Dynamic analysis of Single Machine Infinite Bus system using Single input and Dual input PSS

P. PAVAN KUMAR
M.Tech Student, EEE Department, Gitam University,
Visakhapatnam, Andhra Pradesh, India-533045,
pavan.kumar270489@gmail.com

M. RAVINDRA BABU
Assistant Professor, EEE Department, Gitam University,
Visakhapatnam, Andhra Pradesh, India-533045,
raviravi1983@gmail.com

Dr. G. SARASWATHI
Associate Professor, EEE Department, Gitam University,
Visakhapatnam, Andhra Pradesh, India-533045,
g_saraswathi@gitam.edu

Abstract: *This paper deals with the design of both single input and dual input conventional PSS which is used to damp the low frequency rotor oscillations taking place in power systems. The single input PSS used here are power based derivative type and speed based lead-lag type stabilizer, the dual input stabilizer, PSS3B has two inputs namely from change in speed and deviation of electrical power and has two frequency bands, lower and higher unlike the single input PSS. The PSS parameters are tuned, considering the machine data and operating point of the system used. The optimal parameters of the PSS are obtained using pole placement and genetic algorithm technique and the respective results are compared graphically .The system used is Single Machine Infinite Bus (SMIB) system which is modelled using state space analysis and its dynamic response is analyzed both for system without PSS and with PSS (both single and dual input) using Simulink/Matlab.*

Keywords: *Genetic Algorithm, Pole placement Technique, Power system stabilizer (PSS), Rotor instability, SMIB, PSS3B.*

1. Introduction

Power systems experience low-frequency oscillations due to disturbances. These low frequency oscillations are related to the small signal stability of a power system. The phenomenon of stability of synchronous machine under small perturbations is explored by examining the case of a single machine connected to an infinite bus system (SMIB). The analysis of SMIB gives physical insight into the problem of low frequency oscillations. These low frequency oscillations are classified into local mode, inter area mode and torsional mode of oscillations. The SMIB system is predominant in local mode low frequency oscillations [7]. These oscillations may sustain and grow to cause system separation if no adequate damping is available.

Small signal disturbances observed on the power system are caused by many factors such as heavy power transmitted over weak tie line and the effect of fast acting, high gain automatic voltage regulator (AVRs) [6]. The main function of the AVR is to improve the transient stability during faults conditions. However, its high gain and fast acting effect have an adverse effect on the system damping which is reduced to a negative value. The under damped system exhibits low frequency oscillations also known as electromechanical oscillations. These oscillations limit the power transfer over the network and if not properly damped, they can grow in magnitude to cause system separation. To counteract the adverse effects of the AVRS, Power system stabilizer (PSS) is used in the auxiliary feedback to provide supplementary damping [6] to the system to damp these low frequency oscillations on the rotor.

To overcome this problem, several approaches based on modern control theory, such as Optimal control, Variable control and intelligent control were simulated and tested with satisfactory results. But these stabilizers have been proved to be difficult to implement in real systems. Thus, CPSS remains widely used by power utilities for its simple structure and reliability. Over the past 15 years, interests have been focused on the optimization of the PSS parameters to provide adequate performance for all operating conditions. Hence, many optimizations techniques based on artificial intelligence have been used to find the optimum set of parameters to effectively tune the PSS.

In this paper both single input (speed & power based) and dual input stabilizers (PSS3B) are used to damp the low frequency oscillations associated with the system. PSS3B is used with combination of shaft speed deviation ($\Delta\omega$) and change in electrical power (ΔP_e) which has its own advantages when compared to single input PSS which is described below in section 3. The parameters of both the types of PSS are tuned using Pole Placement technique and Genetic Algorithm and results are thus analyzed.

2. System Modelling

A single machine-infinite bus (SMIB) system is considered for the present investigation. A machine connected to a large system through a transmission line may be reduced to a SMIB system, by using Thevenin's equivalent of the transmission network external to the machine.

The synchronous machine is described as the fourth order model. The two-axis synchronous machine representation with a field circuit in the direct axis but without damper windings is considered for the analysis. The system dynamics of the synchronous machine can be expressed as a set of four first order linear differential equations given in equations below [6]. These equations represent a fourth order generator model.

$$\Delta T_m - \Delta P = M\frac{d^2\Delta\delta}{dt^2} \quad (1)$$

$$\Delta P = K_1\Delta\delta + K_2\Delta E_q' \quad (2)$$

$$\Delta E_q' = \frac{K_3}{1+sT_{do}'K_3}\Delta E_{fd} - \frac{K_3K_4}{1+sT_{do}'K_3}\Delta\delta \quad (3)$$

$$\Delta V_t = K_5\Delta\delta + K_6\Delta E_q' \quad (4)$$

The constants (K_1-K_6) are called Heffron-Phillips constants and are computed using the equations given in Appendix.

