

UTILITY–SCALE APPLICATION OF SODIUM SULFUR BATTERY

D. K. Nichols
American Electric Power Service Corporation
Corporate Technology Development
Groveport, Oh. 43125

Steve Eckroad
Electric Power Research Institute
Substations & Energy Storage
Palo Alto , Ca.

ABSTRACT

The current Electric Energy Industry is in a transitional state, characterized by the emergence of retail energy markets, increased wholesale competition, aging infrastructure and the need for increased reliability, security and high quality service. Faced with economic pressures, population growth, environmental restrictions, and difficult capital markets, energy providers are seeking innovation to create and deliver energy into the grid. These conditions provide opportunity for the application of new technology.

Energy Storage (ES) is a technology that provides a means to meet the needs of a stressed electrical system, improve customer satisfaction and participate in energy markets. ES integration into the existing power grid improves asset utilization without investment in new Generation or Energy Delivery infrastructure.

Rechargeable battery technologies like sodium-sulfur (NAS) technology are attractive candidates for use in many utility-scale energy-storage applications. These advanced battery systems can be utilized with existing infrastructure, helping energy providers to meet peak demands and critical load. The NAS battery's characteristics make it a good candidate for combined power quality and peak shaving applications.

This paper will provide an overview of NAS technology, energy storage applications and the AEP/DOE/EPRI test program and demonstration. The status and plans for demonstrating, deploying, controlling and monitoring the NAS battery on the AEP System will be presented. These plans are focused on an initial project with a combined rating of 500kW for 30 seconds of power quality protection plus 100kW (720kWh) of peak shaving capacity.

INTRODUCTION

The U.S. electric energy market is significant with aggregated sales in excess of \$240 billion and is in an era of transition. Restructuring activity and wholesale competition varies from state to state and has resulted in a mixture of regulated and market based supply. This Industry restructuring is reorganizing the energy value chain from the vertical integration of electric utilities to its unbundled components of Generation, Transmission and Distribution. In this uncertain environment, energy providers are currently focused on controlling costs and conserving capital while at the same time meeting customer service and reliability performance expectations. Increasingly, both the public and private sectors recognize the value that Energy Storage (ES) can provide to meet customer energy demand needs in a cost effective manner. ES systems complement the existing central Generation, Transmission and Distribution infrastructure to help meet peak demand and improve asset utilization. ES integration into the existing power grid improves capacity factors and allows energy providers alternatives to meet peak energy demand without investment in new Generation or Energy Delivery infrastructure. Low cost ES has potential to be one of the more significant growth opportunities for energy providers—perhaps even revolutionary.

It is generally accepted that, with the introduction of the digital society, there is an increasing demand for premium power. Traditional grid operations cannot cost effectively provide the 'six 9s' of reliable, high quality power demanded by some businesses. Although possible, it is an inefficient use of capital funds to design a power system to deliver this high level of reliability to all customers. ES technologies provide flexibility for end users to meet these high reliability and power quality requirements and create alternatives to energy cost management. In addition, on-site ES can provide an economical method to enhance power supply security in a time of increased concern.

ES devices can be used to provide various combinations of the following applications

- Peak Shaving/ Load Leveling
- Improved Power Quality
- Bridge to Emergency/ Backup Generation
- Defer New Central Generation
- Improved Operating Condition
- Voltage Support
- Improved Security
- Transmission & Distribution Capacity Release
- Deferrals of New or Upgraded T&D Infrastructure
- Improved Utility System Reliability
- Low Cost Energy
- Fast Spinning Reserve

ENERGY STORAGE

It is the Department of Energy's objective that 20% of new electric capacity requirements in the US will be provided by distributed resources by the year 2010. Energy storage will be part of this growth. Electrical energy is a rare example of a product that without energy storage must be consumed at the instant it is produced. This inability to economically store energy in meaningful quantity adds complexity to energy delivery and is a contributing factor to price volatility and power quality related problems. As a result, it is necessary to build and operate a power system to meet peak demand, adding significantly to the cost of service. As such, grid infrastructure typically has a low capacity factor and electrical energy providers have long sought technologies to optimize existing assets. Large-scale economic storage can provide that functionality.

