Decentralized Power System Stabilizer Design in Multimachine Power Networks Using Genetic Algorithm

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Abstract: - The paper considers simultaneous and tuning of power system stabilizers for stabilization of power systems over a wide range of operating conditions using genetic algorithm. The power system operating at various conditions is considered as a finite set of plants. The problem of setting parameters of power system stabilizers is converted as a simple optimization problem that is solved by a genetic algorithm and an eigenvalue-based objective function. A single machine –infinite bus system and a multi-machine system are considered to test the suggested technique. The optimum placement and tuning of parameters of PSSs are done simultaneously. A PSS tuned using this procedure is robust at different operating conditions and structure changes of the system.

Key-Words: - Power System stabilizer, Genetic Algorithm, Multimachine, Decentralized Control

1. Introduction

Much effort has been invested in recent years, in the development of power system stabilizers (PSSs) for improving the damping performance of power systems. The requirement for improved damping has arisen from a number of factors, including the development of high speed excitation systems, the use of long high-voltage transmission lines, and improvements in the cooling of turbo-alternators [9, 4]. The application of genetic algorithm (GA) has recently attracted the attention of researchers in the control area [2, 7, 8]. Genetic algorithms can provide powerful tools for optimization. In this work the structure of PSS is imposed and search is done on the parameters of the PSS by GA. The use of high-speed excitation systems has long been recognized as an effective method of increasing stability limits. Static excitation systems appear to offer the practical ultimate in high-speed performance thereby providing a gain in stability limits. Unfortunately, the high speed and gains that give them this capability also result in poor system damping under certain conditions of loading [6]. To offset this effect and to improve the system damping, stabilizing signals are introduced in the excitation systems through fixed parameters lead/lag PSSs [9]. The parameters of the PSS are normally fixed at certain values which are determined under a particular operating condition. It is important to recognize that machine parameters change with loading, making the dynamic behavior of the machine quite different at different operating points [1]. So a set of PSS parameters that stabilizes the system under a certain operating condition may no longer yield good results when there is a change in the operating point. In daily operation of a power system, the operating condition changes as a result of load changes. The power system under various loading conditions can be considered as a finite number of plants. The parameters of the PSS that can stabilize this set of plants can be determined offline using a genetic algorithm and an objective function based on the system eigenvalue. Genetic algorithms are used as parameter search techniques, which utilize the genetic operators to find near optimal solutions. The advantage of the GA technique is that it is independent of the complexity of the performance index considered. The PSS designed in this manner will perform well under various loading conditions and stability of the system is guaranteed. However, the conventional PSS will only perform well at one operating point. The system to be studied is:

A. A single machine connected to an infinite bus through a transmission line.

B. A three machines system. Two kinds of PSS are considered. Derivative type power stabilizer and lead speed stabilizer with washout filter.

2. System Model

The system that described before is shown in fig.1. The synchronous machine is described by Heffron-Philips model. The relations in the block diagram when using derivative power stabilizer is shown in figure 2 apply to two-axis machine representation with a field circuit in the direct axis but without damper windings. The interaction between the speed and voltage control equations of the machine is expressed in terms of six constants K_1-K_6. These constants with the exception of K_3 which is only a function of the ratio of the impedance depend on the actual real and reactive power loading as well as the excitation system in the machine [5].

