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Particle Swarm Optimization Based Power System Stabilizer to Enhance Power System Small Signal Stability

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ABSTRACT: Power system dynamic performance is improved by the damping of system oscillations. PSS is widely used in the electric power industry for improve the performance and functions of power systems during normal and abnormal operations. It can increase the system positive damping, improve the steady-state stability margin, and suppress the low-frequency oscillation of the power system. Design and application of PSS has been the subject of continuing development for many years. Therefore, it is necessary to utilize most efficient optimization methods to take full advantages in simplifying the problem and its implementation. From this perspective, many successful and powerful optimization methods and algorithms have been employed in formulating and solving this problem. This paper proposes Particle Swarm Optimization (PSO) in modern research optimization techniques to develop Power System Stabilizer (PSS).

***Keywords*:** Power system Stabilizer, low frequency oscillation, and optimization, Particle Swarm Optimization.

I. INTRODUCTION

Electrical power systems are often operated in critical situations that may lead to stability problems in the power grid, and in worst-case blackouts. Large interruptions have historically occurred in many of power systems around the world and this may lead to panic and state of emergency in the society. To reach this goal, an increasing amount of renewable energy sources such as wind farms and smaller hydro plants are implemented in the power grids. The results of this may increase the network stability problems and the grid cannot be loaded close to the limit of maximum transfer capacity. This can in some cases reduce the needs of new power lines and thereby valuable space in the community.

"Power system stability is the ability of an electrical power system, for given operating conditions, to regain its state of operating equilibrium after being subjected to a physical disturbance, with the system variables bounded, so that the entire system remains intact and the service remains uninterrupted".

Transient stability which is the ability to maintain synchronism when the system is subjected to a large disturbance. In the resulting system response, the changes in the dynamic variables are large and the nonlinear behavior of the system is important.

Small Signal Stability which is the ability of the system to maintain stability under small disturbance. Such disturbances occur continuously in the normal operation of a power system due to small variations in load and generation.

II. BASICS OF POWER SYSTEM STABILIZER

The basic function of a power system stabilizer is to modulate generator excitation to provide damping to the system oscillations of concern. These oscillations are typically in the frequency range of 0.2to 2.0Hz, and insufficient damping of these oscillations may limit the ability to transmit power [4]. To provide damping, the PSS must produce a component of electrical torque which is in phase with the rotor speed deviation. The implementation details differ, depending on the stabilizer input signal employed. However, for any input signal the PSS transfer function must compensate for the phase lag of the combined generator, excitation system, and power system. They collectively determine the transfer function between the PSS output and the electrical torque component which can be modulated via excitation system.

A. Structure of PSS

The conventional lead–lag structure is chosen in this study as a Conventional PSS (CPSS). The structure of the CPSS controller model is shown in Fig. 1.

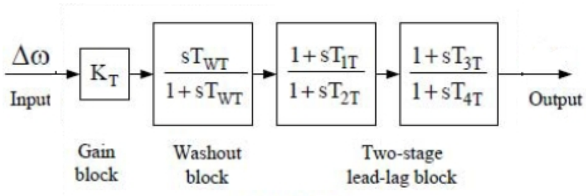

Fig. 1. Structure of Power System Stabilizer.

It consists of a gain block, signal wash out block and a two stage lead-lag phase compensation blocks. It consists of a gain block with gain K_T, a signal washout block and two-stage phase compensation block as shown in figure. The phase compensation block provides the appropriate phase-lead characteristics to compensate for the phase lag between input and the output signals. The signal washout block serves as a high-pass filter, with the time constant T_W high enough to allow signals associated with oscillations in input signal to pass unchanged [2]. The transfer functions of the PSS

$$u_{pss} = K_T \left(\frac{sT\omega}{1+sT\omega} \right) \left(\frac{1+sT_1}{1+sT_2} \right) \left(\frac{1+sT_3}{1+sT_4} \right) \quad (1)$$

III. TEST SYSTEM

This paper deals with Single Machine Infinite Bus (SMIB) system.

