NEW YORK BATTERY AND ENERGY STORAGE TECHNOLOGY CONSORTIUM

ENERGY STORAGE ROADMAP
FOR NEW YORK'S ELECTRIC GRID

>> APPENDICES:

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http://www.ny-best.org/page/ny-best-reports

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>> APPENDIX I:

PRIMARY BENEFITS OF STORAGE

IMPROVING EFFICIENCY AND CAPACITY FACTOR

Energy storage can improve the efficiency and capacity factor of the grid, both from behind the meter and as part of the distribution, generation and transmission systems. From behind the meter, storage can shave peak loads thereby reducing demand charges, avoid interconnection upgrades, and shift loads on a permanent basis. Behind-the-meter storage can also be aggregated in order to provide system-wide benefits to the electric system such as peak shaving and even various ancillary services. On the distribution grid, storage can provide local capacity and thereby defer system upgrades and it can serve as a distributed power source that provides demand response and serves peak load. Storage can also provide load relief to distribution circuits by temporarily absorbing surges and excess power flow. On the backbone of the grid, storage can provide capacity by replacing conventional peaker plants, relieve transmission congestion and defer transmission upgrades. Storage can also absorb surplus baseload generation when the output is higher than minimum demands thereby minimizing costly ramping of generators.

INTEGRATION OF RENEWABLES INTO THE GRID VIA FLEXIBILITY

Energy storage greatly enhances the integration of renewable energy sources on the grid at all levels. Behind the meter, storage allows distributed generators to provide power whenever it is needed and can optimize energy cost by time shifting. Storage provides stability to microgrids that include distributed generation. The presence of storage on the distribution grid can enhance circuit hosting ability and prevent reverse power flow in the presence of substantial amounts of renewables. Overall, storage increases the flexibility and stability of the distribution system. On the grid backbone, storage provides firming for renewables along with ancillary services such as frequency regulation and spinning and non-spinning reserves. For large amounts of renewables penetration, storage can time shift the energy generated and is a solution to the issues created when the output of intermittent sources diminishes or ceases — often called the “duck curve.”[1]

This situation would otherwise require curtailment of generation and rapid ramping of alternative (typically fossil-fueled) resources. With sufficient storage, neither of these actions would be required.

In a grid dominated by intermittent renewable sources, there are essentially three approaches to managing large variable resources: redundancy, time shifting demand (load), and storage. Redundancy means having back-up fossil-fueled energy plants ready to take over for solar and wind resources that go off line. This approach is clearly expensive, inefficient, and environmentally undesirable, even in an era of cheap natural gas, which still produces substantial emissions. Time shifting loads requires users to curtail demand during times when renewable resources are not available. Demand-side management in general is a valuable and effective way to reduce peak energy usage and improve grid performance, but it is not practical on a grid-scale, rapid-response basis to deal with major fluctuations in renewable energy output. Energy storage is the approach that can successfully manage variable renewable resources. It can replace redundant generation sources and it can effectively time shift from the supply side rather than the demand side.

A number of studies have looked at the need for storage to economically maximize the amount of low-carbon electricity on the grid in the presence of large quantities of intermittent renewables.[2,3] Generally, the studies have concluded that once renewables become the majority of generation on the grid, storage is essential to achieve a low-emission electricity system. For smaller amounts of renewable sources, the studies suggest that combined-cycle gas turbines can provide relatively low-emission firming of the power supply. However, these models do not take into account the limitations of the transmission system and the effects of congestion. This issue is exceedingly important in New York, where substantial generation resources — both hydroelectric power and wind power—are located far from the largest center of demand — the New York Metropolitan area. While all scenarios recognize the value of storage for short-term needs such as frequency regulation, the value of storage to meet the specific needs of New York's electric grid is substantially greater because of the constraints of the transmission system.

ENHANCING RELIABILITY AND RESILIENCE OF THE GRID

Energy storage can provide reliability and resilience at all points in the grid. Behind the meter, storage can provide an uninterruptible power supply, maintain power quality and stabilize microgrids. At the distribution level, storage can support voltage and power quality and improve circuit flexibility and stability. At the grid level, storage can provide both spinning and non-spinning reserves, black start services, and can firm the contributions from intermittent renewables. Smoothing out the fluctuations inherent in solar and wind resources can bring added stability to the grid. By integrating PV and storage, customers not only have a more reliable and resilient system, they also benefit from demand charge savings and arbitrage by purchasing power when it is cheaper.

[1] In the presence of variable generation resources, the net load is the difference between the forecasted load and expected electricity production. In certain times of the year, if large amounts of generation occur, these curves fall off during the mid-afternoon to produce a "belly" appearance that quickly ramps up later in the day to produce a "neck", resulting in a shape that resembles the profile of a duck.

