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STABILIZATION OF HYBRID POWER SYSTEM USING SUPERCONDUCTING MAGNETIC COIL

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ABSTRACT

Dynamic system analysis is carried out on an isolated electric power system consisting of a diesel generator. A power conditioning system which consists of a Superconducting Magnetic Energy Storage (SMES) that can be used to smooth out differences between output power of an isolated generator and the diesel generator system has been simulated. The SMES is connected in shunt with the distribution lines through a converter which is a six pulse converter using GTOs. There is a continuous variation of power in the power system. A SIMULINK/MATLAB model of the setup is developed to improve system stability; the output after connecting the SMES unit has been analyzed.

Index Terms: diesel Generator System, Energy Storage, SIMULINK, SMES, Stability

I. INTRODUCTION

A number of storage technologies are available in the market but the most commonly used are pumped storage hydroelectric systems, battery energy storage systems (BESS), and superconducting magnetic energy storage (SMES) systems. Some of the disadvantages of pumped hydro electric are large unit sizes, topographic and environmental limitations while that of BESS include limited life cycle, voltage and current limitations, and potential environmental hazards [1]. SMES is a large superconducting coil which is capable of storing electric energy in the magnetic field. It is generated by dc current flowing through the coil. SMES system not only can enhance the reliability of the power system, but also can be expected to acquire a rapid response of the load fluctuations of the diesel power by absorbing and releasing the energy according to system power requirements. Nowadays, applications of SMES system are increasing in the electrical power system due to their fast response and high efficiency. The one major advantage of the SMES coil is that a large amount of power can be discharged in a small period of time.

Up to now, the application of SMES on hybrid power generation has been demonstrated on several papers [2]-[9]. The main purpose of most of these works [2]-[7] was to solve the system stability of hybrid power system by using SMES, while only a few results [8]-[9] aim to regulate the output power and voltage of the system . However, issue of fluctuations in power system has never been discussed in this works. With such a background, this paper proposes an application of SMES to minimize fluctuations in load of a small scale isolated power system with diesel connected system. The isolated power system is fed by a diesel generator consisting of squirrel cage induction machine. The control strategy is detailed and the proposed system is evaluated by simulation in MATLAB/SIMULINK.

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II. THE SMES TECHNOLOGY

2.1 Components

SMES is the only known technology which stores electrical energy directly into electric current. It stores electric energy as direct electric current passes through an inductor coil made of superconducting material and so that current can circulate indefinitely though it without any loss. Energy can be stored as the magnetic field created by the flow of electric current though the coil. The inductor is maintained in its superconducting state by immersing in liquid helium contained in a vacuum-insulated cryostat. Typically, the conductor is made of niobium- titanium, and the coolant used is liquid helium at 4.2 K, or super fluid helium at 1.8 K.

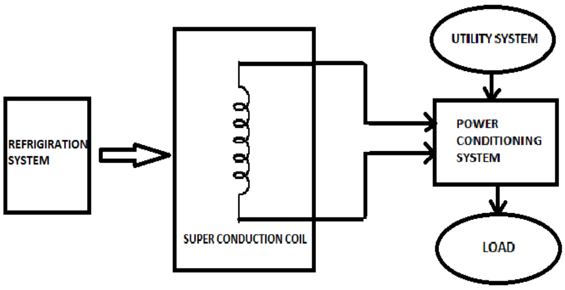

Fig. 1 SMES Conditioning System

The SMES system normally consists of three major components, as shown in Fig. 1, a superconducting unit, a cryostat system (a cryogenic refrigerator and a vacuum-insulated vessel), and a power conversion system[2]. The energy stored in the SMES coil can be calculated by

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

Where,

E is energy measured in joules

L is the inductance of the coil in henries,

I is the current passing through it in amperes

A rapid response (within a few milliseconds) and a very high energy storage efficiency is exhibited by SMES (typically >97%) as compared to other energy storage systems, but only for short periods of time [3]. As compared with batteries, energy output of an SMES system is less dependent on the discharge rate. SMES has a high cycle life hence is suitable for applications that require constant, full cycling and a continuous mode of operation. These features make SMES suitable for use in solving voltage stability and power quality problems for large industrial customers but its high cost and environmental issues associated with strong magnetic field are the major problems that oppose its implementation.