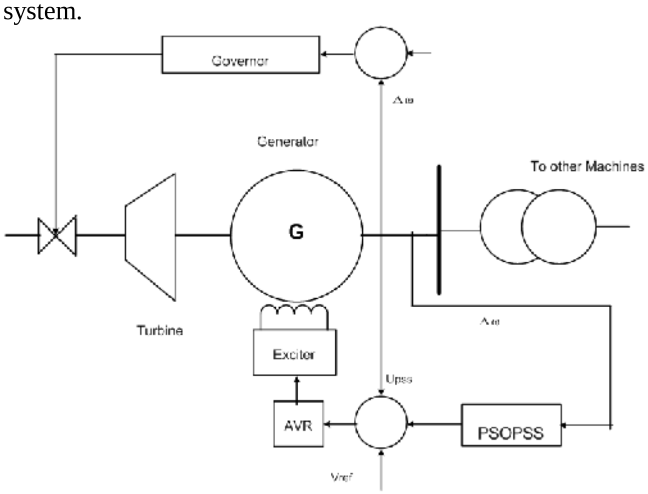

Fig. 2. Single Machine Infinite Bus System.

A SMIB power system model as shown in Fig. 2 is used to obtain the Modified Heffron-Phillip's model parameters. This is a simplified representation of a generator is connected to the load through a transmission line.

For the study of single machine infinite bus system a Heffron Phillips model can be obtained by linear zing the system equations around an operating condition. The obtained Hefffron model is as in Fig.3.

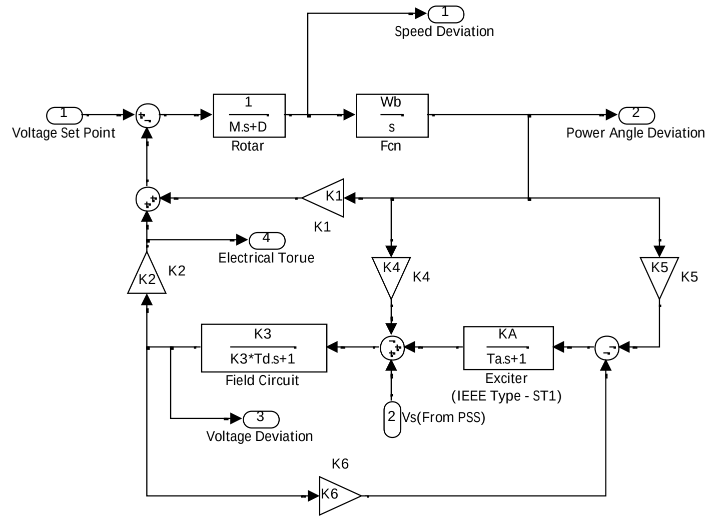

Fig. 3. Phillip Heffron Model of SMIB.

IV. OBJECTIVE FUNCTION

In case of the above lead-lag structured PSS, the washout time constants is usually specified. In the present study, washout time constant T_W =10 sec is used. The controller gain K_T and the time constants T_1,T_2, T_3 and T_4 are to be determined. It is worth mentioning that the PSS is designed to minimize the power system oscillations after a small & large disturbance so as to improve the power system stability. These oscillations are reflected in the deviations in power angle, rotor speed and line power. Minimization of any one or all of the above deviations could be chosen as the objective. In this study, an Integral of Absolute Error (IAE) of the speed deviations is taken as the objective function expressed as follows:

$$j = \int_0^{t1} |\Delta\omega| dt \qquad \ldots(2)$$

In the above equations, Δω denotes the rotor speed deviation for a set of controller parameters X. Here X represents the parameters to be optimized. A total of 5 parameters of PSS controller are being tuned to get the optimal response.t_1 is the time range of the simulation.

