MARKET DEVELOPMENT FOR THE SODIUM SULFUR BATTERY

David K. Nichols,[1] — Makoto Kamibayashi[2]

Energy storage provides Electric Utilities a means of improved asset utilization and can be used to provide high quality (premium), emergency or backup power. Rechargeable battery systems that use sodium/sulfur (NAS) technology are attractive candidates for use in many relatively large-scale energy-storage applications, including those associated with utility generation, transmission and distribution. Significant worldwide research has resulted in several advanced battery systems that can be utilized with electric power generation and distribution equipment for utility load leveling, power quality and peak shaving, helping energy providers meet peak demands and critical load. These stationary battery applications represent a very promising use for the NAS technology primarily because of its small relative footprint, high energy density, excellent electrical efficiency, minimal maintenance requirements, and long cycle life.

INTRODUCTION

Restructuring of US retail energy markets, increased wholesale competition, declining grid reliability and need for increased reliability and high quality service provides opportunity for introduction of new technology into the Energy Delivery system. Energy Storage (ES) can help meet the needs of a stressed electrical system, enhance the quality of service and allows participation in energy markets.

When properly applied, ES systems can supplement the existing central Generation, Transmission and Distribution Infrastructure and help meet peak demand. Large-scale energy storage can be used for a wide range of applications on the utility's power system and at end user facilities. The value proposition for ES is derived from the cumulative value to meet multiple applications. Integration of ES into the existing power grid improves asset utilization by allowing energy providers to better meet peak energy demand without investment in new Generation or Energy Delivery infrastructure. Unique characteristics of the Sodium Sulfur (NAS) battery make it an attractive candidate for these high value applications.

The NAS Battery has been successfully developed by the Tokyo Electric Power Company, Inc. (TEPCO) and NGK Insulators, Ltd. (NGK), demonstrated extensively at several sites in Japan and recently commercialized in Japan. AEP, NGK and TEPCO have an initiative underway to demonstrate the NAS battery in the US and to assess the related market opportunities.

CHALLENGES AND SOLUTIONS FOR ENERGY DELIVERY

The energy supply business in the US is in an era of unprecedented change. State by state restructuring is evolving and wholesale competition continues to grow. This Industry restructuring is reorganizing the energy value chain from the vertical integration of electric utilities to the unbundling of Generation, Transmission and Distribution components. Companies are forced to reinvent themselves to prepare for the future in an increasing complex market place and often must deal with a variety of regulatory conditions This varying status of deregulation adds complexity, uncertainty and risks to energy markets. The situation is exacerbated by a Transmission system that was not designed for an open market and is in need of transformation to meet expected demands. In recent years Transmission investment has failed to track Generation investment, resulting in reduced margins and increased congestion. Transforming the existing legacy Transmission system to that needed for an open market will be costly. These market and restructuring conditions, projected 1.8% per year load growth, declining grid reliability, increased transmission constraints and increased need for high quality service provide electricity providers challenges and opportunities. The challenge utilities face is to figure out how to deliver a higher quality service in this uncertain environment. The successful Energy Provider must transform the existing system, integrate new technology solutions, meet customer needs and create shareholder value.

There are many technology-based solutions to help meet the increasing demands. These solutions are enabled by the application of information and communication technology, power electronics and advanced materials and control systems. Each of these enabling technologies has seen exponential growth in recent years accelerating the rapid development of technology-based solutions for the energy industry.

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[1] American Electric Power Service Corporation, Groveport, Ohio. Email: dknichols@aep.com
[2] Tokyo Electric Power Company, Inc., Tokyo, Japan

Distributed Energy Resource (DER) technologies have received much attention recently as a means of possible reliability, security and delivery enhancement and low cost energy delivery. The DER family consists of several generation and energy storage systems with applications at Distribution substations and end-user sites.

It is expected that initially, DER will play a complementary role to existing central generation and grid infrastructure to meet new load and peak demand plus provide grid stability and end-user power quality solutions and will progressively commercialize over the next 10 years as shown in Figure 1. According to the US Department of Energy, *"Over the next decade, the domestic distributed generation market, in terms of installed capacity to meet the demand, is estimated to be 5-6 gigawatts per year."* Energy storage devices will be part of this growth. Properly located, DER can be used to offset or delay new line construction and equipment upgrade. By locating energy sources near the load, it is possible to reduce the exposure to System disturbances and Transmission and Distribution losses.

