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Optimal Tuning of Power System Stabilizer

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Abstract: - ***In this paper, a Particle Swarm Optimization (PSO) algorithm based Power System Stabilizer (PSS) is proposed to reduce low frequency oscillations that arise in the power system at different Loading Conditions. The low frequency oscillations (LFO's) are related to small signal stability of power system adversely affects the power system security. In this work, authors used PSO algorithm to tune gain settings of Power System Stabilizer. Single Machine Infinite Bus System (SMIB) is taken for their study, and later it is extended to multimachine system to test the effectiveness of proposed power system stabilizer using PSO The results clearly shows that the proposed Power system stabilizer using PSO greatly reduces the oscillations than the Conventional Power System stabilizer.***

Keywords: Small Signal Stability, PSS, PSO, Multimachine, SMIB

1. Introduction

Modern power systems are highly complex and nonlinear. Their operating conditions can vary over a wide range. The increasing size of generating units, the loading of the transmission lines and the operation of high speed excitation systems nearer to their operating limit are the main causes affecting small signal stability of power systems. Dynamic load changes and action of controllers create small oscillations in power systems, which prevent full exploitation of available generating capacity. Different control techniques such as modern and conventional techniques have historically been utilized by many researchers [1-4] for designing PSS. By using these techniques, PSS can provide optimal performance for the nominal operating condition and nominal system parameters. However, a modern power system is a large, nonlinear and complex system and it is subject to different kinds of events which result in many uncertainties. Considering their limitations, it is difficult to effectively solve low-frequency oscillations problem when one depends only on these conventional and linear optimal control approaches.

Power system stabilizer is the most widely used device for resolving oscillatory stability problems. Conventional Power System Stabilizers (CPSS) [6-10] are used to damp out small oscillations and they are designed based on a linearized model, which is valid around a particular operating point. The structure and the parameters of CPSS are determined to provide optimal performance at this operating point. The gain settings of this compensator are fixed by tuning at some specific operating condition to provide optimal performance. Parameters of the power system stabilizer need to be returned to get the desired performance as the power system configuration changes with time.

Particle Swarm Optimization [11], a quite popular method of the swarm intelligence family, is suggested into design robust PSSs.it has received increased attention in many research fields recently. PSO algorithm is proposed in this paper for optimal tuning of PSSs in power systems. This paper also discusses PSO applications to the Multimachine systems to prove its effectiveness and robustness.

In a multi-machine system with several poorly damped modes of oscillation, several power system stabilizers (PSSs) are used. For large scale power systems comprising many interconnected machines, the problem of PSS parameter tuning is not a straight forward exercise and in some cases could become too complex to resolve. For this reason, researchers [12-14] have attempted to simplify this problem by devising simplified and intuitive tuning procedures. For this reason, researchers have attempted to simplify this problem by devising simplified and intuitive tuning procedures based on past experience and systems analysis. Some researchers presented an approach for the design of PSS for a large generating station, wherein enhancement of overall system stability was the main criterion for the selection of PSS and automatic voltage regulator (AVR) parameters. They laid special focus on stability of low frequency inter-area mode oscillations, in which all the machines in the interconnected system participated.

The proposed approach is applied to optimal design of multimachine PSSs [15-17]. In this work three generator interconnected system is considered. Simulations are carried out to assess the effectiveness of the optimized PSSs Gain and compensator gains to damp the electromechanical modes of oscillations and enhance the system dynamic stability. The performance of the proposed method is also compared to that of ordinary system reported in the literature.

2. Problem Statement

2.1 Small Signal Stability

Small-signal stability, or the dynamic stability, can be defined as the behaviour of the power system when subjected to small disturbances. A power system can be modelled by a set of nonlinear differential–algebraic equations. In damping control design, small-signal model obtained by linearizing the system around an operation point is commonly used.
It is usually concerned as a problem of insufficient or poorly damping of system oscillations. These oscillations are undesirable even at low-frequencies, because they reduce the power transfer in the transmission line and sometimes introduce stress in the system. Power system stability may

be generally defined as the characteristic of a power system that enables it to remain in a state of operating equilibrium under normal operating conditions and to regain an acceptable state of equilibrium after being subjected to a disturbance.

