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# DESIGN OF OPTIMAL PID CONTROLLER FOR THREE PHASE INDUCTION MOTOR BASED ON ANT COLONY OPTIMIZATION

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***Abstract --*** *Speed control of an induction motor is an important part of the operation of an induction motor. One method of regulating motor speed is the addition of a PID controller. PID parameters must be tuned properly to get the optimal speed. In this study, the PID controller tuning method uses an artificial intelligence method based on Ant Colony Optimization (ACO). ACO algorithm in an intelligent algorithm that is inspired by the behavior of ants looking for food sources in groups with traces of pheromone left behind. In this study, food sources are represented as optimal parameters of PID. From the computational results obtained optimal parameters respectively, P (Proportional) 0.5359, I (Integral) 0.1173, D (Derivative) 0.0427. ACO computing found the optimal parameters in the 21st iteration with a minimum fitness function of 11.8914. Case studies are used with two variations of the speed of the induction motor input. With optimal tuning, the performance of the induction motor is increasing, marked by a minimum overshoot of 1.08 pu and a speed variation of both overshoots of 1,201 pu, whereas without control 1.49 pu and 1.28 pu, as well as with PID trial control of 1.22 pu and 1.23 pu respectively. The benefits of this research can be used as a reference for the operation of induction motors, by tuning the Ant Colony intelligent method for the PID controller in real-time with the addition of microcontroller components.*

***Keywords:*** *PID; Ant Colony Optimization; Overshoot; Settling Time; Induction Motor.*



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## INTRODUCTION

The optimal operation of induction motors in the industrial sector is increasingly being studied. Several control methods were developed to get optimal performance. One of them is by using Proportional Integral Derivative (PID) control [1] [2].

Research on regulating the speed of the electric motor by optimizing the PID motor controller has been done. The conventional optimization method to the intelligent method has been widely applied to the optimization of electric motor PID parameters, such as Artificial Bee Colony [3], Cuckoo Search, Particle Swarm, Neural Network, Firefly, and Flower Pollination [4] [5, 6, 7, 8, 9, 10, 11]. While specifically on the induction motor, the use of intelligent methods including, Particle Swarm Optimization [12], Genetic Algorithm [13], Fuzzy Logic [14], Bacterial Foraging [15], and Simulated Annealing [16].

In this study, another artificial intelligent method will be used to tune the parameters of the PID of the induction motor, namely the Ant Colony Optimization (ACO) method [17, 18, 19]. The system will be analyzed and compared to the speed response of the induction motor with the conventional method of trial-error PID and induction motor without a controller. The ACO algorithm for optimizing is very accurate, faster, convergence with a minimum fitness function.

## METHOD

This research consists of several stages, including the creation of an intelligent algorithm on the MATLAB m-file software, modeling of an induction motor on a MATLAB Simulink, modeling a PID controller, and implementing an intelligent algorithm and an induction motor. They are described in the following sections.

### Induction Motor Modeling

The induction motor modeling in this study uses a squirrel cage type induction for the motor model. Some parameters of the induction motor are sourced from previous studies and are shown in Table 1 [20].

Table 1. Physical Specifications of the Squirrel Cage Induction Motor [20]

| Variable | Specifications | Value | Notation |
|---|---|---|---|
| $_n$ | Rated source voltage | 230 | *Volt.* |
| $P$ | Number of Poles | 2 | - |
| $f_s$ | Stator Frequency | 60 | *Hz* |
| $J_{eq}$ | Stator inertia | 0.3 | *Kg.m$^2$* |
| $R_s$ | Stator Resistance | 0.08 | *Ohm* |
| $R_r$ | Rotor Resistance | 0.04 | *Ohm* |
| $L_s$ | Stator Inductance | 15.4 | *mH* |
| $L_r$ | Rotor Inductance | 16.38 | *mH* |
| $L_m$ | Magnetic Inductance | 14.60 | *mH* |
| $S$ | Slip | 0.02 | - |
| $B_m$ | Coefficient of Friction | - | *$N_m$/rad/sec* |

The values of these parameters will then be substituted in the form of a function instead of the equation above as an induction motor transfer function, which will be completed and refined with the controller output specifications, as shown in Equation (1).

$$\frac{\omega_m(s)}{V_{sd}(s)} = \frac{1.78}{0.72x10^{-3}s^2 + 0.0157s + 3.168} \quad (1)$$

$$\frac{\omega_m(s)}{V_{sd}(s)} = \frac{2470}{s^2 + 21.79s + 4400} \quad (2)$$

Based on Equation (2), the induction motor modeling can be modeled on Simulink, as shown in Figure 1.

