DESIGN OF PID CONTROLLED POWER SYSTEM STABILIZER FOR STABILITY STUDIES USING GENETIC ALGORITHM

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Abstract- This paper presents the design of a PID controlled Power System Stabilizer (PSS) for stabilization of power systems. Both controllers have been designed for a single machine infinite bus system as well as for a two area interconnected thermal-thermal power system. The controller parameters of both PID and PSS are tuned using genetic algorithm. Simulation results are presented to show the effectiveness of the controllers in stabilizing the power system oscillations.

Keywords- Single Machine Infinite Bus (SMIB), Power System Stability, Power System Stabilizer (PSS), PID, Genetic Algorithm.

I. INTRODUCTION

Increasing demand for electric power has led to the relentless operation of the power system. Power system stability and the quality of power supplied to customers are equally important as to meet the electricity demands. The operation of synchronous generators to work in synchronism and their ability to return to synchronous speed when subjected to disturbances are important for the stability, continuity and steady state operation of power systems. Nowadays, one of the major problems associated with the power system operation is the presence of small signal oscillations, which are caused mainly by transmission of bulk amount of electric power over long distance through relatively weak tie lines. These oscillations often lead to small signal oscillatory instability caused by insufficient natural damping, and can result in instability and black out of power systems. Auxiliary controllers also called power system stabilizers (PSS) are one of the most cost-effective ways to counter such instability by producing additional damping in the system. The concept of PSS and the tuning procedures are well explained in.

The basic function of a PSS is to improve the stability limits when encountered with spontaneously growing low frequency oscillations in the range of 0.2 to 2.5 Hz .

This is achieved by the introduction of a component of electrical torque in the synchronous machine rotor that is in proportion with the deviation of speed from actual speed. The PSS can be used to its highest capability if it is tuned to the corresponding power system characteristics. A conventional power system stabilizer (CPSS) which work in tandem with the generator excitation system may not be able to damp out the small oscillations due to the continually changing operating conditions. Thus a CPSS may invariably affect the dynamic stability of the system.

In the recent years, many design methodologies have been developed by numerous researchers varying from linear to nonlinear and analytical to evolutionary techniques in view of designing PSSs capable of adequate damping of lower frequency oscillations present in the system for all the operating conditions. Modern control techniques like adaptive control, H-infinity, etc. have been developed and tested for both laboratory and online systems, for the design of robust PSSs.

In the present paper, design of controllers namely, PID and a combination of PID-PSS has been considered. First, design is considered for a SMIB system and then for a two area interconnected thermal-thermal system. The effect of PSS alone is not discussed here as it has already been proved ineffective for varying operating conditions by various researchers. Tuning of the parameters has been accomplished using Genetic Algorithm. Performance indices like Integral Absolute Error (IAE) and Integral Time Absolute Error (ITAE) are evaluated for both the designs. The design is done in such a way so that the minimization of the three performance indices is achieved. This controller satisfies the best performance for stability of the power system.

II. POWER SYSTEM MODELLING

The dynamic modelling of various power system components like generators, exciters, etc. are required for small signal stability studies.

A. Single Machine Infinite Bus System

The SMIB system model shown in Fig. 1 is used to obtain the parameters for the Heffron-Philip’s model.

The system is described by nonlinear equations (1)-(4) as given below. The variables used in the equations for the mathematical model are explained in [10].

$$\dot{\Delta\delta} = \omega_B\left(\omega_m - \omega_o\right) \quad (1)$$

$$\dot{\omega}_m = \frac{1}{2H}\left(T_m - T_e - D\left(\omega_m - \omega_{m0}\right)\right) \quad (2)$$

$$\Delta\dot{E}_q' = \frac{1}{T_{do}'}\left[\left(-E_q' + \left(x_d - x_d'\right)i_d\right) + E_{fd}\right] \quad (3)$$

$$\Delta\dot{E}_d' = \frac{1}{T_{qo}'}\left(-E_d' - \left(x_q - x_q'\right)i_q\right) \quad (4)$$

