Power Conditioning and Quality Using Superconducting Magnetic Energy System

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***Abstract*— A large power system is subjected to various disturbances very changes in operating conditions cause's oscillations and electromagnetic torque in the system [1]. The system variables such as frequency,load angle, active and reactive power of generator should be maintained within permissible limits and oscillations should be damped out as quickly as possible for a secured operation of a power system [2-3]. SMES is very effective to improving dynamic performance of power system due to its large energy storage capacity, fast response and negligible losses. The non linear and pulsating loads controlling can be done by utilizing by Superconducting Magnetic Energy Storage System (SMES) . In this paper a power conditioning system(PCS) is designed to achieve SMES to work as a shunt active power filter(SAPF) and power conditioner at the same time. (i) a sinusoidal input source current in phase with fundamental component of line to neutral source voltage irrespective of the load conditions (ii) Charging and discharging of SMES under constant voltage control mode. DC link voltage is kept constant by DC/DC Bidirectional Converter and source current is controlled by Voltage Source Converter (VSC).Simulation has been done in MATLAB/ Simulink and results are presented demonstrating the feasibility of the proposed power conditioning system.**

***Index Terms*— Matlab/ Simulink, MES, PCS, SAPF**

I. INTRODUCTION

Superconductivity is a phenomenon in which when the temperature goes below a certain critical temperature of some material, the property of zero resistance occurs in the material. SMES (Superconducting Magnetic Energy Storage System) is a storage device in a form of long superconducting coil in which energy is stored in the form of magnetic field generated by the direct current flowing in it upto indefinite instant. Applications of Superconducting Magnetic Energy Storage system (SMES) are being studied and presented in many papers in recent years. Some important applications includes energy storage, system stability enhancement, diurnal load leveling and voltage stability (Transient and dynamic), static VAR compensation, current harmonics mitigation. The demand of electricity from consumers and industries is constantly changing from time to time. The voltage at the load end starts falling leading to voltage instability and collapse of total power system is the result of increasing demand during peak load hour if load leveling is not done for the continuation of power supply. Load leveling plays an important role in case of Industrial load where violation of maximum power demands and power factor causes penalty to the industry concern. Load leveling can be ensured by storing the excessive energy of source during low-load hours and delivering the stored energy back in peak load hour. To satisfy the above criteria, energy storage devices are usually required such as batteries or superconducting magnetic energy storage systems.

For the above applications the power conditioning system of SMES consists of a Voltage Source converter (VSC) and a DC/DC bidirectional converter. The first converter VSC interfaces dc-link with the ac supply system. It is regulated to obtain a source current in phase with source voltage irrespective of the load Conditions. DC/DC bidirectional converter is used to control charging and discharging of SMES coil. Making the dc-link voltage constant ensures direct exchange of power between grid and coil.

Hysteresis band controller is used to control both the converter. In the voltage source converter it is used to control the source current, thus acting as a active power filter and in dc/dc converter it controls the charge-discharge cycle and the dc-link capacitor voltage. Hysteresis controller creates a band to bind the controlled variable within it. Switching pulses are generated when the controlled variable reaches the upper and lower bounds. A Fuzzy Logic Controller (FLC) is used to control theSMES coil energy that indirectly controls the charging and discharging of coil. Practically, the operation of a superconductor is in form of pulsed signals that leads to ac current losses in thecoil. These losses should be taken into account during the design of the SMES refrigeration system.

II. DESIGN AND CONSTRUCTION

An SMES is a device that mainly reserve energy in the form of magnetic field. The dc current flowing in a superconducting coil, which is wound around a long core magnet, creates the magnetic field. Here, as the stored energy is in form of circulating current, it can be consumed from an SMES unit with spontaneous response. Here, also energy can be reserved or supplied over short or long periods lasting from milliseconds to many hours.

An SMES unit includes of a large superconducting coil, whose temperature is maintained below the cryogenic temperature by a cryostat or Dewar that contains either helium or nitrogen liquid as the coolant. During standby condition, to reduce the energy losses a bypass switch is used. It also has certain merits that include shorting dc coil current if existing tie line is lost, give protection to the coil if cooling is lost or disconnecting power converters from service .

