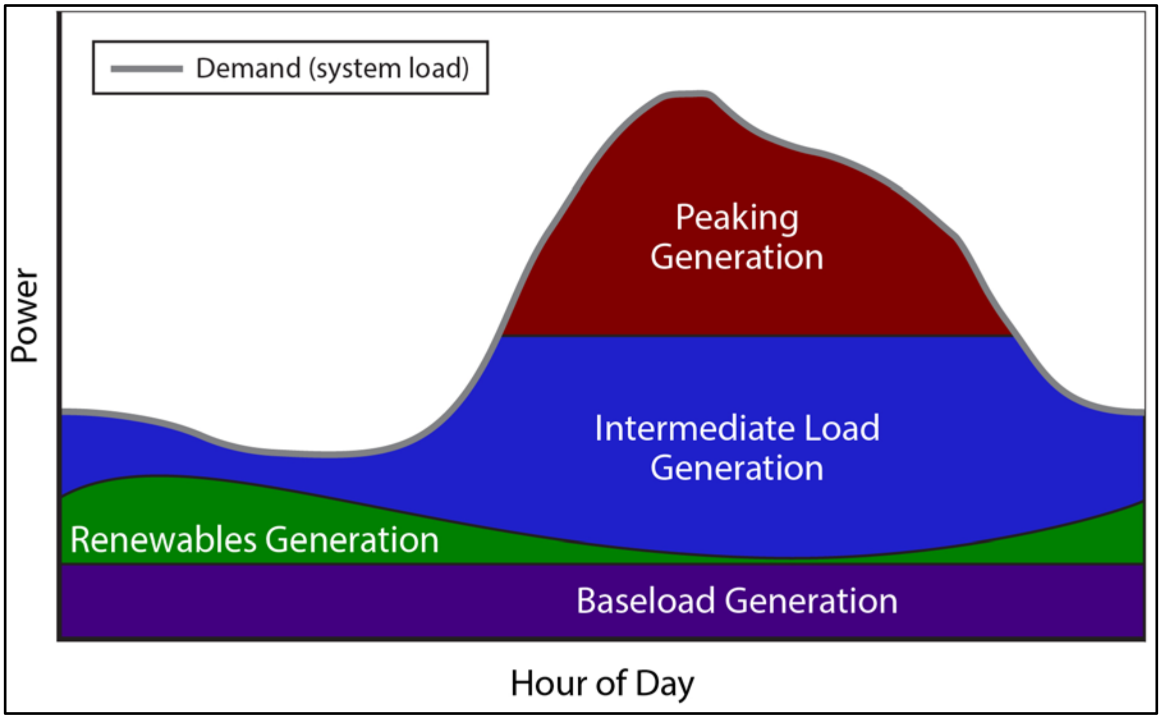

Figure 9. Electric Supply Resource Stack

Normally, generation is used for load following. For load following up, generation is operated such that its output is less than its design or rated output (also referred to as 'part load operation'). Consequently, the plant heat rates, fuel cost, and emission are increased. This allows operators to increase the generator's output, as needed, to provide load following up to accommodate increasing load. For load following down, generation starts at a high output level, perhaps even at design output, and the output is decreased as load decreases.

These operating scenarios are notable because operating generation at part load requires more fuel per megawatt hour (MWh) and results in increased air emissions per MWh relative to generation operated at its design output level. Varying the output of generators (rather than operating at constant output) will also increase fuel use and air emissions, as well as the need for generator maintenance and thus variable operations and maintenance (O&M) costs. In addition, if a fossil plant has to shut down during off-peak periods, there will be a significant increase in fuel use, O&M, and emissions. Plant reliability will also deteriorate, resulting in the need for significant purchases of replacement energy.

Storage is well-suited to load following for several reasons. First, most types of storage can operate at partial output levels with relatively modest performance penalties. Second, most types of storage can respond very quickly (compared to most types of generation) when more or less output is needed for load following. Consider also that storage can be used effectively for both load following up (as load increases) and for load following down (as load decreases), either by discharging or by charging.

In market areas, when charging storage for load following, the energy stored must be purchased at the prevailing wholesale price. This is an important consideration, especially for storage with lower efficiency and/or if the energy used for charging is relatively expensive, because the cost of energy used to charge storage (to provide load following) may exceed the value of the load following service.

Conversely, the value of energy discharged from storage to provide load following is determined by the prevailing price for wholesale energy. Depending on circumstances (i.e., if the price for the load following service does not include the value of the wholesale energy involved), when discharging for load following, two benefits accrue – one for the load following service and another for the energy.

Note that in this case, storage competes with central and aggregated distributed generation and with aggregated demand response/load management resources including interruptible loads and direct load control.

Technical Considerations

Storage System Size Range: 1 – 100 MW
Target Discharge Duration Range: 15minutes – 1 hour
Minimum Cycles/Year: Not Applicable

Storage used for load following should be reliable or it cannot be used to meet contractual obligations associated with bidding in the load following market. Storage used for load following will probably need access to AGC from the respective independent system operator (ISO). Typically, an ISO requires output from an AGC resource to change every minute.

Other considerations include synergies with other services. Large/central storage used for load following may be especially complementary to other services if the charging and discharging for the other services can be coordinated. For example, storage used to provide generation capacity mid-day could be charged in the evening, thus following diminished system demand down during evening hours.

Load following could have good synergies with renewables capacity firming, electric energy time-shift, and possibly electric supply reserve capacity applications. If storage is distributed, then that same storage could also be used for most of the distributed applications and for voltage support.

1.2.5.2 Frequency Response

Frequency response is very similar to regulation, described above, except it reacts to system needs in even shorter time periods of seconds to less than a minute when there is a sudden loss of a generation unit or a transmission line. As shown in Figure 10[13], various generator response actions are needed to counteract this sudden imbalance between load and generation to maintain the system frequency and stability of the grid. The first response within the initial seconds is the primary frequency control response of the governor action on the generation units to increase their power output as shown in the lower portion of the figure. This is followed by the longer duration secondary frequency control response by the AGC that spans the half a minute to several minutes shown by the dotted line in the lower portion of Figure 10. It is important to note that the rate at which the frequency decays after the triggering event – loss of generator or transmission – is directly proportional to the aggregate inertia within the grid at that instant. The rotating mass of large generators and/or the aggregate mass of many smaller generators collectively determines this inertia.

