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# Robustness Analysis of Speed Control Method to Drive AC/DC Motor

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*Abstract* — **The development of industry in Indonesia has an impact on the increasing use of electric motors. There are two main types of motors, DC motor, and AC motor. Both motors have different characteristics according to the settings and controls. Proportional Integral control and Proportional Integral Derivative control are used for setting motor speed. This control has control parameters that are Kp, Ti, and Td. These parameters are derived from derivatives of mathematical calculations on the conventional PI and PID methods. However, determining these parameters can also be done with other methods. There are 4 PI and PID tuning methods t used to get effective control parameters and have the best performance: Ziegler Nichols tuning method, Chien Servo 1 tuning method, Chien Regulator 1 tuning method, and the last is mathematical calculation theory. The result is the best tuning method for DC Motor is the Chien Regulator 1 tuning method with a value of Kp = 5,601 and Ki = 56,01. And for induction motor, the best tuning method with PI control is Chien servo 1 tuning method with Kp = 0,433 and Ki = 4,163, and for PID control, the best tuning method is the Ziegler Nichols tuning method with Kp = 1,4833, Ki = 98,89 and Kd = 0,052, and get a steady-state error approximately is 4%. And when given the interference to the rotor of the motor, the Ziegler Nichols tuning method is the fastest to return the response to the steady state condition.**

*Keywords* — **Induction motor; DC motor; PI controller; PID controller; chien regulator; chien Servo; Ziegler Nichols.**

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## I. INTRODUCTION

Nowadays, the development of the Indonesian development industry is increasing rapidly. This also has an effect on increasing the use of electricity, especially in the industrial and power sectors. This progress has also increased the use of electric motors in the industrial world in all fields, both electric power plants and households. More than 70% of the production process utilizes the performance of an electric motor, both for the use of AC motors and DC motors [1].

AC and DC motors have different characteristics. DC motor is one of the electric motors that is often used as an electric vehicle drive because its speed is easily controlled and has a wide speed variation. If we use different load, the impact of the motor speed will be different [3-7]. Industrial AC motors has been used as the prime mover. The disadvantage of the induction motor is not able to maintain its speed constantly if there is a change in load [8-10]. Whereas in the working system, the motor speed/speed will be changed according to the desired load speed. Of course, the motor speed level will have an effect to help the running of industrial or generator activities, including in the household itself. The increase in the amount of load given will reduce the speed of the motor. Therefore, we need a control in setting the speed.

Proportional Integral (PI) controller and Proportional Integral Derivative (PID) controllers have been used widely in the industry, power plant and electrical systems [22],[36]. This controller has a simple algorithm [12]. Thus, it is more easily understood and applied for most technological objects, the results obtained can achieve the quality control required by the industry [3]. PI and PID controllers can be applied with an open loop or closed-loop systems. Closed-loop systems are better than open-loop systems because closed-loop systems have feedback used to improve system work [34]. The percentage of errors from the system is smaller if an open-loop system is used. The small error gives accurate and effective results if compared with the open-loop system.

The most important part of the design PI and PID controller is the tuning method parameters P, I and D. Hence, the change value of PID parameter gives a big impact on the system response. Several methods can be used to determine the PID parameter.

For this reason, this system will observe the performance of the system, taking into account several parameters, namely maximum overshoot, steady state error, rise time and settling time, then four tuning controller methods will be compared, namely the Ziegler Nichols tuning method, Chien Servo 1 and Chien Regulator 1 and mathematical calculation to get the best performance from the Motor, both for Induction Motor and DC Motor.

## II. Material and Method

A motor is a device used to transfer electrical energy converted into kinetic energy [1]. There are two types of motor, DC motor and AC motor. DC motor has easier motor speed regulation than AC motor. Nowadays, DC motors are one of the most common components used in the industry. Usually, it is used in electronic and electrical devices that use DC power sources such as mobile vibrators, DC fans, and DC electric drills [3-7]. AC motor has the disadvantage of being more complex in speed regulation because this machine operates at speeds below synchronous speed. The induction motor rotates below synchronous speed because the magnetic field generated by the stator will produce flux in the rotor to rotate [8-10], [37].

