GAIN COORDINATION OF AVR-PSS AND AGC BASED ON PARTICLE SWARM OPTIMIZATION TO IMPROVE THE DYNAMIC STABILITY OF THE POWER SYSTEM

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ABSTRACT

This paper presents the coordination axis of the automatic voltage regulation (AVR)-power system stabilizer (PSS) and automatic generation control (AGC) on synchronous generator to improve the dynamic stability of the power system. The critical mode damping value is analyzed by finding the minimum value of damping comprehensive index (CDI) which is used as fitness function of particle in the process of optimization using particle swarm optimization (PSO). Four main parts of the generation system are synchronous generator, AVR/excitation, AGC and PSS modelled linearly. Generator is modelled by a single machine connected to infinite bus (SMIB) which is equipped by AVR and excitation linear model. PSS is modelled as a lead-lag component and AGC as well as the turbine governor is modelled as a linear first order with constant speed drop. Simulations are conducted by inputting step function with 5% load fluctuations as a representation of dynamic load. The simulation results show that the coordination of the proposed method effectively minimizes the oscillation speed of rotor, rotor angle and terminal voltage as showed by the damping, convergence time, over-shoot and the minimum error to reach steady state.

Key words: coordination gain of AVR-PSS-AGC, dynamic stability, PSO

1. INTRODUCTION

Additional control signal for the excitation system and governor on the generator can add extra damping and improve the performance of the power system. PSS has a very significant contribution to maintain stability of power system and improve system performance by providing additional signals to the excitation system. This is a very easy, economical, practical and flexible to improve power system stability.

The development of integrated control of synchronous generator has been developed by most researchers to improve the electrical stability include in: *Continually online trained artificial neural network (COT-ANN)* with *back propagation algorithm* to control the excitation and governor [1], [2]. Design of generator control by using a *dual heuristic programming (DHP)* and *heuristic dynamic programming (HDP)* using *multi layer perceptron neural networks (MLPN*) and *radial basis function neural networks (RBFN)* for the control of AVR and turbine governor [3]-[5], [8] with a *back propagation method*, *genetic algorithms*, *recurrent neural networks*, *fuzzy logic* and *fuzzy PID* controller for the control of PSS [6], [7], [9]-[11]. However, these studies are focused on improving stability by controlling signal on the excitation and governor. This paper applied the method of *Particle Swarm Optimization* to simultaneously coordinate settings of AVR-PSS and AGC gain by minimizing the objective function so that it will improve the dynamic power system stability.

2. METHODOLOGY

Power systems consist of electric power components that make up an integrated and connected system. Equivalent circuit of generator connected to the grid is represented as a single machine connected to infinite bus (SMIB). Configuration of SMIB through impedance is represented in Figure 1.

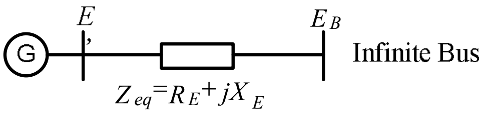

Fig.1. *Model of SMIB*

A linear model of SMIB consists of turbine, governor and excitation system is shown in Figure 2. The linear model subsystem of the governor-turbine system SMIB is shown in Figure 3. Whereas the linear model subsystem of excitation SMIB system is shown in Figure 4.