The system data considered is: (5)
$x_d = 0.973$ $x'_d = 0.19$
$x_q = 0.55$ $T'_{do} = 7.765s$
$D = 0$ $H = 5$ $f = 60Hz$

Transmission line (p.u): (6)
$R_e = 0$ $X_e = 0.4$

Exciter: (7)
$K_E = 200$ $T_E = 0.05s$

Operating point: (8)
$V_{to} = 1.0$ $P_0 = 1.0$
$Q_0 = 0.2$ $\delta_0 = 28.26^{o}$

The Heffron-Phillips constants are dependent on the machine parameters and the operating condition considered for the system. Here K_1, K_2, K_3 and K_6 are positive [6]. K_4 is mostly positive except for cases where R_e is high. K_5 can be either positive or negative and K_5 is positive for low to medium external impedances (R_e+ jX_e) and low to medium loadings. K_5 *is* usually negative for moderate to high external impedances and heavy loadings [6]. The overall linearized block diagram of the SMIB system is shown in Fig.1 below.

For the system considered four state variables are considered and linearized differential equations can be written in the state space form as,

$$\dot{X}(t) = A.x(t) + B.u(t) \quad (9)$$

Where,

$$X(t) = [\Delta\delta \quad \Delta\omega \quad \Delta E_q' \quad \Delta E_{fd}]^T \quad (10)$$

$$A = \begin{bmatrix} 0 & \omega_B & 0 & 0 \\ \frac{-K_1}{2H} & \frac{-D}{2H} & \frac{-K_2}{2H} & 0 \\ \frac{-K_4}{T_{do}'} & 0 & \frac{-1}{T_{do}'K_3} & \frac{1}{T_{do}'} \\ \frac{-K_EK_5}{T_E} & 0 & \frac{-K_EK_6}{T_E} & \frac{-1}{T_E} \end{bmatrix} \quad (11)$$

$$B = \begin{bmatrix} 0 & 0 & 0 & \frac{K_E}{T_E} \end{bmatrix}^T \quad (12)$$

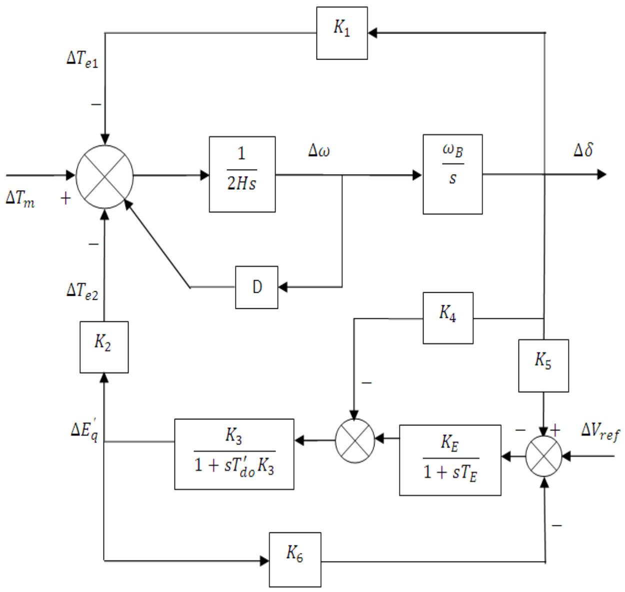


Fig. 1. Linearized block diagram of SMIB

In the above state space equation system state matrix A is a function of the system parameters, which depend on operating conditions, control matrix B depends on system parameters only and control signal U is the PSS output. Using these state equations and state matrices the overall transfer function of the system is computed, since here no controller is used, it is considered as open loop system whose transfer function is G(s).

3. Power System Stabilizer

One problem that faces power systems nowadays is the low frequency oscillations arising from interconnected systems. Sometimes, these oscillations sustain for minutes and grow to cause system separation. The separation occurs if no adequate damping is available to compensate for the insufficiency of the damping torque in the synchronous generator unit. This insufficiency of damping is mainly due to the AVR exciter's high speed and gain and the system's loading.

In order to overcome the problem, PSSs have been successfully tested and implemented to damp low frequency oscillations. The PSS provides supplementary feedback stabilizing signal in the excitation system. The feedback is implemented in such a way that electrical torque on the rotor is in phase with speed variations [7]. PSS parameters are normally fixed for certain values that are determined under particular operating conditions. Once the system operating conditions are changed, PSS may not produce adequate damping into an unstable system.

Since PSSs are tuned at the nominal operating point, the damping is only adequate in the vicinity of those operating points. But power systems are highly nonlinear systems, therefore, the machine parameters change with loading and time. The dynamic characteristics also vary at different points.

3.1 Conventional Power system Stabilizer

The basic function of CPSS is to damp electromechanical oscillations. To achieve the damping, the CPSS proceeds by controlling the AVR excitation using auxiliary stabilizing signal. The CPSS's structure is illustrated in Figure 2.

