FEASIBILITY STUDY OF BATTERY ENERGY STORAGE SYSTEM WITH POWER QUALITY SUPPORT IN MALAYSIA

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ABSTRACT

The paper describes potential of Battery Energy Storage System (BESS) in Malaysia focusing in particular the use of Advanced Sodium Sulfur (NAS) Battery. NAS-BESS is considered because of its special characteristics and capability that enables hybrid use of load levelling and power quality improvement. Various applications of BESS will be described together with case studies of potential benefits to utility and customers in Malaysia. Even though the use of energy storage system is not yet critical in Malaysia, this paper will attempt to present analysis and potential benefits of BESS applications for TNB and its large power users.

1. INTRODUCTION

The adoption of electrical energy storage system on utility networks is likely to result in a significant range of application and benefits. BESS is mostly used for a variety of applications such as power quality assurance, transmission and distribution facility investment deferral, voltage regulation, load levelling and integration with renewable energy generation plants. Battery systems appear to offer the most benefits when providing power management support and when responding to instant voltage spikes or sags and outages.

Since 1983, Tokyo Electric Power Company (TEPCO) has looked into the potential of advanced Sodium Sulfur (NAS) battery for electric energy storage. This promising battery system has been developed for various applications such as emergency power source, uninterruptible power supply and also for load leveling are now ready for commercial development.

This paper describes various types and applications of energy storage technologies focusing on the application of NAS battery. The case studies will be described on the potential benefits (including power quality support) of this advanced battery for both utility and customers in Malaysia. Initial study has also been conducted at a remote island for a possibility of hybrid application together with mini-hydro scheme to reduce dependency on diesel generation thus reducing generation costs.

2. TYPES OF ENERGY STORAGE SYSTEM (ESS)

Number of energy storage technologies available nowadays can be generally categorised by means of chemical, mechanical and electrical. Several types of ESS which have been developed or currently under development are as follows:

2.1 Pumped Hydro Storage

Pumped-hydro storage is the oldest and largest of all of the commercially available energy storage technologies [1], with facilities up to 1000 MW. It differs from conventional hydroelectric projects as they pump water from a lower reservoir to an upper reservoir during the off-peak times. During peak hours, the stored water is then released back down to the lower reservoir, passing through hydraulic turbines to generate electricity. Operating cost per unit energy varies with operational pattern. For a large storage system, the operating cost per “kW” tends to be small. However, the capital cost of a pumped hydroelectric plant is massive, as it often involves building dams and enormous underground pipes. Environmentally, even though it produces no pollution or waste, it disturbs the local habitat as the water level fluctuates daily. Other drawbacks of pumped hydro storage are limitation in site location, remote from demand centre and long construction period.

2.2 Compressed Air Energy Storage (CAES)

Compressed air energy storage system (CAES) uses off-peak power to pressurize air into an underground reservoir (salt cavern, abandoned hard rock mine, or aquifer) which is then released during peak daytime hours to be used in a gas turbine for power production. Typical capacities for a CAES system are around 50-300 MW. It significantly increases the efficiency of a gas turbine plant since roughly two thirds of the energy produced is used to pressurize the air. Apart from fast start-up, a CAES system has the longest storage period of more than a year due to very small losses. The main drawback of CAES is probably the geological structure reliance, with limitation in underground cavern around. However, for locations where it is suitable, it can provide a viable option for storing energy in large quantities and for long times.
2.3 Battery Energy Storage System (BESS)

Batteries are one of the most cost-effective energy storage technologies available, with energy stored electrochemically. Key factors of batteries for storage applications include: high energy density, high energy capability, round trip efficiency, cycling capability, life span, and initial cost [2]. Currently, lead-acid batteries are the primary storage component used in various applications such as power quality improvement. However, due to the reliability and maintenance issues associated with these batteries, other battery technologies such as lithium-ion and advanced sodium sulfur (NAS) that are excellent in supporting power quality application have quickly becoming commercially available.

2.4 Flywheel Storage

A flywheel energy storage system works by accelerating a rotor to a very high speed and maintaining the energy in the system as inertial energy [1], [2]. The stored energy is release by reversing the process and using the motor as a generator where the flywheel's rotor slows until it is discharged. The main applications of flywheels are to supply components and machines with high output power when there is a power surge or a shutdown. Flywheels have been introduced in the electric vehicles market [1] as alternatives to chemical battery as they have unlimited charging-discharging cycles. Nowadays, research is carried out for the use of flywheels in different fields such as the application in starting and braking locomotives.

2.5 Superconducting Magnetic Energy Storage (SMES)

SMES systems store energy in the magnetic field created by the flow of direct current in a coil of cryogenically cooled, superconducting material [2]. In AC applications, the electrical losses can be minimized through appropriate wire architecture and device design, while for both DC and AC applications energy savings will be significant. SMES are highly efficient at storing electricity (greater than 95%), and provide both real and reactive power. These facilities are used to provide grid stability in a distribution system and power quality at manufacturing plants requiring ultra-clean power, such as microchip fabrication facilities.

