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Design of Power System Stabilizer to Improve Small Signal Stability

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ABSTRACT: One of the major problems 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 in the system. Generally Heffron-phillip's Model of a synchronous machine is commonly used for the small signal stability analysis. A Modified Heffron-Phillip's (K-constant) Model is derived for the design of Power System Stabilizers; knowledge of external parameters, such as equivalent infinite bus voltage and external impedance value are required for designing a conventional power system stabilizer, Modified Heffron-Phillip's Model 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 Modified Heffron-Phillip's Model is much better than the conventional power system stabilize.. The proposed work describes the 'Design of Power System Stabilizer by using Modified Heffron-Phillip's model' is simulated by using MATLAB/SIMULINK.

I. 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 synthesis of effective excitation controllers for all operating conditions still remains a difficult task due to the following reasons.

1) Large variations of the possible operating conditions.
2) Large variety of disturbances that can occur in various
Parts of the power systems.
3) Variation of plant parameters as result of power network configuration changes.

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

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damping torque required for improving the stability, the first proposed method is the conventional power system stabilizer [4] it is based and design the Bode plot technique, second method proposed Modified Heffron-Phillip's power system stabilizer, it is based on the Bode plot technique [5]. Generally conventional power system stabilizer is use the information of external parameters, such as equivalent infinite bus voltage and external impedance values. In this Modified Heffron-Phillip's method, information available at the secondary bus of the step up transformer is used to set up a Modified Heffron-Phillip's Model.

II. MODELLING OF SYSTEM

System is treated as in this model is SMIB. 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.

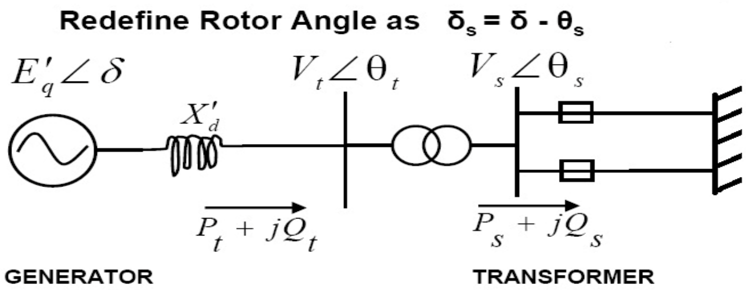

Fig. 1 A Single Machine Power System Model.

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 Model 1.0 are listed below [4], [5].

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

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

$$\frac{dE'_q}{dt} = \frac{1}{T'_{d0}}\left[-E'_q + (x_d - x'_d)i_d + E \right. \tag{3}$$

$$T_{ele} = E_q i_q + (x_d - x_q) i_d i_q$$

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 [5], [6], [7]. Here only the necessary steps to arrive at the Mod HP model are given. From model 1.0 the following equations can be obtained

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$$E_q + x_d i_d - r_a i_q = V_q$$

$$-\dot{x}_q i_q - r_a i_d = V_d \qquad (5)$$

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 [4], [5].

$$K_1 = \frac{V_{s0} E_{q0} Cos\delta_{s0}}{X_q + X_t} + \frac{V_q + V_d'}{X_t + X_d'} V_{s0} Sin\delta_{s0} \qquad (6)$$

$$K_2 = \frac{X_q + X_d}{X_t + X_d'} i_{q0} \qquad (7)$$

$$K_3 = \frac{X_t + X_d}{X_t + X_q} \qquad (8)$$

$$K_4 = \frac{V_d + V_d'}{X_t + X_d'} V_{s0} Sin\delta_{s0} \qquad (9)$$

$$K_5 = \frac{-V_q V_{d0} V_{s0} Cos\delta_{s0}}{(X_q + X_t) V_{t0}} - \frac{V_d' V_{q0}}{(X_t + X_d') V_{t0}} V_{s0} Sin\delta_{s0} \qquad (10)$$