The combined effect of inertia and the governor actions determines the rate of frequency decay and recovery shown in the arresting and rebound periods in the upper portion of Figure 10. This is also the window of time in which the fast-acting response of flywheel and battery storage systems excels in stabilizing the frequency. The presence of fast-acting storage assures a smoother transition from the upset period to normal operation if the grid frequency is within its normal range. The effectiveness of fast-acting storage in this application has been successfully utilized by utilities[14] and also described in other reports and papers[15].

[13] *Use of Frequency Response Metrics to Assess the Planning and Operating Requirements for Reliable Integration of Variable Renewable Generation*, Joseph H. Eto (Principal Investigator) et al., LBNL-4142E, Lawrence Berkeley National Laboratory, Berkeley, CA, December 2010, http://www.ferc.gov/industries/electric/indus-act/reliability/frequencyresponsemetrics-report.pdf), last accessed on March 25, 2013.
[14] See BEWAG and PREPA projects in Appendix G: Noteworthy Projects.
[15] *Energy Storage – a Cheaper, Faster and Cleaner Alternative to Conventional Frequency Regulation*, a white paper by the California Energy Storage Alliance (CESA), Berkeley, CA, (http://www.ice-energy.com/stuff/contentmgr/files/1/76d44bfc1077e7fad6425102e55c0491/download/cesa_energy_storage_for_frequency_regulation.pdf), last accessed March 25, 2013.

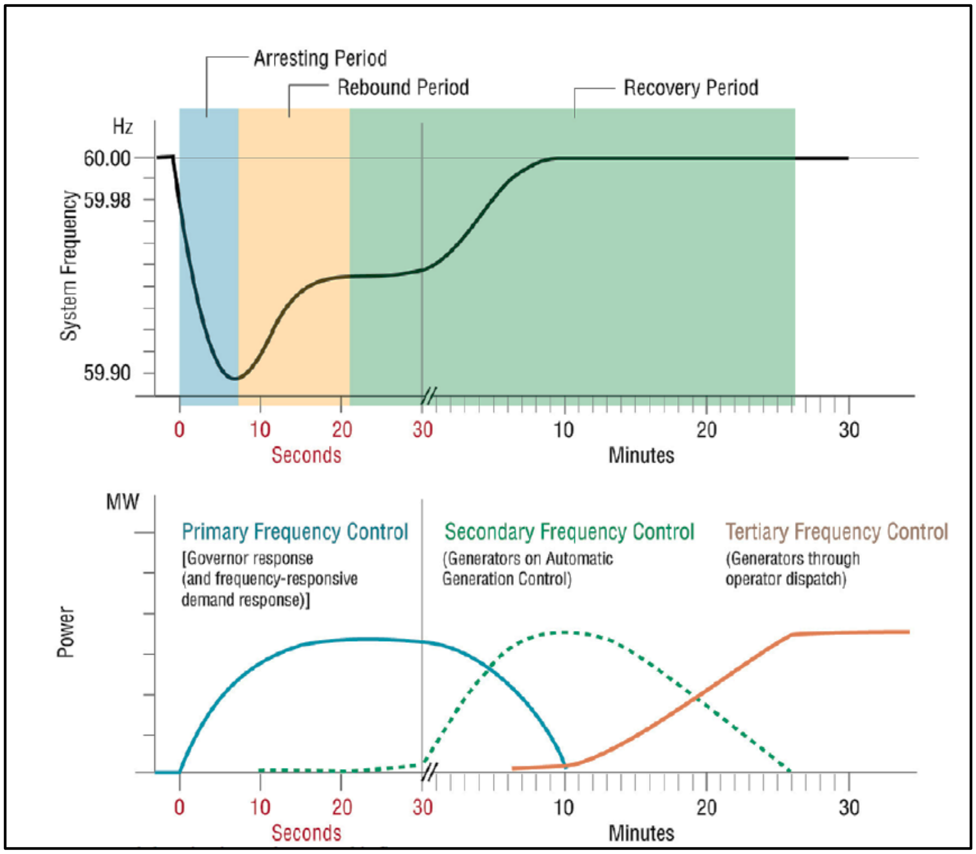

Figure 10. The Sequential Actions of Primary, Secondary, and Tertiary Frequency Controls Following the Sudden Loss of Generation and Their Impacts on System Frequency

The size of storage systems to be used in frequency response mode is proportional to the grid or balancing area in which they are needed. Generally, storage systems in the 20 MW and greater size can provide effective frequency response due to their fast action; some studies[16] have shown that the response is twice as effective as a conventional fossil-fueled generator, including combustion turbines (CTs) and coal units. However, location of the storage system within the grid with respect to other generation, transmission corridors, and loads plays a crucial role in the effectiveness as a frequency response resource.

[16] Ibid.

1.3 Transmission Infrastructure Services

1.3.1 Transmission Upgrade Deferral

Transmission upgrade deferral involves delaying – and in some cases avoiding entirely – utility investments in transmission system upgrades, by using relatively small amounts of storage. Consider a transmission system with peak electric loading that is approaching the system's load-carrying capacity (design rating). In some cases, installing a small amount of energy storage downstream from the nearly overloaded transmission node could defer the need for the upgrade for a few years.

The key consideration is that a small amount of storage can be used to provide enough incremental capacity to defer the need for a large lump investment in transmission equipment. Doing so reduces overall cost to ratepayers, improves utility asset utilization, allows use of the capital for other projects, and reduces the financial risk associated with lump investments.

Notably, for most nodes within a transmission system, the highest loads occur on just a few days per year, for just a few hours per year. Often, the highest annual load occurs on one specific day with a peak somewhat higher than any other day. One important implication is that storage used for this application can provide significant benefits with limited or no need to discharge. Given that most modular storage has a high variable operating cost, this may be especially attractive in such instances.

Although the emphasis for this application is on transmission upgrade deferral, a similar rationale applies to transmission equipment life extension. That is, if storage use reduces loading on existing equipment that is nearing its expected life, the result could be to extend the life of the existing equipment. This may be especially compelling for transmission equipment that includes aging transformers and underground power cables.

