HOW ENERGY STORAGE CAN HELP STRESSED ELECTRICITY SUPPLY SYSTEMS

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INTRODUCTION

The wide fluctuations in electricity price and occasional rolling blackouts in California during the summer of 2000 and winter of 2001 are the best evidence yet that the electricity supply system of the USA is under some stress. Essentially, in some areas of the United States, indeed in some cases in whole regions of the country, growth in demand has outstripped supply, particularly with regard to transmission and "available" on-peak generation. In some other developed countries, electric supply systems are likewise becoming increasingly stressed. Of course, this has been the situation in many parts of the developing World for some time. Such problems are quite likely to increase in the future as electric utilities continue to restructure, with an increasing emphasis on asset utilization making it more difficult to justify the investments necessary to bring demand and supply back into balance. Moreover, ever-increasing environmental constraints, together with "not in my backyard" protests based on both environmental and aesthetic considerations, are making the process of building transmission and conventional generation costlier and more time-consuming.

At the simplest level, energy storage can be used to balance fluctuations in the supply and demand of electricity. As such, energy storage can help stressed electricity supply systems meet customers' needs for a reliable source of electric power. Energy storage in the form of banks of lead-acid batteries was used in early electric supply systems, such as the DC system in New York City in the late 1900s, to allow the nighttime load to be met without running the generators. As electric supply systems became more sophisticated, pumped hydro plants, in which water is pumped to a higher-level reservoir during periods of low demand at night and on the weekends, and then passes back through hydro generators to supply peak demands, were constructed to provide an alternative to fossil-fueled peak generation. Approximately 4% of the U.S. generation capacity is in the form of pumped hydro, and there is more than 10% of this type of energy storage in both Italy and Japan. There are also a few compressed air energy storage (CAES) plants around the World, such as one in Alabama, which like pumped hydro serve as "central station" storage. In a CAES plant, air is compressed and stored in a large underground cavern, such a as solution-mined salt dome, and is then released, with fuel, to be burned in the expander of a combustion turbine to provide power on peak.

It is distributed energy storage technologies, with next-generation storage devices, that appear most likely to fill the role for energy storage in solving the current problems of stressed electricity supply systems. The candidate advanced energy storage technologies are described below, after we first discuss the services in which such technologies might be put to use.

ENERGY STORAGE AS A POSSIBLE SOLUTION FOR STRESSED ELECTRIC SUPPLY SYSTEMS

Energy storage systems can help provide reliable electric service to customers in three ways:

- By augmenting the supply and/or transport of electricity at critical times;
- By shifting demand on electricity supply assets from critical times to off-peak periods;
- By providing electric service to customers during forced outages or other interruptions in service.

Energy storage systems can help in these ways because they help customers meet their needs for reliable service with economically attractive methods for matching supply to demand.

In general, the economics for energy storage are attractive because the cost for supplying electricity goes up as demand changes. The faster the demand changes, and the greater the magnitude of the changes, the greater are the cost increases. For example, the cost for generating electricity during periods of peak demand is significantly higher than in off-peak periods, because the efficiency of peaking generators (with a heat rate of ~12000 Btu/kWh) is lower than that of base-load plants (heat rate of 7500 Btu/kWh for a combined cycle plant), and because more expensive fuel (e.g., non-interruptible natural gas) must be used. As another example, the life-cycle-cost of electricity from an energy storage unit used to provide a reliable source of electricity during a brief interruption in service is significantly less than that from a standby diesel generator.

The economics can be attractive at several points in the electric supply system, but generally, energy storage becomes more attractive the closer to the customer it is placed, always, of course, within the limits of the problem that the energy storage unit is being used to solve. In transmission systems, for example, the problem of supplying electricity during peak use periods is not the efficiency of the transmission, which is greater than 90%, but thermal and stability limits. The use of large energy storage units for very short periods to stabilize transmission systems, thereby allowing higher scheduled power flows, is more economically attractive at the customer end of the transmission line than at the generation end. The economics of electricity supply are such that each individual situation for which energy storage might provide a solution to a problem must be analyzed separately, and it is impossible to generalize on the economics. This is particularly true during the current deregulation process.

An energy storage system can be used for many applications within electricity supply network.[1] A thorough analysis of potential applications as of a few years ago[2] was made by Sandia National Laboratories* with Department of Energy funding. Examples of the more important of the applications that have been considered are shown in Table 1.

Table 1. Some Applications of Energy Storage in Electricity Supply Systems

Generation duties	**Ancillary services**	**Transmission and distribution**
Energy management	Frequency response	Transmission stabilization
Load levelling	Spinning reserve	Power quality and power reliability
Peak generation	Standby reserve	Voltage support (reactive power)
Ramping	Long term reserve	Incorporation of renewables and other distributed generation
Load following	Area regulation	Peak shaving
Aim: Increase generation utilisation, raise efficiency, reduce emissions	**Aim: Allow unbundling of ancillary services from the generator**	**Aim: Increase T&D utilisation while improving reliability of service**
Overall Effect: Reduce total required generating capacity	**Overall Effect: Reduce cost of ancillary services**	**Overall Effect: Defer investments while improving customers' supply**

It is important to note that storage can achieve multiple benefits by combining applications. This can result in increased returns on investment for the owner of the energy storage system. However, it also means that the energy storage system chosen for a group of applications must have capabilities greater than those needed for a single application. The closer the energy storage system is to the customer, the more applications can be combined, this giving the economic advantage to systems sited at the demand end of the electricity supply system. It may be easier to realize these increased returns in a deregulated (unbundled) utility environment than it was in the regulated, vertically integrated utilities of the past.

