SINERGI Vol. 25, No. 2, June 2021: 169-176
http://publikasi.mercubuana.ac.id/index.php/sinergi
http://doi.org/10.22441/sinergi.2021.2.008

OPTIMAL DESIGN PSS-PID CONTROL ON SINGLE MACHINE INFINITE BUS USING ANT COLONY OPTIMIZATION

Nasrun Kadir[1], Muhammad Ruswandi Djalal[2*]
[1]Department of Mechanical Engineering, Mechanical Engineering, Politeknik Negeri Ujung Pandang, Indonesia
[2]Department of Mechanical Engineering, Energy Engineering, Politeknik Negeri Ujung Pandang, Indonesia

Abstract
Optimization of the controller in a generator can improve system performance. The right parameter optimization is needed to get the optimal performance from the controller. The application of the artificial intelligence method as a parameter optimization method is proposed in this study. By using the smart method based on Ant Colony, the optimal PSS-PID parameters are obtained. With optimal tuning, the system gets optimal Single Machine Infinite Bus (SMIB) system frequency and rotor angle response, indicated by the minimum overshoot system response. The SMIB system's stability will be tested. A case study of adding and reducing loads is used, with the proposed control method PSS-PID being optimized using Ant Colony. Based on the analysis using the proposed PSS-PID control, we get the minimum overshoot for the frequency response and rotor angle of the SMIB system. When the load changes at 20 seconds, using the PSS-PID control scheme, the minimum overshoot is -4.316e-06 to 7.598e-05 pu with a settling time of 22.01s. For the rotor angle overshoot response, using the PSS-PID control scheme, the minimum overshoot is -0.01113 to -0.009669 pu with a settling time of 22.36s.

Keywords:
Ant Colony;
Overshoot;
PID;
PSS;
Settling Time;
SMIB;

Article History:
Received: June 22, 2020
Revised: September 5, 2020
Accepted: October 16, 2020
Published: February 10, 2021

Corresponding Author:
Muhammad Ruswandi Djalal
Department of Mechanical Engineering, Energy Engineering, Politeknik Negeri Ujung Pandang, Indonesia
Email: wandi@poliupg.ac.id

INTRODUCTION

In the dynamic stability analysis, because the governor response is slow, the torque is neglected. With the slow governor response compared to the excitation system response, the excitation system regulates the controller. In its application, the addition of an excitation amplifier circuit is not optimal to stabilize the system, especially Low Frequency Oscillation 0.2 - 2.0 Hz [1].

Low frequencies can turn into oscillations between areas, so additional controllers such as Power System Stabilizer and PID are needed. PSS is additional control equipment on generator excitation that is used to provide additional attenuation to generator excitation [2][3]. PID is an additional control that functions to reduce local or global oscillations in the generator and respond to deviations that occur at predetermined variable values [4][5]. It requires precisely adjusting the PSS and PID to reduce oscillation and properly stabilize the system optimally to get maximum results. Controller parameters are optimized using smart methods [6][7].

The Ant Colony Optimization (ACO) algorithm is a Swarm Intelligence group that can solve optimization problems. ACO adopts group or insect swarming behavior [8][9]. In several previous studies, the ACO method was also used for the optimization of PID controllers [10][11]. Several other studies related to the application of smart methods can improve generator performance, such as firefly method [2], bat algorithm [12, 13, 14], flower pollination [15], imperialist competitive [4], and cuckoo search [3][5].

Optimal parameter tuning of the controller will be very influential in stabilizing the system. However, the range of equipment parameters is very diverse and broad, so to get the parameter values quickly, an optimization method using ACO is used. The response value is known by analyzing the overshoot and settling time values, while the objective function minimizes Integral Time Absolute Error (ITAE) [16][17].

The case study used in this research is the Single Machine Infinite Bus (SMIB) system. SMIB is an electric power subsystem consisting of one or more generators that are connected to an infinite bus [18]. Then analyze the simulation results by comparing the simulation system results without control, SMIB with PID, SMIB with PSS, and the proposed method of SMIB with PSS-PID with ACO. In this study, the authors implemented an Ant Colony-based intelligent method to solve the optimization problem of determining the PSS-PID parameters on the SMIB system.

METHOD

There are several steps in conducting research. The research begins with the study of literature, analysis, and conclusions.