PI and PID controller are a controller to determine the precision of an instrumentation system with the characteristics of feedback on the system. The PI Controller equation is [2],[4],[11]:

$$u_t = K_p e_{(t)} + K_i \int_0^t e(t)dt \tag{1}$$

And the PID Controller equation is [2], [17-18],[40] :

$$u_t = K_p e_{(t)} + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \tag{2}$$

Ki = Kp / Ti
Kd = Kp x Td

Where, $u_{(t)}$ is output of PID controller (manipulated value), *Kp* is Proportional value, *Ti* is Integral value, *Td* is Derivative value and $e_{(t)}$ is error [40].

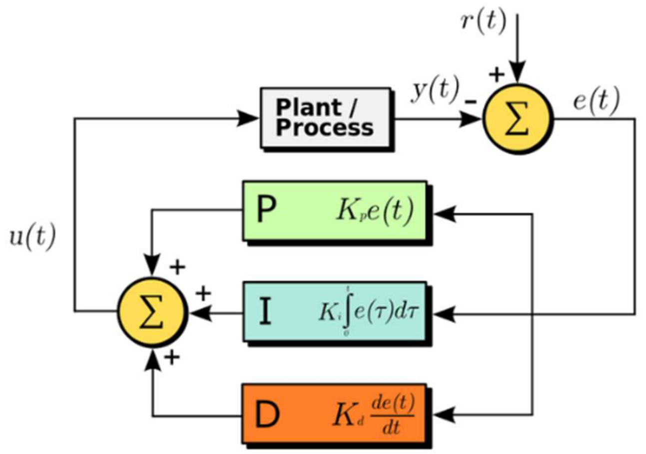



Fig. 1 Block Diagram System of PID Controller [41]

PID is a combination of Proportional, Integral and differential [2]. The function of control parameters P, I, and D is as follows:

- Speed up the reaction of a system reaching its set point.
- Eliminating offsets.
- Produce large initial changes and reduce overshoot.

The characteristics of PI and PID controller are very determined by the big contribution of the two parameters for PI controller, that are P and I parameters [3-4],[9], [11-15], and parameters P, I, and D for PID controller [6], [16-38]. The settings of value on Kp, Ki, and Kd will result in the spike, as shown in Fig.2. One of the three constants or both of them can be setting more preferred than others. In general, that preferred constant will contribute to the overall system response. Fig. 2 shows how the system response to changes in Kp, Ki, and Kd.

