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SMES TECHNOLOGY FOR STABILITY IMPROVEMENT OF RENEWABLE ENERGY SYSTEMS

Rajendra H. Madhavi
Department of Electrical Engineering
Dr.BATU, Lonere, Raigad, Maharashtra, India

Anwar M. Mulla
Department of Electrical Engineering,
ADCET, Ashta, Sangli, Maharashtra, India

Kripasagar Bhagwat Khobre
Department of Electrical Engineering
Dr.BATU, Lonere, Raigad, Maharashtra, India

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ABSTRACT

In today’s world it has become a very important that electrical power must be made available to the customer 24 x 7. This fact attracted researchers and it increased focus on large scale integration of new renewable energy sources like wind power and solar power introduces the need for energy storage. Superconducting Magnetic Energy Storage (SMES) is a recent and promising alternative for active power compensation. Having high efficiency, very high response time and high power capability it is ideal for smoothing fast fluctuations. Superconducting Magnetic Energy Storage is a promising technology that stores electricity from the grid within the magnetic field of a coil comprised of superconducting wires with near zero loss of energy.

INTRODUCTION

Superconducting Inductive Coils combine superconductivity and magnetic energy storage concepts to store electrical energy. Another widely used term for these coils is Superconducting Magnetic Energy Storage (SMES) coils. An SMES device is a direct current (DC) current device that stores energy in the magnetic domain. The current running through the superconducting wire in a large magnet creates the magnetic domain. The main purpose of using SMES devices is to store electrical energy in the magnetic field of a large coil so that it can be used whenever required. They are mainly used to supply large, repetitive power pulses and load smoothing applications. They can also be used in power systems for increasing the power quality.

SMES systems basically consist of a large coil, AC/DC converters and cooling units. The conductors used in the coil are superconductors, and therefore powerful cooling units need to be employed to maintain the superconductivity feature of the conductors. AC/DC converters convert the available AC voltage into DC form which is required for energy storage. By proper control, the AC/DC converters invert the stored DC energy into AC form so that it can be utilized. Now it is possible for third parties to buy the electrical energy from the generating companies and sell it. This open market also causes in concerns for energy storing and power quality issues and SMES systems with their possible application areas and promising future seem to be a good solution.

Battery Energy Storage systems (BESS) are presently used in some applications. However, some of its disadvantages include limited life cycle, voltage & current limitations and potential environmental hazards. SMES storage systems can be used to inject both active and reactive power into the grid simultaneously. This can be also be achieved by using BESS, but the efficiency of the SMES system is greater than 98%, which is far better than that of BESS. Also its fast response adds to its performance.

Some more advantages of SMES system are given below.

- Improves power quality for critical loads and provides carryover energy during momentary voltage sags and power outages.
- Improves load waveform smoothing between renewable energy sources and the transmitting and distribution network.
- Environmentally beneficial as compared to batteries, superconductivity does not bank on a chemical reaction and no toxins are brought out in the operation.
- Enhances the transmission line capability and performance-SMES features a high dynamic range, an almost infinite cycling capability, and an energy recovery rate close to 100%.
- Ultra-High field operation enables long term storage SMES system in a compact device with cost advantages in material and system cost.

TOPOLOGY

The structural figure of the SMES unit with VSC-based PCS includes of a star-delta transformer, a basic six-pulse PWM converter with insulated gate bipolar transistor (IGBT) as the switching device, a two quadrant bidirectional dc-dc chopper using IGBT, and an inductor as the superconducting coil. The decoupling of ac/dc converter and the dc-dc bidirectional converter is obtained by a large dc link capacitor. A power electronic link between the ac supply network and the dc current controlled superconducting coil is established by the PWM VSC. The PWM signal is obtained for the switching of IGBT by comparing the reference signal obtained from abc conversion with the high frequency triangular carrier signal. Throughout the operation the dc voltage across the capacitor is kept at its reference value by the six-pulse PWM converter.