Data Analysis

The case study used is a single machine infinite bus (SMIB) system regarding previous research modeling [19]. Some stages of analysis are, modelling the synchronous machine system, modelling the PSS-PID using Simulink, entering the system data, designing the ACO, plotting the proposed method results, and comparing it with the other control schemes.

Machine Model

The synchronous machine model is modeled in linear modelling, as shown in Figure 1 [19].

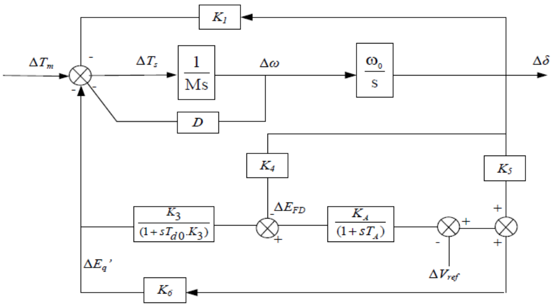

Figure 1. Synchronous Linear Machine Model

Where:
K_1-K_6 = Constant
E_{FD} = Magnetic field flux
T_m = Turbine mechanical torque (N.m)
T_e = Rotor electric torque (N.m)
T_a = Acceleration of torque (N.m)
T = Time (detik)
δ_m = Rotor mechanical angle (rad-mechanical)
D = Engine damping coefficient
Eq' = Stator field flux
$\Delta\delta$ = Change in engine angle
M = Momentum
$\Delta\omega$ = Speed

Exciter Model

Excitation equipment in the system is used to control the generator output variable [2]. This study's excitation modeling refers to the IEEE modeling shown in Figure 2 [19].

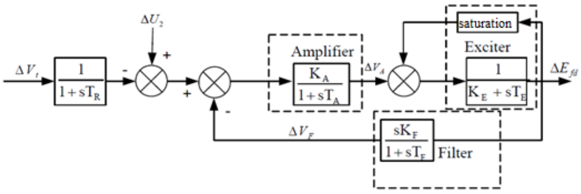

Figure 2. Excitation Model

Where:
K_A = Amplifier gain constant
K_F = Filter gain constant
K_E = Exciter gain constant
T_A = Amplifier response time
T_E = Exciter response time
T_F = Filter response time
ΔU_2 = Change of an engine control signal

Governor Model

Governor is a controller used to regulate the mechanical torque value of Tm, which is input from the generator [19]. Governor modeling is shown in Figure 3.

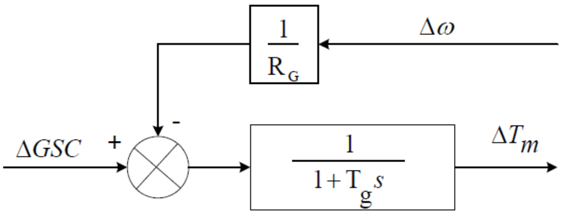

Figure 3. Governor Model

Where:
K_g = Constant gain = $1/R_G$
T_g = Constant governor time
R_G = Governor's groove constant
ΔGSC = Governor Speed Changer

Turbine Model

The turbine model used is a steam turbine power plant model [20]. The model is shown in Figure 4.

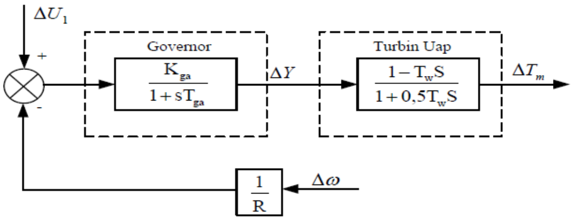

Figure 4. Turbine Model

Where:
ΔY = Change in valve height
T_w = Steam turbine response time
T_{ga} = Steam turbine regulator response time
K_{ga} = Strengthening steam turbine regulator
R = Steam turbine regulator constant
ΔU_1 = Feedback control signal changes

Single Machine Infinite Bus (SMIB)

Model is shown as the Single Machine Infinite Bus (SMIB) model in Figure 5 [14].