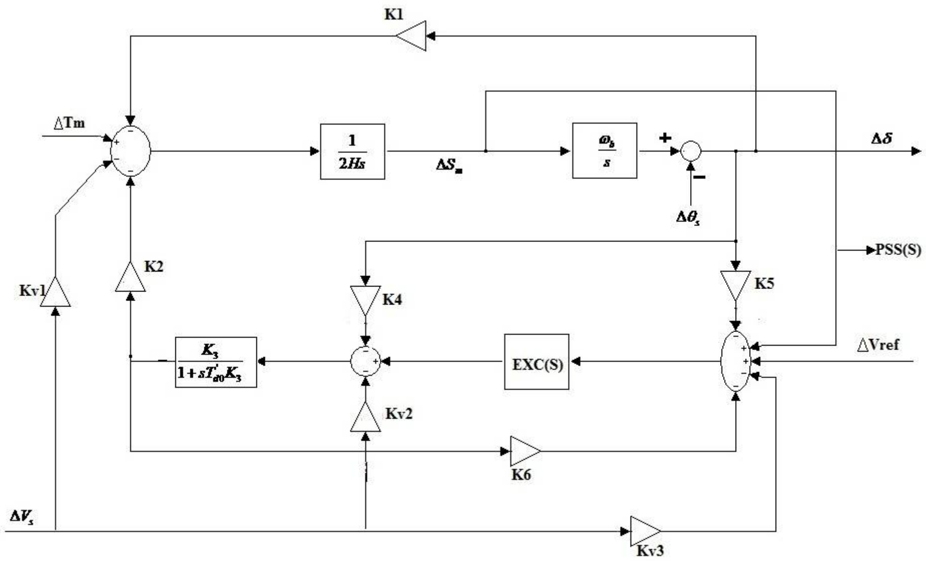
$$K_6 = \frac{X_t}{(X_d' + X_t)} \frac{V_{q0}}{V_{t0}} \qquad (11)$$

$$K_{v1} = \frac{E_{q0} Sin\delta_{s0}}{X_q + X_t} - \frac{V_q - V_d'}{X_t + X_d'} i_{q0} Cos\delta_{s0} \qquad (12)$$

$$K_{v2} = -\frac{V - V'}{X_t + X_d'} Cos\delta_{s0} \qquad (13)$$

$$K_5 = \frac{-X_t V_{d0} Sin\delta_{s0}}{(X_q + X_t) V_{t0}} + \frac{X_d'}{(X_t + X_d') V_{t0}} V_{q0} Cos\delta_{s0} \qquad (14)$$

The block diagram of Modified Heffron-Phillip's Model will be as shown in the Fig. 2.



The expression for the transfer function GEP(s) for Heffron-Phillip's is given by [5]

$$GEP(S) = \frac{K_2 K_3 EXC(s)}{(1 + ST'_{d0}K_3) + K_3 K_6 EXC(s)} \tag{15}$$

The expression for the transfer function GEP(s) for Modified Heffron-Phillip's is given by

$$GEP(s) = \frac{(K_{v1}K_2K_3K_e)}{(K_3T'_{d0}T_e)S^2 + (K_3T'_{d0} + T_e + K_{v1}K_{v2}K_2K_3T_e)S + \left(K_6K_3K_e + K_{v1}K_{v2}K_2K_3 + K_{v1}K_{v2}K_2K_3T_e + 1\right)} \tag{16}$$

Where EXC(S) is the excitation of the system.

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III. 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 of conventional PSS and Modified Heffron-Phillip's Model PSS is based on the Bode plot technique. The Block diagram of the power system stabilizer will be as shown in the Fig. 3. The stabilizer is consists mainly four blocks, these are PSS gain (K_s), Wash out circuit, Compensator and limiter. Compensator is nothing but a simple lag/lead controller.