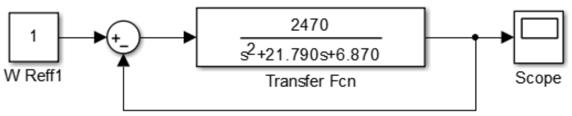


Figure 1. Model of an induction motor in Simulink

### PID Controller Modeling

PID control is a type of controller that is widely used in the industry as an induction motor controller because of its simple structure [2]. The PID controller can be shown by Equation (3).

$$u(t) = k_p[e(t) + \frac{1}{T_i}\int_0^t e(t)dt + T_d\frac{de_t}{dt}] \quad (3)$$

Where u (t) is the control value calculated by the PID controller, Kp is the proportional coefficient, Ti is the time integral, and Td is the time differential constant. The functions of the three elements are:

- The Proportional functions to produce an immediate control effect and reduce the deviation.
- The Integral functions to increase system stability and eliminate static errors.
- The Differential functions to speed up the system response to reduce time management. This gain reflects changes in the signal drift, introducing the correction signal before the signal deviation becomes larger.

The correct PID parameter requires a tuning configuration design. In this study, the Ant Colony smart method is used for optimal PID parameter optimization. The following model block diagram of the control system is shown in Figure 2.

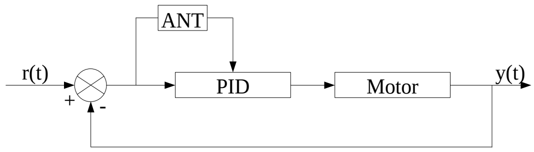


Figure 2. PID Controller System

### Ant Colony Optimization - Ant Tour

The ant chooses the path to be passed from point r to point s on its way with probability:

$$p(r,s) = \frac{\gamma(r,s)}{\sum_t \gamma(r,l)} s, l \in N_r^k \quad (4)$$

The matrix γ (r, s) represents the amount of pheromone intensity between points r and s. Then the pheromone will be updated through the following Equation (5).

$$\gamma(r,s) = \alpha \cdot \gamma(r,s) + \Delta y^k(r,s) \quad (5)$$

Where α at 0 <α <1 is the pheromone resistance, then (1- α) represents the evaporation that occurs in the pheromone and Δγk (r, s) is the number of pheromones the ants drop on the path (r, s).

### Local Pheromone Updates

Local Pheromone Update Pheromone traces (r, s) for the best trips that ants have taken (ants that produce optimal PID parameters) will be updated using Equation (6).

$$\gamma(r,s) = \alpha \cdot \gamma(r,s) + \frac{Q}{f_{best}} r, s \in J_{best}^k \quad (6)$$

Where Q, a positive constant with a large value.

### Pheromone Global Update

Ants will follow the path to avoid the situation of the ants following the same path), which will result in the same solution. Pheromone strength will be limited to Equation (7).

$$\gamma(r,s) = \begin{cases} \tau_{\min} \; if \; \gamma(r,s) \leq \tau_{\min} \\ \tau_{\max} \; if \; \gamma(r,s) \geq \tau_{\max} \end{cases} \tag{7}$$

The upper and lower limits are as follows:

$$\tau \frac{1}{\alpha \cdot f_{best_{max}}} \tag{8}$$

$$\tau \frac{\tau_{max}}{M^2}_{min} \tag{9}$$

Where M, the number of ants that travel.

### Ant Travel Plot

The solution of the ant colony's journey in optimizing the PID parameters is plotted into the graph to the maximum iteration limit.

### The best travel plot

Travel with the best solution of the ant colony (optimal PID parameters) for each iteration plotted to the maximum iteration limit.

### Ant Colony Optimization Flowchart

The flowchart of the Ant Colony Optimization method used to find the optimal PID parameters is shown in Figure 3.