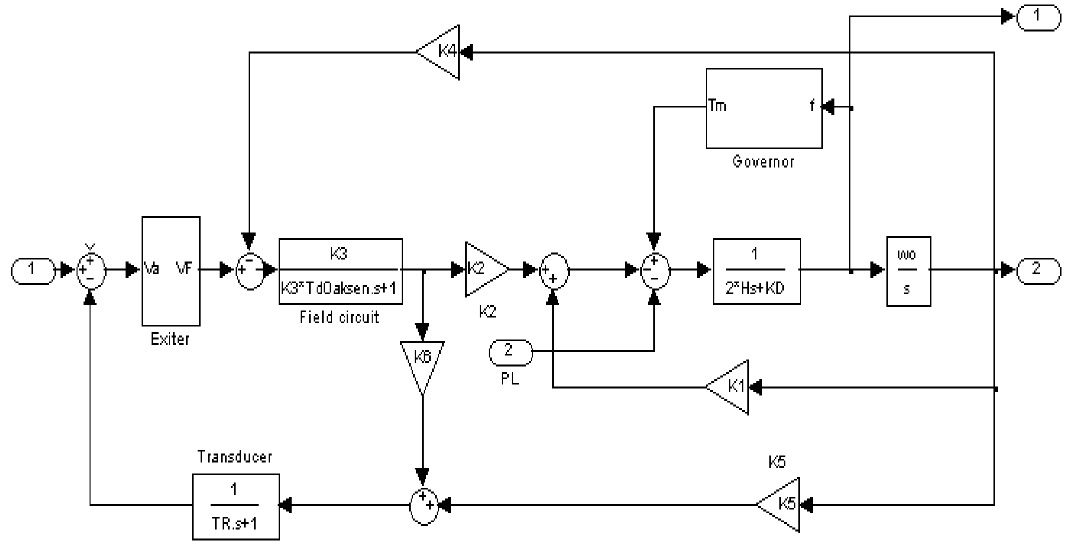

***Fig.2.** Linier Model of SMIB*

Governor-turbine systems used in the research consist of the speed drop of the governor, servomotor and reheater. Linear model of the excitation system shown in Figure 4 which consists of AVR, and exciter.

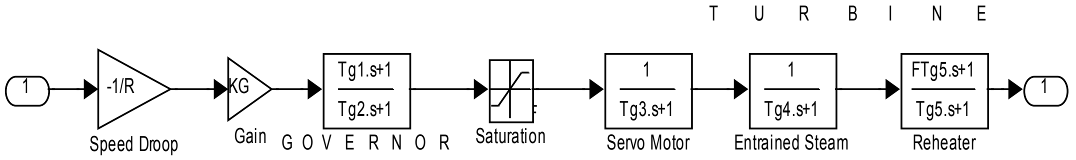

***Fig.3.** Model of Governor-turbine*

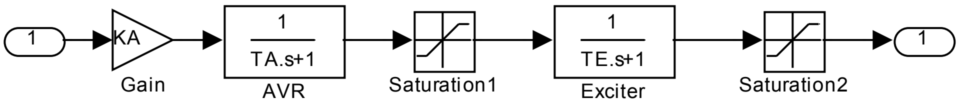

***Fig.4.** Model of excitation system*

Particle swarm Optimization

Particle swarm optimization (PSO) is a stochastic optimization technique based on a collection of population (*swarm*) and inspired by social behaviour of the movement of bird or fish to find food sources. *PSO* algorithm was first introduced by RC Eberhart and J Kennedy [12][13]. To find the optimal solution, every bird, or in this case the particle, set the search direction based on two factor, namely previous best experience (*pbest*) and the best experience of all the birds that exist in this population (*gbest*). PSO model consists of a set of particles is initialized with a population of candidate solutions at random. Particles moving through space with a *d*-dimensional problem to seek new solutions, with *fitness f*, can be calculated as a determined measuring quality. Each particle has a position represented by the vector-position x_i (*i* is the index of the particle) and speed (velocity) is represented by the vector velocity v_i. Each particle has so far resulted in the best position (*pbest*) in vector x_i^k, and the value of the *j*-th dimension is x_{ij}^k. Vector best position among the compounds (*swarm)* so far (*gbest)* is stored in a vector x^l, and the value of the *j*-th dimension is x_j^l. During this time of iteration (t), the particles update the speed of the previous speed with the new speed determined by Eq. (1). The new position is determined by the sum of the previous position and the new velocity as shown in Eq. (2).

$$v_{ij}(t+1)=wv_{ij}(t)+c_1r_1(x_{ij}^k(t)-x_{ij}(t))+c_2r_2(x_{ij}^l(t)-x_{ij}(t)) \quad (1)$$

$$x_{ij}(t+1)=x_{ij}(t)+v_{ij}(t+1) \quad (2)$$

PSO algorithm:

1. Initialization of candidate solutions in a random population of particle is position and velocity of particle.
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 iteration.