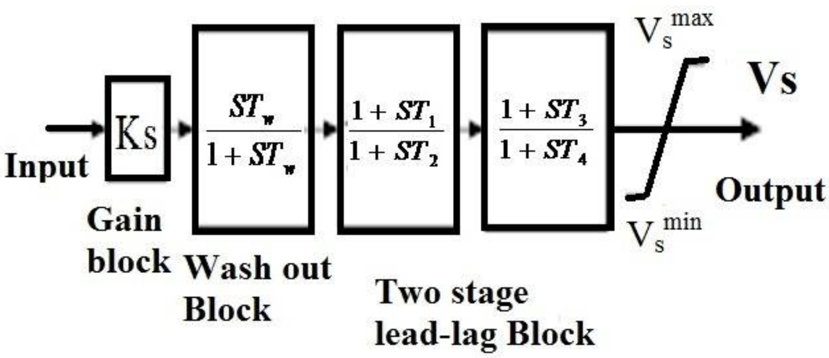

Fig. 3 Block diagram of power system stabilizer. The form of the compensator is assumed as given below,

$$T(s) = K_{PSS}\left[\frac{(1+sT_1)}{(1+sT_2)}\right]^m \qquad (17)$$

Where m is the number of lead-lag stages. In (17) m=1 for the design of Dynamic compensator. In PSS the effect of the washout circuit and torsional filter may be neglected in the design but must be considered in evaluating performance of PSS under various operating conditions. There are two design criteria.

1) The time constants, T_1 to T_2 in equation (17) are to be chosen from the requirements of the phase compensation to achieve damping torque

2) The gain of PSS is to be chosen to provide adequate damping of all critical modes under various operating conditions. It is to be noted that PSS is tuned at a particular operating condition.

If PSS is to provide pure damping torque at all frequencies, ideally the phase characteristics of PSS must balance the phase characteristics of GEP at all frequencies. As this is not practical, the following criteria are chosen to design the phase compensation for PSS.

1) The compensated phase lag should pass through 90° at frequency around 3.5 Hz.
2) The compensated phase lag at local mode frequency should be below 45°, preferably near 20°.
3) The gain of the compensator at high frequencies (this is proportional to T_1/T_2) should be minimized.

From the above assumptions the constants T_1 and T_2 can be obtained from the following assumptions, these are

$$Tan^{-1}(T_1\omega_c) - Tan^{-1}(T_2\omega_c) = \theta$$

Solving the above equation gives T_1 and T_2 values. Using the relation ($m=T_1/T_2$ & θ is the amount of phase lead/lag) and the required gain setting K_s for the desired value of damping ratio $\zeta = 0.5$ is obtained as,

$$K_s = \frac{2\zeta\omega_n M}{GEP(S)T(S)} \qquad 19)$$

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Where GEP(S) and T(S) are evaluated at $s = j\omega_n$.

The value of the washout time constant T_w should be high enough to allow signals associated with oscillations in rotor speed to pass unchanged. From the viewpoint of the washout function, the value of T_w is not critical and may be in the range of 1s to 20s. T_w equal to 2s is chosen in the present studies.

IV. 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.

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	-0.37	Lag
0.8- Weak	1.0	0.5	Lag

By taking one operating condition and calculate the Modified Heffron-Phillip's Model constants and using thus values, we calculate system transfer function GEP(S). We draw the Bode plot for GEP(S) and the Bode plot for GEP(S) for Heffron-Phillip's Model (15) will be as shown in Fig. 4.

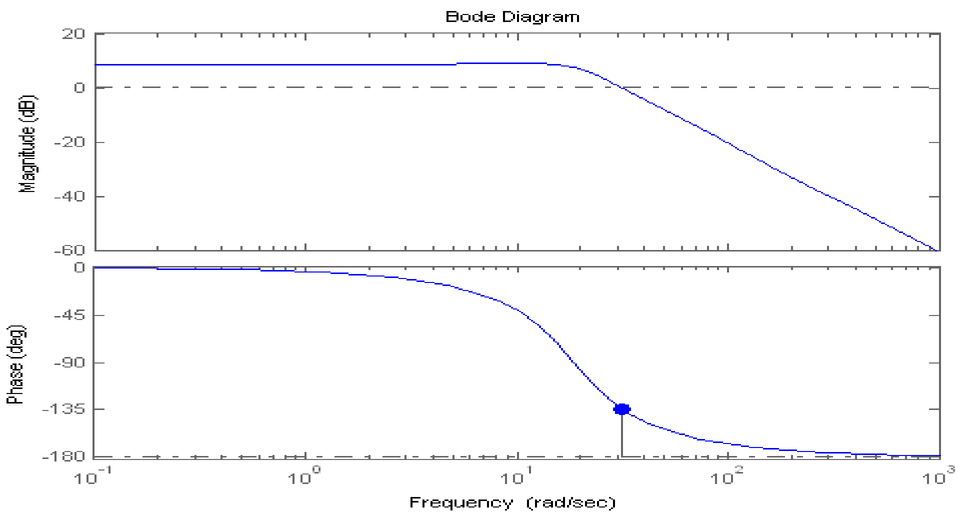

Fig. 4 Bode plot for conventional power system stabilizer.