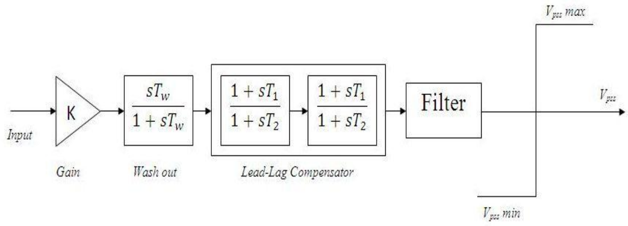


Fig. 2. Structure of CPSS

The CPSS classically uses the following inputs [5]:

· The shaft speed deviation $\Delta\omega$
· Active power output, ΔP_a (Change in accelerating power)
· ΔP_e (change in electric power),
· Bus frequency Δf

3.1.1 Gain

The gain determines the amount of damping introduced by the stabilizer. Therefore, increasing the gain can move unstable oscillatory modes into the left – hand complex plane. Ideally, the gain should be set to a value corresponding to a maximum damping. However, in practice the gain K_{pss} is set to a value satisfactory to damp the critical mode without compromising the stability of other modes.

3.1.2 Washout

The washout stage is a High Pass Filter (HPF) with purpose to respond only to oscillations in speed and block the dc offsets. The Washout filter prevents the terminal voltage of the generator to drift away due to any steady change in speed.

3.1.3 Phase compensation

This stage consists of two lead – lag compensators as shown in Figure 2 (lead – lag compensation stage*)*. The lead stage is used to compensate for the phase lag introduced by the AVR and the field circuit of the generator. The lead – lag parameters T_1-T_4 are tuned in such as way that speed oscillations give a damping torque on the rotor. When the terminal voltage is varied, the PSS affects the power flow from the generator, which efficiently damps the local modes.

3.1.4 Torsional Filter

This stage is added to reduce the impact on the torsional dynamics of the generator while preventing the voltage errors due to the frequency offset.

3.1.5 Limiter

The PSS output requires limits in order to prevent conflicts with AVR actions during load rejection. The AVR acts to reduce the terminal voltage while it increases the rotor speed and the bus frequency. Thus, the PSS is compelled to counteract and produce more positive output. As described in by P. Kundur in [8], the positive and negative limit should be around the AVR set point to avoid any counteraction. The positive limit of the PSS output voltage contributes to improve the transient stability in the first swing during a fault. The negative limit appears to be very important during the back swing of the rotor.

3.1 Single input PSS

The input signals include deviations in the rotor speed ($\Delta\omega=\omega_{mech} - \omega_o$), the frequency ($\Delta f$), the electrical power (ΔP_e) and the accelerating power (ΔP_a) [5].

As mentioned above in this paper two types of PSS are considered to damp the low frequency oscillations they are,

1) Speed based lead-lag PSS: These stabilizers employ the direct measurement of shaft speed ($\Delta\omega$) and employ it as input signal for it. The stabilizer, while damping the rotor oscillations, could reduce the damping of the lower-frequency torsional modes if adequate filtering measures were not taken [1 & 5]. In addition to careful pickup placement at a location along the shaft where low-frequency shaft torsionals were at a minimum electronic filters called torsional filters should be used for adequate damping of low frequency oscillations.

The structure of this PSS is in the form as shown below [1], for which the parameter such as stabilizer gain K_c, lead lag time constants T_1 and T_2 are to be computed such that the overall closed loop system will be stable when the PSS is included in the feedback loop.

$$H(s) = \frac{K_c s T_W}{(1+sT_W)} \frac{(1+sT_1)}{(1+sT_2)} \qquad (13)$$

2) *Power based derivative PSS:* Due to the simplicity of measuring electrical power and its relationship to shaft speed, it was considered to be a natural candidate as an input signal to early stabilizers. The equation of motion for the rotor can be written as follows [1 & 5]:

$$\frac{\partial}{\partial t}\Delta\omega = \frac{1}{2H}(\Delta P_m - \Delta P_e) \qquad (14)$$

Where, H = inertia constant

ΔP_m= change in mechanical power input

ΔP_e= change in electric power output

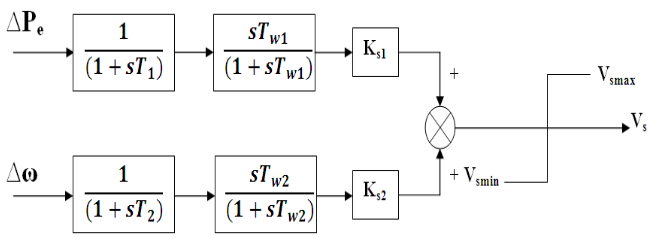
$\Delta\omega$ = speed deviation

As previously mentioned this type of stabilizer uses electrical power (ΔP_e) as input and is of derivative type whose structure is as shown below [1], and the optimal stabilizer parameter K and T are to be computed which ensure closed loop stability of the system.