[2] C. Budischak et al. / Journal of Power Sources 225 (2013) 60e74

[3] http://pubs.rsc.org/en/Content/ArticleLanding/2015/EE/c5ee01452b#!divAbstract

>> APPENDIX II:

GRID ENERGY STORAGE APPLICATIONS

CUSTOMER NEEDS FOR ENERGY STORAGE

DEMAND CHARGE REDUCTION

Commercial electricity customers are generally charged both for the amount of electrical energy they use in kilowatt-hours and separately for the highest level of power demand during a billing period. This peak demand measured in kilowatts can constitute more than half of customers' bills in many places, New York City being a prime example. Customers can deploy energy storage to lower their peak demand. The storage system charges during off-peak periods from grid resources or from on-site generation. The system discharges when power use reaches a certain threshold or at a predetermined time, thereby reducing the magnitude of the peak demand from the grid and the resultant utility bill. Battery storage and thermal (ice) storage can both provide this capability for commercial electricity customers.

AVOIDING INTERCONNECTION UPGRADES

Energy storage can be installed to defer the upgrade of interconnections to the grid. Planned upgrades and additions to customer facilities can exceed the electrical capacity available at the site. Solving the problem typically involves interconnection and substation upgrades which are costly and require permitting. If the excess capacity is only required during peak periods, energy storage can defer or even eliminate the need for interconnection upgrades. Similar to demand charge reduction, a storage system can be charged during off-peak periods and provide the excess power needed during peak periods. Once again, both battery and thermal storage can play this role.

PERMANENT LOAD SHIFTING

Permanent Load Shifting refers to the shifting of energy usage from one period of time to another on a recurring basis for the purpose of lowering cost and reducing the strain on the energy system. Energy storage provides the means for accomplishing this by storing energy produced during off-peak hours and using that energy during peak hours to support loads. Both ice storage and batteries can be used in this way. Ice storage systems use a standard chiller to produce ice overnight which is stored in tanks. The stored ice is used to cool buildings the following day, greatly reducing the demand for electric power. This is a particularly important example because in most locations, air conditioning is the largest factor in taxing the capacity of the grid. Summer spikes in electricity demand are mostly due to the need for cooling.

UNINTERRUPTABLE POWER SUPPLY

UPS is an energy storage application that is already nearly universally used for individual loads such as computers and on a broader basis for critical facilities such as hospitals. For customers, a UPS discharges stored energy to ensure short-term continuous power to local loads when the input power source fails. Many UPS systems also provide protection against periods of degraded power quality. For many customers, UPS technology is the most familiar form of energy storage.

MAINTAINING POWER QUALITY

A battery storage system can improve power quality and protection to downstream loads when utility power experiences problems such as voltage spikes as well as sustained over-voltage or brownouts. The power control systems that are part of battery energy storage products are capable of providing dynamic, bi-directional VAR support to maintain line voltages within defined limits. Such systems also protect loads from line noise, unstable frequency, and harmonic distortion. For some commercial and industrial customers, power quality can be extremely important and can by itself justify energy storage on the customer side of the meter.

MICROGRID STABILITY

The primary purpose of a microgrid is to provide improved reliability and security of power compared to the traditional grid from which it is capable of decoupling while continuing to supply local electricity. Energy storage can enhance the stability and efficiency of microgrids by decoupling their generation sources from their loads. This decoupling is particularly important for microgrids that include diesel generation or intermittent renewables as their means of electricity production. The services that storage provides to microgrids are similar to those it can provide to the traditional grid including firming of renewable sources, stability of power quality, and load management. Storage in a microgrid can also supply power during unfavorable weather conditions when renewable sources may shut down. And storage can improve the efficiency of diesel generators by decoupling them from load variations that impair their performance. Energy storage enhances the very attributes that make microgrids a valuable contributor to the electricity system.

BUILDING EMERGENCY POWER

Building emergency power is closely related to the UPS application except for the duration that it is used. Emergency power requires discharging stored energy for prolonged periods in order to supply power to specified loads when the grid is unavailable. Storage systems are often used in conjunction with generators, which are capable of longer-duration operation. On the other hand, storage-based emergency power systems do not produce polluting gases and can therefore be placed within buildings without concerns about exhaust. In addition, they do not require on-site fuel storage, which is necessary for generators that can function completely independent of the utility infrastructure in a severe emergency.

INTEGRATING DISTRIBUTED GENERATION

For the customer, energy storage can be used to fill in gaps in distributed generation so that the combined output from, for example, renewable energy generation plus storage can meet capacity needs. When net metering is available, the grid itself can ordinarily augment renewable generation to whatever extent is needed. However, what storage can offer beyond the capabilities of net metering is protection against power outages, reduced environmental impact by reducing demand on traditional fossil fuel-powered utility generators, and ultimately the possibility of leaving the grid entirely. Customer-sited storage can be used to provide flexible capacity, which can have value to the customer by reducing peak demand.

