

Research Paper

Static and Dynamic Performance of Vector Control on Induction Motor with PID Controller: An Investigation on LabVIEW

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Abstract

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A three-phase induction motor has high reliability. However, it has problems with speed control during load changes and speed settings due to the decoupled system. Therefore, this study aims to adjust the three-phase induction motor control to become a separate amplifier DC motor by setting the vector control using the IFOC method, which changes the coupled to the decoupled system. The speed settings are equipped with a PID controller where its parameters, which are obtained using Ziegler Nichols, produce speed output with fast research time and small steady-state errors. This research was conducted to observe and analyze the performance of a controller based on the IFOC approach with a PID controller at speed differences, with static and dynamic conditions in the entire speed working area. In the first stage of the research, simulation is carried out with static conditions, namely changes in speed variations throughout the work area (low speed to high speed), the next stage is a simulation with dynamic conditions, which is to provide changes in the value of the load torque when the system is operating. The simulation result carried out with LabVIEW shows a response time of 1.13 ms, a settling time of 9.9 ms, and a steady error of 0.4 % at the 500 rpm set point. It also indicated dynamic characteristics with a recovery time of 4.9 ms at the 300 rpm set point. When operated at low speed, IFOC with PID controller has a stable response. But In dynamic conditions, the use of a PID controller is considered unsuitable. This is because the PID controller is less fast and less robust in responding to the system when conditions change in the value of the load torque.

Keywords: Indirect Field Oriented Control (IFOC); LabVIEW; PID; Ziegler Nichols

Abstrak

Motor induksi tiga fase memiliki keandalan yang tinggi. Namun, ada masalah dengan kontrol kecepatan selama perubahan beban dan pengaturan kecepatan karena sistem yang dipisahkan. Oleh karena itu, penelitian ini bertujuan untuk menyesuaikan kontrol motor induksi tiga fasa menjadi penguat terpisah motor DC dengan pengaturan kontrol vektor menggunakan metode IFOC yang mengubah sistem kopling menjadi decoupled. Pengaturan kecepatan dilengkapi dengan kontroler PID dimana parameternya diperoleh dengan menggunakan Ziegler Nichols, menghasilkan kecepatan keluaran dengan waktu penelitian yang cepat dan kesalahan kondisi tunak yang kecil. Penelitian ini dilakukan untuk mengamati dan menganalisis performansi sebuah pengontrol berbasis pendekatan IFOC dengan pengontrol PID pada perbedaan kecepatan, dengan kondisi statis dan dinamis di seluruh wilayah kerja kecepatan. Pada penelitian tahap pertama dilakukan simulasi dengan kondisi statis yaitu perubahan variasi kecepatan di seluruh area kerja (kecepatan rendah ke kecepatan tinggi), tahap selanjutnya adalah simulasi dengan kondisi dinamis, yaitu memberikan perubahan pada lingkungan kerja. nilai torsi beban saat sistem beroperasi. Hasil simulasi yang dilakukan dengan LabVIEW menunjukkan response time 1,13 ms, settling time 9,9 ms, dan steady error 0,4% pada set point 500 rpm. Ini juga menunjukkan karakteristik dinamis dengan waktu pemulihan 4,9 ms pada titik setel 300 rpm. Saat dioperasikan pada kecepatan rendah, IFOC dengan pengontrol PID memiliki respons yang stabil. Namun dalam kondisi dinamis, penggunaan pengontrol PID dianggap tidak sesuai. Hal ini dikarenakan kontroler PID kurang cepat dan kurang kuat dalam merespon sistem saat kondisi perubahan nilai torsi beban..

Kata-kata kunci: Indirect Field Oriented Control (IFOC); LabVIEW; PID; Ziegler Nichols



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1. Introduction

An induction motor is an electric motor widely used due to several factors, namely simple structure, small volume, relatively low price, easy and flexible electric driving, high efficiency and power density, high starting torque, a wide range of torque, constant power, and reliable torque response under several operating conditions [1]. The induction motor will be the main propulsion for future vehicles and it will replace the internal combustion engine [2],[3]. Several works on the comparative evaluation of electric motors performance as electric car propulsion show that induction motors have a better control and reliability level than DC, PMSM, and SRM [4]. When compared with several other types, induction motors are superior in terms of control, reliability, technological readiness, and low maintenance costs, thereby making them the main choice factors for motorbike users. However, the working conditions of the induction motor are based on parameters that reduce reliability and performance due to the nonlinearity and complexity of the motor model. Therefore, various methods are proposed to maintain the performance of the induction motor.

The three-phase induction motors are significantly utilized in the industrial sector due to their large capacity and operation ease. In general, the induction motor controller consists of scalar and vector controls. In application, scalar control is easier to use, however, one of the major disadvantages is its coupling effect which affects other variables when adjusted [5]. Furthermore, low-speed operation results in a large enough voltage drop, thereby leading to poor torque capability (torque drops). Therefore, the use of scalar control is less suitable at low speeds. In the research that has been done regarding scalar control in induction motor control, it can be seen that from the research results obtained on scalar control has slow speed tracking or takes a long time [6], besides that the control scalar has a slow transient response so it doesn't get good results, on fast dynamic behavior [7]. Besides, other research related to the investigation of transient performance on scalar controls has a longer settling time and consumes large currents, causing lower efficiency. Besides, when it is operated in dynamic conditions with changes in the load torque value, scalar control experiences a

drop in speed so that it cannot go to the desired set point value [8]. Then in other research related to the implementation of scalar control using a PI controller, it was found that scalar control has a long recovery time when operated in dynamic conditions and there is still ripple/oscillation in the speed response [9].

So that in this research, the motor speed regulation was carried out through a vector control approach. On the other hand, the vector control regulates the induction motor as though it were a separate DC motor with the ability to adjust the variable flux and torque separately. This control has numerous advantages such as high performance, the ability to regulate flux, voltage, vector current, and the ability to produce high torque at low speeds. Vector control has a good response to any variation in speed and load and is more constant than the scalar, which has a less good response [10].

The type of vector control used in this research is Indirect Field Oriented Control (IFOC). IFOC does not use a hall effect sensor to measure the flux in the air gap [11], so it does not require a lot of money besides being difficult to place because it is in the air gap of the motor. And the readings are more accurate, especially at low speeds. The IFOC concept is the field control method in induction motors by changing the coupled system to decouple, which leads to the separate control of flux and torque current, using an amplifier DC motor [12].

Apart from using reliable control methods to improve motor performance induction, several regulatory or controlling engineering schemes are used. In previous research, the motor speed regulation was carried out using IFOC with a comparison of P and PI control with static conditions and no load. From this research, it was found that in static conditions no-load speed response using P and PI control at low-speed chattering and oscillation occurred [13]. Besides, other research related to the transient response characteristics of a 3-phase induction motor with a control vector using a PI controller, carried out in high-speed static conditions obtained good transient response characteristics when tested for changes in speed with a steady-state error ranging from 1-1.9% [14].