$$\mathrm{H(s)} = \frac{\mathrm{Ks}}{(s+\frac{1}{\mathrm{T}})^2} \qquad (15)$$

3.2 Dual input CPSS (PSS3B)

In this paper a dual input PSS is used, the two inputs to dual-input PSS are $\Delta\omega$ and ΔP_e, with two frequency bands, lower frequency and higher frequency bands, unlike the conventional single-input ($\Delta\omega$) PSS [2]. The performance of IEEE type PSS3B is found to be the best one within the periphery of the studied system model. This dual input PSS configuration is considered for the present work and its block diagram representation is shown in Figure 3



.Fig. 3. IEEE type PSS3B structure

In the above PSS structure used [2], the unknown parameters are computed using pole placement and genetic algorithm techniques, in case of pole placement technique the transfer function of the pss is computed and is used in feedback to form a closed loop system, for which characteristic equation is formed to compute the unknown parameters of PSS by placing dominant eigen values in place of ‘s’ in the characteristic equation..

$$\frac{Y(s)}{U(s)} = \frac{2Hk_{s1}s^2T_{w1}(1+sT_2)(1+sT_{w2}) + sT_{w2}k_{s2}(1+sT_1)(1+sT_{w1})}{2Hs(1+sT_1)(1+sT_{w1})(1+sT_2)(1+sT_{w2})} = H(s) \quad (16)$$

The transfer function of the PSS3B used is shown above, and the pole placement technique is explained in detail in section 4

4. Pole Placement Technique

Pole placement is a method employed in feedback control system theory to place the closed-loop poles of a plant in pre-determined locations in the s-plane. This method is also known as Full State Feedback (FSF) technique. Placing poles is desirable because the location of the poles corresponds directly to the eigen values of the system, which control the characteristics of the response of the system.

Based on the system data considered and the operating condition, the Heffron-Phillips constants for the system are computed. The state equations are then considered using these constants to compute the state matrices and then the transfer function of the open loop system is computed in matlab using these state matrices. The open loop system transfer function is taken as G(s). Now in the feedback loop, the stabilizer is used for the control of low frequency speed oscillations, whose transfer function is taken as H(s) [4]. The simple block diagram considered for pole placement technique is shown below.

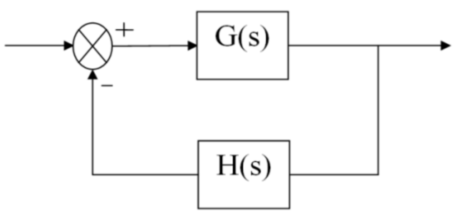


Fig. 4. Closed loop system including PSS

Let the linearized equations of single machine, infinite bus system be expressed in the form,

$$sX(s) = AX(s) + BU(s) \quad (17)$$

$$Y(s) = CX(s) \quad (18)$$

The PSS with the following structure is used [4],

$$\frac{Y(s)}{U(s)} = GPSS(s) = H(s) \quad (19)$$

Where the PSS parameter are to determined such that system dominant eigen values are equal to desired eigen values. Using equations (17),(18) and (19), it can be readily shown that the closed loop system characteristic equation is given by,

$$1 \pm G(s)H(s) = 0 \quad (20)$$

From eqn.(20) the required stabilizer parameters can be computed by replacing ‘s’ by the desired eigen value λ and equating the real and imaginary terms on both sides of the equation [4].

Using the state equations and state matrices mentioned in section 2, the open loop transfer function G(s) of the system is obtained, and the PSS of structure shown in eqns.(13),(15) and (16) is used as feedback H(s) for the open loop system and thus forming the closed loop system with unknown parameters, which are computed as mentioned above by replacing ‘s’ by dominant eigen values.

5. Genetic Algorithm(GA)

Genetic Algorithms (GAs) are heuristic search procedures inspired by the mechanism of evolution and natural genetic. They combine the survival of the fittest principle with information exchange among individuals. GA’s are simple yet powerful tools for system optimization and other applications [11].

This technique has been pioneered few decades ago by Holland, basing the approach on the Darwin’s survival of the fittest hypothesis. In GA’s candidates solutions to a problem are similar to individuals in a population. A population of individuals is maintained within the search space of GAs, each representing a possible solution to a given problem. The individuals are randomly collected to form the initial population from which improvement is sought. The individuals are then selected according to their level of fitness within the problem domain and breed together. The breeding is done by using the operators borrowed from the natural genetic, to form future generations (offsprings) [11]. The population is successively improved with respect to the search objective. The least fit individuals are replaced with new and fitter offspring from previous generation.

The most common operators handled in genetic algorithm are described in detail below, which in whole called as breeding cycle.