Energy storage's value is significant and is expected to grow to meet industry operational challenges and as the cost of power interruption increases. One high value storage application is for load leveling, or peak shaving (PS), which is accomplished by using existing generation, transmission and distribution assets to charge storage devices when load is low and discharge them during heavily loaded periods. Figure 1 illustrates a typical load leveling cycle over a 24-hour period. This process enables efficient operation of generation facilities and maximizes T&D infrastructure utilization. In addition, the charge/discharge cycle allows the ES operator to purchase low cost energy to charge the battery during off peak hours and sell that energy during peak periods when the price of electricity is high. Aggregation of these storage devices enables participation in energy markets and associated revenue streams.

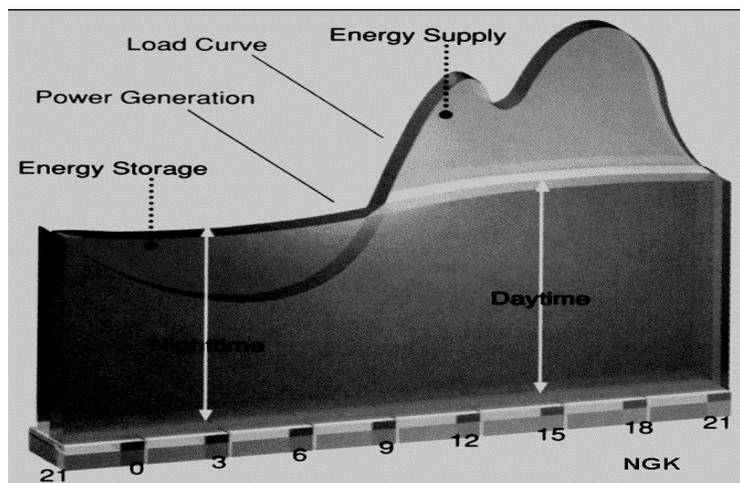


Figure 1: Load Leveling

Increased customer reliability demands often exceed normal levels provided by utilities. In fact, some industries require greater than 99.9999% reliable electricity delivery and losses approaching \$1,000,000/minute have been claimed by high tech businesses. PQ problems are caused by brief momentary power variations lasting less than seconds and long-term outage.

Instantaneous response from an energy storage device can provide sufficient energy to “ride through” short-term power delivery anomalies and provide bridge power to standby power generation. In addition, energy storage can provide backup capability for longer events. Power quality and peak shaving applications described above provide the highest value to the energy provider and end user. Additionally, when properly located, energy storage can be used to offset or delay new line construction and equipment upgrade. The real value of an energy storage application is the aggregated worth obtained from each application value component that accrues in the wholesale market, for the EPS and for locational value. These applications include energy arbitrage, capacity market, ancillary services, energy trading, T&D deferral or substitution, backup power and power quality solutions. Energy storage can also be utilized to stabilize the output of intermittent sources like photovoltaics and wind turbines. The aggregated worth of energy storage is illustrated in Figure 2