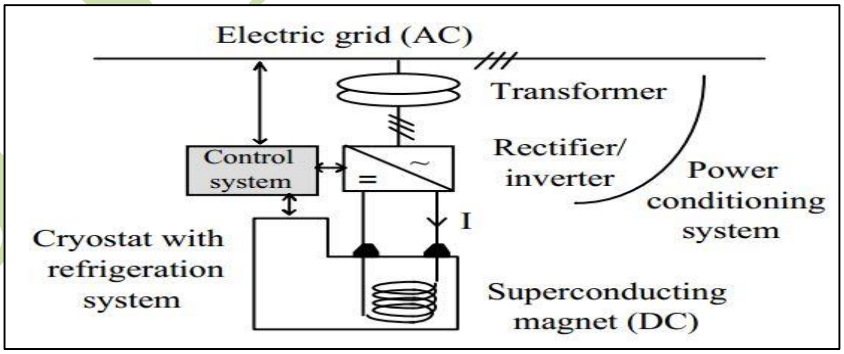

Fig.1 SMES interconnection with Electric Grid

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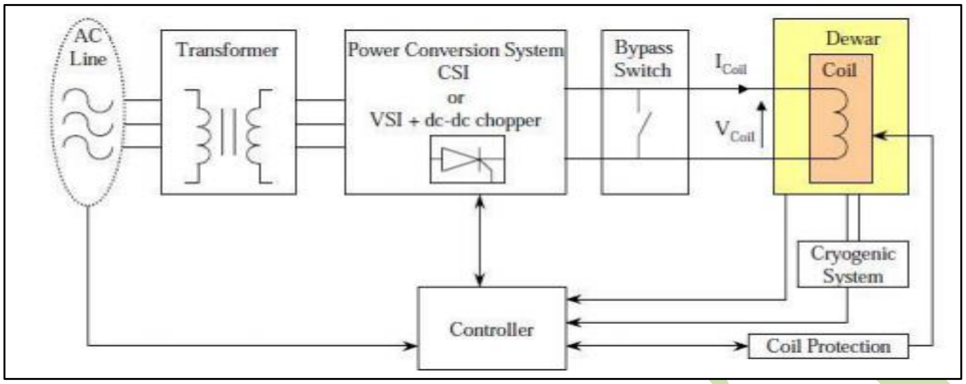

Fig.2 Topology of SMES

A voltage bidirectional dc-dc chopper is used to regulate the charge-discharge of the superconducting coil. The dc-dc chopper is controlled to make the voltage across SMES coil such as positive (IGBTs are switched ON) or negative (IGBTs are switched OFF) and then the energy reserved in SMES can be supplied or consumed accordingly. Hence, the charging and discharging of superconducting coil depends on the average voltage per cycle across the coil that is calculated by the duty cycle of the two-quadrant chopper. In order to obtain the PWM gate pulses for the IGBTs of the dc/dc converter, the estimated signal is compared with the triangular/saw-toothed carrier signal.

Here, the PCS consists of a VSC and A DC/DC converter to control the source current as well as the charge-discharge cycle of SMES. DC/DC converter is a simple voltage bidirectional converter consists of IGBTs and diodes. When the switches are “ON” SMES coil gets charged and positive voltage is applied on it; when they are „OFF‟ negative voltage is applied on it and it discharges through diode. In both modes current remains unidirectional. During standby condition one of the switches is „ON‟ and current circulates between that switch and one diode. The switching of this is regulated to get a constant dc-link voltage. Here, VSC is a six-pulse conventional full bridge converter. IGBT anti-parallel with a diode is used as the switch to get bidirectional current. It is controlled to operate in both rectifying and inverting modes.

DESIGN CRITERIA

Most SMES applications demand a relatively high power rating from the PCS, greater than 1 MW. Due to this power requirement the scope of possible devices is mainly limited to the GTO and IGBT. The main advantage of the GTO is the conduction voltage drop. Conduction losses in a GTO are approximately 25 % that of the IGBT. This is a particularly important detail if current from the magnet is intended to circulate through the chopper for an extended period of time.

However, for this converter the IGBT has many more advantages. The conduction voltage drop is higher than that of the GTO but switching losses are considerably less. This allows the switching frequency to be increased and consequently can lead to smaller reactive components and an overall smaller and cheaper system design. Another disadvantage to the GTO is the need for a snubber circuit. This criteria definitely favors the IGBT as no snubber circuit is needed. The GTO is more difficult to turn off.