1) *Selection (Reproduction):* In this stage, individuals are selected from the current population according to their fitness value, obtained from the objective function previously described. The purpose of the selection is to choose individuals to be mated. The selection can be performed in several ways. But many selection techniques employ a "roulette wheel" [11]. It is a mechanism to probabilistically select individuals based on some measure of their performances.

2) *Crossover (Recombination):* In this stage, the individuals retained (in pairs), from the above stage, exchange genetic information to form new individuals (offsprings). This process helps the optimization search to escape from possible local optima and search different zones of the search space [11]. The combination or crossover is done by randomly choosing a cutting point where both parents are divided in two. Then the parents exchange information to form two offsprings that may replace them if the children are fitter.

3) *Mutation:* After crossover, the strings are subjected to mutation. Mutation prevents the algorithm to be trapped in a local minimum. Mutation plays the role of recovering the lost genetic materials as well as for randomly disturbing genetic information. Mutation has traditionally considered as a simple search operator [11]. If crossover is supposed to exploit the current solution to find better ones, mutation is supposed to help for the exploration of the whole search space.

4) *Replacement:* Replacement is the last stage of any breeding cycle. It is in this process that children populate the next generation by replacing parents, if fitter. Reinsertion can be made partially or completely, uniformly (offspring replace parents uniformly at random) or fitness-based.

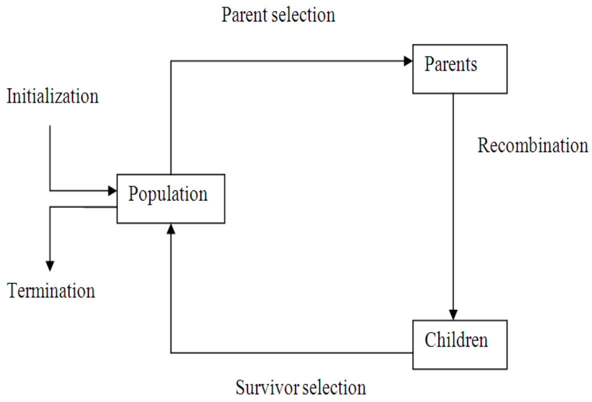


Fig. 5. General Scheme of Genetic Algorithm

All these operation are carried out in Genetic Algorithm toolbox in which the following fitness function has to be defined. The problem of computing optimal parameters of a single power system stabilizer for different operating points implies that power system stabilizer must stabilize the family of N plants [1]:

$$\dot{X} = A_k X + B_k U, \; k= 1,2,3....N \qquad (21)$$

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 [1]. This condition motivates the following approach for determining parameters K_{s1}, K_{s2}, T_1 and T_2 of the power system stabilizer. Selection of K_{s1}, K_{s2}, T_1 and T_2 to minimize the following fitness function,

$$J = \text{Re}\max(\lambda_{i,k})_{\, i=1,2,\ldots N, k=1,2,..N} \qquad (22)$$

Where $\lambda_{i,k}$ is the k*th* closed-loop eigen value of the ith plant [1]. If a solution is found such that $J<0$, then the resulting K_{s1}, K_{s2}, T_1 and T_2 stabilize the collection of plants.

For running the GA toolbox the command **gatool** [10], is to be given in command window of MATLAB and in the tool the fitness function is to be defined in which the state matrix A including PSS is used and the unknown PSS parameters are taken as unknown variables which are to be optimized such that the eigen values of the matrix lie on the left half of s-plane i.e., in the stability region. This method of finding the parameter is applied for the type of PSS described in section 3. The state matrices 'A' and the specifications used for running GA toolbox are mentioned in Appendix.

6. Appendix

6.1 Calculation of Heffron-Phillips constants

All the variables with subscript '0' are values of variables evaluated at their pre-disturbance steady-state operating point from the known values of P_0 , Q_0 and V_{t0}.

$$i_{qo} = \frac{P_o Q_o}{\sqrt{(P_o x_q)^2 + (V_{to}^2 + Q_o x_q)^2}}$$

$$v_{do} = i_{qo} x_q$$

$$v_{qo} = \sqrt{V_{to}^2 - v_{do}^2}$$

$$i_{do} = \frac{Q_o + x_q i_{qo}^2}{v_{qo}}$$

$$E_{qo} = v_{qo} + i_{do} x_q$$

$$E_o = \sqrt{(v_{do} + x_e i_{qo})^2 - (v_{qo} - x_q i_{do})^2}$$

$$\delta_o = \tan^{-1}\frac{(v_{do} + x_e i_{qo})}{(v_{qo} - x_e i_{do})} \qquad \text{(A.1)}$$

The above equations indicated in (A.1) are used to calculate the initial conditions of the system under consideration which are further used to compute the Heffron-Phillips constants (A.2).

