COMPARISON OF DIFFERENT TECHNIQUES FOR DESIGN OF POWER SYSTEM STABILIZER

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Abstract:

The major problem in power system operation is related to small signal instability caused by insufficient damping in the system. The most effective way of countering this instability is to use auxiliary controllers called power system stabilizers, to produce additional damping during low frequency oscillations in the system. Heffron-Phillip's Model of a synchronous machine is commonly used in small signal stability analysis. Different techniques for designing of power system stabilizer is proposed for Modified Heffron-Phillip's model, the parameters of the power system stabilizer has been tuned by the three ways , linear quadratic power system stabilizer, genetic algorithm power system stabilizer and proposed power system stabilizer. The efficiency of the proposed design technique and the performance of the stabilizer has been evaluated over a range of operating and system conditions and the performance of the proposed controller is much better than the linear quadratic power system stabilizer and genetic algorithm based power system stabilizer.

Keywords: Modified **Heffron-Phillip's model (Mod HP), Heffron-Phillip's model (HP), Power System Stabilizers (PSS), Single Machine connected Infinite Bus (SMIB)*****, Linear Quadratic regulator (LQR), Genetic Algorithm (GA).***

1. Introduction

Electric power systems are highly nonlinear systems and constantly experience changes in generation, transmission and load conditions. With the enormous increase in the demand for the electricity almost all major transmission networks in the world are operated close to their stability limits.

In such systems fast excitation control plays a crucial role. The excitation controllers are designed to regulate the terminal voltage. Automatic voltage regulators also enhance the overall stability of the system. Over the years a variety of design procedures and algorithms have been proposed for the design of power system stabilizers for different models of power system.

In order to reduce this instability effect and improve the system stability performance it is useful to introduce supplementary stabilizing signals at low frequency oscillations, to increase the damping torque of the synchronous machine [1], [2], [3]. Different approaches have been proposed in the literature to provide the damping torque required for improving the stability, the first proposed method is the linear quadratic power system stabilizer [4] it is based on the linear optimal control theory, second method proposed power system stabilizer based on the genetic algorithm [7] and the third proposed power system stabilizer method based on pole placement technique [8].

The proposed method for the PSS design in this paper is done for Modified Heffron-Phillip's model. The proposed PSS judges system disturbances such as changes in system configuration or variation in loads etc, based on the deviations in power flow, voltage and voltage angle at the secondary bus of the step-up transformer. The PSS tries to control the rotor angle measured with respect to the local bus rather than the angle δ measured with respect to the remote bus to damp the oscillations. Knowledge of external parameters, such as equivalent infinite bus voltage and external impedance value is required for designing of the proposed power system stabilizer [10].

2. Modelling of Single Machine Infinite Bus

Modelling of SMIB consisting the generator, excitation system, AC network etc. A SMIB power system model as shown in Fig. 1 is used to obtain the Modified Heffron-Phillip's model parameters.

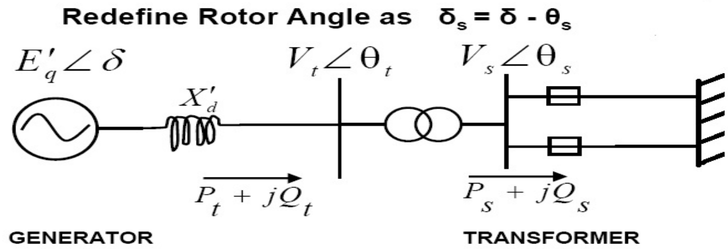

Fig. 1 A Single Machine Power System Model.

This is a simplified representation of a generator is connected to the load through a transmission line. IEEE model 1.0 is used to model the synchronous generator. The dynamic equations corresponding to this SMIB are listed below [11], [13].

$$\dot{\delta} = \omega_b s_m \tag{1}$$

$$\frac{ds_m}{dt} = \frac{1}{2H}\left[-D(s_m) + T_m - T_e\right] \tag{2}$$

$$\frac{dE_q^{'}}{dt} = \frac{1}{T_{d0}^{'}}\left[-E_q^{'} + (x_d - x_d^{'})i_d + E_{fd}\right] \tag{3}$$

2.1 Modified Heffron-Phillip's Model

The Modified Heffron Phillips model can be obtained by linearizing the system equations around an operating condition. The development of the model is detailed in [9], [11], [12]. Here only the necessary steps to arrive at the Mod HP model are given. From model 1.0 the following equations can be obtained

$$E_q^{'} + x_d^{'} i_d - r_a i_q = V_q$$
$$-x_q^{'} i_q - r_a i_d = V_d \tag{4}$$

The subscripts q and d refers to the q and d-axis respectively in Park's reference frame. The detailed derivation of the model and definitions of the constants K_1 to K_6 and Kv1 to Kv3 are given in [9].

