SMES: Redefining the Path to Commercial Demonstration

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SMES (Superconducting Magnetic Energy Storage) is an emerging technology offering tremendous potential benefits to the utility industry. San Diego Gas & Electric (SDG&E) and Bechtel are leading a team of companies and national laboratories working towards design and construction of the world's first demonstration facility for large, commercial SMES for enhancing transmission stability in the Southwestern United States.

Environmental, economic, and regulatory forces are reshaping the way utilities generate, transport, and distribute electricity. Electric power has always been available on instant demand with a high degree of reliability, flexibility, and control. On the other hand, it has never been easily stored in large quantities. Environmental limits on generation and the advent of renewables, deregulation and competition, and the increasing complexity of transmission systems, all point towards the need for a reliable and cost-effective means to store and retrieve electric power.

In SMES, electric energy is stored by circulating a current in a superconducting coil, or inductor. Because no conversion of energy to other forms is involved (e.g., mechanical or chemical), round-trip efficiency is very high, upwards of 90%. SMES can respond very rapidly to dump or absorb power from the grid, limited only by the switching time of the solid-state components connecting the coil to the grid. SMES can typically respond to a grid transient and achieve full power in about 100 ms (or six cycles).

SMES was initially conceived as a load-leveling device to store energy in bulk to reduce a utility's daily peak demand. In that sense, SMES would fill the same market niche as pumped-hydro, batteries and compressed air energy storage (CAES). Because of its fast response, SMES can provide benefit to a utility not just as a load-leveling device, but also by enhancing transmission line stability and power quality. SMES can be viewed as a Flexible AC Transmission System (FACTS), with the added dimension that it can insert real power into the grid. Such capability can significantly improve transmission line dynamics, allowing for higher load transfer without compromising grid stability. Line stabilization will be the utility application leading to the first commercial demonstration of SMES.

Since the technology of low-temperature superconducting (LTS) wire is fully mature, early SMES units will be based on LTS. This will ensure timely demonstration of the integrated technology, and the development of a SMES market. High-temperature superconductors (HTS) can then be introduced as that technology matures in order to further reduce costs and increase the operating efficiency.

For the past six years, Bechtel has led a team of companies and national laboratories in the development and testing of a new and economical design leading to the world's first commercial demonstration SMES unit. This report describes the recent design breakthroughs, and the current efforts by San Diego Gas & Electric and the Bechtel Team to proceed with a utility demonstration of the technology: SMES-1.

PRINCIPLES OF OPERATION

As an energy storage device, SMES is a relatively simple concept. It stores electric energy in the magnetic field generated by DC current flowing through a coiled wire (see Figure 1). If the coil were wound using a conventional wire such as copper, the magnetic energy would be dissipated as heat due to the wire's resistance to the flow of current. However, if the wire is superconducting (no resistance), then energy can be stored in a "persistent" mode, virtually indefinitely, until required.

The coil is cooled to liquid helium temperature to achieve superconductivity. The superconductor of choice for this application is a niobium-titanium alloy. When the coil is energized, it is subject to outwardly radial electromagnetic forces (Lorentz loads) that need to be restrained.

The coil is a DC device, yet charge and discharge are usually accomplished through an AC utility grid, so that a power conditioning system (PCS) is required as the interface. The PCS can use a standard solid-state DC/AC converter to transfer power back between the superconducting coil and the grid/load.

HISTORY OF SMES DEVELOPMENT

Although superconductivity was not discovered until 1911, the idea of storing energy in the magnetic field of a coil is over a hundred years old, going back to the time of Nicola Tesla. Superconducting magnets as energy storage devices were proposed in the early 1960s. The use of SMES for a utility application (load-leveling) was first proposed in the late 1960s in France. In the U.S., research on SMES started in the early 1970s at the University of Wisconsin, and soon after at Los Alamos National Laboratory (LANL). A joint effort between LANL and Bonneville Power Administration (BPA) led to the design, construction, and testing of a 30 MJ (8.3 kWh)/10 MW SMES unit used on the Pacific Intertie transmission line operated by BPA to rid the line of unwanted sub-synchronous oscillations. The SMES unit built, by General Atomics, operated successfully for a year between 1983 and 1984. The BPA unit demonstrated the feasibility of the SMES concept for utility application. Industrial participation in the development of SMES started in the early 1980s, when Bechtel became involved with the technology through work with the Electric Power Research Institute (EPRI) and LANL.

In 1987, the Department of Defense (DOD) selected SMES as the only feasible power supply option for the ground-based free electron laser, which was under development as part of the Strategic Defense Initiative. The DOD launched the SMES Engineering Test Model (ETM) program to demonstrate the feasibility of the technology for the dual purpose of a power supply for military applications and energy storage for the utility industry. The SMES-ETM was designed to store 20 MWh (72 GJ), and deliver up to 400 MW.