$$K_1 = \frac{E_b E_{qo} \cos\delta_o}{(x_e + x_q)} + \frac{(x_q - x_d')}{(x_e + x_d')} E_b i_{qo} \sin\delta_o$$

$$K_2 = \frac{(x_e + x_q)}{(x_e + x_d')} i_{qo} = \frac{E_b \sin\delta_o}{(x_e + x_d')}$$

$$K_3 = \frac{(x_e + x_d')}{(x_d + x_e)}$$

$$K_4 = \frac{(x_d - x_d')}{(x_d' + x_e)} E_b \sin\delta_o$$

$$K_5 = \frac{-x_q v_{do} E_b \cos\delta_o}{(x_e + x_q) V_{to}} - \frac{x_d' v_{qo} E_b \sin\delta_o}{(x_e + x_d') V_{to}}$$

$$K_6 = \frac{x_e}{(x_e + x_d')} \cdot \left(\frac{V_{qo}}{V_{to}}\right) \qquad \text{(A.2)}$$

6.2 Modelling of System including Speed based PSS (Δω)

When PSS of structure described in equation (13) is used as feedback of open loop system, it forms a closed loop system. The state equations involved are,

$$\Delta\delta = \frac{\omega_B}{s} \Delta\omega$$

$$\Delta\omega = \frac{-K_1}{2Hs}\Delta\delta - \frac{K_2}{2Hs}\Delta E_q' - \frac{D}{2Hs}\Delta\omega$$

$$\Delta E_q' = (-K_4 \Delta\delta + \Delta E_{fd}) \frac{K_3}{1 + sK_3 T_{do}'}$$

$$\Delta E_{fd} = (-K_5 \Delta\delta - K_6 \Delta E_q' + \Delta v_2) \frac{K_E}{1 + sT_E}$$

$$\Delta v_1 = k \frac{sT_w}{(1 + sT_w)} \Delta\omega$$

$$\Delta v_2 = \frac{(1 + sT_1)}{(1 + sT_2)} \Delta v_1$$

$$A = \begin{bmatrix} 0 & \omega_B & 0 & 0 & 0 & 0 \\ \frac{-K_1}{2H} & 0 & \frac{-K_2}{2H} & 0 & 0 & 0 \\ \frac{-K_4}{T_{do}'} & 0 & \frac{-1}{K_3 T_{do}'} & \frac{1}{T_{do}'} & 0 & 0 \\ \frac{-K_E K_5}{T_5} & 0 & \frac{K_E K_6}{T_E} & \frac{-1}{T_E} & 0 & \frac{K_E}{T_E} \\ \frac{-K_c K_1}{2H} & 0 & \frac{-K_c K_2}{2H} & 0 & \frac{-1}{T_w} & 0 \\ \frac{K_1 K_c}{2HT_1} & 0 & \frac{-K_2 K_c}{2HT_2} & 0 & \frac{(T_w - T_1)}{T_w T_2} & \frac{-1}{T_2} \end{bmatrix} \qquad \text{(A.3)}$$

6.3 Modelling of System including Power based PSS (ΔP_e)

When PSS of structure described in equation (16) is used as feedback of open loop system, it forms a closed loop system. The state equations involved are,

$$\Delta\delta = \frac{\omega_B}{s}\Delta\omega$$

$$\Delta\omega = \frac{-K_1}{2Hs}\Delta\delta - \frac{K_2}{2Hs}\Delta E'_q - \frac{D}{2Hs}\Delta\omega$$

$$\Delta E'_q = (-K_4\Delta\delta + \Delta E_{fd})\frac{K_3}{1 + sK_3T'_{do}}$$

$$\Delta E_{fd} = (-K_5\Delta\delta - K_6\Delta E'_q - \Delta v_2)\frac{K_E}{1 + sT_E}$$

$$\Delta v_1 = \frac{KT}{(1 + sKT)}(K_1\Delta\delta + K_2E'_q)$$

$$\Delta v_2 = \frac{s}{(s + \frac{1}{T})^2}\Delta v_1$$

$$A = \begin{bmatrix} 0 & \omega_B & 0 & 0 & 0 & 0 \\ \frac{-K_1}{2H} & 0 & \frac{-K_2}{2H} & 0 & 0 & 0 \\ \frac{-K_4}{T'_{do}} & 0 & \frac{-1}{K_3T'_{do}} & \frac{1}{T'_{do}} & 0 & 0 \\ \frac{-K_EK_5}{T_5} & 0 & \frac{K_EK_6}{T_E} & \frac{-1}{T_E} & 0 & \frac{-K_E}{T_E} \\ K_1K & 0 & K_2K & 0 & \frac{-1}{T} & 0 \\ K_1K & 0 & K_2K & 0 & \frac{-1}{T} & \frac{1}{T} \end{bmatrix} \quad (A.4)$$

The wash out time constant for the both speed and power based PSS is taken as T_w= 2sec