Automatic Voltage Regulator (AVR)

The main function of the AVR is to maintain the generator terminal voltage and to keep working at nominal value. Model of the AVR type depend on the injection of DC current source of excitation system. An important part of the AVR consists of amplifiers, exciter, excitation voltage limiter, generator, and transducers. The AVR transfer function is expressed as follow:

$$\frac{V_R(s)}{V_c(s)} = \frac{K_A}{1+sT_A} \tag{3}$$

where V_R *(s)*, V_C *(s)*, K_A and T_A are the output amplifier, control signal, amplifier gain and time constant interval, respectively.

Parameter values have special values between 10-400 pu and 0.02-0.1 s for the K_A and T_A, respectively. Excitation system voltage is limited by using a limiter to avoid over-excitation or under excitation. Linier model of AVR is shown in Figure 5.

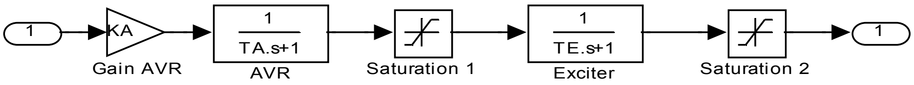

***Fig.5**. Model of AVR in excitation system*

Power System Stabilizer (PSS)

Dynamic stability of the power system determined by the ability of generators respond of dynamic load fluctuation in relatively small (5%). Load fluctuation that occurs suddenly and periodically can't be well responded by generator so that it can affect the stability of dynamical systems.

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 Power System Stabilizer (PSS). PSS can improve the dynamic stability of the system. PSS is a device that produces control signals for the excitation system. However, in a recent approach, the control signal output of the PSS is used as input to the turbine. The basic function of PSS increases stability with a set limit on the generator excitation to provide damping oscillation of the rotor on the synchronous machine. To provide damping, the PSS must produce electrical torque component on a machine that has the same phase. This method can improve the performance stability of the power system. Linear Model Power System Stabilizer (PSS) is shown in Figure 6.

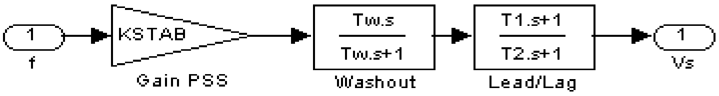

***Fig.6**. Model of Power System Stabilizer*

Automatic Generation Control (AGC)

The AGC function is to maintain or to restore frequency system to the setting range in the form of SMIB of power system model. This can be done by adding an integral controller on *load frequency control (LFC)*, which is serves as input to a reference value for the unit load governor. The AGC block diagrams are shown in Figure 7.

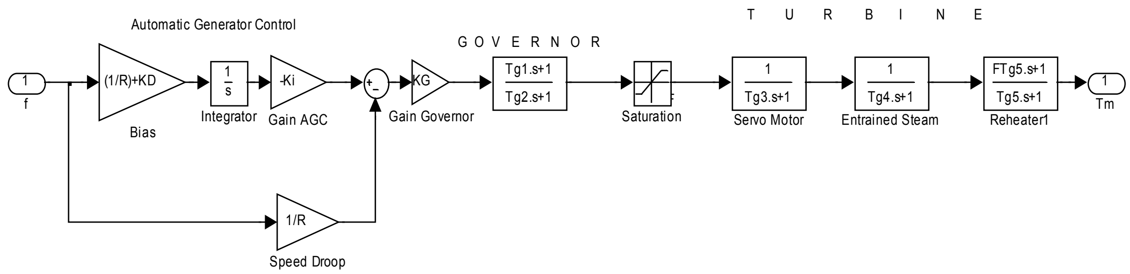

Fig.7. Governor-turbine system model equipped by AGC

The addition of the integral controller intended to set the frequency error in steady-state conditions is zero. SMIB linear model is completed by the AVR, PSS and AGC is shown in Figure 8.

