



## INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

### Performance of Superconducting Magnetic Energy Storage Device with Power Electronics Interface

Kavya B R <sup>1</sup>, Dr.B.V Sumangala <sup>2</sup>

<sup>\*1</sup>Department of Electrical & Electronics, Visvesvaraya Technological University, II year, M.Tech, Dr.Ambedkar Institute of Technology, Bangalore-560056, India

<sup>2</sup>Professor and Head of department, Department of Electrical and Electronics, Dr.Ambedkar Institute of Technology, Bangalore-560056, India

[Kavyabr90@gmail.com](mailto:Kavyabr90@gmail.com)

#### Abstract

This paper presents simulation of a Superconducting Magnetic Energy Storage (SMES) system. SMES technology has the potential to bring real power storage characteristic to the utility transmission and distribution systems. The principle of SMES system operation is reviewed in this paper. To understand performance of a SMES system, a detailed SMES system model is given with simulation results. This system is demonstrated using an Matlab/simulink .

In this paper, Superconducting Magnetic Energy Storage (SMES) found a number of applications in power systems. The heart of the SMES system is the large superconducting coil. There are several reasons for using superconducting magnetic energy storage instead of other energy storage methods. The most important advantage of SMES is that the time delay during charge and discharge is quite short. Power is available almost instantaneously and very high power output can be provided for a brief period of time.

**Keywords:** Superconducting coil, controller, Ac system Power converter, DC link, DC to DC chopper.

#### Introductions

A SMES device is a dc current device that stores energy in the magnetic field. The dc current flowing through a superconducting wire in a large magnet creates the magnetic field. Generally it consists of the superconducting coil, the cryogenic system, and the Power Conversion/Conditioning System (PCS) with control loop[1]. The total efficiency of a SMES system can be very high since it does not require energy conversion from electrical to mechanical or chemical energy. Depending on the control loop of its power conversion unit and switching characteristics, the SMES system can respond very rapidly (MWs/milliseconds). The ability of injecting/absorbing real or reactive power can increase the effectiveness of the control, and enhance system reliability and availability. Consequently, SMES has inherently high storage efficiency, about 90% or greater round trip efficiency. Comparing with other storage technologies, the SMES technology has a unique advantage in two types of applications: Power system transmission control and stabilization, and power quality improvement.

The efficiency and fast response capability of a SMES can be further exploited in different

applications in all levels of electric power systems[2].In order to achieve the best system configuration possible, the design of the SMES system needs to take into account many factors. The performance evaluation of a SMES system also requires extensive knowledge about the SMES and the associated power systems. The simulation results of Matlab/simulink is one of the cost effective ways to carry out. This paper intends to provide a modeling of the SMES system for the SMES related power system computer simulation. The benchmark system will provide the basis for the comparison of the different simulation tools, control strategies and algorithms related to SMES systems. The proposed SMES system will utilize parameters from BWX Technologies, Inc. for the SMES coil modeling. A GTO based Voltage Source Converter will be used for modeling the PCS of the proposed SMES system.

#### Types of energy storage

The way energy is stored depends primarily on the source of energy. According to the latter, we know the following methods of energy storage:

**Electrochemical energy storage.** It involves the use of various devices which convert chemical energy into electricity. Examples include:

**Battery.** It is a widely used device that converts stored chemical energy into electricity. Two basic types of batteries exist which known as the primary batteries or non-rechargeable batteries and secondary batteries which can be recharged and used multiple times. The available batteries are Lead acid: Flooded type and Valve regulated type, Nickel-cadmium, Lithium-ion, Sodium-sulphur, Zebra battery, Metal air, Nickel metal-hydride, Flow batteries: Vanadium redox, Zinc bromide, Cerium-zinc.

**Fuel cell and hydrogen.** It refers to a device which converts chemical energy into electricity through chemical reaction. Several different types of fuel cells exist but all feature a cathode, anode and an electrolyte.

**Electrical energy storage.** It involves the use of an electric field to store energy. Examples include:

**Capacitor and super capacitor (double-layer capacitor).** Both are electrical components that are used to store electric charge but as its name reveals, supercapacitor can store more electric charge. Capacitor is typically used as a short-term backup power, while super capacitor can also be used to power large engines including vehicles. But it is also often used to run low-power devices such as portable media players, PC Cards, etc..

**Superconducting magnetic energy storage (SME).** It refers to a relatively new technology which stores electricity from the grid within a magnetic field that is created by the flow of current in a coil.