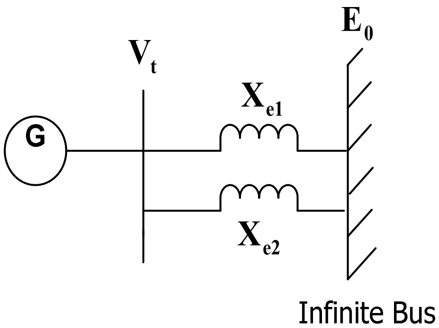

Fig. 1. Single machine connected to infinite bus

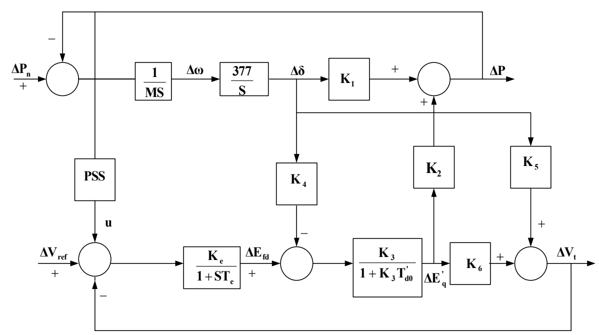

Fig. 2. System block diagram

The equations describing the steady-state operation of synchronous generator connected to an infinite bus through an external reactance can be linearized about any particular operating point as follows:

$$\Delta P_m - \Delta P = Md^2\Delta\delta / dt^2 \qquad (1)$$

$$\Delta \mathrm{P} = \mathrm{K}_1\Delta\delta + \mathrm{K}_2\Delta \mathrm{E}'q \qquad (2)$$

$$\Delta E'q = \frac{K_3\Delta E_{fd}}{(1+ST'_{do}K_3)} - \frac{K_3K_4\Delta\delta}{(1+ST'_{do}K_3)} \qquad (3)$$

$$\Delta V_t = K_5\Delta\delta + K_6\Delta E'q \qquad (4)$$

The constants K_1-K_6 are given in section 5. The system parameters are as follow:

A: Machine Parameters (pu):

$$x_d = 1.6;\ x'_d = 0.32;\ x_q = 1.55$$
$$v_{t0} = 1.0;\ \omega_0 = 120\pi\ rad/\sec;\ T'_{do} = 6\,\mathrm{se} \qquad (5)$$
$$D = 0.0,\ M = 10.0$$

B: Transmission line (pu)

$$r_e = 0.0,\quad x_{e1} = x_{e2} = 0.4, \qquad (6)$$
$$x_e = x_{e1} \| x_{e2} = 0.2$$

C: Exciter

$$K_e = 50,\ T_e = 0.05Sec \qquad (7)$$

D: Loading (pu)

$$P = (0.1,0.2,...,1); Q = (-0.2,-0.1,...,1) \qquad (8)$$

The stabilizing signal considered is:

A: proportional to electrical power and a derivative-type power stabilizer with the transfer function given by:

$$G_s(S) = K\frac{S}{(S+\frac{1}{T})^2} \qquad (9)$$

Where K and T are the PSS parameters to be selected proportional to speed of rotor and a lead stabilizer and washout filter with the transfer function given by:

$$G_s(S) = K_c\frac{ST}{1+ST}\frac{(1+ST_1)}{(1+ST_2)} \qquad (10)$$

Where K_c, T_1 and T_2 are the PSS parameters to be selected. The washout time constant T is considered 2 seconds.

3. Fitness Function

The problem of tuning the parameters of a single PSS for different operating points means that PSS must stabilize the family of N plants:

$$\dot{x}(t) = A_k x(t) + B_k u(t),\ k = 1,2,...,N \qquad (11)$$

Where $x(t) \in R^n$ is the state vector and $u(t)$ is the stabilizing signal. A necessary and sufficient condition for the set of plants in equation (12) to be simultaneously stabilizable with stabilizing signal is that eigenvalue of the closed-loop system lie in the left- hand side of the complex s-plane. This condition motivates the following approach for determining the parameters *K* and *T* of the PSS:

Selection of *K* and *T* to minimize the following objective function:

$$J = \max \mathrm{Re}(\lambda_{k,l}), k = 1,...,N, l = 1,...,N \qquad \mathbf{(12)}$$

Where $\lambda_{k,l}$ is the *l*th closed-loop eigenvalue of the *k*th plant, subject to the constraints that $K<a$ and $T<b$ for appropriate prespecified constant *a* and *b*. clearly if a solution is found such that $J<0$, then the resulting *K* and *T* stabilize the collecting of plants. The existence of a solution is verified numerically by minimizing *J*. The optimization problem is easily and accurately solved using genetic algorithms.