Technical Considerations

Storage System Size Range: 10 – 100 MW
Target Discharge Duration Range: 2 – 8 hours
Minimum Cycles/Year: 10 – 50

Energy storage must serve sufficient load, for as long as needed, to keep loading on the transmission equipment below a specified maximum.

Figure 11 illustrates the use of storage for transmission deferral. The lower plot shows storage being discharged on Wednesday afternoon to compensate for the high load on the substation transformer, as shown in the upper plot. The storage is recharged when the feeder load reduces in the late evening. Alternatively, the storage can be recharged during the late night as long as it is available to serve the peak load that the transformer is likely to see the following day(s).

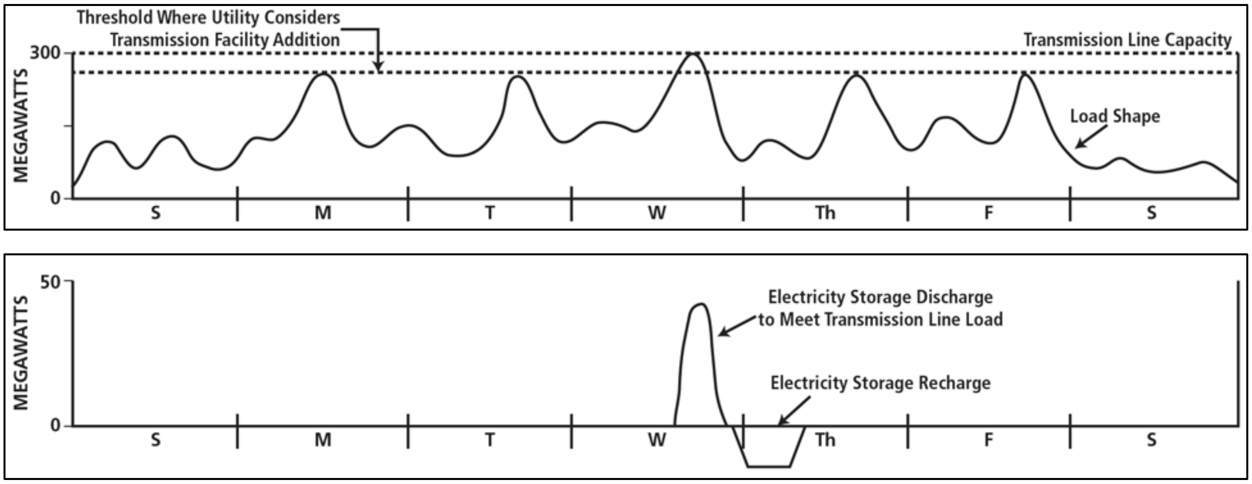

Figure 11. Storage for Transmission and Distribution Deferral

1.3.2 Transmission Congestion Relief

Transmission congestion occurs when available, least-cost energy cannot be delivered to all or some loads because transmission facilities are not adequate to deliver that energy. When transmission capacity additions do not keep pace with the growth in peak electric demand, the transmission systems become congested. Thus during periods of peak demand, the need and cost for more transmission capacity increases along with transmission access charges. Transmission congestion may also lead to increased congestion costs or locational marginal pricing (LMP) for wholesale electricity at certain transmission nodes.

Electricity storage can be used to avoid congestion-related costs and charges, especially if the costs become onerous due to significant transmission system congestion. In this service, storage systems would be installed at locations that are electrically downstream from the congested portion of the transmission system. Energy would be stored when there is no transmission congestion, and it would be discharged (during peak demand periods) to reduce peak transmission capacity requirements.

Technical Considerations

Storage System Size Range: 1 – 100 MW
Target Discharge Duration Range: 1 – 4 hours
Minimum Cycles/Year: 50 – 100

The discharge duration needed for transmission congestion relief cannot be generalized easily, given all the possible options. As with the Transmission upgrade deferral service, it may require only a few hours of support during the year when congestion relief is required. Generally, congestion charges apply for just a few occurrences during a year when there are several consecutive hours of transmission congestion.

Figure 12 illustrates the storage response in transmission congestion relief service. The upper plot shows four instances in which load exceeds the capacity of the transmission line. The lower plot shows storage discharge during those four events and a recharge during the late night when the system load is lower and the transmission line is lightly loaded.

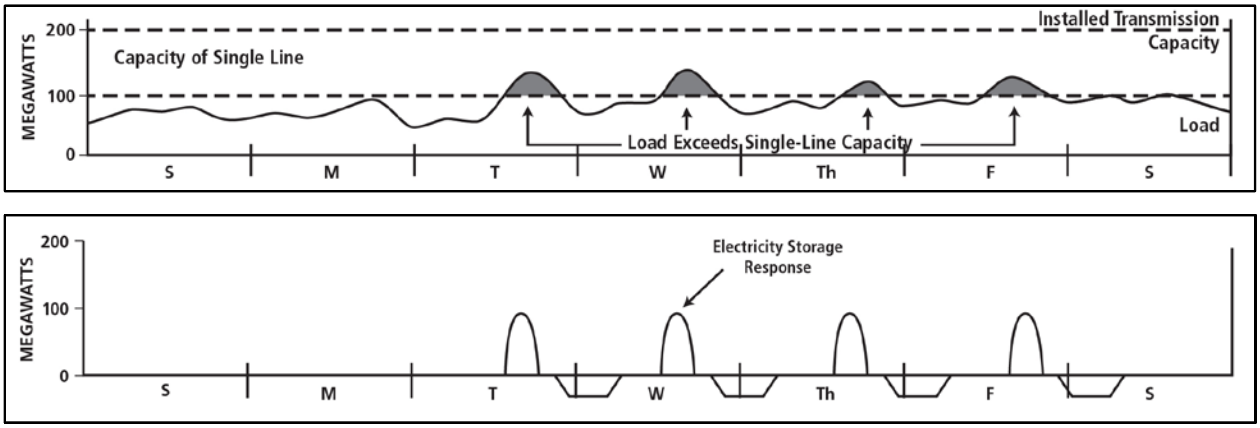

Figure 12. Storage for Transmission Congestion Relief

1.3.3 Other Related Uses

Energy storage used for transmission support improves the transmission system performance by compensating for electrical anomalies and disturbances such as voltage sag, unstable voltage, and sub-synchronous resonance. The result is a more stable system. It is similar to the network stability ancillary service that is not addressed in this Handbook. Benefits from transmission support are highly situation-specific and site-specific. Two cases are briefly described:

Transmission Stability Damping: Increase load-carrying capacity by improving dynamic stability.

