IMPROVEMENT OF POWER SYSTEM TRANSIENT STABILITY USING SMES

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***Abstract* — The use of superconducting magnetic energy storage to improve power system transient stability is presented in this paper. The use of PI controlled superconducting magnetic energy storage improves the transient stability of a power system (SMES). A comparison of SMES and PI controlled SMES was performed. The simulation results show that PI controlled SMES outperform SMES without a PI controller under three-phase faults. The proposed method improves transient stability in a very simple and effective way.**

***Index Terms* — Superconducting Magnetic Energy Storage (SMES), PI controller, Transient Stability**

I. INTRODUCTION

Electric power generation, transmission, distribution, and end-user facilities have all undergone significant modification. Power system operation becomes more complicated and less secure because of ongoing increases in electric load and higher power transmission in a highly interconnected network. In addition, the design and operation of power systems are restricted by a number of considerations, including economic, environmental, and technical constraints. When faced with these difficulties, power system engineers look for ways to manage the system more flexibly and precisely. The use of SMES (superconducting magnetic energy storage) systems is now a realistic option to address some of the issues faced by power systems because of recent developments and advancements in both superconducting and power electronics technology. Even though SMES was initially intended to be a massive load-leveling device. As power systems undergo deregulation, it is now primarily considered as a tool to improve system stability, power transfer, and power quality. The best potential for SMES applications is provided by the need for more adaptable, dependable, and quick real power compensation devices in the power industry [1-3].

Electricity is intended to be stored in the low loss superconducting magnetic coil by the superconducting magnetic energy storage (SMES) unit. Depending on the needs of the system, the coil can either absorb or release power. To improve the power system transient stability, a SMES unit with a proportional-integral (PI) controller is designed in this study using a systematic method. The PI controller's construction is straightforward, and it has been effectively used to the improvement of transient stability.

II. BASIC CONFIGURATION OF SMES

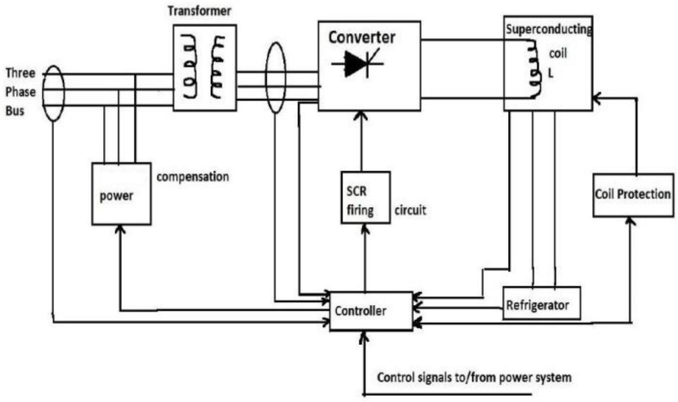

Fig. 1: Basic configuration of SMES

Complete SMES unit consists of a three phase bus connected to a transformer. GTO or other types of converter are attached to the transformer. There are normally 12 pulse convertors connected to the SMES unit. SMES coil 'L' is basically inductor which is in superconducting state. A low temperature is maintained to keep coil in superconducting state through a refrigerator. Normally we use HTS type super conductors where liquid nitrogen is sufficient to lower the temperature below critical temperature. A coil protection is also used that saves the coil in case of large current or magnetic stress. Controller is used to set firing angle of converters which will tell SMES when to charge and when to discharge.

III. MODELING OF SMES

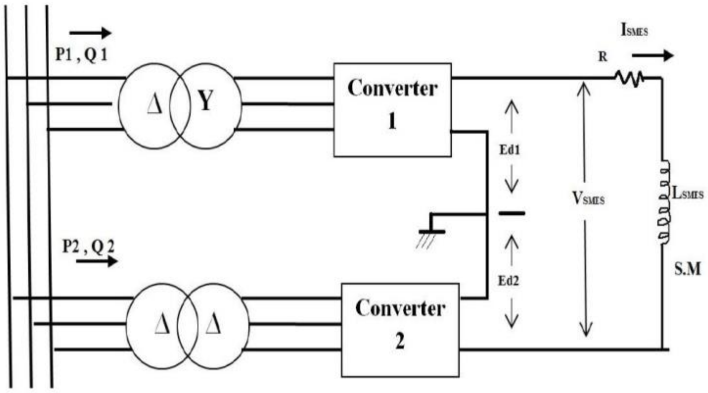

Fig. 2: Circuit diagram of SMES unit

SMES unit consists of two sets of transformer that are connected to A.C three phase line. Other end of the transformer is connected to two a 12-pulse convertor, two sets of 6 –pulse bridge force commutated converter, which is in series with the superconducting inductor L_{SMES}. We are only considering the active power (P) control using the SMES so reactive Q is not considered. That's why we used force commutators where firing angle of thyristor is fix. When no power is transferred, maximum charging mode happens at 0^o and for maximum discharging mode 180˚[6-9].