By considering all the above assumptions mentioned in Power system stabilizer is taken and the equation (18) becomes,

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$$Tan^{-1}(T_1\omega_c) - Tan^{-1}(T_2\omega_c) = 30^0 \quad (20)$$

Solving the above equation gives T_1 and T_2 values. Using the relation ($m=T_1/T_2$), then we get the T_1 and T_2 values.

And using the (19), we get the value of stabilizer gain or PSS gain (K_s). Similarly we can calculate the unknown parameters of Modified Heffron-Phillip's Model.

Fig. 4, 5 shows the response of change in slip speed (S_m) following a 10% step change at V_{ref} input of the generator without PSS & with PSS. At this operating condition (S = P + jQ = 1 + j0.2p.u. X_e = 0.4p.u) the system is unstable without a PSS and the system stable with PSS.

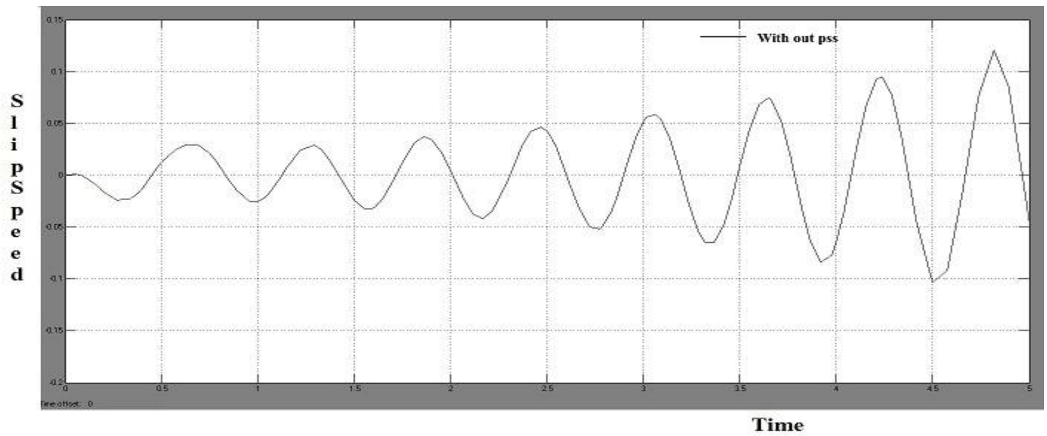

Fig. 5 Response of change in speed for 10% change in V_{ref}, Nominal system(Without PSS).

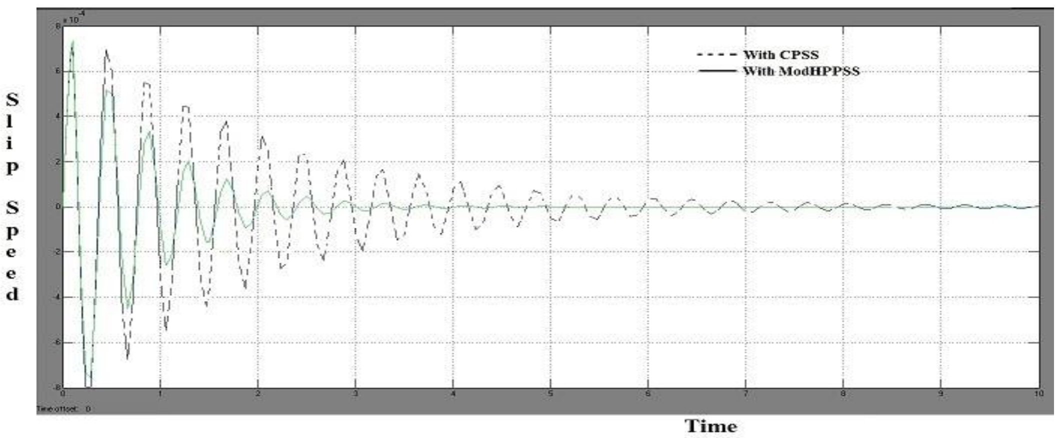

Fig. 6 Response of change in speed for 10% change in V_{ref}, Nominal system(With PSS).

