

# Optimal Design of SMES and PSS for Power System Stability based on Ant Colony Optimization

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**Abstract**—In this paper, the ant colony optimization (ACO) technique is employed to precisely tune the parameters of a superconducting magnetic energy storage unit and power system stabilizer to damp the oscillations in a Single Machine Infinite Bus system during transient and disturbance events. In this regard, an objective function to minimize the integral time absolute error is developed and solved using the ACO. System performance is assessed through its frequency response and the machine's rotor angle along with the eigenvalue characteristic for each control combination scheme. Results reveal the effectiveness of the proposed controller.

**Keywords**—SMES, PSS, ACO, frequency oscillation

## I. INTRODUCTION

To keep the single machine infinite bus (SMIB) system running at its operating point, it is necessary to analyze its performance against interference. Several control schemes have been presented in the literature to improve the performance of SMIB using several flexible ac transmission system devices including superconducting Magnetic Energy Storage (SMES) [1-4]. SMES stores the electric energy within the magnetic field of a superconducting coil of near-zero energy loss. Power System Stabilizer (PSS) has been also widely used to control the performance of SMIB systems.

Several studies have presented the application of SMES unit in wind energy conversion systems and AC/DC systems [5, 6]. On the other hand, several studies investigated the application of PSS and proportional-integral-derivative (PID) controller to damp the oscillations in power systems [7]. In this paper, ant colony optimization (ACO) is used to tune the parameters of the proposed SMES unit and PSS to suppress the frequency oscillations on a SMIB system during transient events.

## II. SYSTEM UNDER STUDY

The SMIB system under study is shown in Fig. 1. In this model, the synchronous machine along with the exciter, steam turbines and governor are modelled in accordance to the IEEE models. PSS produces an electrical torque component to damp

the low frequency oscillations based on the rotor speed deviation. SMES unit consists of superconducting coil, cryogenic cooling system, and power conditioning systems with control and protection functions. The working principle of SMES is divided into three modes, namely charging, standby and discharging modes. These modes are controlled through controlling the duty cycle of the converter interfacing the coil with the system. A block diagram is used to simulate the PID-SMES in which the speed deviation is used as an input signal. The proposed PSS and SMES control block diagrams are shown in Fig. 2.

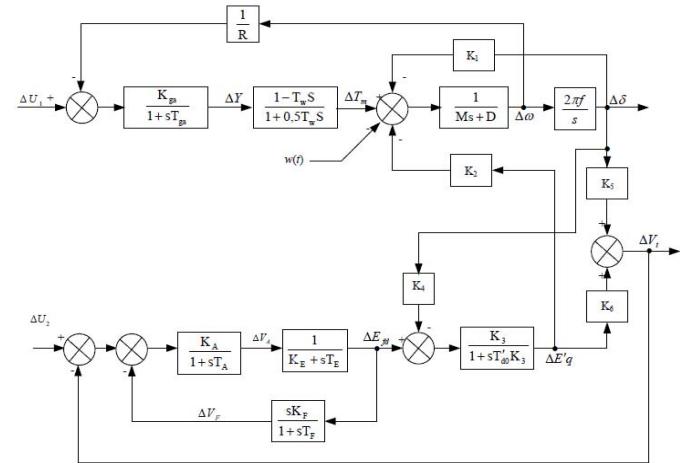


Figure 1. Modelling of SMIB under study

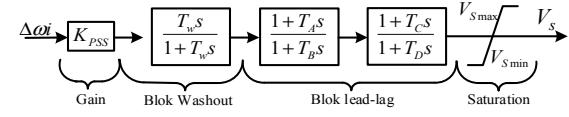


Figure 2. Proposed PSS and SMES controllers

### III. ANT COLONY OPTIMIZATION TECHNIQUE

To assess the robustness of the proposed SMES-PSS controller in improving the dynamic stability of the investigated system, the SMES-PID control parameters are optimized using ACO technique. In this regard, an objective function is developed to minimize the integral time absolute error (ITAE) of the rotor speed deviation  $\Delta\omega$  as given in (1). SMES-PSS control parameters tuned by ACO, as shown in Fig. 2, are  $T_{dc}$ ,  $K_{smes}$ ,  $K_{pss}$ ,  $T_1$ ,  $T_2$ ,  $T_3$  and  $T_4$ .