Implied in the entries in Table 1 is a very large range of times over which energy storage devices will be discharged. For transmission stabilization and frequency control applications, an energy storage system would be discharged and charged over rather short time periods, of say less than 1 second. Longer discharge time periods (a few minutes to ten hours) are required for the various applications involving energy management or provision of a contingency against an undesired event. Energy storage cannot replace generation completely, but it can complement other forms of generation whether on a large power system or in a stand-alone (i.e., non-grid connected) application. . New peaking generating capacity could be deferred or avoided if the utilisation of existing cycling generating capacity was increased. Existing cycling capacity could be run at an increased load factor by storing the energy produced during off-peak periods. During peak periods, the energy could then be discharged to meet peak demands.

As can also be seen in Table 1, an energy storage system can have application within the transmission and distribution (T&D) network. T&D networks have to be designed and built to be able to carry the expected peak loading, which may only exist for a very small part of its annual operating cycle. This results in considerable over-sizing of transmission and distribution equipment. Additional wires, transformers and other equipment are also needed to provide redundancy in the event of sudden loss of transmission capacity (such as a generator failure or an interruption to a transmission link). Strategically placed energy storage systems can reduce the need for reinforcement of a T&D network by reducing peak loadings while providing the needed redundancy.

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The requirements of these various possible applications an electricity supply system are such that conventional energy devices used in traditional ways will not meet the needs and requirements of the potential users. In fact, different groups of applications have such differing requirements that specific equipment has had to be developed to meet the needs. In the next section of the paper, the progress towards commercialization of distributed energy storage will be discussed.

CONVENTIONAL TECHNOLOGY ENERGY STORAGE PROJECTS

Over the past twenty years, there have been a number of energy storage projects based on flooded lead-acid battery cells within electricity supply systems. The most important of these were:

- A 17MW system installed by BEWAG (Berlin, Germany) for short term spinning reserve and frequency regulation. This system was operated successfully for more than ten years before the reunification of Germany made its continued use unprofitable.
- A 500kW, 1hour system installed at a Crescent Electric Membership Coop sub-station in North Carolina. The Crescent battery energy storage system was profitably operated for fifteen years.
- A 10MW, 40MWh load leveling battery system installed by Southern California Edison at their Chino sub-station. This demonstration project was operated successfully for about six years before the changing utility environment in California made it uneconomic to continue.
- A 20MW, 14MWh system installed by the Puerto Rico Electric Power Authority to provide short term spinning reserve and frequency regulation. This project proved quite profitable, such that the batteries originally installed are now in the process of being replaced.[3]

Overall management of each of these projects was provided by the respective host utility, and equipment for the energy storage plant was assembled from relatively standard components. This was done so that project capital costs could be kept low enough for the plant to be projected as profitable. However, the costs for engineering, on-site installation, and maintenance all proved to be more expensive than expected. As a result, energy storage developers moved to a system approach units to help solve electricity supply problems. This approach is termed distributed energy storage.

DISTRIBUTED ENERGY STORAGE TECHNOLOGIES

Distributed energy storage systems could in some circumstances provide solutions to the mismatch of supply and demand locally and/or regionally. Distributed energy storage can also help to alleviate the effects on customers of brownouts, rolling blackouts, and other disruptions to the electricity supply. Distributed energy storage is particularly suited to providing such solutions for the following reasons, among others:

- Distributed storage assets are modularized so that they could be installed quickly with low on-site costs.
- The inherent modularity of distributed storage systems means that the equivalent of local generation can be added in relatively small increments as demand grows.
- Distributed storage systems do not add to the environmental impact of supplying electricity. Indeed, energy storage can help reduce emissions from, and fuel consumption of, central station and distributed generation equipment.
- Storage systems are generally more efficient at part load and can load-follow almost instantaneously, thus helping system operators in matching supply and demand.
- Distributed energy storage allows existing electricity supply assets, both generation and T&D, to be used more cost-effectively.
- Most new-technology distributed energy storage systems can be made multi-functional with little or no additional cost, so that, for example, both UPS and energy management applications can be served by the same equipment.

There are a number of energy storage technologies that have been under development for some time. Some of these have been commercialized while others are either in the process of commercialization or are approaching that stage. The energy storage technologies that continue to receive attention are those that their supporters consider most likely to provide the attractive cost/benefit ratios that electricity suppliers and their customers need.