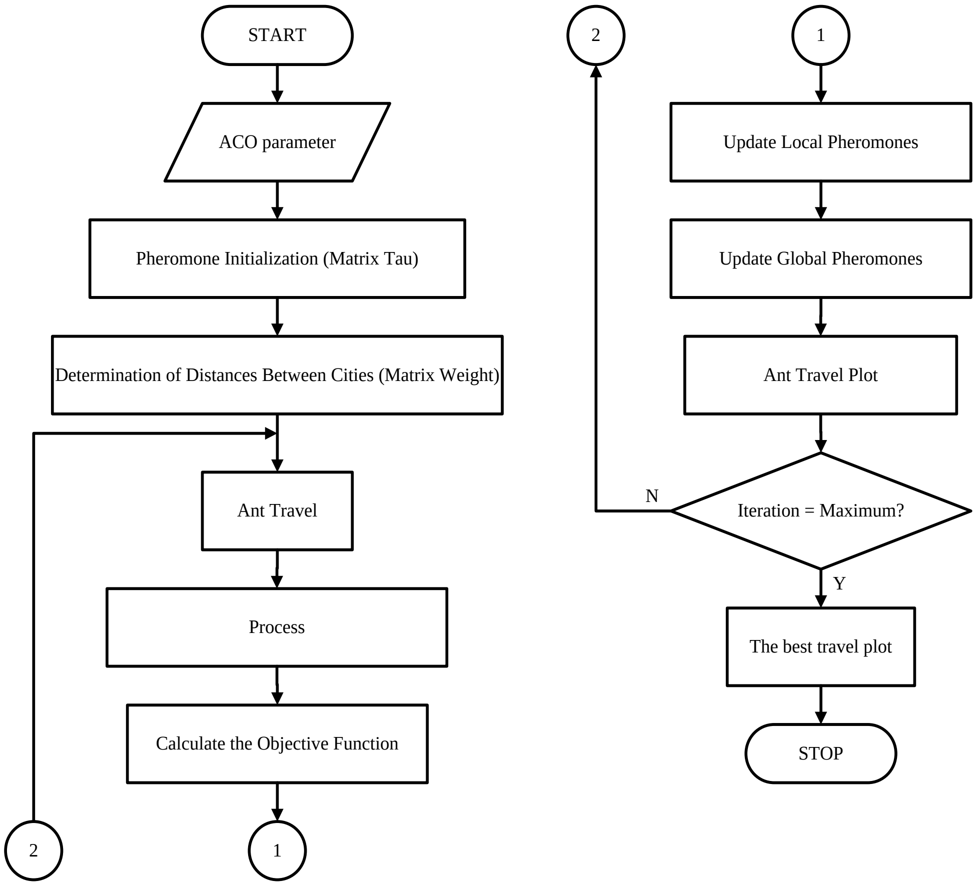


Figure 3. Ant Colony Flowchart

### Ant Colony Optimization Parameters

Some parameters used in the Ant Colony Optimization method in this study are as follows:

- Number of ants = 3
- Iteration max= 50
- Pheromone Resistance (Alpha)= 0.9
- Beta = 2

### Pheromone Initialization (Matrix Tau)

Matrix Tau has a size and a number of controllers in the system. However, the number of PID parameters on a scale of 0 to 1 has an interval of 0.01. The value of this matrix will be updated every time the ant colony travels.

### Tuning PID Control with Ant Colony

Figure 4 shows the flow diagram of the Ant Colony method algorithm used in this study to adjust the PID parameters. The objective function used to test system stability is Integral Time Absolute Error (ITAE).

$$ITAE = \int_0^t t|\Delta\omega(t)|dt \quad (10)$$

The PID parameters set by Ant Colony are Kp, Ki, and Kd. The flow diagram of the PID parameter adjustment process using the Ant Colony method shown by the flow diagram in Figure 3 and Figure 4 show the induction motor modeling on the 2013 Simulink MATLAB, without control, with the PID Trial Test and the Ant PID Colony.

