Design of PSS3B for Multimachine system using GA Technique

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ABSTRACT:

The low frequency electromechanical oscillations caused by swinging generator rotors are inevitable in interconnected power systems. These oscillations limit the power transmission capability of a network and, sometimes, even cause a loss of synchronism and an eventual breakdown of the entire system, thus making the system unstable. Power system stabilizer (PSS) is used to damp out these oscillations and hence improve the stability of the system. This paper discusses the design of multimachine power system stabilizers based on Genetic Algorithm (GA) technique. A comparison is done between the GA technique and Pole placement technique to determine PSS3B stabilizer parameters. Theoretically, PSS3B perform better than the lead lag PSS. The GA is implemented on PSS3B to verify its effectiveness. A three machine theoretical system is used in the simulations. Time domain simulations are presented to show that GA based PSSs perform better than the conventional based PSS. However, the PSSs based on the evolutionary algorithm perform better than the CPSS.

Keywords- **Genetic Algorithm, PSS3B stabilizer, Stability, Low frequency oscillations.**

1. Introduction

Stability of power systems is one of the most important aspects in electric system operation. This arises from the fact that the power system must maintain frequency and voltage levels in the desired level, under any disturbance, like a sudden increase in the load, loss of one generator or switching out of a transmission line, during a fault. Since the development of interconnection of large electric power systems, there have been spontaneous system oscillations at very low frequencies in order of 0.2 to 3.0 Hz. Once started, they would continue for a long period of time. In some cases, they continue to grow, causing system separation if no adequate damping is available. Moreover, low-frequency oscillations present limitations on the power-transfer capability. To enhance system damping, the generators are equipped with power system stabilizers (PSSs) that provide supplementary feedback stabilizing signals in the excitation systems. PSSs augment the power system stability limit and extend the power-transfer capability by enhancing the system damping of low-frequency oscillations associated with the electromechanical modes [1].

Early PSS installations were based on a variety of methods to derive an input signal that was proportional to the small speed deviations characteristic of electromechanical oscillations. After years of experimentation the first practical integral-of-accelerating-power based PSS units were placed in service. PSS3B type is used to damp the oscillations. Due to the fast development of intelligent techniques application to power systems during this decade, many researchers in the field of power systems have pay much more attention to applications of these such techniques to solve the problems in power systems. Genetic algorithm (GA) is o ne kind of those techniques in the field of artificial intelligent that its basic operation is conceptually simple. It has demonstrated its ability as a powerful optimization technique for solving many difficult problems. In this paper, the major part of the proposed PSS tuning method is based on GA's. However, the main disadvantages of those works are the computational time spent by GA's which is still not satisfied and the PSS locations which must be chosen deterministically before starting the tuning procedure. The proposed method is applied to a 3- generator and 9-bus power system [3]. The results demonstrate that PSSs of the study multimachine power system can be tuned to provide satisfactory damping performance over a set of predefined contingencies.

2. System Description

Consider a 3-machine 9-bus power system with loads assumed to be represented by constant power model shown in figure 1.

For the design of the controller the dynamic equations are linearised and the system equations are given by

$$\dot{X} = [A]X + [B]u$$
$$Y = [C]X + [D]u \qquad (1)$$

2.1 Machine Parameters

D_1=D_2=D_3=10;H_1 = 23.46, H_2 = 6.4, H_3 =3.01;X_{d1}= 0.269, X_{d2} = 0.8958; X_{d3}= 1.998; X'_{d1}= 0.0608, X'_{d2}= 0.1198, X'_{d3} =0.1813;X_{q1}=X'_{q1}=0.0969,X_{q2}=X'_{q2}=0.8645,X_{q3}=X'_{q3}=1.2578;T'_{d01}=8.96, T'_{d02}=6.0, T'_{d03}=5.89;T'_{q01} = 0.31, T'_{q02} = 0.535, T'_{q03} =0.6.

2.2 Exciter Parameters

K_{A1}=K_{A2}=K_{A3}=200;
T_{A1}=T_{A2}=T_{A3}=0.05.