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 level and volatility and power quality related problems. As a result, it is necessary to build and operate the power system to meet peak demand, adding significantly to the cost of service. As such, electrical energy providers have long sought large-scale economic storage of electrical energy. Energy Storage can be used to provide various combinations of the following applications.
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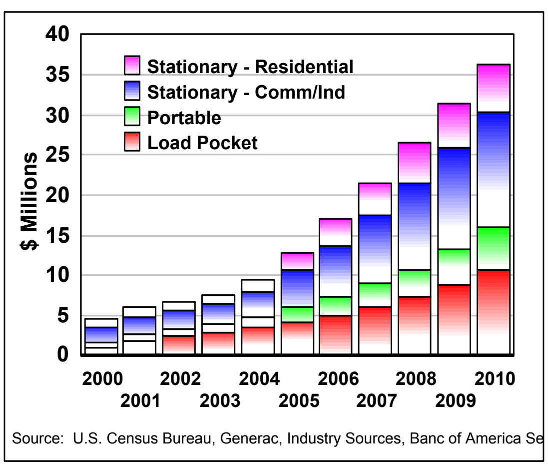
- Peak Shaving/ Load Leveling
- Improved Power Quality
- Emergency/Backup Energy
- Defer New Central Generation
- Improved Operating Condition
- Voltage Support
- Loss Reduction
- Transmission & Distribution Capacity Release
- Deferments of New or Upgraded T&D Infrastructure
- Improved Utility System Reliability
- Low Cost Energy
- Spinning Reserve



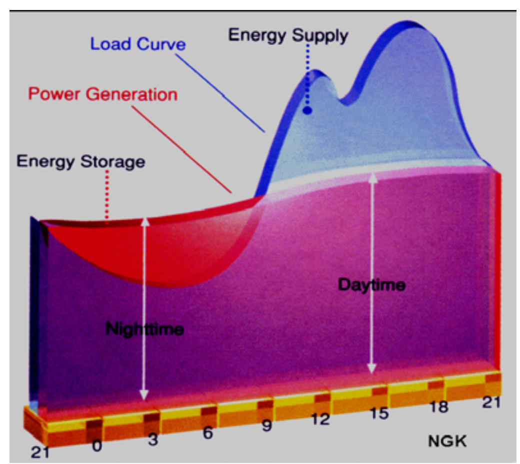


Figure 1 – Projected U.S. Market Penetration: Distributed Generation

Figure 2 – Load Leveling Cycle

The value of Energy Storage is significant and is expected to grow in the new energy markets as deregulation unfolds and 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 2 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, allowing energy providers to better meet peak demand. 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.

Increased customer reliability demands often exceed the normal levels provided by utilities. In fact, some industries require greater than 99.9999% reliable electricity delivery. Losses approaching $1,000,000/minute and $6,000,000 per hour have been claimed by high tech business. 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 back up capability for longer events. Energy storage can be used to achieve reliability levels that exceed the nominal utility delivered reliability level of 99.97%, consisting of 1.7 outages lasting a total of 170 minutes per year.

Energy storage can also be utilized as a means to stabilize the output of intermittent sources like photovoltaics and wind turbines and augment the output of other DER. Power Quality and peak shaving applications described above provide the highest value to the energy provider and end user. The real value of an energy storage application is the aggregated worth obtained from each application value component that accrues in the wholesale market and for locational value. These applications include energy arbitrage, capacity market, ancillary services, trading, T&D substitution, backup power and power quality solutions.

SODIUM SULFUR BATTERY

Sodium Sulfur battery's excellent energy and power density, high electrical efficiency, long life, small footprint, pulse power capability, instantaneous response and reliable operation make it an excellent candidate for Electric Power System (EPS) application. NAS battery modules are compact (.1kWh/kg), efficient (83% excluding necessary power electronics) and last more than 2500 full discharge cycles. The 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. This unique pulse capability makes NAS an excellent choice for PQ (or UPS) and combined PS/PQ applications.

