Robust Tuning of Power System Stabilizer Using Particle Swarm Optimization For Dynamic Stability Improvement

Muhamad Haddin, Dedi Nugroho, Agus Suprajitno, Soebagio, Adi Soeprijanto, Mauridhi Hery Purnomo

***Abstract* — Power system stabilizers (PSSs) are added to excitation system to enhance the damping during low frequency oscillations. In this paper, particle swarm optimization (PSO) technique is applied to design a robust tuning power system stabilizer (PSS) for stability enhancement on a single machine power system. This tuning is done by determining the fitness function gain of PSS (K_{PSS}) by finding the minimum value of damping comprehensive index (CDI) for optimization process using PSO. Simulations are conducted by inputting step function with 5% load fluctuations as a representation of dynamic load. Simulation results show that the robust tuning of the proposed method effectively minimizes the oscillation speed of rotor, rotor angle on the open loop state with using the PSS optimized PSO are 56% and 26,6% respectively, while decreasing settling time of speed and rotor angle deviation are 48% and 56 % respectively.**

***Key words*— power system stabilizer, particle swarm optimization, dynamic stability improvement**

I. INTRODUCTION

The electric power system is a complex system with highly non-linear dynamics. Its stability depends on the operating conditions of the power system and its configuration. Low frequency oscillations are a common problem in large power systems. Excitation control or automatic voltage regulator (AVR) is well known as an effective means to improve the dynamic stability of the power system. A supplementary excitation controller referred to as power system stabilizer (PSS) have been added to synchronous generators to counteract the effect of high gain AVRs and other sources of negative damping. To provide damping, the stabilizers must produce a component of electrical torque on the rotor which is in phase with speed deviations.

The application of a PSS is to generate a supplementary stabilizing signal, which is applied to the excitation system or control loop of the generating unit to produce a positive damping. Tuning of PSS provides the appropriate characteristics of phase-lead and compensates the phase-lag between the reference input of the AVR and electrical torque oscillation frequency outside the specified range, so that the components of electrical torque in phase with the speed deviation for improved damping. The problem of PSS parameter tuning is a complex exercise. The most widely used conventional PSS is the lead-lag PSS, where the gain settings are fixed at certain value which are determined under particular operating conditions to result in optimal performance for that specific condition. However, they give poor performance under different synchronous generator loading conditions.

A number of conventional techniques have been reported in the literature pertaining to design problems of conventional power system stabilizers namely: the eigenvalue assignment, mathematical programming, gradient procedure for optimization and also the modern control theory [1]. Unfortunately, the conventional techniques are time consuming as they are iterative and require heavy computation burden and slow convergence. In addition, the search process is susceptible to be trapped in local minima and the solution obtained may not be optimal.

Most of the research on PSS parameter tuning are based on small disturbance as a representation of dynamic load that required linearization of the system involved. The development of integrated control of synchronous generator has been developed by most researchers to improve the electrical stability include in: Design of generator control with PSS and excitation has been done by multi layer perceptron (MLP) and radial basis function (RBF) [2]-[3], genetic algorithms [4], recurrent neural networks [5], fuzzy logic [6]-[7]. This paper applied the method of Particle Swarm Optimization to tuning gain of PSS in that the controller tuned to provide desired performance at small signal condition which can improve the dynamic stability of SMIB.

II. POWER SYSTEM MODEL

The power system considered in this study is modelled as a synchronous generator connected through a transmission line to infinite busbar. Equivalent circuit of a synchronous generator connected to the grid is represented as a single machine infinite bus (SMIB). A Linear model of a SMIB with PSS is shown in Figure 1. The nominal operating conditions and system parameters are given in Appendix.

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Dynamic stability of the power system is determined by the ability of generators to respond to load changes that occur are relatively small (5%). Load changes that occur suddenly and periodically can not be responded by generator so that it can affect the stability.

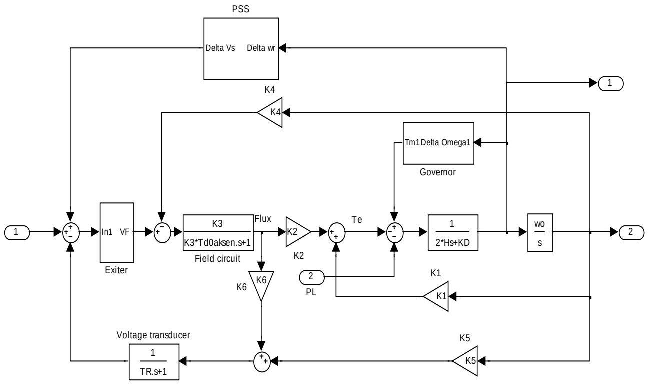

Fig. 1 Linear model of SMIB with PSS

This response causes the frequency oscillation in the long term and cause a decrease in the transfer of power to the electric power system. This problem can be covered by using additional equipment called PSS. Linear model of PSS is shown in Figure 2.

