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DESIGN OF POWERSYSTEM STABILIZER FOR SMALL SIGNAL STABILITY IMPROVEMENT

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Abstract:-

The complexity of interconnected power systems due to competitive energy markets, growth of population and economy made the power system to operate at their capacity limits. This effects the dynamic behavior and stability(small signal stability). In this paper power system stabilizer equipped with PID controller using linearized modified Heffron-Phillips model for a singe machine infinite bus system is presented. The PSS designed based on this model utilizes signals available within the generating station and does not require the knowledge about external system parameters like line impedance and infinite bus voltage. Different loading conditions are considered to study the dynamic behavior of single machine infinite bus system. In this paper the effectiveness of conventional PSS,PSS design based on modified Heffron-phillips model and PID-MPSS are compared.

Keywords: - small signal stability, modified Heffron-phillips model, power system stabilizer (PSS), PID controller.

1. INTRODUCTION

Power systems have developed from the original central generating station concept to a modern interconnected system with improved technologies affecting each part of the system separately. Successful operation of a power system depends largely on providing reliable and uninterrupted service to the loads by the power utility. Ideally, constant voltage and frequency should be supplied to the load at all times. In practical terms this means that both voltage and frequency must be held within close tolerances so that the consumer loads run without interruption. For example, the motor loads on the system may stop by a drop in voltage of l0-15% or a drop of the system frequency of only a few hertz. Thus it can be accurately stated that the power system operator must maintain a very high standard of continuous and reliable electrical service.

Small-signal stability, or the dynamic stability, can be defined as the behavior of the power system when subjected to small disturbances. 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. Several types of these oscillations could be found in the system, but the two most critical types that of concern are the local mode and the inter-area mode. The local mode is associated with a single unit or station with respect to the whole system, whereas the inter-area mode is associated with many units in an area with respect to other units in another area. The aim of this project is to assess these low-frequency disturbances by having fast and efficient computational tools in online stability assessment, Extensive emphasis on the economic design of generators, especially those of large ratings was placed in the middle of the 20th century. This leads to the development of machines with very large values for steady-state synchronous reactance, and that resulted in poor load-voltage characteristics, especially when connected through long transmission lines. On load, significant drop in the overall synchronizing torque caused by reduction of field flux which is due to the armature reaction. Therefore, the transient stability related problems for synchronous operation became the major concern. The problem was resolved by using high gain, fast acting excitation control systems that provide sufficient synchronizing torque by virtually eliminating the effect of armature reaction on reduction in synchronizing torque. However, voltage regulator action was found to introduce negative damping torque at high power output and weak external network conditions represented by long overhead transmission lines, a very common operating situation in power systems around the world. Negative damping gave rise to an oscillatory instability problem. The contradicting performance of the excitation control loop was resolved by adjusting the voltage regulator reference input through an additional stabilizing signal, which was meant to produce positive damping torque. The control circuitry producing this signal was termed a power system stabilizer (PSS).

A single machine infinite bus system(SMIB), Heffron-Phillips model with conventional stabilizer is used to carry out the small signal stability studies.Recently Gurunath and Indranel sen proposed a modified Heffron-Phillips model with PSS to carry out the small signal stability analysis.The main advantage of this system is it does not require knowledge of system parameters external to generating station. A PID controller is incorporated to further enhance the system stability using modified Heffron-Phillips model over a range of system operating conditions.

2. THE POWER SYSTEM MODELLING

In this paper we considered the single machine infinite bus system(SMIB). It consists of Automatic Voltage Regulator (AVR), synchronous generator, excitation system etc. The SMIB system is linearized to get the modified Heffron-Phillip's model.

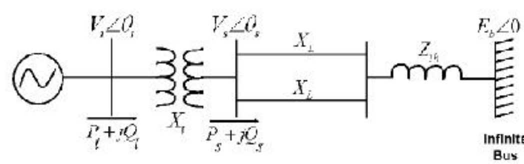

Figure: 1 A Single Machine Infinite Bus Power System Model

$$\dot{\delta} = \omega_B S_m$$

$$\dot{E}'_q = \frac{1}{T'_{do}} \{ -E'_q + (X_d - X'_d) i_d + E_{fd} \}$$

$$\dot{E}_{fd} = \frac{1}{T_e} \{ -E_{fd} + K_e (V_{ref} + V_{pss} - V_t) \}$$

$$\dot{S}_m = \frac{1}{2H} \{ T_{mech} - T_{elec} - D S_m$$

$$T_{elec} = E^t_q i_q + (X'_d - X'_q) i_d i_q$$

The dynamic equations with respect to the secondary bus voltage $V_s \angle^{-}{}_s$ of the step

up transformer,the rotor angle δ is replaced by δ_s and are expressed as

¢ s = ¢ − ¯ s

$$\delta_s = \arctan \frac{p_s(X_t + X_q) - Q_s R_a}{P_s R_a + Q_s(X_t + X_q) + V_s^2}$$