3. The Linear Quadratic Power System Stabilizer

The problem is to design a stabilizer which provides a supplementary stabilizing signal to increase the damping torque at low frequency oscillations in the system. The design linear quadratic power system stabilizer is based on the theory of linear optimal control theory [4], [6]. In order to formulate the problem of stabilization using linear optimal control theory, a set of state variables must selected. Then the state equation for the Modified Heffron-Phillip's model is as follows [5], [10].

$$\dot{X} = AX + BV_{pss} + B_1\begin{bmatrix}\Delta\theta_s \\ \Delta V_s\end{bmatrix} \tag{5}$$

Where X is the state matrix and the state variables are X = [$\Delta\delta_s$; ΔS_m ; $\Delta E_q^{'}$; ΔE_{Fd}]; and A,B and B_1 are system matrix, system input matrix and disturbance matrix respectively. Suppose that the performance index is to minimize the objective function. This objective function will be,

$$J = \tfrac{1}{2}\int_0^T \left(X^T Q X + V_{pss}^T R V_{pss}\right)dt \tag{6}$$

The state feedback controller is obtained as

$$V_{pss} = -K_{lqr} X \tag{7}$$

Where
$$K_{lqr} = R^{-1} B^T P \tag{8}$$

And the matrix P is the solution of the algebraic Riccati equation (ARE) [4].

$$PA + A^T P - PBR^{-1} B^T P + Q = 0 \tag{9}$$

4. Genetic Algorithm Power System Stabilizer

The problem of tuning the parameters of a single power system stabilizer for different operating points means that power system stabilizer must stabilize the family of N plants:

$$\dot{X} = A_k X + B_k U + \Gamma_k W \quad , \text{k = 1, 2, …, N} \tag{10}$$

Where X(t) is the state vector and U(t) is the input stabilizing signal. A necessary and sufficient condition for the set of plants in the system to be simultaneously stabilizable with stabilizing signal is that Eigen values of the closed-loop system lie in the left- hand side of the complex s-plane. This condition motivates the following approach for determining the parameters K and T_1 and T_2 of the power system stabilizer. Selection of K, T_1 and T_2 to minimize the following fitness function [7]

$$J = \max \mathrm{Re}(\lambda_{i,k}),\ \ i = 1, \dots, N,\ k = 1, \dots, N \tag{11}$$

Where $\lambda_{i,k}$ is the k^{th} closed-loop Eigen value of the i^{th} plant. Clearly if a solution is found such that $J<O$, then the resulting K, T_1 and T_2 stabilize the collecting of plants. The existence of a solution is verified numerically by minimizing J. The optimization problem is-easily and accurately solved using genetic algorithms [7].

5. Proposed Power System Stabilizer

In this proposed power system stabilizer based on the pole placement technique [8]. In this technique, first we have to calculate the system transfer function G(s) and then power system stabilizer has been connected. Transfer function of the system is expressed in equation (12).

$$G(s) = \frac{a_m s^m + a_{m-1} s^{m-1} + \dots\dots\dots + a_1 s^1 + a_0}{b_n s^n + b_{n-1} s^{n-1} + \dots\dots\dots b_1 s^1 + b_0} \tag{12}$$

Generally power system stabilizer act as a feedback to the system and this feedback function H(s) can be represented in equation (13).

$$H(s) = K\left(\frac{ST_w}{1+ST_w}\right)\left(\frac{1+ST_1}{1+ST_2}\right)^m \tag{13}$$

Where m = number of lead/lag stages (here m=2)

Then the system equivalent block diagram will be as shown in Fig. 2.