OPTIMIZING ENERGY COST (TIME-SHIFTING)

Both residential and commercial customers under time-of-use rate structures have the ability to lower utility bills by using energy storage to shift when they draw power from the grid. This is a form of energy arbitrage. Time-of-use rate structures are used by some utilities to charge different rates for electricity at different times of day: higher prices are charged during periods of high demand and lower prices are charged during periods of low demand. Energy time-shifting means purchasing inexpensive electric energy when prices or system marginal costs are low in order to charge the storage system. The stored energy can then be used at a later time when the price or costs are high. Customers reduce their energy costs by reducing their grid electricity consumption during peak periods by discharging stored energy from the battery. Ice storage is extensively used for this same function.

>> APPENDIX II:

GRID ENERGY STORAGE APPLICATIONS (CONT)

DISTRIBUTION GRID NEEDS FOR ENERGY STORAGE

DEFER SYSTEM UPGRADES

Energy storage can be used to delay or avoid investments in the distribution system that are driven by the need for additional capacity to serve changing load requirements. Such system upgrades include replacing aging or undersized substation transformers or undersized distribution lines. In many cases, the real source of system strain is peak demand, not average load. In such cases, upgrades can be deferred by deploying a storage system to offload demands on the distribution system. The value of this application may not necessarily be the cost of the alternatives but rather timing and feasibility. Such system upgrades are often made in advance of anticipated growth due to new commercial or residential development and are designed to accommodate the projected needs over a 15-20-year period. In some cases, and for a variety of reasons, planned load growth ends up being delayed or even does not occur at all and significant investments end up being of little value. A storage system makes it possible to defer the upgrade decision point and allows time to assess the prospects for planned load growth to actually occur. A storage system can also be containerized, which means that 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.

DISTRIBUTED PEAKER

Peakers are the last power plants to be turned on in the electrical system and the last to be dispatched to provide power during times when peak demand occurs. Distributed peaker storage is installed at or near loads and has the distinct advantage that it provides peak power where it is needed rather than as a result of demand in the overall system. A primary benefit of distributed peaker capability is the reduced need for generation equipment. The stored energy in a distributed peaker can come from less expensive off-peak power and often can come from a relatively efficient generation source — quite possibly a zero-emission source rather than the typical fuel-inefficient combustion turbine plant. Using storage as a distributed peaker offers advantages in production cost, air emissions, and maintenance costs. Aggregated, individual storage resources can act as a virtual power plant with grid-scale impact and benefits. Furthermore, storage used for peaking can provide other services during the great majority of time when it is not needed to meet peak demand.

CIRCUIT LOAD RELIEF/DEMAND RESPONSE

The use of distributed storage systems can help address challenges associated with peak load on a local substation basis. These systems can become overloaded and congested and struggle to maintain the delicate balance between electricity supply and consumer demand. By discharging storage systems downstream to points of high demand, the distribution grid can relieve overloaded circuits and respond to increased demand.

CIRCUIT FLEXIBILITY AND STABILITY

In the conventional energy system, the major source of power demand variations is peak and off-peak usage by customers as well as seasonal changes during the year. Against this background, energy storage can contribute to the stability of the electrical supply by contributing to reactive and active power adjustments, frequency stabilization, voltage levels, and other parameters. Storage at the distribution level can help solve local voltage and reactive power problems that can occur at the substation and thus improve the stability and efficiency of the distribution equipment for the utility. Distinct advantages are derived from the ability to be sited and sized for location-specific challenges. With increasing amounts of renewable generation on the edges of the grid, the volatility of solar and wind resources is superimposed on the preexisting load dynamics.

Integrating these resources into the grid makes the balancing process more difficult. The need for flexibility is increasing. Effective energy storage can match total generation to total load precisely on a second-by-second basis. It can load-follow, adjusting to changes in wind and solar input over short or long time spans, as well as compensating for long-term changes.

IMPROVING SYSTEM RELIABILITY

Having storage sited at a substation or closer to loads can help improve service reliability by discharging to serve the load of a specific distribution substation for multiple hours. This provides utilities a defined window of time to fix an outage at a substation without their customers seeing any power interruption or loss of service. The closer energy storage is located to loads, the better job it will do increasing overall grid reliability. This can manage the variability associated with widely distributed, small-scale renewable energy generators, and can integrate electric and hybrid electric vehicles into community grids. At the substation and feeder levels, storage provides peak shaving and load leveling, time-shifting of renewable energy, voltage stabilization, reduced cold loads and load transfers, and reactive power compensation. In addition, battery energy storage is already used in tens of thousands of substations in the United States for the purpose of providing continuous power to protection equipment and to substation communication and control equipment when grid power is not available.