2.2 Uses

SMES technology has become a lot more advanced in recent years. It has the potential to store real power in order to protect consumers from the grid voltage fluctuations.

Power systems have been experiencing dramatic changes in the generation, transmission and distribution of electric power. Continuous growth in electric load and higher power transfer in a largely interconnected network

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has lead to complex and less secure power system operation. Power system engineers are facing challenges to find solutions to operate the system in more a flexible and controllable manner. Hence energy storage devices play an important role to utilities that maintain instantaneous balance between the demand and the supply.

Energy storage devices can be classified into two different categories, depending on their application: short-term response energy storage devices and long-term response energy storage devices. Short term response energy devices include flywheel, super capacitor, SMES whereas long term response energy storage devices include compress air, hydrogen fuel cell and batteries. Here we are more concerned with short term response energy devices [4, 11].

Flywheel and super capacitor have less power and energy rating so they cannot be used for short time high power application. So in order to overcome this deficiency SMES can be used to improve performance of power system. It has high power rating with max efficiency than any other energy storage devices.

The power industry demand for more flexible, reliable and fast real power compensation devices provides the ideal opportunity for SMES applications. SMES technology can be used for various applications such as Power Quality improvement, Power Stabilization, Voltage/VAR Control, Load Leveling, Dynamic Response, Spinning Reserve and Frequency Control Application.

2.3 Modeling of SMES

In this paper, an SMES model using 6 pulse thyristor based converter and GTOs has been developed in SIMULINK software as shown in fig 2. The inductance of the SMES coil has been taken as 1.2H with certain amount of initial current flowing through it. The six pulse converter has been used for it its simplicity but a higher pulse converter can also be used for more accurate results.

