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Design of Power System Stabilizer Using Particle Swarm Optimization (PSO) Technique

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***Abstract*— Modern civilization is driven mainly by electricity and hence a reliable and secure power system plays a vital role. One very important aspect of this vital system is stability. Over the years generations of power engineers studied the stability aspects and a lot of research was conducted and methods of maintaining the stability of this highly nonlinear distributed system of very high order are suggested. One of the developments over the years is use of supplementary signals to keep the system dynamically stable over a wide range of operating conditions. In power system parlance, this is called power system stabilizer (A controller). Various classical and modern control theory techniques are used to design power system stabilizers. This work address the problem of designing a power system stabilizer for a Single Machine Infinite Bus (SMIB) system. The SMIB is modelled as a fourth order system and the Power System Stabilizer (PSS) is designed using PID controller using Particle Swarm Optimization technique. The results obtained are compared with stabilizers designed using phase lead compensator and a PID controller using Ziegler-Nichols method. Comparison made for a small disturbance in the mechanical torque, for a wide range of operating conditions, to ensure robustness of the controller. The responses are generated using MATLAB-SIMULNK software.**

***Index Terms*—About four key words or phrases in alphabetical order, separated by commas.**

I. INTRODUCTION

The stability of a power system relates to synchronous machine maintaining synchronism under all conditions. Transient and dynamic stability are the major types of stabilities that are of concern to the power system engineer. Transient stability of a power system is improved by providing high gain voltage regulators and fast acting excitation system. But they have adverse effect on the dynamic stability of the system. Occurrence of electromechanical oscillations of a sustained or growing nature has been reported in large interconnected power systems, provided with high gain voltage regulators and static excitation systems. These electromechanical oscillations appear as low frequency oscillations. Due to these oscillations the power transferred on the network is reduced and they can grow in magnitude leading to systeminstability. To neutralise the adverse effects of the high gain voltage regulators and the fast acting excitation system, Power system stabilizer (PSS) are used in the auxiliary feedback path to provide supplementary damping to damp out these low frequency electromechanical oscillations of the rotor.

The basic function of power system stabilizers [2][3] is to add damping to the generator electromechanical oscillations by controlling its excitation system using auxiliary stabilizing signals. The PSS should be able to supply the required phase lead to compensate the phase lag between exciter input and electrical torque. The Conventional PSS (CPSS) transfer function, is made of gain K, T1-T4 constants for a lead compensator [4][5] and gains of Kp, Ki, Kd for a PID controller [4]. These parameters require fine tuning for any particular operating condition. As the power system is highly nonlinear and operating conditions change from time to time. It is difficult to tune the stabilizer parameters for all operating conditions. The CPSS parameters may need to be tuned from time to time. Thus, finding a set of parameters that yields adequate damping over the entire range of operating conditions needs use of optimization techniques.

PSO method [7] can be used to tune the parameters of the stabilizers, as this gives global optimum values and also the method can be easily implemented in MATLAB software.

The PID parameters (K_p, K_i, K_d) are tuned using PSO technique [1] and the resulting controller performance is simulated using Simulink, for three representative operating conditions (P=0.9 Q=0.7, P=1.0 Q=0.0, P=0.5 Q=0.5).

For comparison purposes, a lead controller and a PID controller designed using classical Ziegler-Nichols method are designed and their performance is simulated, at all the above mentioned operating conditions.

II. SINGLE MACHINE INFINITE BUS SYSTEM

A synchronous machine connected to an infinite bus through transmission line is shown in Fig.1

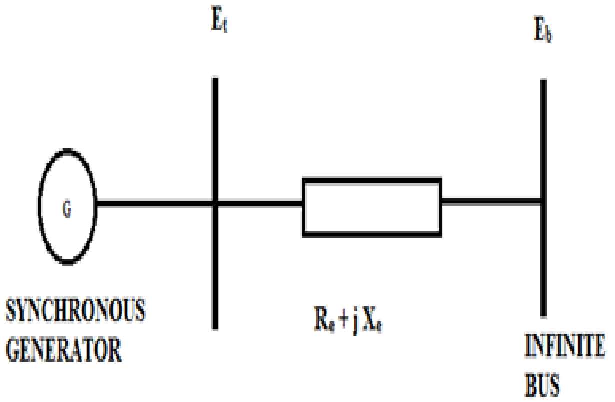

Fig.1. Single line diagram of single machine infinite bus system

The system is represented by a linear fourth order model. The model consists of six constants, K_1 to K_6 which are the functions of the operating condition, except K_3.