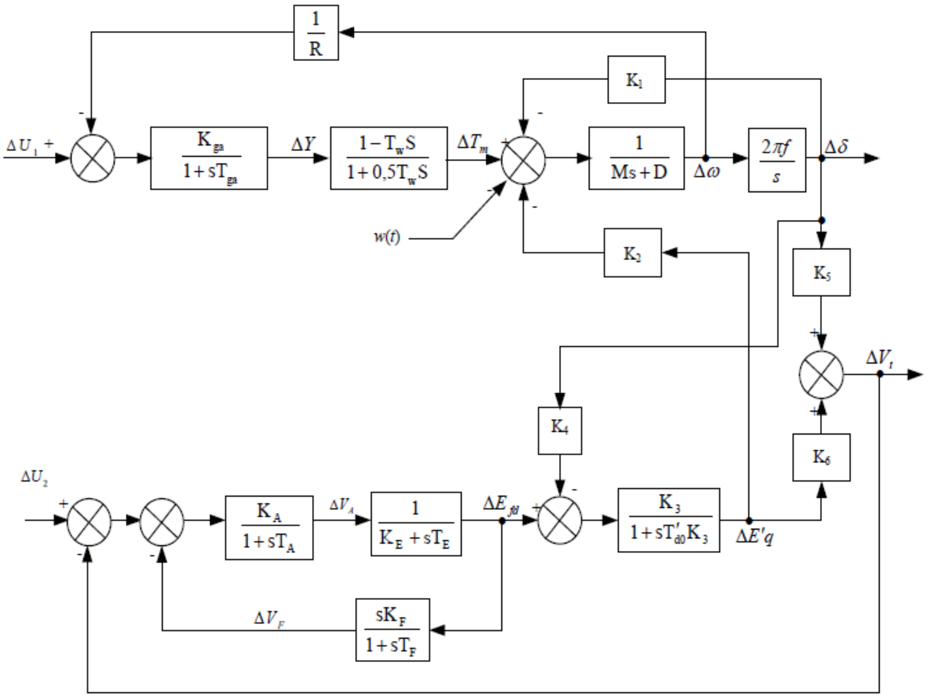

Figure 5. SMIB Model

Power System Stabilizer

Power System Stabilizer is a device used to optimize system stability; in this study, the modeling is shown in Figure 6.

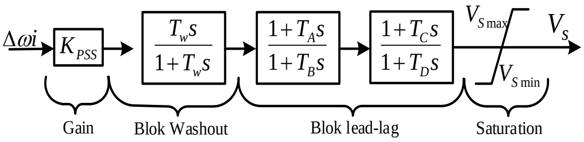

Figure 6. PSS Modeling

Where:
Kpss = Gain
T1-T4 = Fase Lag/Lead
Tw = Washout
Vs = Limiter

Ant Colony Optimization (ACO)

Ant Colony Optimization (ACO) is an algorithm that uses artificial ants to find the optimal value of an optimization problem. ACO was discovered by Marco Dorigo in 1990 [10]. ACO adopts the ant behavior in finding the shortest path between the nest and food.

Ants provide information to each other using pheromones on the path that is traversed. Pathways that contain large pheromones attract ants. Every time they go on a tour, the ants leave pheromones on every path they take. The pheromone levels in the ants' paths will increase, while the pheromone levels in the trails where ants don't pass will experience evaporation [9]. The shortest path will often be traversed by ants so that the pheromone levels in that pathway increase and attract other ants to pass the path [21].

The ants tour according to a probabilistic function that takes two things into account. First, it calculates the visited nodes whose accumulation is calculated as the distance from the tour. Second, the Ants detect the pheromones that other Ants leave behind. The ant then selects city j on the candidate list following the transition rule in (1). P is the Ant's movement from i to j.

$$j = \begin{cases} \operatorname{argmax}_{u \in J_l^k} \{[\tau_{iu}(t)][\eta_{iu}(t)]^{\beta}\} & \text{,if } q \leq q0 \\ J & \text{, the other} \end{cases} \quad (1)$$

$$P_{iJ}^{k} = \frac{[\tau_{iu}(t)][\gamma_{iu}(t)]^{\beta}}{\sum_{l \in J_l^k} [\tau_{il}(t)][\gamma_{il}(t)]^{\beta}} \quad (2)$$

Where:
τ = Pheromones
η = the distance between two nodes
q = A random variable [0,1]
q_0 = Parameters that can be set at intervals [0,1]
J = A list of candidates

Ant Colony Optimization Parameter

Some parameters used in the ACO method in this thesis are as follows, the number of ants = 10, the maximum iteration = 50, and the Pheromone Resistance (alpha) = 0.9

Tuning PSS-PID Control with Ant Colony

The objective function used in this study is to optimize the Integral Time Absolute Error.

$$ITAE = \int_0^t t\left|\Delta\omega(t)\right| dt \quad (3)$$

Where ω is a speed that is tested for stability. The PSS-PID parameters tuned by ACO are Kp, Ki, Kd, Kpss, T1, T2, T3, T4.