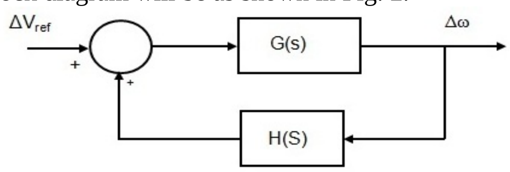

Fig. 2 Reduced Block diagram off Modified Heffron-Phillip's model.

By using above equations and Fig. 2, calculate the characteristic equation and solve that characteristic equation then the power system stabilizer parameters K, T_1 and T_2 are calculated.

6. Simulation Results

The performance of the stabilizers designed by using modified K-constants is evaluated on a SMIB test system over a range of different operating conditions as shown in Table 1. The transformer reactance X_t = 0.1p.u. Q=Diag ([1, 1, 0.000001, 0.000001]) and R=0.8 are taken for designing of LQR [10]. Designing the PSS parameters in the LQR model and GA model we neglect the disturbance matrix in state space but included in simulation.

Table 1. Range of operating conditions for SMIB

Xe	**P_t**	**Q_t**	**Power factor**
0.4-Nominal	1.0	0.2	Lag
0.2- Strong	0.8	0.15	Lag
0.8- Weak	1.0	0.5	Lag

Fig.3, Fig. 4, Fig. 7 shows the system speed response in terms of change in slip speed under nominal system for considering Heffron-Phillip‘s model and Modified Heffron-Phillip’s model (X_e = 0.4 p.u., S = 1+j0.2 p.u.). At this condition the system is unstable without PSS and stable with PSS. Fig. 5, Fig. 8 shows the system response for HP model and Mod HP model respectively when a fault occurs at the transformer bus. Fig. 6, Fig. 9 shows the system speed response for the same system condition, after clearing the fault in the transmission line for HP model and Mod HP model respectively.

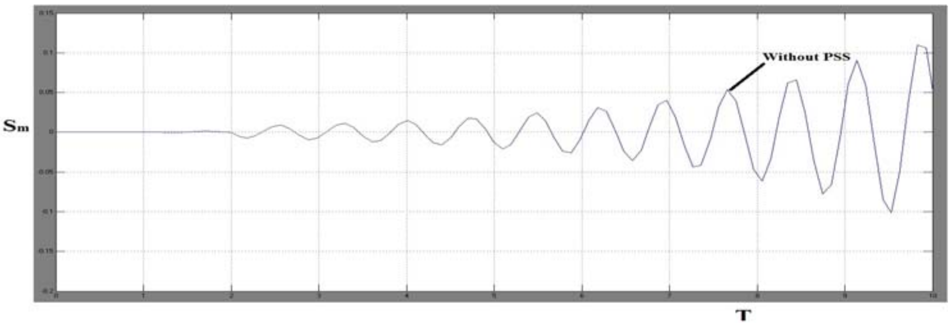

Fig. 3 Response of change in speed for 5% change in V_{ref}, Nominal system(Without PSS).

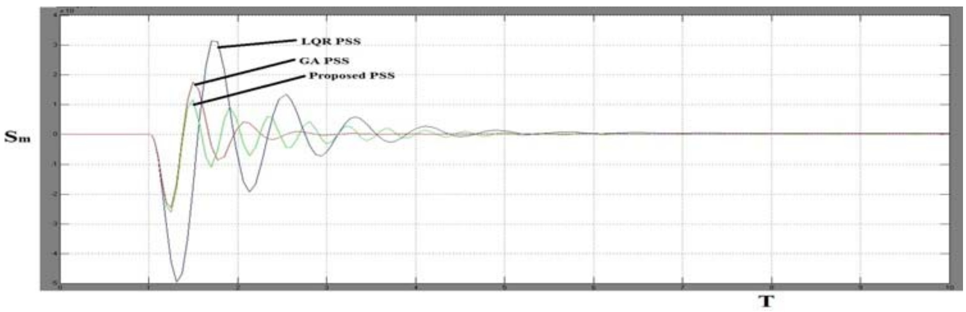

Fig. 4 Response of change in speed for 5% change in V_{ref}, Nominal system(With PSS), at pre fault, HP model.