Sub-synchronous Resonance Damping: Increase line capacity by allowing higher levels of series compensation by providing active real and/or reactive power modulation at sub-synchronous resonance modal frequencies.

Technical Considerations

Storage System Size Range: 10 – 100 MW
Target Discharge Duration Range: 5 seconds – 2 hours
Minimum Cycles/Year: 20 – 100

Energy storage must be capable of sub-second response, partial state-of-charge operation, and many charge-discharge cycles. For storage to be most beneficial as a transmission support resource, it should provide both real and reactive power. Typical discharge durations for transmission support are between one and 20 seconds.

Figure 13 shows two plots that illustrate the storage response to momentary voltage sag and a deviation in the phase angle that persists for a few seconds, as shown in the upper plot. The storage response is a quick discharge and recharge to damp the oscillation caused by the voltage sag and phase angle deviation. As shown in the lower plot, the storage response needs to be very fast and requires high power but lower energy capacity.

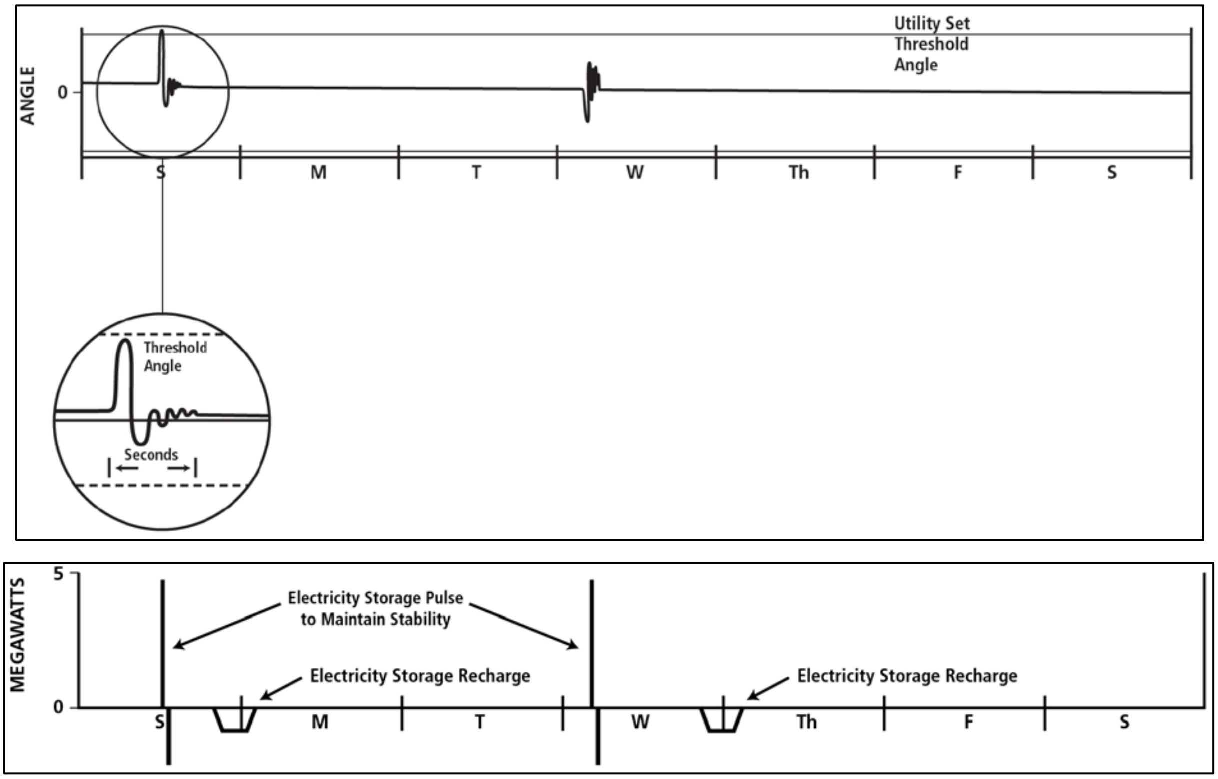

Figure 13. Storage for Customer-side Power Quality

1.4 Distribution Infrastructure Services

1.4.1 Distribution Upgrade Deferral and Voltage Support

Distribution upgrade deferral involves using storage to delay or avoid investments that would otherwise be necessary to maintain adequate distribution capacity to serve all load requirements. The upgrade deferral could be a replacement of an aging or over-stressed existing distribution transformer at a substation or re-conductoring distribution lines with heavier wire.

When a transformer is replaced with a new, larger transformer, its size is selected to accommodate future load growth over the next 15-year to 20-year planning horizon. Thus a large portion of this investment is underutilized for most of the new equipment's life. The upgrade of the transformer can be deferred by using a storage system to offload it during peak periods, thus extending its operational life by several years. If the storage system is containerized, then it can be physically moved to other substations where it can continue to defer similar upgrade decision points and further maximize the return on its investment.

A corollary to this strategy is that it also minimizes the ever-present risk that planned load growth does not occur, which would strand the investment made in upgrading the transformer or re-conductoring the line. This could be the case when a large load, such as a shopping mall or a residential development, did not materialize because the developer delayed or cancelled the project after the utility had performed the upgrade in anticipation of the new load. A storage system allows not only deferring the upgrade decision point, but also allows time to evaluate the certainty that planned load growth will materialize, which could be a two-year to three-year window.

Notably, for most nodes within a distribution system, the highest loads occur on just a few days per year, for just a few hours per year. Often, the highest annual load occurs on one specific day with a peak somewhat higher than any other day. One important implication is that storage used for this application can provide significant benefits with limited or no need to discharge.

