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BATTERY ENERGY STORAGE SYSTEM
Unique Asset for Power Generation & Flexible Grid Operation

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SUMMARY

Energy storage systems encompass a broad range of renewable energy technologies that store excess energy and deliver it during peak demand. Some of the existing energy storage technologies include electro-technical (battery energy), compressed air, pumped hydro, thermal and inertia (flywheel). Placing energy storage systems strategically across utility transmission systems offers a way to optimize the entire power system.

A battery energy storage system consists of power conversion hardware, including battery charging controller, storage batteries, DC to AC inverters, MV/HV power transformers and reactive power management equipment. This system provides the flexible means to peak load leveling as well as fast response to power shortages or brownouts, grid stability and reliability. Fourteen cutting-edge battery technologies are available in the market and another 9 emerging battery technologies are being tested. There are four test facilities where battery storage systems can be tested by independent entities under controlled conditions.

Some of the regulatory requirements and utility policies remain ambiguous or unknown presently and create financial risks in deployment of battery storage systems. Effort is being directed towards developing a set of technical specifications and standards to create a model for a modular architecture. Large-scale battery energy storage systems are expected to become a very important part of the power delivery system in coming years. Independent technical due-diligence assessment is essential to confirm the commercial maturity of the selected battery technology, design reliability, system configuration, system testing and regulatory compliance.

KEYWORDS

Battery Energy Storage System (BESS), Modular Energy Storage Architecture (MESA), Battery Energy Storage System Facility (BESSF) Energy Storage Management System

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INTRODUCTION

Energy storage systems encompass a broad range of renewable energy technologies that store excess energy and deliver it during peak demand, and thus, support power generation. Some of the current energy storage technologies include: electrochemical (battery energy), compressed air, pumped hydro, thermal and inertia (flywheel) energy systems. There are very few locations where either pumped hydro or compressed air storage are feasible. The other technologies are in their infancies and have no ability to scale up to the size of energy storage that is economically viable. The locations of such energy storage systems also require different considerations and solutions.

A battery energy storage system (BESS) offers least-cost technology and the opportunity for providing stability and reliability to the transmission grid. Placing battery energy storage systems strategically across the utility transmission system provides a way to optimize the entire power system. BESS is becoming a vital component of the transmission grid that provides peak leveling of electrical loads resulting in improved power flow, voltage and frequency support, and power quality. Battery energy storage facilities could reduce the need to buy new central station generation capacity. They also could reduce the need to purchase capacity in the wholesale electricity marketplace. BESS offers good business opportunities to investors and independent power producers (IPPs) in the independent system operator (ISO) energy capacity markets.

BATTERY ENERGY STORAGE SYSTEM

BESS technology stores electrical energy from the traditional power generation sources during off-peak periods, and from the intermittent generation sources, such as solar energy and wind turbine power farms. BESS consists of a battery charging controller, storage batteries, direct current (DC) to alternating current (AC) inverters, medium voltage (MV) to high voltage (HV) power transformers, reactive power controller and HV interconnection hardware for connection to the grid. It also includes data acquisition, communication and control systems.

Utilities favor battery energy storage systems because they are easily scalable and can be located almost anywhere in the system. The required battery energy storage system size ranges from 1 MW to 500 MW with target discharge duration ranging from one to six hours. BESS ratings are moving forward from 1 MW for one hour or less in demonstration projects built a few years ago to more mature bankable projects rated at 100 MW for one hour and higher.

Viable large-scale battery energy storage systems are being developed and deployed by IPPs, solar and wind energy producers, and the power transmission and distribution utilities (PTDUs) to provide economically viable power to the grid. Battery energy storage systems offer least-cost opportunity for potential levelized energy cost to a PTDU. This goal is achieved by cooperation between IPPs, the utility, ISO and the end user. Large-scale battery energy storage systems are being applied in many countries across the globe.