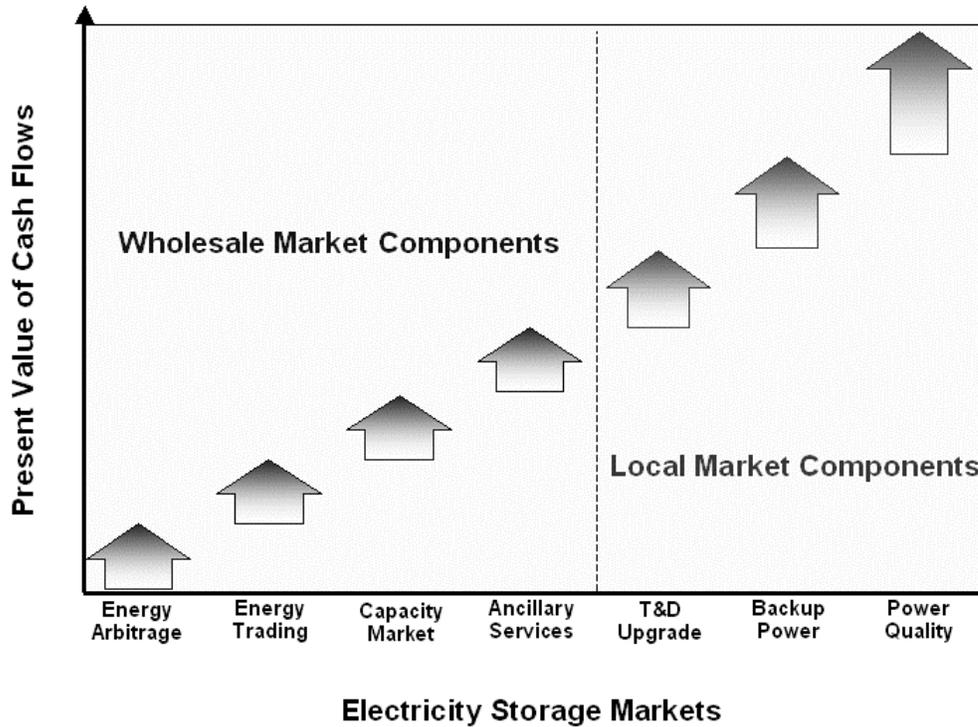


Figure 2: ES Value Aggregation

For economic analysis of T&D deferral and off peak/on peak price differential, it is necessary to use specific cost estimates for the improvement and local energy rates. As a T&D substitution, ES application can reduce cost of reconductoring, right-of-way purchase, or station equipment upgrade. A review of eight random upgrade projects at AEP and some national averages shows that project costs vary greatly. To illustrate, the cost of the projects ranged from \$29/kW to \$169/kW, with a \$74/kW average. Over a recent 12- month period, the difference between off peak and on peak pricing varied from 6.6¢/kWh to 34.3¢/kWh with variation in this price differential across the U.S., hourly and seasonally.

High pulse power capability makes the sodium sulfur (NAS) battery a viable candidate for peak shaving (PS) and power quality (PQ) solutions and combined PS/PQ application. The NAS battery is the most commercially advanced of several emerging energy storage devices intended for these applications. Other energy storage devices in varying stages of development include metal/air, Lithium-ion and advanced lead acid batteries, super capacitors, flywheels and Zinc Bromide, Vanadium Redox and Regenesys flow batteries.

Plans for demonstrating the NAS battery on the AEP System are focused on an initial two-battery module project with a combined rating of 500 kW for 30 seconds of power quality protection plus 100 kW of peak shaving capacity. ABB was selected to supply the power electronics and system integration for the project. The project includes a rigorous acceptance test program and long-term monitoring to assess NAS performance and cost effectiveness and determine electrical characteristics. Specifications require compliance with several Standards including IEEE 1547.

SODIUM SULFUR BATTERY

The sodium sulfur battery possesses excellent energy and power density, high electrical efficiency, long life, a small footprint, pulse power capability, instantaneous response, and reliable operation making it an excellent candidate for Electric Power System (EPS) application. Modules have a pulse power capability up to five times their continuous rating (for 30 seconds) that is limited by the cell temperature rise, internal resistance, and depth of discharge

Attractive features of the NAS battery include:

- Per unit volume, the NAS batteries deliver about three times more energy than lead acid batteries. Per unit weight, the factor is almost 10.
- The NAS battery is designed to last 15 years, through 2,500 full charge-discharge cycles.
- Sulfur is used as an active material at the positive electrode and sodium is used at the negative electrode. Electrodes are separated by a sodium-ion-conductive ceramic solid electrolyte. High temperature keeps the electrode active materials in a liquid state while the electrolyte is solid. These conditions reduce resistance and enable efficient battery performance, averaged over lifetime discharge.

BATTERY ENERGY STORAGE SYSTEM

The battery system consists of external and internal switch-gear, an SCR based static switch, two high density NAS Battery modules and a power conversion system. The following sections describe the system components in the Gahanna demonstration project in more detail.

NAS Battery Modules

The system for the Gahanna demonstration uses two NAS battery modules as the dc energy source. The NAS batteries are manufactured and supplied by NGK insulators, Ltd. in Japan and each module has the capacity to provide 375 kilowatt-hours of dc energy at 50kW rated. The NAS batteries also have the capability to provide 5 times the rated power for a short time, up to 30 seconds, and peak shaving. The duration of peak power is limited by the internal temperature rise of the battery. With appropriate thermal management, the NAS battery can deliver pulse power for longer durations with tradeoffs on the number of peak shaving cycles.

