Design of PID Controller Module Using PLC On 3 Phase Motor

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Abstract -- Proportional Integral Derivative (PID) is a control system that combines proportional, integral, and derivative elements. PID control is often used in industrial machines. One of these machines is a 3-phase motor. Another important component in the industrial world is the Programmable Logic Controller (PLC) which is usually paired with an interface tool, namely HMI. The importance of a deep understanding of PID, PLC, HMI, and 3-phase motors is very important for students to be better prepared to face the real world of work. The application of the PID controller module using PLC as a learning tool at the Semarang State Polytechnic is still lacking, one of the reasons being the availability of PID controller modules that are inadequate. This study aims to design a PID controller module using PLC on a 3-phase motor. The creation of this practical module uses Omron HMI as a monitor in controlling 3-phase motor movements. Push buttons and switches are used as input components. Omron CP1E PLC is used as a processing component according to motor movement. The encoder is used to read the motor speed with an output in the form of a square signal which will be the feedback input read by the PLC. The inverter is used as a 3-phase induction motor driver. Buzzer and lights are used as indicators in controlling 3-phase motors. 3-phase induction motors are the main output components in this PID system. The power supply is used as a voltage source for the PLC so that the power supply must always be connected to a 220 VAC source. MCB is used as a protection system on the module.

Keywords-- HMI, 3 Phase Motor, PID, PLC

1. Introduction

PID or Proportional Integral Derivative is a type of control system that combines proportional, integral, and derivative elements. PID control is often used in industrial machines. One of the machines in the industry is a three-phase induction machine [4]. However, this machine is unable to maintain a constant speed [5]. In large-capacity industries, maximum machine performance must be achieved by having a constant machine rotation speed. To control a 3-phase induction motor, an inverter is needed [8]. An inverter is a tool for controlling motor speed by changing the frequency value entering the motor. Setting this frequency value is intended to obtain the desired rotation speed or according to needs [3]. However, a controller needs to be added to the inverter itself so that the motor can be controlled according to needs. Another important component in the industrial world is the Programmable Logic Controller (PLC) which is usually paired with an interface tool, namely HMI [1]. The importance of a deep understanding of PID, PLC, HMI, and 3-phase motors is very important for students to be better prepared to face the real world of work. The application of the PID controller module using PLC as a learning tool at the Semarang State Polytechnic is still lacking, one of the reasons being the inadequate availability of PID modules. Based on the existing problems, the author conducted a study entitled "Design and Construction of a PID Controller Module using PLC on a 3-Phase Motor. This research was conducted in an effort to help the learning process and mastery of control systems that are often used in industry. So that this can help create a learning atmosphere that is more relevant to the needs of the industry, so that graduates of the Semarang State Polytechnic can be better prepared to enter the world of work. Through this research, it is hoped that synergy can be created between the world of education and industry, so that the Semarang State Polytechnic curriculum can be more responsive to technological developments and job market demands.

2. Literature Review

Research on the manufacture of PID modules has been conducted by several researchers. The first study, the manufacture of PID modules using PLC Omron CJ1M, Arduino, 3-phase inverter, MAD42 module, 3G3JV Inverter, 3-phase induction motor and tachogenerator [7]. The second study, using a microcontroller, 3-phase inverter, MOSFET, and 3-phase induction motor [2]. The third study, using PLC Omron, MAD42, VSD TeoFM50, induction motor and tachometer generator [6]. Based on previous research, in this study a PID module was made using PLC Omron SP1E N30DRA, CP1W-DA041, HMI Omron, Push Button, and 3-phase Motor.

3. Research Methods

The Design of PID Controller Module Using PLC on 3 Phase Motor is divided into three separate sub-chapters to facilitate the technical manufacturing, namely: Mechanical System Design, Electronic System Design and Programming.