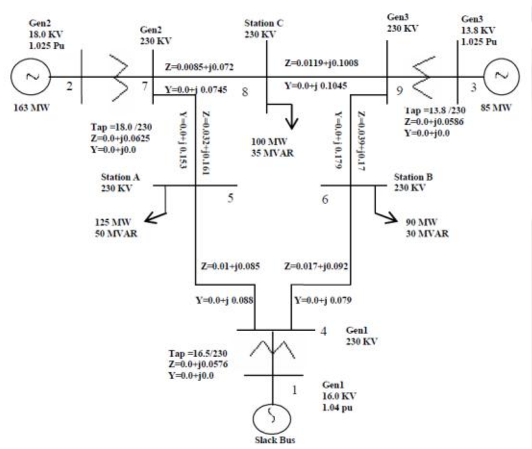

Fig 1: 3-Machine 9-Bus system

3. State-space Representation of system

The state space representation is concerned not only with input and output properties, but also with its complete internal behavior. In contrast, the transfer function representation specifies only the input/output behavior. If state-space representation of a system is known, the transfer function is uniquely defined. In this sense, the state space representation is a more complete description of the system, and it is ideally suited for the analysis of multi-variable MIMO systems. In this work, loads are modeled as constant impedances, and the network is reduced to its internal generator nodes. A generator can be expressed as classical model.

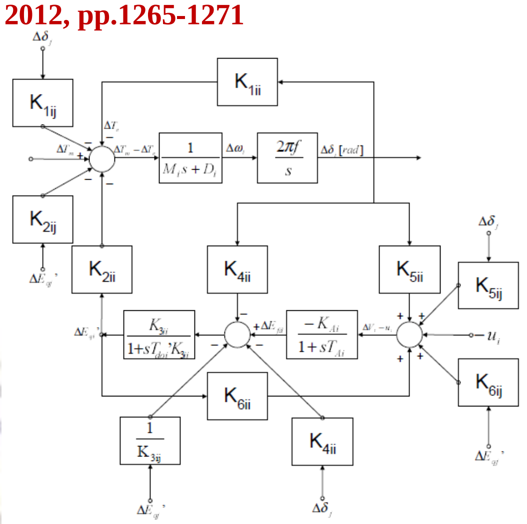

Fig 2 Transfer function block diagram representation of Multimachine system

The complete mathematical formulation of the multi-machine dynamics. Based on the transfer function block diagram (figure 2), the system dynamics can be expressed by a set of linear differential equations in the state variables $\Delta\omega_i$, $\Delta\delta_i$,$\Delta E'_{qi}$,ΔE_{fdi} as follows[2]:

$$\frac{d(\Delta\omega_i)}{dt} = -\frac{D_i}{M_i}.\Delta\omega_i - \frac{K_{1i}}{M_i}.\Delta\delta_i - \frac{K_{2i}}{M_i}.\Delta E'_{qi} + \frac{1}{M_i}.\Delta T_{mi}$$

$$\frac{d(\Delta\delta_i)}{dt} = 2.\pi.f.\Delta\omega_i$$

$$\frac{d(\Delta E'_{qi})}{dt} = -\frac{K_{4i}}{T'_{d0i}}.\Delta\delta_i - \frac{1}{T'_{d0i}.K_{3i}}.\Delta E'_{qi}$$

$$\frac{d(\Delta E_{fdi})}{dt} = \frac{K_{Ai}.K_{5i}}{T_{Ai}}.\Delta\delta - \frac{K_{Ai}.K_{6i}}{T_{Ai}}.\Delta E'_{qi} - \frac{1}{T_{Ai}}.\Delta E_{fdi} + \frac{K_{Ai}}{T_{Ai}}.u_{Ei}$$

for all i=1,2,3…..n

(2)

The expressions for the K-constants are expressed using the electrical torque expression, internal voltage equation, and from the terminal voltage relation [2].
The following A and B- matrices in the equation (2.1) are obtained from the above differential equations.

$$A=\begin{bmatrix} \frac{-D_i}{M_i} & \frac{-K_{1i}}{M_i} & \frac{-K_{2i}}{M_i} & 0 \\ 0 & 2\pi f & 0 & 0 \\ 0 & \frac{-K_{1i}}{T'_{d0i}} & \frac{-1}{K_{3i}.T'_{d0i}} & \frac{1}{T'_{d0i}} \\ 0 & \frac{K_{Ai}.K_{5i}}{T_{Ai}} & \frac{K_{Ai}.K_{6i}}{T_{Ai}} & \frac{-1}{T_{Ai}} \end{bmatrix}$$

$$B=\begin{bmatrix}0\\0\\0\\\frac{K_{Ai}}{T_{Ai}}\end{bmatrix}$$

where x(t) = $\begin{bmatrix}\Delta\omega_i & \Delta\delta_i & \Delta E'_{qi} & \Delta E_{fdi}\end{bmatrix}$