4. Genetic Algorithm

Genetic algorithms (GA) have been used to solve difficult problems with objective functions that do not possess well properties such as continuity, differentiability, etc., these algorithms maintain and manipulate a population of solutions and implement the principle of survival of the fittest in their search to produce better and better approximations to a solution. This provides an implicit as well as explicit parallelism that allows for the exploitation of several promising areas of the solution space at the same time. The implicit parallelism is due to the schema theory developed by Holland, while the explicit parallelism arises from the manipulation of a population of points. The power of the Genetic Algorithms (GA) comes from the mechanism of evolution, which allows searching through a huge number of possibilities for solutions.

5 Simulation Results

A…Unstabilized system (u=0)

Without any stabilizing signal, the system equation can be expressed in the following state variable form:

$$\dot{x}(t) = Ax(t) \qquad \mathbf{(13)}$$

Where *x(t)*, the state vector, is given by

$$x = [\Delta\delta \quad \Delta\omega \quad \Delta E_q^{'} \quad \Delta E_{fd}]^T \qquad \mathbf{(14)}$$

The system matrix *A* is given by

$$A = \begin{bmatrix} 0 & \omega_0 & 0 & 0 \\ \frac{-K_1}{M} & 0 & \frac{-K_2}{M} & 0 \\ \frac{-K_4}{T_{do}^{'}} & 0 & \frac{-1}{K_3 T_{do}^{'}} & \frac{1}{T_{do}^{'}} \\ \frac{-K_e K_5}{T_e} & 0 & \frac{-K_e K_6}{T_e} & \frac{-1}{T_e} \end{bmatrix} \qquad \mathbf{(15)}$$

By varying *P* and/or *Q* to cover a wide range of system loading, the parameters K_1 to K_6 are computed. Then for every *P* and *Q* combination, the eigenvalues of the system are calculated.

B Stabilized system

B.1. With the power stabilizing signal activated the order of the system increases to six. In this case

$$u = \frac{K_1\Delta\delta + K_2\Delta E_q^{'}}{(S + \frac{1}{T})^2} \qquad \mathbf{(16)}$$

The state vector is given by

$$x = [\Delta\delta \quad \Delta\omega \quad \Delta E_q^{'} \quad \Delta v_1 \quad \Delta v_2]^T \qquad \mathbf{(17)}$$

Where Δv_1 and Δv_2 are auxiliary state variables. The closed-loop system matrix is given by equation (18). To stabilize the system over all changes of loading, the genetic algorithm is used. It is called genitor algorithm [4]. To calculate the objective function as given by equation 13, the eigenvalues of the system matrix *A* are computed for a selected set of grid points in the real-power/reactive power domain for each of the members of the current population. The values of the objective functions thus obtained are fed to the GA in order to produce the next generation of chromosomes. The procedure is repeated until the population has converged to some minimum value of objective function producing the optimal parameter set. The following GA parameters were used in this case: Population size=100, Length of each chromosome=48, Maximum number of generation=320, Crossover probability: 0.9, Mutation probability: 0.001. The optimum values of the PSS parameters were found to be K=7.4712, T=0.3104, J=-0.4137. These values of K and T ensure that eigenvalues corresponding to the operating points, are located in the left-hand side of the complex s-plane for the entire loading range, in fact to the left of the line S=-0.4137 as evident from the value of the objective function.

$$A = \begin{bmatrix} 0 & \omega_0 & 0 & 0 & 0 & 0 \\ -\frac{K_1}{M} & 0 & -\frac{K_2}{M} & 0 & 0 & 0 \\ -\frac{K_4}{T_{do}^{'}} & 0 & -\frac{1}{K_3 T_{do}^{'}} & \frac{1}{T_{do}^{'}} & 0 & 0 \\ -\frac{K_e K_5}{T_e} & 0 & \frac{K_e K_6}{T_e} & -\frac{1}{T_e} & 0 & -\frac{K_e}{T_e} \\ K_1 K & 0 & K_2 K & 0 & -\frac{1}{T} & 0 \\ K_1 K & 0 & K_2 K & 0 & -\frac{1}{T} & -\frac{1}{T} \end{bmatrix} \qquad \mathbf{(18)}$$