The excitation system can be described by,

$$\Delta\dot{E}_{fd} = -\frac{1}{T_A}E_{fd} + \frac{K_A}{T_A}\left(V_{ref} - V_i\right) \quad (5)$$

The electrical torque can be expressed as,

$$T_e = E_d' i_d + E_q' i_q + \left(x_d' - x_q'\right)i_d i_q \quad (6)$$

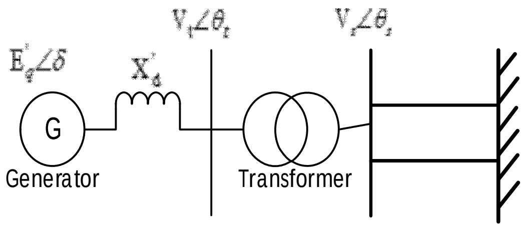

Fig. 1 Single Machine Infinite Bus System

The Heffron-Philip's model or K-constant model of the SMIB system is shown in Fig. 2 below. The entire machine data and the values of the K_1 – K_6 are given in the appendix.

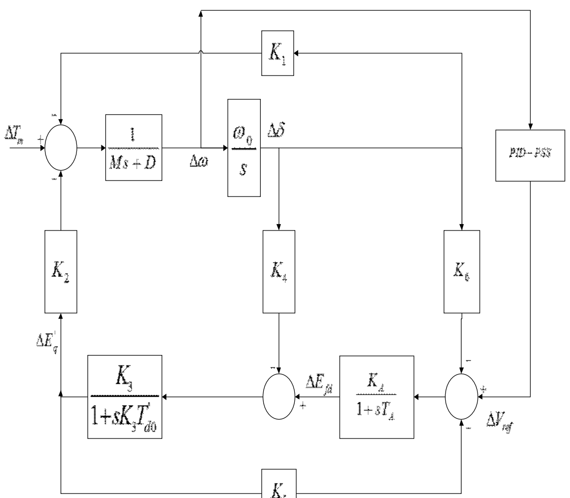

Fig. 2 Heffron-Philip's block diagram model of SMIB System [11]

B. Two Area Interconnected Thermal System

The block diagram model of the two area interconnected thermal system is represented in Fig. 3 and the variables of the system are described in [12].

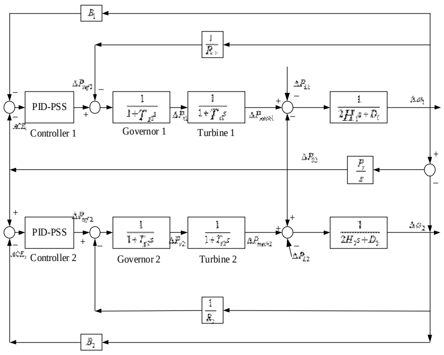

Fig. 3 Transfer function model of two area thermal system [12]

The differential equations describing the i[th] area are as follows,

$$\dot{\omega}_i = \frac{1}{2H_i}\left[-D_i\Delta\omega_i + \Delta P_{mechi} + \Delta P_{12} - \Delta P_{Li}\right] \quad (7)$$

$$\Delta\dot{P}_{vi} = \frac{1}{T_{gi}}\left[\frac{-\Delta\omega_i}{R_i} - \Delta P_{vi} + \Delta P_{refi}\right] \quad (8)$$

$$\Delta\dot{P}_{mechi} = \frac{1}{T_{ti}}\left[\Delta P_{vi} - \Delta P_{mechi}\right] \quad (9)$$

$$\Delta\dot{P}_{12} = P_s\left[\Delta\omega_i - \Delta\omega_j\right] \text{ i} \neq \text{j} \quad (10)$$

The area control error (ACE) for the i[th] area is given by,

$$ACE_i = \Delta P_{12i} \pm B_i\Delta\omega_i \quad (11)$$

where B_i is the frequency bias constant.

