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OPTIMAL SETTING GAIN OF PSS-AVR BASED ON PARTICLE SWARM OPTIMIZATION FOR POWER SYSTEM STABILITY IMPROVEMENT

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ABSTRACT

This paper presents the settings of automatic voltage regulator (AVR) and power system stabilizer (PSS) on a single machine infinite bus (SMIB) to improve the dynamic stability of the power system. This setting is done by determining the fitness function of AVR (K_A) and PSS (K_{PSS}) gain using Particle Swarm Optimization (PSO) algorithm. The main purpose of this setting is to minimize the oscillation frequency so that it would improve the stability of electric power. Simulations are conducted by inputting step function with 5% load fluctuations as a representation of dynamic load. Simulation results show that the proposed method is very effective for improving the damping of electromechanical oscillations of the power system. The proposed method shows that the power system produces a reduced rate of 11% overshoot and settling time 40%.

Keywords: *Setting Gain of PSS-AVR, Dynamic Stability, Modified PSO*

1. INTRODUCTION

Generally, the power system stabilizer (PSS) design methods involve the frequency response based on the concept of increasing the damping torque. PSS is equipment used to improve dynamic stability. PSS will function properly when set appropriately. 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 variation of velocity for improved damping. PSS has a very significant contribution to maintaining stability in power systems and improve system performance by providing additional signals to the excitation system. This is a very easy, economical, practical and flexible for power system stability improvement.

The development of integrated control of synchronous generator has been developed by most researchers to improve the electrical stability include in: c*ontinually online trained artificial neural network (COT-ANN)* with *back propagation algorithm* to control the excitation and governor [1]-[2]. Design of generator control with PSS and excitation has been done by using the dual heuristic programming (DHP) and the heuristic dynamic programming (HDP) based multi layer perceptron (MLP) and radial basis function (RBF) [3]-[6], [8], genetic algorithms [7], recurrent neural networks [9], fuzzy logic [10]-[11]. However, these studies focused on the improvement of stability by PSS. This paper applied the method of Particle Swarm Optimization to simultaneously settings gain of PSS-AVR which can improve the dynamic stability of power system.

2. DESIGN AND METHODOLOGY

Power system consists of electrical power components which form an integrated system. There are three essential components of the electric power system generation, transmission and load. Equivalent circuit of a synchronous generator connected to the grid is represented as a single machine infinite bus (SMIB). Configuration of the interconnected generator interconnected with the load impedance is represented in Figure 1.

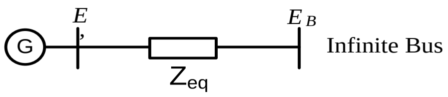

Fig.1. *Model **of** SMIB*

2.1. Automatic Voltage Regulator (AVR)

AVR function is to keep the generator voltage at fixed nominal value. Model AVR depends on the type of DC current injection source to the excitation system. An important part of the AVR consists of amplifiers, exciter, excitation voltage limiters, generators, and transducers. AVR transfer function can be written as in Eq.(1).

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

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 in exitation system is shown in Figure 2.

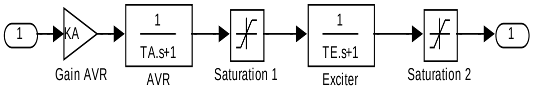

Fig.2. *Model of AVR in excitation system*

2.2. Power System Stabilizer (PSS)

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. 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). Linear model of PSS is shown in Figure 3.

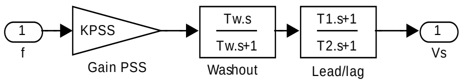

Fig.3. *Model of Power System Stabilizer*

PSS is the equipment that generates control signals for excitation and turbine system and works to increase the limit of stability with a set of generator excitation to provide damping to the rotor of the synchronous oscillations. To improve the damping, the PSS must produce electrical torque component on a machine that has the same phase. This method can improve the performance of the power system stability. Linear modeling of governor-turbine system at the show in Figure 4. Governor-turbine system used in this research consisted of the speed drop, governor, servomotor, and reheater.

