Optimal Tuning of PID Control on Single Machine Infinite Bus Using Ant Colony Optimization

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***Abstract*—Sudden changes in the load on the electric power system will cause a dynamic disturbance. This interference causes the generator stability to be disrupted because the generator does not respond to the interference quickly. This causes oscillations in the generator in the form of frequency oscillations and rotor angles. One additional control equipment that can improve the stability of a generator is the Power System Stabilizer (PID). When there is a disturbance oscillation on the generator, the PID provides an additional signal to the excitation equipment to provide additional attenuation to the generator. The use of PID is needed to coordinate the determination of the right parameters to achieve good performance control for the system. In the application, the determination of PID parameters still uses the trial & error method, this method is very difficult to get the right parameters. To solve this problem, here the author uses one of the computational techniques (soft computing) artificial intelligence, namely the Ant Colony Optimization (ACO) algorithm to optimize the tuning of the PID parameters. From the simulation results, the optimal PID parameters obtained are P (Proportional) of 53.4899, I (Integral) of 14.6551, and D (Derivative) of 10.5383. With optimal tuning, the SMIB frequency response is perfect compared to the system without PID trial error control and control, this is indicated by the system response that has improved, where the controller is able to provide stability so that the overshoot oscillation can be muted, and the settling time performance is faster for the system goes to steady-state condition. By tuning the right PID parameters, Overshoot that occurs in this system can be muted that is equal to -0.0002609 up to 0.0001954.**

Keywords—Power system stabilizer, Ant Colony Optimization, Eigenvalue, SMIB, Settling Time, Overshoot.

I. INTRODUCTION

In a dynamic stability study, it is assumed that the torque change due to the governor's responder is ignored because the governor's response is very slow compared to the excitation system response, so the controlling factor is the excitation system. The addition of strengthening excitation circuits is less able to stabilize the system, especially for low-frequency oscillations. Low-Frequency Oscillation between 0.2 to 2.0 Hz[1]. Lower frequencies can be expanded to become inter-area oscillations so that additional controls are needed such as PID controls. PID is an additional control tool that serves to reduce fermentation oscillations and voltages locally or globally at the generator, in response to deviations that occur in the value of the variable that has been set[2]. To obtain maximum results, precise and optimal tuning of the PID is needed to reduce oscillation and stabilize the system as a system stability response. Tuning these parameters can use intelligent method optimization, or commonly called artificial intelligence. One smart method is adopted from animal behavior in looking for something.

Ant-Colony Optimization (ACO) is included in the Swarm Intelligence group, which is one type of paradigm development used to solve optimization problems where the inspiration used to solve the problem comes from the behavior of a group or insect swarm[3]. Each ant in a walking herd will leave a pheromone (a kind of chemical) in the path it passes. This Pheromone is a signal for fellow ants. Short paths will leave a stronger signal. The next ant, when deciding which path to choose, will usually tend to choose to follow the path with the strongest signal, so that the shortest path will be found because more ants will pass through the path. The more ants that pass a path, the stronger the signal on that line. The use of the ACO method was also used in this study as a method to tune the PID control parameters. Several studies have explained the implementation of intelligent methods for optimizing generator control parameters and the results given to the system are very good at maintaining generator stability, such as the firefly method[4], bat algorithm [5-7], flower pollination [8], imperialist competitive [2], and cuckoo search [9, 10]. Fitting parameter values of a controller will significantly affect the system stability. However, the parameters range might be quite large and unique from one system to another. Therefore to find the fitness value of the parameters, ACO is employed. The response values can be evaluated simply by analyzing the overshoot and the settling time. Moreover, the objective function of this technique could minimize Integral Time Absolute Error (ITAE). Single Machine Infinite Bus (SMIB) is used as a case study where it consists of one or more generators that are connected to the infinite bus [11]. The analysis is done by comparing the simulation results of the system without PID, with PID and with PID tuning using ACO.