Fig. 7 shows the system response for the same system condition, following a 3φ fault of 4 cycle's duration at the bus containing transformer. Fault is cleared by tripping one of the parallel lines. In both the cases, the conventional and the proposed PSS have damped the system oscillations effectively.

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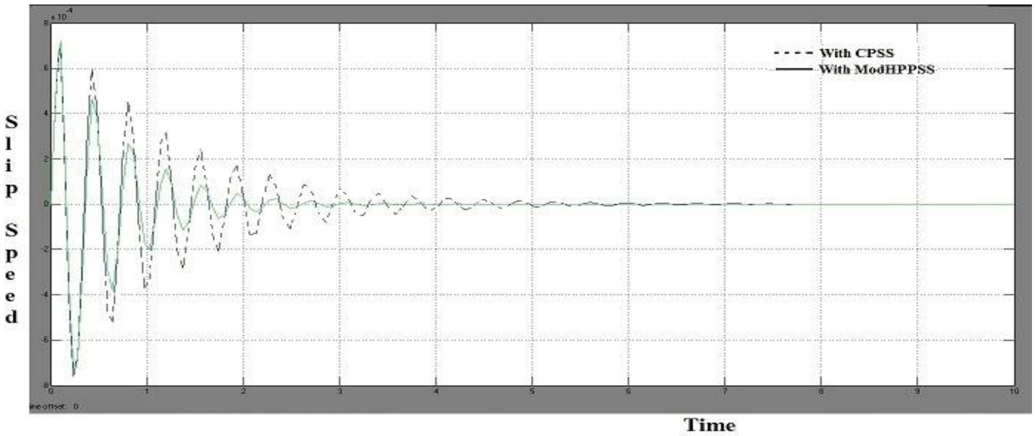

Fig. 7 Response of change in speed for 3-φ fault at tranformer, Nominal system.

Fig. 8 shows system response in terms of S_m under relatively strong system ($X_e = 0.3$p.u., $S = 0.8 - j0.37$) and leading power factor conditions and Fig. 9 shows the system response for the same system condition, following a 3φ fault of 4 cycles duration at the transformer bus. Fault is cleared by tripping one of the parallel lines. In both the cases, the conventional and the proposed PSS have damped the system Oscillations effectively.

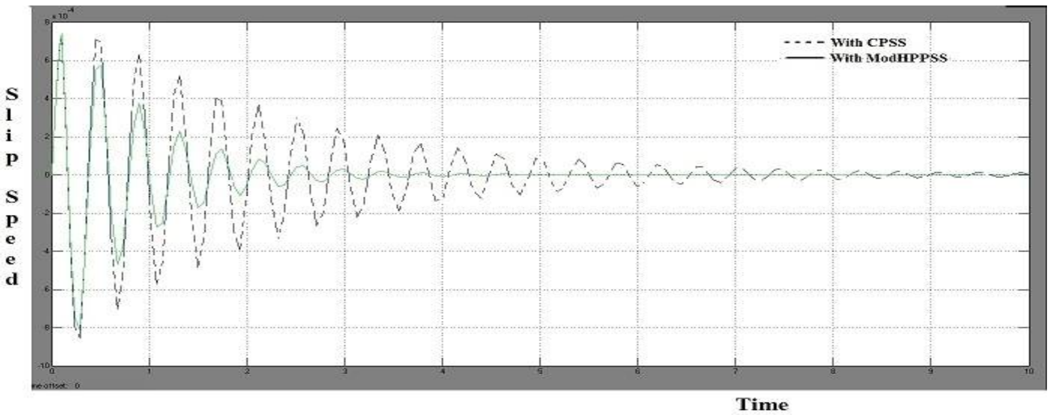

Fig. 8 Response of change in speed for 10% change in V_{ref} ,Strong system.