A storage system that is used for upgrade deferral could simultaneously provide voltage support on the distribution lines. Utilities regulate voltage within specified limits[17] by tap changing regulators at the distribution substation and by switching capacitors to follow load changes. This is especially important on long, radial lines where a large load such as an arc welder or a residential PV system may be causing unacceptable voltage excursions on neighboring customers. These voltage fluctuations can be effectively damped with minimal draw of real power from the storage system.

Technical Considerations

Storage System Size Range: 500 kilowatts (kW) – 10 MW
Target Discharge Duration Range: 1 – 4 hours
Minimum Cycles/Year: 50 – 100

Figure 14 illustrates the use of storage for T&D deferral. The lower plot shows storage being discharged on Wednesday afternoon to compensate for the high load on the substation transformer, as shown in the upper plot. The storage is recharged when the feeder load reduces in the late evening. Alternatively, the storage can be recharged during the late night, as long as it is available to serve the peak load that the transformer is likely to see the following day(s).

[17] ANSI C84.1 "American National Standard for Electric Power Systems and Equipment – Voltage Ratings (60 Hz)" establishes nominal voltage ratings for utilities to regulate the service delivery and operating tolerances at the point of use.

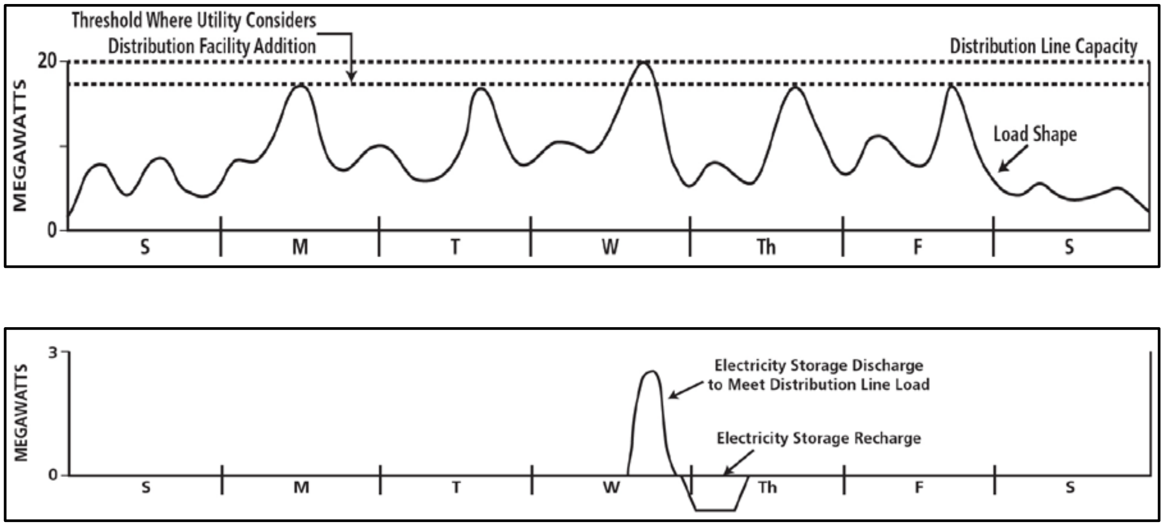

Figure 14. Storage for Distribution Upgrade Deferral

1.5 Customer Energy Management Services

1.5.1 Power Quality

The electric power quality service involves using storage to protect customer on-site loads downstream (from storage) against short-duration events that affect the quality of power delivered to the customer's loads. Some manifestations of poor power quality include the following:

- Variations in voltage magnitude (e.g., short-term spikes or dips, longer term surges, or sags).
- Variations in the primary 60-hertz (Hz) frequency at which power is delivered.
- Low power factor (voltage and current excessively out of phase with each other).
- Harmonics (i.e., the presence of currents or voltages at frequencies other than the primary frequency).
- Interruptions in service, of any duration, ranging from a fraction of a second to several seconds.

Technical Considerations

Storage System Size Range: 100 kW – 10 MW
Target Discharge Duration Range: 10 seconds – 15 minutes
Minimum Cycles/Year: 10 – 200

Typically, the discharge duration required for the power quality use ranges from a few seconds to a few minutes. The on-site storage system monitors the utility power quality and discharges to smooth out the disturbance so that it is transparent to the load.

The upper plot in Figure 15 shows a voltage spike of 50 volts (V) and the lower plot shows storage absorbing the 50V-spike to maintain a constant 480V to the load. These anomalies in the electric supply to the customer, which can occur several times in quick succession due to events in the T&D network that supplies the customer, need to be corrected to protect sensitive processes and loads at the customer site.