So that in this research, PID is used as a controller to improve the response to changes in

the specified speed. The PID controller is used to obtain a stable output because it combines the three parameters in parallel [15]. This controller produces output with fast rise time, small, steady error, and does not produce overshoot [16]. The determination of PID parameter values in this study uses the Ziegler Nichols method because it is easier to determine the parameters and obtain the optimal value.

This research carried out simulations using Laboratory Virtual Instrumentation Engineering Workbench (LabVIEW), a virtual instrument that supports real-time observations in data acquisition. Also, it excels in building user interfaces with easy graphical programming [17]. LabVIEW enables the real-time observation of the speed response or motor performance.

This research aims to deepen the LabVIEW development by specifically observing the speed response of a three-phase induction motor with the IFOC method using a PID controller. The IFOC used is vector control, while the inverter uses the Sinusoidal Pulse Width Modulation (SPWM) generation technique. Therefore, the purpose of this research is to determine the application of IFOC with PID controllers in the three-phase induction motor observed and analyzed for its static and dynamic performances using the LabVIEW.

2. Method

2.1. Field Oriented Control (FOC)

Vector control or FOC is a method of controlling the field in an electric motor (AC).

With this system, torque and flux currents control are separately controlled, as in a DC motor [18]. The FOC method consists of two techniques, namely Direct FOC (DFOC) and Indirect FOC (IFOC). DFOC is a technique for obtaining a rotor flux vector by measuring directly into the air gap. Meanwhile, the IFOC is a technique for obtaining the rotor flux vector by estimating using the FOC (current model) equation with a speed sensor as feedback. Figure 1 is a block diagram of IFOC, from the block diagram there are several parts including the Park transformation and the Clark transformation to get the DQ coordinate transformation, the theta calculation, and the flux estimation.

The FOC utilizes two constants as input references, the torque component (parallel to coordinate q) and the flux component (parallel to coordinate d) [19]. The system in the block diagram above is simulated using LabVIEW tools. LabVIEW is a virtual instrument that supports real-time observations in data acquisition. LabVIEW excels in building user interfaces with easy graphical programming [17]. By using LabVIEW, the speed response or motor performance can be observed in real-time. The program of IFOC on LabVIEW is presented in Figure 2.

The I_{qs}^* calculation functions to generate a reference current q (I_q^*) with the input reference torque output from the speed controller (PID) and the rotor flux (ϕ_{ir}). The output from the I_q^* calculation becomes the input to the DQ to ABC conversion block. I_q^* can be calculated using Eq. (1).

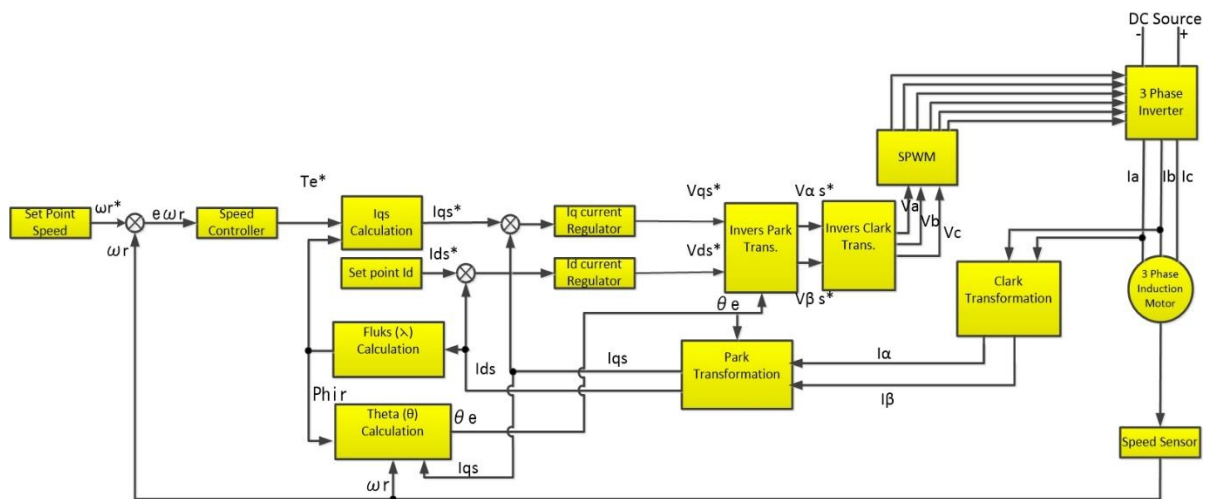


Figure 1. IFOC block diagram

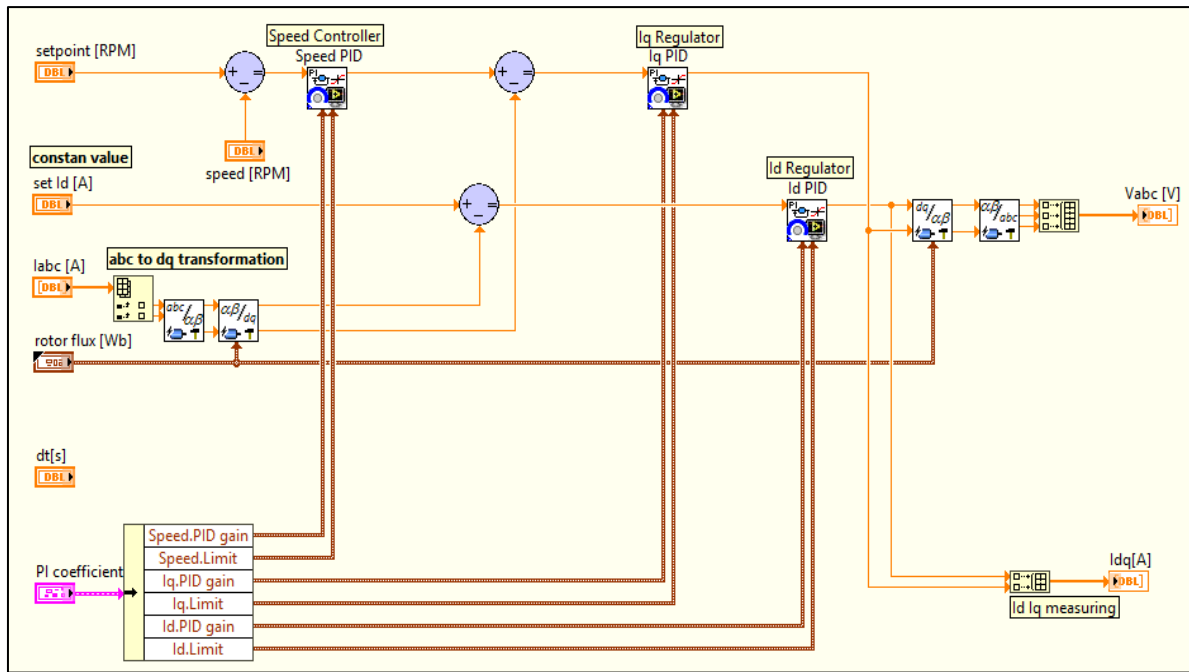


Figure 2. IFOC program

$$i_{qs*} = \frac{2}{3} \frac{2L_r T_{e*}}{PL_m \lambda_r} \quad (1)$$

$$\lambda^* = L_m i_{ds} \quad (7)$$

Where P is the number of poles, L_r is the rotor inductance, L_m is the mutual inductance, and λ_r is the approximate rotor flux. The I_{ds}^* calculation has the function of generating the d reference current (i_{d}^*) by inputting the reference rotor flux (phir^*). The i_{d}^* size depends on the reference flux input [20].