B.2. With the speed stabilizer signal the order of the system becomes 6 again. Here:

$$u = K_c \frac{ST}{1+ST}\frac{(1+ST_1)}{(1+ST_2)}\Delta\omega \quad \textbf{(19)}$$

The state vector is given by:

$$\dot{x}(t) = Ax(t),$$
$$x = [\Delta\omega \quad \Delta\delta \quad \Delta E_{fd} \quad \Delta v_1 \quad \Delta v_2]^T \quad \textbf{(20)}$$

It is worth noting that the sign of speed change is vice versa in relation to the sign of power change, so the output of speed PSS applied to the AVR reference must be opposite to power PSS. The following GA parameters were used in this case: Population size=150, Length of each chromosome=48, Maximum number of generation=350, Crossover probability: 0.96, Mutation probability: 0.001. The optimum values of the PSS parameters were found to be K_c=13.236, T_1=2.134, T_2=0.032; J=-0.5423. In order to get view of two PSS performances and effect of them some time domain simulations were done, it was tried to check the PSS performance under some critical points such as heavy duty, light duty and lead duty. Three operating points were chosen: (P=1pu, Q=-0.2pu), (P=0.1pu, Q=-0.2pu), (P=1pu, Q=0.8pu).The first point is the worse operating point of system. Tables 1, 2 and 3 show the mechanical eigenvalues of the system at different operating points with and without PSS's.

Table.1. Eigenvalues of system at P0=1pu, Q0=0.2pu, Xe=0.2pu

DEFENITION	WORST CASE EIG
Without PSS	0.0484+j7.8331
With power PSS	-0.4237+j13.2457
With speed PSS	-0.9216+j1.1256

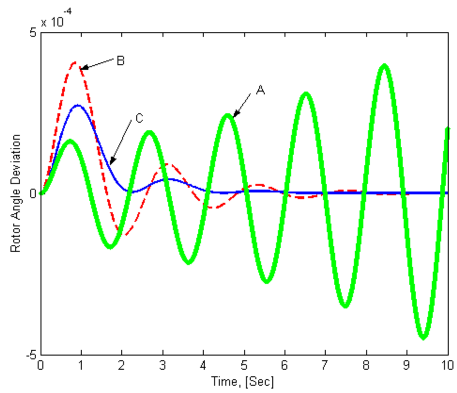

Fig.3. Rotor angle deviation of system at P=1pu, Q=-0.2pu, X_e=0.2pu, A: without PSS, B: with power input PSS, C: with speed input PSS

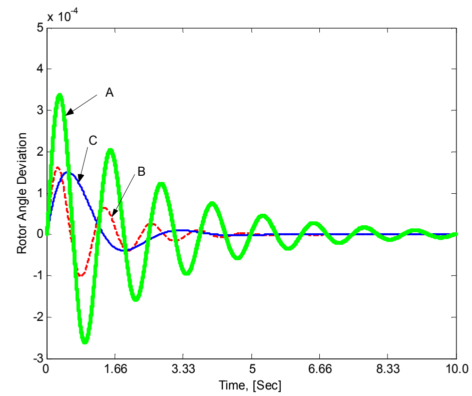

Fig.4. Rotor angle deviation of system at P=0.1pu, Q=-0.2pu, X_e=0.2pu, A: without PSS, B: with power input PSS, C: with speed input PSS