If $\delta_s < 0$ *then* $\delta_s = \pi - |\delta_s|$

$$E'_q = \frac{(X_t + X'_d)}{X_t}\sqrt{V_t^2 - \left(\frac{X_q}{(X_t + X_q)} V_S \sin\delta_s\right)^2} - \frac{X'_d}{X_t} V_S \cos\delta_s$$

3. THE MODIFIED HEFFRON-PHILLIPS MODEL

By linearizing the system equations around an operating condition the standard Heffron-Phillips model can be obtained. The development of this model is detailed in [6] and following equations can be obtained

$$E'_q + X'_d i_d - R_a i_q = V_q$$

$$-X'_q i_q - R_a i_d = V_d$$

The q and d subscripts refers to q-axis and d-axis respectively. In terms of transformer secondary the machine terminal voltage is given by

$$V_q = R_t i_q - X_t i_d + V_s \cos\delta_s$$

$$V_d = R_t i_d - X_t i_q + V_s \sin\delta_s$$

Substituting and re-arranging the above equations gives the following matrix

$$\begin{bmatrix} X'_d + X_t & -R_t \\ -R_t & X_q + X_t \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} V_s \cos\delta_s - E'_q \\ -V_s \sin\delta_s \end{bmatrix}$$

To obtain the k-constants the system mechanical equations, electrical equations and the matrix are linearized.

$$K_1 = \frac{v_{s0} E_{q0} \cos\delta_{s0}}{X_q + X_t} + \frac{X_q - X'_d}{X_t + X'_d} V_{s0} \sin\delta_{s0}$$

$$K_2 = \frac{X_q + X_t}{X_t + X'_d} i_{q0};$$

$$K_3 = \frac{X_t + X'_d}{X_d + X_t};$$

$$K_4 = \frac{X_d - X'_d}{X_t + X_d} V_{s0} \sin\delta_{s0};$$

$$K_5 = -\frac{X_q V_{d0} V_{s0} \cos\delta_{s0}}{(X_q + X_t)V_{t0}} - \frac{X'_d V_{q0} V_{s0} \sin\delta_{s0}}{(X_t + X'_d)V_{t0}}$$

$$K_6 = \frac{X_t}{X_t + X'_d} \frac{V_{q0}}{V_{t0}};$$

$$K_{v1} = \frac{E_{q0} \sin\delta_{s0}}{(X_t + X_q)} - \frac{(X_q - X'_d) I_{q0} \cos\delta_{s0}}{(X'_d + X_t)}$$

$$K_{v2} = -\frac{(X_d - X'_d)\cos\delta_{s0}}{(X'_d + X_t)}$$

$$K_{v3} = -\frac{X_q V_{d0} \sin\delta_{s0}}{(X_q + X_t)V_{t0}} + \frac{X'_d V_{q0} \cos\delta_{s0}}{(X_t + X'_d)V_{t0}}$$

The conventional Heffron-Phillips model consists of six constants i.e., k1 to k6. In Modified Heffron Phillips model three additional constants kv1 to kv3 are added at the torque, field voltage, and terminal junction points as V_s is not a constant. The modified k-constants are also no longer the functions of equivalent reactance X_e.They are the functions of V_s, δ_s, V_t and machine currents.

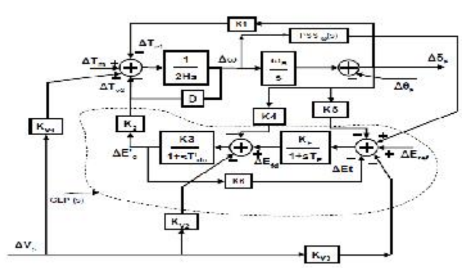

Figure: 2 Modified Heffron-Phillips Model

4. STRUCTURES OF PSS

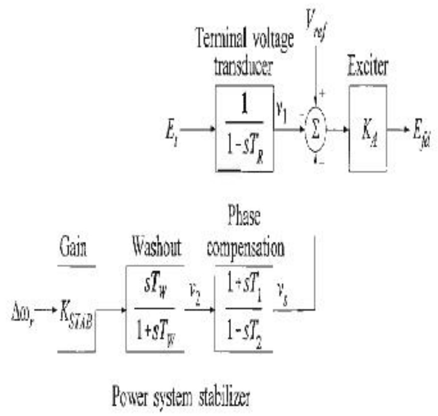

Figure: 3 Structure of PSS

Where, Kpss = PSS gain

Tw = wash out time constant

T1,T2,T3,T4 = lead and lag time constants

Power system stabilizer is a device which provides additional supplementary control loops to the automatic voltage regulator systems.The basic function of PSS is to introduce a damping torque component in phase with the speed deviation that compensates the oscillation of the voltage error of the excitation system during the dynamic/transient state. The main function of the wash out block is to serve as a high pass filter. The stabilizer gain function is to determine 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