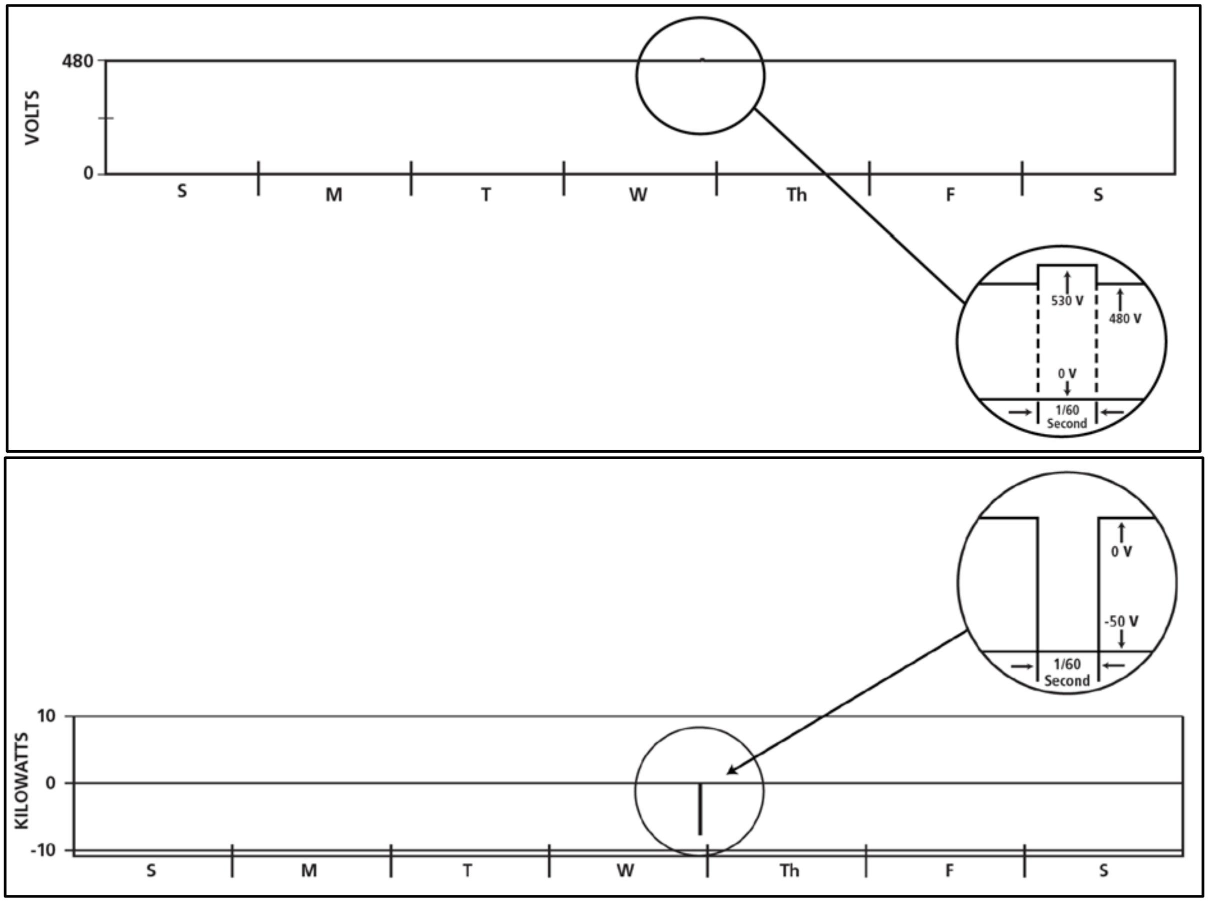

Figure 15. Storage for Customer-side Power Quality

1.5.2 Power Reliability

A storage system can effectively support customer loads when there is a total loss of power from the source utility. This support requires the storage system and customer loads to island during the utility outage and resynchronize with the utility when power is restored. The energy capacity of the storage system relative to the size of the load it is protecting determines the time duration that the storage can serve that load. This time can be extended by supplementing the storage system with on-site diesel gen-sets that can continue supporting the load for long-duration outages that are beyond the capacity of the storage system.

The storage system can be owned by the customer and is under customer control at all times. An alternate ownership scenario could be that the storage system is owned by the utility and is treated as a demand-side, dispatchable resource that serves the customer needs as well as being available to the utility as a demand reduction resource.

1.5.3 Retail Energy Time-Shift

Retail electric energy time-shift involves storage used by energy end users (utility customers) to reduce their overall costs for electricity. Customers charge the storage during off-peak time periods when the retail electric energy price is low, then discharge the energy during times when on-peak time of use (TOU) energy prices apply. This application is similar to electric energy time-shift, although electric energy prices are based on the customer's retail tariff, whereas at any given time the price for electric energy time-shift is the prevailing wholesale price.

For example, a hypothetical TOU tariff is shown in Figure 16. It applies to Commercial and Industrial electricity end users from May to October, Monday through Friday, whose peak power requirements are less than or equal to 500 kW.

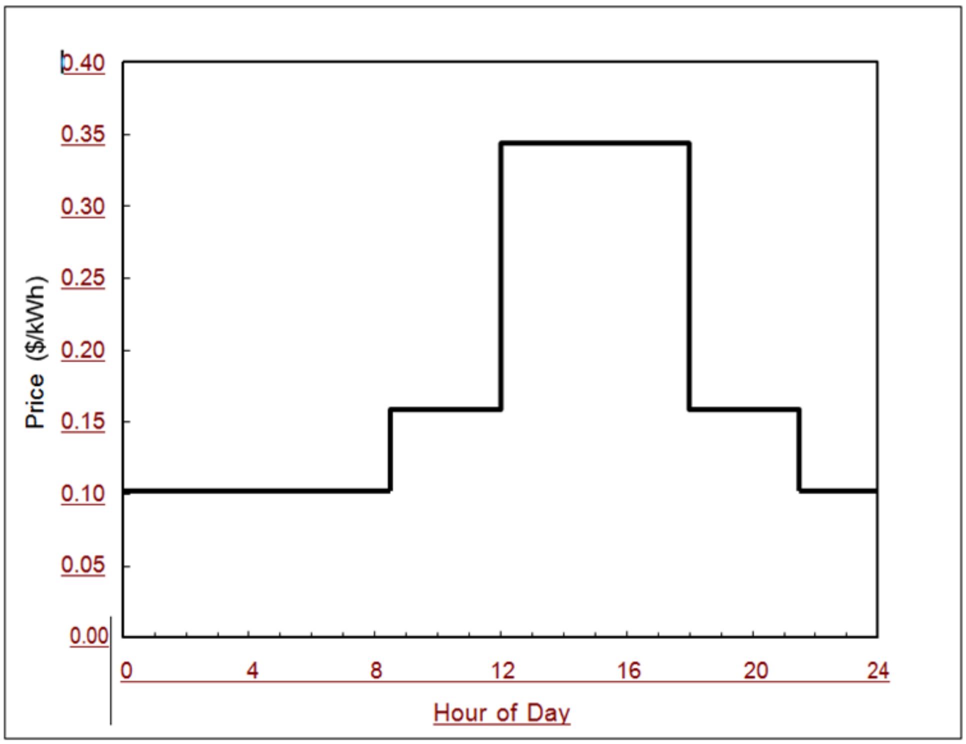

Figure 16. Time of Use Summer Energy Prices for Small Commercial/Industrial Users

As shown in Figure 16, energy prices are about 32¢/kilowatt hour (kWh) on-peak (12:00 p.m. to 6:00 p.m.). Prices during partial-peak (8:30 a.m. to 12:00 p.m. and 6:00 p.m. to 9:30 p.m.) are about 15¢/kWh, and during off-peak (9:30 p.m. to 8:30 a.m.), prices are about 10¢/kWh.