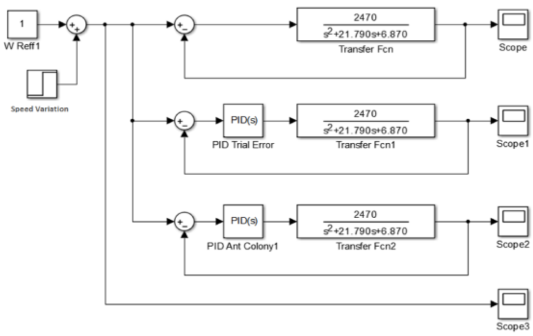


Figure 4. Modeling of an induction motor in Simulink

Several parameters are needed to run the Ant Colony algorithm, which is mentioned in the following Table 2. The ant colony algorithm was created using MATLAB software (m.files) and motor modeling using MATLAB Simulink. The ant colony parameter data is as follows,

After entering several parameters in Table 2, the next ant colony algorithm is run to optimize the PID value of the controller. The right value will greatly affect the performance of the response of the induction motor designed in this study.

Tabel 2. Parameter ant colony

| Parameters | Values |
|---|---|
| Number of Ants | 3 |
| Max Iteration | 50 |
| Pheromone (Alpha) | 0.9 |
| Beta | 2 |

The ant colony algorithm requires a calculation process to find the optimal value. Figure 4 shows the flow diagram of the ant colony algorithm in performing the optimal computing process of PID parameters. Then, starting from the initialization of the ant colony algorithm parameters, ant travel, local and global pheromone updates, and the best travel plots.

Figure 5 shows a graph of the convergence of the ant colony algorithm in optimizing the PID value for 50 iterations. From the optimization results, the ant colony algorithm found the optimal PID parameter in the 21st iteration, with a fitness function value of 11.8914. For complete results, see Table 3 and Figure 5.

Table 3. Optimization Results with ACO

| | | | |
|---|---|---|---|
| Total number of iterations | 50 | | |
| fmin | 11.8914 | | |
| T_best | 0.5359 | 0.1173 | 0.0427 |
| kp_ant | 0.5359 | | |
| ki_ant | 0.1173 | | |
| kd_ant | 0.0427 | | |

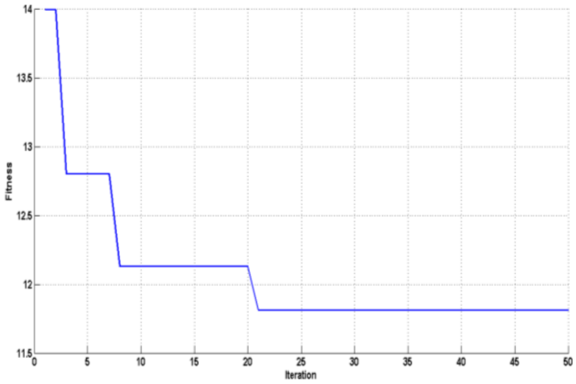


Figure 5. Graph of Convergence Optimization of PID Control of Induction Motor with Ant Colony Optimization (ACO)

Ant colony optimization results obtained the value of the fitness function of 11.8914, with 50 times iteration, the n best value is the best ant colony, which is known as the result of PID parameter optimization, namely Kp, Ki, and Kd. Table 4 shows the results of the optimization of the PID parameters optimized by the ant colony. As a comparison, PID control is used based on trial error or trial and error. Ant Coloni's algorithm, in principle, looks for food sources based on feromone traces, which then in groups will follow the trail that has the largest feromone. With this principle, the algorithm will find the most optimal parameters to be filled in the PID parameters, so that the optimal control of the speed of the induction motor is obtained, as listed in Table 4.

Table 4. PID Parameter Tuning Results

| Param. | Trial Error | Ant Colony |
|---|---|---|
| Kp | 0.8572 | 0.5359 |
| Ki | 0.7990 | 0.1173 |
| Kd | 0.0131 | 0.0427 |

## RESULTS AND DISCUSSION

### Induction Motor Speed Response without Control

The first analysis begins by looking at the performance of the induction motor without control. The following simulation results using MATLAB. With variations in changes in motor speed, the motor response will be seen in tracking the given setpoint.

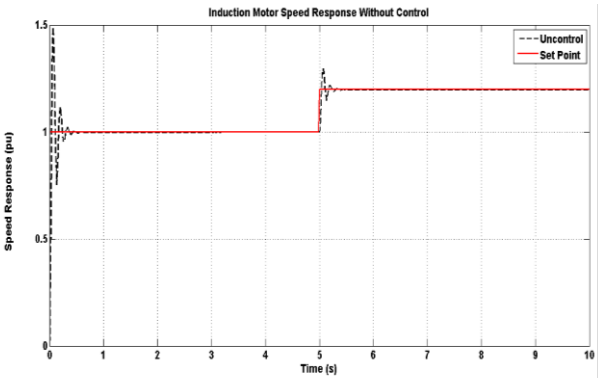


Figure 6. Induction Motor Speed Response without control, for t = 10s.