In research [11, 12] discusses the control of the Power System Stabilizer on the SMIB system. In research [13], it discusses the implementation of PID control in the SMIB system, by tuning the PID parameters using a trial-error method. In research [14], it discusses the implementation of PID control on SMIB by optimizing the PID tuning based on the firefly method. The intelligent algorithm-based tuning method is an inspiration for the authors to propose a new method for tuning PID parameters in the SMIB system, which in this study will use an ACO-based method. Several other studies that implement smart methods for tuning the SMIB system such as using genetic algorithm [15], from the optimal tuning results produce a good SMIB performance.

II. SYSTEM MODELING

All systems used in this paper are modeled, simulated and conducted using Matlab/Simulink. The models involved in this study are elaborated as follows:

A. System Model

System single machine infinite bus (SMIB) used in this paper is based on the system studied in Ref [12]. The model of the synchronous machine is shown in Fig. 1. [12].

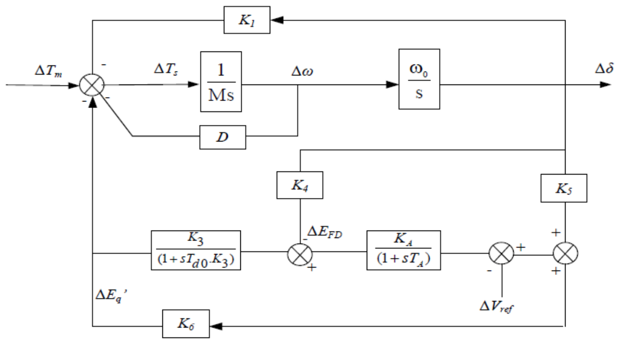

Fig. 1. A linear model of synchronous machine

B. Excitation Model System.

Excitation device is one of important part in a generator system. It uses to variable output of generators such as voltage, current, and power factor [4]. This model is referred to as the IEEE model as exhibits in Fig. 2 [12].

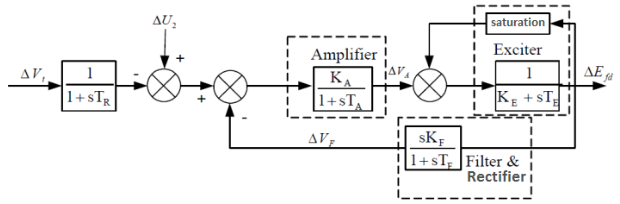

Fig. 2. Excitation block diagram

C. Governor Model

Governor is a controller to control mechanical torque (Tm) which becomes an input for a generator [12]. The governor model is depicted in Fig. 3.

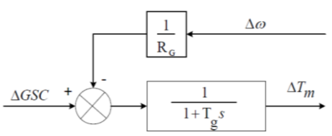

Fig. 3. Governor model

D. Turbine Model

In this paper, a model of IEEE steam turbine model is used [13] that can be seen in Fig. 4.

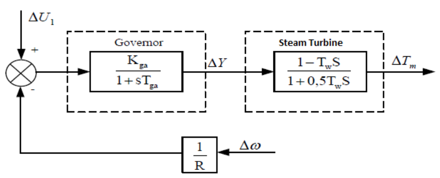

Fig. 4. Turbine model

E. Single Machine Infinite Bus (SMIB) Model

The overall model of the system under study is shown in Fig. 5

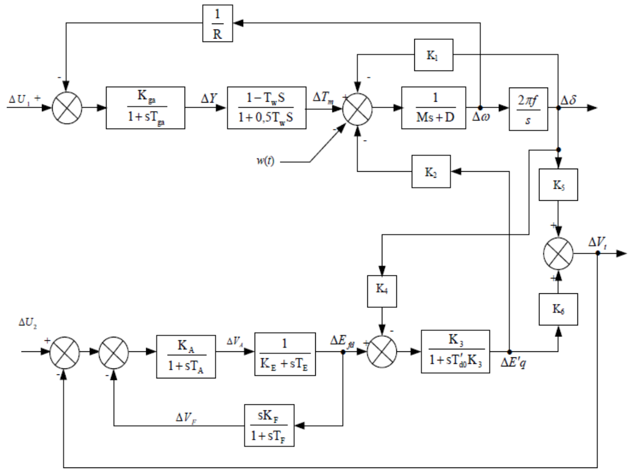

Fig. 5. SMIB model

III. ANT COLONY OPTIMIZATION (ACO)

Ant colony optimization (ACO) algorithm has several steps to perform before fit with the best optimal result as elaborated as follows:

- Determination of the distance between cities

  City in this term is aimed for representing the value of generation of each generator. Before traveling, the distance between the value of generation and the others is initiated first. After that, ants are placed in the first city randomly. Ants then will continue to travel from one city to another until reaching the final city destination randomly. At the end of the journey, the location of passed cities will be used to count the solution that yielded from the journey.

- Ants journey

  An ant chooses a lane starts from *r* to *s* in a tour with probability:

$$p(r,s) = \frac{\gamma(r,s)}{\sum_{t} \gamma(r,l)} s, l \in N_r^k \tag{2}$$

  Matrix γ(r,s) represents the intensity of pheromones between point *r* and *s*. After that, pheromones will be updated through the following equation:

$$\gamma(r,s) = \alpha \cdot \gamma(r,s) + \Delta y^k(r,s) \tag{3}$$

  Where α with interval 0 < α < 1 is pheromones endurance, and (1- α) represents evaporation of pheromones and $\Delta\gamma^k(r,s)$ is a number of pheromones where the ants drop at the lane (r,s).

- Pheromones local update

  Pheromones track (r, s) for the best journey of the ants (which will be used to obtain the optimal PID parameters) will be updated using the following equation:

$$\gamma(r,s) = \alpha \cdot \gamma(r,s) + \frac{Q}{f_{best}} r,s \in J^k_{best} \quad (4)$$

Where Q is a positive constant with a very large value.

- Pheromones global update

  To avoid stagnancy (a situation where the ant follows the same track that yielding the same solution), the gain of pheromones track is limited within the interval stated below:

$$\gamma(r,s) = \left\{ \begin{array}{l} \tau_{min} \text{ if } \gamma(r,s) \le \tau_{min} \\ \tau_{max} \text{ if } \gamma(r,s) \ge \tau_{max} \end{array} \right\} \quad (5)$$

Where the upper limit and lower limit are formulated as follows:

$$\tau_{max} = \frac{1}{\alpha \cdot f_{best}} \quad (6)$$

$$\tau_{min} = \frac{\tau_{max}}{M^2} \quad (7)$$

Where M is the number of ants which are traveling.

- Ants travel plot

  The solution of ants colony travel in PID parameters optimization will be plotted into a graph until the maximum of iteration limit.

- Best ants tour plot

  Travel with the best solution from the ant colony for every iteration will be plotted until the maximum iteration limit.

- Flowchart of Ant Colony Optimization

  Flowchart for the optimization process in finding the optimal PID parameters is shown in Fig. 4.

- Parameters of Ant Colony Optimization

  Parameters used for Ant Colony Optimization in this paper are listed in Table 1.

TABLE I. PARAMETER OF ANT COLONY

Parameters	Values
Number of Ants	6
Max Iteration	50
Feromone (Alpha)	0.9
Beta	2

- Tuning Control of PID using ACO

  Fig. 7 shows the algorithm flowchart of ACO to tune the PID parameters. The objective function used to examine the system stability is Integral Time Absolute Error (ITAE).

$$ITAE = \int_0^t t\left|\Delta\omega(t)\right| dt \quad (8)$$

The PID parameters tuned by Ant Colony are Kp, Ki, and Kd. The flow diagram of the PID parameter tuning process using the Ant Colony method is shown by the flowchart in Figure 8 and Figure 6 shows the modeling of SMIB in Simulink Matlab 2013, without control, with PID Trial and PID Ant Colony.

To run the Ant Colony algorithm several parameters are needed, which are mentioned in the following table. The ant colony algorithm is made using Matlab software (m.files) and SMIB modeling using Simulink Matlab. The data for ant colony parameters are shown in Table 1.