$$V_s = K_{pss}\left(\frac{sT_W}{1+sT_W}\right)\left(\frac{1+sT_1}{1+sT_2}\right)\left(\frac{1+sT_3}{1+sT_4}\right)$$

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 (ΔV_s).

5. PID-PSS CONTROLLER

Transfer function of PID-PSS is given by

$$V_s = K_{pss}\left(\frac{sT_W}{1+sT_W}\right)G_c(s)$$

Where

$$G_c(s) = \left(K_p + \frac{K_i}{s} + K_d s\right)$$

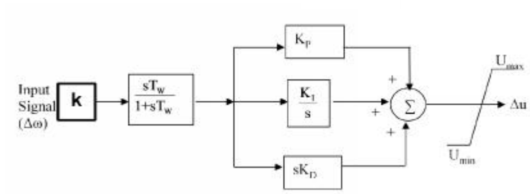

Figure: 4 Structure of PSS with PID-controller

The rise time is reduced by proportional gain K_P by providing a control action proportional to the error. The steady state error is eliminated by integral gain K_I by performing an integral action. The overshoot is reduced by derivative gain K_D improves stability of the system by improving the transient response of the system. The K_P, K_I, K_D values are optimized by using PSO technique.

7. SIMULATIONS AND RESULTS

Loading Conditions	P (pu)	Q (pu)
Higher	1.1	0.5
Nominal	0.8	0.4
Lower	0.4	0.1
Leading p.f.	0.7	-0.2

Table 1: Loading conditions tested for SMIB

OPERATING POINTS	Kpss	T1	T2	T3	T4	TW
P=1.1;Q =0.5	10	0.7	0.07	0.6	0.05	10
P=0.8;Q =0.4	10	0.6	0.05	0.9	0.05	10
P=0.4;Q =0.1	10	0.5	0.05	0.7	0.04	10
P=0.7;Q =-0.2	10	0.3	0.05	0.6	0.04	10

Table 2: Parametric values of PSS for modified Heffron-Phillips model

Parameters	Higher loading S=1.1+j 0.5	Nominal loading S=0.8+j 0.4	Weak loading S=0.4+j 0.1	L.P.F loading S=0.7-j0.2
Kp	10	10	10	4
Ki	6	6	5	2
Kd	4	4	8	3