The GTO requires approximately 1/5 of the anode current to gate the device, where the IGBT only requires a small gate current to charge the device gate capacitance. Since the design stage of this project, the IGCT, built by ABB, and ETO, developed at CPES, have shown significant improvements in device technology. These devices have the voltage and current ratings and conduction voltage drop benefits of the GTO with reduced switching losses comparable to the IGBT. A 2 MW or higher PCS for SMES is slated for the next phase of the project. At this power level the IGCT or ETO come into heavy consideration as their benefits begin to outweigh those of the IGBT.

Two SMES demonstrations, sponsored by the Office of Naval Research (ONR), has been planned in this project. The first is a high temperature superconducting (HTS) SMES demo at the Naval Research Lab (NRL) in Washington, D.C. The second demo is with a low temperature superconducting (LTS) magnet at the National High Magnetic Field Lab (NHMFL) in Tallahassee, FL.

The magnet at NRL, shown in fig. 3, is a 7.25 T, 12 H, high temperature superconducting (HTS) magnet. Energy storage capabilities of the magnet are determined by the inductance, 12 H, and maximum rated current, 120 A at 7.25 T. The energy stored, $E = 0.5*L*I^2$, is 86 kJ. The operational voltage of the magnet, $L*di/dt$, is 240V and the absolute maximum voltage rating is 500 V. The operating parameters of this HTS magnet work well with the new power electronics. The PCS has been routinely operated between 200 – 500 V at 100 A.

Fig.3 HTS superconductor

The magnet shown in fig 3 is LTS magnet has a current capability of 2000 A and an inductance of 32 H, resulting in maximum energy storage of 64 MJ. Unfortunately, the majority of the energy storage capabilities of this magnet cannot be utilized because of the parameter mismatch between the power electronics and the magnet. The operational parameters of the LTS magnet are 200V and 2000A while the PCS is 1800V and 150A.