Manuscript received March 24, 2015.

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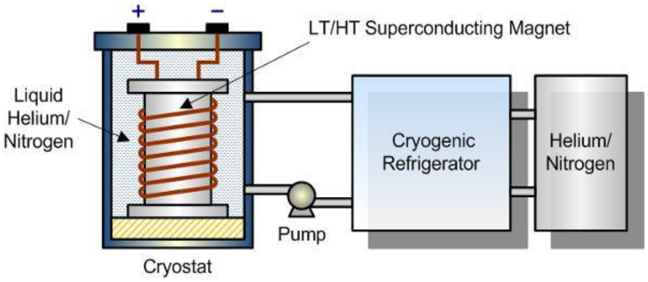


Fig1:SMES design and construction

Power condition system (PCS) is interconnected between ac system and superconducting coil of SMES to control the energy flow rapidly. STATCOM and three level dc-dc chopper has been used as ac/dc power conversionsystem to convert electrical energy from ac to dc or vice-versa [11]. The current in the coil continuously circulates during steady state operation (in standby mode). When a disturbance is sensed, the controller directs the PCS to exchange the real power between SMES coil and power system. The systematic exchange of energy between SMES coil and power system, stabilizes the power system quickly and hence maintained interruption free operating condition for optimum performance of critical processes. The current and voltage of the superconducting inductor are related as given in eqn. (1).

$$i_L = \frac{1}{L}\int_{t_0}^{t} V_L\,dt + I_{L0} \quad (1)$$

Where L is the equivalent inductance of the SMES coil and IL0 is the initial current of the inductor. The inductively stored energy (E in Joule) and the rated power (P in Watt) of SMES can be expressed as follows:

$$P = V_L I_L$$
$$W = \frac{1}{2} L I_L^2 \quad (2)$$

III. PRINCIPLE OF OPERATION

The systems works on the principle of energy balance between sources, load and SMES coil. The source current can be described as

$$I_s = I_l \pm I_i \quad (1)$$

Where Is= Source Current
Il= Load Current
Ii= Inverter Current

The output current of inverter is

$$I_i = f(I_0, D, M) \quad (2)$$

Where Io= SMES coil current
D = Duty cycle of dc/dc converter
M = Modulation index of inverter

Under load leveling condition the source current charges the coil when load power is less then source power. When, there is an increase in load occurs source power increases with load to its maximum and coil discharges to make energy balance between source, load andSMES. In the whole operation dc link voltage is kept constant. When the superconducting coil is in charging mode, the voltage across the capacitor will be decreased by

$$V_{dc}(t+\Delta t) = V_{dc}(t) - (\frac{I_0(t)}{C})\Delta t \quad (3)$$

Where Vdc is the capacitor voltage (V), C is is the dc-link capacitance (F), and Io is the current in the inductor that increases by an amount of

$$I_o(t+\Delta t) = I_o(t) + (\frac{V_{dc}(t)}{L})\Delta t \quad (4)$$

When the coil is in discharging mode, the voltage across the capacitor increased by

$$V_{dc}(t+\Delta t) = V_{dc}(t) + (\frac{I_0(t)}{C})\Delta t \quad (5)$$

And current in the inductor reduces up to

$$I_o(t+\Delta t) = I_o(t) - (\frac{V_{dc}(t)}{L})\Delta t \quad (6)$$

Similarly, in the inverter side, the function of the hysteresis controller to control the value of ac source current so as to modify the effective value of capacitor voltage in the following fashion. When current builds up, i.e., source current increases toward the upper-limit

$$I_s(t+\Delta t) = I_s(t) + (\frac{V_s - V_{dc}(t)}{L_s})\Delta t \quad (7)$$

The capacitor voltage will be build up as

$$V_{dc}(t+\Delta t) = V_{dc}(t) + (\frac{I_s(t)}{C})\Delta t$$

In the same manner, when the upper limit is reached, the current will now start to fall towardthe lower limit; the value of the source current then becomes

