An overview of Superconducting Magnetic Energy Storage (SMES) and Its Applications

Conference Paper · January 2018

3 authors:


Md. Abdullah Al Zaman
Northern University Bangladesh


Sabbir Ahmed


Nusrath Jahan Monira
University of Chittagong

An Overview of Superconducting Magnetic Energy Storage (SMES) and Its Applications

Md. Abdullah Al Zaman[1], Sabbir Ahmed[2], Nusrath Jahan Monira[3]

[1,2,3]Department of Physics
University of Chittagong
Chittagong-4331, Bangladesh
01627041786
E-mail: Proyashzaman@gmail.com

ABSTRACT

Superconducting magnetic energy storage (SMES) is a promising, highly efficient energy storing device. It's very interesting for high power and short-time applications. In 1970, first study on SMES appeared and since then it's a topic of interest for many scientists and the people working on energy sectors. A SMES device possesses excellent efficiency of energy transfer conversion which is greater than 96%. A superconducting magnet is the heart of this device. High capital cost is still the obstacle for widespread utilization of SMES devices. In this paper we have focused on the organization of the SMES device, discussed about its history, opportunities and limitations and after that we have talked about some of the applications of this technology. We think that in future this technology may replace many other devices that we use today.

I. INTRODUCTION

SMES is an energy storage system that was first proposed in 1979, capable of storing electric energy in the magnetic field generated by DC current flowing through it. Superconductivity is a phenomenon of exactly zero electrical resistance and expulsion of magnetic fields occurring in certain materials when cooled below a characteristic critical temperature. The metals following the character are called superconductors. In SMES, conductors for carrying the current operate at cryogenic temperatures where it becomes superconductor and thus has virtually no resistive losses as it produces the magnetic field. In this state the current in a coil can flow for infinite time. This can also be seen from the time constant of a coil $\tau = L/R$, where R goes to zero and τ then goes to infinity. The energy stored is inductive.

The energy stored in such circuit can be written in the form,

$$E = \frac{1}{2} L I^2$$

II. COMPONENTS OF A SMES SYSTEM

A SMES system consists of four components and they are

1. Superconducting magnet with its supporting structure
2. Cryogenic refrigerator or cryogenic system
3. Power conditioning system (PCS)
4. Control system.

Figure 1 illustrates the organization of a typical SMES system.

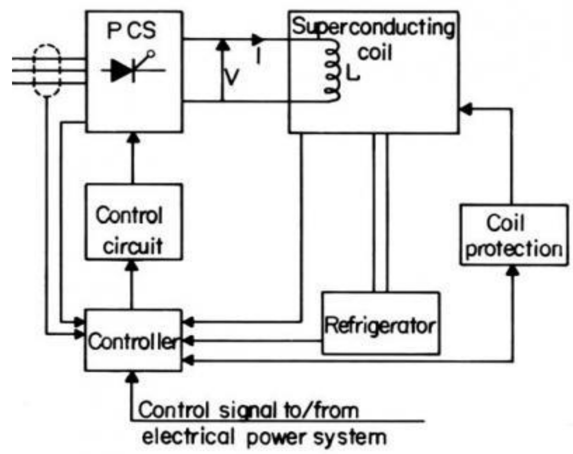

Figure 1: Schematic diagram of a SMES system.

A. **Superconducting magnet and supporting structure** includes a superconducting coil, magnet and coil protection. The superconducting coil is the heart of a SMES system, stores energy in the magnetic field generated by a circulating current. The maximum stored energy can be determined by two factors [15]
   - **i.** Size and geometry of the coil, larger the coil, the greater the energy.
   - **ii.** Characteristics of the conductor, which determines the maximum current.

There are two main magnet topologies; Solenoid and Toroid [7][14]. Because of relatively lower conductor amount and supporting structure requirement with low cost, Solenoids are more used than toroid arrangement.

Superconducting materials used as magnet in SMES system are of two types

- **i.** Low-temperature superconductor magnet (LTS)
- **ii.** High-temperature superconductor magnet (HTS)

At present a superconducting alloy of **Niobium** and **Titanium** (Nb-Ti) is utilized in the SMES systems. But this alloy requires being operated at 4.2 k. Though it's good at work but remains pretty expensive in terms of investment and operational cost. [14] Due to this researchers are more interested to utilize the HTS where the temperature requirement is relatively easier to attain. Some research-based SMES systems use HTS. The protection system can vary with the size and power requirement of the SMES system. Its main function is to dissipate energy in any kind of failure in the system and also making the arrangement stable. [13]

B. **The cryogenic refrigerator** or cryogenic system includes cryostat, compressor, vacuum enclosures, coolant, etc. In order to maintain superconducting state extremely low temperature (4.2k) is required, so helium is used as the coolant because it is the only material that is not solid at those temperatures. There are one or more compressors for gaseous helium. The vacuum enclosure receives the compressed helium and produces liquid helium for the coil [7][14][15].