Since the I_{SMES} current going through bridge is not reversible, active power P_{SMES} simply has positive and negative value depending upon the situation it can deliver or withdraw power hence keeping the system stable [4-5]..

Active power of SMES P_{SMES}, current I_{SMES} and voltage V_{SMES} of SMES is related as

$$P_{SMES} = V_{SMES} \cdot I_{SMES} \quad (1)$$

If V_{SMES} is positive value that means that energy is transferred to SMES from power system and if V_{SMES} is negative that means energy is taken out from SMES and transferred to the power system. We know current across a coil is given as

$$\frac{dI_{SMES}}{d\tau} = \frac{(V_{SMES} - R_{SMES} I_{SMES})}{L_{SMES}} \quad (2)$$

Since we are taking a superconductive coil , we know its resistance is zero , so putting R_{SMES}=0 in Equation (2) and Integrating equation (2) from initial time 'to' to 't' with initial current of superconducting coil as I_{SMO}, we get current I_{SMES} in terms of Voltage V_{SMES} of superconductor and initial current I_{SMO} is given by

$$I_{SMES} = \frac{1}{L_{SMES}} \int_{t_0}^{t} V_{SMES} \; d\tau + I_{SMO} \quad (3)$$

Energy that is being stored inside the superconducting coil can be written as

$$W_{SMES} = W_{SCO} + \int_{t_0}^{t} P_{SMES}\,(\tau) d\tau \quad (4)$$

Where W_{SCO} is the energy stored inside the coil at t=to and is given as

$$W_{SCO} = \frac{1}{2} L_d I_{SMO}^2 \quad (5)$$

Change in the rotor angular speed is caused due to any external disturbance that is related to the SMES voltage V_{SMES} as given below.

$$\Delta V_{SMES} = \frac{K_C}{1+sT_C} \cdot \Delta\omega \quad (6)$$

Where, K_C is the gain of control loop of SMES and T_C is the time constant of the control loop. Equation (3) and (6) are used to design the SMES model in MATLAB for simulation.

Using the above analysis and equations we can easily design a SMES model that can be used in the MATLAB with the synchronous generator connected to infinite bus. From Equations (3) and (6) we can make a model that will give us the power of the SMES, P_{SMES} which will vary in accordance to the change or deviation of the angular rotor speed of the synchronous generator.

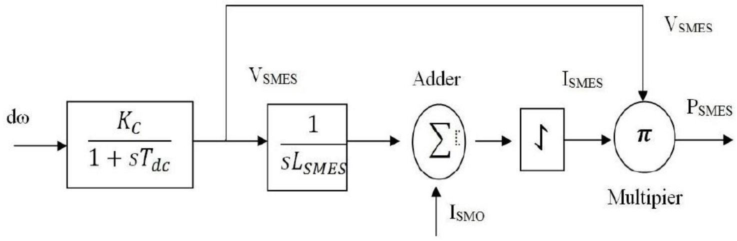

Fig. 3: Block diagram of SMES model

The deviation in the angular speed of the rotor of the synchronous generator is feed to the transfer function containing loop gain and time constant of feedback loop of the SMES coil. From Equation (6) we know that this change in ω will give the changed V_{SMES} i.e. voltage across the coil. Using the equation (3) we get current I_{SMES} across the coil from the voltage V_{SMES} by integrating and adding the initial current I_{SMO}.

For the system to not get damaged we use a saturator to limit the current across the coil. Now current across the coil of superconductor I_{SMES} and voltage across the coil of superconductor V_{SMES} is sent to a multiplier and we know from equation (1) it will give power P_{SMES} across the coil.