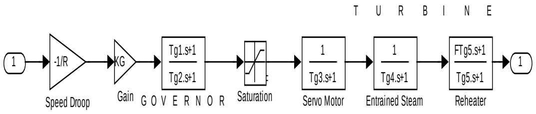

Fig.4. *Model of governor turbine*

SMIB linear models equipped with AVR and PSS are shown in Figure 5.

2.3. Particle Swarm Optimization

Development of PSO algorithm is done based on the behavior of individuals in the particle swarm [12]. 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

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

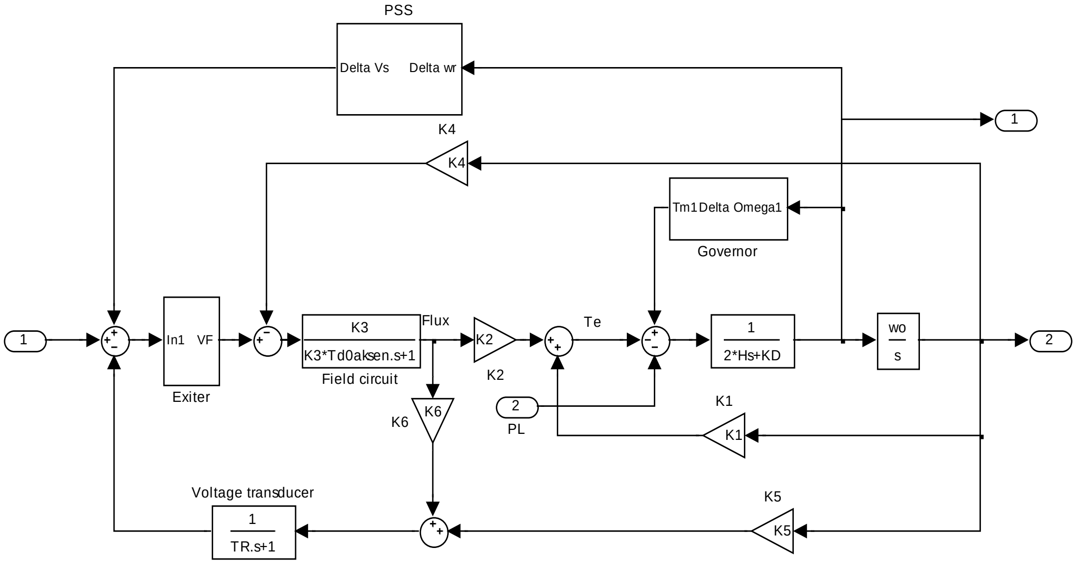

Fig.5. *Linear model of SMIB with PSS-AVR- AGC*

3)

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
Each individual moves from an initial position to the next position by modifying the position of the individual by using a modified of velocity according to Eq.(1).
While the modification of individual positions expressed in Eq.(3)

One of the simplest dynamical system which shows *chaotic* behavior of an iterator is called map function shown in Eq.(4).

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

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

The basic equation of PSO algorithm is modified (MPSO) by using *inertia weight approach* (IWA) as shown in Eq.(1)-(3). Inertia weight is introduced to balance ability between global and local.

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.
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

Linear modeling of SMIB equipped an PSS and AVR linear models are combined and is represented in the Eq.(7) and (8). By using the matrix *A* of the linear model of SMIB the value of the *eigenvalue* obtained by using Eq.(9). Gain settings of AVR (K_A), and gain setting of PSS (K_{PSS}) is done by calculating the *eigenvalue* of the matrix *A*. *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.(10) is a formula of the CDI is used as the fitness function of the particle in the optimization process. By minimizing Eq. (11), *eigenvalue* power system can be shifted to the negative real.