It is aimed to minimize this objective function in order to improve the system response in terms of the settling time and overshoots under different operating condition. The design problem can be formulated as the following constrained optimization problem, where the constraints are the controller parameters bounds, as follow,

Minimize J subjected to following constraints:

$K_T^{MIN} < K_T < K_T^{MAX}$

$T_i^{MIN} < T_i < T_i^{MAX}$

where I = 1,2,3,4

V. DESCRIPTION OF PSO

Particle Swarm Optimization (PSO) is an evolutionary computation technique, developed for optimization of continuous non linear, constrained and unconstrained, non differentiable multimodal functions .PSO is inspired firstly by general artificial life, the same as bird flocking, fish schooling and social interaction behaviour of human and secondly by random search methods of evolutionary algorithm [20]. Animals, especially birds, fishes etc. always travel in a group without colliding, each member follows its group, adjust its position and velocity using the group information, because it reduces individual's effort for search of food, shelter etc.

In this study, the PSS design problem is formulated as an optimization problem and solved by PSO method to improve optimization synthesis and find the global optimum value of the fitness function. Selection of a desirable fitness function is very important to optimize PSS parameters. Because, different fitness functions promote different PSO PSS behaviors. For our optimization problem, an Integral of Absolute Error (IAE) based objective function for multiple operation conditions is considered where; t_1 is the time range of simulation.

The salient feature of this objective function is that it needs the minimal dynamic plant information. It is aimed to minimize this objective function in order to improve the system response in terms of the settling time and overshoots. The design problem can be formulated as the following constrained optimization problem, where the constraints are the PSS parameters bounds the proposed approach employs PSO to solve this optimization problem and search for the optimal set of PSSs parameters. Robustness is verified by considering numerous operating conditions.

Table 1: Parameter Boundaries for CPSS.

Parameter	Lower Bound	Upper Bound
K	0	200
T_1	0.1	0.5
T_2	0.1	0.5
T_3	0.1	0.5
T_4	0.1	0.5

Table 2. Parameter Boundaries for PSOPSS.

Parameter	Lower Bound	Upper Bound
K	0	199.4552
T_1	0.1	0.5000
T_2	0.1	0.1026
T_3	0.1	0.5000
T_4	0.1	0.10115

VI . SIMULATION STUDY

For this study Heffron Phillips model is obtained by linearizing the system equations around an operating condition and can be implemented by simulink. IEEE type ST1 model of static excitation System & Conventional PSS has been considered [7].

The dynamic performance of the PSS with optimum parameters obtained using the proposed method has been analyzed through dynamic analysis for different operating conditions small perturbation.

The behavior of the proposed PSO based designed PSS under faulty conditions is verified by applying the small perturbation for SMIB . System responses in the form of Speed Deviation, Power angle deviation Voltage deviation & Electrical torque are plotted. It can be seen that the system without PSS is highly oscillatory.

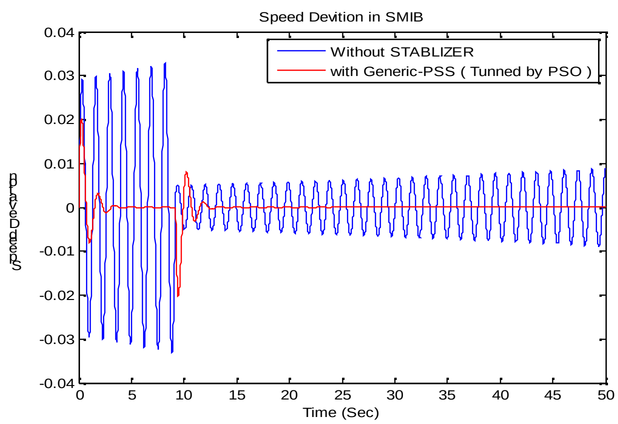

Fig. 4. Speed deviation without PSS & with PSO based PSS fault at t = 5 sec (ΔT = 0.05p.u).