**3. Thermal energy storage.** It refers to methods that are used to store thermal energy in order to use it to cool or heat buildings when the temperature inside is above or below the internal energy in the stored substance.

**Hot water storage tank.** It refers to a water tank that stores hot water for space heating, washing, bathing, etc.. Hot water storage tanks are a common feature of wood furnaces and solar thermal collectors.

**Storage heater.** It is an electric heater that stores energy during the evening or night and releases heat during the day when the price of base load electricity is higher. Storage heaters work by accumulating heat in ceramic material or clay bricks.

**Steam accumulator.** It refers to a steel tank that contains steam under pressure. It is used to balance between supply and demand by accepting steam when the supply is greater than demand and to release it when demand exceeds the supply.

Borehole community thermal

Ceramic thermal storage

Thermal fluid storage

**Mechanical energy storage.** Methods to store energy that is produced by motion include:

**Hydraulic accumulator.** It is a storage reservoir which stores non-compressible fluid under pressure.

There are several types of hydraulic accumulators but the most widely used is the so-called compressed gas accumulator which contains gas under pressure, usually nitrogen.

**Flywheel energy storage.** Like its name suggests, it is a method to store energy through a flywheel. This type of mechanical energy storage is used to store grid energy and energy that is generated by wind farms but it also shows potentials in transportation and as an emergency power source.

**Compressed air energy storage.** During off-peak periods, CAES plants are used to store excess electrical energy by compressing air in the form of pneumatic energy. When the power demand increases, the air is released to drive a conventional gas turbine-turbine generator set for producing electricity. CAES is being used for grid connected applications

**5.Virtual energy storage[VES]** By controlling the demand of consumers intelligently, VES technology is able to compensate the load demand between peak and off-peak periods. Two types of VES system, namely

**Demand side management:** In demand side management, less sensitive loads are switched off for short periods

**Demand response:** In demand response, more energy is purchased than the actually required at light loads periods

For example, temperature of cold storage can be decreased further during off-peak periods. Alternatively, the plant can be kept switched-off during peak periods

### **6.Electric drive vehicle Batteries[EDV]**

EDV can be utilized in a power system network to compensate the frequency deviations and load levelling purposes

By vehicle to grid concept, it is expected that the combustion engine of vehicles will be replaced by electric motors. The motors need power from battery to run.

This concept is based on the idea that the electric vehicles are typically idle for more than 20 hours per day and the fleet of electric vehicles could be connected to the grid during idle time, essentially to serve as an energy storage[9]

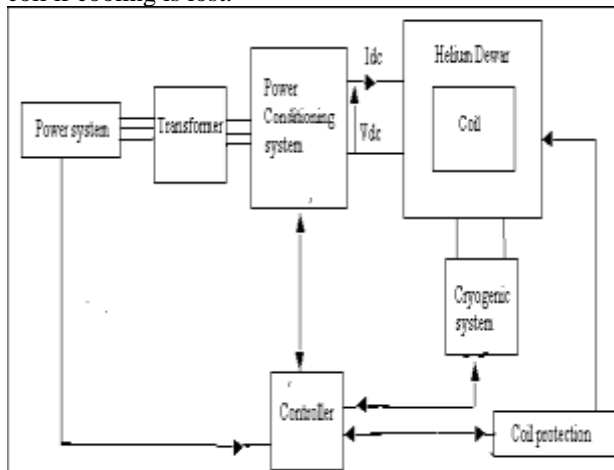
### **SMES system overview**

As can be seen from Fig. 1, a SMES system consists of several sub-systems. A large superconducting coil is the heart of a SMES system, which is contained in a cryostat or dewar consisting of a vacuum vessel and a liquid vessel that cools the coil. A cryogenic system is also used to keep the temperature well below the critical temperature of the superconductor. An ac/dc PCS is used for two

purposes: One is to convert electrical energy from dc to ac, and the other is to charge and discharge the coil. Finally, a transformer provides the connection to the power system and reduces the operating voltage to acceptable levels for the PCS. For a SMES system, the inductively stored energy ( $E$  in Joule) are commonly the given specifications for SMES devices, and can be expressed as follows:

During SMES operation, the magnet coils have to remain in the superconducting status. A refrigerator in the cryogenic system maintains the required temperature for proper superconducting operation. Since the refrigeration load can affect the overall efficiency and cost of a SMES system..