Various discharge profiles that successfully combine the peak shaving and power quality applications are implemented. The choice of profile for an application is made based on the desired level of PQ protection, peak shaving energy, and the desired lifetime of the batteries. A package of various profiles for a wide range of applications is loaded into the system memory and can be selected easily through the user interface. External heaters are needed to keep the battery maintained at an elevated temperature at all times to accomplish energy storage function. These heaters are only needed on start up or when in an idle state. The nominal operating voltage of the batteries is 700Vdc with variation between 325V and 790V. Each module has current rating up to 810A dc.

CB-DC1 and CB-DC2, shown in Figure 3, are 1000V and 1000A dc breakers that are operated by either battery module controllers or the PCS controllers. Abnormalities internal to the battery modules, such as cell failure, over current, abnormally low cell voltages, extreme temperatures, etc., which are monitored by the battery controllers, can trip the dc breakers to protect the batteries from failure. The PCS protection scheme can trip the dc breakers to protect the power electronics and balance of the system.

Power Conversion System (PCS)

The PCS is required to convert the battery dc voltage to an ac voltage required by the grid. The PCS uses two IGBT based high frequency bi-directional converters to process energy in each direction and uses PWM techniques to regulate a voltage or a current depending on the operating mode. A low pass three-phase filter placed at the output of each converter is used to eliminate the high switching frequency noise and unwanted harmonics from going into the power system lines. The output of the filter, as shown in Figure 3, goes into a step-up transformer.

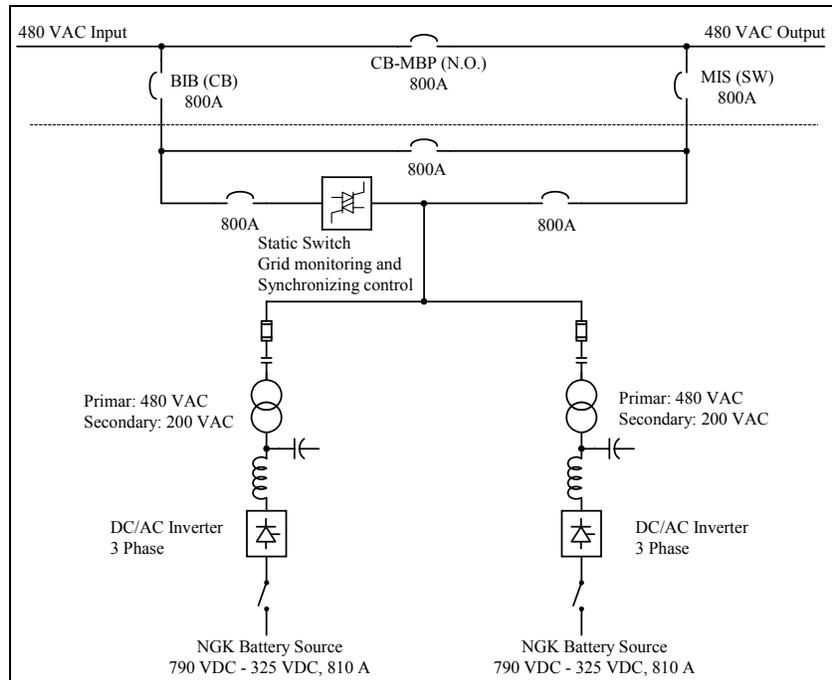


Figure 3 : PCS Configuration

Operational Issues

Because PQ events are random in nature, it is not known when the battery needs to perform a PQ operation. Therefore, PQ availability is an extremely important concept for the battery system. Test results showed the NAS battery is capable of handling high PQ powers as long as there is sufficient remaining charge and that short duration PQ events have minimal affect on battery performance. The only PQ limitation is the possibility of exceeding safe operating temperature limits, which may occur near the end of discharge when the temperature is highest.

GAHANNA DEMONSTRATION PROJECT

The installation in Gahanna will be operated for two years as a demonstration of the NAS battery. The objective of the Gahanna demonstration is to validate NAS PQ/PS operating characteristics gain familiarity with the technology and develop needed economic models for its use. AEP partners in the project include NGK Insulators Ltd, Tokyo Electric Power (TEPCO), ABB, the U.S. Department of Energy/Sandia National Laboratories and the Electric Power Research Institute (EPRI). The installation is shown below in Figure 4.