3.1 Mechanical System Design

In the mechanical system section, it is divided into 3 parts, namely the PLC Trainer Digital Analog Module, 3 Phase Inverter Module, and 3 Phase Motor. In the PLC Trainer Digital Analog Module, there is an Omron CP1E N30DRA PLC and an Analog Output Module CP1W DA041, HMI NB7W TW00B, 24 Volt DC Power Supply and Input Output Devices. The input devices in this module are push button switches and toggle switches, while the output device used is a 24 volt DC pilot lamp. The design of the PLC Trainer Digital Analog Module can be seen in Figure 1. In the 3 Phase Inverter module, there is an Analog Input and Clockwise or Counter Clock Wise rotation control direction and an output for the 3 phase motor. The design of the 3 Phase Inverter Module can be seen in Figure 2.

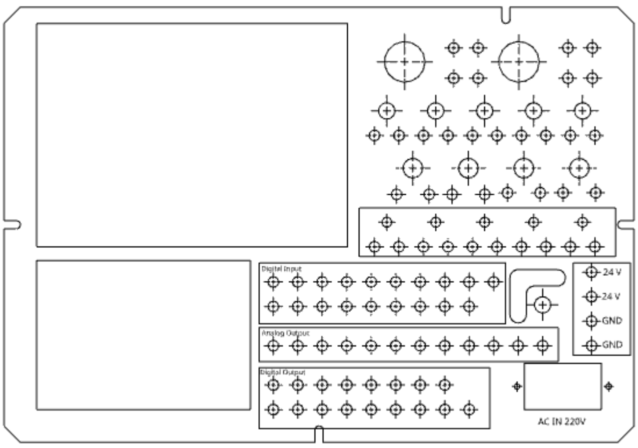

Figure 1 Acrylic Design PLC Trainer Module Digital Analog

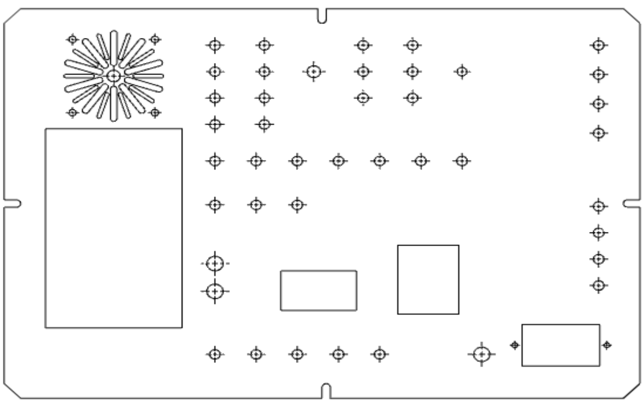

Figure 2 Acrylic Design of 3 Phase Inverter Module

3.2 Electronic System Design

The electronic system section is divided into two, namely the electronic system section for the Digital Analog PLC Trainer Module and the 3 Phase Inverter Module. The electronic systems in both modules are connected using NYAF cables. The digital and analog input outputs use NYAF 22 AWG type cables, while the DC and AC voltage sources are connected using NYAF 16 AWG type cables. In the Digital Analog PLC Trainer Module, do not forget to use 2 3 ampere time lag fuses to protect the PLC from AC voltage. The 3 Phase Inverter module uses an 8 ampere time lag fuse and a 6 ampere dual MCB to protect the Inverter from the AC source. The PID Module block diagram can be seen in Figure 3.

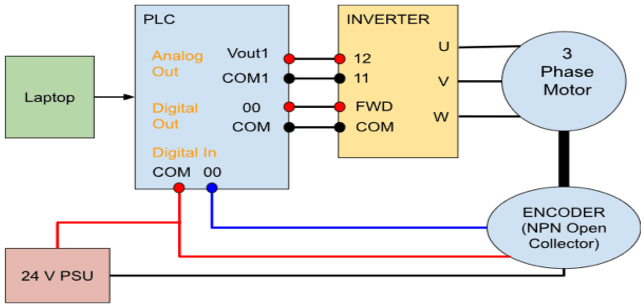

Figure 3 Block Diagram of PID Controller Module Using PLC on 3 Phase Motor

How the PID controller module works using PLC on a 3-phase machine consists of three main parts, namely the PLC Trainer Digital Analog module, the 3-Phase Inverter module, and the Motor with encoder. In the PLC Trainer module, this tool uses the Omron HMI as a monitor in controlling the 3-phase motor movement. Push button switches and toggle switches are used as input components. The Omron CP1E N30DRA PLC is used as a processing component according to the motor movement. In the inverter module, the inverter is used as a 3-phase induction motor driver. The lamp is used as an indicator in controlling the 3-phase motor. The 3-phase induction motor is the main output component in this PID system. The power supply is used as a voltage source for the PLC so that the power supply must always be connected to a 220 VAC source. MCB is used as a protection system in the inverter module.