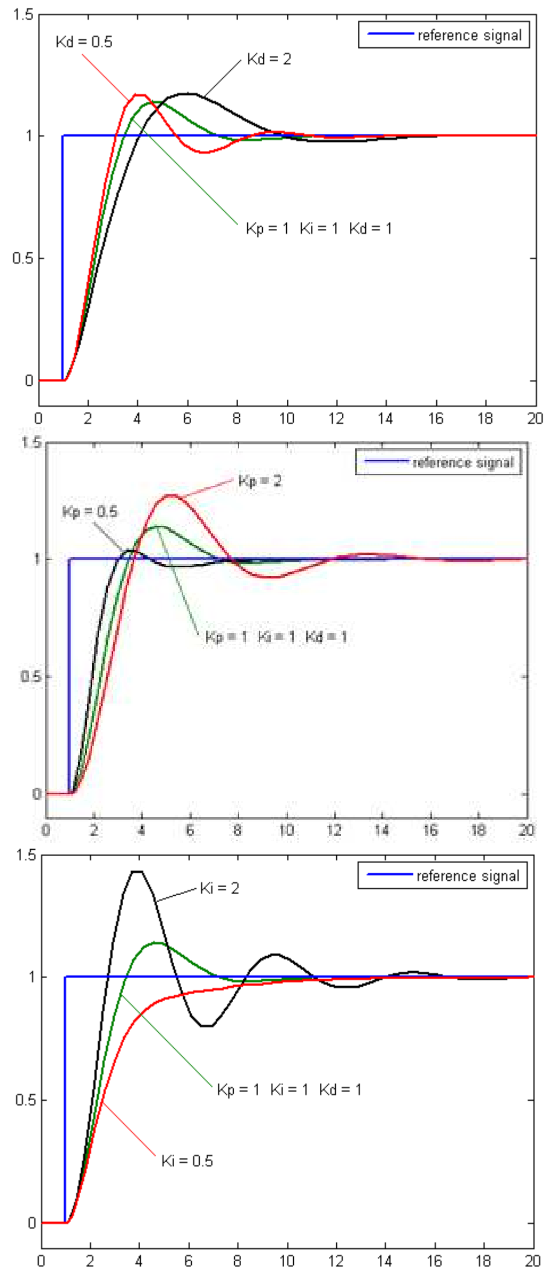



Fig. 2 Response of PID Controller

PID Controller is an important controller that is often used in industry. A good control system has a good response to various input signals [24],[32],[39].

PID controller design is very important to obtain an accurate speed [18], [34]. This is also called controller tuning. Sometimes mathematical modelling of a plant is difficult to do. If this happens, the analytical design of the PID controller is not possible, so the design of the PID controller must be done experimentally. Ziegler - Nichols proposed Kp, Ti, and Td value based on the characteristics responses from open-loop system [2],[35].

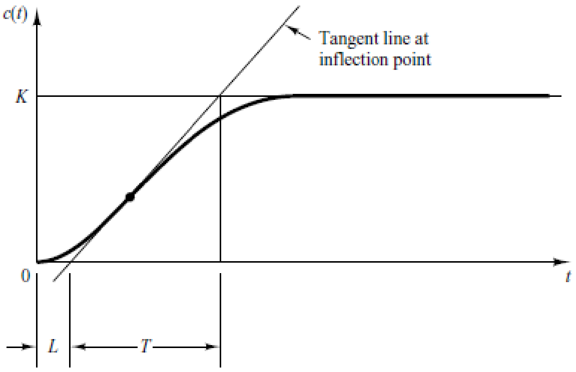



Fig. 3 Ziegler Nichols Rules for Tuning PID Controller [2]

The characteristic curve S has two constants. For detailed information, it can be shown in Fig. 3. The time delay and time constant are determined by drawing the tangent at the turning point of the S curve and the tangent intersection with the time axis and line c (t) [2],[42].

TABLE I
ZIEGLER NICHOLS TUNING RULE BASED ON STEP RESPONSE OF PLANT [2],[42]

| ***Control type*** | ***Kp*** | ***Ti*** | ***Td*** |
|---|---|---|---|
| P | $\frac{T}{L}$ | $\infty$ | 0 |
| PI | $0{,}9\,\frac{T}{L}$ | $\frac{L}{0{,}3}$ | 0 |
| PID | $1{,}2\,\frac{T}{L}$ | 2L | 0,5L |

The rules of the intersection of straight lines occur under the linear conditions of the S curve of the system. The accuracy in taking this intersection is very important because it determines the T and L parameters that are the controller's reference. Table I shows that Ziegler and Nichols make the formula to get Kp, Ki, and Kd based on parameters P, I, and D [2], [35].

## III. RESULT AND DISCUSSION

PI and PID controller have a control parameters value. The parameter value calculates and simulates with MATLAB. All of the results measured with the scope and for robustness test used step signal with a variable value.