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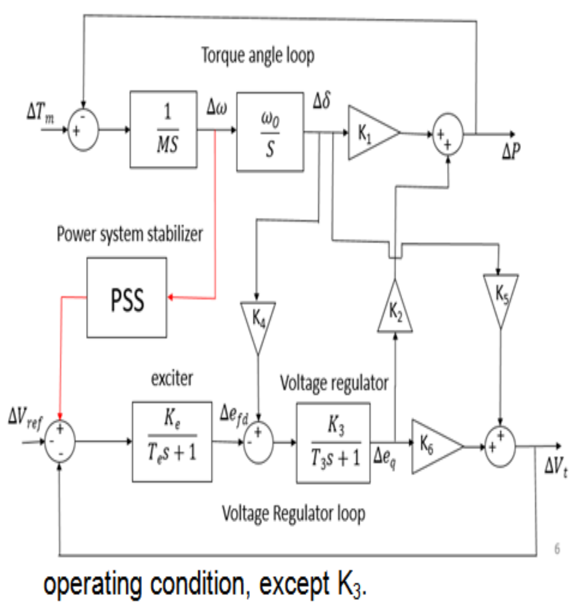

Fig.2. Block diagram of single machine infinite bus system

III. DESIGN OF THE POWER SYSTEM STABILIZER

To design power system stabilizer following methods are used

1.PID controller design using Particle Swarm Optimization (PSO) Technique [1]

2. Phase compensator design[4][5].

3. PID controller design using Ziegler-Nichols (ZN) tuning method[4][5].

3.1 PID controller design using PSO method

Particle Swarm Optimization (PSO) is a population based stochastic optimization technique. The particles travel through the problem space by following the current optimum particles and search for optimal points by updating their positions [7]

3.1.1 PSO-PSS design:

A PSO-PSS is designed to place the eigenvalues of the SMIB in the left hand side of the s-plane so that system is stable under small disturbances. The PSS design should be such that unstable poles (which are in the right hand side of the s-plane) and/or poorly stable poles (poles nearer to the imaginary axis) are shifted to optimum values, so that the system will be stable over a wide range of operating conditions.

The characteristic equation with a PID controller is placed in the system is given by

$$1.08\, S^4 + 22.1\, S^3 + (129.7+17.5K_d)\, S^2 + (718+17.5K_p)\, S + (3304+17.5K_i) = 0$$

The objective function used for the design consists of three variables (K_p, K_i, K_d) is

J= minimize {max Re (eigenvalues)}

The constraints are $0 < K_p < 50$

$0 < K_i < 50$

$0 < K_d < 10$

A MATLAB code is developed to implement the above minimization and the following parameters are used for the PSO technique are in table 1

Table 1
Parameters of PSO

Number of particles	4
Number of swarms(variables)	3(K_p, K_i, K_d)
No. iteration	1000
c1	2
c2	2
w_{max}	0.9
w_{min}	0.4
Maximum Velocity	0.05
Minimum Velocity	-0.05

The optimum values obtained are

$K_p = 29.3$

$K_i = 3.39$

$K_d = 5.93$

The transfer function of the PID controller is

$$T(s) = 29.3 + \frac{3.39}{s} + 5.93s$$

The above controller is placed in the system and the performance for a representative operating condition (P= 0.9 Q=0.7), for a small disturbance in mechanical torque is obtained using Simulink. The responses are shown in fig.6.

3.2 Phase compensator design:

The primary function of lead compensator is to provide sufficient phase lead angle to offset the excessive phase lag angle associated with the components of a system. The transfer function of lead compensator is as follows

$$T(s) = K\alpha \frac{Ts+1}{\alpha Ts+1} \quad (0 < \alpha < 1) \quad (1)$$

Where α = Attenuation factor

T = Time constant

K = Gain

In this system lead compensator using bode plot employed to compensate the phase lag between the exciter input and the electrical torque.