The main way this system works is that the three-phase motor is connected to the 3-phase inverter as a control as a medium for controlling the speed of the motor in rotating, in addition, 1-phase electricity is connected to the PLC. When the power is turned on, the PLC program will send voltage control data to the inverter as input data from the inverter, then the inverter will run and regulate the motor speed. On the rotor motor there will be an encoder that is connected to the counter input from the PLC so that the RPM reading from the three-phase motor will be displayed and will become a feedback value from the speed setting point that we have previously determined.

3.3 Programming

Programming is done on CX-Programmer software. The program in question is ladder diagram programming. This programming functions to run the traineee. The trainer will run according to the program that has been created on the CX-Programmer software.

4. Results and Discussion

4.1 Results of Mechanical Equipment Construction

Based on the system design, mechanical design, and trainer manufacturing, the trainer construction results are as shown in Figures 4, 5, and 6. Descriptions of the parts of the images can be seen in Tables 1, 2, and 3.

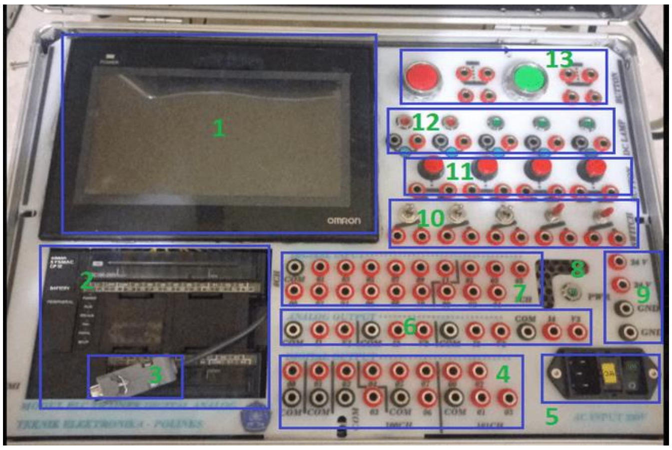

Figure 4 Analog Digital PLC Trainer Module

Table 1 Description of the Parts of the Analog Digital PLC Trainer Module

No.	Details	No.	Details
1	HMI	8	24V Power Indicator
2	PLC	9	Output Power Supply 24 V
3	DB9 HMI Connection to PLC	10	Toggle Switch
4	PLC Digital Output	11	Push Button NO
5	AC 220V Power Inlet (3A)	12	DC Led 24V
6	PLC Analog Output	13	Push Button NO and NC
7	PLC Digital Input		

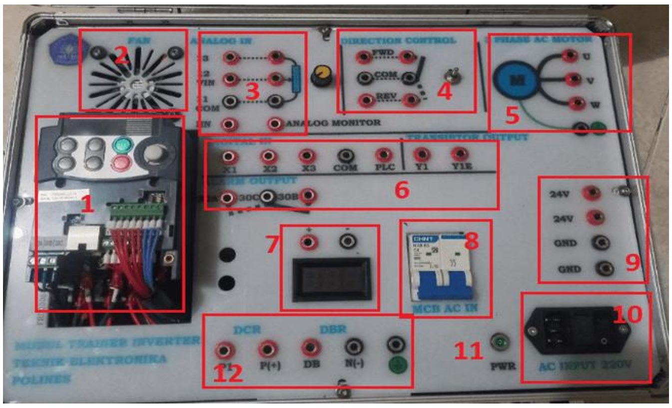

Figure 5. 3 Phase Inverter Module

Table 2. Description of 3 Phase Inverter Module Parts

No.	Details	No.	Details
1	Inverter Module	7	DC Voltmeter
2	12V Circulation Fan	8	AC Dual MCB 6A
3	Analog Input Speed Control	9	Output Power Supply 24 V
4	Digital Input Direction Control	10	AC 220V Power Inlet (8A)
5	Output To 3 Phase AC Motor	11	24V Power Indicator
6	Digital Input Output Inverter	12	DC Reaktor dan Resistor Braking