C. PID-PSS Structure

The controller is a PID-PSS structure as shown in Fig. 4. It consists of a stabilizer gain block with gain K_{pss}, a signal washout block and then the PID controller. The stabilizer gain determines the amount of damping introduced by the PSS. The signal washout block, with a time constant T_w, serves as a high-pass filter. The time constant is high enough to allow signals associated with the oscillations in the input signal to pass unchanged. In the PID controller, the proportional gain K_p, provides a control action proportional to the error and reduces the rise time. The integral gain K_i, with its integral action reduces the steady state error and the derivative gain K_d, reduces the overshoot by improving the transient response, thereby improving the stability of the system.

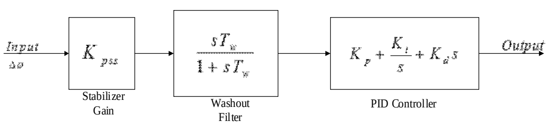

Fig. 4 PID-PSS controller structure

The transfer function of the PID-PSS structure is given by,

$$u(s) = K_{pss}\left(\frac{sT_w}{1+sT_w}\right)\left(K_p + \frac{K_i}{s} + K_d s\right) \quad (12)$$

where $u(s)$ is the output.

Here the K_{pss}, T_w, K_p, K_i and K_d values for both the above systems are tuned using genetic algorithm.

III. PROBLEM FORMULATION

State space modelling of the block diagrams is performed for determining the transfer function of the above two models. The above systems can be represented in state space as,

$\dot{X} = AX + BU$ (13)

$Y = CX + DU$ (14)

where X is the state vector, U is the input vector and Y is the output vector. A, B, C and D are the system matrices whose dimensions depend upon the system parameters.

In SMIB system, these vectors can be described as,

$$X = \begin{bmatrix} \Delta\delta & \Delta\omega & \Delta E_q^{'} & \Delta E_d^{'} & \Delta E_{fd} \end{bmatrix}^T$$

$$U = \begin{bmatrix} \Delta T_m & V_{ref} \end{bmatrix}^T$$

$$Y = \begin{bmatrix} \Delta\omega \end{bmatrix}$$

For the two area interconnected thermal system, the vectors are described as,

$$X = \begin{bmatrix} \Delta\omega_1 & \Delta\omega_2 & \Delta P_{v1} & \Delta P_{v2} & \Delta P_{mech1} & \Delta P_{mech2} & \Delta P_{ref1} & \Delta P_{ref2} & \Delta P_{12} \end{bmatrix}^T$$

$$U = \begin{bmatrix} \Delta P_{L1} & \Delta P_{L2} \end{bmatrix}^T$$

$$Y = \begin{bmatrix} \Delta\omega_1 & \Delta\omega_2 & \Delta P_{12} \end{bmatrix}^T$$

Using the help of the above vectors and the system matrices, the transfer function of the above two systems can be obtained as,

Transfer Function $= C\left[sI - A\right]^{-1} B + D$

In order to achieve the optimum results, multiple objective functions are used which are minimized and the results are compared. The objective functions used for the systems are as given below.

For SMIB system,

$$IAE = \int_0^\infty \left|\Delta\omega\right| dt \quad (15)$$

$$ITAE = \int_0^\infty t\left(\Delta\omega\right) dt \quad (16)$$

For two area interconnected thermal system,

$$IAE = \int_0^\infty \left(\left|\Delta\omega_1\right| + \left|\Delta\omega_2\right| + \left|\Delta P_{12}\right|\right) dt \quad (17)$$

$$ITAE = \int_0^\infty t\left(\left|\Delta\omega_1\right| + \left|\Delta\omega_2\right| + \left|\Delta P_{12}\right|\right) dt \quad (18)$$

The above objective functions are minimized for tuning the controller parameters with the help of genetic algorithm.

IV. PARAMETER TUNING USING GENETIC ALGORITHM

The genetic algorithm (GA), is a randomized search and optimization technique guided by the principle of natural genetic systems. At each level of GA, a new set of approximations is created by the process of selecting the individuals according to their level of fitness in the problem domain and reproducing those using operators from the natural genetics.

This process leads to the creation of a new set of population which are better suited to the environment than the older ones.