Between 1987 and 1990 DOD, through the Defense Nuclear Agency (DNA), funded a design competition to develop a conceptual design for the SMES-ETM. Two design teams, one of which was led by Bechtel, were awarded contracts of approximately $15 million each over a 2.5 year period. When the SDI's free electron laser project was terminated the SMES-ETM program was halted. However, after a 2-year hiatus, DOD resumed the SMES development competition and awarded a total of $30 million as part of a program to reduce risks of the conceptual designs and to better define costs (the latter with EPRI support). Under DNA's sponsorship, the Bechtel Team recently completed this successful risk reduction program through component development and testing. As a result of this work, the Bechtel Team design has broken with prevailing thinking, and moved from using the earth to contain the electromagnetic forces to a self-supporting coil concept. The tremendous advantages of self-supported SMES are apparent in Figure 2. The result of this paradigm shift is a more reliable, affordable, marketable product, and a new path to technology demonstration.

DNA also conducted a Utility Application seminar to determine the ranges of energy and power for different applications. The results of this workshop are summarized in Figure 3. To assure low risk technology, DNA formed a Technical Review Committee (TRC) consisting of EPRI and recognized experts on superconductivity applications and chartered them with reviewing the design. In addition to reviewing the underground earth supported design, the TRC also conducted an in-depth review of Bechtel's above-ground self supporting coil design described in the next section.

SELF-SUPPORTING SMES DESIGN

The major elements comprising a self-supported SMES plant are shown in Figure 4. The proportions shown are for a 1 MWh/500 MW unit. The centerpiece is the superconducting coil, enclosed in a vacuum vessel to minimize heat loads to the helium cryogen. The power conditioning building houses the power conditioning system equipment required to interface between the electric power grid (and switchyard) and the coil. The switchyard is also part of this system. The cryogenics building houses the major components of the cryogenic and vacuum pumping systems that cool the coil, and the administration building houses offices and the control room.

All the magnetic forces to which the coil is subjected are reacted to by the coil structure itself, so that the system can be built above ground. Initially it was believed that large-scale SMES would only be economical with earth (warm) support. The present design, however, uses a strong cable-in-conduit conductor which allows for an efficient support structure. In this concept, a self-supporting coil is substantially cheaper than its earth-supported counterpart for stored energies up to 3,000 MWh. This is a major departure from prevailing thinking.

The added cost for coil material (alloy aluminum) in the self-supporting design are more than offset by cost savings through simplification and enhanced constructibility. Major systems and components are eliminated: trench, cold-to-warm supports, shield penetrations, coil attachments, associated instrumentation and parts, etc. The simplified self-supporting system is shown in Figure 5.

The self-supported design is also easier to construct, leading to cost reductions through shortened schedule and reduced risk. There are fewer parts to install and keep track of, construction is above grade, and the thermal shield system (a labor intensive item) is much easier to install due to less demanding tolerances and absence of complicated penetrations. The end result is a 30% cost reduction and a 25% reduction in construction schedule.

In addition to lower capital costs, the elimination of conduction losses through the cold-to-warm supports also reduces operating costs. As the coil is above ground, siting flexibility is excellent because soil conditions and water table considerations are completely removed.

The self-supporting SMES system is not only lower in risk, it is also very scalable. By changing the size of the conductor, the aluminum dump shunt/support, and pultrusion support/insulation member, the same basic design can be adapted for coils storing from 1 MWh to 1,000 MWh and more (see Figure 6). This scalability, and the reduced cost and risk of the self-supporting design define a new path for the demonstration and commercialization of SMES.

THE NEXT STEP: SMES-1

While the key components have been successfully manufactured and tested, demonstration of SMES technology as an integrated system is a prerequisite to broad acceptance and application by the utility industry. In addition to demonstrating SMES technical performance, it would provide the cost and schedule information needed to back future investment decisions by the utilities.

SDG&E and Bechtel are presently actively pursuing the formation of a consortium to design, construct, and operate a demonstration unit. The mission is to stimulate the development of a domestic SMES industry through a government, utility, and industry cost-sharing demonstration (SMES-1 prototype) program while simultaneously enhancing utility asset efficiency in the Southwest United States. Although still in its definition phase, SMES-1 is envisioned as a 1 to 3 MWh device, with a power capability of 500 MW, and connected to the grid in a transmission stabilization mode (the dimensions shown in Figure 4 roughly correspond to a 1 MWh coil and a 500 MW PCS). SMES-1 will be located at SDG&E's Blythe, California site and would increase simultaneous load-transfer operating limits by 8% for import of power to Southern California. The experience gained with this plant would advance SMES technology for other utility applications, providing such benefits as increased transmission capacity, voltage control, SSR damping, tie line control, spinning reserve, frequency control, energy storage (renewables), underfrequency load shedding reduction, and black start. The SMES-1 plan is fully responsive to DOE's national energy strategy which calls for the utility industry to meet the challenges of accommodating increased transmission system access, resulting in greatly increased complexity of control and protection without compromising reliability of service; accommodating the need to increase asset utilization while minimizing new capital investment through modernization and plant life extension and reliability-centered maintenance; automation of the energy delivery system for expanded customer services and full adoption of integrated resource/delivery planning and operation; integrating distributed generating resources that may not be utility-owned or -controlled; increasing the power transmission capability of existing right-of-way corridors to offset difficulties in siting new corridors; and incorporating energy storage technologies as a viable option.