2.2 Modelling of PSS

In this paper we considered the single machine infinite bus system (SMIB). It consists of Automatic Voltage Regulator (AVR), synchronous generator, excitation system etc.

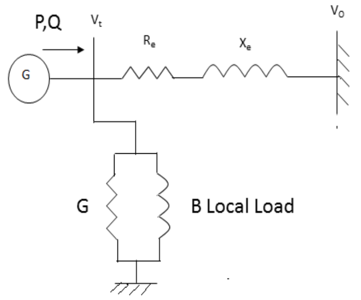

Figure 1: A Single Machine Infinite Bus Power System Model

A two pole generator is connected to the infinite bus system. R_e is the Transmission line resistance, X_e is the Transmission line reactance.

The Dynamic characteristics of the system are expressed in terms of K-constants.

It also consists of AVR and exciter for better performance. The effect of AVR on Damping and Synchronizing torque component is therefore influenced by excitation system.

K-constants are developed below.

$K_1 = (-\frac{1}{\Delta})[I^{\circ}_q V(X'_d - X_q)\{(X_q+X_e)\sin\delta^{\circ} - R_e\cos\delta^{\circ}\}]$
$K_2 = (\frac{1}{\Delta})[I^{\circ}_q \Delta - I^{\circ}_q (X'_d - X_q)(X_q+X_e) - R_e(X'_d - X_q) I^{\circ}_d + R_e]$
$1/K_3 = 1+[(X_d - X'_d)(X_q+X_e)]/\Delta$
$K_4 = [V(X_d - X'_d)/\Delta[(X_q+X_e)\sin\delta^{\circ} - R_e\cos\delta^{\circ}]$
$K_5 = (\frac{1}{\Delta})\{(V^{\circ}_d/V_t)X_q[R_e V\sin\delta^{\circ} + V\cos\delta^{\circ}(X'_d$
$+X_q)]+(V^{\circ}_q/V_t)[X'_d(R_e V\cos\delta^{\circ} - V(X_q+X_e)\sin\delta^{\circ}]\}$
$K_6 = (\frac{1}{\Delta})\{(V^{\circ}_d/V_t)X_q R_e - (V^{\circ}_q/V_t)X'_d(X_q+X_e)\} + (V^{\circ}_q/V_t)$

These are the K-constants of SMIB system. Now PSS is introduced in the system for effective Damping and reducing the amortisseurs effects should be neglected.

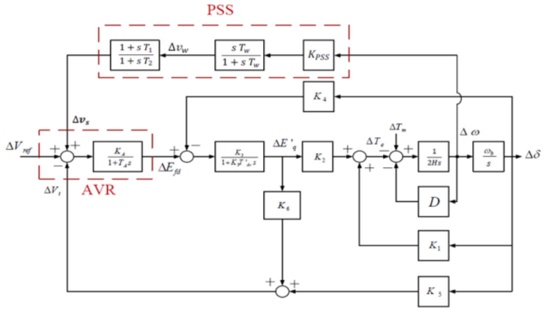

Figure 2: Block diagram representation of PSS

The basic function of Power System Stabilizer is to add damping to the generator rotor oscillations by controlling its excitation using auxiliary stabilizing signal(s).

The classical generator model having components K_s is synchronizing torque coefficient, K_d is damping torque coefficient, H is inertia constant. As K_s increases frequency also increases and K_d decreases. Increase in damping torque coefficient increases the Damping ratio.

3. Model of PSS

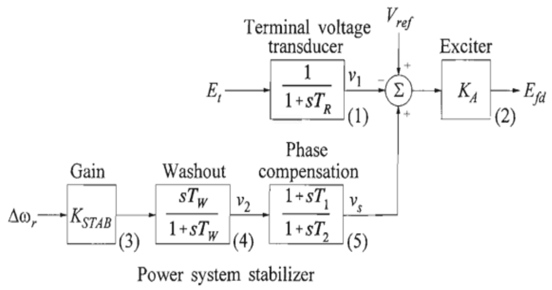

Figure 3: Structure of PSS

Where, K_{pss} = PSS gain, Tw = wash out time constant. T1, T2, T3, T4 = lead and lag time constants.