The stability characteristic of the system is dependent on the Eigen values of the state matrix A as follows [2]:

a) A real Eigen value corresponds to a non-oscillatory mode. A negative real Eigen value represents a decaying mode, while a positive real Eigen value represents a periodic instability.
b) A pair of complex Eigen value represents an oscillatory mode. The real component of the Eigen value gives the damping, and the imaginary component gives the frequency of oscillation. A negative real part represents a damped oscillation whereas a positive real part represents oscillation of increasing amplitude.

4. Design of Power System Stabilizer

4.1 Overview of PSS structures:

Shaft speed, electrical power and terminal frequency are among the commonly used input signals to the PSS. Alternative forms of PSS have been developed using these signals. This section describes the practical considerations that have influenced the development of each type of PSS as well as its advantages and limitations [4].

4.1.1 *Speed-Based (Δω) Stabilizer*

Stabilizers employing a direct measurement of shaft speed have been used successfully on hydraulic units since the mid-1960s. Among the important considerations in the design of equipment for the measurement of speed deviation is the minimization of noise caused by shaft run-out (lateral movement) and other causes Conventional filters couldnot remove such low-frequency noise without affecting the electromechanical components that were being measured. Runout compensation must be inherent to the method of measuring the speed signal. In some early applications, this was achieved by summing the outputs from several pick-ups around the shaft, a technique that was expensive and lacking in long-term reliability. The stabilizer, while damping the rotor oscillations, could reduce the damping of the lower-frequency torsional modes if adequate filtering measures were not taken. In addition to careful pickup placement at a location along the shaft where low-frequency shaft torsionals were at a minimum, electronic filters were also required in the early applications. While stabilizers based on direct measurement of shaft speed have been used on many thermal units, this type of stabilizer has several limitations. The primary disadvantage is the need to use a torsional filter. In attenuating the torsional components of the stabilizing signal, the filter also introduces a phase lag at lower frequencies. This has a destabilizing effect on the "exciter mode", thus imposing a maximum limit on the allowable stabilizer gain. In many cases, this is too restrictive and limits the overall effectiveness of the stabilizer in damping system oscillations. In addition, the stabilizer has to be custom-designed for each type of generating unit depending on its torsional characteristics. The integral-of-accelerating power-based stabilizer, referred to as the Delta-*P*-Omega (ΔPω) stabilizer throughout this section, was developed to overcome these limitations [4].

4.1.2. *Frequency-Based (Δf) Stabilizer*

Historically terminal frequency was used as the input signal for PSS applications at many locations in North America. Normally, the terminal frequency signal was used directly. In some cases, terminal voltage and current inputs were combined to generate a signal that approximates the machine's rotor speed, often referred to as "compensated" frequency. One of the advantages of the frequency signal is that it is more sensitive to modes of oscillation between large areas than to modes involving only individual units, including those between units within a power plant. Thus it seems possible to obtain greater damping contributions to these "inter-area" modes of oscillation than would be obtainable with the speed input signal. Frequency signals measured at the terminals of thermal units contain torsional components. Hence, it is necessary to filter torsional modes when used with steam turbine units. In this respect frequency-based stabilizers have the same limitations as the speed-based units. Phase shifts in the ac voltage, resulting from changes in power system configuration, produce large frequency transients that are then transferred to the generator's field voltage and output quantities. In addition, the frequency signal often contains power system noise caused by large industrial loads such as arc furnaces [4].