VOLTAGE SUPPORT AND POWER QUALITY

Voltage support refers to maintaining voltage levels on the electric system which is generally accomplished by providing or absorbing reactive power or by the use of voltage tap changers that mechanically adjust voltages by selecting different transformer windings. Providing and absorbing reactive power can be accomplished using distributed storage. Distributed storage has the advantage of being local given that reactive power cannot be effectively transmitted over long distances. Problems related to transmitting reactive power are a common cause of power outages. Effective voltage management can be accomplished by locating storage within load centers where the need for reactive power is greatest. More generally, energy storage enhances power quality by protecting on-site loads downstream against short-duration events that affect the voltage, frequency, power factor, or other quality of power delivered to the load.

INCREASE RENEWABLE INTEGRATION

Many distribution utilities are faced with the challenge of integrating increasing amounts of Distributed Energy Resources, for the most part solar PV. As the penetration levels of PV rise, there may be time periods during the day when the net power flow is from the load (distributed PV) towards the substation — a situation not normally anticipated in the distribution system. The associated reverse power flow tends to raise the voltage on the distribution feeder. It can also lead to overload of equipment from excessive reverse power flow, incorrect operation of control equipment, and eventually, the forced reprogramming or replacement of protective equipment. Because most DERs are not stand-alone systems, they require the local distribution system to host them. The amount of distributed generation that can be interconnected to a distribution system without causing voltage and protection problems is that system's hosting capacity. Exceeding the hosting capacity becomes a problem when the rated power of the renewable power installation exceeds the peak demand in the system. Dealing with added distributed generation that approaches or surpasses this limit can involve nontrivial engineering and equipment upgrade costs in order to keep the distribution circuit properly protected. While curtailing the amount of distributed generation occurring in the system is a way to prevent such problems, a more desirable solution is to store excess energy in decentralized storage thereby preventing reverse power flow and effectively increasing the hosting capacity of the substation.

>> APPENDIX II:

GRID ENERGY STORAGE APPLICATIONS (CONT)

GENERATION AND TRANSMISSION NEEDS FOR ENERGY STORAGE

CAPACITY

Peaker plants or peakers are a critical but particularly expensive element of the grid that addresses its peak capacity needs. Energy storage provides an attractive alternative to peakers and to demand-side approaches to manage peak demand. Historically, much of utility-owned pumped hydro-electric storage installed capacity has been used extensively as peaking resources. The use of energy storage (in lieu of combustion turbines or other generators) to provide the system with additional generation capacity during peak hours can defer and/or reduce the need to buy new central station generation capacity and/or purchase capacity in the wholesale electricity marketplace. Storage offers a number of advantages over conventional peakers: storage systems can start up much faster and their output can be varied (ramped) more rapidly, which makes them more flexible. By charging a storage peaker at night, it increases the utilization of cleaner, more efficient generation sources and increases asset utilization on the grid. Generation is freed up to provide service for which it is designed: generation of electricity at the plants' full-rated output and at a constant rate. That optimizes production cost, fuel use, air emissions and maintenance cost. Storage peakers themselves have no direct emissions and produce limited or no noise at all, simplifying siting. The ability to both absorb and discharge energy adds to system flexibility. Finally, apart from the limited hours of peak demand, storage used for peaking could be used for ancillary services and other purposes throughout the year.

TRANSMISSION CONGESTION RELIEF

Transmission congestion occurs when available, often favorably-priced energy cannot be delivered to all or some loads because transmission facilities are not adequate to deliver that energy. In New York, congestion is often the result of outdated infrastructure. Ample and lower-cost supplies of power in upstate New York are often constrained from being delivered to high-demand areas downstate and thus high-cost power must be purchased for consumers. The state's growing energy needs have led to the rapid development of generation capacity in many grids, particularly in the form of wind and solar power. The addition of intermittent renewable resources amplifies the challenges facing transmission circuits and requires greater flexibility than these circuits were ever designed to provide. In some cases, this growth has led to outputs that reach the power limitations of critical nodes of the transmission system. Energy storage can be used to avoid such congestion that can lead to increased costs or higher locational marginal pricing (LMP) for wholesale electricity. These costs can be quite substantial in the presence of significant transmission system congestion. Storage systems installed at locations that are electrically downstream from the congested portion of the transmission system can store energy when there is no transmission congestion and discharge that energy (during peak demand periods) to reduce peak transmission capacity requirements.