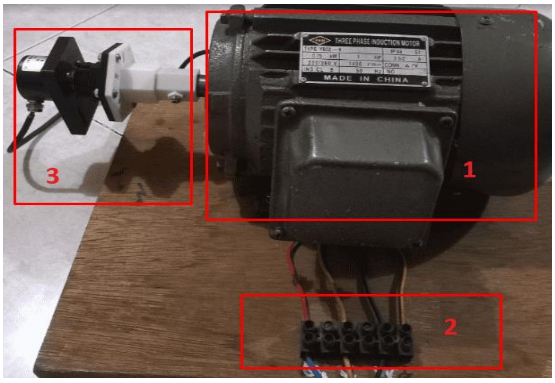

Figure 6. 3 Phase Motor with Encoder

Table 3 Description of 3 Phase Motor Parts with Encoder

No.	Details
1	3 Phase AC Motor
2	U, V, W Connector for Motor
3	Encoder Shaft and Bracket

4.2 Testing and Discussion

4.2.1 Measurement of DAC conversion data from PLC has been carried out

The measurement was carried out by connecting a laptop to the PLC via USB to download the program design, for the PLC analog output "VOUT 1" is connected to a voltmeter (+), while "COM1" is connected to a voltmeter (-). The measurement results can be seen in Table 4 and the graph as in Figure 7.

Table 4 PLC DAC Conversion

NO	DAC Input			Voltage output measurement (v)	Error (%)
	Digital (hex)	Digital (Decimal)	Analog (v)		
1	0	0	0	0	0.01
2	258	600	1	1.01	0.01
3	4B0	1200	2	2.01	0.01
4	708	1800	3	3.01	0.01
5	960	2400	4	4.01	0.01
6	BB8	3000	5	5.01	0.01
7	E10	3600	6	6.01	0.01
8	1068	4200	7	7.01	0.01
9	12C0	4800	8	8.01	0.01
10	1518	5400	9	9.01	0.01
11	1770	6000	10	10.01	0.01

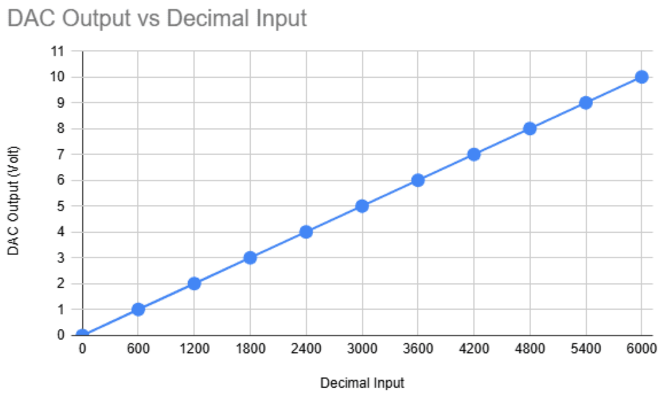

Figure 7. DAC Conversion Graph

From the measurement results, it can be seen that the DAC PLC conversion value to voltage is very precise according to the existing data sheet, with the error value of the comparison of theory and measurement being 0.01%. So that the comparison formula is obtained in Equations 1 and 2.

$$V_{out} = \frac{decimal\ value}{6000} \times 10 \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$decimal\ input = \frac{Vout}{10} \times 6000 \ldots\ldots\ldots\ldots\ldots(2)$$

4.2.2 Inverter control data measurement has been carried out with a Tachometer

The measurement is used to find the comparison value of the 0-10V voltage control input from the inverter to the 0-60Hz frequency output, so that with this setting the speed of the 3-phase AC motor can be adjusted, then the tachometer is used as a rotation reading and will be changed to the RPM (rotation per minute) value. According to the first data sheet that must be done is to replace the speed control input configuration from the inverter, to the speed input is regulated from the 0-10V voltage input.