$$i_{d}^* = \frac{\lambda^*}{L_m} \quad (8)$$

The Phir^* value is generally close to one depending on the slip of the induction motor, in this simulation, it is determined to be 1 PU (i_{d}^*). This calculation serves to produce theta. The flux angle for the transformation is obtained from the calculation between rotational speed (ω_m) and slip velocity (ω_{sl}) with Eq.(9 - 10) [20].

$$\frac{d\lambda_{dr}}{dt} + \frac{R_r}{L_r} + \lambda_{dr} - \frac{L_m}{L_r} R_r i_{ds} - \omega_{sl} \lambda_{qr} = 0 \quad (2)$$

$$\theta_e = \int \omega_e dt = \int (\omega_m + \omega_{sl}) dt \quad (9)$$

$$\frac{d\lambda_{qr}}{dt} + \frac{R_r}{L_r} + \lambda_{qr} - \frac{L_m}{L_r} R_r i_{qs} - \omega_{sl} \lambda_{dr} = 0 \quad (3)$$

$$\omega_{sl} = \frac{L_m R_r}{\lambda^* L_r} i_{qs} \quad (10)$$

In a decoupling controller, it is desirable that [20]:

$$\lambda_{qr} = 0 \quad (4)$$

$$\frac{d\lambda_{qr}}{dt} = 0 \quad (5)$$

By substituting the Eq.(4) and (5) with Eq.(2) and (3), Eq.(6) is obtained.

$$\frac{L_r}{R_r} + \frac{d\lambda^*}{dt} + \lambda^* = L_m i_{ds} \quad (6)$$

Flux calculation functions to produce an approximate value of rotor flux (phir), with the input current i_d from the output of the ABC to dq conversion. The rotor flux is obtained based on Eq.(11), with the value $\tau_r = \frac{L_r}{R_r}$ is the rotor time constant.

$$\lambda_r = \frac{L_m i_d}{1 + \tau_r s} \quad (11)$$

Where R_r is the rotor resistance, λ_{dr} is the rotor flux d stationary, λ_{qr} is the rotor flux q stationary. If the value of λ^* is constant, then Eq.(6) will get Eq.(7) and (8) [20].

This space vector current is a three-phase sinusoidal system, therefore it needs to be transformed into a two-time invariant coordinate system [21]. The transformation process is divided

into two parts, namely the Clark (a, b, c to α , β) Park (α , β to dq) transformation, which produces a two-time variant and invariant coordinate system, respectively [11].

$$\begin{aligned} i_{s\alpha} &= i_a \\ i_{s\beta} &= \frac{1}{\sqrt{3}}i_a + \frac{2}{\sqrt{3}}i_b \end{aligned} \tag{12}$$

$$\begin{bmatrix} i_{\alpha} \\ i_{\beta} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ \frac{1}{\sqrt{3}} & \frac{2}{\sqrt{3}} & 0 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{13}$$

2.2. Clarke transform (ABC to $\alpha\beta$)

The Clarke transform in the FOC is used to convert the three-phase currents (i_a , i_b , and i_c) in the stationary plane to two-phase (i_{α} and i_{β}) in the orthogonal plane. Figure 3 is the Clarke transformation program in LabVIEW.

The process used to change the three-phase current (a, b, c) to a two-phase system (α, β) is mathematically written in Eq.(12) and in matrix form as in Eq.(13) [21].

2.3. Park transform ($\alpha\beta$ to dq)

This transformation aims to change the orthogonal two-phase component (α, β) in the stator frame to the rotor frame dq with angular velocity ω . When the d-axis is parallel to the rotor flux then this research dicusses the flux orientation system. The current vector in the dq frame is formulated in Eq.(4) [21]. Figure 4 is the park transformation program in LabVIEW.