At the reproduction stage, a fitness value is derived from the individual performance of the objective function and is used in the selection process. Highly fit individuals have more chances of getting selected and therefore pass on important genetic information to the next generation. In this way, GA traverses from a wide range and eventually narrow its search to the areas of best performance.

Genetic operators like crossover and mutation alter the ‘genes’ that constitute the chromosomes entirely, in the hope that certain genetic code are more fit.

Genetic Algorithms are more likely to converge to global optima than conventional optimization techniques, since they search from a population of points, and are based on probabilistic transition rules. The flowchart for the GA used is shown in Fig. 5. Here the PID-PSS parameters of both systems are subjected to the following constraints in (19)-(23).

The genetic algorithm parameters used are shown in Table 1.

TABLE I
GENETIC ALGORITHM PARAMETERS

Population Size	30
Maximum Generations	100
Selection Rate	0.8
Mutation Rate	0.15

To compute the optimal solution a load change of 0.5 p.u. is considered and the controller parameters are tuned using genetic algorithms such that the objective functions are minimized.

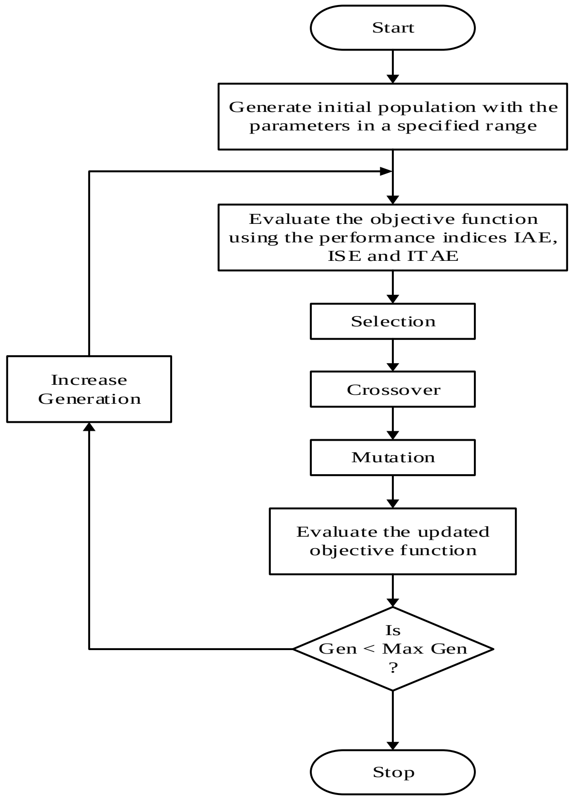

Fig. 5 Genetic algorithm flowchart

$$K_{pss}^{\min} \le K_c \le K_{pss}^{\max} \quad (19)$$

$$T_w^{\min} \le T_w \le T_w^{\max} \quad (20)$$

$$K_p^{\min} \le K_p \le K_p^{\max} \quad (21)$$

$$K_i^{\min} \le K_i \le K_i^{\max} \quad (22)$$

$$K_d^{\min} \le K_d \le K_d^{\max} \quad (23)$$

V. RESULTS AND DISCUSSIONS

To compute the optimal solution, MATLAB simulation is carried out to evaluate the minimum value of the objective functions using both PID and PID-PSS controllers, for a time span of 50 seconds. The values of the three performance indices are provided to the genetic algorithm, which in turn minimizes them by finding an optimal solution for the controller parameters. The results obtained are shown in the following figures and tables.