Pioneer development of the sodium-sulfur battery was conducted during the 1960s by the Ford Motor Company and BBC (now ABB) for EV applications and later in the 1970s by GE and others for stationary applications. TEPCO, the largest private electric utility in the world has been developing NAS battery technology jointly with NGK since 1984. During that time and since, TEPCO and NGK have engaged in extensive R&D, testing and demonstration to improve battery performance and reduce costs. NGK established a cooperative technology exchange with ABB in the late-1980s with a resultant worldwide license for the ABB-based sodium-sulfur technology in 1998. NGK utilized its ceramic expertise to master NAS Battery ceramic component design. TEPCO/NGK R&D activities enlarged the size of the cell, improved efficiency, increased durability, reassured safety, integrated thousands of cells and added sophisticated control.

Through March 2002, 43 demonstration and precommercial projects have been deployed with a combined 27 MW, 200 MWh capacities. These demonstrations include two 6 MW, 48 MWh systems, respectively at TEPCO's Tsunashima and Ohito stations. Table 1 illustrates the high level of cell integration and reliability that has been achieved with the latest cell design (T5). Figure 3 shows the Ohito 6 MW installation. The NAS battery technology is mature, as evidenced by the TEPCO installations and confirmed performance. TEPCO has now initiated the commercialization of the NAS battery in their service area, with emphasis on site entry peak shaving, back up power, and power quality applications. To meet this demand plus provide NAS battery systems throughout the rest of Japan, NGK is building an expanded, automated production facility with an initial capacity of 50MW/yr scheduled for April 2003.

Table 1 - Reliability of NAS Battery

Name	Commissioning	No. of Cells	No. Of Cycles
Ohito No. 1	1999, 3	15,360	655
Ohito No. 2	1999, 6	15,360	487
Ohito No. 3	1999, 10	15,360	486
Tsunashima No. 2	2000, 11	12,800	432
Shinagawa	2001, 3	12,800	304

Figure 3 – TEPCOs Ohito Station

AEP's ENERGY STORAGE INTERESTS, ACTIVITIES AND FINDINGS

AEP seeks to understand market issues, new technologies and their applications and the value proposition created by adoption. Understanding technical aspects of new technology is accelerated through testing at the Dolan Technology Center. Application knowledge is advanced through prototype installation and continued monitoring and analysis of that experience. In the end, the adoption of any new technology is driven by the market.

AEP’s activities with Energy Storage include developing adequate test facilities to validate system performance, assessing optimization strategies, directing interconnection, integration and aggregation analyses and conducting economic and business modeling. Test facilities were developed based on AEP’s past test experiences and include equipment and development of appropriate test protocols to simulate known power system disturbances and anomalies. The facility is intended for testing of various types DER and has already been used for evaluation of micro turbines and energy storage, photovoltaic and wind turbine systems. The test facilities are used to determine electrical characteristics of devices and include infrastructure for compatibility testing and economic assessment. Compatibility testing addresses User considerations for survivability and functionality, EPS performance issues, compliance with IEEE P1547 and identifies issues and problems associated with applications.

Initial US NAS Project efforts are focused on high value applications for combined power quality and peak shaving markets for commercial and industrial end-users and different combinations of power quality, load leveling, ancillary services, and infrastructure deferral for utility-based markets. NAS system operational power quality durations of 30 seconds and five minutes allows for bridge power to diesel gensets and gas turbines, respectively .The 5 minute capability can be used for prompt spinning reserve response.