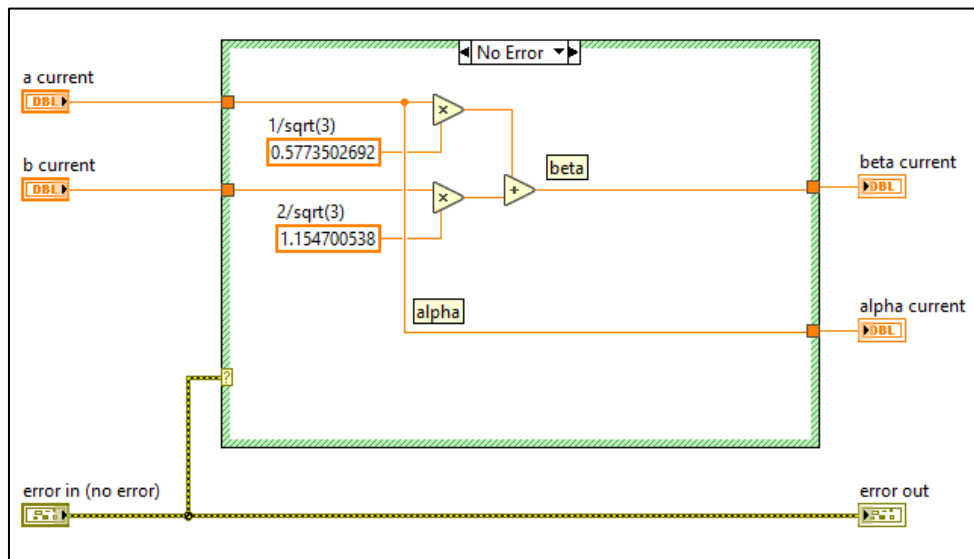


Figure 3. Clarke transformation program

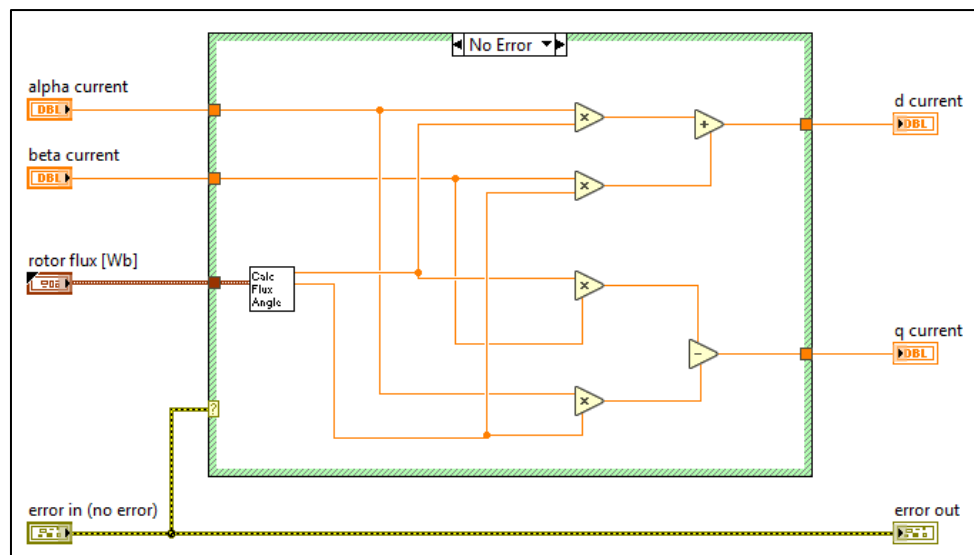


Figure 4. Park transformation program

The current vector in the dq frame is formulated in Eq.(14), the equivalent are shown in Eq.(15), and in matrix form as in Eq.(16) [21].

$$i_s = i_{ds} + i_{qs} \quad (14)$$

$$\begin{aligned} i_{ds} &= i_\alpha \cdot \cos(\theta) + i_\beta \cdot \sin(\theta) \\ i_{qs} &= -i_\alpha \cdot \sin(\theta) + i_\beta \cdot \cos(\theta) \end{aligned} \quad (15)$$

$$\begin{bmatrix} i_{ds} \\ i_{qs} \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \sin(\theta) \\ -\sin(\theta) & \cos(\theta) \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (16)$$

2.4. PID controllers

The PID controller is a combination of three controllers that produce less optimal results when used individually [22]. Therefore, the three controllers are combined into one control system to obtain an optimal response. With the combination of the three controls, it has advantages over using only each controller. Figure 5 is a PID control program in LabVIEW.

In this research, the PID controller is used for speed regulation, so that the PID controller is located at the output of the speed error signal as shown in Figure 5. The PID controller equation is written in Eq.(17) [23].

$$m(t) = K_p e(t) + \frac{K_p}{T_i} \int_0^t e(t) dt + K_p T_d \frac{de(t)}{dt} \quad (17)$$

In getting a good system response, the PID controller parameters need to obtain optimal parameter values. In this research, the Ziegler

Nichols method was used to obtain the parameter value of the PID. With the Ziegler Nichols method, the optimal PID parameter values are easily obtained through the open-loop system response [24]. Based on Figure 5, the limiter is used to limit the value of the PID parameter, so that it serves to improve the output of the PID control signal. Ziegler Nichols one of the methods used to obtain optimal parameter values [25][26].

With the existence of PID Control, the speed response obtained has several advantages for regulating motor speed, namely proportional control has the advantages of fast research, integral control has the advantage of minimizing errors, and derivative control has the advantage of reducing overshoot/undershoot.

3. Results and Discussion

3.1. Simulation design on LabVIEW

Figure 6 is a LabVIEW front panel display with several different functions. Part 1 is a block in setting/entering the PID controller's parameter values, including speed, flux current (I_d Gain), and torque current settings (I_q Gain). In this research, the setting is only conducted at speed, therefore the PID parameters on I_d and I_q are kept constant. Part 2 is a block used to set RPM as the input setpoint (in units of RPM), which is utilized as a speed error signal and input from the PID controller. Furthermore, in part 2, there is also a set value of the load (Newton-meters (Nm) units).