Power system stabilizer (PSS) is a device which provides additional supplementary control loops to the automatic voltage regulator (AVR). PSSs are often used as an effective means to add damping to the generator rotor Oscillations. The basic function of PSS is to add Stabilizing signal that compensates of the excitation system during the dynamic/transient state, and to provide damping component when it's on phase with rotor speed deviation of machine. Signal Wash out block serves as a high pass filter with time constant T_w to allow signals associated with oscillations in W_r to pass unchanged. It allows PSS to respond only to changes in speed. The stabilizer gain K_{STAB} determines the amount of damping introduced by the PSS. The function of phase compensation block is to provide appropriate phase lead characteristic to compensate for the phase lag between the exciter input and the generator electrical torque.

Transfer function of the PSS is given by

$$V_s = K_{PSS}\left(\frac{sTw}{1+sTw}\right)\left(\frac{1+sT1}{1+sT2}\right)\left(\frac{1+sT3}{1+sT4}\right)$$

In this design all the PSS parameters are pre specified. The speed deviation (Δw) is the input signal of the proposed PSS and the supplementary output signal is (ΔVs).

Table 1: K-constants for SMIB Model

Operating Points	K1	K2	K3	K4	K5	K6
P=1;Q=0.2 Higher Loading	1.467	2.434	0.354	1.698	-0.221	0.4611
P=0.8, Q=4.1 Nominal Loading	1.04	1.805	0.37	1.572	-0.692	0.48

The table 1 gives the K-constants for Single Machine Infinite Bus system for various operating points such as higher loading and nominal loading. These K-constants are obtained by running the load flow in the MATLAB environment for these operating points.

4. Multimachine Power System Stabilizer

Analysis of inter area oscillations in a large interconnected Power Systems requires detailed modelling of the entire system. In effect, during the optimization running, the values of one or more parameters to be optimized may reach one of the associated search space boundaries. This may happen after many generations or even from the beginning of the optimization. However, the optimal parameter values may exist outside the proposed search space boundaries. As a result, the objective function evolution will decelerate converging to a local optimal solution.

The principle of this proposed work consists of optimal tuning of Power System Stabilizer under different loading conditions like higher loading and nominal loading conditions to the Multimachine system. Particle Swarm Optimization (PSO) is used to optimize the parameters of PSS. Figure 4 shows how the three generators are interconnected with Loads and bus bars.

Generator-1 is at higher loading, Generator-2 is at nominal loading, Generator-3 is at higher loading. Each generator contains PSSs and they are tuned for 10% step change at V_{ref}.

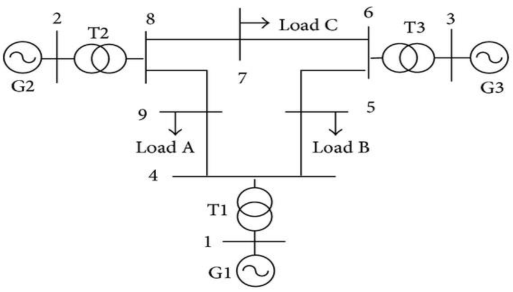

Figure 4: Multimachine system with interconnected generators

4.1 Introduction to PSO

PSO is a novel population based stochastic optimizer with faster convergence speed and simpler implementation than genetic algorithms. PSO is ant colony optimization, it has been successfully applied to solve electric power optimization problems such as optimal power flow, economic dispatch, generation transmission and planning, maintenance scheduling, state estimation, model identification, load forecasting, control etc. The primary objective of the paper is to provide a summary of PSO-based optimization method used in Multimachine PSS**.**

To date, the question of which approach (sequential or simultaneous) to adopt for the tuning of PSS in multi-machine power systems is still unanswered. This is due to the fact that reported results have thus far been concerned with use of either sequential or simultaneous tuning methods and no comparison between their performances has been provided. Obviously, without such a comparative study it is difficult to justify the merit of choosing one approach over the other. The present work attempts to address this aspect of multi-machine PSS tuning. A tuning method based on integral of squared error (ISE) has been used which tunes the PSS of the machines sequentially. It has also been examined whether iterating the tuning process twice or more improves the system damping. Furthermore, this sequentially tuned PSS is compared for dynamic responses with a previously reported simultaneously tuned PSS.

