INTEK Jurnal Penelitian
Vol. 8, No. 1, pp. 91-95, April 2021

Optimal Design of PSS on SMIB Using Particle Swarm Optimization

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***Abstract*-- Dynamic disturbances in the power system are caused by sudden changes in load. This condition causes the stability of the generator to be disturbed, such as the emergence of oscillations in the generator in the form of oscillations of frequency and rotor angle. Power System Stabilizer (PSS) is an additional control that can increase generator stability. To get optimal PSS performance, proper tuning of PSS parameters is needed. Optimal performance of PSS can cause the frequency response and angle of the SMIB rotor to be stable. In this study, PSO is used for optimization of PSS parameters. PSS is able to provide stability so that overshoot oscillations can be suppressed, as well as faster settling time performance for the system to reach steady state conditions. To test the reliability of the SMIB, a case study of adding and subtracting loads was used.**

Keywords: PSO, PSS, SMIB, Settling Time, Overshoot.

I. Introduction

For stability analysis, the torque change due to the governor response is ignored, because the governor response is slower than the excitation device, therefore, that the control is on the excitation. The addition of excitation is not able to manage stability of the system in low-frequency oscillations condition. [1].

Additional controls such as Power System Stabilizer (PSS) are needed because lower frequencies can spread to oscillations between areas. PSS can be an additional control on generator excitation, PSS provides additional damping on generator excitation [2], [3]. PSS can also serve to reduce local or global oscillations in generators [4], [5]. This research uses a case study on Single Machine Infinite Bus (SMIB). SMIB is one part of the electric power system which consists of several generators connected to an unlimited bus [6], [7].

Particle Swarm Optimization is one of the artificial intelligence methods that is widely used in solving power system optimization problems. The way PSO works is like a flock of birds or fish in finding food sources where each individual is called a particle and the population is called a swarm (colony). PSO is initialized with a set of particles as candidate solutions at random positions. Each particle is given an initial position and initial velocity. PSO has advantages such as fast and accurate optimization speed. Several conventional PSS applications in the SMIB control system include [8], [9]. Meanwhile, the optimization of intelligent algorithms includes [10] discussing the application of the bat algorithm for tuning PID and PSS parameters. Ref [11] discusses the application of the Ant Colony algorithm for tuning PID and PSS parameters. For this reason, in this study the PSO method was used for optimization of PSS control. System analysis by comparing the simulation results of the system without control and with SMIB-PSS.

II. System Modeling

a. Synchronous Machine Linear Modeling

The machine modeling is shown in Figure 1.

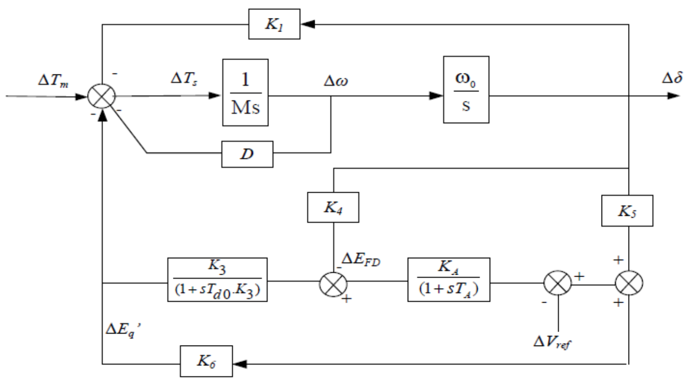

Figure 1. Synchronous Machine Linear Model

b. Excitation Modeling

Excitation functions to regulate voltage, current and power factor [2]. Excitation modeling is shown in Figure 2 below [12].

DOI : http://dx.doi.org/10.31963/intek.v8i1.2893

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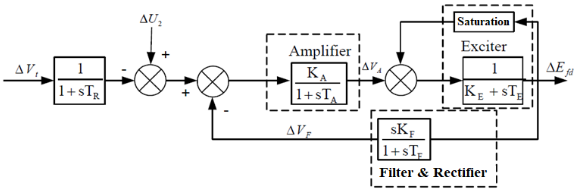

Figure 2. Block Diagram of Excitation

c. Governor Modeling

The modeling of the governor is shown in Figure 3 [12].

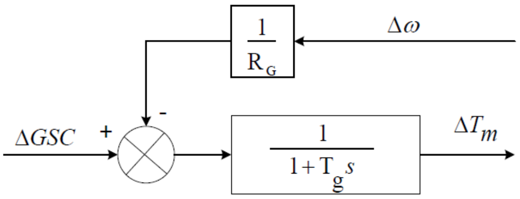

Figure 3. Governor Model

d. Turbine Modeling

Turbine modeling is shown in Figure 4 [13].