TRANSMISSION UPGRADE DEFERRAL

Transmission systems with peak electric loading that approaches the system's load carrying capacity (design rating) are candidates for upgrading that generally requires sizeable capital expenditures and often presents time-consuming challenges with respect to siting and other logistical issues. Energy storage can be utilized to defer the need for replacing existing transmission infrastructure to a later time period. In many cases, locating relatively small amounts of storage downstream from a nearly overloaded transmission node can defer the need for the upgrade for a few years. In such cases, a small amount of storage can provide enough incremental capacity to defer the need for a large lump investment in transmission equipment. For most nodes within a transmission system, the highest loads occur on just a few days per year, and in total, for just a few hours per year. By deploying energy storage downstream from regions of congested transmission, the demands on the system can be met by the system's load-carrying capacity, eliminating the need for an upgrade and thereby reducing overall cost to ratepayers, improving utility asset utilization, and allowing the use of capital for other projects.

This strategy also allows for transmission equipment life extension by reducing the loading on aging equipment that is nearing its expected life.

SPINNING/NON-SPINNING RESERVE

Utilities keep generation capacity on reserve that can be accessed quickly if there is a disruption to the power supply. Typically, this reserve capacity is created by generators that are already synchronized with the power grid but are not operating at full capacity. This type of reserve capacity is often said to be "spinning" because rotating machinery associated with generation must indeed be spinning to be synchronized with the grid. Generally, spinning reserves must be available within ten minutes. Energy storage can be implemented onto the power grid as spinning reserve assets. Compared with traditional methods, storage systems provide a cleaner, more efficient mechanism for utilities to compensate for disruptions to the power supply while enabling them to leverage the full capabilities of their generation assets to deliver baseload power. Energy storage has the advantage that it can provide immediate backup for a shortfall in the power supply while still retaining the excess power that was generated but left unutilized. The most advanced storage solutions are also equipped with sophisticated monitoring and control systems, enabling them to detect disruptions in the power supply and communicate quickly with the grid to near-instantaneously discharge and provide the reserve capacity when it is needed. Non-spinning or non-synchronized reserve are generation capacity that may be offline or may be a block of curtailable and/or interruptible loads that can still be available within 10 minutes. These contingency reserve applications of energy storage have been demonstrated using a variety of technologies including flywheels and SMES as well as battery storage.

RENEWABLE FIRMING

Capacity firming of renewable energy sources is an important application for energy storage. Because the output of solar and wind generation is variable, storage can be used to fill in energy when generation levels drop so that the combined output from the renewable energy generation source plus storage can meet the capacity needs of utilities or grid operators. By providing a fairly constant output, the combination can be relied upon as a firmed capacity, which offsets the need to purchase or rent additional dispatchable electric supply resources. In some cases, having firmed renewable energy output can also offset the need for upgrading transmission and distribution equipment. The goal of energy storage firming is to maintain power output at a committed level for a specified period of time. In the context of renewable firming, there is a distinction between the expected variability of renewable generation (such as the setting of the sun or forecasted wind abatement) and unexpected variability. Firming is primarily aimed at unanticipated intermittency and is employed to firm up the expected output of a renewable generation source to create a reliable and resilient electric system.

>> APPENDIX II:

GRID ENERGY STORAGE APPLICATIONS (CONT)

REDUCE RENEWABLES CURTAILMENT AND CONGESTION

Over-generation and transmission constraints can lead to curtailment of renewable resources, which drives up costs and reduces the effectiveness of installed wind and solar generation. Over-generation has already become an issue for solar resources in California and for wind resources in Texas. Solutions have included demand management approaches such as offering free power at night (in Texas) or even negative energy pricing. Storing the excess generation provides system operators with increased reserves and avoids costly curtailment. Storage can be used to mitigate curtailment due to transmission constraints. Power limitations in the transmission system can lead to bottlenecks that overstress substations and power lines. Properly situated storage can provide congestion relief in the presence of high renewable generation. It can deal with load variations during periods of low demand and high variable generation as well as periods of high demand and low generation.

BLACK START

Black start capability is the ability of a generator to begin generating power without station power and is important in recovering from system outages. To provide a black start, some power stations have small dedicated diesel generators that can be used to start larger generators (of several megawatts capacity), which in turn can be used to start the main power station generators. Black start units provide energy to help other units restart and provide a reference frequency for synchronization. Energy 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. Most storage types are well-suited to serve as black start resources because, unlike generators, they do not need special equipment, and storage does not have to operate while awaiting dispatch. Historically, pumped hydro units have sometimes been used for this application.