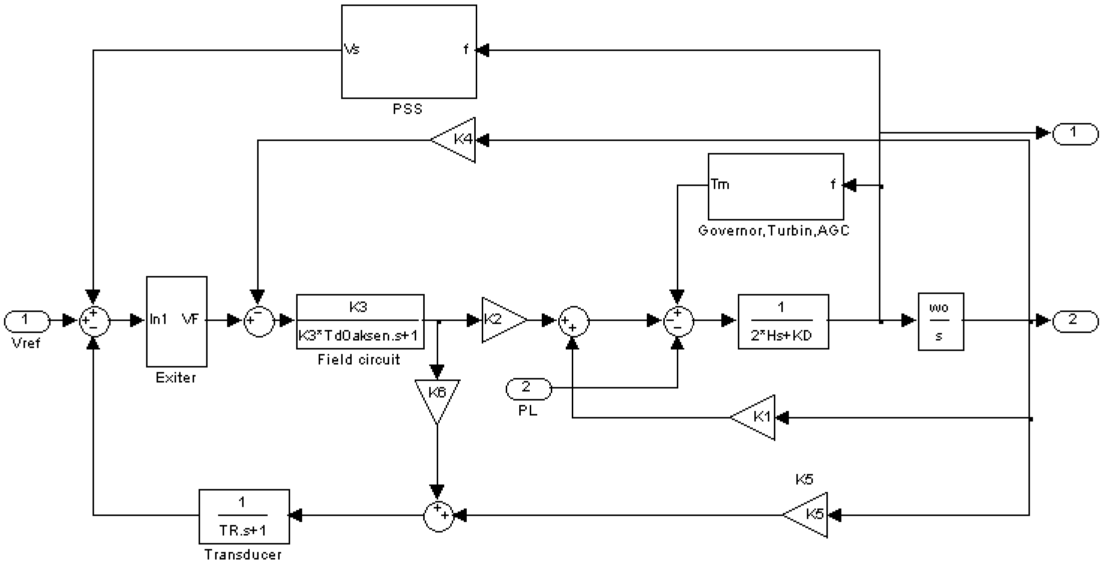

Fig.8. Linear model of SMIB with AVR-PSS and AGC

Implementation of Particle Swarm Optimization

Linear model of the PSS and complete model of the SMIB with AVR and AGC are combined and converted into the Eq. (4) and (5). The linier model of a power system is evaluated by using a matrix **A** and its *eigenvalues* as expressed in Eq. (6). The setting process of the AVR (K_A), PSS ($K_{PSS/STAB}$) and AGC (K_i) gains of the governor shall take into account the *eigenvalue* of matrix A. It is possible that *eigenvalue* of the power system can be shifted to the negative real area by finding the maximum value of damping ratio for each *eigenvalue.* Searching for the maximum value of damping ratio is equal to the minimum value of comprehensive damping index (CDI). The CDI is used as fitness function of particles on the optimization process as expressed in Eq. (7). By minimizing Eq. (8) the power system *eigenvalue* can be shifted to areas of real negative.

$$\Delta\dot{x} = \mathrm{A}\,\Delta x + \mathrm{B}\,\Delta u \tag{4}$$

$$\Delta y = \mathrm{C}\,\Delta x + \mathrm{D}\,\Delta u \tag{5}$$

$$\lambda_i = \sigma_i + j\omega_i \tag{6}$$

$$CDI = \sum_{i=1}^{n} (1 - \zeta_i) \tag{7}$$

$$\zeta_i = \frac{-\sigma_i}{\sqrt{\sigma_i^2 + \omega_i^2}} \tag{8}$$

where Δx , Δy , Δu , A, B, C, D, $\lambda_i , \sigma_i , \omega_i , \zeta_i$ 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, whereas the settings of the AVR gain (K_A), PSS gain ($K_{PSS/STAB}$) and AGC gain (K_i) at the governor was determined by using of PSO. Eq. (9) shows the PSO formula by using CDI as a fitness which containing the sum of gain values. The CDI is allowed as a delimiter in the process of optimization.

$$\min = f(z) = CDI = \sum_{i=1}^{n}(1-\zeta_i) \tag{9}$$

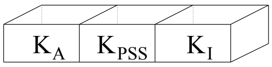

Fig.9. *The structure of each particle in PSO*

In addition to those three gain value, the value of damping ratio is also used as a limiting factor. CDI is a function of **z**. **z** is the row matrix element which is the gain of the AVR-PSS and AGC. In the *PSO* method, **z** is called the position of the particle with *d*-dimensional problem space. The structure of the particles which are used in Figure 9 consists of three local search space problems of each particle. Each particle consists of the AVR gain, PSS gain and AGC gain. Optimization algorithm is shown in Figure 10 and the parameter value of SMIB shown in table 1.