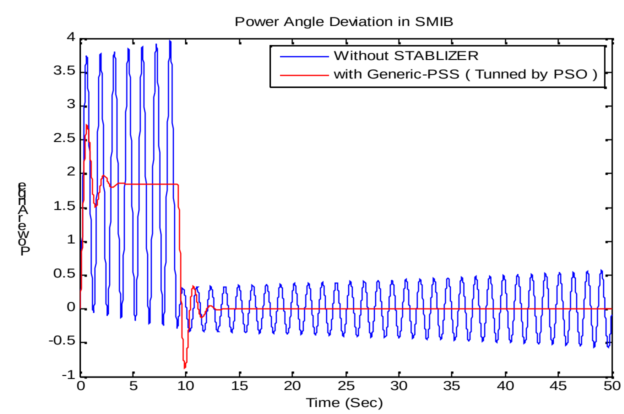

Fig. 5. Power Angle without PSS & with PSO based PSS fault at t = 5 sec (ΔT = 0.05p.u).

PSO based PSS tuned are able to damp the oscillations reasonably well and stabilize the system at faulty conditions. System is more stable in this case, following 5% change in Mechanical Input. PSO based PSS improve its dynamic stability considerably. The proposed PSO based PSS is effectual and achieves good system damping characteristics.

These simulation have been carried out on program has been coded in MATLAB and the performance of the algorithms have been obtained by using MATLAB 7.10.a on a core 2 duo, 2 GHz, 2.99 GB RAM.

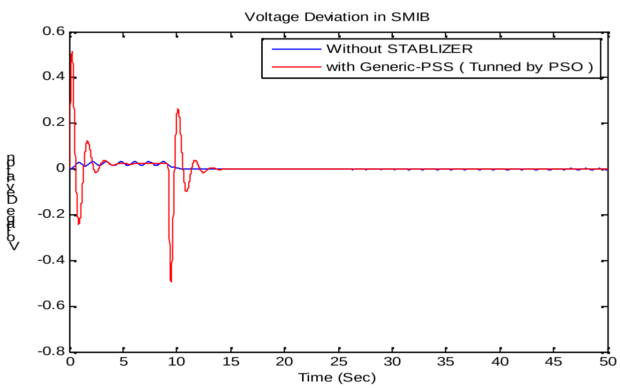

Fig. 6. Voltage deviation without PSS & with PSO based PSS fault at t = 5 sec (ΔT = 0.05p.u).

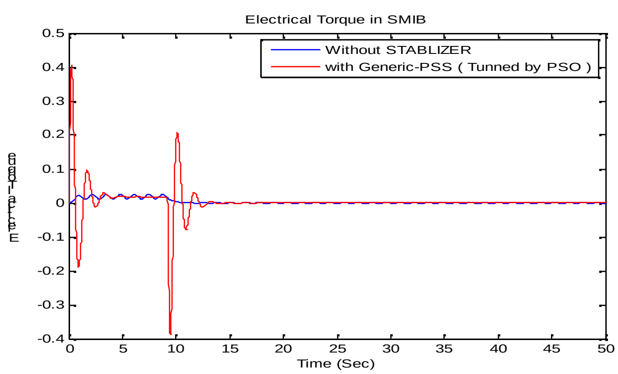

Fig.7. Electrical Torque without PSS & with PSO based PSS fault at t = 5 sec (ΔT = 0.05p.u).

VII. CONCLUSIONS

In this paper, the PSO algorithm has been proposed to optimally tune the PSS parameters for the improvement of the power system stability and secure operation of the single machine power systems. The dynamic performance of the system with the proposed PSO based PSS have been investigated over a small disturbance conditions. The system performance characteristics reveal that the proposed stabilizers demonstrate that the overshoot, settling time and speed deviations of the machine are greatly reduced under severe disturbance conditions.

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