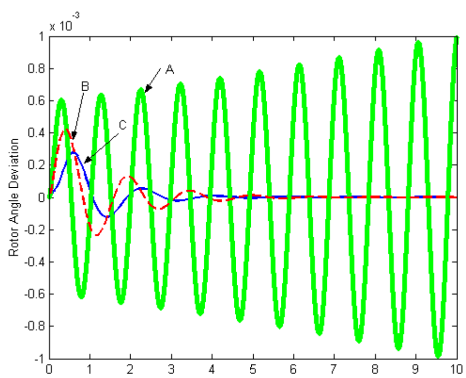

Fig.5. Rotor angle deviation of system at P=1pu, Q=0.8pu, X_e=0.2pu, A: without PSS, B: with power input PSS, C: with speed input PSS PSS

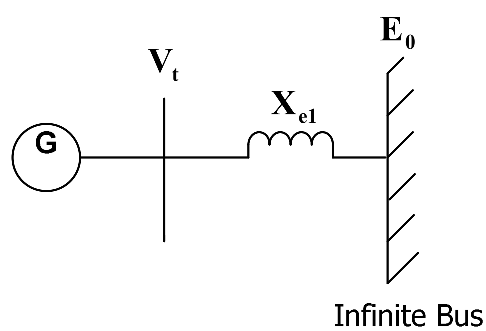

Fig.6. System after cut off one tie line

For test of system at first and second operating points an impulse input of reference torque by magnitude of .05pu and for third operating point an impulse input of reference voltage by magnitude of 0.1pu are applied to system as disturbances. Simulation results are shown in figures 3 to 5. It happens many times in power systems that after occurring a fault, a tie line cuts off by reclosures, this weaks the system stability and starts low frequency oscillations. During the tuning process of PSS parameters the case of cutting off one tie line was considered, Here the PSS performance is shown by time domain simulation, the operating point is chosen as (P=0.9pu; Q=-0.1pu) and it is considered that a fault occurs in the system and then clears by cutting off a tieline. Figure 6 shows the system after clearing the fault.

Table.2. Eigenvalues of system at P0=0.1pu, Q0=-0.2pu, Xe=.2pu

DEFENITION	WORST CASE EIG
Without PSS	-0.1759+j4.1871
With power PSS	-0.6338+j2.9514
With speed PSS	-0.8934+j2.1056

The simulation results in this case are shown in figure 7. It is worth noting that the suggested technique can be applied to stabilize a multimachine system. It only differs from the single machine-infinite bus case in the amount and time of computation. Meanwhile, the PSS design can be achieved using the suggested technique by considering one operating point only, i.e. N=1. To test this idea on multimachine systems and one operating point, a three machine system is considered which is shown in figure 8. Using Heffron-Philips model for multimachine systems, the K_1-K_6 matrixes are computed and the model analysis is done. Table 4 shows the mechanical eigenvalues of the system without any PSS.

Table.3. Eigenvalues of system at P0=1pu, Q0=0.8pu, Xe=0.2pu

DEFENITION	WORST CASE EIG
Without PSS	0.0120+j7.3691
With power PSS	-1.5427+j11.1238
With speed PSS	-1.6738+j2.3547

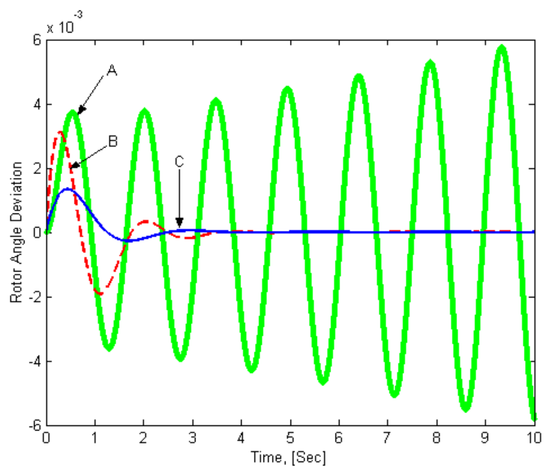

Fig.7. Rotor angle deviation of system at P=0.9pu,Q=-0.1pu, X_e=0.4pu, A: without PSS, B: with power input PSS, C: with speed input PSS