Technical Considerations

Storage System Size Range: 1 kW – 1 MW
Target Discharge Duration Range: 1 – 6 hours
Minimum Cycles/Year: 50 – 250

The maximum discharge duration in this case is determined based on the relevant tariff. For example, for the assumed hypothetical tariff, there are six on-peak hours (12:00 p.m. to 6:00 p.m.). The standard value assumed for this case is five hours of discharge duration.

1.5.4 Demand Charge Management

Electricity storage can be used by end users (i.e., utility customers) to reduce their overall costs for electric service by reducing their demand during peak periods specified by the utility.

To avoid a demand charge, load must be reduced during all hours of the demand charge period, usually a specified period of time (e.g., 11:00 a.m. to 5:00 p.m.) and on specified days (most often weekdays). In many cases, the demand charge is assessed if load is present during just one 15-minute period, during times of the day and during months when demand charges apply.

The most significant demand charges assessed are those based on the maximum load during the peak demand period (e.g., 12:00 p.m. to 5:00 p.m.) in the respective month. Although uncommon, additional demand charges for 1) part peak or (partial peak) demand that occurs during times such as shoulder hours in the mornings and evenings and during winter weekdays and 2) base-load or facility demand charges that are based on the peak demand no matter what time (day and month) it occurs.

Because there is a facility demand charge assessed during charging, the amount paid for facility demand charges offsets some of the benefit for reducing demand during times when the higher peak demand charges apply. Consider a simple example: The peak demand charge (which applies during summer afternoons, from 12:00 p.m. to 5:00 p.m.) is $10/kW-month, and the annual facility demand charge is $2/kW-month. During the night, when charging occurs, the $2/kW facility demand charge is incurred; when storage discharges mid-day (when peak demand charges apply), the $10/kW-month demand charge is avoided. The net demand charge reduction in the example is

$$\$10/\text{kW-month} - \$2/\text{kW-month} = \$8/\text{kW-month}$$

Note that the price for electric energy is expressed in $/kWh used, whereas demand charges are denominated in $/kW of maximum power draw. Tariffs with demand charges have separate prices for energy and for power (demand charges). Furthermore, demand charges are typically assessed for a given month; thus demand charges are often expressed using $/kW per month ($/kW-month).

To reduce load when demand charges are high, storage is charged when there are no or low demand charges. (Presumably, the price for charging energy is also low.) The stored energy is discharged to serve load during times when demand charges apply. Typically, energy storage can discharge for five to six hours, depending on the provisions of the applicable tariff.

Consider the example illustrated in Figure 17. The figure shows a manufacturer's load that is nearly constant at 1 MW for three shifts. During mornings and evenings, the end user's direct load and the facility's net demand are 1 MW. At night, when the price for energy is low, the facility's net demand doubles as low-priced energy is stored at a rate of 1 MW, while the normal load from the end user's operations requires another MW of power. During peak demand times (12:00 p.m. to 5:00 pm in the example), storage discharges (at the rate of 1 MW) to serve the end user's direct load of 1 MW, thus eliminating the real-time demand on the grid.

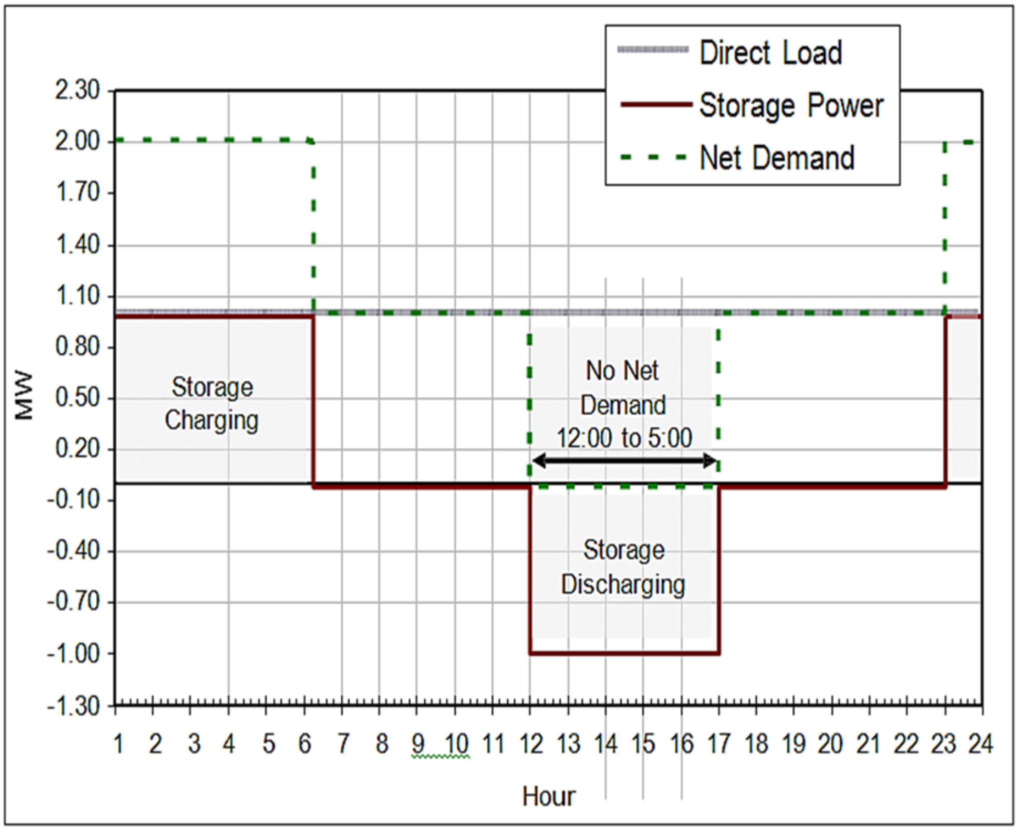

Figure 17. On-peak Demand Reduction Using Energy Storage

In the above example, storage is 80% efficient. To discharge for 5 hours, it must be charged for

$$5 \text{ hours} \div 0.8 = 6.25 \text{ hours.}$$

The additional 1.25 hours of charging is needed to offset energy losses. If a facility demand charge applies, it would be assessed on the entire 2 MW (of net demand) used to serve both load and storage charging.