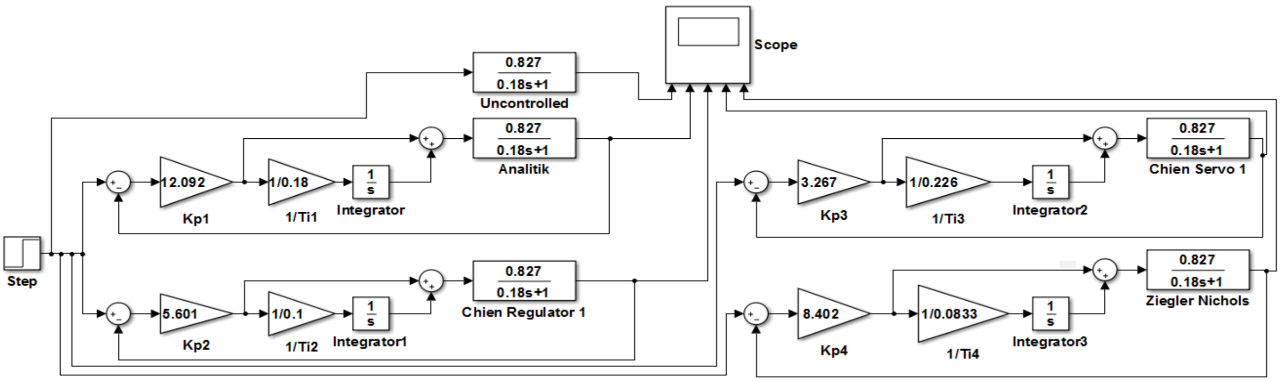



Fig. 4 The simulation's circuit for Control DC Motor with PI Controller

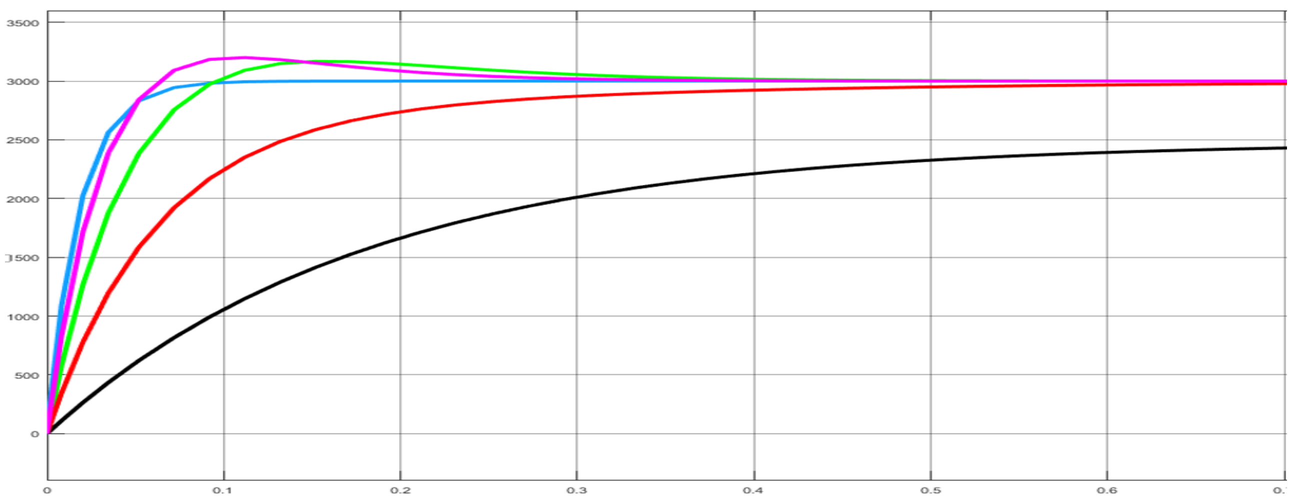
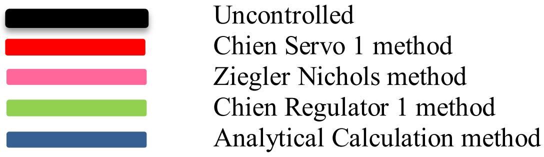



Fig. 5 The simulation's result of Control DC Motor with PI Controller

Figure 4 shows the results of DC Motor speed chart obtained with the expected setpoint. It can be seen that by using these four tuning methods, the motor speed can reach the setpoint. However, these four methods require different times to reach the expected setpoint speed.




This result shows that the best method is analytic with 3000 rpm setpoint and no speed overshoot or speed oscillation (as shown in Fig. 5). Another method, the setpoint has been reached, but when starting, there are still produce overshoot.

Furthermore, the best tuning control analysis for 1 phase induction motor is also carried out using PI control and PID control. The simulation circuit in Fig. 6 is shown in circuit PI control with four tuning methods as in the DC motor in Fig. 5.