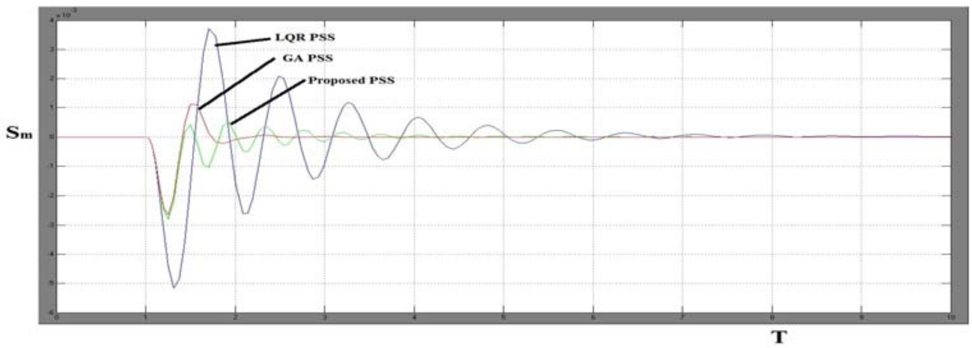

Fig. 5 Response of change in speed for 5% change in V_{ref}, Nominal system(With PSS), at fault, HP model.

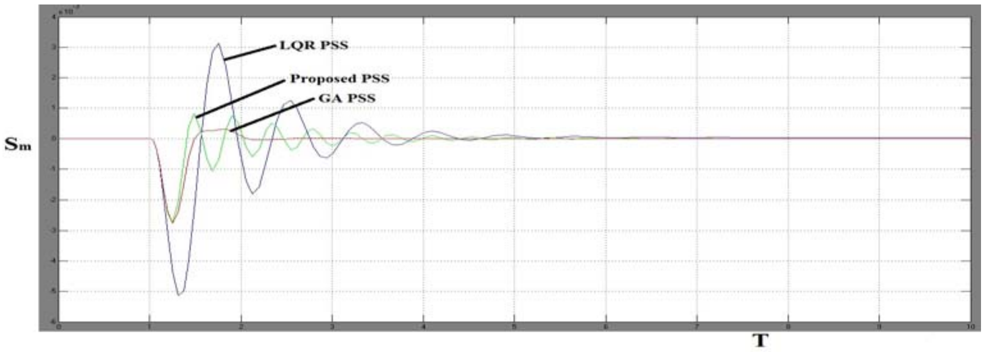

Fig. 6 Response of change in speed for 5% change in V_{ref}, Nominal system(With PSS), at post fault, HP model.

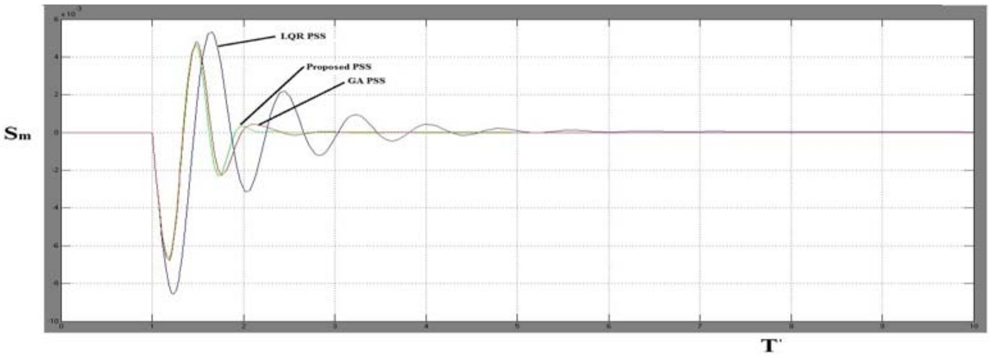

Fig. 7 Response of change in speed for 5% change in V_{ref}, Nominal system(With PSS), at pre fault, Mod HP model.