D. SMIB System

TABLE II
PARAMETERS FOR PID CONTROLLER

	IAE	ITAE
K_p	13.624	9.6431
K_d	4.6392	1.1137
K_i	28.381	19.31
Settling Time (sec)	7.18	4.97
Overshoot	0.0093	0.0257

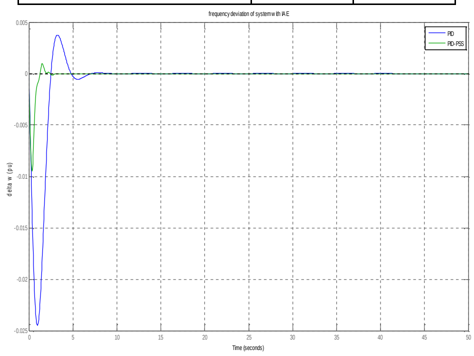

Fig. 6 Frequency deviation of SMIB system with IAE

TABLE III
PARAMETERS FOR PSS-PID CONTROLLER

	IAE	ITAE
K_p	15.443	18.855
K_d	3.502	6.6863
K_i	29.431	29.431
K_{pss}	2.8408	2.8294
T_w	6.467	9.886
Settling Time (sec)	2.87	3.56
Overshoot	0.00937	0.00904

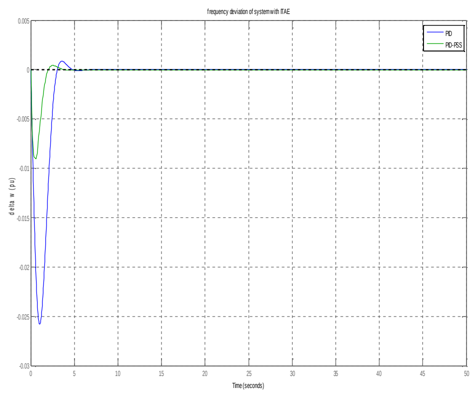

Fig. 7 Frequency deviation of SMIB system with ITAE

E. Two Area Interconnected Thermal-Thermal System

TABLE IV
PARAMETERS FOR PID CONTROLLER

	IAE	ITAE
K_{p1}	16.588	25.529
K_{p2}	13.294	20.235
K_{d1}	12.235	10.353
K_{d2}	3.6471	6.3529

K_{i1}		19.765	28.471
K_{i2}		28.471	29.647
Settling Time (sec)	$\Delta\omega_1$	16.3	6.55
	$\Delta\omega_2$	12.1	7.19
	ΔP_{12}	14.7	11.6
Overshoot	$\Delta\omega_1$	0.00468	0.00589
	$\Delta\omega_2$	0.0144	0.00855
	ΔP_{12}	0.0117	0.0068