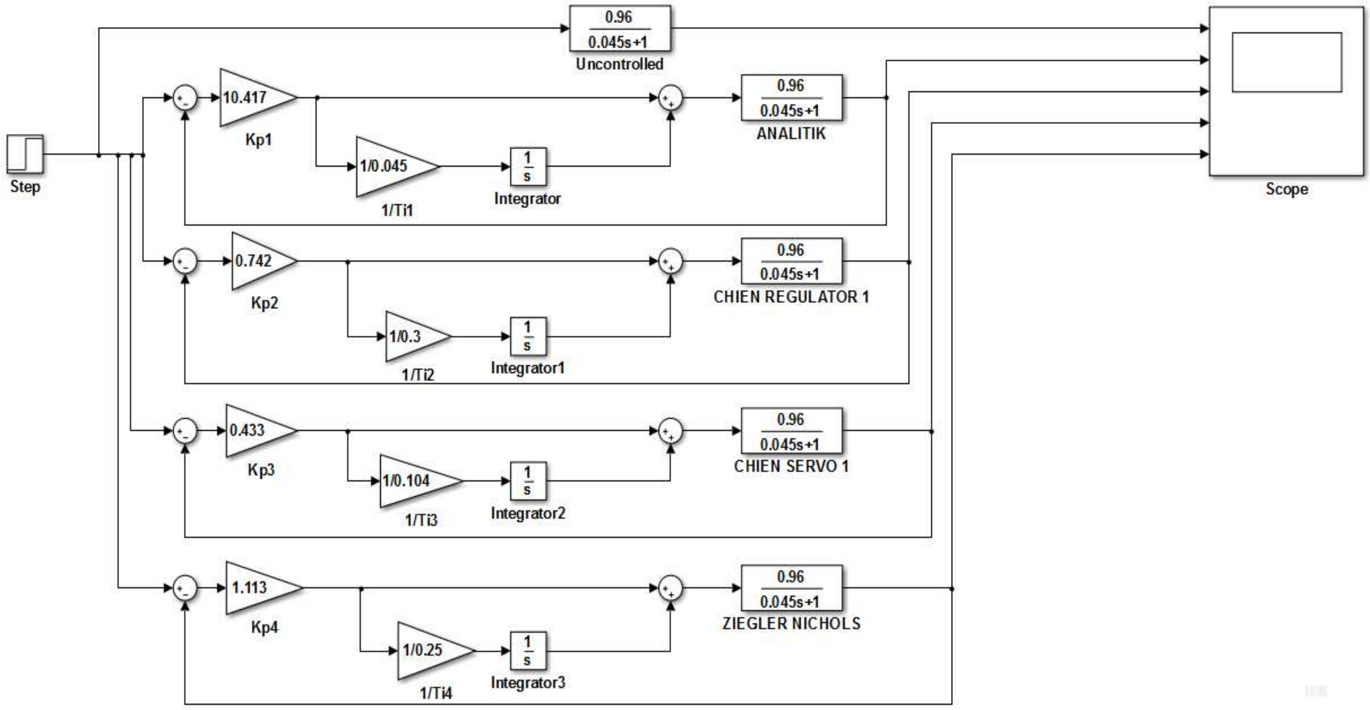



Fig. 6 The simulation's circuit for Control Induction Motor with PI Controller

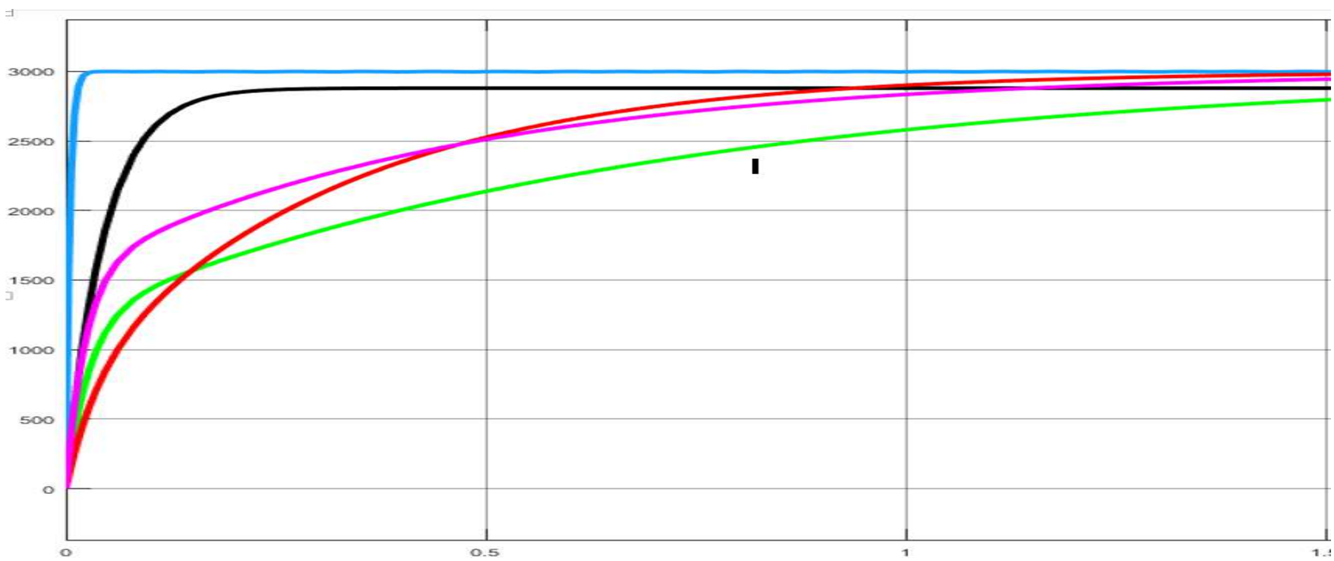



Fig. 7 The simulation's result of Control Induction Motor with PI Controller

The simulation results in Figure 6 shows tuning methods for the induction motor speed reaching the setpoint at different times.

Uncontrolled
Chien Servo 1 method
Ziegler Nichols method
Chien Regulator 1 method
Analytical Calculation method

This result shows that the best method is analytic with a 3000 rpm setpoint and no speed overshoot or speed oscillation (as shown in Fig. 7). The setpoint has also been reached for other methods, but there is still an overshoot when starting. Furthermore, the best tuning control analysis for 1 phase induction motor is done using PID control with four tuning methods such as the two simulations above.

The control circuit is shown in Figure 8 to generate accurate control Kp, Ki, and Kd must calculate from the open-loop data.