4.1.3 Power-Based (ΔP) Stabilizer

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:

$$\frac{\partial}{\partial t}\Delta\omega = \frac{1}{2H}(\Delta P_m - \Delta P_e) \qquad (3)$$

where
H = inertia constant
ΔPm = change in mechanical power input
ΔPe = change in electric power output
Δω = speed deviation

If mechanical power variations are ignored, this equation implies that a signal proportional to shaft acceleration (i.e. one that leads speed changes by 90°) is available from a scaled measurement of electrical power. This principle was used as the basis for many early stabilizer designs. In combination with both high-pass and low-pass filtering, the stabilizing signal derived

in this manner could provide pure damping torque at exactly one electromechanical frequency.
This design suffers from two major disadvantages. First, it cannot be set to provide a pure damping contribution at more than one frequency and therefore for units affected by both local and inter-area modes a compromise is required. The second limitation is that an un-wanted stabilizer output is produced whenever mechanical power changes occur. This severely limits the gain and output limits that can be used with these units. Even modest loading and unloading rates produce large terminal voltage and reactive power variations unless stabilizer gain is severely limited. Many power-based stabilizers are still in operation although they are rapidly being replaced by units based on the integral of accelerating power design.

4.1.4 Integral-of-Accelerating Power (ΔPω) Stabilizer

The limitations inherent in the other stabilizer designs led to the development of stabilizers that measure the accelerating power of the generator. The earliest systems combined an electrical power measurement with a derived mechanical power measurement to produce the required quantity. On hydroelectric units this involved processing a gate position measurement through a simulator that represented turbine and water column dynamics [10]. For thermal units a complex system that measured the contribution of the various turbine sections was necessary [4]. Due to the complexity of the design, and the need for customization at each location, a new method of indirectly deriving the accelerating power was developed. The operation of this design of stabilizer is described in th following section.

4.2 PSS3B structure and design

The principle of this stabilizer is illustrated by the following equation that shows how a signal proportional to rotor speed deviation can be derived from accelerating power [5].

$$\Delta\omega_{eq} = \frac{1}{2H}\int(\Delta P_m - \Delta P_e)dt \qquad (4)$$

The objective is to derive $\Delta\omega_{eq}$ so that it does not contain torsional modes. Torsional components are inherently attenuated in the integral of ΔP_e signal. The problem is to measure the integral of ΔP_m free of torsional modes. In many applications, the component ΔP_m is neglected. This is satisfactory, except when changing loads on the unit and other system conditions when the mechanical power changes.Under such conditions, a spurious stabilizer output is produced if ΔP_e, alone os used as the stabilizing signal. This in turn results in transient oscillations in voltage and reactive power. The integral of mechanical power is related to shaft speed and electrical power as follows [5]:

$$\int \Delta P_m\, dt = M\Delta\boldsymbol{\omega} + \int \Delta P_1 \qquad (5)$$

The delta P-omega stabilizer makes use of the above relationship to simulate a signal proportional to the integral of mechanical power change by adding signals proportional to shaft-speed change and integral of electrical power change [5].

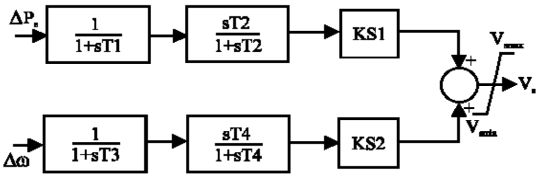

Fig 3 IEEE type PSS3B

This signal will contain torsional oscillations unless a filter is used. Because mechanical power changes are relatively slow even for fast valve movements, the derived integral of the mechanical power signal can be conditioned with a simple low-pass filter to remove torsional frequencies.
The overall transfer function for deriving the equivalent rotor speed deviation signal from shaft speed and electrical power measurements is given by:

$$\Delta\omega_{eq} = -\frac{\Delta P_e(s)}{2Hs} + G(s)\left[\frac{\Delta P_e(s)}{2H(s)} + \Delta\omega(s)\right] \qquad (6)$$

where, G(s) is the transfer function of the torsional filter.
The delta-P-omega PSS has two major advantages over the delta-omega PSS.

The ΔP_e signal has a high degree of torsional attenuation and hence, there is generally no need for a torsional filter in the main stabilizing path. This eliminates the exciter mode stability problem, thereby permitting higher stabilizer gain which results in better damping of system oscillations.

