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On Stabilizers for Multi Area Power Systems

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Abstract: Large power systems are often characterized by spontaneous inter-area oscillations, which may be caused by small disturbances such as changes in load that take place continually. Inter-area oscillations are detrimental to the goals of maximum power transfer and optimal power system security. A contemporary solution to this problem is the addition of Power System Stabilizers to the Automatic Voltage Regulators of the generators in the power system. The damping, provided by these PSS, reduces the restraining effects of the oscillations. In this paper, conventional PSS and PID based PSS have been studied. The designed PSSs are applied to three area power system model and the stability of the system has been restored. It is observed that PID controller's performance is better.

Index Terms: Inter area oscillations, Conventional Power System Stabilizer, PID Controller, Three area power system.

1. INTRODUCTION

Large power systems are often characterized by spontaneous inter-area oscillations [5], which may be caused by small disturbances such as changes in load that take place continually. Inter-area oscillations are very harmful and may cause a total breakdown of the power transfer, especially when there are transmission lines weakly coupled in power systems carrying large loads. These Inter-area oscillations are detrimental to the goals of maximum power transfer and optimal power system security [8].

A contemporary solution to this problem is the addition of Power System Stabilizers (PSS) to the Automatic Voltage Regulators (AVR) of the generators in the power system. As well known, a voltage regulator in the power system is necessary to improve transient stability and power system oscillation damping properties. Hence each machine is generally equipped with an AVR and a PSS. A variety of methods are proposed to design the PSS. Some of them are particle swarm optimization [2], genetic algorithm [3], frequency response [10], Pole Placement [6] and PID and PI controller [9].

The basic function of a Power system stabilizer is to add damping to generator rotor oscillations by controlling its excitation using auxiliary stabilizing signal [1]. To provide damping, the stabilizer must produce a component of electrical torque in phase with rotor speed deviation. Its washout block inhibits the PSS action when the power system has reached the steady state.

When PSSs are used in power system, it is required to look for an adjustment among them in order to obtain their optimal performance. To achieve this we have to calculate the best parameters of PSS, the time constants and gains.

PID controller is a very popular industrial controller and it can be used as stabilizer. There are many methods available for tuning of PID controllers. If properly tuned it gives superior performance. Now a days simulation softwares are widely popular. MATLAB Simulink is one of them. A method is proposed to tune PID controller using Simulink [13]. The same method is used to tune PID based PSS.

This paper investigates the design and performance of PSSs for damping the inter area oscillations of a three area power system with conventional PSS and PID based PSS. The simulation is carried out on a three area power system model using MATLAB Simulink.

2. SYSTEM MODELING

Firstly consider a power system with a Synchronous Machine connected to Infinite Bus (SMIB). The

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system modelling comprises synchronous machine, excitation system and power system stabilizer [11]. The system model is developed as follows:

A. Synchronous Machine Model

The configuration of synchronous machine connected to infinite bus through transmission network is represented as shown in Fig 1.

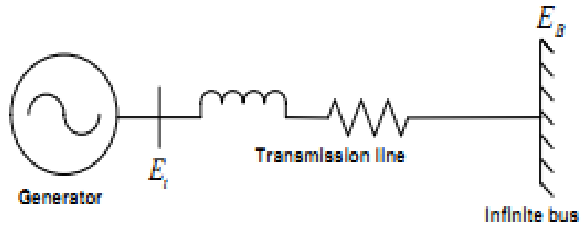

Fig.1: The equivalent of synchronous machine connected to infinite bus

The equations governing the machine model are:

$$p\Delta\omega_r = \frac{1}{2H}(\Delta T_m - \Delta T_e - K_D \Delta\omega_r) \quad (1)$$

$$p\Delta\delta = \omega_o \Delta\omega_r \quad (2)$$

where

$$\Delta T_e = K_2 \Delta\varphi_{fd} \quad (3)$$

$$\Delta\varphi_{fd} = \frac{K_3}{1+pT_3}[\Delta E_{fd} - K_4\Delta\delta] \quad (4)$$

T_m and T_e are prime mover input and electrical output torques respectively. p = d/dt.