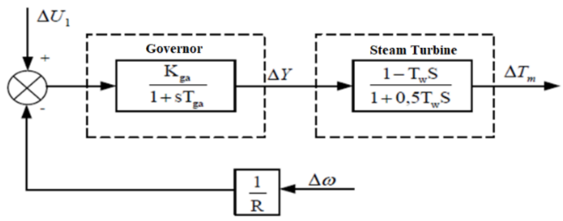

Figure 4. Turbine Model

e. Single Machine Infinite Bus (SMIB) Modeling

SMIB modeling is shown in figure 5 [14].

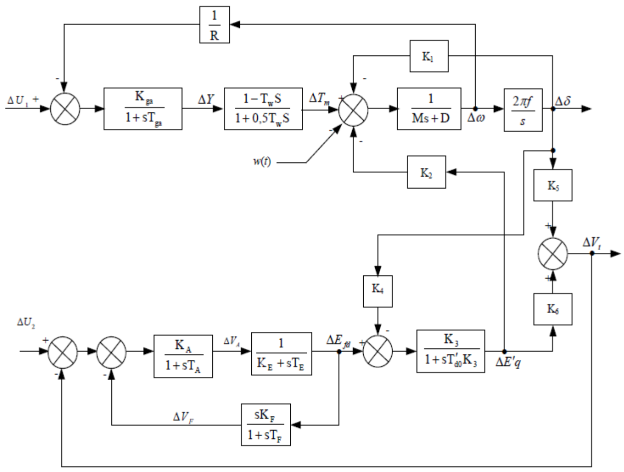

Figure 5. SMIB Model

f. Power System Stabilizer (PSS) Modeling

PSS serves to provide additional damping to the generator. PSS model is shown in Figure 6.

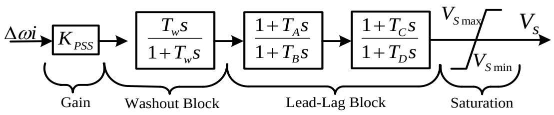

Figure 6. PSS Modeling

Particle Swarm Optimization (PSO)

PSO is a population algorithm technique. The PSO process starts by spreading the particle population in an optimization problem. With implementing the objective as an evaluation function for each particle, it will be known the effect of the position of each particle on the optimum value of the target. The different objective used for each problem. From the results of this evaluation, the local best position and the good global position will be obtained respectively $pbest_i = (p_{i1}, p_{i1}, \ldots, p_{id})$ and $pbest_g = gbest = (p_{g1}, p_{g2}, \ldots, p_{gd})$, where g is the particle in the position with the optimum yield function. Each particle will try to modify its position using the velocity function between the pbest and gbest distances. The velocity improvement function (velocity update) and the position update function of each particle are written in the following equation..

$$v_i^{k+1} = w^k v_i + c1r1(pBest_i - x_i^k) + c2r2(gBest - x_i^k) \quad (1)$$

$$x_i^{k+1} = x_i + v_i^{k+1} \quad (2)$$

Where,

k	=	Iteration
v_i	=	Particle speed
x_i	=	Position Particle
$c1$	=	Acc. constant 1
$c2$	=	Acc. constant 2
$r1$	=	Random constant 1
$r2$	=	Random constant 2
$pBest$	=	Best Local particle position
$gBest$	=	Best Global particle position

In the equation, it is written that there is the use of the w^k variable which is a weighing function. The purpose of placing the weight function is to regulate the local and global exploration carried out by the particle for each iteration. It should be explained earlier that the amount of movement carried out by the particle is determined by the number of iterations to be applied. The weight improvement function is written in the following equation,

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$$w^k = (w_{max} - w_{min}) \times \left(\frac{iter_{max} - iter^k}{iter_{max}}\right) + w_{min} \tag{3}$$

Where,

w = *weight*
w_{max} = Maximum weighing value
w_{min} = Minimum weighing value
$iter_{max}$ = Maximum iteration
$iter$ = Iteration

The PSO and PSS parameters used are shown in Tables 1 and 2 below.