2.6 Supercapacitors

Supercapacitors (also known as ultracapacitors) are DC energy sources and must be interfaced to the electric grid with a static power conditioner, providing 50/60-Hz output. Small supercapacitors are commercially available to extend battery life in electronic equipment, but large supercapacitors are still in development, but may soon become a viable component of the energy storage field. Even though they have a lower energy density, can supply larger power, supercapacitors are well suited to replace batteries in many applications especially in power quality support. Supercapacitors has unlimited number of charging/discharging cycles and capable to discharge in milliseconds while producing enormous currents. Other advantages of supercapacitors are long lifetime, environmentally friendly and their performance does not degrade with time.

2.7 Thermal Energy Storage

Another efficient way of storing energy is by means of underground thermal. Thermal system can either be ice-based (for peak-shaving commercial and industrial cooling loads), or heliostat-based (mirror-based) using molten salt for electric power production. Thermal energy storage with a storage tank is widely used in Japan. One of its drawbacks is form of energy stored. Electrical energy is transformed to thermal energy and reverse transformation is not effective, so usage of stored energy shall be limited to thermal energy use, such as air conditioning and hot water only. As for heliostat-based thermal storage, it might be disadvantage in terms of cost effectiveness.

3. APPLICATION AND BENEFITS OF ENERGY STORAGE SYSTEM

One of the most common applications of ESS is for load leveling. Output of ESS can be adjusted in accordance with customers load curve and therefore peak demand can be suppressed effectively. This will assist customers in providing energy cost reduction.

For utilities, ESS has application within the transmission and distribution (T&D) network that could enhance their asset utilization and defer transmission upgrades. ESS can be used for operating T&D at higher load factor or for individual transmission lines approaching peak rating by decreasing demand side peak load. These will avoid the needs to upgrade/enhancement or to construct new lines and substation while at the same time relieve transmission constraints. An ESS can also support T & D system in terms of voltage, VAR and capacity by giving the utility the ability to incrementally add their capacity and stabilize voltage level on transmission lines as needed. At distribution level, voltage drops can also be mitigated by real and reactive power control.

Another application of ESS is for power quality support and improvement, mitigating power disturbances especially at premium industrial facilities such as automated manufacturing plants. ESS is the key component, not only in the commonly used battery-backed uninterruptible power supply (UPS) system but also in alternatives such as flywheel-UPS system and SMES that are designed to provide ride-through power during interruption and to correct voltage sags and anomalies [2].
As for electricity generation application especially for utilities, ESS as a generating resource could provide savings in operation costs or in capital expenditures in many ways. ESS can be used for inter-temporal energy price arbitrage by taking advantage of price differentials between peak and off-peak. Power can be bought and stored during off-peak times and sold back into the market during peak times.

Constant load generators such as some types of biomass can be integrated with ESS to provide ramping and peaking duties on a local grid. In addition, embedded generation facilities could also use the system that will significantly reduce their operating cost. ESS can also be alternatives for conventional generating units to provide spinning reserve and other auxiliary services, with associated cost and environment savings.

By integrating with renewable energy generation plants, ESS enables intermittent renewable energy sources such as sunlight and wind on the electric grid. This hybrid renewable system will become more widely used for grid-tied application as ESS increases the value of intermittent renewable generation such as photovoltaic and wind-generated electricity.

4. CASE STUDY 1: APPLICATION OF NAS-BESS WITH PQ SUPPORT

As many other countries in the world, frequent voltage sags becomes the main concern among various power quality issues in Malaysia since it can cause process shutdown to sensitive customers resulting great losses in time, material and financial. With such a high usage of electricity from industrial customers using sensitive electronics devices, power quality problem is taken seriously by Tenaga Nasional Berhad (TNB) as the main utility company in Malaysia.

4.1 Features of NAS Battery

Advanced NAS Battery is considered because of its special characteristics and capabilities as follows:

- High pulse power can be supplied for a short period.

Since one of its main features is large capacity, NAS battery is suitable for hybrid application for both power quality improvement and load leveling. For load leveling use, necessary output is ranging from 20 to 30% of contract power with output duration of 2 to 8 hours. For power quality use, necessary output is equal to important load capacity, (in some cases 100% contract power) while necessary duration of output is several seconds to minutes [3].

4.2 System Design Requirements

Prior to designing NAS battery energy storage system (BESS) for load leveling and power quality improvement, the requirements for each application must be clearly defined.

For load leveling use, electricity tariff structure and typical load curve at a customer site are important. In the TNB tariff system for industrial customers, there are only two categories, peak and off-peak for demand charge. Peak period starts from 8am to 10pm. NAS Battery will be used to store cheaper electricity during the off-peak period. Since the daily charge-discharge efficiency of NAS battery is around 80%, the stored electricity can be discharged at rated power for 8 hours.

A simple study has been completed based on customer’s actual load profile. Based on the current tariff structure, the requirement for load leveling is not so important and attractive in terms of energy saving gained [3].