SIMULATION MODEL

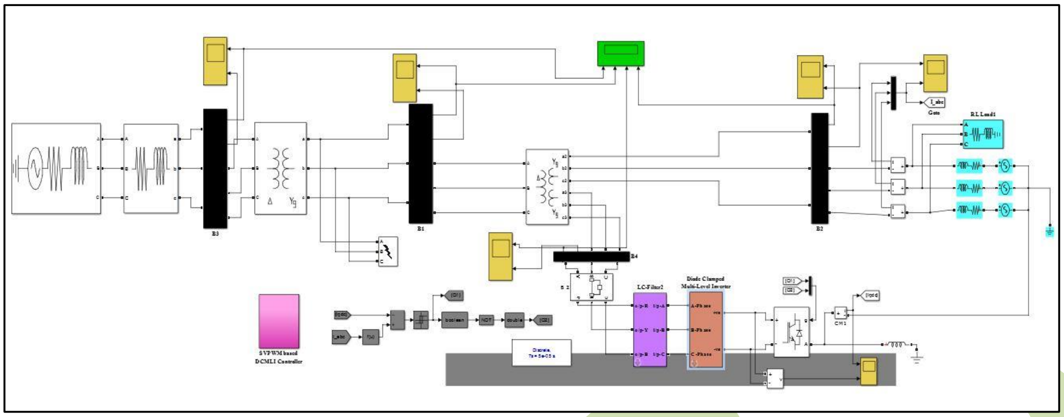

Fig. 4 MATLAB SMES with electric grid Model

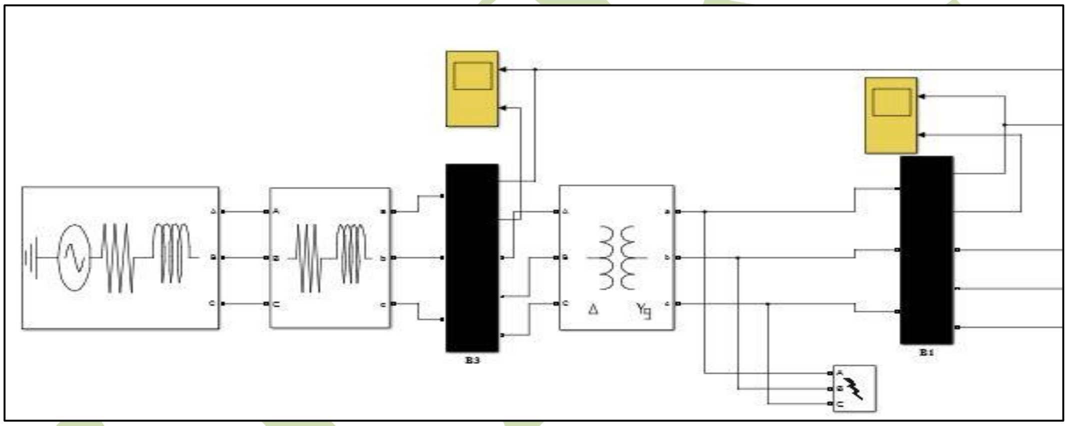

Fig. 5 Source Side MATLAB Simulink Model

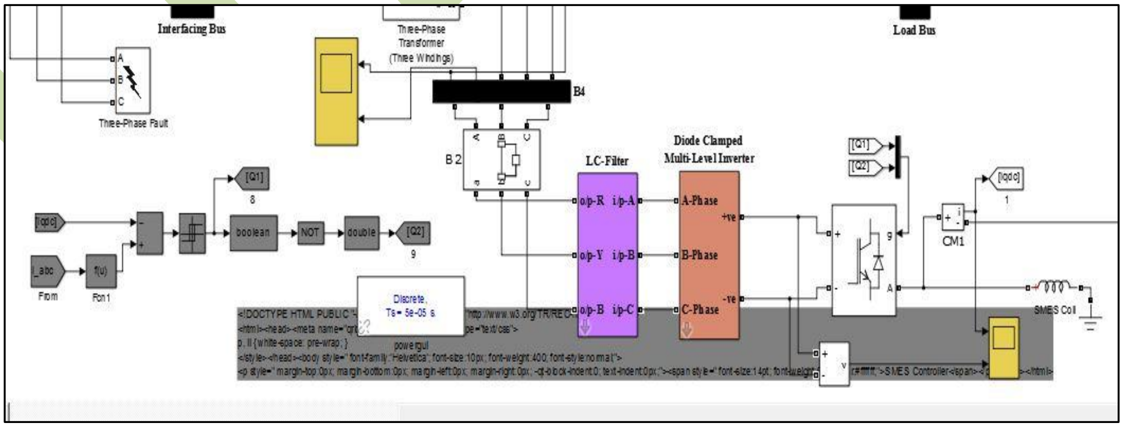

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Fig. 6 SMES Simulation Model