Table 1. PSO Parameters

Particles	30
Iteration	50
Variables	3
Social Constant (C2)	2
Cognitive Constant (C1)	2
Moment Inersia (W)	0.9

Table 2. Constraint of PSS Parameters [3]

No	Parameter	Lower	Upper
1	Kpss	10	50
2	T1	0	0.05
3	T2	0	0.05
4	T3	0	1
5	T4	0	2
6	Tw	10	

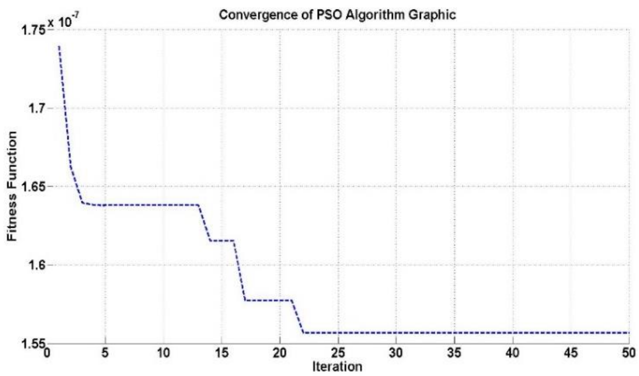

Figure 7. PSO convergence graph

Figure 7 shows the optimization process for PSS parameters. The calculation process converges on the 22nd iteration. PSS optimization results is shown in table 3.

Table 3. Tuning Results of PSS Parameter with PSO

No	Parameter	PSS	PSS-PSO
1	K_{pss}	30.9788	50.6243
2	T_1	1.1687	0.0601
3	T_2	1.1292	0.0236
4	T_3	1.3008	1.2051
5	T_4	1.1590	6.1021
6	Tw	2	

III. Results and Analysis

Analysis of the frequency and angle of the rotor will be analyzed. With several SMIB system schemes such as systems without control and systems with control of Power System Stabilizer. PSS gain is optimized using Particle Swarm Optimization. To test the reliability of the system, SMIB is given the load changes.

a. Frequency Response

The first process is SMIB frequency analysis. Figure 8 is the frequency response of SMIB, where the disturbance is in the form of a load change of 0.01 pu, then after how many seconds a load release of 0.005 pu occurs. In the first response, an increase in load occurs when the electrical power is not equal to the mechanical power Pe > Pm, resulting in an imbalance between the electrical torque and the mechanical torque. Under these conditions the electrical frequency (Δf) will also change. The speed of rotor (Δω) becomes out of sync during unstable conditions. From the graph, it can be seen that in this condition the frequency moves down before it reaches steady state. The overshoot response shown in table 4.

Table 4. Frequency Deviation

Deviation	Overshoot (pu)
SMIB	-0.0002386 s/d 0.0001873
SMIB-PSS	-0.0002104 s/d 9.915e-05
SMIB-PSS-PSO	-0.0001678 s/d 3.99e-05

Table 4 shows the SMIB overshoot when there is an additional load. The uncontrolled scheme has overshoot of -0.0002386 to 0.0001873 pu with settling time of 15s. SMIB-PSS scheme has overshoot of -0.0002104 to 9.915e-05pu with settling time of 7 seconds. The PSS-PSO SMIB scheme has an overshoot of -0.0001678 to 3.99e-05pu with a settling time of 4s. Then a disturbance occurs in the system in the form of a change in load which causes the electrical power (Pe) to change. In this condition the electrical power is not equal to the mechanical power Pe < Pm, which causes the electrical torque and mechanical torque to become unbalanced. This condition causes the electrical frequency (Δf) to also change. Rotor rotation speed (Δω) becomes out of sync when conditions are unstable. So in this condition, the frequency response on the

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graph moves up before returning to a steady state. In this condition, control is needed to return to steady state condition. In this condition the overshoot is shown in table 5. Figure 8 is a graph of the system's electrical frequency response (Δf).

Table 5. Frequency Deviation

Deviation	Overshoot (pu)
SMIB	-9.299e-05 s/d 0.0001198
SMIB-PSS	-4.427e-05 s/d 0.0001048
SMIB-PSS-PSO	-1.978e-05 s/d 7.0333e-05

The overshoot on the uncontrolled system is -9.299e-05 to 0.0001198 pu with a settling time of 35 seconds. The SMIB-PSS System Overshoot is -4.427e-05 to 0.0001048 pu with a settling time of 25 seconds. The SMIB-PSS-PSO overshoot is -1.978e-05 to 7.0333e-05 pu with a settling time of 22s. Table 5 shows the overshoot system when the load changes at 20 seconds.