3.2.1 The procedure for designing a lead compensator

1. Determine the transfer function between exciter input and mechanical torque of single machine infinite bus system.
2. Plot the bode diagram for the above transfer function. From the bode diagram, observe the gain margin and phase margin. If the phase margin is above 50^0 use two lead compensators because each block compensates only 50^0.
3. Determine the value of α by using

$$\text{Sin}\ \phi = \frac{1-\alpha}{1+\alpha}$$

4. Determine the frequency where the maximum phase lead to be occurred. For that calculate geometric mean of the two corner frequencies.

i.e. $\omega_c = \frac{1}{\sqrt{\alpha}T}$

Where ω_c = geometric mean of two corner frequencies

The frequency ω_c corresponds to where the magnitude of the uncompensated system is equal to

$- 20 \log \left({}^{1}/_{\sqrt{\alpha}} \right)$.

5. Determine the zero and pole of the lead compensator as follows

Zero of lead compensator $= \frac{1}{T} = \sqrt{\alpha}\,\omega_c$

Pole of lead compensator $= \frac{1}{\alpha T} = \frac{\omega_c}{\sqrt{\alpha}}$

6. Determine the gain K of a lead compensator using

$K = \frac{2\xi\omega_c M}{|Gc|\,|Ge|}$

Where |Gc|=Magnitude of lead compensator at ω_c

|Ge|= Magnitude of uncompensated system at ω_c

$\omega_c =$ New gain cross over frequency

M = Moment of inertia

$\xi =$ Damping ratio

To find the damping ratio use the following equation

$$\xi = \frac{D}{2\sqrt{K1 * m * \omega_o}}$$

Where D = Damping coefficient

7. Finally, the transfer function of lead compensator is

$$T(s) = \frac{176\,(s+3.04)(s+3.04)}{(s+11.83)(s+11.83)}$$

After placing lead compensator into the system, the change in rotor angle for a change of 0.1pu in the mechanical torque for SMIB with lead compensatorfor a representative operating condition (P= 0.9 Q=0.7) are obtained using Simulink and are shown in Fig.4.

3.3 PID controller design using Ziegler-Nichols (ZN) tuning method

The transfer function of the PID controller is assumed as

$T_{PID}(s) = K_p + \frac{K_i}{s} + K_d s$

Procedure to obtain the values of K_p, K_i, K_d is given below [4]

1. Set all the gain values to zero.
2. Increase the value of K_p until the response becomes steady state condition
3. By placing K_p constant value, increase the value of K_d until the response obtains without oscillations.
4. By placing K_p, K_d constant value, increase the value of K_i until the response obtains with less settling time.

By following the above procedure, a PID controller parameters are obtained and the transfer function is

$T_{PID}(s) = 50 + \frac{10}{s} + 20s$

After placing the above PID controller using Ziegler-Nichols method into the system, the change in rotor angle for a change of 0.1pu in the mechanical torque for SMIB with PID controller for a representative operating condition.
(P= 0.9 Q=0.7) are obtained using Simulink and are shown in Fig.5.

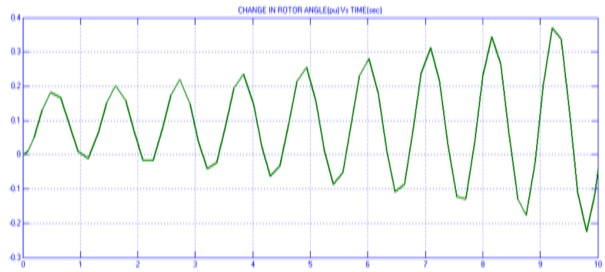

Fig.3. change in rotor angle of the rotor of SMIB

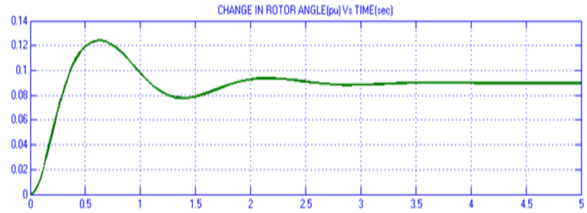

Fig.4.change in rotor angle of the rotor of SMIB with PSS (lead compensator)

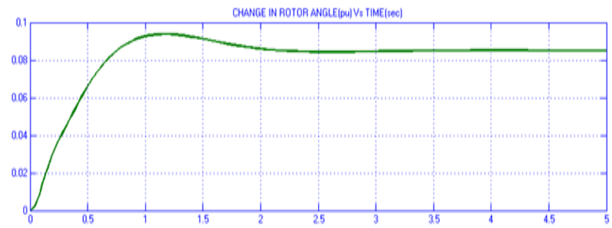

Fig.5. change in rotor angle of the rotorofSMIB with PSS (PID-ZN method)