$$\Delta \dot{x} = \mathbf{A}\,\Delta x + \mathbf{B}\,\Delta u \tag{7}$$

$$\Delta y = \mathbf{C}\,\Delta x + \mathbf{D}\,\Delta u \tag{8}$$

$$\lambda_i = \sigma_i + j\omega_i \tag{9}$$

$$CDI = \sum_{i=1}^{n}\left(1-\zeta_i\right) \tag{10}$$

$$\zeta_i = \frac{-\sigma_i}{\sqrt{\sigma_i^2 + \omega_i^2}} \tag{11}$$

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 setting the gain of the AVR (K_A), and PSS (K_{PSS}) optimized using the MPSO. Eq. (12) showed that MPSO method using CDI as fitness and gain value allowed as a delimiter in the optimization process. In addition to the two values of gain, 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 (K_A) and PSS (K_{PSS}). In the *PSO* method, **z** is called the position of the particle with *d*-dimensional problem space. Figure 6 shows the structure of the particle consists of three regions of the problem search space of each particle. Each particle consists of the AVR gain (K_A) and PSS (K_{PSS}). Optimization algorithm is shown in Figure 7.

$$\min = f(z) = CDI = \sum_{i=1}^{n}\left(1-\zeta_i\right) \tag{12}$$

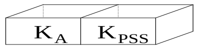

Fig.6. *The structure of each particle in PSO*

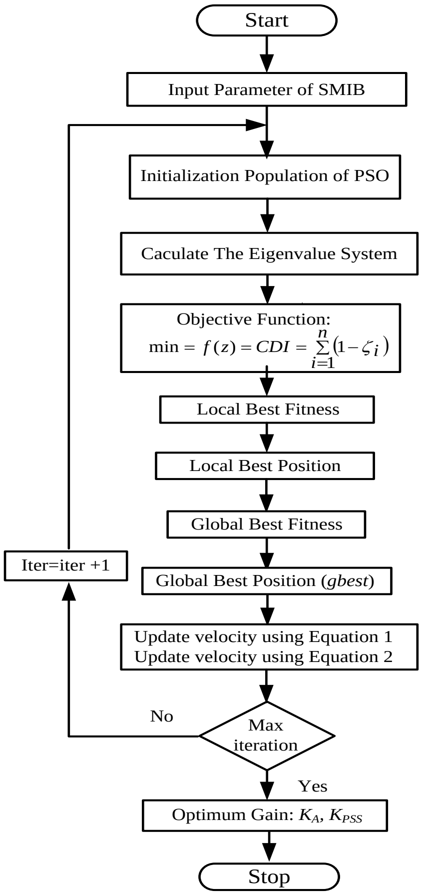

Fig.7. *PSO algorithm flow chart*

3. RESULT AND ANALYSIS

Simulations performed using Matlab 7.1 was applied to the system to provide dynamic stability performance information based on the rotor speed, rotor angle, electrical torque and terminal generator on the SMIB with the parameters shown in table 5.

Figure 8 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.

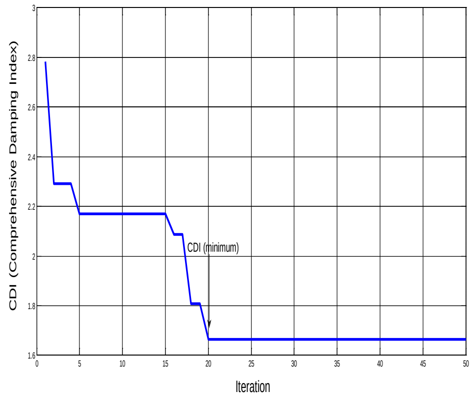

Fig.8. *Graphics CDI as a function of iteration*

Figure 9, 10, 11, and 12 showed that the response of the rotor speed deviation, rotor angle, electrical torque, and the terminal generator of the SMIB. Deviation of the response rotor speed, rotor angle, electrical torque, and the terminal generator of the SMIB with AVR and PSS settings showed an improvement of the response without the use of setting the AVR-PSS and open loop.