Figure 6 shows the results of the simulation without a controller with t = 10s; the response speed of the induction motor is very slow, not even reaching the setpoint that has been determined. This is because the system does not have a speed controller. The results of this uncontrolled system simulation are used as a reference for designing PID-based motor controls that are tracked with intelligent algorithms using Ant Colony Optimization, and as a comparison of PID methods used trial and error. The following are the results of the simulation of the control induction motor without control.

Table 5 shows the overshoot response of the induction motor speed without control, in which 2 case variations of speed are used.

Table 5. System Overshoot Response

| Case | Case Speed (pu) | Overshoot (pu) |
|---|---|---|
| 1 | Speed 1pu | 1.49 |
| 2 | Speed 1.2 pu (5s) | 1.28 |

In the first case, the speed variation is 1pu. The motor response experiences a maximum overshoot of up to 1.49pu. In the second case, the speed is raised to 1.2pu. The motor response is overshoot to 1.28pu. In addition to overshoot, system performance can also be viewed from the settling time criteria, which shows the long settling time for each speed variation to achieve the same conditions as the given setpoint. The system performance can also be seen when there is a change in speed at t = 5s, and the system experiences an overshoot oscillation before reaching the same steady-state as the setpoint, this will certainly interfere with the performance of the induction motor.

The results of the simulation of an induction motor without control are used as an initial reference to design a system with a PID controller based on the ant colony smart method.

### Induction Motor Speed Response with Full PID Trial Error

The next analysis looks at the performance of the induction motor speed response with the installation of the PID control, where the PID parameters are tuned using a trial error, following the results of the simulation.

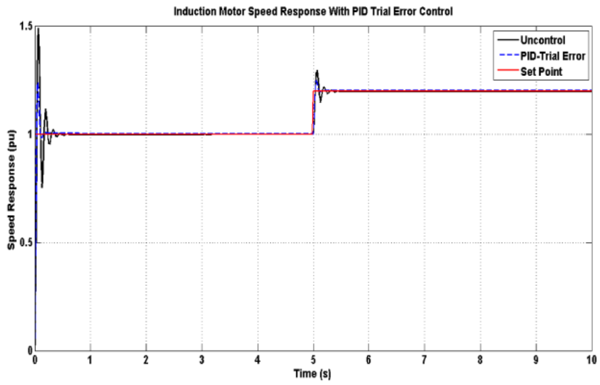


Figure 7. Induction Motor Speed Response with PID Trial, t=10s.

Figure 7 shows the simulation results with a PID controller run with trial error, with t = 10s. From this design, the response of the speed of the induction motor is improved compared to the uncontrolled system, indicated by a reduced overshoot. The following are the results of the simulation of induction motor control with PID trial error.

Table 6. System Overshoot Response

| Case | Case Speed (pu) | Overshoot (pu) |
|---|---|---|
| 1 | Speed 1pu | 1.22 |
| 2 | Speed 1.2 pu (5s) | 1.23 |

Table 6 shows the overshoot response of the motor speed induction control PID trial error, using the same case for two variations of speed. In the first case, the speed variation is 1pu, and the motor response experiences a maximum overshoot of up to 1.22pu. In the second case, the speed is raised to 1.2pu, and the motor response is overshoot to 1.23pu. In addition to overshoot, system performance can also be viewed from the settling time criteria, which shows an improved settling time compared to the uncontrolled system condition - shown with each variation of speed that is able to approach a given setpoint.

However, PID performance on this system can still be optimized with the right tuning. In this method the P (Proportional) parameter is 0.8572, I (Integral) is 0.7990, and D (Derivative) is 0.0131. This parameter is, in principle, not optimal because the system performance still contains errors from the set point that have been determined.

**Induction Motor Speed Response with PID Ant Colony Optimization**

The next simulation is the control of the induction motor using the PID, which is simulated using the ACO algorithm, with the results of the simulation.