After entering some of the parameters in the table above, then the ant colony algorithm is executed to optimize the PID value of the controller. The right value will greatly affect the performance of the SMIB response designed in this study. The ant colony algorithm requires a calculation process to find the optimal value. The following figure shows a convergence graph optimization of PID values using the ant colony algorithm. Convergence is a fitness value function that describes the optimal criteria for an optimization problem.

Figure 6 shows a convergence graph of optimization of PID values using ant colony, where according to the graph it appears that the ant colony algorithm does not require a long time in the optimization process. e-08. For full results can be seen in table 2.

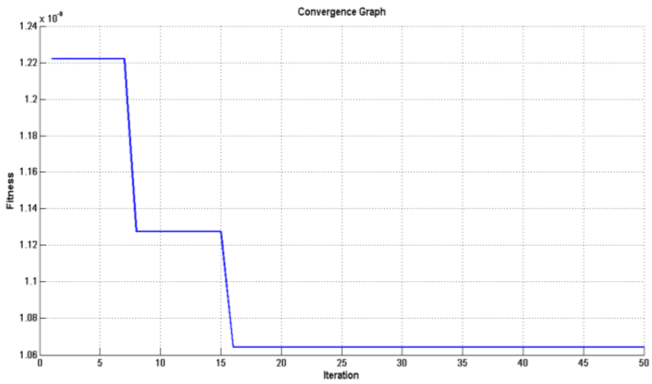

Fig. 6. Convergence Graph

The results of the ant colony optimization obtained a fitness function value of 1.0642e-08, with 50 iterations converging at the 16th iteration, the best value was the best ant colony, which is known as the PID parameter optimization, Kp, Ki, and Kd. Table 2 shows the results of the optimization of PID parameters tuned by the ant colony. As a comparison used controls run by way of trial errors or trial and error. The Ant Colony algorithm in principle searches for food sources based on traces of feromone which then in groups will follow the footsteps that have the largest feromone. With this principle, the algorithm will find the most optimal parameters to be filled in the PID parameters, so that optimal control is obtained in the SMIB.