The inverter frequency is adjusted by rotating the voltage control potentiometer, until it shows an increase of 5 Hz for each data collection, then the voltage input is measured using a voltmeter and for the motor speed output a tachometer is used to obtain speed data in the form of RPM (Rotation Per Minute), RPS (Rotation Per Second) value data is obtained manually through calculations by dividing 60 RPM values. The test results can be seen in Table 5, Graph 8, and Graph 9.

Table 5 Inverter Control Conversion With Tachometer

No	Frequency Setting (Hz)	Voltage Control (V)	Motor Speed (RPM)	Motor Speed (RPS)
1	5	0.86	149.1	2.45
2	10	1.7	302.6	5.0433333
3	15	2.54	453.7	7.56166666
4	20	3.35	598.7	9.978333333
5	25	4.18	748.4	12.47333333
6	30	5.03	900.7	15.0116666
7	35	5.85	1047	17.45
8	40	6.69	1198	19.96666667
9	45	7.5	1345	22.41666667
10	50	8.33	1496	24.93333333
11	55	9.17	1646	27.43333333
12	60	10.19	1800	30

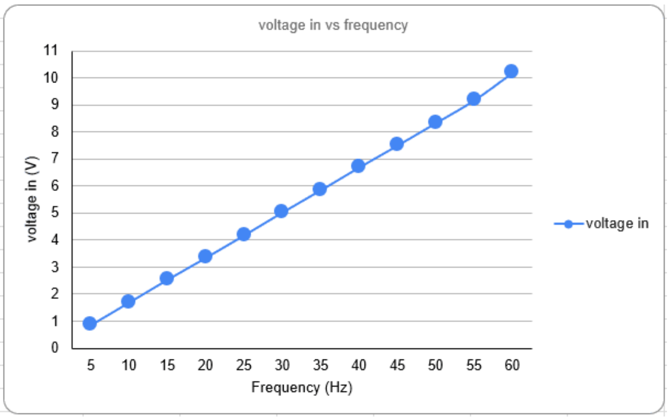

Figure 8. Comparison graph of input voltage to output frequency

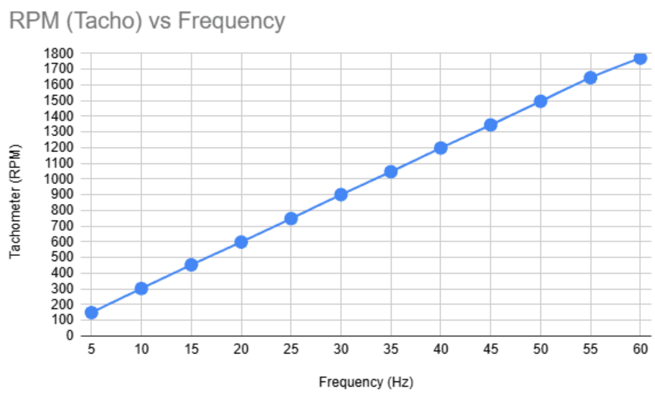

Figure 9. Comparison graph of tachometer speed against frequency output.

From the measurement results, it can be seen that the conversion value of the comparison of input voltage to output motor speed has a value that is close to linear. The maximum motor speed obtained when the inverter is given a voltage of 10V is around 1800 RPM (30 RPS), so that the comparison formula is obtained in Equation 3.

$$V_{in} = \frac{rpm\ value}{1800} \times 10 \quad (3)$$

4.2.3 Inverter control data measurement has been carried out with an encoder

This measurement is used to find the comparison value of the 0 - 10V voltage control input from the inverter to the 0-60Hz frequency output, so that with this setting the speed of the 3-phase AC motor can be adjusted, then the Encoder is used as a reading of the motor rotation and the encoder output will be connected to the oscilloscope so that the frequency value will be obtained in the form of (hz). The Encoder PPR (pulse per rotation) value is obtained = 400 and the RPS value from the frequency value divided by 400. The results of the measurements can be seen in Table 6.