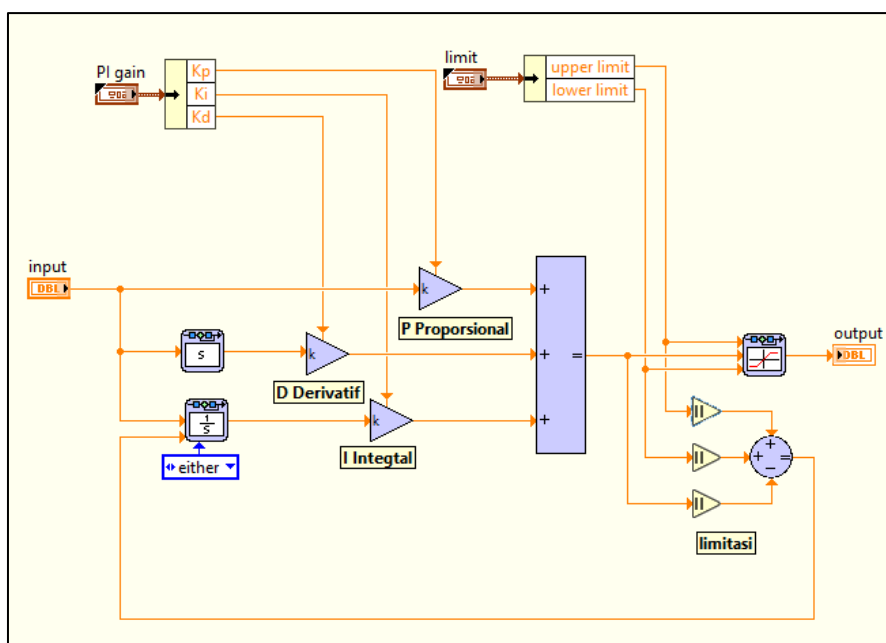


Figure 5. PID program

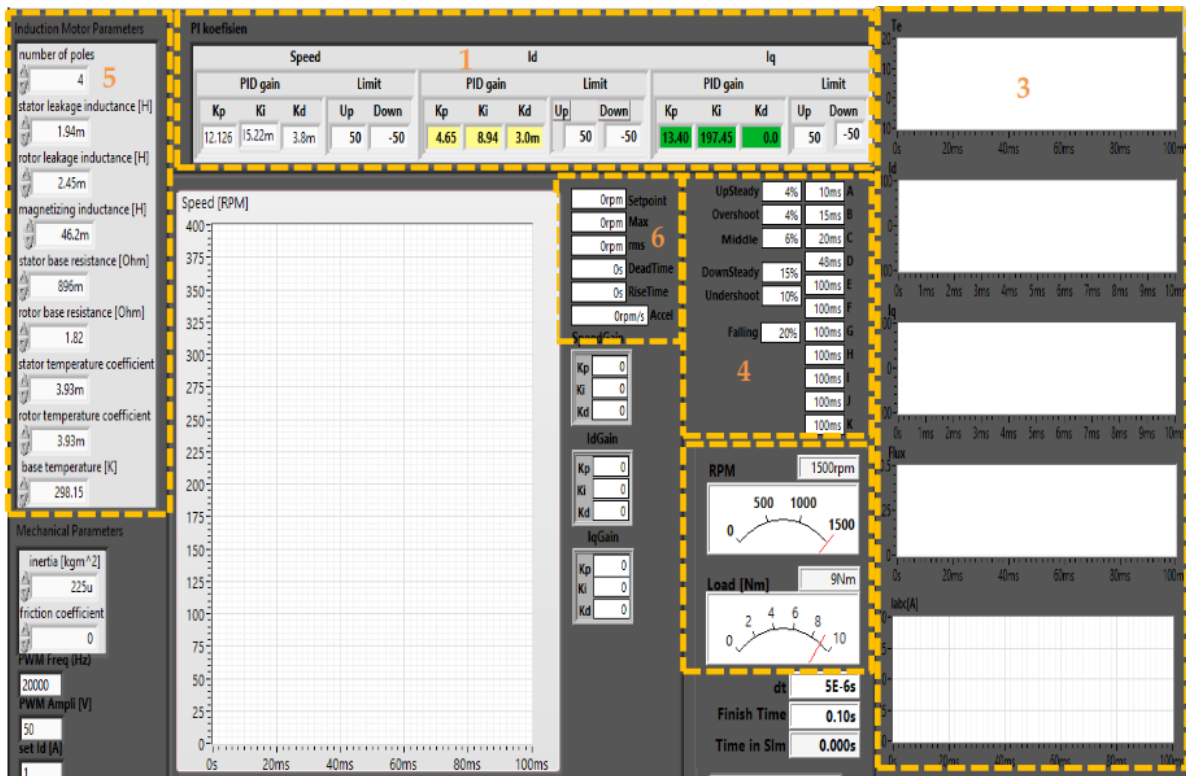


Figure 6. LabVIEW front panel view

In this research, the value of the load changes when it reaches a steady-speed state to observe and analyze its dynamic conditions (load changes). Part 3 is a display block of several waves, including motor torque, flux current (I_d), torque current (I_q), flux, and 3-phase current (I_{abc}). Part 4 is a block for observing system performance. Part 5 is a block for inputting values from motor parameters. The values used are shown in Table 1. The measurement program of the system in LabVIEW is shown in Figure 7.

Table 1. Three-phase induction motor parameters

No	Parameter	Score	Unit
1	R_{stator}	0.896	Ω
2	R_{rotor}	1.82	Ω
3	L_{stator}	1.94	mH
4	L_{rotor}	2.45	mH
5	$L_{magnetization}$	46.2	mH
6	frequency	50	Hz
7	pole	4	unit

Figure 7 is a block diagram of the parameter measurement program that is measured on LabVIEW. In the block diagram above, several parameters are measured, namely flux, torque, speed, Id, and Iq. This research focuses on speed settings so that the observed parameters are on the speed response

side. It can be observed in the Figure 7, that the speed measurement block is expected to match the desired speed setpoint value by having a good response or not outside of the desired response scheme.

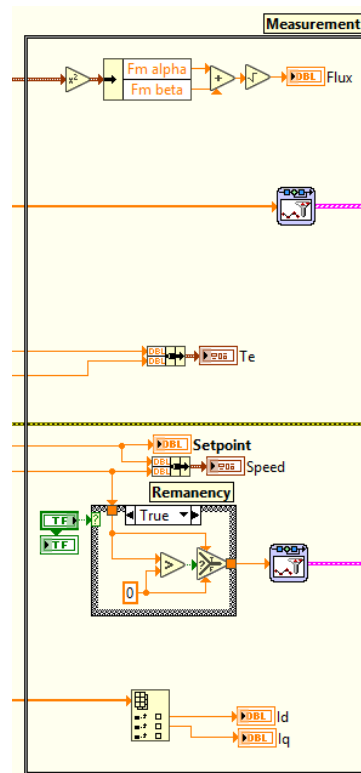


Figure 7. Measurement Program on LabVIEW

Several parameters are used to analyze a control system's response, including research time, settling time, deadtime, steady time, overshoot, and undershoot. Therefore, the maximum limit of these parameters must first be used to determine whether the system has a good response. Furthermore, the system is analyzed from the designed timer scheme to have a good speed response between the minimum and maximum limits (in the white area) of the timer scheme. **Figure 8** shows the time scheme designed in simulation.

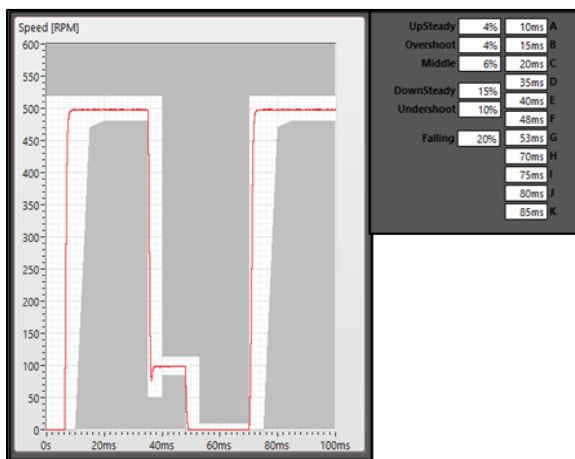


Figure 8. The timer schematic design in the simulation

Part 6 is a block of speed response values generated by the system, including the system's

setpoint, maximum and minimum speed. The program block diagram of the system in LabVIEW is shown in **Figure 9**. Part 1 is a block of vector control and FOC. Part 2 is a block of three-phase inverter with SPWM signal generation technique. Part 3 is the block of induction motor modeling. Part 4 is a block of setting the speed set points. Part 5 is a block when observing dynamic conditions, namely the setting of changes in load values, which are carried out when the system is steady. Therefore, it can be observed and analyzed from the recovery time to steady again. Part 6 is a block of the PID parameter values set for speed, I_d , and I_q settings. The actual speed obtained is compared with the speed setpoint value to produce an error signal used as input from the speed setting's PID controller. In this study, the setting is only carried out on speed, therefore the setpoint I_d value is kept constant, which is 1 Pu. The simulation performance investigations are carried out in the simulation using the computer specifications listed in the **Table 2**.