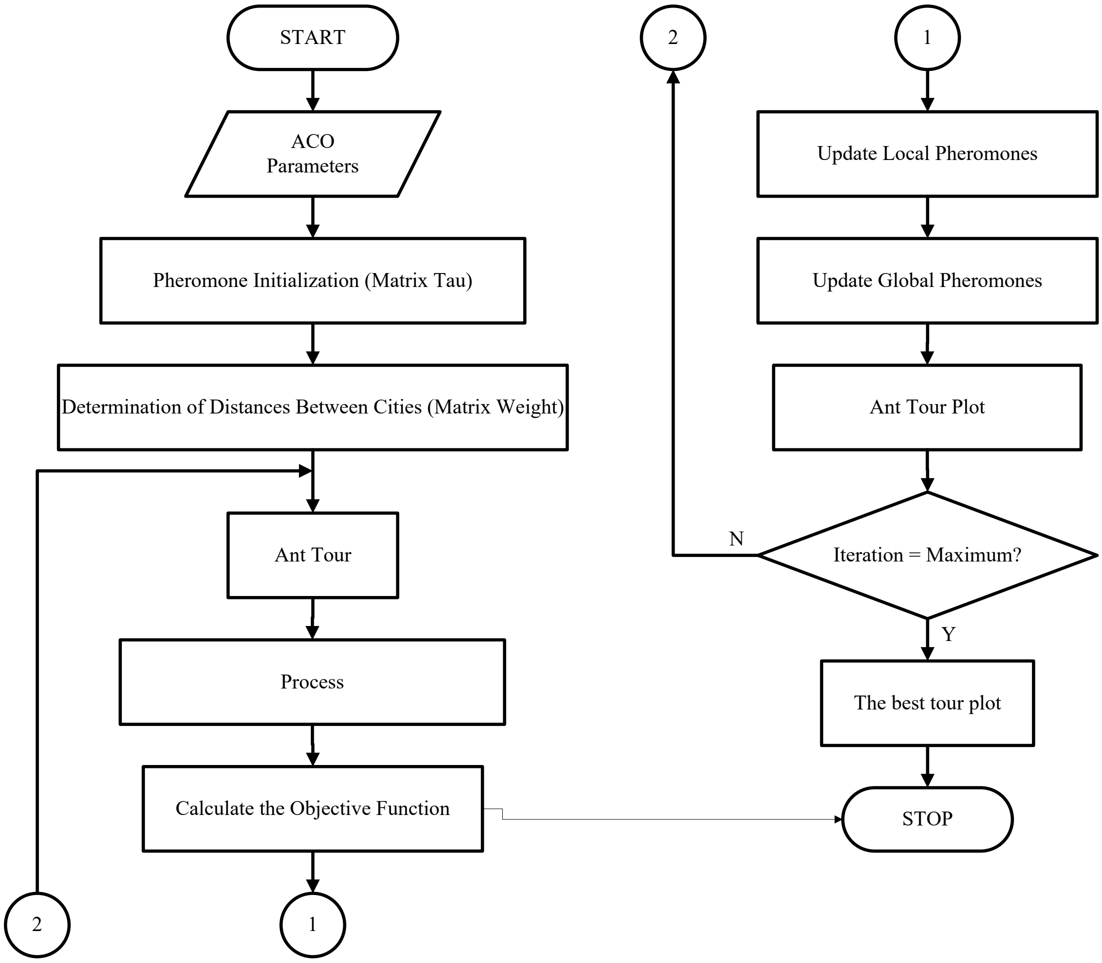

Fig. 7. Flowchart of ACO

IV. Results and Discussion

System analysis is done with several approaches, namely, such as the SMIB system without control, with PID control trial-error method, and with the proposed method of PID tuning using the ant colony method.

A. SMIB Frequency Response Without Control

The first analysis begins by reviewing the response of the SMIB stability to a system without control. The simulation results are shown in the following figure.

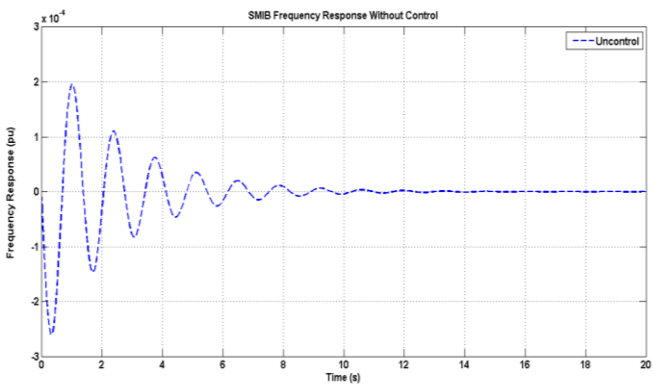

Fig. 8. SMIB response without a controller

Figure 8 shows the results of the SMIB simulation without a controller, obtained a very slow SMIB frequency response, indicated by a high overshoot and a long settling time. This is because the system does not have a frequency controller. The simulation results of this uncontrolled system are used as a reference for designing PID-based SMIB controls run with intelligent algorithms using Ant Colony Optimization, and as a comparison, the PID method is trial-error / trial. From the SMIB simulation without control, the SMIB overshoot frequency oscillation parameter is -0.0002611 up to 0.0001957. From the results of the uncontrolled SMIB simulation, this is used as an initial reference for designing systems with PID controllers based on intelligent methods of the ant colony.

B. Frequency Response SMIB PID Control Trial Error

The next analysis looks at the frequency response performance of the SMIB with the installation of the PID control, where the PID parameters tuned using the trial error method, along with the simulation results. Table 2 shows the results of PID tuning using the trial-error method.