$$ITAE = \int_0^t | \Delta\omega(t) | dt \quad (1)$$

ACO optimization results in a least fitness function of  $4.6954e-07$ , after 50 iterations as shown in Fig. 3. It can be seen that the ACO algorithm is converging at the 26<sup>th</sup> iteration in about 21 s which gives it an advantage over other optimization techniques in terms of the rapid execution time. The optimized parameters are found to be:  $K_{smes}=97.9520$ ,  $K_{pss}=64.7055$ ,  $T_1=0.0509$ ,  $T_2=0.0268$ ,  $T_3=1.0909$ ,  $T_4=5.4077$ .

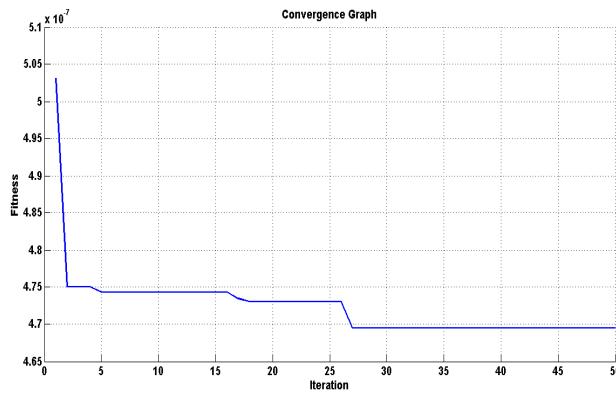


Figure 3. Ant Colony Optimization Convergence Performance

### IV. SIMULATION RESULTS

To assess the dynamic stability of the SMIB system under study, a step load change of 0.05 pu at  $t=0$  s for the system under study is assumed. Fig. 4 shows the frequency deviation of the system in per unit (pu) under four scenarios; without any controller, with SMES, with PSS and with both SMES-PSS controllers. Results show that, without any controller, the system will exhibit a low frequency oscillations of 1 Hz with a relatively large maximum overshooting and settling time. Using a controller, the frequency oscillation is significantly suppressed with substantial reduction in the maximum overshooting and settling time. It can be observed that the performance of the SMES unit is a slightly better than PSS. Using SMES-PSS will transform the system from underdamped to critically/overdamped mode in which oscillation is fully eliminated and the system reaches a steady state condition in a very short time compared to the other 3 scenarios. Fig. 5 shows a similar performance for the investigated controllers in suppressing the oscillation of the rotor angle of the synchronous machine. Without a controller, the overshooting in the rotor angle may result in instability condition. Similar to the above observation, the maximum overshooting along with the settling time have been

substantially reduced with the use of the investigated controllers.

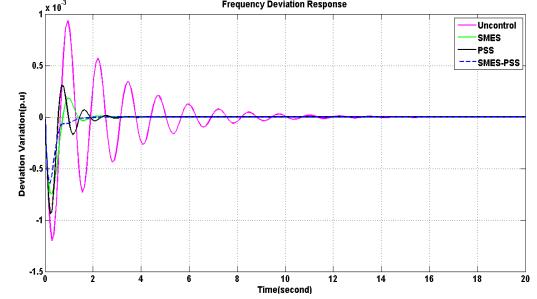


Figure 4. Frequency response due to a load step change

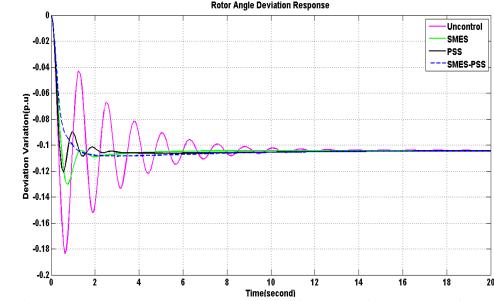


Figure 5. Rotor angle response due to a load step change

### V. CONCLUSION

In this paper, SMES-PSS controller is proposed to suppress the low frequency oscillations of a SMIB system. Control parameters are optimized using ACO technique. Results show that best control performance is achieved when both SMES-PSS are employed followed by the SMES unit then the PSS. While the high cost of SMES unit may restrict its implementation in various power systems applications, rapid advancement in superconducting materials will facilitate the full utilization of this technology in the future.

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