B. Excitation System Model

The Excitation system as shown in Fig. 2 is considered.

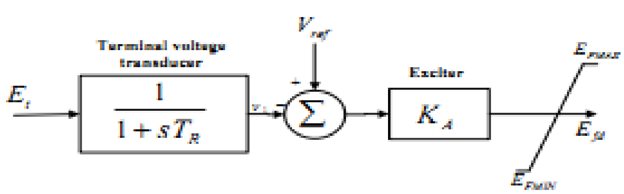

Fig. 2: Thyristor excitation system

The equations governing the exciter model are:

$$p\Delta v_1 = \frac{1}{T_R}[\Delta E_t - \Delta v_1] \quad (5)$$

$$E_{fd} = K_A(V_{ref} - v_1) \quad (6)$$

$$\Delta E_t = K_5 \Delta\delta + K_6\Delta\varphi_{fd} \quad (7)$$

C. Power System Stabilizer Model

The PSS is used to provide damping to electromechanical oscillations. The PSS counters the oscillations by forcing the change in excitation level appropriately. Without PSS, the reduced damping in power system is due to phase lags resulted by the field time constants and the phase lags in the normal voltage regulation loop. The PSS uses phase compensation by adjusting the timing of correction signal opposing the rotor oscillations. A power system stabilizer can therefore increase the generator's damping coefficient. The PSS as shown in Fig. 3 has three components, the phase compensation block, the signal washout block and gain block.

The phase compensation block provides the appropriate phase lead characteristics to compensate for the phase lag between exciter input and generator electrical torque.

The signal washout block serves as high pass filter, with time constant Tw high enough to allow signals associated with oscillations in ω_r to pass unchanged. The stabilizer gain K_{STAB} determines the amount of damping introduced by PSS.

For the conventional PSS the following transfer functions are considered:

$$\Delta v_2 = \frac{pT_W}{1+pT_W}(K_{STAB}\Delta\omega_r)$$

$$\Delta v_s = \frac{1+pT_1}{1+pT_2}(\Delta v_2)$$

T_W is the washout filter time constant. The implementation of the PSS in K constant model is shown in Fig. 4.

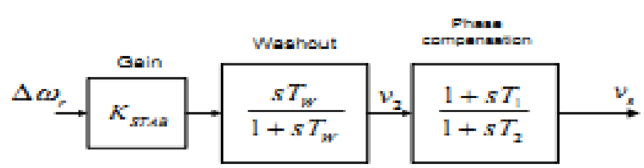

Fig. 3: Conventional lead-lag PSS

The parameters of the SMIB system shown in Fig. 4 are given in Table 1.

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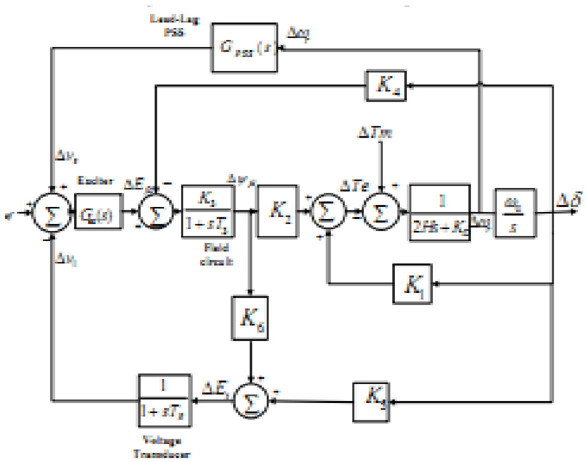

Fig. 4: Block diagram representation with AVR and PSS

3 .THREE AREA POWER SYSTEM MODEL

The system consists of three areas connected by a weak tie line. Each area consists of a single generator, each having a rating of 900MVA and 20KV.The generator parameters in per unit on the rated MVA and KV base are given in Table 2.