Table 3: Parameters of PID Controller using PSO technique

A. Simulation results of PSS with modified heffron-phillips model

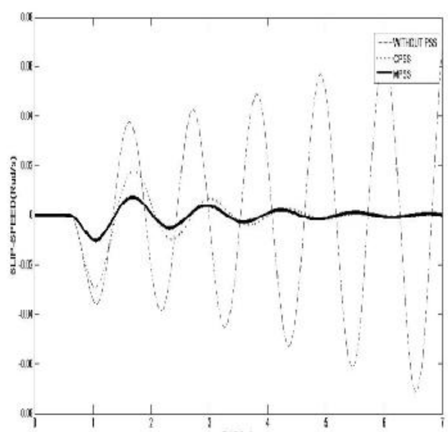

Figure 5: S_m for 10% step change in (Δ Vref) at higher loading condition

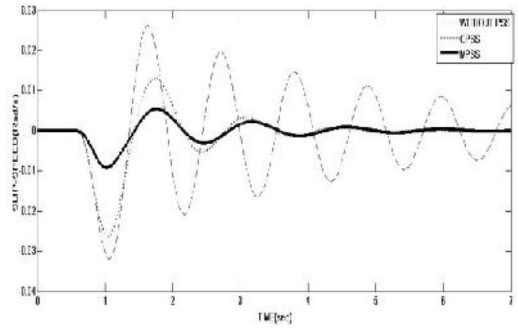

Figure 6 : S_m for 10% step change in (Δ Vref) at nominal loading condition

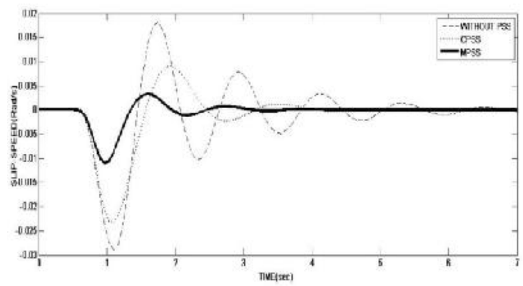

Figure 7 : S_m for 10% step change in (Δ Vref) at lower loading condition

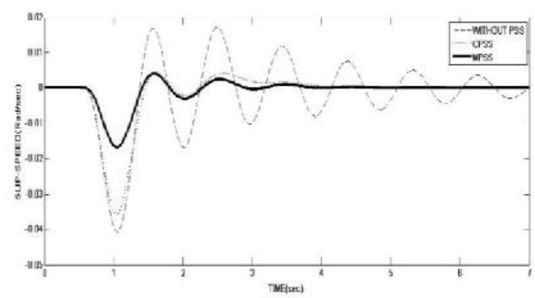

Figure 8: S_m for 10% step change in (Δ Vref) at leading p.f loading condition

B. Simulation results of PID-PSS with modified Heffron-Phillips model

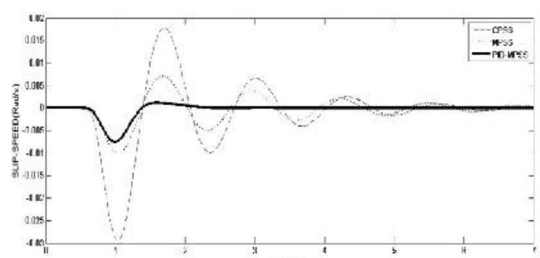

Figure 9: S_m for 10% step change in (Δ Vref) at higher loading condition

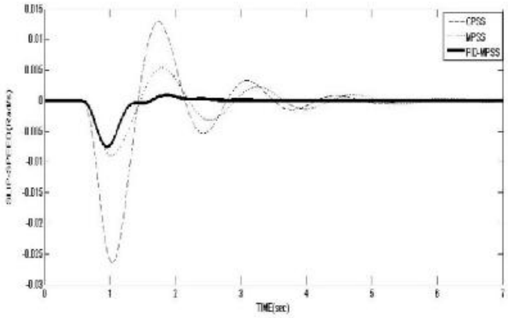

Figure 10 :S_m for 10% step change in (Δ Vref) at nominal loading condition

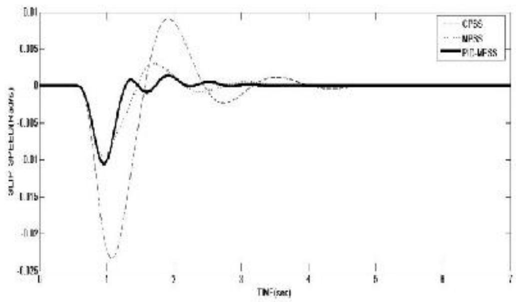

Figure 11: Sm for 10% step change in (Δ Vref) at lower loading condition

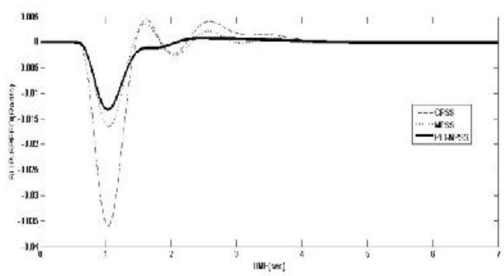

Figure 12: S_m for 10% step change in (Δ Vref) at leading p.f loading condition

For a given 10% step change in input (Δ Vref) the responses obtained for higher, nominal, weak and leading p.f are depicted in terms of rotor speed deviations. Table 1 shows the loading conditions tested for SMIB. Table 2 shows the PSS parameters and table 3 shows the PID controller gains for different loading conditions. For the loading conditions tested the system results in poor dynamic behavior without PSS. When PSS is included it is observed that the PSS has introduced positive damping to the power system, and this is obvious by looking at the settling time of the rotor speed response with PSS is much shorter than it without PSS. The PSS designed for modified Heffron-Phillips model performed well compared to conventional PSS and oscillations are effectively damped. When PSS is replaced by PID-MPSS all the time domain specifications are improved thus improves the dynamic behavior of the system.

CONCLUSIONS

The stabilizer is designed for proposed modified Heffron-Phillips model. The information available at secondary bus of the step up transformer is used and no assumptions are made about the system connected beyond secondary bus. For designing effective stabilizers at different loading conditions the proposed method of PSS design is well suited. This paper also presents a PID based power system stabilizer using modified Heffron-Phillips model. The rotor speed deviations are recorded for different loading conditions. The performance of CPSS , MPSS , PID-MPSS are compared.

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:

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

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