The algorithm design is mentioned in Table 1, to run the Ant Colony optimization. The Ant Colony algorithm was created using the MATLAB-Simulink software.

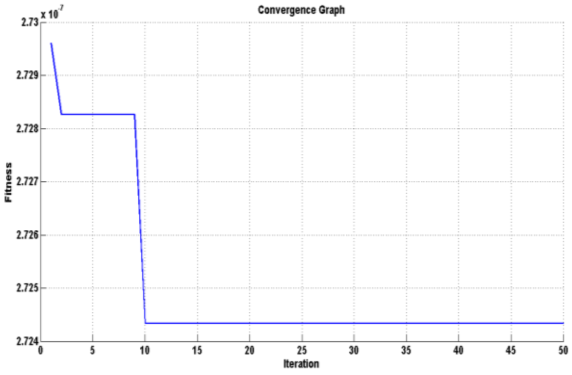

Figure 7. Convergence Graph

Table 1. Ant Colony Parameter

Parameters	Values
Number of Ants (n)	8
Max Iteration (It)	50
Pheromone (α)	0.9
Beta (β)	2

After entering several parameters in Table 1, the Ant Colony algorithm is run to optimize the PSS-PID value. The exact value will greatly affect the SMIB response performance designed in this study. The Ant Colony algorithm requires a calculation process to get the optimal value. Figure 7 shows a graph of PID convergence optimization using the Ant Colony algorithm. Convergence is the value of the fitness function, which describes the optimal criteria for an optimization problem.

Figure 7 displays the convergence graph of PSS-PID value optimization using Ant Colony. The Ant Colony algorithm does not take a long time to perform the optimization process. In the 10th iteration, the algorithm has found the optimal PSS and PID values with a minimum fitness value of 2.724e-07.

The ACO results obtained a fitness function value of 2.724e-07, with iteration 50 times convergent in the 10th iteration, the nbest value is the best Ant Colony known as the PID parameter optimization results, namely Kp, Ki, Kd, Kpss, T1, T2, T3, T4. Table 2 shows the limits and values of the PSS-PID parameter optimization results set by the Ant Colony.

Table 2. Limits and ACO Optimization Results

Parameter	Limits		Results
	Lower	Upper	
Kp	0	10	5.0311
Ki	0	100	1.1755
Kd	0	10	1.0043
Kpss	0	10	64.1961
T1	0	10	0.5266
T2	0	10	0.2317
T3	0	10	1.0971
T4	0	10	5.4010

As a comparison, several control schemes are used, namely the combination of PID, PSS and PSS-PID. In principle, the Ant Colony algorithm looks for food sources based on pheromones, which then in groups will follow the trail with the largest pheromone [10]. With this principle, the algorithm will look for the most optimal parameters to be filled in the PID parameters, so that optimal control is obtained at the SMIB. The flow chart in this study is shown in Figure 8.