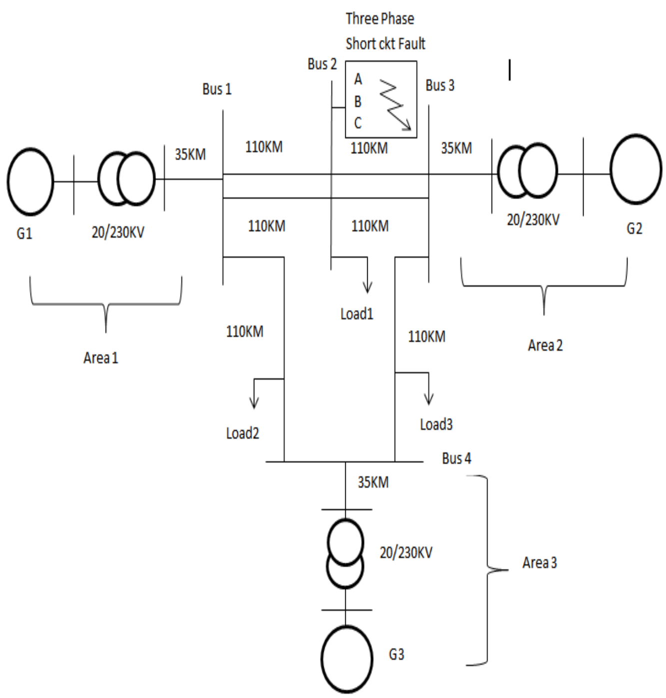

Fig.5 Three area Power System

Each step-up transformer has an impedance of 0+j0.15 per unit on 900MVA and 20/230KV base, and has an off-nominal ratio of 1.

The transmission system nominal voltage is 230KV. The line lengths are identified in Fig.5.The parameters of the lines in per unit on 100MVA, 230KV base are

r = 0.0001 pu/km

x_L = 0.001 pu/km

x_C = 0.00175 pu/km

The generating units are loaded as given in Table 3

The loads and reactive powers supplied by the shunt capacitors at each area are as follows

P_L= 967MW Q_L= 100MVAr Q_c = 200MVAr

The rotor speed deviations of this Three Area Power system Model are shown in Fig. 6 after a three phase short circuit.

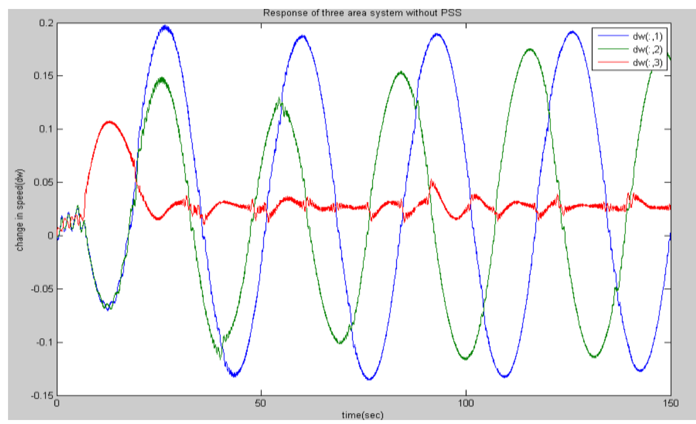

Fig. 6 Speed deviation of generators without PSS

The simulation result shown in Figure 6 represents a highly unstable system. Speed deviations of areas 1 and 2 are unstable while that of area 3 is oscillatory. Hence the system requires a controller to damp the frequency oscillations and to operate in a stable way.

4. DESIGN OF STABILIZERS FOR A THREE AREA POWER SYSTEM

The three area power system considered is sh own in Fig. 5. The parameters of power system stabilizer are to be tuned such that the overall system stability is enhanced, not just the small-signal stability. Power system stabilizer is designed using the frequency response method. The input to PSS is the generator speed deviation Δω. The stabilized output voltage of PSS is given as input signal to the exciter of each generator of this system [7]. This stabilizer adds damping to the generator rotor oscillations by controlling its excitation using auxiliary stabilizing signal(s).

A. CONVENTIONAL PSS

PSS parameters are tuned by using frequency response method [10]. The resulting parameters of PSS for this three area power system are given in Table 4. The designed PSS is added to the generators of the three area power system considered. The addition of PSS enhanced the ability of the system to damp the frequency oscillations and attain overall system stability.