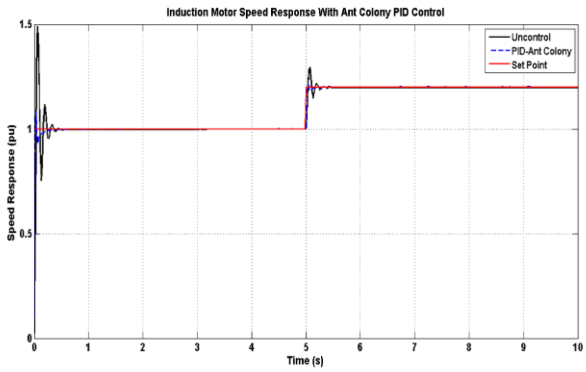


Figure 8. The response of induction motor speed with PID Ant-Colony, t=10s

Figure 8 shows the simulation results with the PID controller run by the ant colony smart method, with t = 10s. From this design, the perfect induction motor speed response is obtained compared to the system without control and PID trial error control; a reduced overshoot indicates this. The following are the results of the simulation of induction motor control with PID Ant Colony.

Table 7. System Overshoot Response

| Case | Case Speed (pu) | Overshoot (pu) |
|---|---|---|
| 1 | Speed 1pu | 1.08 |
| 2 | Speed 1.2 pu (5s) | 1.201 |

Table 7 shows the speed overshoot response of the Ant Colony PID control induction motor, using the same case for two-speed variations. In the first case, the speed variation is 1pu; the motor response only experiences a maximum overshoot of 1.08pu. In the second case, the speed is raised to 1.2pu; the motor response only overshoots up to 1,201pu. In addition to overshoot, system performance can also be viewed from the settling time criteria, which shows an improved settling time compared to an uncontrolled system condition and PID trial error. The status is shown with every variation in speed that can approach a given setpoint Figure 9 shows a comparison of induction motor control.

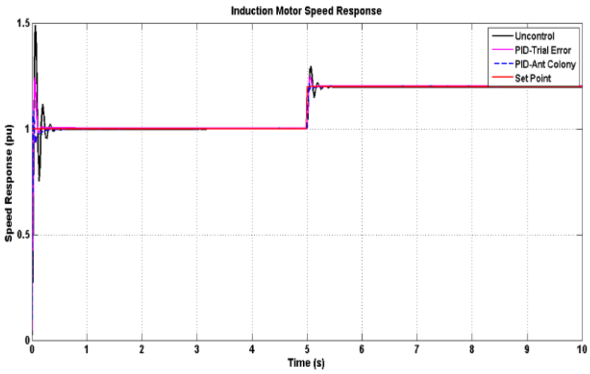


Figure 9. Comparison of Induction Motor Speed responses with PID Ant-Colony, t=10s

The working principle of the Ant Colony Algorithm is a group of ants looking for food sources based on the pheromone. Pheromone is a trail left by an ant, then a swarm of ants follows that trail. Based on this principle, the optimal parameters of PID are stunning, and an optimum induction motor performance will be obtained. The optimization results obtained PID parameters of each P (Proportional) of 0.5359, I (Integral) of 0.1173, and D (Derivative) of 0.0427. With this optimal parameter combination, the optimum response performance for induction motor speed is indicated by the settling time response of the fast motor speed and minimum overshoot compared to the PID trial method and the uncontrolled system.

The use of electric motors with PID controls has been increasingly developed. Therefore, it needs an optimal control mechanism to support the performance of induction motors by tuning of parameters properly. The combination of tuning with smart methods is very good for optimizing PID controllers.

**CONCLUSION**

Ant colony optimization results obtained the value of the fitness function of 11.8914, with 50 times iteration, and the optimal PID value parameter where the Kp parameter is 0.5359, Ki is 0.1173, and Kd is 0.0427.

ACO computing found the optimal parameters in the 21st iteration with a minimum fitness function of 11.8914. Case studies are used with two variations of the speed of the induction motor input. With optimal tuning, the performance of the induction motor is increasing, marked by a minimum overshoot of 1.08 pu and a speed variation of both overshoots of 1,201 pu, whereas without control 1.49 pu and 1.28 pu, as well as with PID trial control of 1.22 pu and 1.23 pu respectively.

The benefits of this research can be used as a reference for the operation of induction motors, by tuning the Ant Colony intelligent method for the PID controller in real-time with the addition of microcontroller components.

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