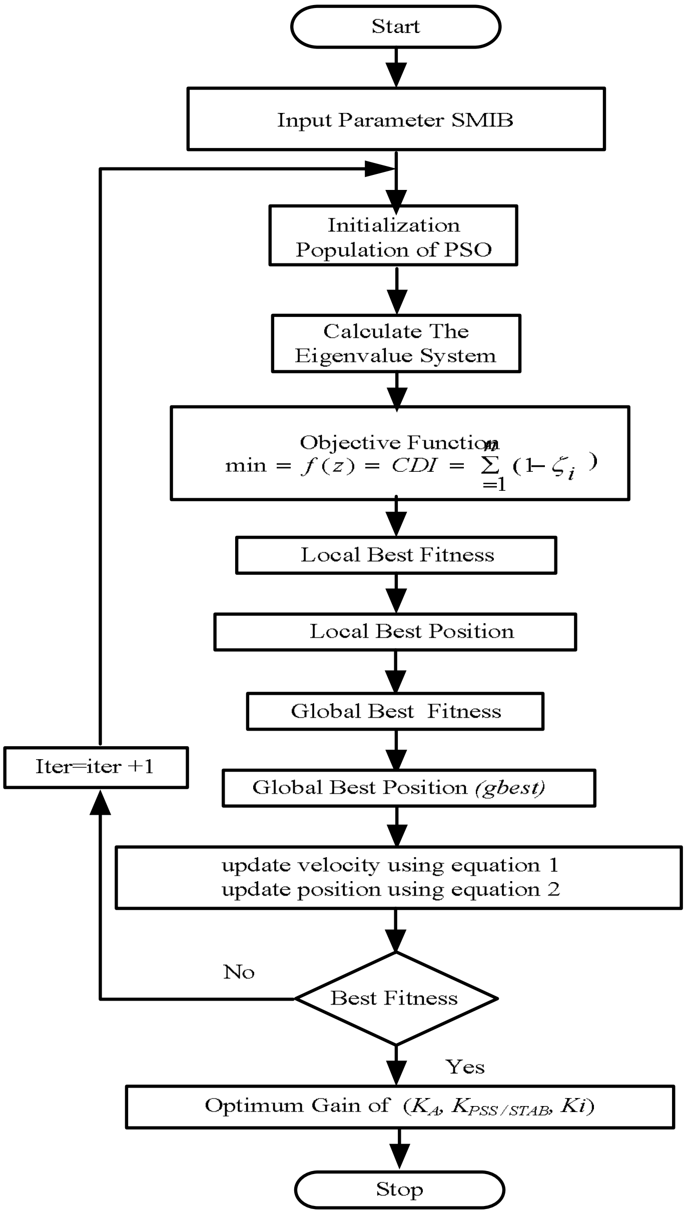

Fig.10. *PSO Algorithm Implementation*

Table 1. Parameter values of SMIB

Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
K_1	1.591	K_D	0	K_A	200	F	0,322	V_{t0}	1
K_2	1,5	T_1	0,4	Tw	0,5	T_A	0,01	i_{q0}	1
K_3	0,333	T_2	0.3	H	3,0	V_{AMIN}	-1	X_d	1,6
K_4	2	T_3	1,91	Ks	2,191	T_{MMIN}	0	X_c	1,6
K_5	0,12	T_R	0,02	Tg_1	0,0264	V_{FMIN}	-1	$Td0'$	6
K_6	0,3	K_{STAB}	3	Tg_3	0,15	E_{q0}	1,05	Ki	0,05
f_o	50	Tg_4	0,594	V_{AMAX}	1	R	1	X_E	0,4
K_G	20	Tg_5	2,662	T_{MMAX}	1,2	E_b	1	Xd'	0,32
Tg_2	0,0264	T_E	0	V_{FMAX}	1	X_q	1,55	E_{d0}	1

3. RESULTS AND DISCUSSION

Simulation were done by Matlab/Simulink 7.1, the simulation results show the dynamic performance of the power system based on the deviation of rotor angular velocity and rotor angle of the SMIB. Figure 11 shows that the global minimum particle fitness is achieved at the 4th iteration. This shows that the minimum value of the CDI can be achieved in the 4th iteration.