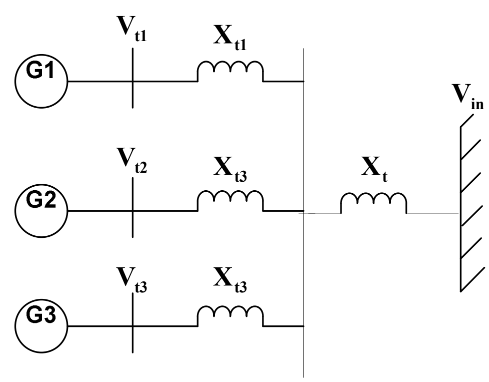

Fig.8. A three machine test system

It is clear that eigenvalues 5 and 6 have a very poor damping. To give a sufficient damping to this system, it is tried to tune the parameters of 3 power input stabilizers each mounted on one generator by help of genetic algorithm, for each PSS 2 parameters must be tuned. The following GA parameters were used in this case: Population size=150, Length of each chromosome=48, Maximum number of generation=350, Crossover probability: 1.0, Mutation probability: 0.003.

Table 5 shows the eigenvalues of system after tuning and installing of PSS's. The simulation results are shown in figure 9.

Table.4. Mechanical eigenvalues of system without PSS design

Number	Mechanical eigenvalues of system without PSS's
1,2	-1.9867+j12.3417;-1.9867-j12.3417
3,4	-4.6712+j8.9615; -4.6712-j8.9615
5,6	-0.1012+j9.0142; -0.1012-j9.0142

The suggested technique not only tunes the parameters of PSSs but also finds the optimum location for mounting of PSSs simultaneously and is more effective than SPE method [5,6] which depends on operating point and considered placement of PSSs and tuning of parameters individually.

Table.5. Mechanical eigenvalues of system without PSS design

Number	Mechanical eigenvalues of system after installation of PSS's
1,2	-0.7218+j3.1467,-0.7218- j3.1467
3,4	-0.7632+j5.8716, -0.7632-j5.8716
5,6	-0.9114+j2.7154, -0.9114-j2.7154

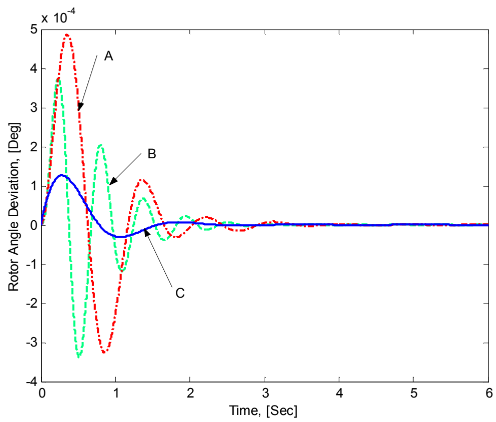

Figure 9: Rotor angle deviation of three machine system in existence of PSS's,
A: Rotor angle of machine 1, B: rotor angle of machine 2,
C: rotor angle of machine 3

6. Conclusion

The coordinated placement and tuning of decentralized power system stabilizers over a wide range of operating condition was investigated. The power system operating at various loading is treated as a finite set of plants .The problem of selecting the parameters of a PSS which stabilizes this set of plants has been converted to a simple optimization problem solved by GA and an eigenvalue based objective function. A single machine-infinite bus system demonstrated the suggested technique. It was shown that it is possible to select a single set of the PSS parameters to ensure the stabilization of the system for the entire loading range. The suggested technique was also applied on a multi-machine system, the results of time domain simulation showed that the designed PSSs have good performance in the system and work coordinately. It is clear that if the results of genetic algorithm lead to a very small K_i (the gain of PSS for ith machine) it means that the PSS shall not be mounted on ith generator, and simultaneous placement and tuning of power system stabilizers is achieved. For the speed input PSS, at least *m* parameters must be optimized more than power input PSS and the computation time increases in this case and the optimization problem may not converge. By analyzing behavior of system when different PSSs exist, it is understood that either power PSS or speed PSS have special advantages and disadvantages so the use of a combined PSS using both power and speed signals as input is recommended.

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