BATTERY TECHNOLOGIES

The cutting-edge battery technologies are being tested and deployed to make utility-scale battery storage systems that are easier and cheaper to build. Energy storage is based on one of the following existing and emerging battery technologies:

- Lithium-ion (Li-Ion)
- Lithium-ion-phosphate and graphite
- Lithium-titanate
- Lithium-sulfur
- Lithium-air

- Lithium-cobalt
- Lithium-phosphate
- Zinc-bromide
- Zinc-air flow
- Zinc-iron redox
- Zinc hybrid cathode
- Nickel-cadmium (Ni-Cd)
- Advanced lead acid flow
- Sodium-sulfur (NaS)
- Sodium-nickel-chloride
- Deep-cycle VRLA, valve-regulated
- Deep-cycle AGM maintenance-free
- Deep-cycle sealed, maintenance-free
- Power-Cube (PbC)
- Vanadium-redox (VR)
- Iron-chromium Fe-Cr)
- Hydrogen bromide (H-Br) flow
- Magnesium-antimony liquid metal

The aim of battery developers is to achieve a low-cost, modular, high-energy density, four to eight hours of energy storage, fast response and environmentally sustainable electrical energy storage system. The market share analysis shows a rise in popularity for lithium-ion, zinc bromide and sodium-sulfur battery technologies. The lithium-ion battery manufacturers are aware of the limited lifespan and safety hazards associated with these batteries and they are developing new chemistries.

MODULAR BATTERY ENERGY STORAGE FACILITY ARCHITECTURE

Battery energy storage systems are being designed and constructed in conformance with various industry codes and standards such as ANSI, IEEE, IEC and ASTM. Sandia National Laboratories Report, SAND2013-5-5131 is a good reference document which provides general guidelines on important aspects of energy storage systems. Efforts also are being directed toward development of a set of technical specifications and standards to create a model for flexible transportable modular energy storage architecture (MESA), which could be used for different size projects.

Figure A below shows a typical single-line diagram of battery energy storage system facility (BESSF) and generally includes the following major equipment:

1. An HV substation located outside the BESSF area, connecting BESSF to the utility HV system. The substation includes power transformers to transfer power at medium voltage (generally 34.5 kV) between BESSF and the utility transmission or distribution system.
2. Energy storage management system (SMS), which provides an interface between a stored energy source and the utility grid. An SMS unit has about two 600 kW DC systems, and includes battery chargers, inverters and a master control system. The DC system charges the storage batteries from the utility source during off-peak periods, and discharges the stored energy as AC power to the utility source during peak demand periods. A complete HVAC system is provided for air temperature control of the complete assembly. Four SMS units can be installed in a single factory pre-fabricated container providing about 5 MW of capacity for one hour. The quantity of SMS depends on the required MW-hour rating of BESSF.
3. Battery containers mounted on concrete piers. Two containers can be stacked on top of each other to limit the area needed for these containers.
4. Additional equipment includes: 34.5 kV/480V pad-mounted transformers to service the SMS units; 480-120/208 V low-voltage transformer for control and power in each SMS container; HV

substation transformers and associated equipment; and utility interconnection transmission line dead-end towers.

5. For higher capacity battery energy storage facilities, several power converter systems are connected in parallel that provide a better dynamic control of active and reactive power flow in both directions.

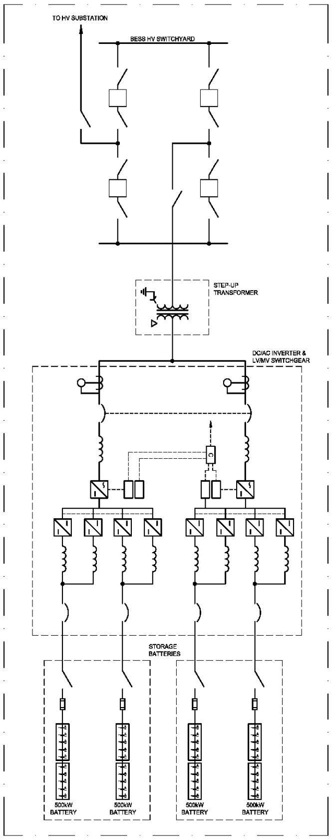

Figure A: Typical Single-Line Diagram of Battery Energy Storage System.

CODES AND REGULATIONS

Codes and regulations prepared by independent system operators and transmission system grid operators traditionally focused on static reactive power control, power factor and dynamic requirements, such as low-voltage, ride-through capability. The codes and regulations now evolving have more demanding requirements, including dynamic control of reactive power. Utilities that operate transmission and distribution grids identify the weak points where electrical energy available cannot meet the load demand in certain time periods on their networks. The grid study is performed to optimize the location of optimal point of connection where a battery energy storage system can help to enhance the system reliability.

The grid operators' decisions also are based on electricity price predictions, and how often battery energy storage facilities will run and how profitable they will be over a particular time period. Additional inputs, such as load demand forecast, system lifetime and life-cycle costs, are considered to see if the system will improve operational efficiency.