Table 2. Computer specifications

Description	Specification
Operating system	Windows 8.1 64 bit
Processor	Intel Core i5-6200U CPU@2.3GHz
Memory	8Gb Ram
Software	LabVIEW 2016 student version
Discrete Time	5E-6s
Simulation Time	100ms

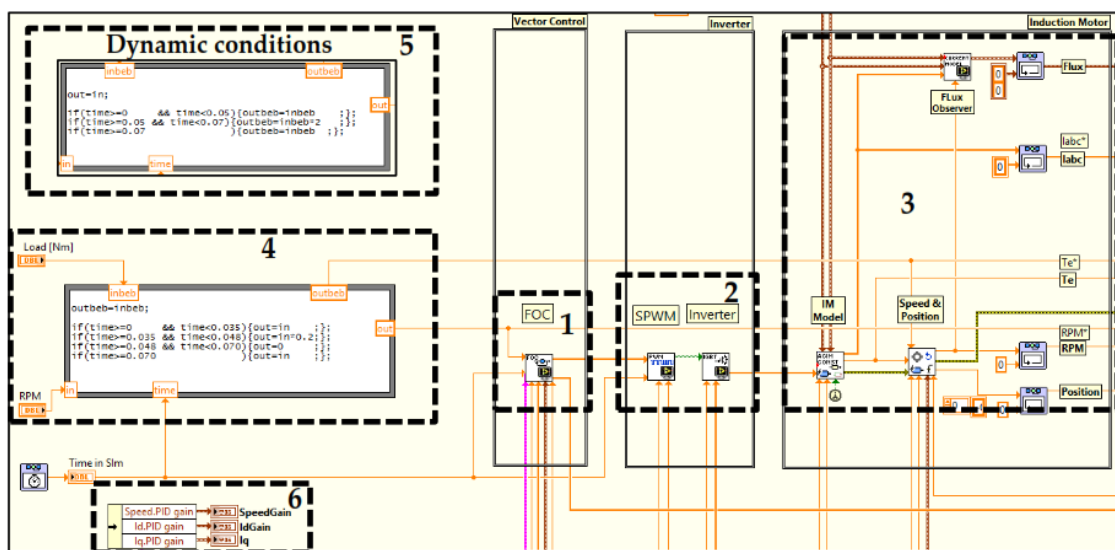


Figure 9. Block diagram of the system program in LabVIEW

3.2. Simulation results

In this research, simulation testing was carried out with 2 conditions, static and dynamic conditions. Furthermore, based on these tests, observations and analysis of the control system response performance were carried out, namely dead time, rise time, settling time, and steady error. This research setting was carried out on speed, therefore the PID parameter value at I_d and I_q was kept constant. Table 3 is the PID parameter value at I_d and I_q .

Table 3. PID parameter values on I_d and I_q

No	Kp	Ki	Kd	Description
1	4.65	8.94	0.005	I_d
2	13.4	197.45	0	I_q

The Simulation testing with static conditions with speed variations is carried out using a constant load torque value of 9 Nm with a variation of the low-speed setpoint value, namely 500 rpm and 800 rpm and high-speed 1000 rpm

and 1200 Rpm. Therefore, based on the open-loop system speed response obtained with the setpoint variation value, the PID parameter value can be calculated using the Ziegler Nicholz method, as shown in Table 4.

Table 4. PID parameter values at speed settings

No	Set Point (rpm)	Kp	Ki	Kd
1	500	8.201	0.01524	0.00381
2	800	9.338	0.01526	0.003815
3	1000	9.342	0.01556	0.00389
4	1200	8.398	0.0156	0.0039

Therefore, by setting the PID parameter value as in Table 4, the response to the closed-loop system condition is obtained at the speed regulation of a three-phase induction motor with the IFOC method as in Figure 10, Figure 11, Figure 12, and Figure 13. The speed response at low-speed (500 rpm and 800 rpm) conditions is obtained as shown in the Figure 10 and Figure 11.

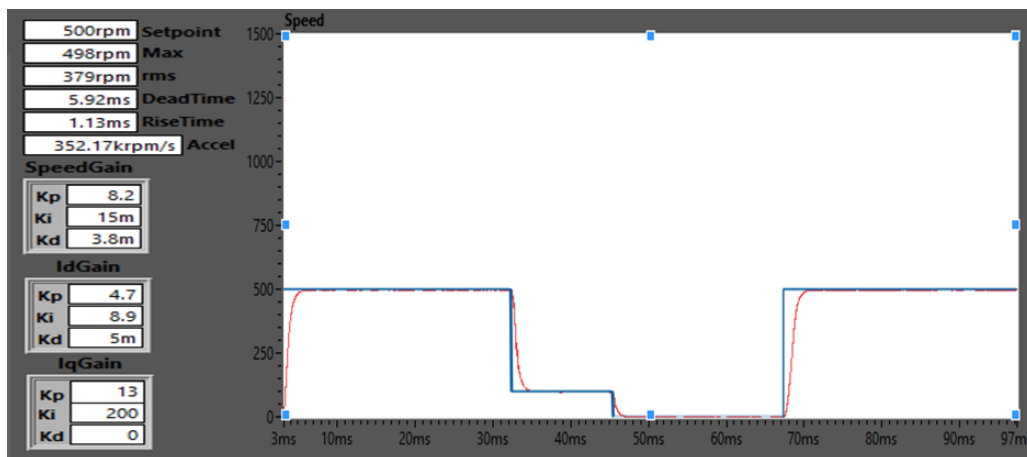


Figure 10. Response of a closed-loop system with a set point of 500 rpm

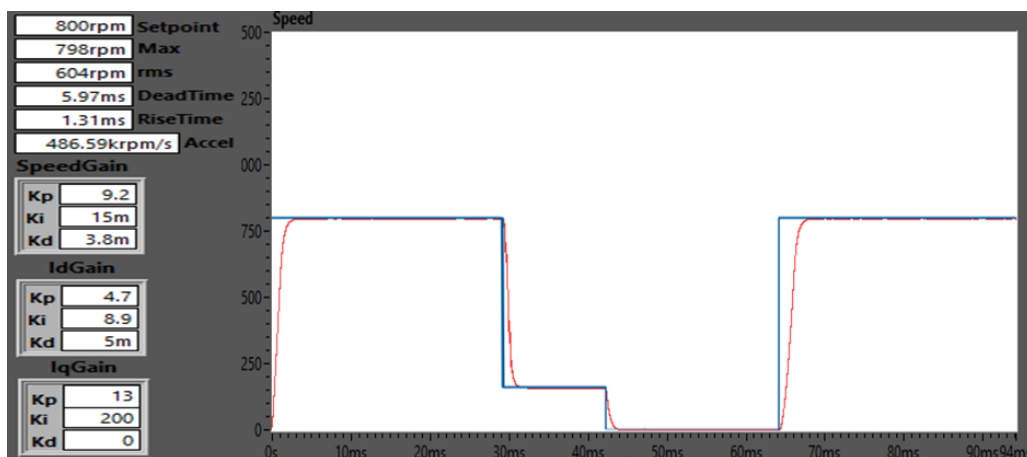


Figure 11. The response of the closed-loop system with a set point of 800 rpm

In testing the conditions low-speed (500 rpm and 800 rpm) with a simulation time of 0.1 seconds, the closed-loop system speed response is obtained, as shown in Figure 10 and Figure 11. The response obtained by adjusting the PID parameter values that the low-speed response obtained is better. This is due to an increase in the value of the rise and settling time or the faster motor speed response to a steady-state. Settling time is the time taken by the motor to reach a steady state. Meanwhile, the rise time shows that the system response has increased from 10% to 90% of the steady response value. The settling and rise time values obtained using the PID controller on the IFOC speed setting produces a good speed response. Furthermore, the closed-loop response obtained shows that no system response is outside the maximum and minimum limits of the white area's timer response scheme. Therefore, it can be stated that the system has a good response rate. The closed-loop has a good response when compared with the open-loop system's conditions

(no controller), with a fast rise and settling time and a decrease in steady error. Furthermore, when viewed from the response obtained and operated at low-speed conditions, such as at the set point of 500 rpm and 800 rpm, the response received is more stable. Therefore, one of the advantages of the Indirect Field Oriented Control (IFOC) is the ability to operate at low speed with a stable response, compared to scalar control. The speed response at high-speed (1000 Rpm and 1200 Rpm) conditions is obtained as shown in the Figure 12 and Figure 13.