Table 6 Inverter Control Conversion With Encoder

No	Frequency Setting (Hz)	Voltage Control (V)	Encoder Frequency (Hz)	Encoder Speed (RPS)	Encoder Speed (RPM)	Tachometer Speed (RPM)	Error RPM (%)
1	5	0.86	1020	2.55	153	149.1	2.6156941
2	10	1.7	2010	5.025	301.5	302.6	0.3635161
3	15	2.54	2998	7.495	449.7	453.7	0.8816398
4	20	3.35	3999	9.9975	599.85	598.7	0.1920828
5	25	4.18	5022	12.555	753.3	748.4	0.6547300
6	30	5.03	6053	15.1325	907.95	900.7	0.8049294
7	35	5.85	6990	17.475	1048.5	1047	0.1432664
8	40	6.69	8011	20.0275	1201.65	1198	0.3046744
9	45	7.5	9005	22.5125	1350.75	1345	0.4275092
10	50	8.33	9980	24.95	1497	1496	0.0668449
11	55	9.17	10989	27.425	1648.35	1646	0.1427703
12	60	10.19	11980	29.95	1797	1800	0.1666666
						Error Average	0.5636937

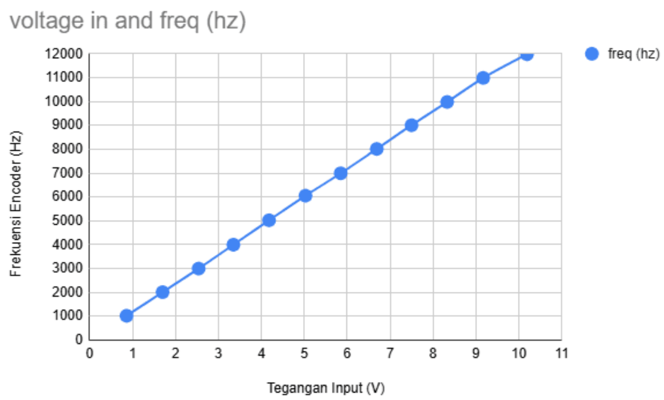

Figure 10. Comparison graph of encoder reading speed against voltage input.

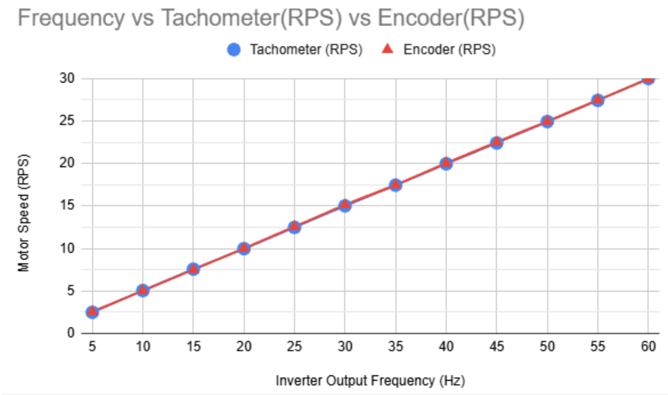

Figure 11. Comparison graph of motor speed readings with a tachometer and encoder.

From the experimental results, it can be seen that the conversion value of the comparison of input voltage to output motor speed has a value that is close to linear. The maximum motor speed obtained when the inverter is given a voltage of 10V is around 1797 RPM (29.95 RPS) or with an average error in reading speed from the tachometer and encoder of around 0.5636937342%.

4.2.4 High Speed Counter Reading data measurement has been carried out

This measurement is used to read the input of the square signal from the signal generator with a maximum input voltage of 10V and a frequency of 12Khz, this is used as a comparison value before the PLC can read the input signal from the encoder, so that reading calibration is required using the signal generator. The measurement results can be seen in Table 7.

Table 7 Signal Generator Input Conversion With PLC Reading

Signal Generator Output (Hz)	D102 Value (Hex)	Convert To Decimal
1000	3E8	1000
2000	7D0	2000
3000	BB8	3000
4000	FA0	4000
5000	1388	5000
6000	1770	6000
7000	1B58	7000
8000	1F40	8000
9000	2328	9000
10000	2710	10000
11000	2AF8	11000
12000	2EE0	12000

From the measurement results, the conversion value of the generator signal frequency input comparison with the output frequency read on the PLC shows the same value, so it can be concluded that the PLC high speed counter function can be used to read the pulse value from the encoder with a maximum encoder frequency of almost 12 Khz.