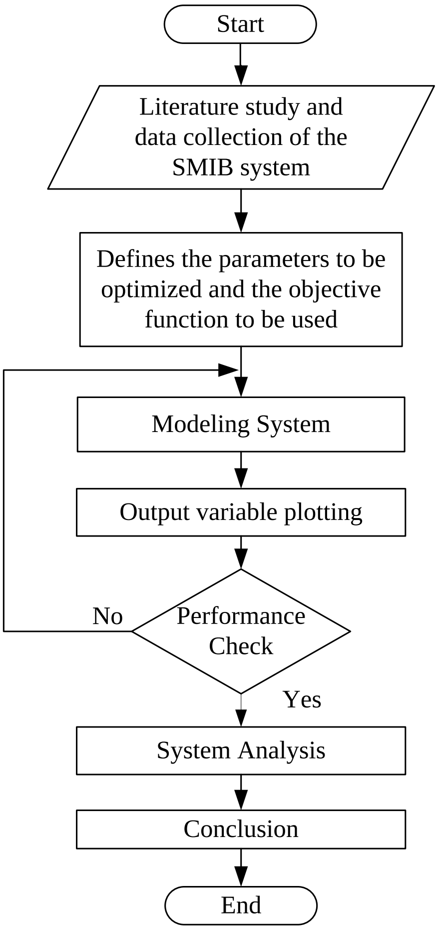

Figure 8. Research Flowchart

RESULTS AND DISCUSSION

The system analysis is performed, namely the analysis of the system frequency and SMIB rotor angle. The analysis was carried out using several control methods, such as the uncontrolled system, SMIB-PID, SMIB-PSS, and PSS-PID SMIB. PSS and PID parameters are simulated using the Ant Colony Optimization algorithm. The SMIB system is given a disturbance in the form of load changes to test the system's stability.

SMIB Frequency Response

The first analysis begins by reviewing the frequency stability response of the SMIB system. The simulation results are shown in Figure 9. Figure 9 display the simulation results of the SMIB frequency response with several control methods.

From the SMIB system's simulation results, a load change disturbance of 0.01 pu is given in the second, then the load shedding that occurs in the 20th second is 0.005 pu. At the first load change, the load increase increases the condition where the electric power is not the same as the mechanical power (Pm). In this condition, Pe> Pm, the electric torque and mechanical torque are not balanced. This condition causes the electric frequency (Δf) to change as well. During this instability, the rotor rotational speed (Δω) becomes out of sync. In this condition, the frequency response graph drops before returning to a steady state. The control system function is then required to return to steady state. The characteristics of the overshoot response in this condition are shown in Table 3.

Table 3. Frequency Deviation

Deviation	**Overshoot (pu)**
SMIB	-0.0002409 & 0.0001865
SMIB-PID	-0.0002069 & 0.0002129
SMIB-PSS	-0.0001748 & 1.787e-05
SMIB-PSS-PID	-0.0001533 & 7.662e-05

Table 3 shows the overshoot system's characteristics when the load changes at the 1st second in the form of additional loads. The uncontrolled SMIB system has an overshoot of -0.0002409 to 0.0001873 pu with a turnaround time of 15.09s. With PID control, the SMIB system gets an overshoot of -0.0002069 to 0.000131 pu with a settling time of 11.78s. With PSS control, the SMIB system obtained an overshoot of -0.0001748 to 8,743e-05 pu with a settling time of 2,334s. With the proposed method using PSS-PID, the smallest overshoot is obtained from -0.0001533 to 7.662e-05 pu with a settling time of 3.334s.

Then in the next load change in the form of a load reduction which causes the electric power (Pe) to change. In this condition, the electric power is not the same as the mechanical power (Pm) Pe <Pm, so that the electric torque and mechanical torque are not balanced. This condition causes the electric frequency (Δf) to change as well. During this instability, the rotor rotational speed (Δω) becomes out of sync. In this condition, the frequency response graph rises before returning to a steady state. The control system function is then required to return to steady state. The characteristics of the overshoot response in this condition are shown in Table 4. Figure 9 is a graph of the system's electrical frequency response (Δf).

Table 4. Frequency Deviation

Deviation	**Overshoot (pu)**
SMIB	-9.314e-05 & 0.0001203
SMIB-PID	-6.515e-05 & 0.000131
SMIB-PSS	-9.369e-06 & 8.743e-05
SMIB-PSS-PID	-4.316e-06 & 7.598e-05

Table 4 displays the overshoot method's features when the load shifts in the form of a load reduction at the 20th second. With a turnaround period of 32.17s, the uncontrolled SMIB device surpassed -9.314e-05 to 0.0001203 pu. The SMIB system obtained an overshoot of -6.515e-05 to 0.000131 pu with PID control with a settling time of 26.54s. The SMIB network obtained an overshoot with PSS control.

Rotor Angle Response

The subsequent analysis looked at the performance of the SMIB rotor response angle by installing a PSS-PID control. In this study, the test for SMIB was given in the form of a change of 0.05 pu at 1s. The change in question is an increase and an increase in expenses. An increase in load will cause changes in electrical power also to increase. Suppose that the generator's mechanical power is greater than the electric power; it can cause acceleration in the rotor. In this case, the rotor acceleration will also affect the change in rotor angle. The rotor angle response will be reduced or negative from the conditions before the disturbance, shown in Figure 10. The response of the generator rotor angle for each method is shown in Table 5.