FREQUENCY REGULATION

In order to synchronize generation assets for grid operation, the AC frequency must be held within tight tolerance bounds. This frequency regulation is mainly provided by the ramping (up and/or down) of generation assets. This typically takes minutes rather than seconds. Energy storage has the capability for doing the job in milliseconds. A number of energy storage technologies, particularly batteries and flywheels, are well suited for frequency regulation applications. They are able to quickly respond to calls for both regulation up (adding stored energy into the system) and regulation down (soaking up excess electricity). Among the various ancillary services provided on the grid, frequency regulation has generally been assessed with the highest value. Storage with a very fast ramp rate can provide the relatively new ancillary service called frequency response. Frequency response is similar to regulation with an important distinction: frequency response resources monitor the AC frequency and they respond to frequency excursions whereas regulation responds indirectly based on control signals that reflect a difference between electric supply and electric demand. Storage used for frequency response service reduces the need for fast-responding generation sources that otherwise consume fuel and produce greenhouse gas emissions. Under FERC Order 755, the market for energy storage for frequency regulation is well established and has been implemented in the PJM, MISO, NYISO, CAISO, and ISO-NE grids.

RAMP RATE REDUCTION

Ramping rate as a general problem for the grid refers to a significant change of generation power output over time frames ranging from a few seconds to a few minutes. Renewables are subject to ramping because of wind generation that ramps as a result of rapid wind-speed variations and solar generation that ramps when large clouds pass over the generator. On a large scale, these variations require the system to respond in order to prevent the grid from becoming unstable. Being able to respond to ramping is an ancillary service to the grid. Resources used for ramping service need to provide output variability that is the reverse of other generators' output variability due to ramping. Conventional ramping service resources make use of combustion turbines and similar devices but are both limited in their ability to make rapid output changes and defeat the primary purpose of using renewable generation. Energy storage can provide ramping by charging and discharging the system as required. With very high levels of variable renewable energy sources (especially solar systems) on the grid, two problems arise: the risk of over-generation in the afternoon when there is maximum insolation and an increased need for ramping up alternative generation sources as solar drops off in the late afternoon. The drop-off in net load in the afternoon and abrupt rise in net load later in the day results in aforementioned "duck curve" in time dependence of a net load that was widely discussed in California. In this case, the ramping problem is not associated with the variability of a particular renewable asset but rather with having a large fraction of a grid's overall generating capacity drop off in a short period of time. Widespread use of distributed storage can be an effective way to diminish the effects of the duck curve. Dynamically aggregating storage assets can effectively deal with both excess generation and the need to ramp up other generation sources later in the day. In this configuration, storage can act as a large virtual power plant.

TIME SHIFTING ENERGY

Intermittent renewable energy sources have their maximum production at times completely out of the control of grid operators. They often produce a significant portion of electric energy when that energy has a low financial or strategic value (when demand is low) — generally referred to as off-peak times. Energy storage systems used in conjunction with renewable energy generation can be charged using low-value energy from the renewable energy generation so that energy may be used when it is more valuable. Such a system can transfer a part of the load to off-peak periods as a way of absorbing excess generation. This is particularly important for wind power generation, which often exhibits inverse-peaking characteristics; they generate more power during off-peak periods at night and early morning and less power during peak demand periods. Solar power generation, on the other hand, tends to be more synchronous with demand (but not necessarily co-located with it), but still may benefit from storage because of potential over-generation as in the duck curve scenario. By storing excess generation from renewable sources due to insufficient demand, curtailment can be avoided. Storage used for renewable energy time-shift could be located at or near the renewable energy generation site or in other parts of the grid, including at or near loads. Storing energy near generation sources still has to be transported during peak times via the transmission system; on the other hand, storage near loads can be charged by energy transported during off-peak times. Typical storage duration for energy time shift may be in the range of four to six hours. Thermal solar plants use molten salt technology to time-shift the output of their generation assets.

>> APPENDIX III:

GRID ENERGY STORAGE TECHNOLOGIES

Energy storage technologies basically fall into four categories: electrochemical, mechanical, electrical, and thermal. Each has its own properties and accompanying advantages and disadvantages. Central to any storage technology is the electrical performance provided in terms of both energy and power density. Depending upon the nature of the application, one or the other of these parameters may be the dominant issue. Apart from electrical performance, size and weight, capital costs, efficiency, cycle life, and operating costs are all factors that greatly influence the use of storage technologies. Some technologies can be utilized in a wide range of physical locations, including behind the meter at a customer's site. Others are only suitable for utility-scale installation. The amount of energy that can be stored using different technologies and the time associated with extracting that energy vary tremendously. For example, there are both long duration and short duration applications. Ancillary services applications for the grid are often only minutes in duration and in any case are no longer than an hour or two. In contrast, bulk storage applications such as renewable energy time shifting and peak shifting in general have much longer durations. There are storage technologies that are in the developmental stage, particularly exotic and advanced battery technologies. Some may eventually have a significant impact on the industry. The grid energy storage technologies that are already being used in the field are described here. Numerous other battery chemistries are under active development, including many by NY-BEST members.