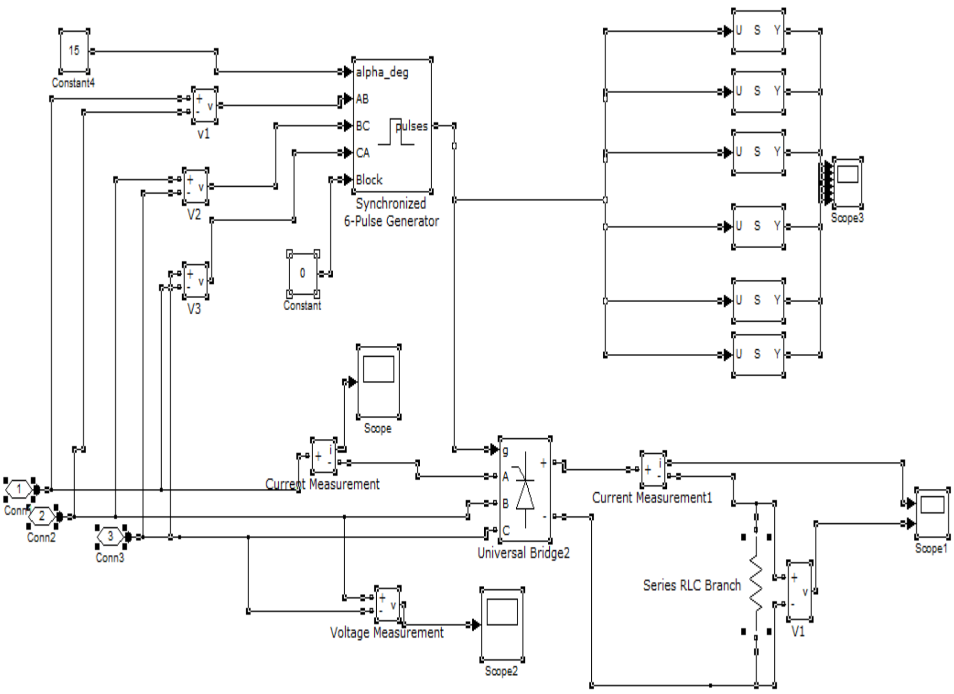

Fig. 2 SIMULINK Model of SMES System

III. THE DIESEL GENERATOR SYSTEM

The global electrical energy consumption is rising continuously & there is urgent need to increase the power capacity. It is expected that the power capacity has to be doubled within the next 20 years. Investment in large power plants has been lowered by the deregulation of industry, which means the need for new electrical power sources will be high in the near future [5]. One solution to solve the future problem is to change the electrical power production sources from the conventional, fossil or short term based energy sources to renewable energy resources.

The diesel dynamics is associated with diesel power and the nature of the dynamic behavior. It is dominated by the diesel speed governor control. There are certain fluctuations in the diesel-generator system which may take place in certain intervals of time. These fluctuations can be caused by many sources like misfiring of diesel engine, transients, load variations etc [6]. The purpose of the adjustable power provided by SMES unit is to check these variations and to allow system to manage its power without overloading the isolated generator.

Operation of diesel for extended periods at low power levels could result in possible engine damage. During less load demand the excess energy will be stored in the magnets with superconductive windings of SMES unit. Charging and discharging is achieved by varying the dc voltage, applied to the inductor, through a wide range of positive and negative values. This can be achieved by controlling the delay angle of converters.

IV. THE POWER SYSTEM

An isolated generator with capacity of 200 KVA, 50 Hz has been considered in this model shown in fig 3. It is connected to a total load of 150 KW via a transmission line of 30 km. This isolated generator is connected to a diesel generator system having maximum capacity of 20 KVA, 50 Hz through a circuit breaker.