Although it is the electricity customer who internalizes the benefit, in this scenario, it may be that the design, procurement, transaction cost, etc., could be challenging for many prospective users, especially those with relatively small peak loads.

Technical Considerations

Storage System Size Range: 50 kW – 10 MW
Target Discharge Duration Range: 1 – 4 hours
Minimum Cycles/Year: 50 – 500

In this example, the storage plant discharge duration is based on a hypothetical applicable tariff. For example, a hypothetical Medium General Demand-Metered TOU tariff defines six on-peak hours from 12:00 p.m. to 6:00 p.m. It is assumed that this requires five hours of storage duration.

Figure 18 shows an example where the peak loads exceed the threshold set by the first peak of the month on Monday afternoon. That sets the level for the remaining month; loads must remain below that threshold to avoid demand charge penalties.

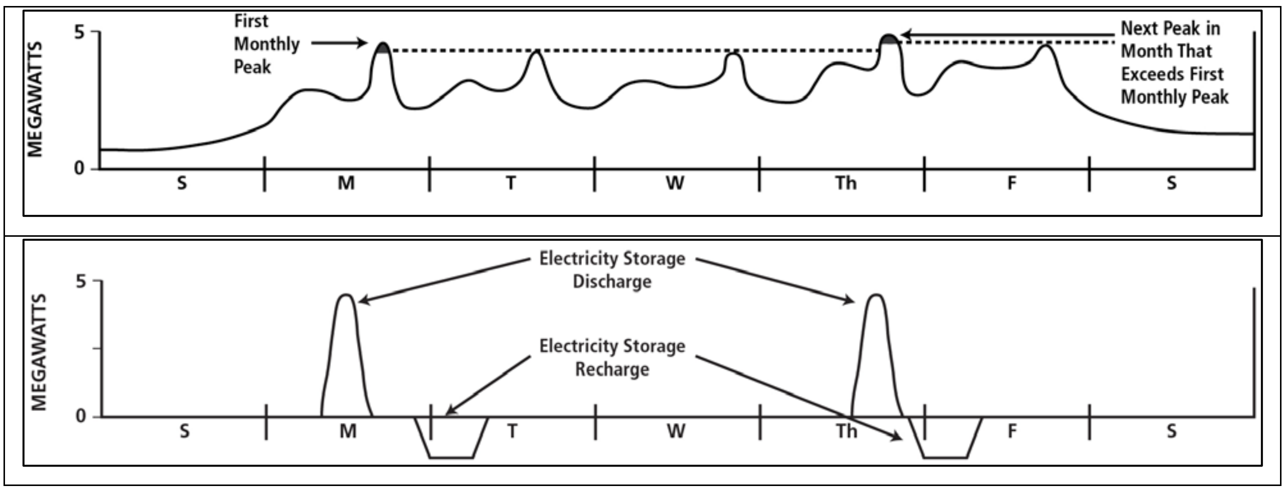

Figure 18. Storage for Customer-side Demand Management

1.6 Stacked Services—Use Case Combinations

Electricity storage can be used for any of the services listed above, but it is rare for a single service to generate sufficient revenue to justify its investment. However, the flexibility of storage can be leveraged to provide multiple or stacked services, or use cases, with a single storage system that captures several revenue streams and becomes economically viable. How these services are stacked depends on the location of the system within the grid and the storage technology used. However, due to regulatory and operating constraints, stacking services is a process that requires careful planning and should be considered on a case-by-case basis.

In the California Public Utility Commission's (CPUC's) energy storage proceeding R1012007, a series of electricity storage use cases was considered and studied by multiple stakeholders. CPUC divided the use cases into three general categories based on the location of the storage as shown in Table 2. When connected to the grid at the transmission level, energy storage can provide grid-related service to ancillary markets under the control of ISOs while bidding into the energy market. Energy storage can also act as a peaker to provide system capacity. When placed on the distribution circuits, energy storage can help solve local substation-specific problems (mitigating voltage problems, deferring investment upgrades, etc.) while providing ancillary services to the grid. On the customer side of the meter, energy storage system can shave the customer's peak load and reduce the electricity bill while improving power quality and reliability. Detailed documents about the CPUC-defined electricity storage use cases can be found on the CPUC website.[18] As part of the CPUC proceeding's effort to understand better the cost-effectiveness of different electricity storage use cases, EPRI conducted cost-benefit analyses using the Energy Storage Valuation Tool (ESVT), discussed in Chapter 3, for a subset of the CPUC use cases, including the bulk storage peaker substitution use case, the ancillary services only use case, and the distributed peaker use case. The results of the EPRI analyses[19] were presented in a public workshop in March 2013.

Table 2. Illustration of California Public Utility Commission Use Cases

(Source: EPRI presentation in CPUC Storage OIR Workshop, March 25, 2013[20])

Use Case	Categories
Transmission-Conneced Energy Storage	Bulk Storage System
	Ancillary Services
	On-Site Generation Storage
	On-Site Variable Energy Resource Storage
Distributed-Level Energy Storage	Distributed Peaker
	Distributed Storage Sited at Utility Substation
	Community Energy Storage
Demand-Side (Customer-Sited) Energy Storage	Customer Bill Management
	Customer Bill Management w/ Market Participation
	Behind the Meter Utility Controlled
	Permanent Load Shifting
	EV Charging

A detailed discussion of the methodology to determine and evaluate viable electricity storage use cases can be found in Chapter 3 of this Handbook. Various business models for acquiring storage systems can be found in Chapter 4.

18 http://www.cpuc.ca.gov/PUC/energy/electric/storage.htm, last accessed March 15, 2013.
19 *Energy Storage Valuation Tool Draft Results—Investigation of Cost Effectiveness Potential for Select CPUC Inputs and Storage Use Cases in 2015 and 2020*, EPRI Energy Storage Program, CPUC Storage OIR Workshop (R.10-12-007), http://www.cpuc.ca.gov/PUC/energy/electric/storage.htm ; last accessed March 25, 2013.
20 Ibid.