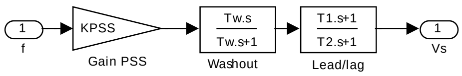

Fig.2. Structure of Power System Stabilizer

The structure consists of a sensor, a gain block with gain K_{PSS}, a signal washout block and one stage phase compensation blocks. The input signal of the proposed controller is the speed deviation (Δω), and the output is the stabilizing signal V_S which is added to the reference excitation system voltage. The signal washout block serves as a high-pass filter, with the time constant T_W, high enough to allow signals associated with oscillations in input signal to pass unchanged. The phase compensation block (time constants T_1, T_2) provides the appropriate phase-lead characteristics to compensate for the phase lag between input and the output signals.

III. PARTICLE SWARM OPTIMIZATION

Development of PSO algorithm is done based on the behavior of individuals in the particle swarm [8]. PSO algorithm searches in parallel with use of a similar group of individuals with other artificial intelligence based heuristic optimization techniques. Form of *n*-dimensional search space, position and velocity of individual *i* is represented as a vector $X_i = (x_{i1},\ldots,x_{in})$ and $V_i = (v_{i1},\ldots,v_{in})$ in the PSO algorithm. If $Pbest_i = (x_{i1}^{Pbest}, .., x_{in}^{Pbest})$ and $Gbest = (x_1^{Gbest}, ..., x_n^{Gbest})$ is individual *i* who is the current best position. Update the velocity on individual *i* is to modify the basic equation of the PSO algorithm.

$$V_i^{k+1} = wV_i^k + c_1 rand_1 (Pbest_i^k - X_i^k) + c_2 rand_2 (Pbest_i^k - X_i^k)$$
(1)

where:

V_i^k = velocity of individual *i* at *k* iteration
w = parameter of weight
c_1, c_2 = coefficient of acceleration
$rand_1$, $rand_2$ = number of random between 0and 1
X_i^k = position of individual *i* at *k* iteration
$P_{best\,i}^{\;k}$ = P_{best} individual *i* until *k* iteration
$G_{best_i}^{\;k}$ = G_{best} group until *k* iteration

In the process of updating this velocity, the values of parameters such as *w*, c_1 and c_2 should be determined in advance. Weight parameter *w* is obtained by using the following Eq.(2).

$$w = w_{\max} - \frac{w_{\max} - w_{\min}}{Iter_{\max}} xIter \qquad (2)$$

where:

w_{min}, w_{max} = weight of initial and final
$Iter_{max}$ = number of max iteration
$Iter$ = number of iteration now

While the modification of individual positions

$$X_i^{k+1} = X_i^k + V_i^{k+1}$$

(3) One of the simplest dynamical system which shows *chaotic* behavior of an iterator is called map function

$$f_k = \mu . f_{k-1} .(1 - f_{k-1}) \qquad (4)$$

where μ is the control parameter and has a real value between 0-4.

Equation (4) is obtained by a combination of inertia w*eigth and chaotic sequences* with the new value of inertia weight according to Eq.(5).

$$W = wf_k \qquad (5)$$

PSO algorithm:

1. Initialize a population of candidate solutions at random particles, i.e. the position and velocity of particles.
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2 Calculating the *fitness* value for each particle.
3. From the results of the calculation value of fitness, the best fitness known locally is the best *fitness* value for each particle and the local best position that is the best position of each particle. The current *fitness* value is compared to the previous *fitness* value. If the value is better so the change of the previous particle positions with the current position has a better *fitness* value and the fitness value becomes the reference of the next *fitness* value.
4. Finding the *global best fitness* value, namely a minimum value of the *local best fitness*.
5. Determining the *global best position*. This is obtained by replacing each candidate particle solutions with *local best position* of particles that meet the requirements of the *global best fitness*.
6. Updating the velocity and position
7. Repeating steps 2 through 6 to comply with the specified

IV. ROBUST TUNING PSS USING SWARM OPTIMIZATION

Linier modeling of SMIB equipped an PSS is represented in the Eq.(6) and (7). By using the matrix *A* of the linear model of SMIB the value of the *eigenvalue* obtained by using Eq.(8). Gain settings of PSS (K_{PSS}) is done by calculating the *eigenvalue* of the matrix *A*. The *eigenvalue* can be shifted to the negative real by finding the maximum value of damping ratio for each *eigenvalue* are possible. Search the maximum value of damping ratio equal to find the minimum value of the *comprehensive damping index* (CDI). Eq.(9) is a formula of the CDI is used as the fitness function of the particle in the optimization process. By minimizing Eq. (10), *eigenvalue* power system can be shifted to the negative real.