A PCS provides a power electronic interface between ac power system and superconducting coil. It allows the SMES system to respond within tens of milliseconds to power demands that could include a change from maximum charge rate to maximum discharge rate of power. This rapid response allows a storage unit to provide spinning reserve and improve system stability. Converters may produce harmonics on the ac bus and in the terminal voltage of the coil. Using higher pulse converters can reduce these harmonics. A PCS could be either a bidirectional current source converter or a voltage source converter with a dc-dc chopper interface. A bypass switch is used to reduce energy losses when the coil is on standby. And it also serves other purposes such as bypassing dc coil current if utility tie is lost, removing converter from service, or protecting the coil if cooling is lost.



Figure(1). A typical SMES system.

## SMES system elements modeling

### 1) SMES Coil Modeling:

A mathematical model is the most convenient method with the lowest cost. At the same time, a greater variety of design alternatives and

detailed analysis can be achieved with the mathematical model of a winding.

The most detailed model would require a representation of single turns, which take the magnetic mutual couplings to all other turns into account. However, such a model is difficult to obtain and to handle as well as impractical in most cases. Unless the time delay of traveling wave phenomena is really of interest, e.g., for very fast transients such as a lightning surge, a lumped parameter network model proves sufficient [9].

A lumped parameter network model contains magnetic and dielectric circuits, which have the following sets of elements: The magnetic circuit is represented by self and mutual inductance ( $L$  and  $M$ ) of each turn. The dielectric circuit is represented by capacitances between shunt capacitance ( $C1, C4, C6$ ) and series capacitance ( $C2, C3, C5, C6, C7$ ). Due to the high memory and computing costs, various degrees of simplification are necessary. A relatively small number of dominant resonance frequencies are sufficient for the analysis. Therefore, a distributed winding can be represented by an equivalent circuit of a finite number of lumped elements. When a superconducting coil is simulated for a purpose of dynamic operation, it is a common practice to represent the coil as an inductor. On the other hand, for transient analyses, the more detailed coil model representing disks, even turns with associated mutual.

2) Calculation of Electrical Parameters: An electrical lumped parameter model, illustrated in Fig. 2 is constructed for a superconducting coil to determine voltage distribution and frequency response of the coil. It is assumed that the coil consists of a number of disks (pancakes) comprised of a number of turns. Given the geometrical dimension of a coil, the following parameters need to be calculated for each turn of the coil including  $L, M, C1, C2, C3, C4, C5, C6, C7$  [3].

$$E = \frac{1}{2} LI^2$$

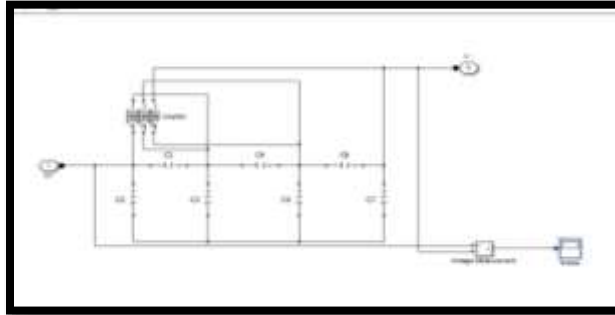
Where

$E$  = energy measured in joules

$L$  = inductance measured in henries

$I$  = current measured in amperes

In order to avoid computing cost, a lumped double pancake parameter model is developed using the parameters computed for turns. In transient analysis simulations, representing the first and last few double pancakes with turn-to-turn representation may satisfy the requirement for the detailed modeling.



Figure(2). Three pancake SMES model.

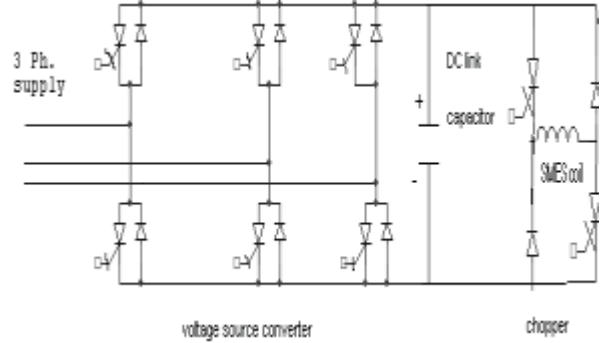
**Model of power electronics conversion and control unit**

The power electronics interface between a superconducting coil and the ac power system is called SMES PCS. A PCS is expected to transfer energy into or out of the SMES on command to control real and reactive power, and to be able to bypass the coil when there is no need for energy into or out of the coil [5]–[6]. Certain factors such as semiconductor device types, switching technologies, system configuration and reactive power requirement have been considered/evaluated for a PCS design.