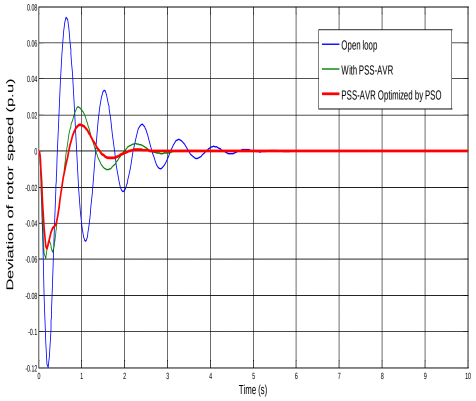

Fig.9*. Response of rotor speed deviation*

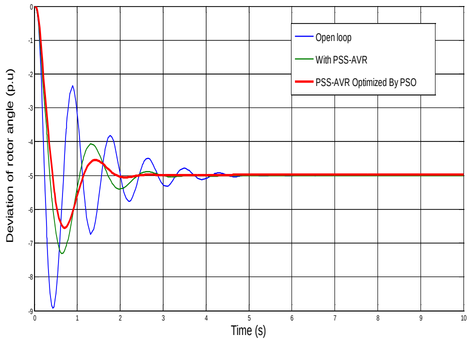

Fig.10*. Response of rotor angle deviation*

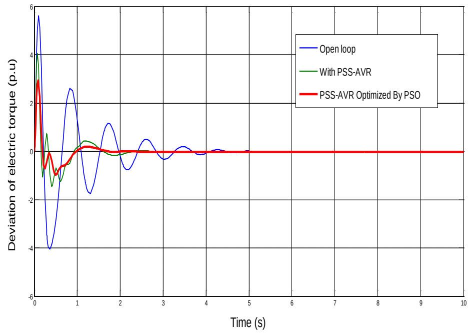

Fig.11. *Response of electric torque deviation*

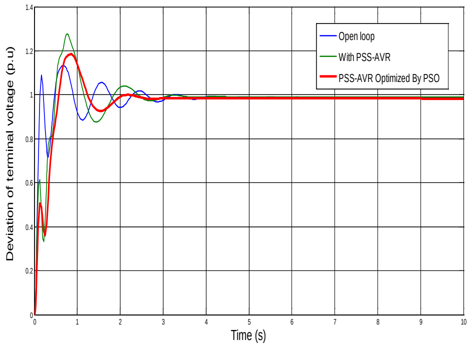

Fig.12*. Response of terminal voltage deviation*

Simulation results in Figure 9, 10, 11 and 12, showed that the gain settings of the PSS-AVR based on MPSO can improve the performance or response of the deviation of rotor speed, rotor angle, electrical torque and terminal voltage of the generator so that the resulting improvement of power system stability. Overshoot and settling time in a state of open-loop, setting the PSS-AVR and optimized with MPSO are shown in Tables 1 and 2. This suggests that the gain settings of PSS-AVR based on MPSO able to reduce the overshoot and steady state speed up.

Table 1. Overshoot (p.u)

	Open loop	With PSS-VR	PSS-AVR Based MPSO
$\Delta\omega$	-0.1183	-0.05938	-0.05248
$\Delta\delta$	-8.852	-7.218	-6.493
ΔP_e	5.62	4.039	2.933
ΔV_t	1.091	1.276	1.184

Table 2. Settling time (s)

	Open loop	With PSS-AVR	PSS-AVR Based MPSO
$\Delta\omega$	5.077	3.173	2.227
$\Delta\delta$	4.609	3.361	2.397
ΔP_e	4.953	2.676	1.546
ΔV_t	3.986	3.639	2.584

Table 1 shows that the decrease in rotor angle overshoot on the open-loop conditions and using the PSS-AVR based MPSO is 36%, while using the PSS-AVR and PSS-AVR based MPSO is 11%. Table 2 shows that the difference in settling time reduction of rotor angle in a state open loop using the PSS-AVR based MPSO is 92% and using the PSS-AVR with PSS-AVR based MPSO is 40%.