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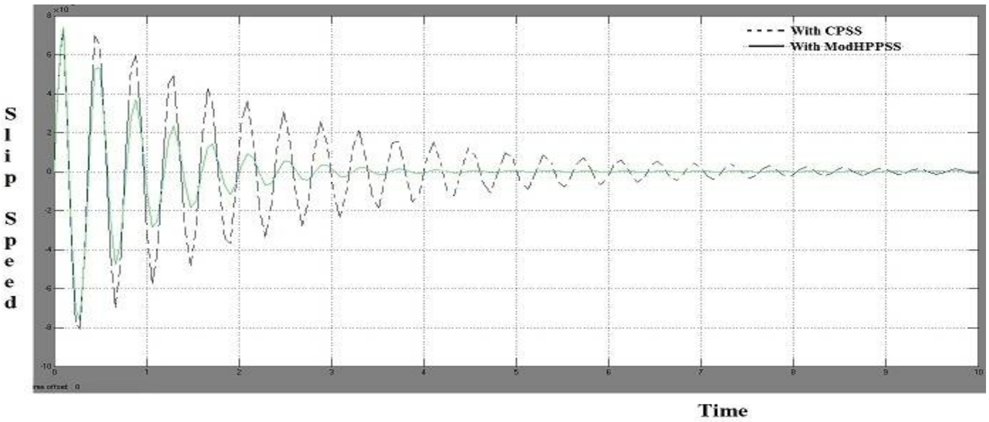

Fig. 9 Response of change in speed for 3 ϕ fault at transformer,Strong system.

Fig. 10 depicts very weak system (X_e = 0.8p.u. S = 1+ j0.5 p.u.) Conditions. Leading power factor operations are not possible under these conditions. The performance of both stabilizers are again comparable and the system oscillations have been effectively damped and Fig. 11 shows the system response for the same system condition, following a 3φ fault of 4 cycles duration at the bus containing transformer.

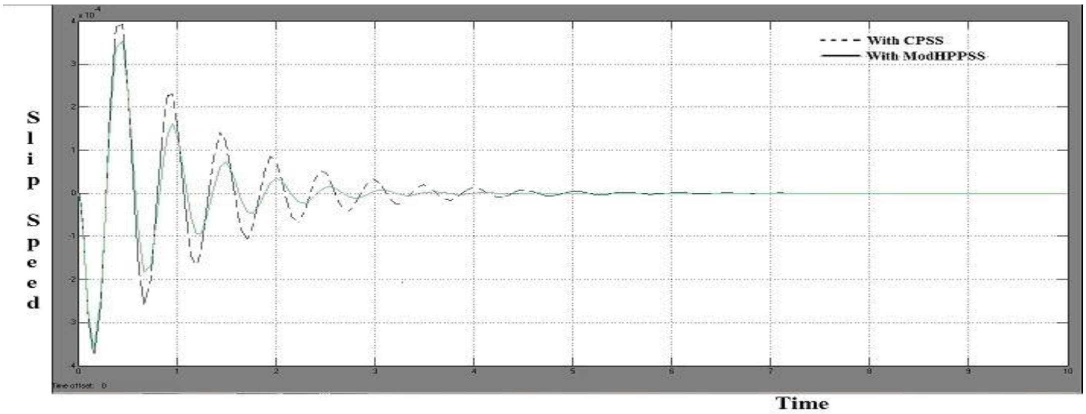

Fig. 10 Response of change in speed for 10% change in V_{ref} ,Weak system.