Table 2: Operating point and Parameter values of CPSS

Parameters of CPSS	Loading conditions	
	Higher loading P=1, j=0.2	Nominal loading P=0.8, j=4.1
K_s	16	32
T_1	0.0952	0.0952
T_2	0.0217	0.0217
T_3	0.0952	0.0952
T_4	0.0217	0.0217

Table 2 shows the parametric values of conventional power system stabilizer. With this values the system gets stable. But some oscillations are present. In order to reduce the oscillations particle swarm optimization is introduced.

Table 3: Operating point and Parameter values of PSO-PSS

Parameters of CPSS	Loading conditions	
	Higher loading P=1, j=0.2	Nominal loading P=0.8, j=4.1
K_s	25	35
T_1	0.0800	0.0800
T_2	0.0300	0.0300
T_3	0.0952	0.0952
T_4	0.0217	0.0217

Table 3 shows the parametric values of power system stabilizer by tuning with PSO algorithm. In this PSS gains, and lead compensator values are tuned, the results obtained are given in table 3.

Table 4: Operating condition and Parameter Values of PSS for Multimachine system

Parameters of CPSS	Loading conditions		
	Higher Loading Generator-1 P=1,Q=0.2	Nominal Loading Generator-2 P=0.8,Q=4.1	Higher Loading Generator-3 P=1,Q=0.2
K_s	16	32	16
T_1	0.0952	0.0952	0.0952
T_2	0.0217	0.0217	0.0217
T_3	0.0952	0.0952	0.0952
T_4	0.0217	0.0217	0.0217
T_w	2	2	2

Multimachine system having three generators is developed with two loading conditions. The operating conditions and parameter values of PSS are shown in table 4.

Table 5: Operating condition and Parameter values of PSO-PSS for Multimachine system

Parameters of CPSS	Loading conditions		
	Higher Loading Generator-1 P=1,Q=0.2	Nominal Loading Generator-2 P=0.8,Q=4.1	Higher Loading Generator-3 P=1,Q=0.2
K_s	17	35	35
T_1	1.1000	1.1000	1.1000
T_2	0.0230	0.0230	0.0215
T_3	0.0952	0.0952	0.0952
T_4	0.0217	0.0217	0.0217
T_W	2	2	2

Now the parameters of PSS is tuned with PSO algorithm and tuned values are shown in table 5.

5. Simulation results and Discussions

A. Simulation results of SMIB without PSS

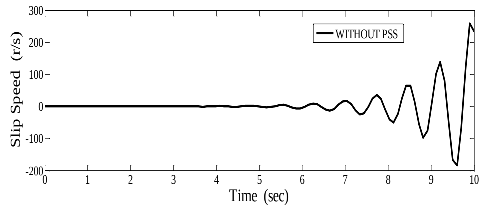

Figure 5: Speed deviation responses of SMIB without PSS at Higher loading condition

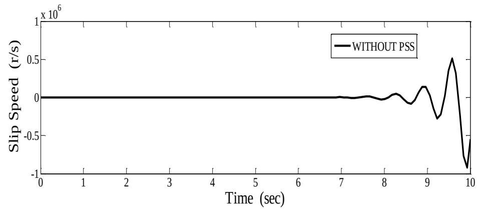

Figure 6: Speed deviation responses of SMIB without PSS at Nominal loading condition

The figure 5, 6 depicts system oscillations without PSS for higher loading and nominal loading conditions. It shows that the SMIB system is completely unstable for two Loading conditions. By introducing conventional PSS the results shows that the system gets stable with some oscillations. To reduce the oscillations further particle swarm optimization based PSS is introduced.