TABLE II. TUNING RESULTS OF PID

Method	Kp	Ki	Kd
Trial Error	4.8818	2.7438	2.0190

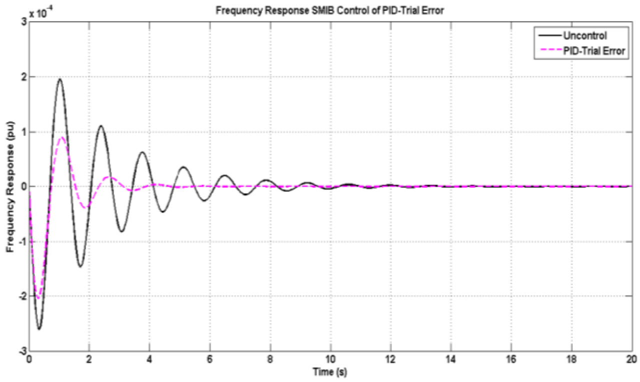

Fig. 9. SMIB frequency response with Trial PID

Figure 10 shows the simulation results of the PID trial error controller, obtained a better SMIB frequency response compared to a system without control, indicated by reduced overshoot and faster settling time. From the PID control SMIB simulation running by trial error, the oscillation frequency SMH overshoot parameter is - 0.000206 up to 9.222e-05. PID performance on this system can still be optimized with the right tuning. In this method the parameters Kp = 4.8818, Ki = 2.7438, and Kd = 2.0190. This parameter is not optimal in principle because the system performance still has an oscillation error in SMIB overshoot.

C. Frequency Response SMIB with PID Ant Colony Optimization

The next simulation is the SMIB control using PID which runs using the ACO algorithm, along with the simulation results. Table 3 shows the PID tuning results using the ant colony method.

TABLE III. TUNING RESULTS OF PID WITH ACO

Method	Kp	Ki	Kd
Ant Colony	53.4899	14.6551	10.5383

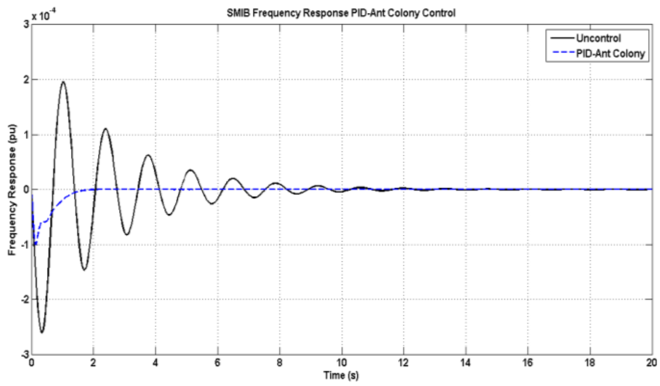

Fig. 10. SMIB frequency response with ACO- PID

Figure 10 shows the simulation results with the PID controller tuned with the smart ant colony method, with t = 10. From this design the frequency response of the SMIB is perfect compared to the system without PID trial error control and control, this is indicated by the system response that has improved, where the controller is able to provide stability so that the oscillation overshoot is muted, and the settling time performance is faster for the system to go to a steady-state condition. By tuning the right PID parameters, Overshoot that occurs in this system can be muted that is equal to -0.0002609 up to 0.0001954. Following is the comparison chart of SMIB controls.