In testing the conditions high-speed (1000 rpm and 1200 rpm) with a simulation time of 0.1 seconds, the closed-loop system speed response is obtained, as shown in Figure 12 and Figure 13. The response obtained by adjusting the PID parameter values that the high-speed response obtained is better. This is due to an increase in the value of the rise and settling time or the faster motor speed response to a steady-state. The observed responses are tabulated in Table 5.

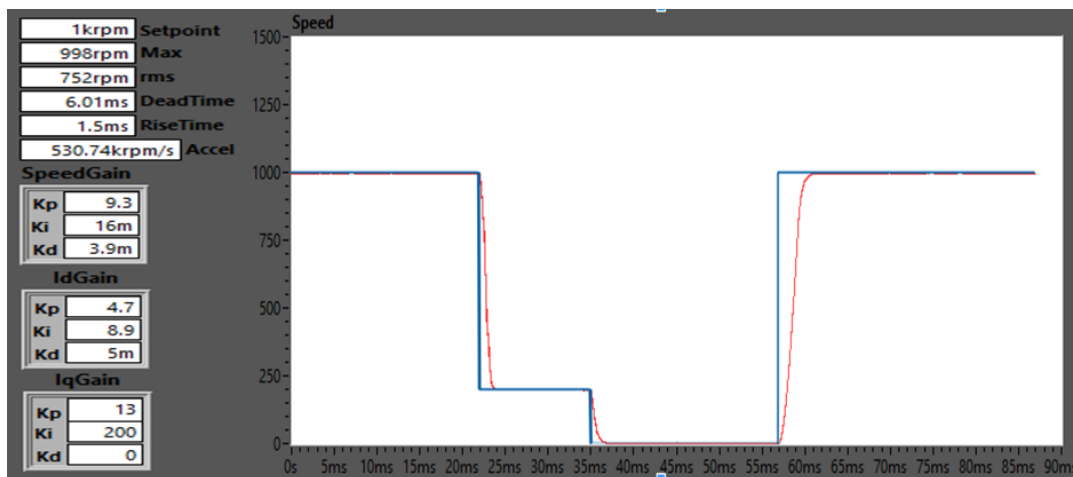


Figure 12. The response of the closed-loop system with a set point of 1000 rpm

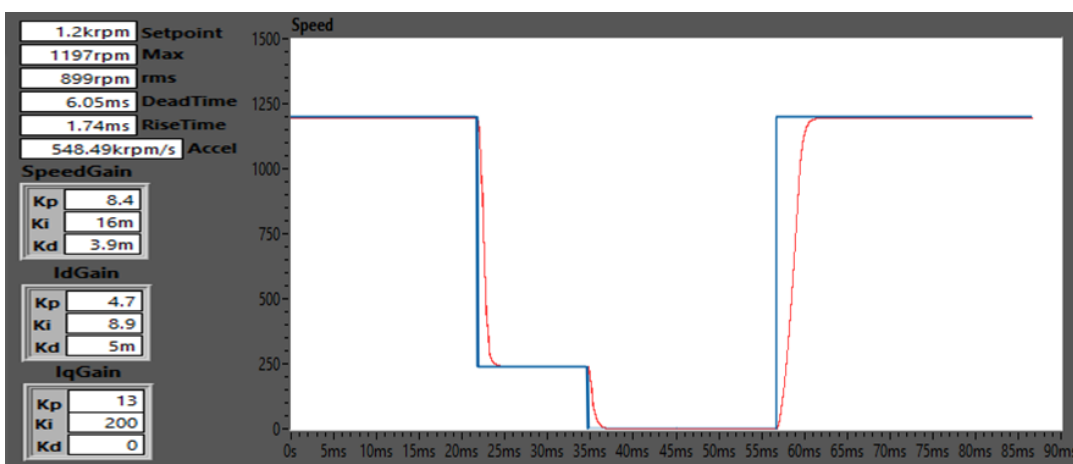


Figure 13. The response of the closed-loop system with 1200 rpm set point

Table 5. Comparison of the motor speed characteristics in the simulation results with variations in the setpoint

Setpoint (rpm)	Kp	Ki	Kd	Dead time (ms)	Rise time (ms)	Settling time (ms)	Error steady (%)
500	8.201	0.01524	0.00381	5.92	1.13	9.9	0.4
800	9.338	0.01526	0.003815	5.97	1.31	10.1	0.25
1000	9.342	0.01556	0.00389	6.01	1.5	10.25	0.2
1200	8.398	0.0156	0.0039	6.05	1.74	11	0.25

From the results, if compared with the results of other research related to the performance of IFOC on a three phase induction motor with PI control, it was found that when operated at low-speed conditions, the results obtained were smoother / no oscillation, this is because of the derivative controller which works to reduce oscillations. Besides, if it is operated in high-speed conditions when compared with other research results related to the performance of IFOC with PI control, it is found that if it is observed from the point of view of the steady-state error it has decreased, as in [Table 6](#).

Table 6. Comparison of the motor speed characteristics with PI and PID controller

Set point (rpm)	IFOC with PI control	IFOC with PID control
	Error Steady (%)	Error Steady (%)
1000	1.654	0.2
1200	1.104	0.25

From the results, when compared with other research results related to scalar control, it was found that when it was operated at low-speed

conditions, namely 500 Rpm and high speed 1000 Rpm, it was found that it was observed from the settling time and steady-state error, it increased in rise time and decreased in the steady-state error is significant, so it can be said that the use of IFOC in the 3-phase induction motor speed setting can improve the speed response to low speed to high speed, as in [Table 7](#).

Table 7. Comparison of the motor speed characteristics with scalar control and vector control (IFOC)

Set Point (rpm)	Scalar control		Vector control (IFOC)	
	Settling time (s)	Steady State error (%)	Settling time (s)	Steady State error (%)
500	0.028	0.35	0.0099	0.4
1000	0.033	0.4	0.011	0.2

In simulation testing with dynamic conditions, the load torque value changes when the system reaches a steady-state. The changes are made at the simulation time of 50 ms - 70 ms by adding two times the initial load torque value. [Figure 14](#) and [Figure 15](#) indicate the speed response.