And capacitor voltage will be reduced up to

$$I_s(t+\Delta t) = I_s(t) + (\frac{V_s - V_{dc}(t)}{L_s})\Delta t \quad 8)$$

$$V_{dc}(t+\Delta t) = V_{dc}(t) - (\frac{I_s(t)}{C})\Delta t \quad 9)$$

The exchange of power in load leveling condition is represented in . Under load leveling condition the source current charges the coil when load power is less then source power. When, there is an increase in load occurs source power increases with load to its maximum and coil discharges to make energy balance between source, load and SMES. In the whole operation dc link voltage is kept constant.

IV. STRUCTURAL TOPOGRAPHY

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 .

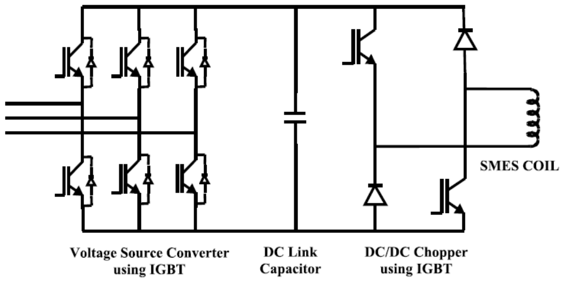


Fig 2:VSC Based SMES

V. PROPOSED SYSTEM TOPOLOGY

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 thePWM gate pulses for the IGBTs of the dc/dc converter, the estimated signal is compared with the triangular/saw-toothed carrier signal .

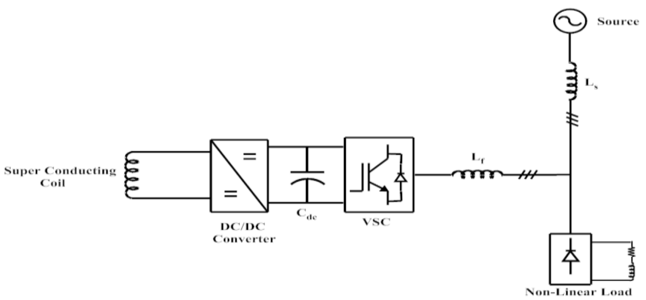


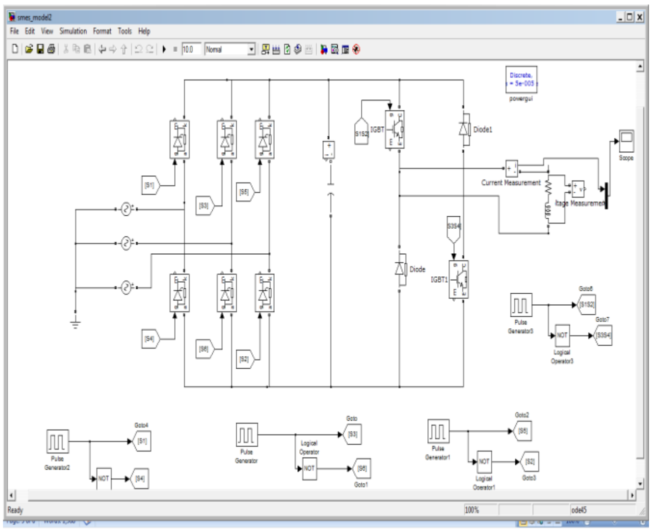
Fig3: Proposed system topology

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.

VI. SIMULATION

The diagram of the SMES system three phase star connected source of 400V rms voltage is used to supply power to a nonlinear load that is a three phase six pulse diode rectifier.