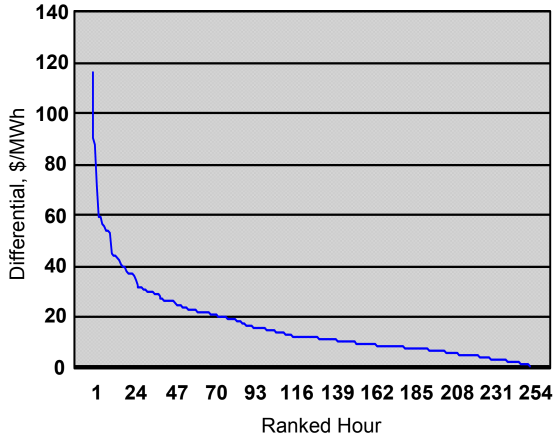


Figure 4 – Daily Price Differential

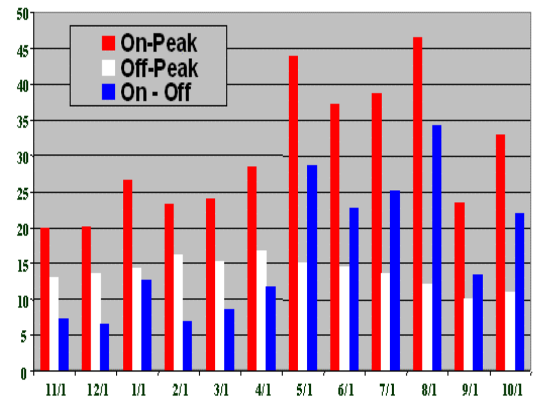


Figure 5 – Average On- and Off-Peak Prices

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, NAS application can reduce the cost of reconductoring, right of way purchase or station equipment upgrade. A review of 8 random upgrade projects at AEP and some national averages shows that the costs of projects vary greatly. To illustrate, the cost of the eight reviewed projects ranged from $29/kW to $169/kW with a $74/kW average. Over a recent 12 month time 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 both across the US, hourly and seasonally, as shown in figures 4 and 5.

Our studies show that the highest value opportunities for NAS battery reside in combining load leveling with power quality applications. Accordingly, AEP's attention has been focused on confirming the suitability of NAS battery technical attributes for such applications.

AEP has completed extensive Laboratory testing of a 12.5 kW NAS system at the Dolan Technology Center including routine nominal power level peak shaving testing and select high power level/short duration testing associated with power quality applications. Familiarization tests were performed on this system to better understand the relationship between NAS battery performance drivers - internal temperature and resistance, open circuit voltage and depth of discharge.

Temperature is one of the most important parameters that define NAS PQ performance as it has a direct affect on the resistance. By controlling temperature, it is possible to obtain the necessary internal resistance required for PS or PQ operation. Test results have shown that the PQ capability of the battery improves at high temperatures. While the PQ readiness of the battery is achieved by keeping the temperature high, the maximum allowable temperature limits the PQ availability. Therefore, proper thermal management is needed for optimum performance.

Internal resistance consists of two components: ohmic and polarization resistance. Ohmic resistance consists of the beta alumina tube and other components and decreases with increasing temperature. Polarization resistance is a result of chemical states and varies with depth of discharge and temperature. Polarization increases as the depth of discharge increases up to some depth of discharge, which is characterized by a change in chemical state and then gradually decreases. Figure 6 shows the variation of battery temperature and the total internal resistance for given discharge condition in PS mode.

Figure 7 shows the battery terminal voltage and the temperature variations when a set of short duration PQ events was performed with the battery in PS mode and the same discharge condition as in Fig. 6. Comparing Figures 6 and 7 reveals that a 30-second 500% power pulse has minimal affect on battery temperature and depth of discharge. However, consecutive PQ events result in accumulative increase in temperature. The apparent voltage spikes during PQ events in Fig. 7 resulted from anomalies caused by the test method. An alternate measurement indicated that the terminal voltage decreased during the PQ event dependent on the internal resistance, temperature and depth of discharge.

Another parameter that affects PQ performance is the open circuit voltage, which is dependent on the depth of discharge. Deep discharge of the battery causes a decrease in open circuit voltage that limits PQ capability.

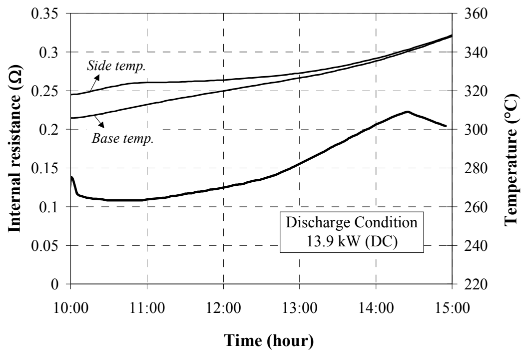


Figure 6 - The battery total internal resistance and temperature profile for given discharge condition in PS mode. The thick solid curve is the internal resistance.

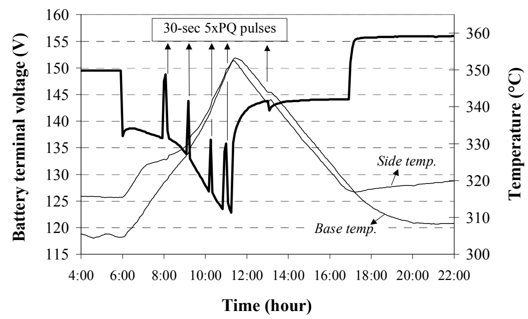


Figure 7 - The battery terminal voltage and temperature profile for operation under combined PS and PQ. Discharge condition is the same as in Fig. 6. The thick solid curve is the battery terminal voltage.