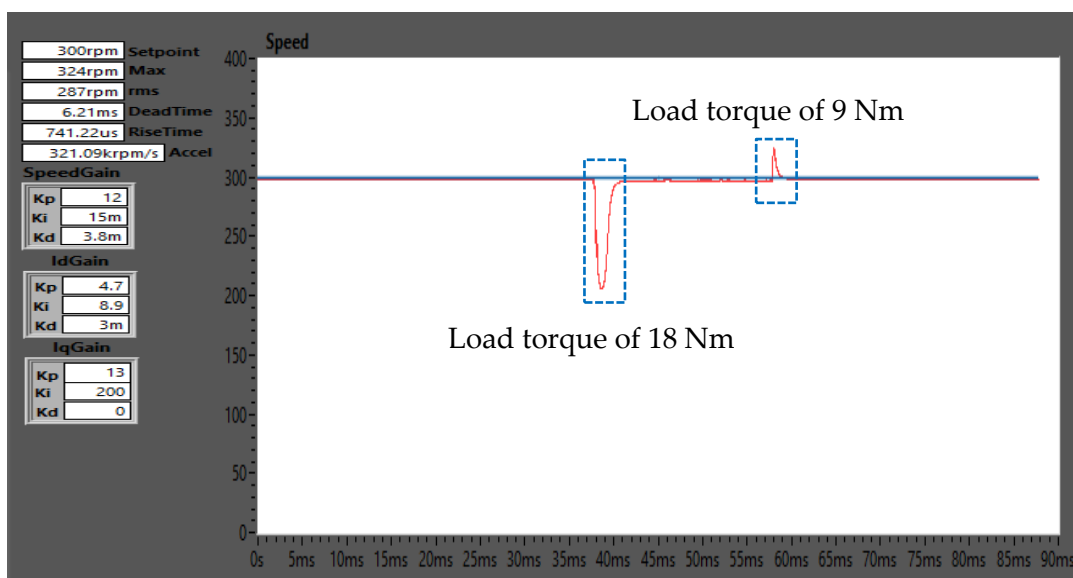


Figure 14. System dynamic response with a set point of 300 rpm

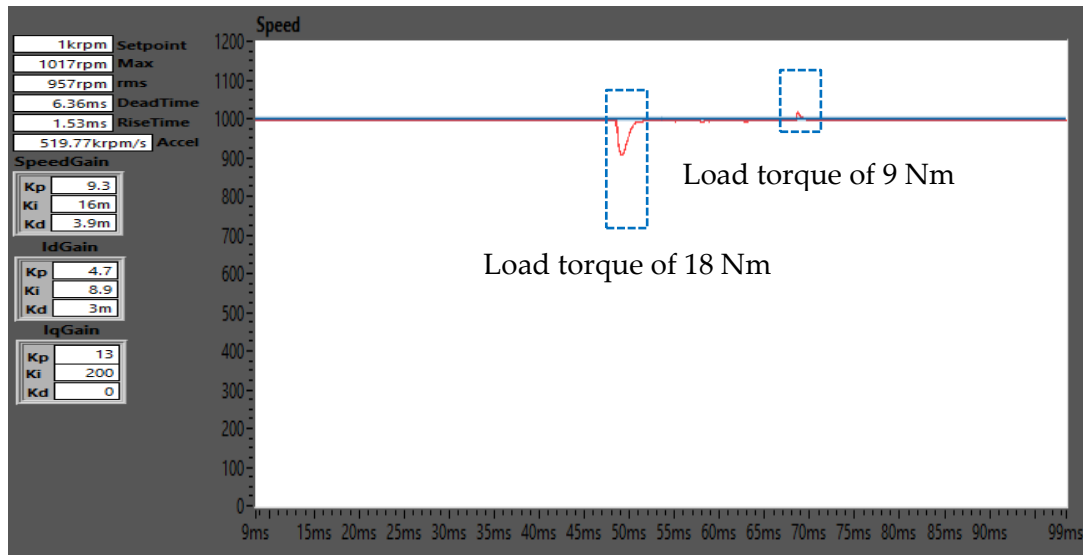


Figure 15. System dynamic response with a set point of 1000 rpm

In dynamic conditions testing with a simulation time of 0.1 seconds, the closed-loop system speed response is obtained, as shown in Figure 14 and Figure 15. Based on the response obtained with changes in load torque, the PID controller has a long response to parameter changes.

Therefore, it requires a long recovery time to return to a steady-state. Figure 14 shows that when the load torque value changes from 9 Nm to 18 Nm at the simulation time of 50 ms - 70 ms and speed setpoint of 300 Rpm, a recovery time of 4.9 ms is needed to return to a steady-state again. Conversely, there is a response from the controller to maintain a steady-state of oscillations which causes the system to be less stable and does not reach the desired set point. In Figure 15, with a setpoint value of 1000 rpm when the load torque value changes from 9 Nm to 18 Nm at the simulation time of 50 ms-70 ms, a recovery time of 1.95 ms is needed for it to return to a steady-state again. However, the PID controller fails to respond quickly and cannot maintain the desired setpoint value. Therefore, it is not suitable to be used in dynamic conditions such as changes in parameters from internal and external in the load torque value.

From the results, when compared between PID using the Ziegler Nichols method with PID using trial error, speed response using PID trial and error, there is an overshoot in the response, and the response is unstable. So that this condition can be optimized by determining the PID parameter

value using the right tuning method. Determining PID parameters by trial error is not optimal in principle because the system performance still has a steady-state error from the setpoint value. By using the Ziegler Nichols method in determining the value of the PID parameter, the parameters and obtain the optimal value, so that the speed response obtained is more stable at each setpoint value.

4. Conclusion

The three phase induction motor control system with IFOC method using the PID controller in LabVIEW purpose to observe the response at the speed of the 3-phase induction motor in static and dynamic conditions with variations in the setpoint value, namely in the entire working area of the speed. From the results obtained. Furthermore, the PID parameter value obtained using the Ziegler Nichols theorem at each speed setpoint value has a good speed response. This is due to an increase in the value of the rise and settling time as well as the faster response of the motor speed to a steady-state at each setpoint value. The PID controller suppresses a steady error of up to 0.2%. When operated at low speed, IFOC with PID controller has a better response than scalar control. This is the advantage of IFOC which can be operated at low speed with a stable response. However, in dynamic conditions simulation, the use of a PID controller is considered less suitable. This is because it is not fast enough to respond to the system when there

is a change in the load torque value. Hence, it requires a long recovery time of up to 4.9 ms at the set point of 300 rpm.

Author's Declaration

Authors' contributions and responsibilities

Compiling and designing research (A.A.M, E.P, B.S, H.H.F, R.A.N.A); Designing simulation on LabVIEW (A.A.M, H.H.F, R.A.N.A); Performing simulations (A.A.M, H.H.F, R.A.N.A); Analyzing and interpreting data (A.A.M, E.P, B.S, H.H.F, R.A.N.A); and Writing manuscripts (A.A.M, E.P, B.S, H.H.F, R.A.N.A).

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Competing interests

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