$$\Delta\dot{x} = \mathbf{A}\,\Delta x + \mathbf{B}\,\Delta u \quad (6)$$

$$\Delta y = \mathbf{C}\,\Delta x + \mathbf{D}\,\Delta u \quad (7)$$

$$\lambda_i = \sigma_i + j\omega_i \quad (8)$$

$$CDI = \sum_{i=1}^{n}(1-\zeta_i) \quad (9)$$

$$\zeta_i = \frac{-\sigma_i}{\sqrt{\sigma_i^2 + \omega_i^2}} \quad (10)$$

where Δx, Δy, Δu, **A, B, C, D**, λ_i, σ_i, ω_i, ζ_i are state variable, output variable, input variable, matrix system, matrix input, matrix output, *i*-th eigenvalue, real part of the *i*-th eigenvalue, real imaginer part of the *i*-th eigenvalue and damping ratio of the ***i***-th, respectively.

Parameter in the lead-lag block and washout in PSS was defined, while tuning the gain of the PSS (K_{PSS}) using the PSO. Eq. (11) showed that PSO method using CDI as fitness and gain value allowed as a delimiter in the optimization process. In addition to the values of gain, the value of damping ratio is also used as a limiting factor.

$$\min = f(z) = CDI = \sum_{i=1}^{n}(1-\zeta_i) \quad (11)$$

CDI is a function of **z**. **z** is the row matrix element which is the gain of PSS (K_{PSS}). In the *PSO* method, **z** is called the position of the particle with *d*-dimensional problem space. Optimization algorithm is shown in Figure 3.

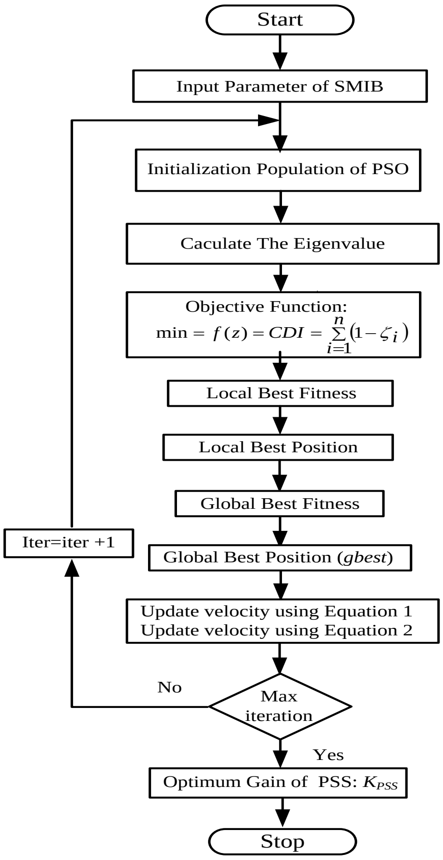

Fig.3. Flowchart of particle swarm optimization algorithm

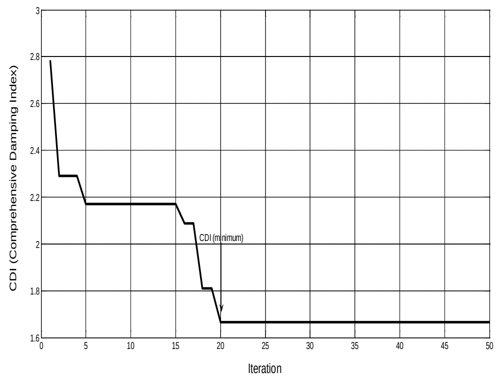

Fig.4. Graphics CDI as a function of iteration

V. RESULT AND ANALYSIS

To assess the effectiveness and robustness of the proposed controller, simulation studies are carried out for small disturbances of step increase in mechanical torque was applied at nominal operating condition. Simulation were done by Matlab/Simulink 7.1, the simulation results show the dynamic performance of the power system based on the rotor speed, rotor angle and electrical torque of the SMIB with the parameters shown in appendix.

Figure 4 shows that the global minimum of fitness particle is achieved at 20th iteration. This shows that the minimum value of the CDI can be achieved in the 20th iteration.

The dynamic responses of the proposed robust tuning PSS based PSO are compared with no power system stabilizer (without PSS) are shown in Figure 5-7.