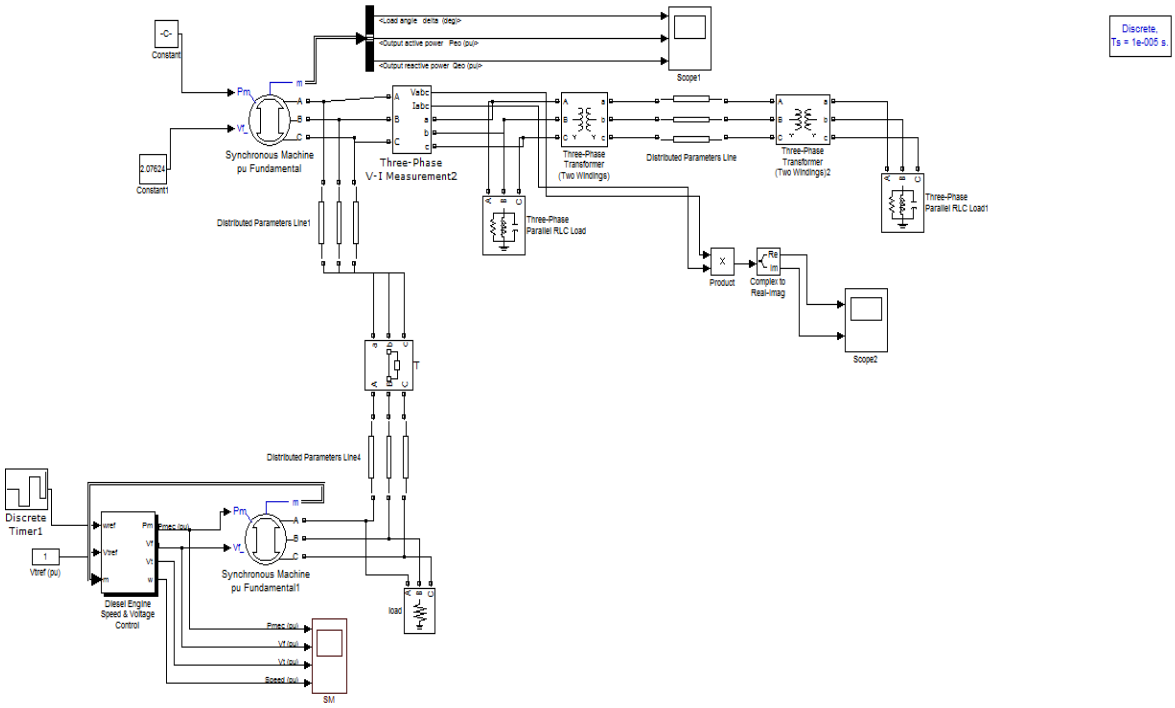

Fig. 3 SIMULINK Model of Power System

The generator and diesel system together supply the load. The main generator operates at degree load angle and 0.5 p.u. of Power capacity. When the system is operated, there is fluctuation in the diesel generator system during the time interval from 2 to 3 second. During this time, the power is supplied by the isolated generator alone and hence its output power increases as shown in the simulation results.

4.1 Mathematical Model

The basic configuration of a thyristor-based SMES unit, consisting of a Wye-Delta transformer, an ac/dc thyristor controlled bridge converter, and a superconducting coil or inductor is shown in fig. 4.

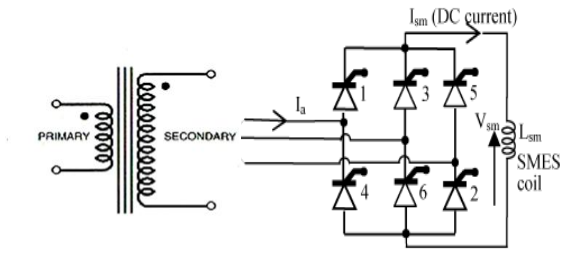

Fig. 4 SMES Unit with Six-Pulse Bridge Ac/Dc thruster Controlled Converter

The converter drives positive or negative voltage on the superconducting coil. By simply changing the delay angle α that controls the sequential firing of the thyristors, charging and discharging can be easily controlled. If α is less than 90, the converter operates in the rectifier mode (charging) and if α is greater than 90, the converter operates in the inverter mode (discharging) [7]. Hence, power can be absorbed from or released in to the power system according to requirement. SMES should not consume any real or reactive power at the steady state.

The voltage Vout at DC side of converter can be expressed by-

$Vout = Vm \cos$ … (1)

And current can be expressed by –

$Iout = \frac{1}{Lo} \int_{t0}^{t} Vout \, dt + i$ … (2)

Im is the initial current of the inductor, and the real power absorbed or delivered by the SMES is given by-

$Pout = Vout \, Io$ … (3)

Since, the bridge current is not reversible; the bridge output Pout is uniquely a function of firing angle α, which can be positive of negative depending upon the voltage Vout. So direction of power flow will depend on the firing angle α [3]. The energy stored in the super conducting inductor is

$Wout = Wm + \int_{t0}^{t} Pout$ … (4)

Where,

$Wm = \frac{1}{2} Lm \, Ir$ … (5)

Wm is the initial energy in the inductor.

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V. SIMULATION RESULTS

The isolated generator and diesel system is connected to SMES system. The fluctuations occur in diesel system and during the time when the output of the diesel generator system becomes less than 50 percent, the energy is provided by the SMES system. The output obtained by connecting SMES system is shown in the figure

5.1 When SMES Is Not Connected

The following output shown in fig. 5 is obtained when SMES is not connected to the system. There is variation in the diesel generator system at various time periods during which the load on the isolated generator is increased. The model has been simulated for 5 seconds.