4. CONCLUSION

Modified Particle Swarm Optimization (MPSO) can be applied for setting gain of PSS (K_{PSS}) and AVR (K_A),. Tuning method is able to reduce the of comprehensive damping index (CDI) of SMIB. Minimum value of CDI produced can be achieved at the 20th generation. The proposed method is proved improving response of the the dynamic stability power system to reach steady state compared with no arrangement and open loop.

REFERENCES:

[1] Kumar, G. and R. Harley, “A Continually Online Trained Artificial Neural Network Identifier for a Turbo generator”, *Proceedings of the International Joint Conference on Neural Network.* 1999.

[2] Kumar, G. and R. Harley, “Two Separate Continually Online-Trained Neuro-controllers for Excitation and Turbine Control of a Turbo generator”, *IEEE Trans.On Industry Application*, 38(3), 2002, pp.887-893.

[3] Park, J.W. and R. Harley, “Adaptive Critic Based Optimal Neuro-control for Synchronous Generator in a Power System Using MLP/RBFNN”, *IEEE Trans. On Industry Applications*, 39(5), 2003, pp.261-269.

[4] Park, J.W. and R. Harley, “Indirect Adaptive Control for Synchronous Generator: Comparison of MLP/RBFNN Approach with Lyapunov Stability Analysis”, *IEEE Trans. On Neural Networks*, 15(2), 2004, pp.460-464.

[5] Park, J.W. and G. Kumar, “Multilayer Perceptron Neural Network Based Online Global Model Identification of Synchronous Generator”, *IEEE Trans. On Industrial Electronics*, 52(6). 2005

[6] Liu, W., Venayagamoorthy, and G.K. Wunsch, “Adaptive Neural Network Based Power System Stabilizer Design”, *Proceedings of the International Joint Conference On Neural Networks*, July, 2003.

[7] Dubay, M. and P. Gupta, “Design of Genetic-Algorithm Based Robust Power System Stabilizer”, *International Journal of Computational Intelligence*, Vol.2, 2006.

[8] Park, J.W. R. Harley, and G. Jang, “Dual Heuristic Programming Based Optimal Control for a Synchronous Generator”, *Elsevier Engineering Applications of Artificial Intelligence*, Vol.21, 2008.

[9] Chen, C.J. and T. Chen, “Design Of A Power System Stabilizer Using A New Recurrent Network”, *International Journal of Innovative Computing, Information and Control (ICIC)*, 3(4), 2007, pp.97-105.

[10] Taher, S.A. and Shemshadi, “Design Of Robust Fuzzy Logic Power System Stabilizer”, *Proceeding Of World Academy Of Science, Engineering And Technology*, 21(5), 2007.

[11] Corcau, J.I. and E. Stoenescu, “An Adaptive PID Fuzzy Controller for Synchronous Generator”, *WSEAS International Conference on Systems*, Greece, July, 2008, pp.434-437.

[12] Ebenhart, R. and Kennedy, “Particle Swarm Optimization”, *Proc. IEEE Inter Conference on Neural Networks*, Perth, Australia, Piscat-away, NJ, 4, 1995, pp.1942–1948.

APPENDIX

Table 3. Parameter of PSO

Parameter MPSO	
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

Table 4. Parameters of K_A, K_{PSS}

	K_A	K_{PSS}
Before optimization	400	3
After optimization	245.2207	3.3634

Table 5. Parameter of SMIB

Parameter	**Value**	**Parameter**	**Value**	**Parameter**	**Value**	**Parameter**	**Value**	**Parameter**	**Value**
K_1	1.591	K_D	0	K_A	400	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_{PSS}	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