Energy Storage Systems

After early demonstrations of utility energy storage (see below) that involved custom installation of the various components, the focus turned to the development and utilization of energy storage plants designed from a system perspective. The successful operation of plants such as those designed and built by in a collaborative effort by GNB* and GE* in Vernon CA (a 3.5MW, 1 hour plant) and Metlakatla AK (a 1MW, 1 hour plant) with VRLAs as the energy storage element, is more than adequate demonstration of the value of this approach.[4] Recently, the system approach, with VRLAs and with nickel cadmium batteries, has been required in the bidding of a 40MW, 20 minute battery energy storage facility for the Golden Valley Electric Association in Fairbanks AK.[5]

Power Conversion Equipment

Advanced power conversion equipment has become available in the past several years. This equipment has higher performance and uses lower cost power semiconductors, thus are allowing cleaner waveforms and faster connection times for energy storage plants, at more attractive prices. Such equipment has allowed use of conventional batteries in more-effective ways, such as the 2MVA PureWave™ system[6] with lead-acid starter batteries already being sold in significant numbers by S&C Electric*.

Advanced Batteries

Advanced batteries have been under development for electric supply applications since the early 1970s, with funding for much of the time from the Department of Energy (through Sandia National Laboratories) and EPRI*. There has also been a development program in Japan.[7] Recently, the technologies that had been under development have been supplemented by efforts resulting from electric vehicle battery development funded through the USABC.[8] From the many battery systems on which development has been conducted, work is continuing in earnest for applications within electric supply systems on just a few.

In Japan, sodium/sulfur batteries have already been demonstrated in two 48MWh/6MW plants that are utilized for load leveling service by the Tokyo Electric Power Co.[9] The primary developer of the technology, NGK*, is now attempting to commercialize the sodium/sulfur battery technology in both Japan and the US.

Two US companies, Powercell* and ZBB*, have been developing the zinc/bromine battery system. Powercell is in the process of commercializing their 100kWh PowerBlock units based on the Zinc Flow Battery developed originally by their subsidiary SEA in Austria.[10] ZBB recently demonstrated a 400kWh unit at a Detroit Edison site in Michigan.[11]

Sumitomo Electric Industries* (SEI) and Mitsubishi Chemical are both developing the vanadium redox system in Japan, and in the late 1990s both demonstrated batteries of a few hundreds of kWh in capacity. SEI has a 100kWh battery in an office building in Osaka, as proof of their determination to commercialize the VRB technology.[12]

In England, Innogy* (formerly National Power, a major electric generator) has been developing the sulfur/bromine redox, or Regenesys, technology, and has had systems with capacities of several hundreds of kWh under test.[13] Innogy is currently in the process of building a 15MVA/120MWh prototype energy storage plant at the Little Barford generating station in the UK, and they have announced that, with TVA*, a second plant will be built in the US. At the Little Barford site, the energy storage plant will be used for black start and energy arbitrage.

In addition to proposing the use nickel/cadmium batteries for utility applications, Saft* has been developing lithium/ion batteries for electric vehicle and stationary storage applications[14]. Lithium/ion batteries are said to be being sold in limited quantities for distributed node telecomm service.

A new commercialization prospect for electricity supply applications on the customer side is the semi-rechargeable zinc-air technology of Evonyx*. However, the main focus of this developer is smaller systems.[15]

Flywheels

Conventional (steel) flywheels are being commercialized for the protection of critical loads by Pillar in Germany and by Active Power in the US, among others. Several companies in the US and Europe are developing advanced (carbon fiber composite) flywheels, with Trinity appearing to be focusing most on systems of a scale (hundreds of kW) appropriate for electric supply applications.

SMES

American Superconductor* (ASC) is the most active of a few organizations that have been involved in the development of superconducting magnetic energy storage or SMES. ASC has several 1MVA/2 second systems in the field, which provide short-term protection of critical loads. A group of ASC SMES devices is being used for a transmission stabilization application in Wisconsin.

Supercapacitors

Supercapacitors, which are a potential option for seconds-duration storage in smaller applications such as motor drives, have been under development for many years. Maxwell is the most active company commercializing this product in the US.

CAES

Micro-CAES, in which the compressed air is stored in steel pipes, has been in development for several years. Recently, the developers of this type of energy storage system announced that they are seeking a demonstration site.

CONCLUDING REMARKS

The mission of the Energy Storage Association (ESA), members of which non-profit trade association are involved in the development, commercialization, implementation, and use of these technologies, is to promote the use of energy storage by electric utilities and their customers. We think it is clear from the above descriptions of energy storage applications and systems that commercialization is proceeding apace, and that the energy storage technologies should be able to provide some of the solutions to the problems of stressed electricity supply systems.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the financial support of the Department of Energy, through a contract with Sandia National Laboratories, for the preparation of this paper. I wish to particularly to thank Garth Corey, who managed the work for Sandia, and who provided many useful insights during its preparation. I also want to acknowledge two members of the Board of the Energy Storage Association, Anthony Price of Innogy in the UK, and Gerard Thijssen of KEMA in The Netherlands; the current paper is an elaboration and extension, with much new material, of the work the three of us did in preparing a paper for Distributech 2000 in Vienna Austria.

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