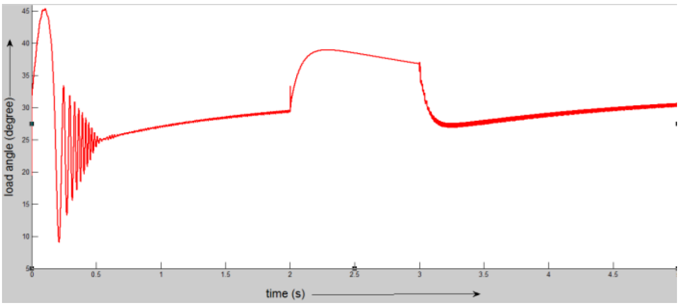
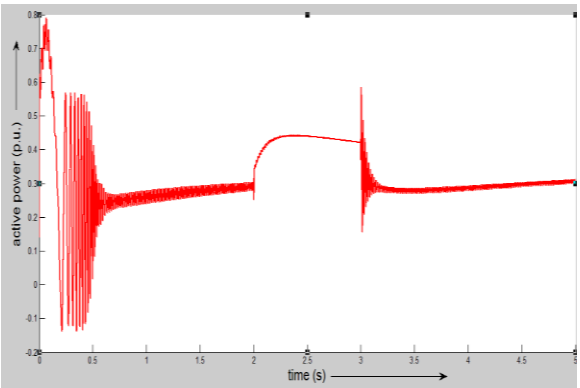


Fig 5 (A). Load Angle



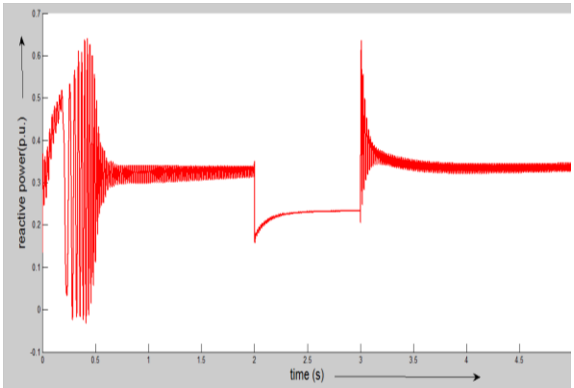


Fig. 5(B) Active Power

Fig. 5(C) Reactive Power

Fig. 5 Simulation Results of Isolated Generator System

5.2 When SMES is connected

The SMES system provides the energy required by the isolated generator system when no output is obtained by the diesel generator. During the time when diesel generator is connected in the system, the firing angle α of the 6 pulse converter system is adjusted to less than 90 degree by the PI controller, and charging of SMES coil takes place. The period when diesel generator is not connected to the isolated generator system, the firing angle α is adjusted to a value greater than 90 degree. The simulation results are shown in the fig. 6.

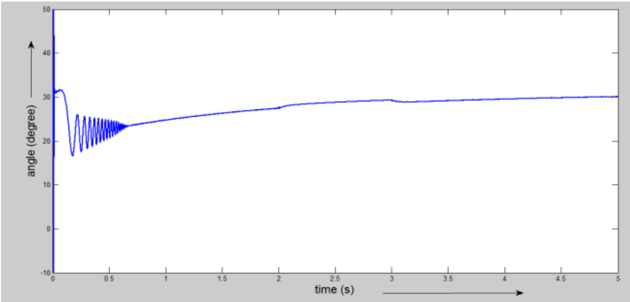
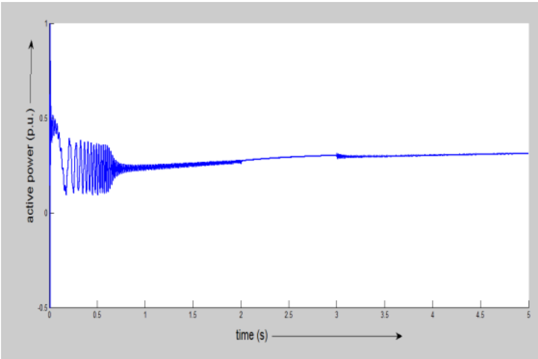