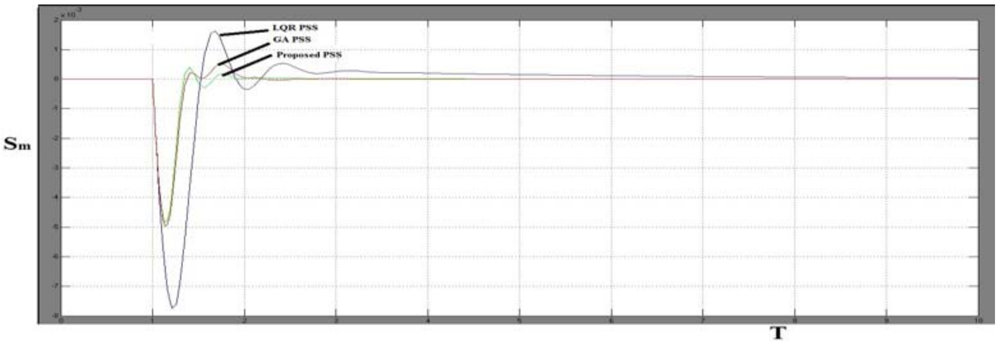

Fig. 8 Response of change in speed for 5% change in V_{ref}, Nominal system(With PSS), at fault, Mod HP model.

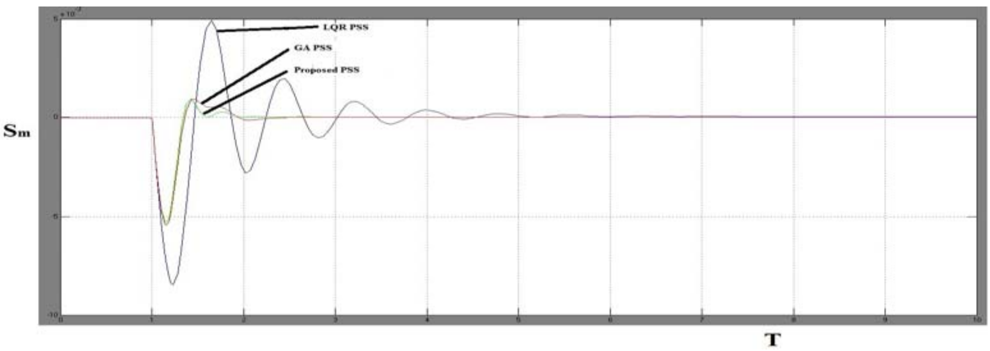

Fig. 9 Response of change in speed for 5% change in V_{ref}, Nominal system(With PSS), at post fault, Mod HP model.

By using Table 1, the speed response for nominal system at pre fault, fault and post faulted conditions are shown in Fig. 3, 4, 5, 6, 7, 8, 9. and similarly the speed response for strong and weak systems at pre fault, fault and post faulted conditions are also observed. In this work pre fault means line reactance is neglected, fault condition means half of the reactance of the faulted line is considered and post fault means the total reactance of the line is considered. Under these conditions the system is unstable without PSS and it will become stable with PSS. By observing the all responses of Mod HP model and HP model, Mod HP model stabilizes the system quickly compare to HP model.

7. Conclusion

By using Modified Heffron Phillip’s model three different types of power system stabilizers has been designed. This stabilizer is synthesized using information available at the local buses and makes no assumptions about the rest of the system connected beyond the secondary bus of the step up transformer. As system information is generally not accurately known or measurable in practice, the proposed method of PSS design is well suited for designing effective stabilizers at different system operating conditions. The performance of the proposed stabilizer is comparable to that of a linear quadratic stabilizer and genetic algorithm stabilizer which has been designed assuming that all system parameters are known accurately.

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Appendix

Machine Data:

X_d = 1.6; X_q = 1.55; $X_d^{'}$ = 0.32; $T_{do}^{'}$ = 6; H = 5; D = 0; f_B = 60Hz; E_B = 1p.u; X_t = 0.1; Model 1.0 is considered for the synchronous machine.

Exciter data:

K_e = 200; T_e = 0.05s; E_{fdmax} = 6p.u.; E_{fdmin} = −6p.u.;

LQR PSS data:

K_{lqr} = [-0.0958 -50.5525 0.9036 0.0051]

GA PSS data:

T_1 = 0.188; T_2 = 0.022; K = 7.3; T_w = 2; PSS output limits ± 0.05

Proposed-PSS data:

T_1 = 0.0663; T_2 = 0.0217; K = 14.4; T_w = 2; PSS output limits ± 0.05