ELECTROCHEMICAL TECHNOLOGIES

LEAD ACID BATTERIES

Deep-cycle lead acid batteries have been the mainstay for residential renewable energy storage and uninterruptable power systems for decades and research continues on advanced versions of lead acid technology for some storage applications. It remains the lowest-cost battery technology and continues to have multiple applications in the transportation sector.

LITHIUM ION BATTERIES

Lithium ion batteries are almost universally used in consumer electronics for such applications as cell phones and portable computers. There are a number of different combinations and mixtures of cathode materials used that compete on the basis of their power and energy density, safety, and reliability. Because of the tradeoffs in these areas and the desire for improved performance, research continues on multiple lithium ion formulations as well as more advanced technologies such as lithium-air batteries. For grid applications, lithium-iron-phosphate (LFP) — batteries account for 38.1% of the MWh market share, followed by nickel-manganese-cobalt (NMC). Lithium ion batteries are currently the standard technology for electric vehicles and the economies of scale provided by the growth of that application has been driving costs down for grid storage applications. There are now hundreds of megawatts of lithium ion battery grid storage systems in the field including several in the 30+ MW class supporting renewable energy installations in China and the United States. Lithium ion battery storage systems for homes and businesses are now a standard product being offered in conjunction with solar energy systems.

SODIUM SULFUR AND SODIUM METAL HALIDE BATTERIES

These batteries use sodium, ceramic electrolyte separators, and operate at an elevated temperature (300°C) at which the active materials are molten and thereby resist corrosion. The intrinsic high energy density and high power density of these batteries make them one of the most compact battery technologies for grid storage. They have seen a significant amount of deployment in Japan as well as in Europe, Latin America, the Middle East and Africa. Their high operating temperatures make these systems well-suited to applications in regions of high ambient temperature. The Rokkasho-Futamata Wind Farm in Japan has a 34 MW sodium sulfur battery storage system.

FLOW BATTERIES

A flow battery is a rechargeable battery that converts chemical energy directly to electricity using an electrolyte that flows through an electrochemical cell. Flow batteries can be recycled repeatedly and have lengthy (10-20 years) operating lives. The systems can readily be scaled up in size, and costs are typically reduced with increased size. The storage capacity of these systems is limited only by the size of the storage tanks. Such large systems are particularly attractive for use in storage applications at the subsystem level. Vanadium redox flow batteries (VRB) are considered to be one of the the most commercially viable large-scale flow battery technologies. The Tomamae Wind Villa Power Plant in Japan utilizes 4 MW of VRB storage. The 1 MW Turner Distribution System in Pullman, Washington, utilizes VFB technology in the largest flow battery installation in North America. Zinc bromine (ZnBr) flow batteries are attractive from a $/kWh perspective and may eventually see widespread application on the commercial or residential level as well as the utility level. Hydrogen bromide (HBr) technology also has great promise as a cost-effective and long-lived battery technology.

ULTRACAPACITORS

Ultracapacitors, also known as supercapacitors, are similar to batteries in that they store energy and use electrolytes, but they store charges electrostatically instead of chemically. Compared to batteries, they have much lower energy density but much higher power density. They also can be charged and discharged hundreds of thousands of times, unlike batteries. Ultracapacitors are being used in tandem with batteries in vehicles for the purpose of handling the short bursts of power to and from electric drive systems. To date, although applications for ultracapacitors have primarily been for vehicle storage, there are potential applications on the grid such as for wind turbine pitch control.

HYDROGEN AND FUEL CELLS

Hydrogen provides a way to continue to use a chemical fuel for energy storage that eliminates carbon from the equation. The transition to hydrogen technology has become a major goal for many of the major players in the automobile industry. The first generally available hydrogen technology cars — utilizing fuel-cell power plants — are presently entering the market. As a storage technology, hydrogen would ideally be obtained by using surplus energy to electrolyze water. The hydrogen can then be stored indefinitely on an arbitrarily large scale, transported, and used either directly as a transportation fuel or used to regenerate electricity by using a stationary fuel cell or a modified natural gas turbine. The Energiepark Mainz in Germany utilizes excess power from four nearby wind parks to produce hydrogen by electrolysis. The facility produces about 200 tons of hydrogen a year, earmarked for fuel cell vehicles. Large stationary fuel cell systems — operated on a variety of fuels — are being used for both primary power and for combined heat and power (CHP) applications in retail establishments, hospitals, data centers, water treatment plants, and other facilities. These systems are particularly well suited for providing reliable power in the event of a grid failure or blackout.