The rotor speed deviations for all the three areas with the addition of Conventional Power System Stabilizer are as shown in Fig. 7. Now the speed deviations of all the areas are stable with a settling time of 4s.

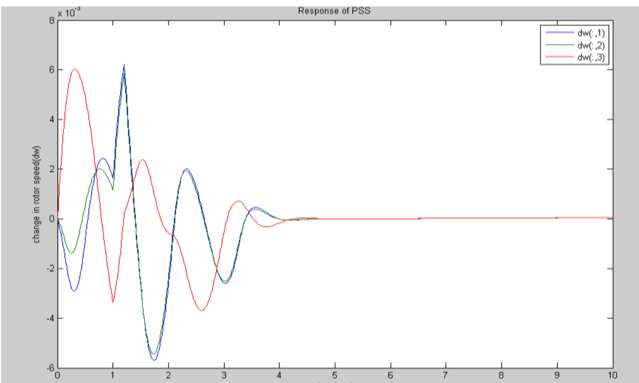

Fig. 7 Speed deviation of generators with Conventional PSS

B. PID BASED PSS

In order to enhance the system stability PID based Power System Stabilizer has been tuned and was added to the generators of a three area power system model. The basic structure of a PID controller is

$$G_C(s)=K_P+\frac{K_I}{s}+sK_D$$

where K_P, K_I and K_D are proportional, integral and derivative gain constants. Proportional control results in decrease of rise time but also results in oscillatory performance. Derivative control reduces the oscillations by providing proper damping which results in improved transient performance and stability. Integral control reduces the steady state error to zero.

PID controller tuning can be achieved in three steps using MATLAB Simulink [13]. In Step 1 we select K_P that results in a highly oscillatory stable response with $K_D = K_I = 0$. In Step 2 we fix the parameter K_D, for K_P selected in Step1, taking care of transient performance. In Step 3 we fix the parameter K_I, for K_P and K_D selected in Steps 1 and 2, taking care of steady state performance. This completes the tuning of PID controller. Following this tuning method the resulting parameters of PID based Power System Stabilizer are given in Table 5

The rotor speed deviations for all the three areas with the addition of PID based Power System Stabilizer are as shown in Fig. 8. These results are obviously better with less overshoot and settling time (3s) compared to the system with conventional PSS.

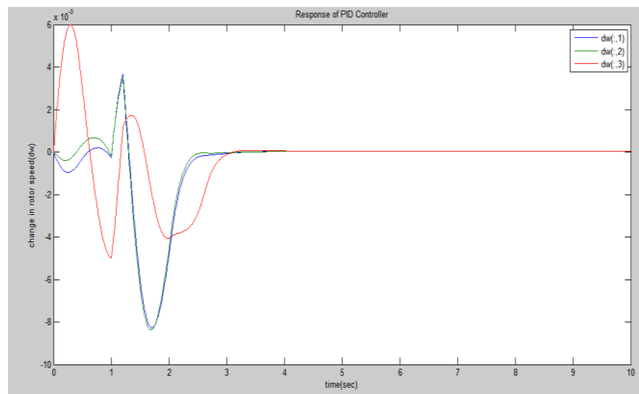

Fig. 8 Speed deviation of generators with PID based PSS

COMPARISON RESULTS FOR EACH AREA USING CONVENTIONAL PSS AND PID BASED PSS:

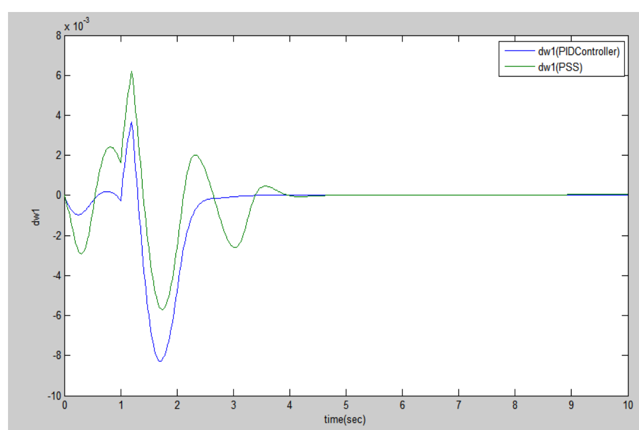

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Fig. 9 Speed deviation of generators in area 1 using conventional PSS and PID based PSS