Table 5. Rotor Angle Deviation

Deviation	Overshoot (pu)
SMIB	-0.03651 & -0.00874
SMIB-PID	-0.01306 & -0.03332
SMIB-PSS	-0.01888 & -0.02264
SMIB-PSS-PID	-0.02093 & -0.02197

Table 5 shows the system overshoot characteristics for the load change conditions at the 1st second. The uncontrolled SMIB system has an overshoot from -0.03651 to -0.00874 pu with a turnaround time of 18.88s. With PID control, the SMIB system obtained an overshoot of -0.01306 to -0.03332 pu with a settling time of 11.59s. With PSS control, the SMIB system gets an overshoot of -0.01888 to -0.02264 pu with a settling time of 5.026s. With the proposed method using PSS-PID, the lowest overshoot is -0.02093 to -0.02197 pu with a settling time of 3.283 pu.

Then in the next load change in the form of a load reduction at the 20th second. In this condition, the generator's mechanical power is less than the electric power, causing a slowdown in the rotor. This situation occurs because the magnetic coupling will push the stator field with the rotor field to increase the generator rotor angle, as shown in Figure 10. The characteristics of the overshoot system in this condition are shown in Table 6.

Table 6 displays the features of the overshoot system for load change conditions at the 20th second. The uncontrolled SMIB system goes beyond -0.01651 to -0.002530 pu with a completion time of 36.47 seconds. The SMIB system obtained an overshoot of -0.01437 to -0.003934 pu with PID control with a settling time of 129.55s. The SMIB system gets an overshoot of -0.01145 to -0.009567 pu with PSS control, with a settling time of 23.54s. The smallest overshoot is -0.01113 to -0.009669 pu, with a settling time of 22.36s, with the proposed approach using PSS-PID.

Table 6. Rotor Angle Deviation

Deviation	Overshoot (pu)
SMIB	-0.01651 & -0.002530
SMIB-PID	-0.01437 & -0.003934
SMIB-PSS	-0.01145 & -0.009567
SMIB-PSS-PID	-0.01113 & -0.009669