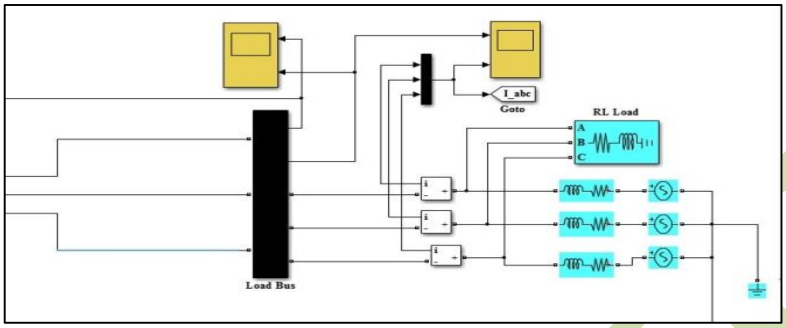

Fig. 7 Load Side Simulation Model

SIMULATION RESULTS

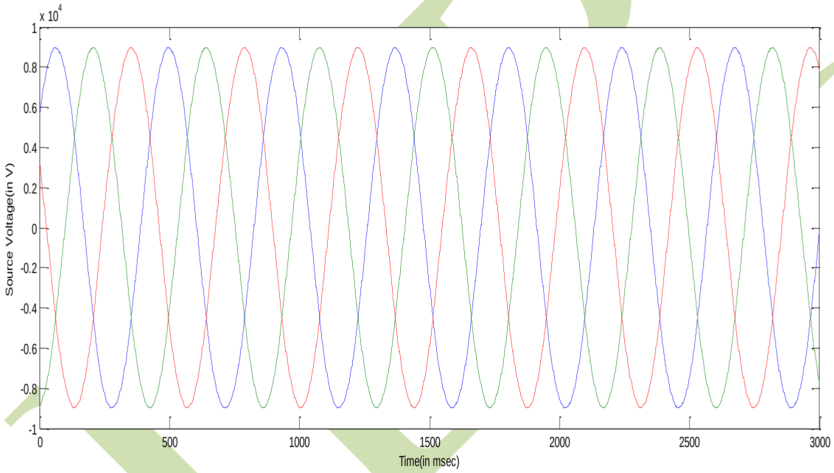

Fig.8 Source Voltage

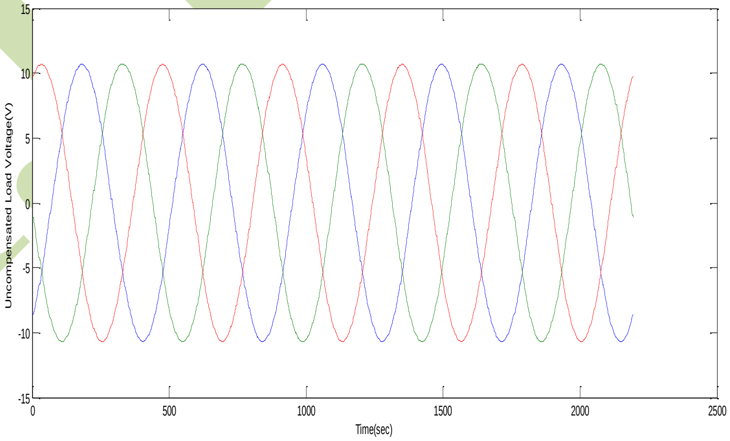

Fig.9. Uncompensated Load Voltage

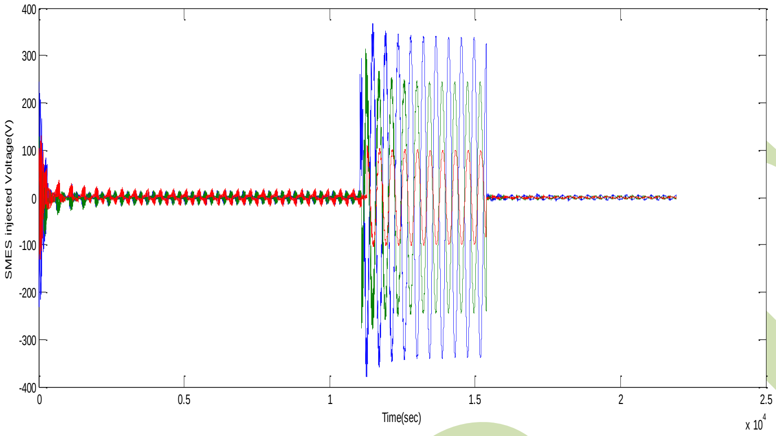

Fig.10 SMES Injection Voltage

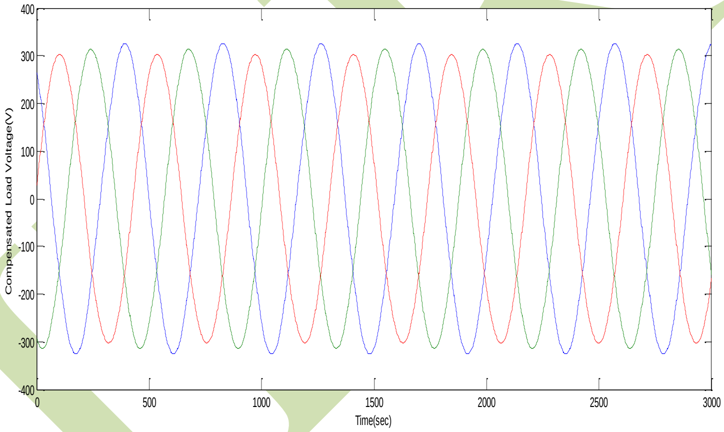

Fig.11. Load Voltage

CONCLUSION

From this paper, we can conclude that an improved control over power transferred can be obtained by using different Superconductors (LTS or HTS) at different cryogenic temperature with different materials, different power conditioning system (VSC, CSC, Thyristor, GTO, IGCT, etc.), different Multi level inverter along with various control techniques. It can be also seen from the research that SMES is more useful, efficient and less costlier when it is interfaced with hybrid storage system and FACTS devices.

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