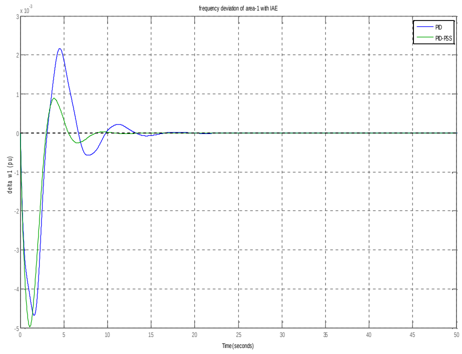

Fig. 8 Frequency deviation of area-1 with IAE

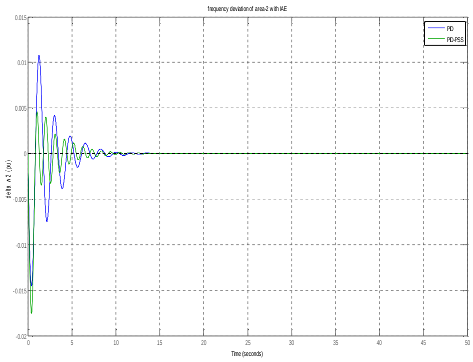

Fig 9 Frequency deviation of area-2 with IAE

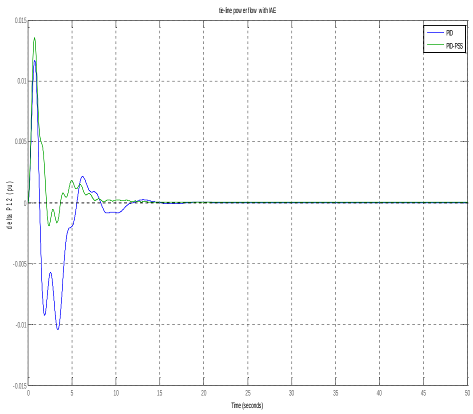

Fig 10 Tie-Line power flow with IAE

TABLE V
PARAMETERS FOR PID-PSS CONTROLLER

		IAE	ITAE
K_{p1}		17.604	8.1647
K_{p2}		1.3412	6.1176
K_{d1}		17.149	12.6
K_{d2}		1.1137	1.9098
K_{i1}		18.286	26.361
K_{i2}		14.078	27.953
K_{pss1}		1	1
K_{pss2}		2.9773	8.8471
T_{w1}		7.8392	5.7292
T_{w2}		3.2812	1.1137
Settling Time (sec)	$\Delta\omega_1$	10.4	5.58
	$\Delta\omega_2$	11	5.43
	ΔP_{12}	12.4	8.32
Overshoot	$\Delta\omega_1$	0.00492	0.00395
	$\Delta\omega_2$	0.0169	0.00917
	ΔP_{12}	0.0173	0.00345

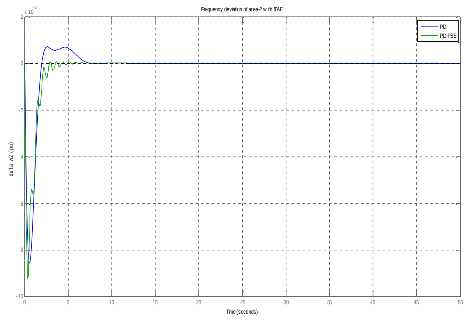

Fig. 11 Frequency deviation of area-1 with ITAE

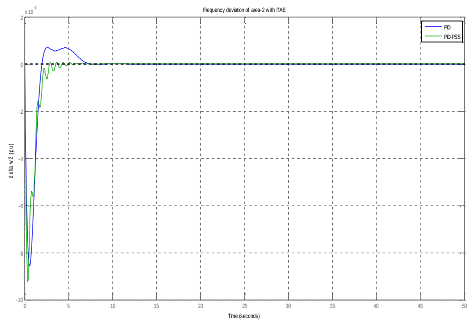

Fig. 12 Frequency deviation of area-2 with ITAE

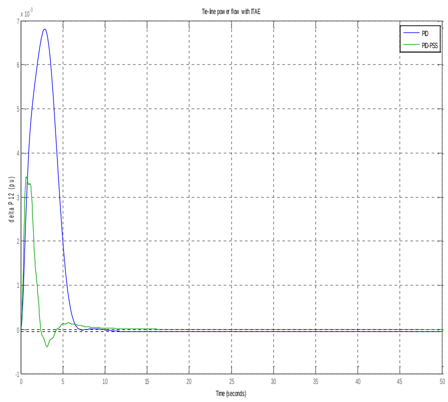

Fig. 13 Tie-Line power flow with ITAE

The above results shows that the use of PID-PSS controller is much more effective than a standalone PID controller.

The PID-PSS reduces the settling time to a lesser value than that of a PID controller but both have relatively same peak overshoot. The effect of PID-PSS can be much more improved if the lead-lag structure of PSS is used along with washout block.

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APPENDIX

All system data are in per unit unless specified.

SMIB System Data:

x_d =1.7572, x_q =1.5845, $x_d^{'}$ =0.4245, $x_q^{'}$ =1.04, $T_{d0}^{'}$ =6.66, $T_{q0}^{'}$ =0.44, H =5s, ω_B = 314 rad/sec, x_t =0.1364, x_e =0.8125, K_A =400, T_A =0.025, V_t =1.05, x_{th} =0.1363.

K_1 =1.0297, K_2 =1.0124, K_3 =0.3600, K_4 =1.2959, K_5 =0.0016, K_6 =0.4633.

Two Area Interconnected System Data:

H_1 =5, H_2 =4, D_1 =0.6, D_2 =0.9, T_{t1} =0.5s, T_{t2} =0.6s, T_{g1} =0.2s, T_{g2} =0.3s, R_1 =0.05, R_2 =0.0625, B_1 =20.6, B_2 =16.9, P_s =2.

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