An end-of-shaft speed sensing arrangement can be used. This allows the use of a standard design for all units irrespective of their torsional characteristics. There are dual input type stabilizers PSS3B.
The state matrix of the system including PSS3B
A=

$$\begin{bmatrix}
\frac{-D_i}{M_i} & \frac{-K_{1i}}{M_i} & \frac{-K_{2i}}{M_i} & 0 & 0 & 0 & 0 & 0 \\
2\pi f & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \frac{-K_{1i}}{T'_{d0i}} & \frac{-1}{K_{3i}.T'_{d0i}} & \frac{1}{T'_{d0i}} & 0 & 0 & 0 & 0 \\
0 & \frac{K_{Ai}.K_{5i}}{T_{Ai}} & \frac{K_{Ai}.K_{6i}}{T_{Ai}} & \frac{-1}{T_{Ai}} & 0 & \frac{-K_A}{T_A} & 0 & \frac{-K_A}{T_A} \\
\omega_i K_{1i} K_{s1} & \frac{-K_{1i}K_{4i}K_{s1}}{T'_{d0i}} & \frac{-K_{2i}K_{s1}}{K_{3i}.T'_{d0i}} & \frac{-K_{s1}K_2}{T'_{d0}} & \frac{-1}{T_w} & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \frac{1}{T_1} & \frac{-1}{T_1} & 0 & 0 \\
0 & \frac{-K_{1i}K_{s2}}{M_i} & \frac{-K_{2i}K_{s2}}{M_i} & 0 & 0 & 0 & \frac{-1}{T_\omega} & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{T_2} & \frac{-1}{T_2}
\end{bmatrix}$$

Where $x(t) = [\Delta\omega_i \quad \Delta\delta_i \quad \Delta E'_{qi} \quad \Delta E_{fdi} \quad \Delta V_1 \quad \Delta V_2 \quad \Delta V_3 \quad \Delta V_4]$

5. Optimum Parameters Tuning Techniques

5.1 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. The system must be considered controllable in order to implement this method [8]. The required stabiliser parameters can be computed using the pole placement technique.

5.2 Genetic Algorithm

5.2.1 Introduction

Genetic Algorithms are general purpose optimization techniques based on principles inspired from the biological evolution using metaphors of mechanisms such as natural selection, genetic recombination and survival of the fittest. They are member of a wider population of algorithm, Evolutionary Algorithms. The idea of evolutionary computing was introduced in the year 1960 by I.Rechenberg in his work "Evolution strategies" ("Evolutions strategy", in original). His idea was then developed by other researchers. Genetic Algorithm was invented by John Holland and thereafter numbers of his students and other researchers have contributed in developing this field. With the advent of the GA, many non-linear, large-scale combinatorial optimization problems in power systems have been resolved using the genetic computing scheme. The GA is a stochastic search or optimization procedure based on the mechanics of natural selection and natural genetics. The GA requires only a binary representation of the decision variables to perform the genetic operations, i.e., selection; crossover and mutation. Fig 4 shows the binary representation of decision variables to perform the genetic operations [13].

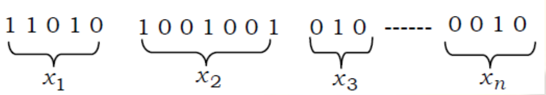

Fig 4 Binary representation of decision variables

5.2.2 Biological Background

All living organisms consist of number of cells. Each cell consists of same set of chromosomes. Chromosomes are strings of DNA and serves as a model for the whole organism. A chromosome's characteristic is determined by the genes. Each gene has several forms or alternatives which are called alleles, producing differences in the set of characteristics associated with that gene. The set of chromosome which defines a phenotype (individual) with certain fitness is called the genotype. The fitness of an organism is measured by success of the organism in its life. According to Darwinian Theory the highly fit individuals are given opportunities to reproduce whereas the least fit members of the population are less likely to get selected for reproduction and so "die out" [13].

5.2.3 Working mechanism of GA

In nature, a combination of natural selection and procreation permits the development of living species that are highly adapted to their environments. GA is an algorithm that operates on a similar principle. When applied to a problem the standard genetic algorithm proceeds as follows: an initial population of individuals (represented by chromosomes) 'n' is generated at random. At every evolutionary step, called as generation, the individuals in the current population are decoded and evaluated according to predefined quality criterion referred to as fitness function. To form a new population (next generation), individuals are selected according to their fitness. Then some or all of the existing members of the current solution pool are replaced with the newly created members. Creation of new members is done by crossover and mutation operators [13].