C. Inverters, rectifiers, electronic circuits, etc. are typically the parts of the **power conditioning system (PCS).** It can also be referred as power conversion system. In general, this portion of a SMES system contains converters that convert DC currents to AC and vice versa. According to the utilization of the various converters and other circuits, a SMES system can be classified into 3 major categories [3][7][14],

i. Thyristor based SMES,
ii. Voltage source converter (VSC) based SMES,
iii. Current source converter (CSC) based SMES.

D. **Control system** develops a link between the power demand from the grid and power flow to and from the SMES coil. It also measures the condition of the SMES coil in order to maintain safety by controlling other equipment like the refrigerator. The control system usually composed of controlling devices or circuits like Microcontroller, DSP etc. [7][11][13].

Besides these, the mechanical design of a SMES system is firmly important. The magnet conductor must be designed in such a way that it can withstand high stresses and deformations without limiting or changing the superconducting properties. If the bedrock can support the SMES structure then the SMES system can be installed anywhere useful to the power system [11].

III. CHARACTERISTICS OF A SMES SYSTEM

The main characteristics of a SMES system are [4][7][11][13][14][15]

- A SMES system provides high power density but relatively lower energy density.
- The response time of a SMES system is pretty fast.
- The number of charge-discharge cycle is very high i.e. the cycle efficiency is more than appreciable. For that reason fast recharge is possible.
- There are no moving parts in a SMES system which ensures that the maintenance cost is comparatively lower than the other cotemporary storage systems.
- The energy conversion efficiency is very high (>95%) which is comparatively higher than batteries (60 to 90%) or Pumped hydro (up to 70%).
- Life time of a SMES system is very high, more than 30 years.
- Environmentally sound.

IV. APPLICATIONS OF SMES

A. FACTS (FLEXIBLE AC TRANSMISSION SYSTEM)

SMES systems are utilized in the FACTS devices. It is a static device which can be installed in the electric grid in order to enhance the controllability and power transfer capability of the grid. A SMES system operating as FACTS was the first superconducting application operating in a grid. In 1980 Bonneville power authority in U.S. A. utilized a SMES system in the grid condition to damp the low frequency [13] [14]. They were successful in that and continued it for about one year. In other words, a SMES system as a FACTS device acts as a system stabilizer. In 2000 American superconducting company installed six SMES units at key points in the grid in Northern Winston (USA) to enhance the stability of the grid. FACTS is also useful in renewable energy technologies like wind generator [14][15].

B. ELECTROMAGNETIC LAUNCHERS

The Electromagnetic launcher is an electric weapon that can launch a projectile at a very high velocity. Some electromagnetic launchers require high power pulse sources. Due to high power density and quick release of the stored energy [14], SMES is a potential energy storage device for an electromagnetic launcher [7][14].

C. LOAD LEVELING

Electric power demands vary with predictable magnitude. Both commercial and residential demands are greater during the day and less at night. The demands also vary with seasons. A SMES unit has the ability to follow system load changes almost instantaneously which provides for conventional generating units to operate at a constant output. It can store energy at fewer demand situations and deliver it back to the grid during high demands [2] [7] [15].

D. UPS (UNINTERRUPTIBLE POWER SUPPLIES)

It has been used to sustain a continuous power supply to certain critical loads protecting them against unexpected power outages as well as over and under voltage conditions. Fast response, compensation and instant availability of electrical power are the basic requirements of UPS. In recent years, due to the dynamic capabilities and long-term lifecycle of SMES, it has received a great attraction as an energy storage unit instead of conventional batteries. Because of its storage capacity, SMES is a potential option for the industrial customers in case of loss of the utility main power supply [2] [7] [9].

E. CIRCUIT BREAKER RECLOSING

A conventional circuit breaker attempts to reclose and return the affected transmission line to service by following the clearance of a fault. This is done routinely whenever the power angle difference across the circuit breaker is within a certain limit. However, if the angle difference is too large, protective relays prevent the circuit breaker from reclosing. SMES can reduce the power angle difference across a circuit breaker and allow reclosure of the circuit breaker by briefly supplying some fraction of the power normally transmitted by the transmission line. This allows restoration of the system power transfers quickly following outages of major transmission lines [2] [7].

F. SPINNING RESERVE

Due to the fast recharge time and fast AC-DC conversion process, SMES can be utilized as a spinning reserve when a major grid or transmission line is out of service [2][7][11].