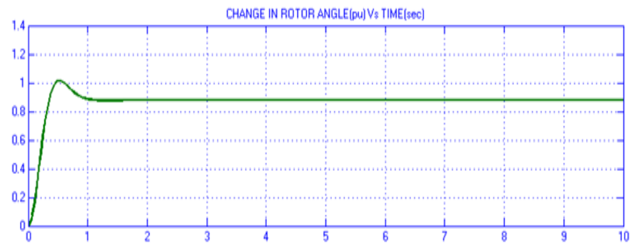

Fig.6.change in rotor angle of the rotorofSMIB with PSS (PID-PSO)

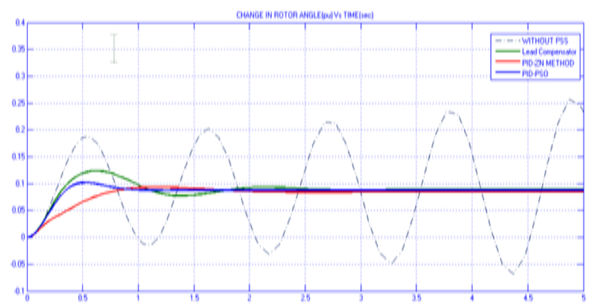

Fig.7.change in rotor angle of the rotorofSMIB with PSS (P=0.9, Q=0.7)

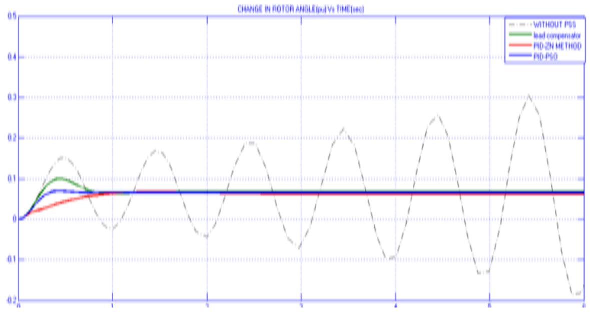

Fig.8.change in rotor angle of the rotorofSMIB with PSS(P=1.0, Q=0.0)

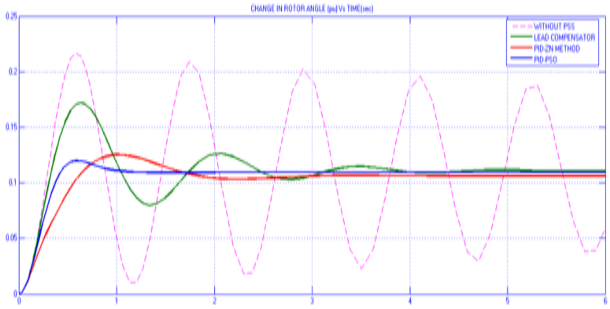

Fig.9. change in rotor angle of the rotorofSMIB with PSS(P=0.5, Q=0.5

IV. CONCLUSION

Stabilizers are used to improve the dynamic stability of power systems. It is an additional control block, used to enhance stability using feedback signals such as speed, terminal frequency and/or power. This work consists of designing a PID block whose input is the angular velocity and the output controls the excitation of the generator. The PID control block is designed using phase lead, Ziegler Nichols and particle swarm optimization methods. The performance of the controller is simulated over three different operating conditions (P=0.9 Q=0.7, P=1.0 Q=0.0, P=0.5 Q=0.5), for a small step disturbance in the mechanical torque. MATLAB-SIMULINK is used to simulate the responses for a SMIB system, which is represented as a fourth order linear model. From the plots, it can be concluded that the PID controller designed using the PSO method is a better choice, as seen from the performance graphs for change in rotor angle.

V. APPENDIX

In this work, all the above techniques are designed by the following operating condition.

- OPERATING CONDITION

P=0.9, Q=0.7, f=50 Hz.

- GENERATOR PAREMETERS

H=5, Tdo = 6sec, Xd = 1.6, Xq = 1.55,
X_d^1=0.32, W_0=314rad/sec, D=0, M=10, V_{t0}=1.05.

- EXCITER DATA

KA= 50, TA= 0.05 sec

- TRANSMISSION LINE

Xe= 0.4

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