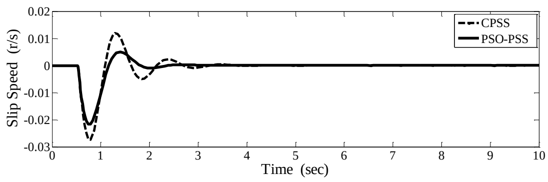

Figure 7: Speed deviation responses of SMIB with PSS at Higher loading condition

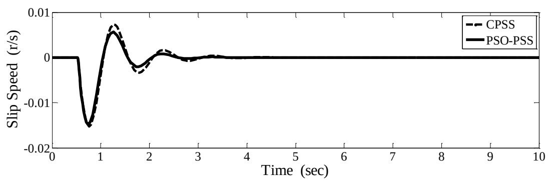

Figure 8: Speed deviation responses **of** SMIB with PSS at Nominal loading condition

Figures 7, 8 shows the system is stable with less oscillations and PSO-PSS is more stable than CPSS. Now author extended work towards multimachine power system stabilizer and the results are discussed below.

B. Simulation results of CPSS and PSO-PSS for Multimachine PSS

Finally to get the optimal solution of Multimachine PSS which is interconnected with three generators, a comparison of CPSS and PSO-PSS results obtained.

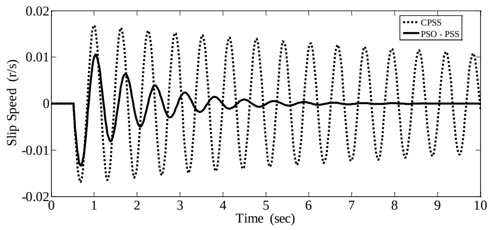

Figure 9: Speed deviation responses of generator-1 for Multimachine PSS with CPSS and PSO-PSS at higher loading condition

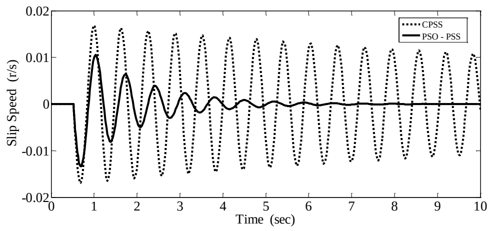

Figure 10: Speed deviation responses of generator-2 for Multimachine PSS with CPSS and PSO-PSS at nominal loading condition

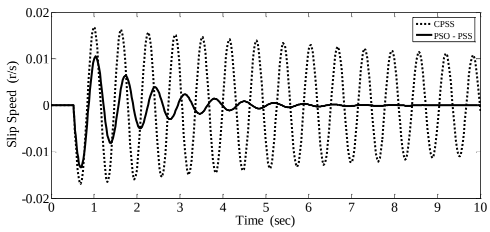

Figure 11: Speed deviation responses of generator-3 for Multimachine PSS with CPSS and PSO-PSS at higher loading condition

The figures 9, 10, 11 represents CPSS is stable with more oscillations. After tuning the multimachine system PSO-PSS is stable with less oscillations. The effectiveness of PSO-PSS over CPSS is proved.

6. Conclusion

In this paper optimal tuning of power system stabilizer is proposed for both single machine infinite bus system and three generator multimachine inter connected system. Here PSO is used to tune the gain settings of Power System Stabilizer to reduce electromechanical oscillations. And results are compared with existing conventional power system stabilizer for both SMIB and multimachine systems. The proposed power system stabilizer greatly reduced the oscillations when compared to the conventional power system stabilizer for both test systems at various operating conditions.

Appendix

Machine Data:

$X_d = 1.7$; $X_q = 1.64$; $X'_d = 0.32$; $T'_{do} = 5.9$; $H = 5$; $D = 0$; $f_B= 50$ Hz; $E_B = 1$ p.u; $X_t = 0.4$.

Exciter Data:

$K_e = 400$; $T_e = 0.05s$; $E_{fdmax} = 6$ p.u; $E_{fdmin} = -6$ p.u.

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