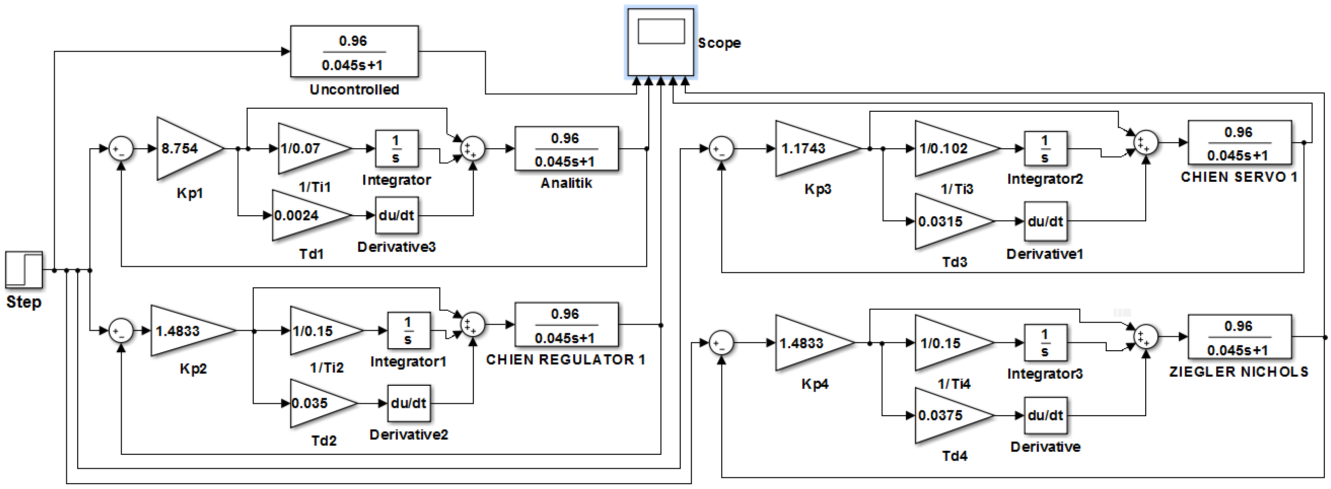



Fig. 8 The simulation's circuit for Control Induction Motor with PID Controller

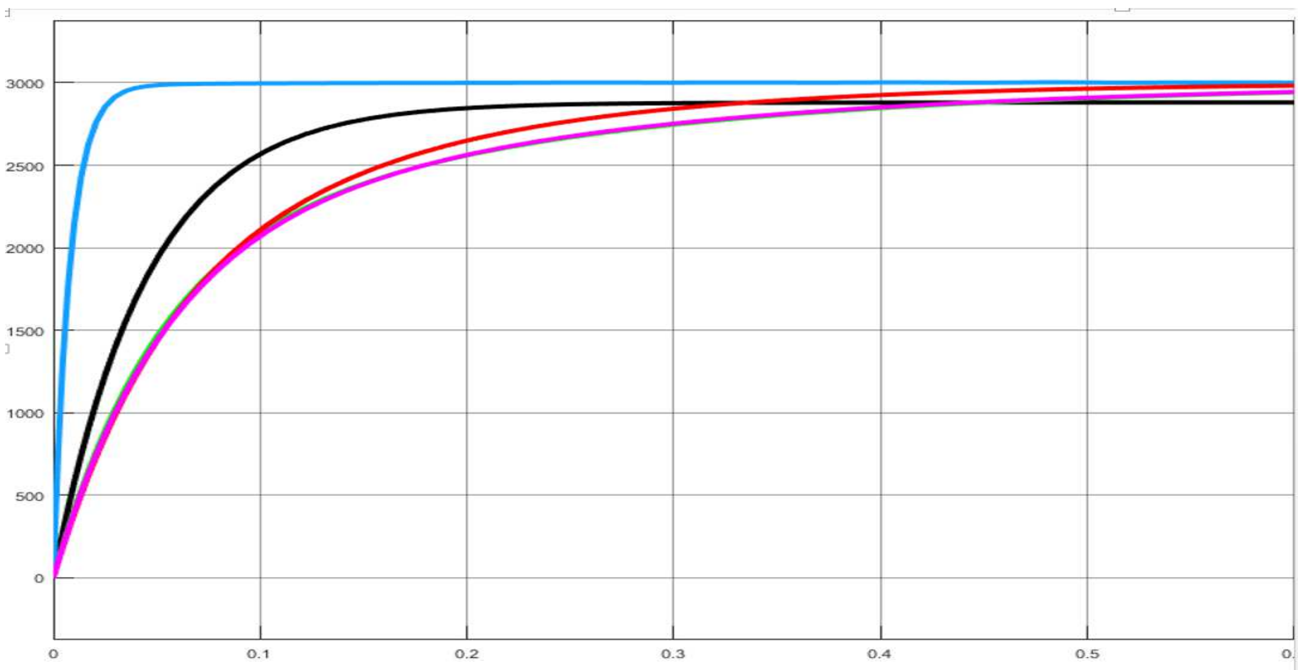



Fig. 9 The simulation's result of Control Induction Motor with PID Controller

Uncontrolled
Chien Servo 1 method
Ziegler Nichols method
Chien Regulator 1 method
Analytical Calculation method

PID control reduces overshoot when motor starting. This is a better result when compared with using PI control. Motor response testing is carried out for each control with two motor loads. After testing with a DC motor load, the system response is obtained as in Fig. 10 and Table II. From the four tuning methods that have been used, the results of testing the DC motor speed control with several tuning methods of control parameters can be summarized and explained as shown in Table II.

TABLE II
THE EXPERIMENT'S RESULT OF DC MOTOR CHARACTERISTIC WITH PI CONTROLLER

| *Tuning Methods* | *Setpoint* (rpm) | *Steady state* (rpm) | *Settling time (ts)* | *Rise time (tr)* | *Error steady state* |
|---|---|---|---|---|---|
| Uncontrolled | 3000 | 2480 | 0,9 s | 0,56 s | 17,33 % |
| Analytical Calculation | 3000 | 3000 | 1 s | 0,485 s | 4% |
| Chien Regulator 1 | 3000 | 3000 | 0,95 s | 0,56 s | 4% |
| Chien Servo 1 | 3000 | 3000 | 1,15 s | 0,63 s | 4% |
| Ziegler Nichols | 3000 | 2880 | 0,85 | 0,555 s | 4 % |

After testing the integration without providing control, the characteristic results show the expected speed value has not reached the desired setpoint, and there is still an unstable speed oscillation. Therefore, control is done by using PI Control with its four tuning parameter methods. The results are obtained as Table III.