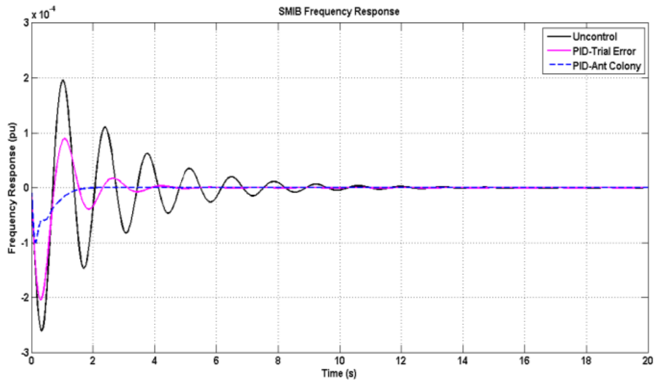

Fig. 11. Comparison of Frequency Response SMIB

The Ant Colony algorithm in principle searches for food sources based on traces of feromone which then in groups will follow the footsteps that have the largest feromone. 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 on the SMIB frequency. In the results of the intelligent method tuning, the optimal PID parameter is obtained, the P (Proportional) parameter is 53.4899, I (Integral) is 14.6551, and D (Derivative) is 10.5383. With the optimal combination of parameters, the optimal performance of the SMIB frequency response is obtained, indicated by a fast response of SMIB settling time-frequency and minimum overshoot compared to the PID trial and controlless systems.

The SMIB application is very much used with a combination of PID controls, so the right SMIB controller design is needed, in this case, it is highly recommended to use the PID controller because it is very simple to control the system by tuning parameters using the right intelligent method to get good performance.

V. CONCLUSION

From the simulation results, the optimal PID parameters obtained by ant colony tuning are P (Proportional) of 53.4899, I (Integral) of 14.6551, and D (Derivative) of 10.5383. By optimally tuning the SMIB frequency response is perfect compared to the system without PID trial error control and control, this is indicated by the system response that has improved, where the controller is able to provide stability so the oscillation overshoot is muted, and the settling time performance is faster for the system to go to steady-state condition. By tuning the right PID parameters, Overshoot that occurs in this system can be muted that is equal to -0.0002609 up to 0.0001954.

REFERENCES

[1] P. Kundur, *Power system stability and control* vol. 7.

[2] 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," in *Intelligent Technology and Its Applications (ISITIA), 2015 International Seminar on*, 2015, pp. 147-152.

[3] Q. Aliklas, N. Satyahadewi, and H. Perdana, " The Application of Max-Min Ant System Algorithm in the Compilation of Course Schedules in the Mathematics Department of Fmipa Untan," *BIMASTER,* vol. 8.

[4] 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, pp. 250-259, 2017.

[5] 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, 2017.

[6] M. R. Djalal, M. Y. Yunus, H. Nawir, and A. Imran, "Optimal Design of Power System Stabilizer In Bakaru Power Plant Using Bat Algorithm," *2017,* vol. 1, p. 6, 2017-11-10 2017.

[7] Suharto, "Power System Stabilizer (Pss) Tuning For Dynamic Stability Repair On Electricity System Using Bat Algorithm (Ba)," Undergraduate, ITS Surabaya, 2015.

[8] M. R. Djalal and S. Sonong, "PSS Tuning in Power Generator Systems Using Interest Pollination Algorithms," *Jurnal Teknologi dan Sistem Komputer,* vol. 6, pp. 93-99, 2018.

[9] 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, pp. 800-812, 2017.

[10] 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, pp. 1-8, 2018.

[11] A. Kharrazi, "Tuning of power system stabilizer in Single Machine Infinite Bus (SMIB) using genetic algorithm and Power Factory Modal Analysis," in *2015 Australasian Universities Power Engineering Conference (AUPEC)*, 2015, pp. 1-6.

[12] B. S. Surjan and R. Garg, "Power system stabilizer controller design for SMIB stability study."

[13] B. S. Surjan, "Linearized modeling of single machine infinite bus power system and controllers for small signal stability investigation and enhancement," *International Journal of Advanced Research in Computer Engineering & Technology (IJARCET),* vol. 1, pp. 21-28, 2012.

[14] Z. Farhad, E. Ibrahim, S. S. Tezcan, and S. J. Safi, "A robust PID power system stabilizer design of single machine infinite bus system using firefly algorithm," *Gazi University Journal of Science,* vol. 31, pp. 155-172.

[15] E. F. Shair, S. Y. Khor, A. R. Abdullah, H. I. Jaafar, N. Mohd Ali, and A. F. Zainal Abidin, "A brief review of Cuckoo Search Algorithm (CSA) research progression from 2010 to 2013," *International Review of Automatic Control (I. RE. A. CO.),* vol. 7, pp. 428-435, 2014.