Figure 4: NAS 100kW Gahanna Demonstration Project (Gahanna, OH)

Acceptance Tests/Monitoring Systems

Acceptance tests were done on the battery modules in Japan prior to delivery to the US. In addition, the entire system was tested at the ABB facility in New Berlin prior to shipment to Gahanna. Final acceptance tests were done at the Gahanna site to validate compliance with standards and specification. That testing included robust protocols to assess the battery/PCS interface, PCS/grid interface and System compatibility. All testing was successfully completed and the NAS battery was put in service in September 2002.

A monitoring program is underway that will be utilized by the project partners to assess PQ/PS performance and to develop economic models for energy storage. The monitoring package includes advanced communications between internal NGK and ABB controllers and a central computer located at the NAS Center at AEP's Dolan Technology Center to provide real time and historical data on battery performance.

Sample Results/Data- PQ Event

Figure 5 shows the response of the system to a power quality event test. Only two phases, a and b, were plotted to provide visibility of the dynamics. The data during the PQ tests were measured and recorded by a high-speed 16-channel data acquisition instrument. As shown in Figure 5, phase a of the source voltage was sagged below 80% of nominal (480V) and initiated the PQ event. The system responded to the disturbance in 2 milliseconds and picked up the load. The load voltages (second trace) and the load currents (bottom trace) show a smooth transition and continuous power flow to the load. Comparison of the load currents and source currents indicate peak shaving prior to the PQ event. During this test, the load was set at 300kW and the system was peak shaving at 100kW correspondingly the power coming from the source is 200kW.

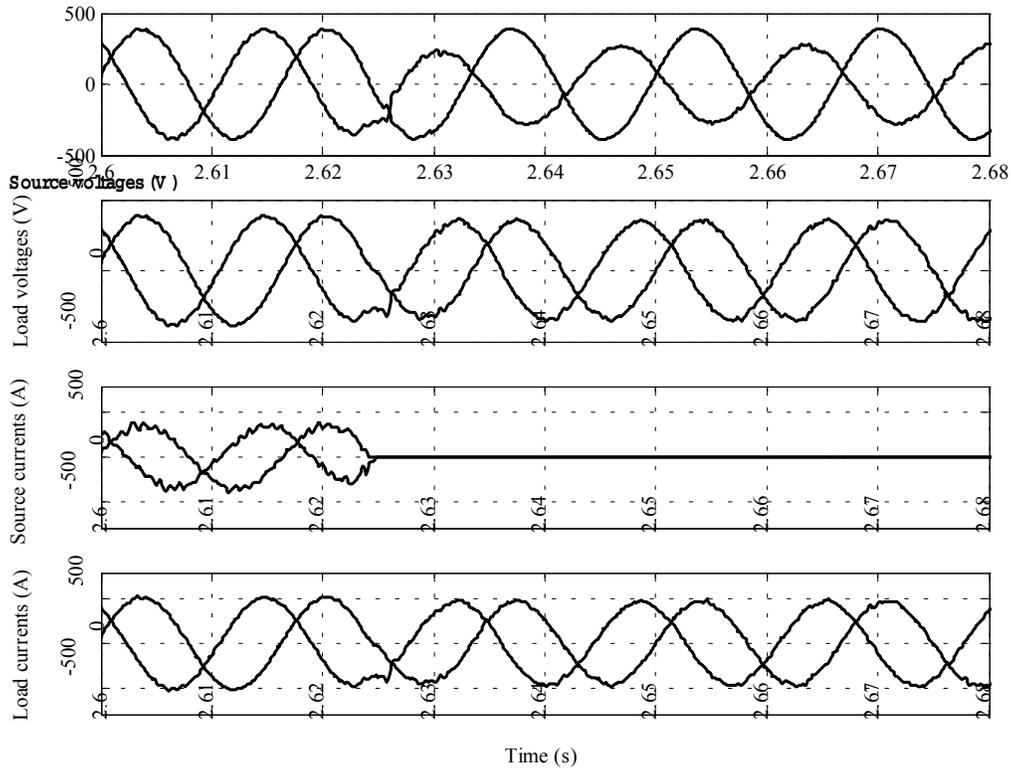


Figure 5: The system response to a PQ event test during a peak shaving cycle. The top trace shows the two phases (a, b) of source voltages, the second trace is the load voltages, the third trace is the source currents and the bottom trace is the load currents.