6.4 Modelling of System including PSS3B

The state equations of the system when PSS of structure shown in section 3 is used in the feedback loop are derived as below (A.3).

$$\Delta\delta = \frac{\omega_B}{s}\Delta\omega$$

$$\Delta\omega = \frac{-K_1}{2Hs}\Delta\delta - \frac{K_2}{2Hs}\Delta E'_q - \frac{D}{2Hs}\Delta\omega$$

$$\Delta E'_q = (-K_4\Delta\delta + \Delta E_{fd})\frac{K_3}{1 + sK_3T'_{do}}$$

$$\Delta E_{fd} = (-K_5K_E\Delta\delta - K_6K_E\Delta E'_q - K_E(\Delta v_2 + \Delta v_4))\frac{1}{1 + sT_E}$$

$$\Delta v_1 = k_{s1}\frac{sT_{w1}}{(1 + sT_{w1})}\Delta P_e$$

$$\Delta v_2 = \frac{1}{(1 + sT_1)}\Delta v_1$$

$$\Delta v_3 = k_{s2}\frac{sT_{w2}}{(1 + sT_{w2})}\Delta\omega$$

$$\Delta v_4 = \frac{1}{(1 + sT_2)}\Delta v_3 \quad (A.5)$$

The state matrix 'A' of the system including PSS3B is shown below (A.6) which is used in the objective function to evaluate the fitness using GA tool box.

$$\begin{bmatrix} 0 & \omega_B & 0 & 0 & 0 & 0 & 0 & 0 \\ \frac{-k_1}{2H} & \frac{-D}{2H} & \frac{-k_2}{2H} & 0 & 0 & 0 & 0 & 0 \\ \frac{k_4}{T'_{do}} & 0 & \frac{-1}{k_3T'_{do}} & \frac{-1}{T'_{do}} & 0 & 0 & 0 & 0 \\ \frac{-k_Ek_5}{T_E} & 0 & \frac{-k_Ek_6}{T_E} & \frac{-1}{T_E} & 0 & \frac{-k_E}{T_E} & 0 & \frac{-k_E}{T_E} \\ \frac{-k_2k_4k_{s1}}{T'_{do}} & \omega_Bk_1k_{s1} & \frac{-k_2k_{s1}}{k_3T'_{do}} & \frac{-k_{s1}k_2}{T'_{do}} & \frac{-1}{T_{w1}} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{T_1} & \frac{-1}{T_1} & 0 & 0 \\ \frac{-k_1k_{s2}}{2H} & 0 & \frac{-k_2k_{s2}}{2H} & 0 & 0 & 0 & \frac{-1}{T_{w2}} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{T_2} & \frac{-1}{T_2} \end{bmatrix} \quad (A.6)$$

The washout time constants is taken as T_{w1}=T_{w2}=10sec.

6.5 Specifications of Genetic Algorithm

For using GA toolbox to optimize the PSS parameters the following specifications are used,

Table 1. Genetic Algorithm Specifications for Toolbox

Population size	75
Creation function	Use constraint dependent default
Scaling function	Rank
Selection function	Roulette
Crossover fraction	0.7
Mutation function	Use constraint dependent default
Crossover function	Single point
Migration direction	Forward
Number of generations	300

The application of GA tool box for optimization of PSS parameters, the following constraints on the parameters has to be considered,

For speed based PSS,

$10 \leq K_c \leq 50; 0.01 \leq T_1 \leq 1; 0.01 \leq T_2 \leq 0.1$

For power based PSS,

$0.1 \leq K \leq 10; 0.01 \leq T \leq 1$

$-3 \leq K_{s1} \leq 0$; $20 \leq K_{s2} \leq 60$; $0 \leq T_1 \leq 0.3$; $0 \leq T_2 \leq 0.1$

7. Results

The parameters of the PSS obtained using pole placement and Genetic Algorithm techniques are shown below.

Single input parameters:

1) Speed based PSS using Pole placement technique are,

K_c=9.6763, T_1=0.285sec, T_2=0.05sec

Parameters obtained using Genetic Algorithm is,

K_c=10.541, T_1=0.498sec, T_2=0.1sec

2) Power based PSS using Pole placement technique are,

K=0.8954, T=0.3104sec

Parameters obtained using Genetic Algorithm is,

K=3.4, T=0.498sec

Table 2. PSS3B parameters

PSS3B Parameters	Pole Placement	Genetic algorithm
K_{s1}	-0.5	-0.354
K_{s2}	48.259	20.003
T_1	0.05sec	0.15sec
T_2	0.25sec	0.1sec