>> APPENDIX III:

GRID ENERGY STORAGE TECHNOLOGIES (CONT)

MECHANICAL TECHNOLOGIES

PUMPED HYDRO STORAGE

Pumped hydro storage utilizes conventional hydroelectric technology. The facility consumes electricity (usually at inexpensive off-peak times) and uses it to pump water from one reservoir into another at a higher elevation. When energy is required, the water stored at higher elevation is released and runs through hydraulic turbines that generate electricity. This system can provide very large amounts of long-term storage and has been in use in the U.S. since 1930. Pumped hydro storage is limited to the uncommon locations having two closely situated large reservoirs with an appropriate elevation difference. Construction costs are high, so pumped storage only makes sense for large installations. There are more than 150 installations around the world that account for over 125 GW of energy capacity.

COMPRESSED AIR ENERGY STORAGE

Compressed air energy storage (CAES) converts off-peak electrical energy into a mechanical form of energy by compressing air using a motor and compressor. The compressed air is then stored in sealed underground air pockets, caverns, or large tanks. When electricity is required, the air is taken from the storage volume, heated with natural gas, and put through expanders to power an electrical generator. With suitably large caverns, CAES can be implemented in systems with very large amounts of storage capacity ranging from 50 MW to over 300 MW. The Huntorf CAES Plant in Germany, commissioned in 1978, has a rated capacity of 321 MW over two hours. Originally focused on applications like spinning reserve, the plant is now being used to level the variable output of German wind farms. The MacIntosh CAES Facility in Alabama has a rated capacity of 110 MW over 26 hours. It is primarily used to reduce the need for additional generation during periods of peak demand.

FLYWHEEL STORAGE

Flywheel energy storage (FES) systems convert electrical energy into mechanical energy by accelerating a rotor to a very high speed and maintaining the energy in the form of rotational energy. Energy is extracted from the system by running a generator, which gradually reduces the flywheel's rotational speed. High-performance flywheels can come up to speed in a matter of minutes, which is much quicker than many other forms of energy storage. Individual flywheels can only provide tens of kilowatt-hours of energy, so the technology is best suited to high-power, short-duration applications such as frequency regulation. Beacon Power operates three grid-sited flywheel storage systems in the United States providing more than 40 MW of capacity. A 2MW flywheel system built by Temporal Power was installed in 2014 and provides regulation services to Ontario, Canada's Independent Electricity System Operator.

ELECTRICAL TECHNOLOGY

SUPERCONDUCTING MAGNETIC ENERGY STORAGE

Superconducting Magnetic Energy Storage (SMES) systems store energy in the magnetic field created by current flowing through a superconducting coil. Once a current is established in a closed loop of superconductor, it will flow without decaying and the magnetic energy will be stored for as long as the cryogenic operating temperature of the superconductor is maintained. Both the cryogenic refrigeration and the superconducting coil are quite expensive, which limits the use of SMES to short duration energy storage. Its most important advantage is that the time delay during charge and discharge is quite short with power being available almost instantaneously and at very high output levels for a brief period of time. There have been a number of test bed projects for SMES technology including 1 MWh units used for power quality control in installations requiring ultra-clean power, such as microchip fabrication facilities.

THERMAL TECHNOLOGIES

ICE STORAGE

Ice storage uses low-priced nighttime electricity to freeze a liquid and then utilizes the ice to help offset electric air conditioning loads when power prices peak during the day. During the day, the ice provides cooling alongside of or instead of the air conditioning compressor. Two companies have extensively applied this technology in the field. CALMAC has installed over 4,000 systems worldwide providing more than 500 MW of storage capacity to end user customers. Ice Energy's business is primarily selling to utilities. In 2014, Southern California Edison awarded it power purchase agreements for 26 MW of ice storage in its local capacity requirement procurement. The company is now also developing solar-plus-ice applications as a way to reduce demand charges.

MOLTEN SALT STORAGE

Molten salt storage is increasingly being used for solar thermal generating plants, allowing them to continue to operate for many hours after the sun has set or during cloudy periods. Various salt mixtures are used for the purpose, but a mixture of sodium nitrate, potassium nitrate and calcium nitrate is most common. That mixture melts at 131º C but is heated up to 288º C (550º F) by the concentrated heat from the solar collectors and is stored in an insulated tank. To generate electricity, a thermal fluid is heated by the molten salt to produce superheated steam to run a turbine genset. The technology is in use at the Solana Solar Energy Generating Station in Arizona, and provides six hours' worth of solar energy to the 280 MW plant. The Andasol Solar Power Station in Spain uses molten salt to provide 7.5 hours of solar thermal energy to the 150 MW plant. The Crescent Dunes Solar Energy Project in Nevada is a solar tower project that utilizes molten salt technology to provide up to 10 hours of generation to the 110 MW plant.