INTERCONNECTION SERVICE

Commercial BESS offers a cost-effective, viable alternative alongside a peaking plant and other resources. Its ability to act both as short-time power generation source and load during a low-demand period is unique, which helps in building a smarter and better high-voltage grid. BESS provides a more responsive, fast, economic and reliable reserve resource to the grid as it can be applied both as energy resource or capacity resource when applying for network interconnection service to an area transmission system ISO.

Commercial software now available are capable of monitoring and controlling more than a single battery energy storage facility and also enables the grid operators to visualize their entire grid network.

TESTING, INSPECTION, VERIFICATION AND CERTIFICATION

Type tests on battery storage components including cells, module and power converters, etc., are performed to provide assurance on the design and manufacturing technologies adopted for these components. There are a number of test facilities in United States and in Europe where battery storage system developers and vendors can test their battery storage components or complete systems under controlled conditions by independent entities. Some of these energy storage test facilities are:

- DOE/SNL, Albuquerque, New Mexico
- DNV-KEMA (DNV.GL), Netherlands
- EPRI, Knoxville, Tennessee
- Bonneville Power Authority, Vancouver

These facilities provide services in product development, testing, performance validation, safety evaluations and performance of grid support. They follow “Uniformly Measuring and Expressing the Performance of Energy Storage Systems” protocol and, thus, play an important role in the acceleration and commercialization of battery energy storage technologies.

TECHNOLOGY ASSESSMENT

Each battery energy storage project requires extensive technical and economic analysis. The important factors in selection of a BESSF include selection of the right type of battery technology, understanding of the battery lifespan and output degradation. Additional important factors include full or partial charging duty, required operating time, number of cycles and efficiency. Other factors that require consideration include understanding how battery storage technology will be used to improve utility system operation, finding a right site and its availability, and filing of necessary permits.

Sophisticated technical-economic assessment and evaluation software tools are now available that help in selecting the best BESS technology option. The evaluation tools analyze operation requirements of the grid system, including deliverable power, discharge duration, cycle life, system regulation, efficiency and grid upgrade deferral. They also perform a set of applications that determine the total cost of an energy storage system, return on investment and cost-benefit ratio, which enables better investment decisions.

PJM Interconnection in Audubon, Pennsylvania, has established a Storage Application Center, which tests and validates the next generation of storage applications in a real-world environment. The center also helps in refining commercial applications, such as dynamic voltage support, peaking capacity, real-time autonomous dispatch, faster regulation and protocols for merit order dispatch to validate implementation capabilities of battery-based energy storage technologies for these critical services.

ECONOMIC ASSESMENT

The key challenges to battery energy storage system sustainable growth are project uncertainty, product guarantees, insurance protection, government tax incentives and energy capacity warranties.

The costs of BESS are high compared to traditional power generation resources and no single battery technology has emerged as a preferred choice so far. However, battery energy storage systems represent a unique asset as a power supply resource with varying levels of scalability at rapid speeds that offer promise of grid flexibility.

Government incentives, loan guarantees and innovative financing models are available and are being introduced to spark strong interest in the BESS industry. Green Charge Networks' Power Efficiency Agreements (PEAs) is one of the several models being used by a number of enterprises.

INDEPENDENT ENGINEERING REVIEW

An independent engineering (IE) review is required to assess the commercial maturity of the selected battery technology, design reliability, system configuration, power conversion hardware, battery management system, testing, regulatory, safety and environmental compliance, warranty and guarantees. It also includes an independent review of ISO or utility capacity contracts and customer performance agreements, potential penalties and guarantees to capture the risk to near term and future revenues. It generally ensures that the selected battery technology and project designs are reliable and robust enough to satisfy the performance and lifetime projections that will support the project. The IE report is very valuable tool to financial institutions, which are looking for opportunities in financing promising projects.

CONCLUSIONS

A battery energy storage system provides commercial or industrial customers, power marketers and utilities the flexible means to respond to power shortages or brownouts. Adequate deployment of BESS can reduce power fluctuations, enhance system flexibility and stabilize the price spikes to the wholesale energy buyer that occur during times of peak demand. It also can delay or potentially avoid the need to construct capital-intensive power plants that use conventional fuels and produce greenhouse gases. Some IPPs and area utilities have more than eight years of operating experience with BESS rated 50 MW and higher, and have reported high satisfaction with the facilities and substantial savings to customers. Forecasts call for lots of growth for battery energy storage systems. Large-scale battery energy storage systems are expected to become a very important part of the power delivery system in the coming years.

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