Fig. 6 (A). Load Angle



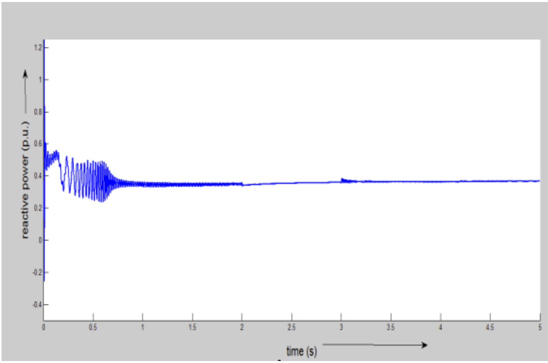


Fig. (B) Active Power **Fig(C). Reactive Power**

Fig. 6 simulation results when SMES is connected to the system

5.3 Comparison of the Results

The output obtained before connecting SMES and after connecting SMES system has been compared. It can be concluded that the system in which SMES has been connected, shows less variation in its output. Hence, the stability of isolated generator connected with diesel generator having fluctuating output improves when SMES coil has been connected.

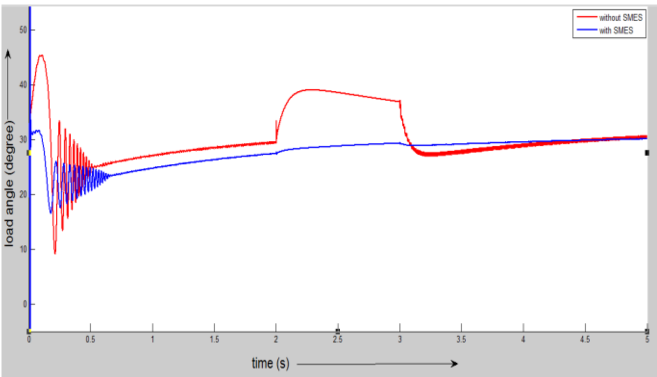


Fig7(A). Load Angle

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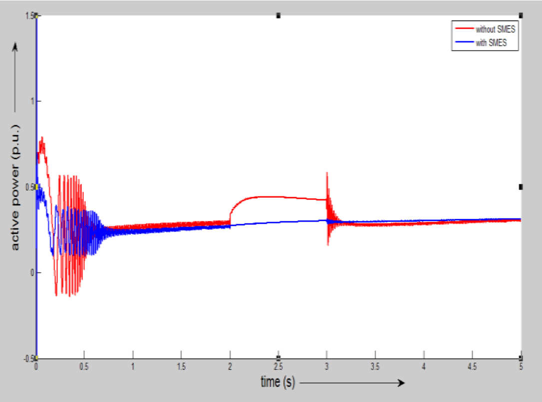

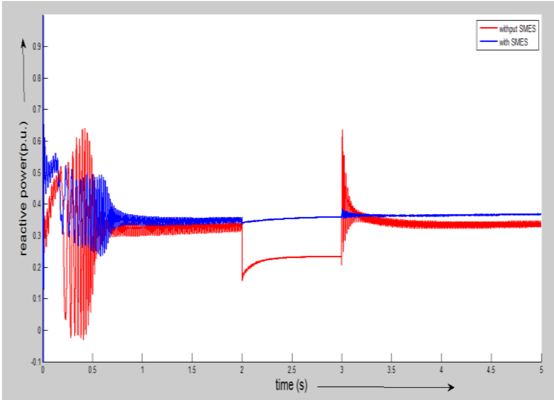

Fig7(B). Active Power **Fig7(C). Reactive Power**

Fig. 7 Comparison of load Angle and Power with and Without

VI. CONCLUSION

SMES technology has become a lot more advanced in recent years. It has the potential to store real power in order to protect consumers from the grid voltage fluctuations. The results obtained suggest that the fluctuations in the output angle and power decreases and the system have been stabilized. The SMES system can hence be used as a spinning reserve for a short period. Apart from using a 6-pulse converter a higher pulse generator or voltage source converter (VSC) and current source converter (CSC) can be used to improve the system's accuracy.

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