IV. PI CONTROLLER

Basic PI controller block is given by,

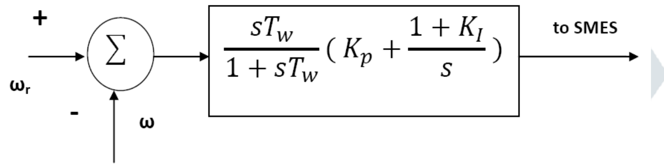

Fig. 4: Block diagram of PI controller

The PI controller is fed with the reference angular speed taken 1 pu generally ω_r and rotor angular speed ω. This PI controller output is attached to the SMES unit. T_W is known in system parameters, values of K_I and K_P are given below.

Kp = 44
Ki = 900

V. POWER SYSTEM MODEL

In this paper for the analysis of transient stability, the power system model connected with a PI controlled SMES under the three-phase fault at infinite bus as shown in the power system model shown in Fig. 5 has been simulated in MATLAB Simulink environment. The 3LG fault occurs at 15.1 to 15.2 s. The model system consists of a synchronous generator (SG) feeding an infinite bus through a transformer and transmission line. To effectively control the power balance of the synchronous generator during a dynamic period, the SMES unit is placed in the generator terminal bus.

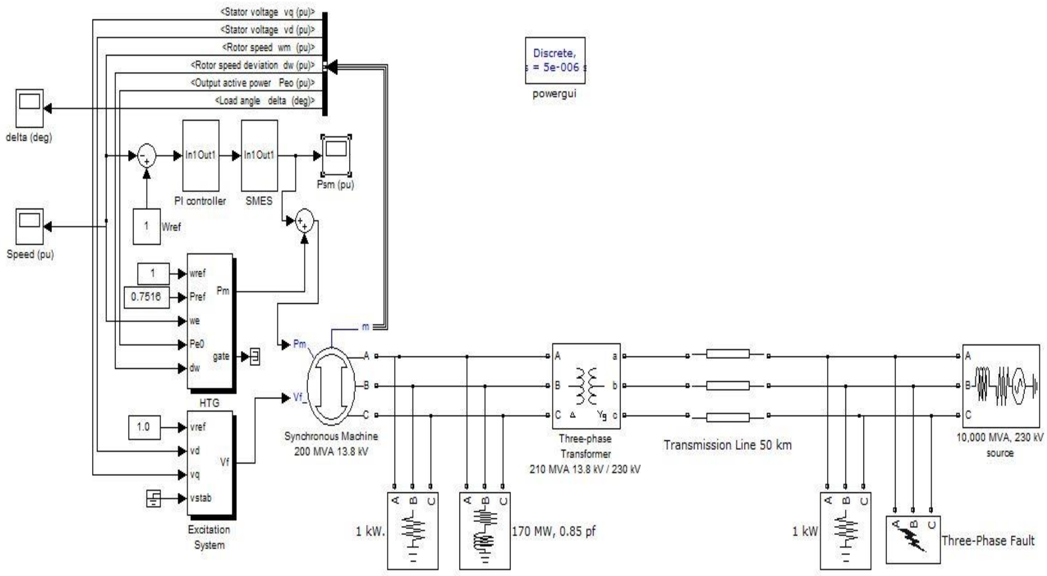

Fig. 5: MATLAB model of power system with PI controlled SMES

VI. SIMULATION RESULTS

Simulations are performed for two different fault conditions,
Case-1: 3LG fault at infinite bus
Case-2: 3LG fault at generator bus
These simulations are carried out in MATLAB Simulink environment for above mentioned cases.