In the case of using NAS battery for voltage sags protection, duration and interval of voltage sags are key factors for system design. Typical duration of voltage sags depends on power network protection system and nature of faults. According to a study funded by the Malaysian Electricity Supply Industry Trust Account, the voltage sag events profile (compiled in a year) has been plotted against the SEMI F47 curve. Majority duration of less than 0.2 seconds and sags with more than 1.5 seconds scarcely occur [4]. However it should be noted that different customer plants and industries has a varying degrees of sensitivity level with respect to power quality events. Proper power quality audit must be performed before deciding on a suitable solution.

4.3 System Design

Based on the requirement in Malaysia mentioned above, design for a NAS battery hybrid system is planned especially for a high-tech industry in Malaysia [3]. For load leveling use, energy charge reduction is not so important. It is recommended to restrict depth of discharge (DOD) and to make full use of pulse power capability.
For power quality use, especially voltage sag protection, duration of voltage sag is usually in milliseconds order. It is assumed that accumulated duration of voltage sags in one hour is less than 30 seconds even though the frequency of voltage sag varies by location, network performance and weather condition. The typical key specifications of the hybrid system are shown in Table 1.

### Table 1: Key Specification of NAS Battery System for a High-Tech Industry in Malaysia

<table>
<thead>
<tr>
<th>Load leveling</th>
<th>Rated Output</th>
<th>10% of peak demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power quality</td>
<td>Pulse Power Output</td>
<td>5 times rated output (half of demand secured)</td>
</tr>
<tr>
<td></td>
<td>Duration of Pulse Power</td>
<td>30 seconds in one hour</td>
</tr>
</tbody>
</table>

Other key factor that must be considered is system configuration. Standby power supply mode operation is preferable instead of UPS mode to avoid energy loss. In the case of using standby supply mode, high speed transfer switch is required to ensure load side would not be affected during voltage sag events. There are no definitive criteria applicable to any equipment even though there are some guidelines for immunity of electrical equipment such as SEMI F47 and ITIC-CBEMA curve. Thus the target is for system response time to be as short as possible by adopting solid state transfer switch.

For standby power supply mode, event detection speed is also important to ensure very fast recovery. It is thought that instantaneous d-q transformation method is appropriate for detection of an event. The threshold can be set according to equipment immunity level.

For the purpose of maintenance of this hybrid system, automatic bypass mode can be adopted. This mode is also required in the event that any faults are detected within the system. In addition, remote control and monitoring features are provided to customers for easy access and direct control from their own control centre.

### 5. CASE STUDY 2: HYBRID SYSTEM APPLICATION OF NAS-BESS FOR REMOTE ISLAND SUPPLY

Initial study has been conducted at a remote island with peak load during dry season (from April to October) of about 1000 - 1800kW, while off-peak load during rainy-season (from November to March) is about 500kW. Power is generated by reservoir type mini-hydro power station (250kW x 2) and diesel generators.

Since all the necessary diesel fuel is transported from the main land (Peninsular Malaysia), cost of diesel generation is expensive, RM0.64/kWh. On the design, mini-hydro can be operated at rated output of 500kW during half of year. However this mini-hydro is unmanned station and is not remotely controllable due to bad access. Thus, TNB is obliged to operate at reduced output to reserve required minimum output for diesel generator as illustrated in Figure 1.

For these reasons, NAS BESS is considered for hybrid application together with mini-hydro scheme to reduce dependency on diesel generation thus reducing generation costs. To realize this, NAS BESS is considered to execute output adjustment and control. This is illustrated in Figure 2 thus enabling better utilisation of the mini hydro scheme.

![Figure 1: Balance of power supply and demand in off-peak season (imaginary) [Without NAS BESS]](image1)

![Figure 2: Balance of power supply and demand in off-peak season (imaginary) [With NAS BESS]](image2)

Based on actual generation data of 4 months during off peak season, desk-top effectiveness of NAS BESS is evaluated by calculating the energy difference from diesel generator before and after installation. In this case, available mini-hydro output is set to the rated output of 500kW at any time since it is in rainy season.

After the installation, the generated energy is only 15% of those before installation, with total reduction in generation is approximately 1GWh within these 4 months. This reduction of diesel generation will lead to cost saving of fuel consumption of approximately RM650,000. However it should be noted that this result will also be affected by the reliability and availability of the mini hydro system. A further study shall be carried before implementation.
6. CONCLUSION

This paper has given an overview of various types of energy storage. Different applications and benefits are summarised with potential usage for both utility provider as well as individual customers. Through a joint research with TEPCO R&D, TNB Research has studied the potential benefits of NAS Battery with various features as described in the paper. This battery offers most benefits when serving dual purposes in both energy management and power quality support. Even though the current concern is on the system price, the mass production of NAS BESS since April 2003 may lead to further price reduction. Further study and analysis of the usage of this promising battery is on going prior to installation at a suitable customer site.

REFERENCES