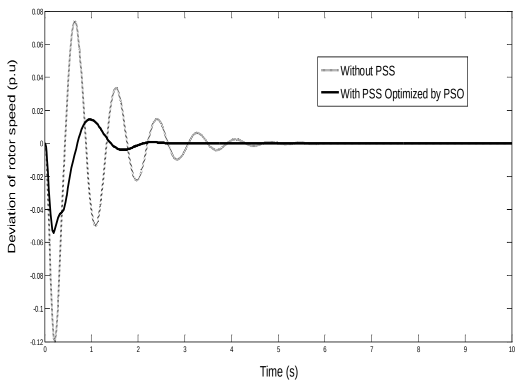

Fig.5. Response of rotor speed deviation

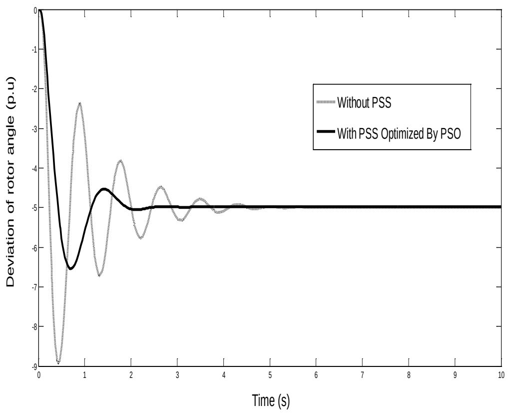

Fig.6. Response of rotor angle deviation

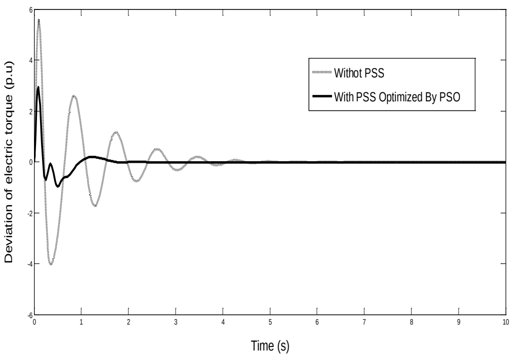

Fig.7. Response of electric torque deviation

Simulation results in Figure 5-7 showed that the gain settings of the PSS based on PSO can improve the performance or response of the deviation of rotor speed, rotor angle and electrical torque of the generator so that the resulting improvement of power system stability.

Overshoot and settling time in a state of open-loop (without PSS), setting the PSS optimized with PSO are shown in Tables 1. This suggests that the gain tuning of PSS based on MPSO able to reduce the overshoot and steady state speed up.

Table 1. Overshoot and settling time

	Overshoot (p.u)		Settling time (s)	
	Without PSS	With PSS Based PSO	Without PSS	With PSS Based PSO
$\Delta\omega$	-0.1183	-0.05248	5.077	2.227
$\Delta\delta$	-8.852	-6.493	4.609	2.397

In Table 1 are shown that the decrease of speed and rotor angle deviation overshoot on the open loop state (without PSS) with using the PSS optimized PSO are 56% and 26,6% respectively, while decreasing settling time of speed and rotor angle deviation are 48% and 56 % respectively.

VI. Conclusion

In this paper, power system stability enhancement by power system stabilizer is presented. For the proposed robust controller design problem, a non liner simulation based objective function to increase the system damping was developed. The dynamic performance of proposed tuning of PSS based PSO compared with open loop (without PSS) has shown its superiority. The non linear simulation results presented under small disturbance conditions, show the effectiveness and robustness of the proposed PSO optimized PSS controller and their ability to provide efficient damping of low frequency oscillations.

Appendix

Parameter of SMIB

K_1= 1.591	T_1 = 0,4	K_A = 400	T_A= 0,01
K_2= 1,5	T_2 = 0,3	K_{PSS} =3	R = 1
K_3=0,333	T_3 = 1,91	Tw = 0,5	X_d = 1,6
K_4= 2	T_R = 0,02	H = 3	X_c = 1,6
K_5= 0,3	Tg_1 = 0,0264	Ks = 2,191	X_E = 0,4
f_o = 50	$Tg3$= 0,15	Ki = 0,05	Td_0'=6
K_D=0	$Tg4$ = 0,594	E_{q0} = 1,05	

Parameter of PSO

Number of particle	= 20
maximum iteration	= 50
Number of dimention	= 2
C_1(Cognitive constants)	= 2,05
C_2 (Social constants)	= 2,05
w_{max}	= 0,9
w_{min}	= 0,4
μ	= 0,4
f_{k-1}	= 0,75

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