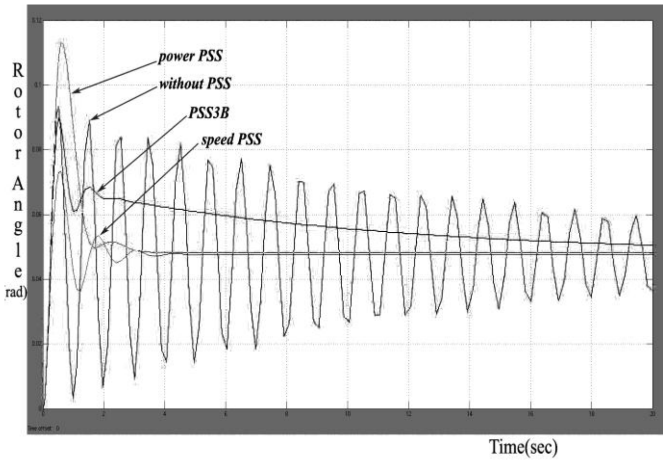


Fig. 6. Simulation output of SMIB with GA-PSS

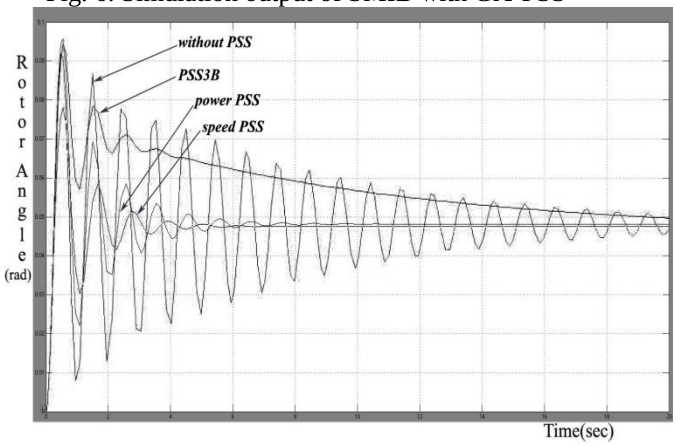


Fig. 7. Simulation output of SMIB with Pole Placement-PSS

The settling time of the simulation response for PSS3B are compared in table shown below,

Table 3. Settling time comparison

	Single input PSS		Dual input PSS
Settling Time	Speed based PSS	Power based PSS	PSS3B
Without PSS	56.43sec	56.43sec	56.43sec
Pole placement PSS	4.14sec	5.79sec	3.66sec
GA PSS	3.29sec	1.93sec	1.74sec

8. Conclusion

The optimal parameters of dual input conventional pss, PSS3B is obtained using pole placement and genetic algorithm technique and are simulated to analyse the dynamic response in both the cases.

The technique of computing parameters becomes complex with the increase in number of machines in case of pole placement technique, where as the technique of Genetic Algorithm can be used to compute optimal parameters of PSS for wide range of operating conditions in power system and also can be implemented for multi-machine system. The settling time of the PSS is less in case of Genetic Algorithm technique when compared to Pole Placement Technique.

References

[1]. "**Tuning of Power System Stabilizers via Genetic Algorithm for Stabilization of power Systems**" by MehranRashidi, FarzanRashidi, Hamid Moaavar, **0-7803-7952-7/03/$17.00** ***0 2003 IEEE***

[2]. M. Sreedevi and P. Jeno Paul, "**Comparison of Two Power system stabilizers for Power system stability"** International Journal of Signal System Control and Engineering Applications, 3(4): 70-76, 2010 ISSN: 1997-5422

[3]. Joe H. Chow, George E. Boukarim, and Alexander Murdoch, "**Power System Stabilizers as Undergraduate Control Design Projects**", IEEE transactions on power systems, vol. 19, no. 1, February 2004. pp. 144-151

[4]. "**Efficient pole-assignment method for designing stabilisers in multimachine power systems**" by S. Elangovan and CM. Lim, *IEE PROCEEDINGS, Vol. 134, Pt. C, No. 6, NOVEMBER 1987*

[5]. G.R. Bérubé, L.M. Hajagos, Members Kestrel Power Engineering Ltd. **Accelerating-Power Based Power System Stabilizers**

[6].K.R.Padiyar, "**Power system Dynamics Stability and Control**". John Wiley; Interline Publishing, 1996

[7].P. M. Anderson and A.A Fouad "**Power system control and stability**",Iowa state university Press 1977

[8].P.Kundur, "**Power system stability and control**". McGraw-Hill, New York 1994.

[9]. E.V Larsen and D.A. Swann, "**Applying Power System Stabilizers**, Parts I, I1 and III", IEEE Trans., Vol. PAS-100, June 1981, pp. 3017- 3046

[10]. A. J. Chipperfield and P. J. Fleming "**The MATLAB Genetic Algorithm Toolbox"** From IEE Colloquium on Applied Control Techniques Using MATLAB, Digest No. 1995/014, 26/01/95

[11]. S.N.Sivanandam, S.N .Deepa "**Introduction to Genetic Algorithms**".Springer-Verlag Berlin Heidelberg 2008.