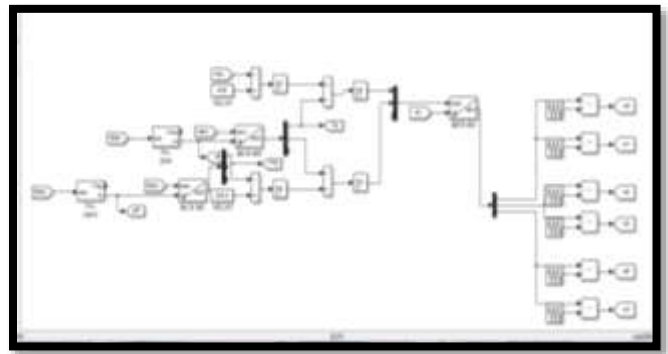
Two basic types of Converters,

- 1) Current-Sourced converter(CSC)
- 2) Voltage-Sourced Converters (VSC) are commonly used for

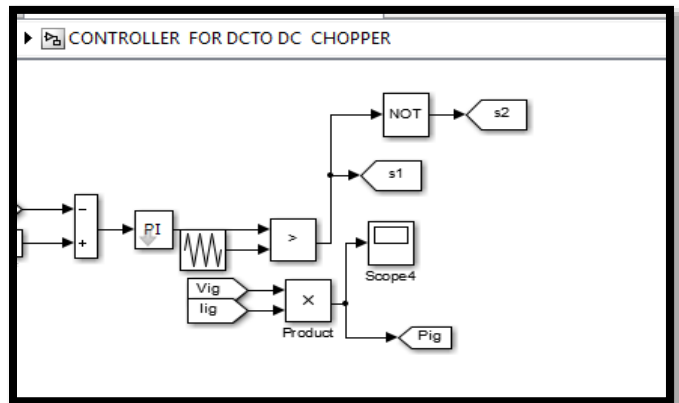
the power conversion unit between SMES and ac power system. and VSC along with a dc–dc chopper interface, a dc link capacitor are used. It should be noted that the VSC must have bi-directional valves to allow current flow in either direction. Natural commutated devices initially used in power conversion of SMES systems are replaced by high power forced (self)commutated semiconductor devices, which offer more controllability and flexibility. And since GTOs are well established and employed devices, the simulation work presented in this benchmark work uses GTO devices for the power electronics interface. Varying the width of the voltage pulses, and/or the amplitude of the dc bus voltage can control the ac output voltage. Due to the nature of converters, harmonics are present. To reduce harmonic magnitude, either a multi-pulse VSC with 180-degree conduction or a three-phase PWM scheme is utilized. PWM scheme has not been justified for high power converters due to the switching losses [7]. The use of VSC for SMES applications has been proposed for the Engineering Test Model (ETM) project [8], [9], [10].



Figure(3): Voltage source converter and DC-DC Chopper for SMES system



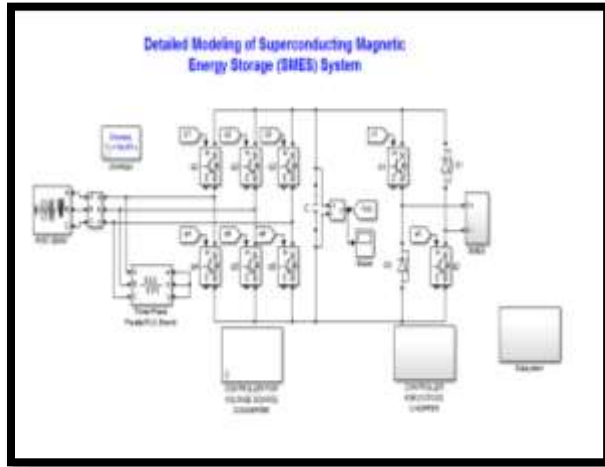
Figure(4): Controller unit for Voltage source converter.



Figure(5): Controller for DC-DC Chopper

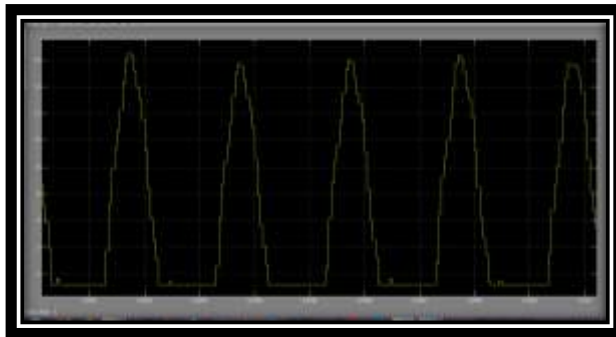
A 24-pulse VSC and a two-quadrant multi-phase dc–dc chopper for SMES have been introduced. The VSC and the chopper are linked by a dc link capacitor that behaves as a stiff but controllable dc voltage source providing the desired characteristics. A three-phase VSC and single-phase chopper connection is illustrated in Figure(6).