5.2.3.1 Selection: According to Darwin's evolution theory the best ones should survive and create new offspring. There are many methods to select the best chromosomes, for example roulette wheel selection, rank selection, steady state selection etc. Roulette wheel selection method has been used in this work to select the chromosomes for crossover because of its simplicity and also the fitness values do not differ very much in this work [3].

Roulette wheel selection: Parents are selected according to their fitness. The better the chromosomes are, the more chancesto be selected they have. A roulette wheel (pie-chart) is considered where all chromosomes in the population are placed in according to their normalized fitness. Then a random number is generated which decides the chromosome to be selected [3].

5.2.3.2. Crossover: The main operator working on the parents is crossover, which happens for a selected pair with a crossover probability (pc). Crossover takes two individuals and cuts their chromosome strings at some randomly chosen position, to produce two "head" segments and two "tail" segments. The tail segments are then swapped over to produce two new full-length chromosomes. As a result the two offspring each inherit some genes from each parent. Crossover is not usually applied to all pairs of individuals selected for mating. A random choice is made, where the likelihood of crossover being applied is typically between 0.6 and 1.0. If the crossover is not applied, offspring's are produced simply by duplicating the parents. The crossover operation performed on two parents 'A' and 'B' is given below [13].

Parent A 0 0 0 0 0 1 0 1

5.2.3.3. Mutation: Mutation is applied to each child individually after crossover. It randomly alters each gene with a small probability (pm). Mutation provides a small amount of random search and helps ensure that no point in the search space has a zero probability of being examined. The mutation operation performed on two child strings obtained after crossover operation is given below these three operators are applied repeatedly until the off springs take over the entire population. When new solution of strings is produced, they are considered as a new generation and they totally replace the parents in order for the evolution to proceed [13].

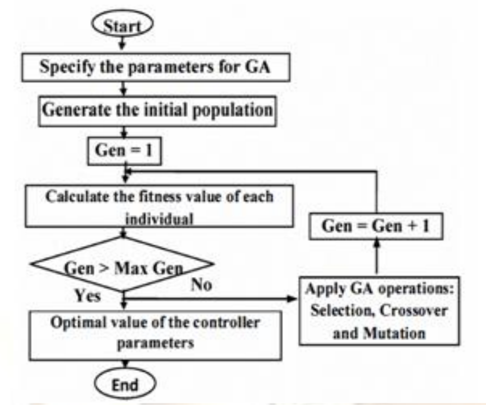

Fig 5 Flow chart of Genetic Algorithm

5.2.4 Application of GA to PSS Design
The following parameters were used in designing the PSS using GA and configured in the following way:
Chromosome representation: real
Population: 400
Generation: 200
Mutation: 0.01
$-10 \leq K_{s1} \leq 0$; $0 \leq K_{s2} \leq 10$