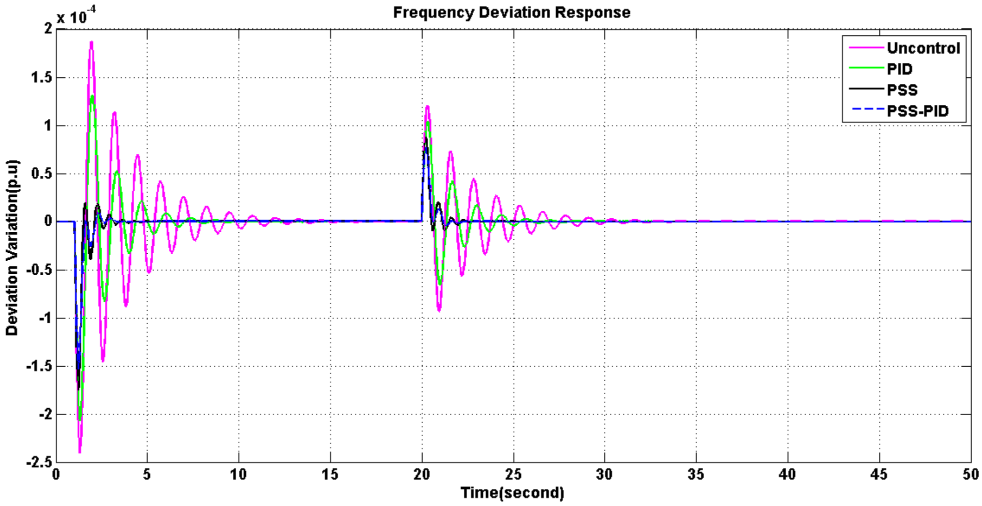

Figure 9. SMIB Frequency Response

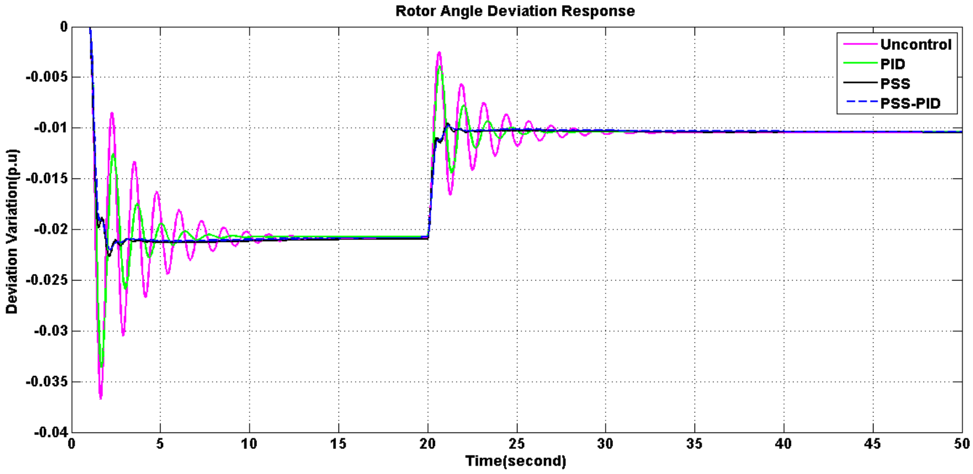

Figure 10. SMIB Rotor Angle Response

CONCLUSION

According to the comparative results, the optimal parameters of PSS-PID tuned by using ACO are Kp = 5.0311, Ki = 1.1755, Kd = 1.0043, Kpss = 64.1961, T1 = 0.5266, T2 = 0.2317, T3 = 1.0971, T4 = 5.4010. A perfect SMIB frequency response is obtained with optimal tuning compared with an uncontrolled system, SMIB-PID and SMIB-PSS. The condition is indicated by an improved system response, where the controller can provide stability—increased system performance with minimum overshoot oscillations and faster settling times.

REFERENCES

[1] P. Kundur, *Power system stability and control*, 1st Ed., McGraw-Hill Education, NY, US, 1994

[2] M. Y. Yunus, M. R. Djalal, and Marhatang, "Optimal Design Power System Stabilizer Using Firefly Algorithm in Interconnected 150 kV Sulselrabar System, Indonesia," *International Review of Electrical Engineering (IREE)*, vol. 12, no. 3, pp. 250-259, 2017, DOI: 10.15866/iree.v12i3.11136

[3] M. R. Djalal, M. Y. Yunus, H. Setiadi, and A. U. Krismanto, "Small-Signal-Stability Enhancement using a Power-System Stabilizer based on the Cuckoo-Search Algorithm against Contingency N-1 in the Sulselrabar 150-kV System," *Makara Journal of Technology*, vol. 22, no. 1, pp. 1-8, 2018, DOI: 10.7454/mst.v22i1.3407

[4] M. R. Djalal, A. Imran and I. Robandi, "Optimal placement and tuning power system stabilizer using Participation Factor and Imperialist Competitive Algorithm in 150 kV South of Sulawesi system," *2015 International Seminar on Intelligent Technology and Its Applications (ISITIA)*, Surabaya, Indonesia, 2015, pp. 147-152, DOI: 10.1109/ ISITIA.2015.7219970

[5] M. R. Djalal, H. Setiadi, D. Lastomo, and M. Y. Yunus, "Modal Analysis and Stability Enhancement of 150 kV Sulselrabar Electrical System using PSS and RFB based on Cuckoo Search Algorithm," *International Journal on Electrical Engineering and Informatics*, vol. 9, no. 4, pp. 800-812, 2017, DOI: 10.15676/ijeei.2017.9.4.12

[6] L. Handayani, A. Abu-Siada, S. Suwarno, N. Hariyanto and M. R. Djalal, "Power System Performance Enhancement using Superconducting Magnetic Energy Storage unit and Proportional Integral Derivative Control," *2020 2nd International Conference on Smart Power & Internet Energy Systems (SPIES)*, Bangkok, Thailand, 2020, pp. 281-286, DOI: 10.1109/SPIES48661.2020.9242922

[7] R. S. Utami, A. Abu-Siada, Suwarno, N. Hariyanto, M. R. Djalal and J. Hartono, "Optimal Tuning of Unified Power Flow Controller Using Firefly Algorithm to Improve Damping of Inter-Area Oscillations in Multi-Machine System," *2020 2nd International Conference on Smart Power & Internet Energy Systems (SPIES)*, Bangkok, Thailand, 2020, pp. 436-441, DOI: 10.1109/ SPIES48661.2020.9243095