SIMULATION OF VSC BASED SMES



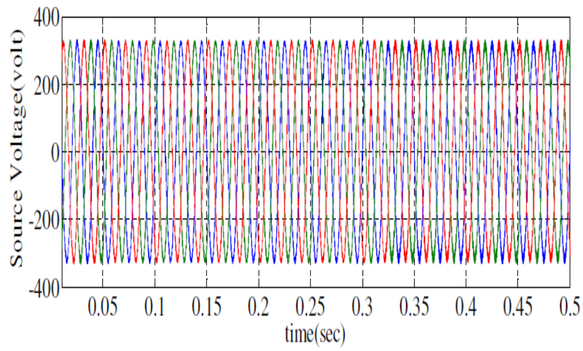


Fig 4 Source voltage

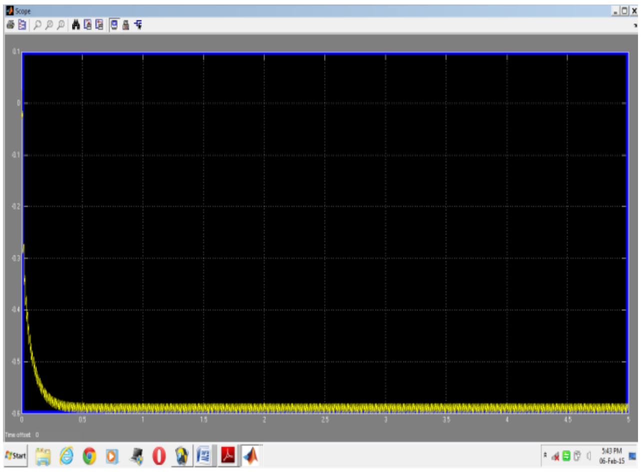


Fig 5:SMES coil inductor current during standby mode

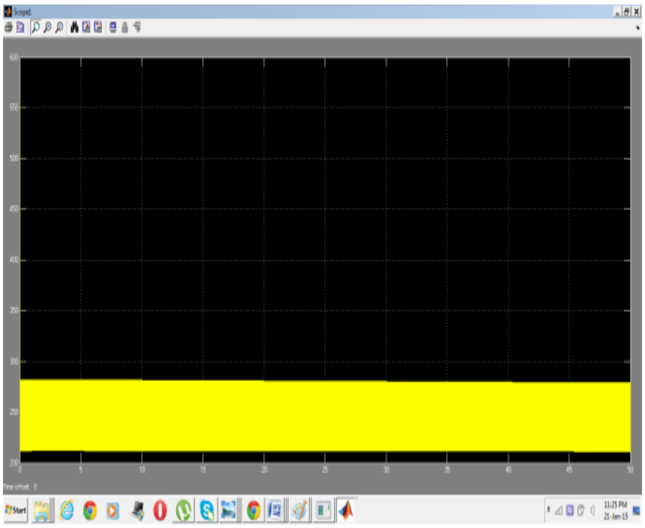


Fig6:Capacitor dc link voltage

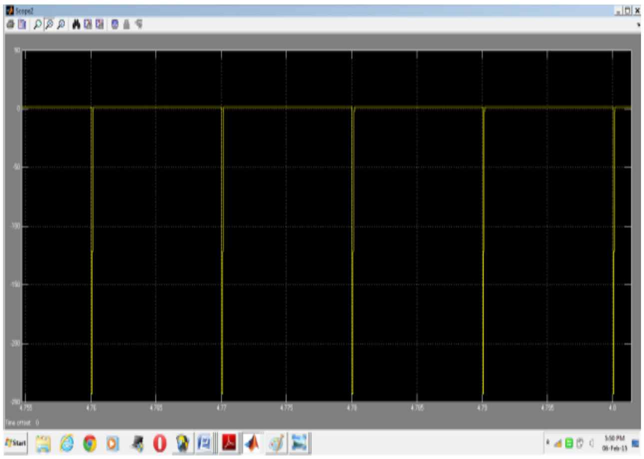


Fig6: SMES voltage

VII. CONCLUSION

In this paper SMES acts a as shunt power filter & Power conditioning system and In the above results and analysis it has shown that the complete cycle of SMES that is charging, stand by and discharging can be controlled along with the sinusoidal nature of source current irrespective of load conditions.

The above concept is fully exploited in this paper to derive the analytical expressions of load leveling and active power filter provided by a SMES in a simple power system..

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