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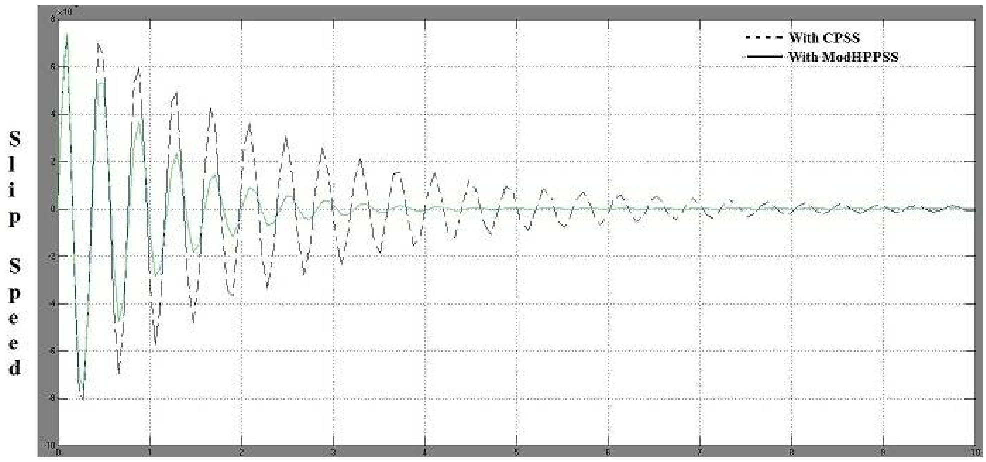

Fig. 11 Response of change in speed for 3 ϕ fault at transformer,Weak system.

Fig. 12 shows the response of change in rotor angle following a 10% step change at Vref input of the generator with PSS. At this operating condition (S = P + jQ = 1 + j0.2p.u., X_e = 0.4p.u) the system is unstable without a PSS and the system stable with PSS and also check the response of rotor angle for different range of operating conditions of Single Machine connected infinite bus as displayed in the Table 1.

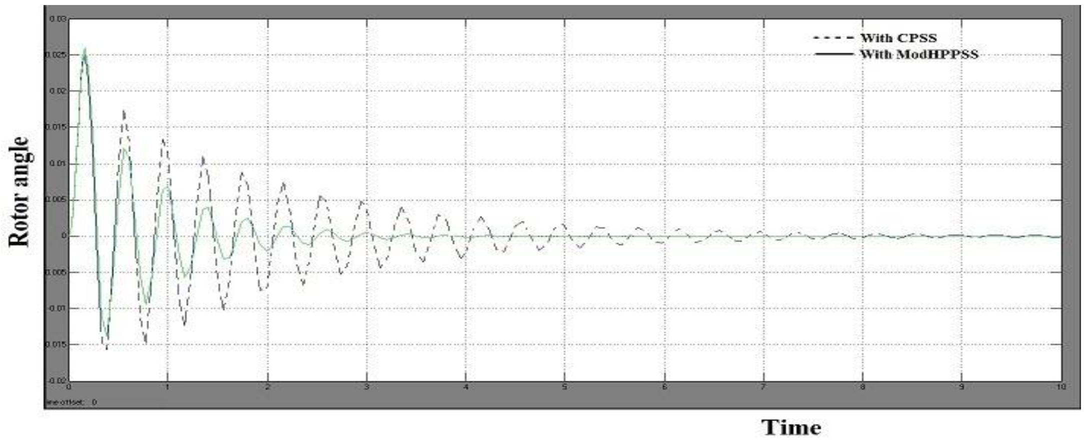

Fig. 12 Response of change in Rotor Angle for 10% change in V_{ref}, Nominal system(With PSS).

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 Power system stabilizer stabilizes the system quickly compare to HP model.

V. CONCLUSION

The Modified Heffron-Phillip's model has been derived for the design of power system stabilizers. 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 varied system conditions. The performance of the proposed stabilizer is

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comparable to the responses of change in speed and change in rotor angle of conventional stabilizer which has been designed assuming that all system parameters are known accurately. As the proposed design is based on local measurements and it may be possible to extend to multi-machine systems.

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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; $f_B = 60$Hz; $E_B = 1$p.u; $X_t = 0.1$; Model 1.0 is considered for the synchronous machine.

Exciter data:

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

CPSS data:

$T_1 = 0.078$; $T_2 = 0.026$; K = 15; $T_w = 2$; PSS output limits ± 0.05

ModHPPSS data:

$T_1 = 0.0798$; $T_2 = 0.0217$; K = 12.1; $T_w = 2$; PSS output limits ± 0.05