TABLE III
THE EXPERIMENT'S RESULT OF INDUCTION MOTOR CHARACTERISTIC WITH PI CONTROLLER

| *Tuning Methods* | *Setpoint (rpm)* | *Steady state (rpm)* | *Settling time (ts)* | *Rise time (tr)* | *Error steady state* |
|---|---|---|---|---|---|
| Uncontrolled | 3000 | 2880 | 0.25 s | 0.195 s | 4 % |
| Analytical Calculation | 3000 | 2880 | 0.225 s | 0.165 s | 4 % |
| Chien Regulator 1 | 3000 | 2880 | 0.2 s | 0.17 s | 4 % |
| Chien Servo 1 | 3000 | 2880 | 0.2 s | 0.157 s | 4 % |
| Ziegler Nichols | 3000 | 2880 | 0.22 s | 0.185 s | 4 % |

In accordance with the data as shown in Table III, the best tuning method for 1 Phase Induction Motor is to use the Chien Servo 1 tuning method with a steady-state motor speed value of 2880 rpm, ts of 0.2 seconds, and tr of 0.157 seconds. From this result, a steady-state error of 4% was obtained. The result is obtained as Table IV.

In accordance with the data in Table IV, the best tuning method for 1 Phase Induction Motor is b Zielger Nichols tuning method, steady-state value of motor speed is 2880 rpm, ts of 0.22 seconds and tr of 0.175 seconds. From this result, a steady-state error of 4% was obtained.

TABLE IV
THE EXPERIMENT'S RESULT OF INDUCTION MOTOR CHARACTERISTIC WITH PID CONTROLLER

| *Tuning Methods* | *Setpoint* (rpm) | *Steady state* (rpm) | *Settling time (ts)* | *Rise time (tr)* | *Error steady state* |
|---|---|---|---|---|---|
| Uncontrolled | 3000 | 2880 | 0.25 s | 0.195 s | 4 % |
| Analytical Calculation | 3000 | 2880 | 0.225 s | 0.17 s | 4 % |
| Chien Regulator 1 | 3000 | 2880 | 0.22 s | 0.182 s | 4 % |
| Chien Servo 1 | 3000 | 2880 | 0.25 s | 0.165 s | 4 % |
| Ziegler Nichols | 3000 | 2880 | 0.22 s | 0.175 s | 4 % |

For testing the performance of PI and PID controls, interference with the motor is given. The result shown in Fig. 13 and Table V.

TABLE V
THE EXPERIMENT'S RESULT OF INDUCTION MOTOR CHARACTERISTIC WITH PI CONTROLLER AFTER BEING INTERRUPTED

| *Tuning Methods* | *Setpoint (rpm)* | *Steady state (rpm)* | *Time (second)* |
|---|---|---|---|
| Analytical Calculation | 3000 | 3000 | 0,24 |
| Chien Regulator 1 | 3000 | 3000 | 0.3 |
| Chien Servo 1 | 3000 | 2800 | 0.4 |
| Ziegler Nichols | 3000 | 3000 | 0.26 |

In accordance with Table V, it can be seen that the best tuning method for returning motor speed to steady state is an analytical calculation method with a time of 0.24 seconds and Ziegler Nichols method for 0.26 seconds.

## IV. CONCLUSION

DC motors used in this research, the best control tuning method is to use chien regulator one method, with a value of Kp = 5.601 and Ki = 56.01. who is able to provide the speed value in accordance with the expected setpoint. For the 1 Phase 125 Watt Induction motor used, the best tuning method when PI Control is by Chien Servo 1 method with Kp = 0.433 and Ki = 4.163. Single-phase induction motor with PID control provides a speed value of 2880 rpm with setpoint 3000 rpm, steady-state error of approximately 4% is obtained. Kp value = 1.4833, Ki value = 98.89 and Kd value = 0.052. When given the interference with the tuning method Ziegler Nichols is the fastest to return the response to the steady-state with a time of 0.26 seconds.

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