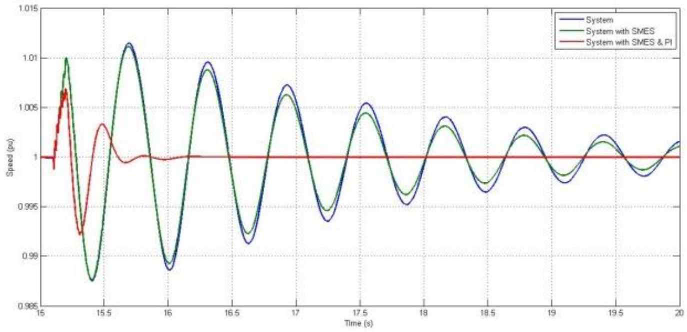

Fig. 6: Graph of Rotor Speed and Time for Case-1

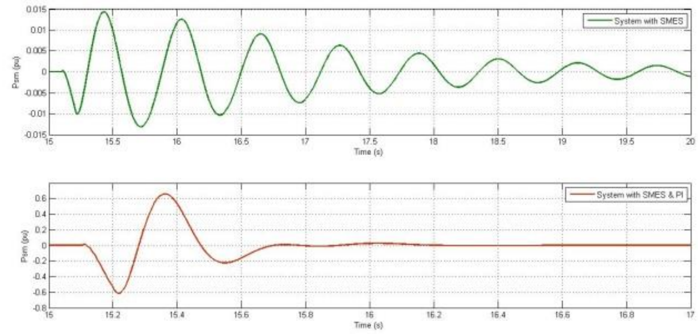

Fig. 7: Graph of SMES Power and Time for Case-1

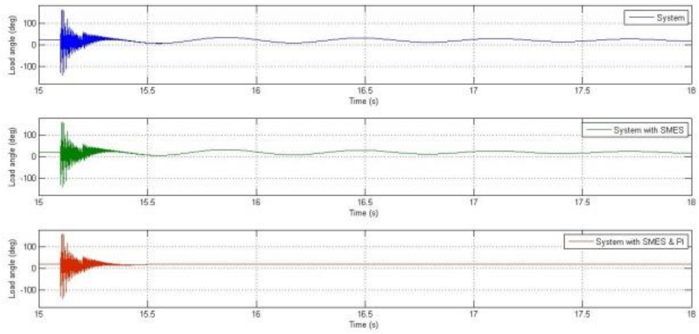

Fig. 8: Graph of Load Angle and Time for Case-1

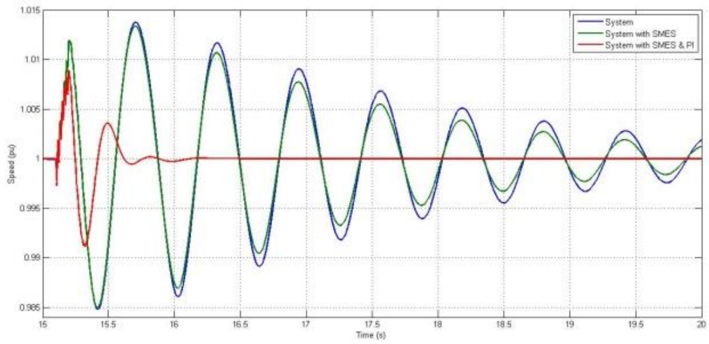

Fig. 9: Graph of Rotor Speed and Time for Case-2

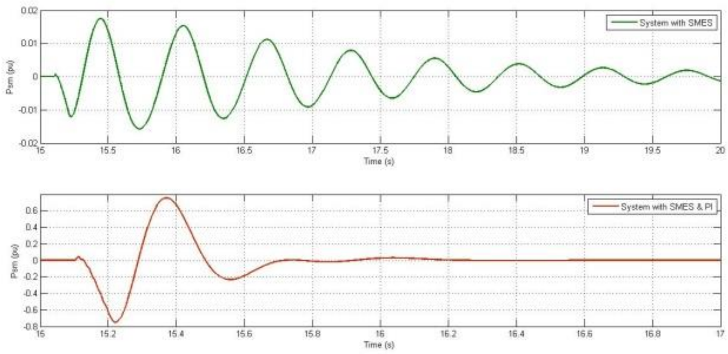

Fig. 10: Graph of SMES Power and Time for Case-2

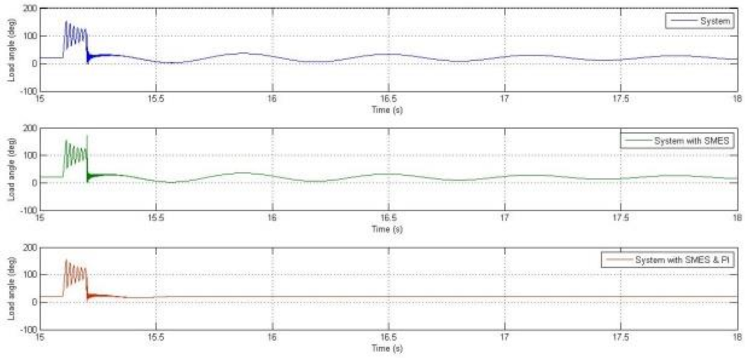

Fig. 11: Graph of Load Angle and Time for Case-2

CONCLUSION

In this paper, the superconducting magnetic energy storage (SMES) unit with a proportional-integral (PI) controller is proposed to enhance the transient stability of the power system. Simulation results clearly shown that the validity and effectiveness of the proposed method in enhancing the transient stability.

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