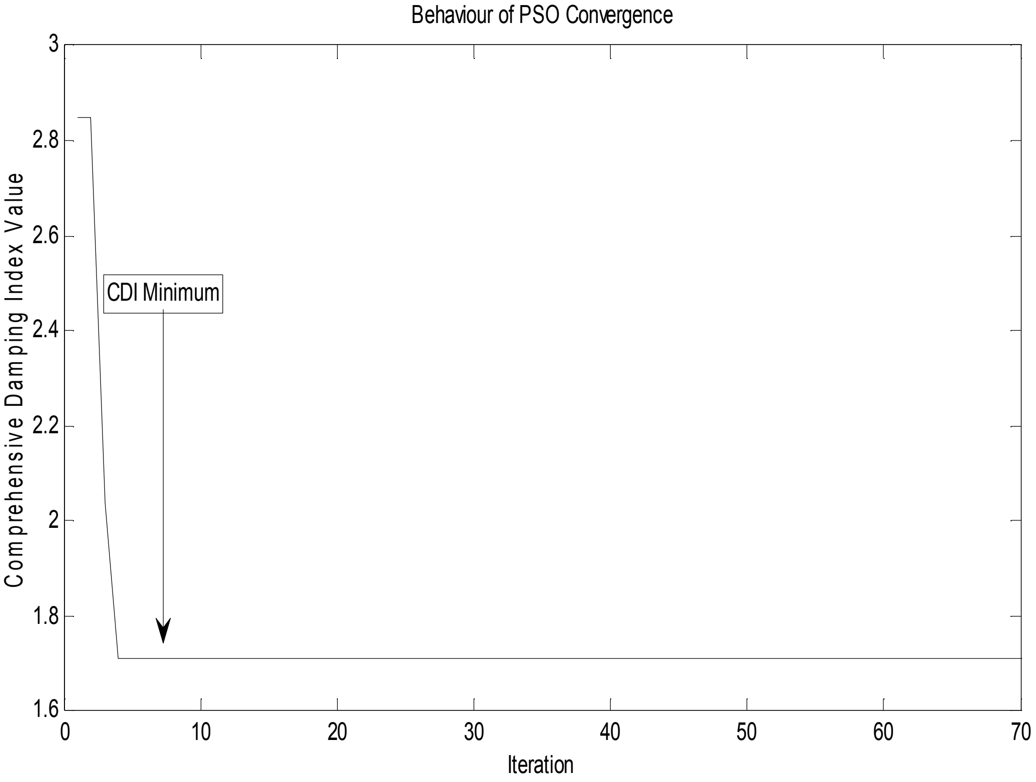

Fig.11. *Graphics CDI as a function of iteration*

Figure 12. and 13 show the deviation of rotor angular velocity and rotor angle of the SMIB. From Figs.12 and 13 we can see that the improvement of stability by using a coordination of the proposed controller (AVR-PSS and AGC) gain optimized by PSO.