V. CHALLENGES OF SMES

A. HIGH COST

The SMES system utilizing LTS has to be operated at a very low temperature (4.2k). Though the energy conversion and related issues are satisfactory but maintaining the refrigeration system at that temperature requires huge investments. In order to increase the refrigeration temperature HTS superconducting materials have been developed. HTS magnets offer the possibility to operate at relatively higher temperatures (50-70K) which would reduce the operating cost of the cryogenic refrigerator. Higher operating temperatures also make the system stable and viable. For coolant, liquid nitrogen is using these days which are also less expensive than liquid Helium. But as we can see that refrigeration process is only a part of the whole arrangement and in the case of large systems, the cost does not reduce significantly [5][6][9][7][11][12][14][15].

B. REQUIREMENT OF ADDITIONAL PROTECTION

The energy stored in the superconducting magnet can be released in a very short time. The power per unit mass does not have a theoretical limit and can be extremely high (100 MW/kg) so the system must be contained in an excellent electric isolation [14].

Again, in case of coil failure, the energy has to be released otherwise; the coil will be damaged [11]. Due to the release, the conversion system and the whole arrangement may undergo system failure also. Some conceptual designs of SMES system propose the absorption of energy by the superconducting cable and the support structure in case of system failure. [11][14]

C. LONG PRECOOLING TIME

As the operating temperature of a SMES system is very low, it takes about four months to cool the superconducting magnet from room temperature to operating temperature. In case of coil failure or emergency energy release, it requires the same amount of time to recover [11].

VI. CONCLUSION

So we have presented an overview of the SMES system. We have talked about its principle, organization, and applications. We have also discussed its major limitations. SMES is an excellent technology in today's world even it is a good option for the people who are concerned about the environment. SMES can also reduce the cost of oil and gas by a good amount. The high capital cost is still an obstacle to the widespread availability of the SMES system but still many projects have been utilizing SMES successfully. Research works are going on and in the future it will surely come within the range of commercial usages.

REFERENCE

1. Luo, X., Wang, J., Dooner, M., & Clarke, J. (2015). Overview of current development in electrical energy storage technologies and the application potential in power system operation. Applied Energy, 137, 511-536.
2. Ali, M. H., Wu, B., & Dougal, R. A. (2010). An overview of SMES applications in power and energy systems. IEEE Transactions on Sustainable Energy, 1(1), 38-47.
3. Heydari, H., & Mohammadpour, G. (2010, March). Application of a SMES to protect a sensitive load in distribution networks from two consecutive voltage sags. In Advanced Computer Control (ICACC), 2010 2nd International Conference on (Vol. 1, pp. 344-347). IEEE.
4. Chen, H., Cong, T. N., Yang, W., Tan, C., Li, Y., & Ding, Y. (2009). Progress in electrical energy storage system: A critical review. Progress in Natural Science, 19(3), 291-312.
5. Rong, C. C., & Barnes, P. N. (2017, December). Developmental Challenges of SMES Technology for Applications. In IOP Conference Series: Materials Science and Engineering (Vol. 279, No. 1, p. 012013). IOP Publishing.
6. Hassenzahl, W. (1989). A comparison of the conductor requirements for energy storage devices made with ideal coil geometries. IEEE Transactions on Magnetics, 25(2), 1799-1802.
7. M. R. Islam, "Study of SMES technology for electric power supply and investigation of its utility and possible implementation in Bangladesh." A project report, University of Chittagong. (July, 2014).
8. V.G. Welsby, The theory and design of inductance coils. (Macdonald, London, 1960).
9. Kwon, C. S., & Kang, F. S. Superconducting Magnet Energy Storage Unit.
10. Vulusala G, V. S., & Madichetty, S. (2018). Application of superconducting magnetic energy storage in electrical power and energy systems: a review. International Journal of Energy Research, 42(2), 358-368.
11. Hsu, C. S., & Lee, W. J. (1993). Superconducting magnetic energy storage for power system applications. IEEE Transactions on industry applications, 29(5), 990-996.

12. Xu, Y., Tang, Y., Ren, L., Jiao, F., Song, M., Cao, K., ... & Dong, H. (2013). Distribution of AC loss in a HTS magnet for SMES with different operating conditions. Physica C: Superconductivity, 494, 213-216.
13. Yuan, W., & Zhang, M. Superconducting Magnetic Energy Storage (SMES) Systems. Handbook of Clean Energy Systems.
14. Tixador, P. (2012). Superconducting magnetic energy storage (SMES) systems. In High temperature superconductors (HTS) for energy applications (pp. 294-319).
15. http://www.climatetechwiki.org/technology/jiqweb-ee