[8] Q. Aliklas, N. Satyahadewi, and H. Perdana, "Penerapan Algoritma Max-Min Ant System Dalam Penyusunan Jadwal Mata Kuliah Di Jurusan Matematika Fmipa Untan," *BIMASTER: Buletin Ilmiah Matematika, Statistika dan Terapannya*, vol. 8, no. 2, pp. 273-280, 2019, DOI: 10.26418/bbimst.v8i2.32351

[9] M. R. Djalal and F. Faisal, "Design of Optimal PID Controller for Three Phase

Induction Motor Based on Ant Colony Optimization," *SINERGI*, vol. 24, no. 2, pp. 125-132, 2020, DOI: 10.22441/sinergi.2020.2.006

[10] A. M. Shiddiq Yunus and M. Ruswandi Djalal, "Optimal Tuning of PID Control on Single Machine Infinite Bus Using Ant Colony Optimization," *2019 International Conference on Technologies and Policies in Electric Power & Energy*, Yogyakarta, Indonesia, 2019, pp. 1-6, DOI: 10.1109/IEEECONF48524.2019.9102569

[11] R. D. Muhammad and H. Herman, "Speed Control Series Dc Motor Using Ant Colony Optimization," *Techno*, vol. 20, no. 2, pp. 105-116, 2019, DOI: 10.30595/techno.v20i2.4531

[12] M. R. Djalal, M. Y. Yunus, H. Nawir, and A. Imran, "Application of Smart Bats Algorithm for Optimal Design of Power Stabilizer System at Sengkang Power Plant," *International Journal of Artificial Intelligence Research*, vol. 1, no. 2, pp. 47-53, 2017, DOI: 10.29099/ijair.v1i2.26

[13] M. R. Djalal, M. Y. Yunus, H. Nawir, and A. Imran, "Optimal Design of Power System Stabilizer in Bakaru Power Plant Using Bat Algorithm," *JEEE-U (Journal of Electrical and Electronic Engineering-UMSIDA),* vol. 1, no. 2, p. 40-44, 2017, DOI: 10.21070/jeee-u.v1i2.10017

[14] Suharto, "Penalaan Power System Stabilizer (PSS) Untuk Perbaikan Stabilitas Dinamik Pada Sistem Tenaga Listrik Menggunakan Bat Algorithm (BA)," *Thesis*, ITS Surabaya, 2015

[15] M. R. Djalal and S. Sonong, "Penalaan PSS pada Sistem Generator Tenaga Menggunakan Algoritma Penyerbukan Bunga," *Jurnal Teknologi dan Sistem Komputer*, vol. 6, no. 3, pp. 93-99, 2018, DOI: 10.14710/jtsiskom.6.3.2018.93-99

[16] A. M. S. Yunus, A. Abu-Siada, M. R. Djalal and J. X. Jin, "Optimal Design of SMES and PSS for Power System Stability based on Ant Colony Optimization," *2020 IEEE International Conference on Applied Superconductivity and Electromagnetic Devices (ASEMD)*, Tianjin, 2020, pp. 1-2, DOI: 10.1109/ASEMD49065.2020.9276201

[17] Y. A. M. S. Yunus, R. D. Muhammad, and S. A. Yusri, "SMIB stability enhancement using capacitive energy storage and PID based on ant colony optimization," *IOP Conference Series: Earth Environment Science,* vol. 575, ID: 012241, 2020

[18] H. D. Laksono and I. R. Putra, "Analisa Performansi Single Machine Infinite Bus (SMIB) dengan Metoda Linear Quadratic Regulator (LQR) (Studi Kasus: PLTA Singkarak)," *Teknika*, vol. 20, no. 2, pp. 53-60, 2013

[19] I. Robandi, *Modern Power System Control*, Penerbit ANDI, Yogyakarta, 2009

[20] K. R. Padiyar, *Power System Dynamics*, John Wiley & sons Ltd, Interlaine Publishing Ltd, 1996

[21] M. R. Djalal and H. HR, "Bat Algorithm Implementation to Optimally Design the Stabilizer Power System on The SUPPA Generator," *SINERGI,* vol. 23, no. 3, p. 233-238, 2019, DOI: 10.22441/sinergi.2019.3.007