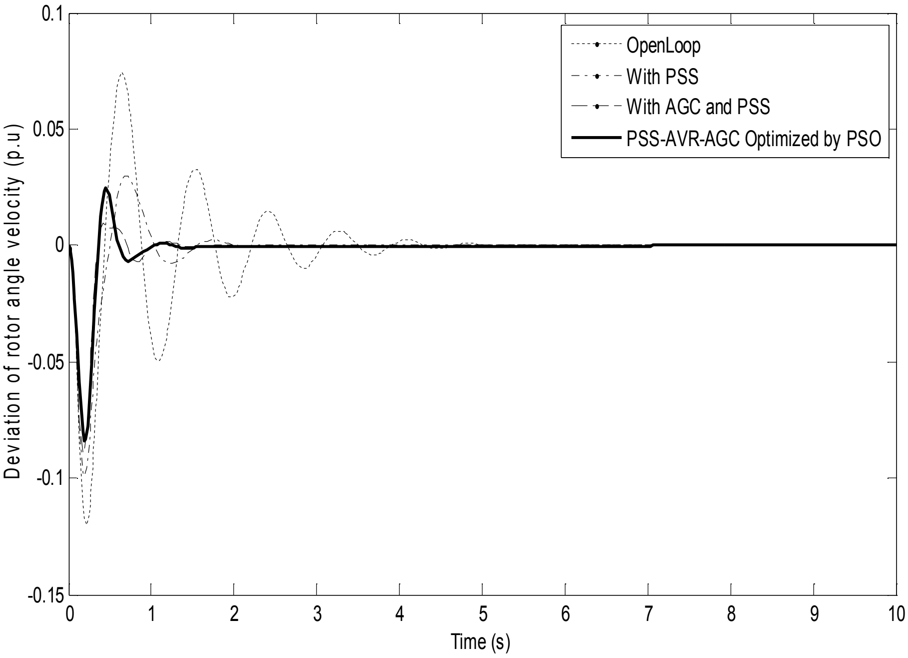

***Fig.12**. Deviation of rotor angular velocity*

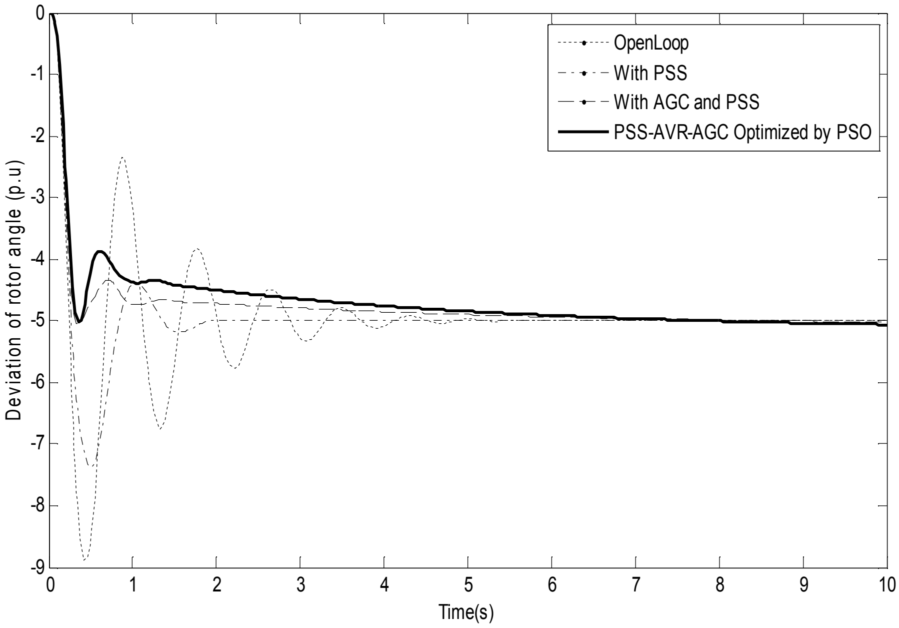

***Fig.13**. Deviation of rotor angle*

The simulation results in Figure 12, 13, and 14 showed that the use of PSO for setting the gain of (AVR-PSS, and AGC) to improve dynamic stability during disturbances by improving the damping oscillation is better compared with the other methods. Response deviation of the rotor angular velocity and angle of the rotor of the third coordination of gain indicate the improvement of the response to pre-coordination, open-loop and only SMIB with PSS. Comparison of CDI, damping ratio eigenvalue, eigenvalue, overshoot, and time settings are shown in table 2, 3, 4, 5 and 6.