Correct operation of the NAS battery system has been validated for all operational states of the system for single phase and multiple phase disturbances and outage.

Sample Results/Data- Peak Shaving Example

When this project was started, the building load was estimated to be near 500kW . Since that time, occupancy has been reduced resulting in a reduction in building load . As a result, the building load is now less than optimal for demonstrating the value of peak shaving . It was decided to continue the project at this location to get valued experience with the technology and to demonstrate the dynamics of combined PQ/PS operation . Additionally, it is felt that the value proposition can be determined through analysis and simulation.

The example below illustrates a case where there is little variation between on and off peak building demand and in fact, this type of load is not a good candidate for peak shaving application. The example does illustrate peak shaving dynamics. The example shows that during daytime hours, the demand from the grid is reduced by approximately 100kW. At night, the NAS charging current is added to the building load and in this case causes a higher peak than during the day. This is not an entirely bad situation and is referred to as peak shaping. That is, the peak is moved from the heavily loaded daytime hours to an off peak period, providing load leveling to the EPS. From an end user perspective, dynamics shown in figure 1 are preferred.

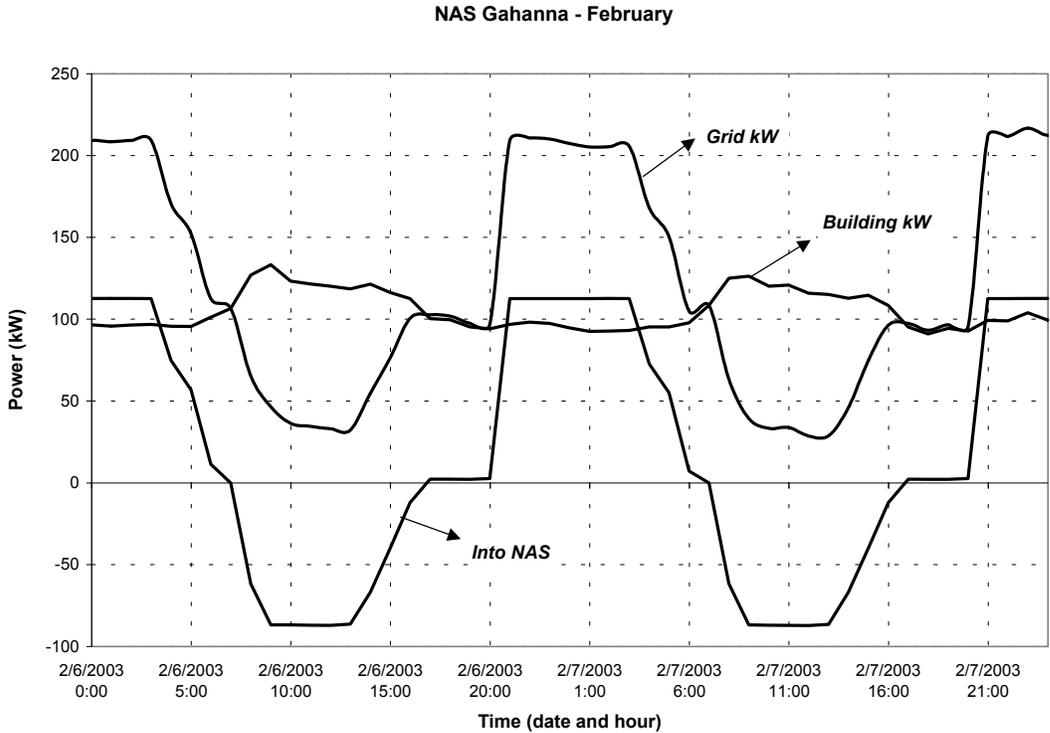


Figure 6: A peak shaving cycle ,showing grid, building and NAS power flows

Closing Comments

Innovative energy suppliers will utilize cost effective ES technology to deliver high quality service in this complex market. Energy Storage and in particular the sodium sulfur battery offer unique solutions to energy management (peak shaving), reliability (outage) and power quality (momentary interruption) issues. These applications increase asset utilization and provide alternatives to meet peak demand and critical load. A project to demonstrate an NaS battery system is in operation in Gahanna, Ohio. Both AEP and EPRI have several on-going projects related to Energy Storage .

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