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. The test results showed that NAS battery is capable of handling high PQ powers as long as there is sufficient remaining charge. The only PQ limitation is the possibility of exceeding safe operating temperature limits, which may occur near the end of discharge where the temperature is the highest. With advanced controllers, this is not a challenging problem. In conclusion, the test results indicate that the battery is available for pulsed duty throughout the charge /discharge cycle. NAS battery integrated with advanced power electronics and with embedded smart controllers can adequately satisfy the needed power quality and load leveling requirements.

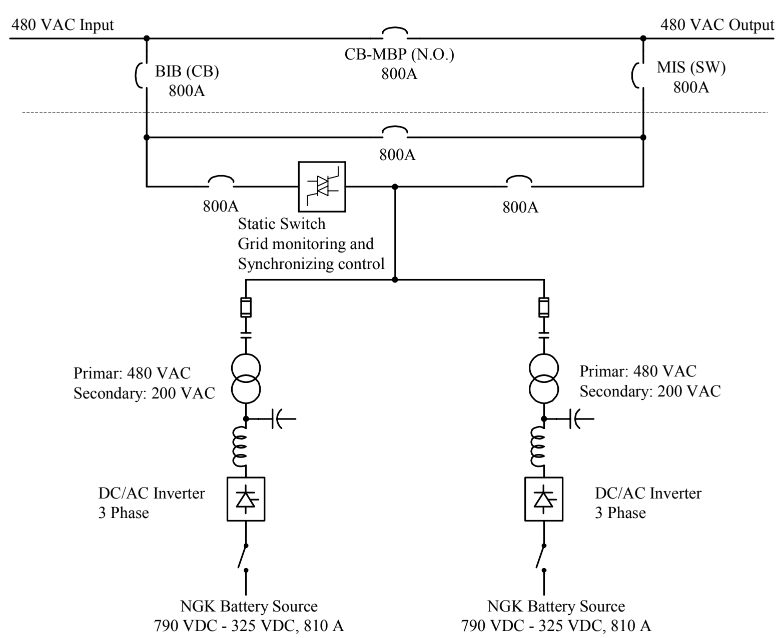


Figure 8 – ABB 500 kW PQ, 100 kW PCS.

Plans for demonstrating the NAS battery on the AEP System are focused on an initial two-battery module project with a combined rating of 500kW for 30 seconds of power quality protection plus 100kW of peak shaving capacity. ABB was selected to supply the power electronics and system integration for the project, which has a targeted end of July in service to date at an AEP office building near Columbus, Ohio. The project includes a rigorous acceptance test program and long term monitoring to assess NAS performance and cost effectiveness and determine electrical characteristics. A block diagram of the ABB supplied Power Conversion System (PCS) is shown in Fig. 8. The specifications require compliance with several Standards including IEEE P1547. The monitoring package includes wireless 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.

CONCLUSION

The energy delivery business in the US is in an unprecedented era of change. Restructuring, wholesale competition and application of new technologies introduces uncertainty into energy markets. 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. Innovative energy suppliers will utilize this technology to deliver high quality service in a complex market.

With a base of successful experience, TEPCO and NGK have now committed to commercialize the NAS battery in Japan. Beginning in April 2002, TEPCO will market NAS battery systems within their service area with emphasis on medium-to-large commercial, industrial and water/sewer system customers with an incentive for peak shaving and enhanced power quality/reliability. In response, NGK has committed to expand their NAS battery manufacturing operations to about 50MW/yr by April 2003 with plans for further expansion. In addition, NGK has teamed with major Japanese power electronics suppliers to be able to offer a fully integrated NAS system throughout Japan.

In parallel with the commercialization of the NAS battery in Japan, market development efforts in the U.S. have been advancing. In cooperation with TEPCO and NGK, over the past two years, AEP has been assessing market applications of common interests, conducting familiarization testing of a NAS test module at their Dolan Technology Center, and advancing plans for the demonstration and deployment of the NAS battery on the AEP system and other systems.

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