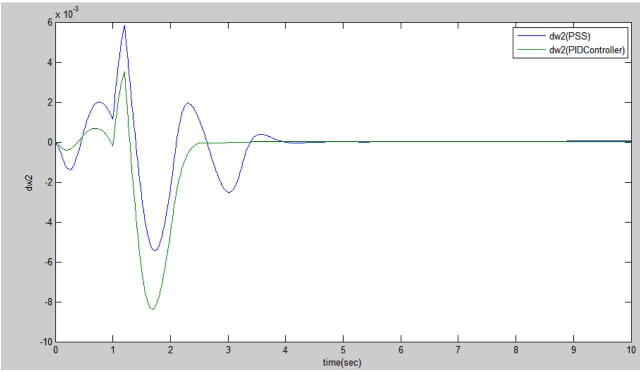

Fig.10 Speed deviation of generators in area 2 using conventional PSS and PID based PSS

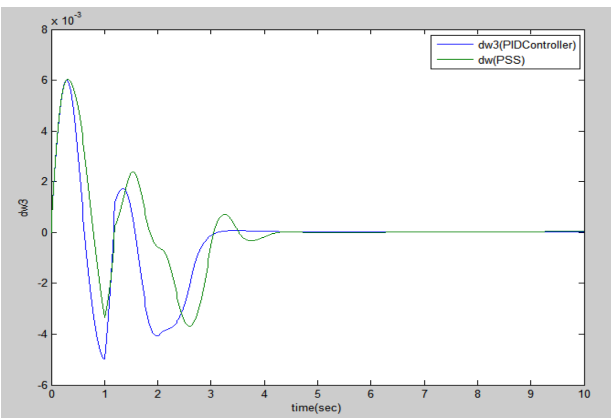

Fig.11Speed deviations of generators in area 3 using conventional PSS and PID based PSS

Table 1: Parameters for modelling SMIB system

K_1	0.7643
K_2	0.8649
K_3	0.3230
K_4	1.4187
K_5	-0.1463
K_6	0.4168
T_3	2.365
T_R	0.02
K_A	200

Table 2: Generator Parameters of three area system

X_d =1.8	X_q=1.7	X_l=0.2	X_d'=0.3
X_q'=0.55	X_d''=0.25	X_q''=0.25	R_a=0.0025
T_{do}'=8.0s	T_{qo}'=0.4s	T_{do}''=0.03s	T_{qo}''=0.05s
H=6.5	K_D=0		

Table 3: Load parameters

G1	P=700MW	Q=185MVAr	E_t=1.03∠20.2°
G2	P=700MW	Q=235MVAr	E_t=1.01∠10.5°
G3	P=719MW	Q=176MVAr	E_t=1.03∠-6.8°

Table 4: Parameters of Conventional PSS

PSS PARAMETERS	G1	G2	G3
K_{STAB}	40	40	40
T_W	10s	10s	10s
T_1	0.09s	0.09s	0.11s
T_2	0.1s	0.1s	0.1s

Table 5: Parameters of PID based PSS with filter coefficient N = 100

PID PARAMETERS	G1	G2	G3
K_P	100	100	140
K_D	12	12	15
K_I	-2	-2	-2

Table 6: Error values

Integral Absolute Error:	
Conventional PSS	0.08
PID based PSS	0.06

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5. CONCLUSIONS

In this paper, conventional and PID controller based stabilizers have been designed for a three area power system. Both the stabilizers restore the stability of the system after a three phase short circuit. Also a performance comparison is made with these stabilizers. The addition of PID based PSS has shown improvement in damping the inter area oscillations present in the three area system more effectively compared to the conventional PSS. The integral absolute error calculated for PID based PSS is less compared to conventional PSS (Table 6). Therefore properly tuned PID based power system stabilizer is a very effective controller suitable for a large scale power system's stability improvement.

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