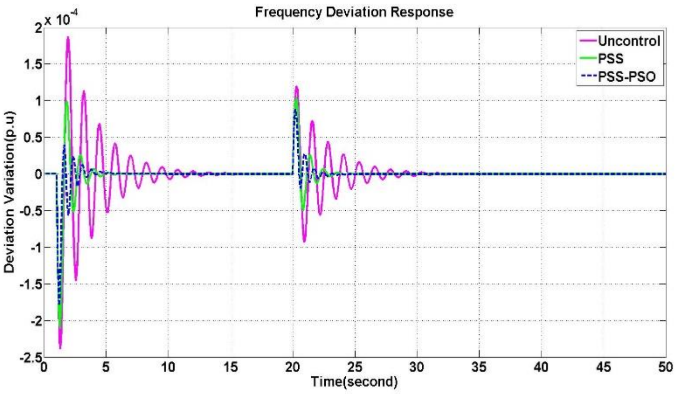

Figure 8. Frequency Response of SMIB

b. Rotor Angle Response

Next is the analysis of the SMIB rotor angle response with PSS installation. By providing a disturbance in the form of an increase in load of 0.05 pu at 1s. The increase of load load causes changes in the electrical power to increase. The generator experiences rotor acceleration when the mechanical power of the generator is greater than the electrical power, this will have an impact on the rotor angle, the rotor angle response becomes negative from the conditions before the disturbance, as shown in Figure 8. The rotor angle oscillation is shown in table 6.

Table 6 . Rotor Angle Deviation

Deviation	Overshoot (pu)
SMIB	-0.03667
SMIB-PSS	-0.0290
SMIB-PSS-PSO	-0.0238

Table 6 is an overshoot of the rotor angle when a disturbance occurs in the form of an additional load. The SMIB scheme without control produces an overshoot of -0.03667 pu with a settling time of 18 seconds. The SMIB-PSS system has an overshoot of -0.0290 pu with a settling time of 8s. The SMIB-PSS-PSO scheme produces an overshoot of -0.0238 pu with a settling time of 5s. The next test is to reduce the load on the SMIB, which causes the generator to experience a slowdown in the rotor because the mechanical power of the generator is smaller than the electrical power. The deceleration of the rotor affects the change in the rotor angle, so that the rotor angle response becomes positive. This is because the magnetic coupling will push the stator field with the rotor field, so that the generator rotor angle will increase, as shown in Figure 9. The system overshoot in this condition is shown in Table 7.

Table 7 is an overshoot of the rotor angle when there is a change in load at 20 seconds. The uncontrolled SMIB has an overshoot of -0.01652 pu with a turnaround time of 36.8 seconds. The SMIB-PSS scheme has an overshoot of -0.01245 pu with a settling time of 28 seconds. SMIB-PSS-PSO obtained an overshoot of -0.01162 pu with a settling time of 25s.

Table 7. Rotor Angle Deviation

Deviation	Overshoot (pu)
SMIB	-0.01652
SMIB-PSS	-0.01245
SMIB-PSS-PSO	-0.01162

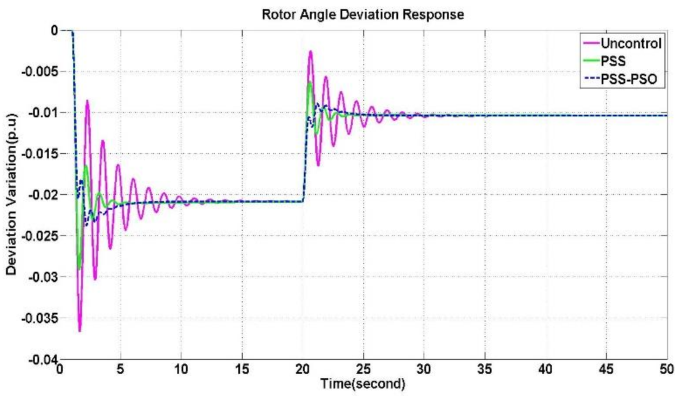

Figure 9. SMIB Rotor Angle Response

DOI : http://dx.doi.org/10.31963/intek.v8i1.2893

IV. Conclusion

By tuning the optimal PSS parameters using PSO, the optimal SMIB frequency response is obtained, compared to the uncontrolled scheme, this is indicated by the optimal system frequency response. PSS is able to provide additional damping so that the overshoot oscillations can be damped. With proper optimization of PSS parameters, Overshoot on the system can be reduced..

Acknowledgements

The authors would like to thank Ministry of Education, Culture, Research and Technology, director general of higher education, Director of Resources of Education, Culture, Research and Technology and Center for Research and Community Service State Polytechnic of Ujung Pandang for supporting the Research

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DOI : http://dx.doi.org/10.31963/intek.v8i1.2893