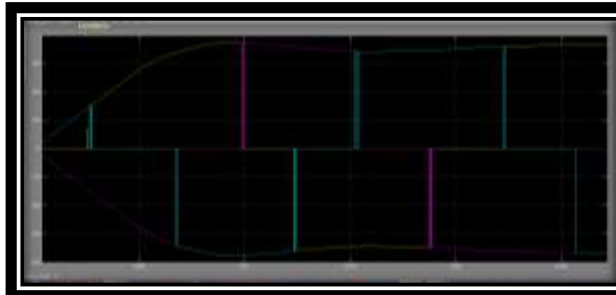


Figure(6). VSI/dc-dc chopper configuration for SMES.

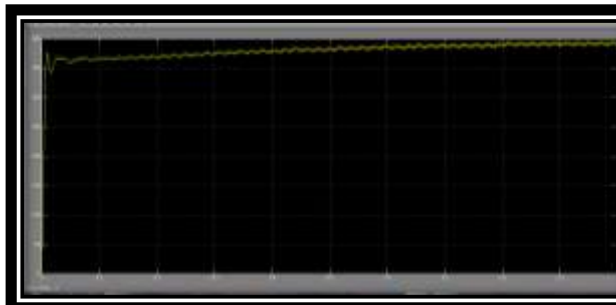
### Simulation results



Figure(5):DC voltage across SMES coil



Figure(6): Voltage across the load



Figure(7): Dc voltage across the controller

### Conclusion

This paper gives the performance of superconducting coil with power electronics interface in power system application and improves the system stability. Various technologies are in use for grid connected and off-grid power system applications. With advent of improved energy storage technologies, it can be expected that energy storage technologies would play role models to improve power qualities. To establish economic and reliable power systems and develop enhanced penetration renewable energy system.

### References

1. W. V. Hassenzahl, "Superconducting magnetic energy storage," *IEEE Trans. Magn.*, vol. 25, no. 2, pp. 750-758, Mar. 1989.
2. P. F. Ribeiro, "SMES for enhanced flexibility and performance of FACTS devices," in *Proc. IEEE Summer Meeting, Edmonton, AB, Canada, Jul. 1999*.
3. P. Chowdhury, "Calculation of series capacitance for transient analysis of windings," *IEEE Trans. Power Del.*, vol. PWRD-2, no. 1, pp. 133-139, Jan. 1987.
4. A. Greenwood, *Electrical Transients in Power Systems*. New York: Wiley, 1991.
5. R. L. Kustom, J. J. Skiles, J. Wang, K. Klontz, T. Ise, K. Ko, and F. Vong, "Research on power conditioning systems for superconductive magnetic energy storage (SMES)," *IEEE Trans. Magn.*, pt. 4, vol. 27, no. 2, pp. 2320-2322, Mar. 1991.
6. R. H. Lasseter and S. G. Jalali, "Power conditioning systems for superconductive magnetic energy storage," *IEEE Trans. Energy Convers.*, vol. no. 3, pp. 381-387, Sep. 1991. [15] R. H. Lasseter and S. J. Jalali, "Dynamic response of power conditioning systems for superconductive magnetic energy storage," *IEEE Trans. Energy Convers.*, vol. 6, no. 3, pp. 388-393, Sep. 1991.
7. B. M. Han and G. G. Karady, "A new power conditioning system for superconducting magnetic energy storage," *IEEE Trans. Energy Convers.*, vol. 8, no. 2, pp. 214-220, Jun. 1993.
8. N. G. Hingorani and L. Gyugyi, *Understanding FACTS Concepts and Technology of Flexible AC Transmission Systems*. New York: IEEE Press, 2000.
9. I. D. Hassan, R. M. Bucci, and K. T. Swe, "400MWSMES power conditioning system

*development and simulation,” IEEE Trans. Power Electron., vol. 8, no. 3, pp. 237–249, Jul. 1993.*

11. *P.J Lee[Ed],Engineering superconductivity, Wiley-Interscience, John Wiley and Sons, Inc.*