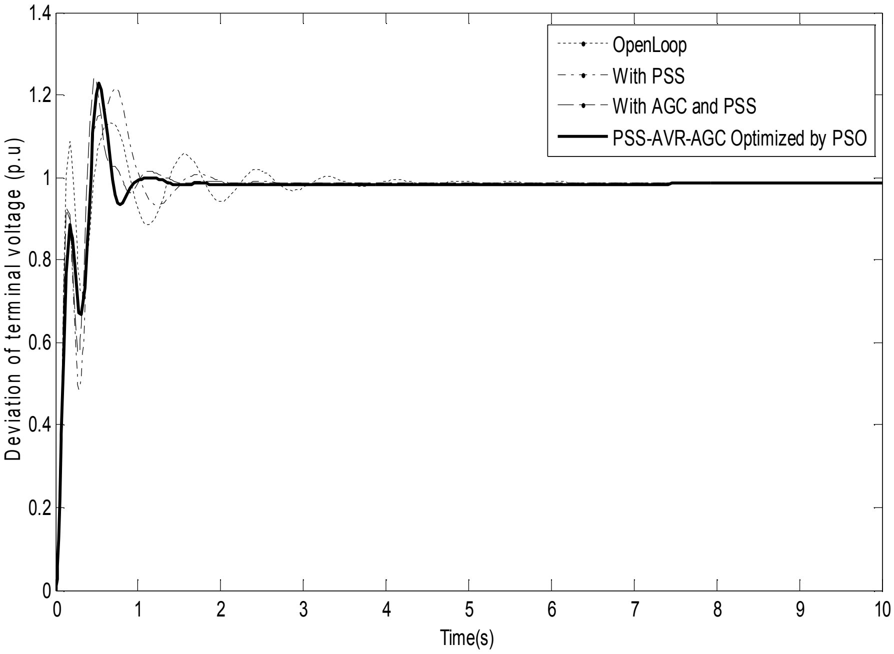

***Fig.14**. Deviation of terminal voltage*

Table 2. Comprehensive Damping Index (CDI)

Without PSS and AGC	With PSS	With PSS and AGC	Optimized by PSO
3.0675	2.8828	2.8823	1.7353

Table 3. Damping Ratio of Eigenvalues

Without PSS and AGC	With PSS	With PSS and AGC	Optimized by PSO
1	1	1	1
1	1	1	1
0.35	0.226	0.226	0.32
0.35	0.226	0.226	0.32
1.16	0.33	0.332	1
1.16	0.33	0.332	1
1	1	1	1
1	1	1	1
1	1	1	1
	1	1	1
	1	1	1
		1	1

Table 4. Eigenvalues

Without PSS and AGC	With PSS	With PSS and AGC	Optimized by PSO
-104.53	-105.10	-105.10	-101.66
-39.52	-39.47	-39.46	-39.32
-6.92 + 18.51i	-4.67 + 20.10i	-4.67 + 20.10i	-1.81 + 13.58i
-6.92 - 18.51i	-4.67 - 20.10i	-4.67 - 20.10i	-1.81 - 13.58i
-1.21 +10.35i	-3.25 + 9.21i	-3.24 + 9.21i	-20.00
-1.21 - 10.35i	-3.25 - 9.21i	-3.24 - 9.21i	-12.52
-5.04	-4.11 + 0.09i	-4.11 + 0.09i	-5.55
-1.46	-4.11 - 0.09i	-4.11 - 0.09i	-2.81
-0.26	-0.26	-2.04	-1.36
	-1.48	-1.48	-0.22
	-2.04	-0.26	-0.10
		-0	-0.

Table 5. Overshoot (pu)

	Without PSS and AGC	With PSS	With PSS and AGC	Optimized by PSO
$\Delta\omega$	-0.1198	-0.09781	-0.08921	-0.0839
$\Delta\delta$	-8.873	-7.335	-5.035	-5.034
ΔV_t	1.088	1.215	1.228	1.227

Table 6. Settling time (s)

	Without PSS and AGC	With PSS	With PSS and AGC	Optimized by PSO
$\Delta\omega$	5.019	2.09	1.505	1.286
$\Delta\delta$	5.215	2.429	8.8	6.7
ΔV_t	4.261	2.021	1.542	1.286

Setting the values gain of (AVR-PSS, and AGC) using the PSO, generate CDI values are lower than without coordination. Table 1 shows that by using the proposed method the CDI values decreased significantly, which means that the stability condition is better. The result of other performance such as eigenvalues, overshoot and time setting can be seen at table 2, 3, 4, 5 and 6 which is shown a better stability for the proposed method.

4. CONCLUSION

PSO can be applied to coordinate the gain setting of (AVR, PSS and AGC) simultaneously. Coordination method is able to reduce the value of CDI on the SMIB. Minimum value of CDI produced can be achieved at the 4th generation. This coordination method gives the best results to improve the dynamic stability of power systems under fault conditions or load fluctuation when compared to other methods.

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