6. Simulation Results:

6.1 Power system output without installing PSS

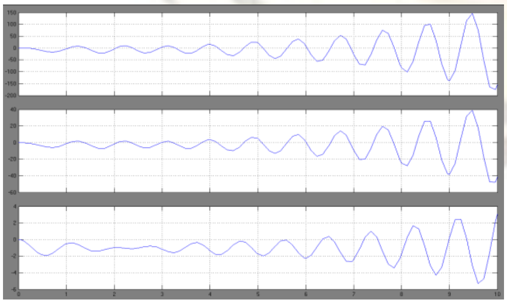

Figure 6 Rotor angle variations w.r.t time

6.2 PSS parameters determined using pole placement technique

When PSS installed at machine 1

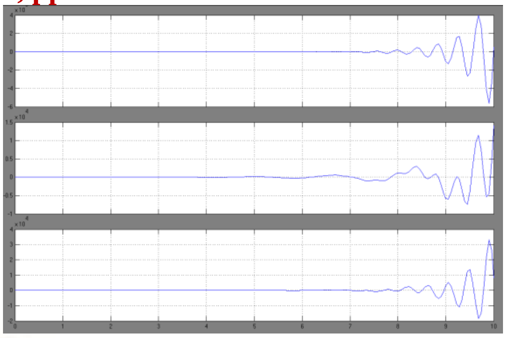

Fig 7 Rotor angle variations w.r.t time

When PSS installed at machine 2

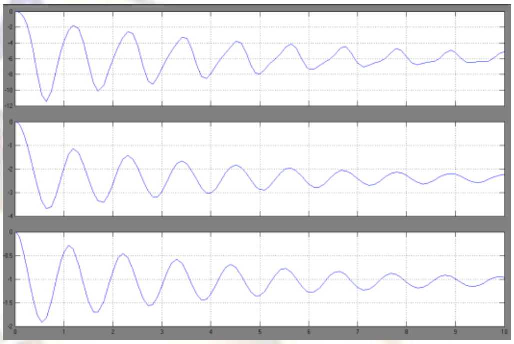

Figure 8 Rotor angle variations w.r.t time

When PSS installed at machine 3

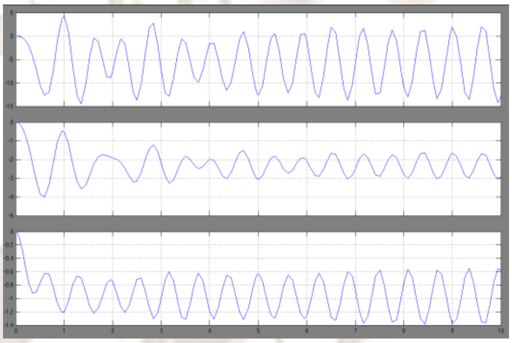

Figure 9 Rotor angle variations w.r.t time

6.2 PSS parameters determined using GA technique

When PSS installed at machine 1

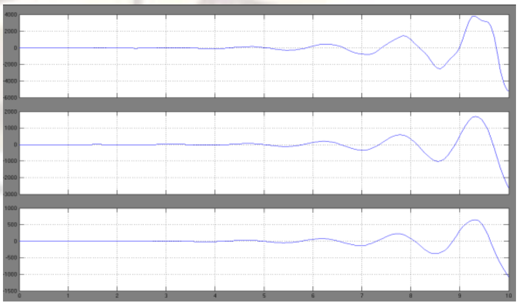

Figure 10 Rotor angle variations w.r.t time

When PSS installed at machine2

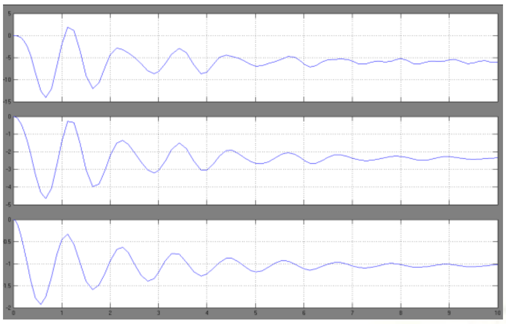

Figure 11 Rotor angle variations w.r.t time

When PSS installed at machine 3

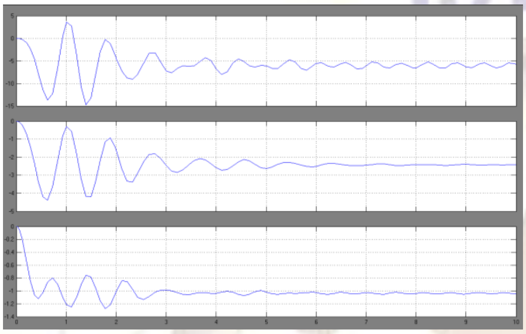

Figure 12 Rotor angle variations w.r.t time

Settling Time (sec):

Table 1 Settling Time (sec)

	Pole placement Technique	GA Technique
Machine 1	17.8	8
Machine 2	18	6.7
Machine 3	17.72	7

7. Conclusion

Application of the proposed PSS 3B type stabilizer to multimachine power system has shown its effectiveness in enhancing the damping characteristics of the power system low frequency oscillations. The proposed Genetic Algorithm technique has shown better performance than that of pole placement technique. GA technique is proven to be more attractive as a valid tool in tuning existing PSS in system when compared to pole placement technique. Dynamic simulations were carried out using 3-generator and 9-bus Power system model to validate the proposed techniques for tuning the PSS parameters. Time domain simulations show that the oscillations of synchronous machine can be quickly and effectively damped for power system with proposed PSS.

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