4.2.5 HMI design has been carried out

HMI design is a process carried out to design an interface display on the HMI display related to the control motor, the HMI here will display the motor speed setting point value in RPM (this value can be set by the user), then display the real-time value of the motor speed reading using encoder feedback, in designing the HMI interface display using the "NB-Designer" software, to enter design data we must need a USB that is connected to the HMI directly, then the connection to the PLC uses a DB9 cable with RS232 serial connection mode, the value data displayed on the HMI is data that is read or written from the data memory (DM) register in the PLC. The HMI design can be seen in Figure 12.

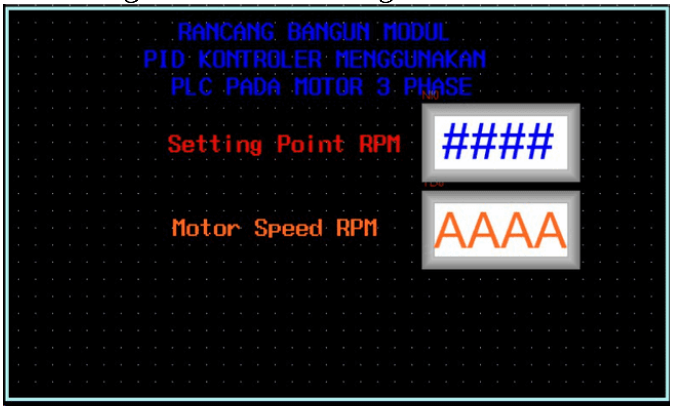

Figure 12. HMI design

4.2.6 System Response Data Measurements Have Been Carried Out On Open Loop Control

This measurement aims to find the response of a 3-phase AC motor system when given a certain step input (voltage), so that with the presence of this system response graph it helps in determining the PID parameter value using the Ziegler Nichols method, to obtain a system response graph of motor speed value (RPM) against response time.

Connection for taking system response data on open loop control, the inverter speed control output (pin 12) is connected to, the voltage output of the PLC which has been set to produce an output voltage in the range of 0-10V according to the inverter specifications, then for motor rotation direction control (FWD pin) is connected to the PLC digital output at address 100.00. The encoder is connected to the motor shaft directly and the frequency reading value will be read by the Arduino and will be displayed in the form of a graph along with its sampling response time.

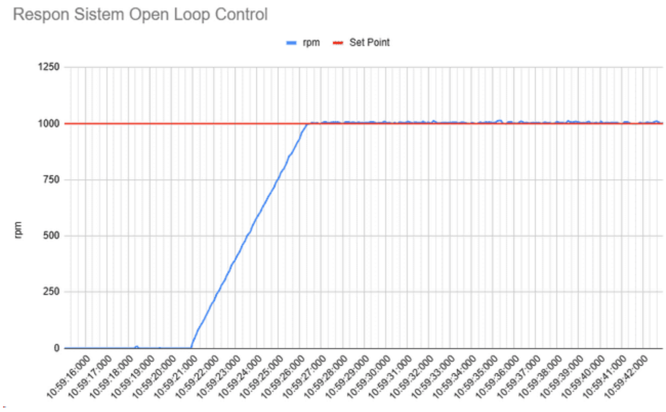

Figure 13. Open Loop Response System graph

From the results of the open loop control measurements, a system response graph was obtained as in Figure 13, namely the motor can reach a speed of 1000 rpm according to the set point requiring an acceleration time of 5.5 seconds.

4.2.7 HMI design has been carried out

This measurement aims to obtain motor speed output data from open loop control by reading the output speed value with an encoder connected to the PLC through a reading method using a high speed counter.

Connection for retrieval of open loop control data, the inverter speed control output (pin 12) is connected to, the voltage output of the PLC which has been set to produce an output voltage in the range of 0-10V according to the inverter specifications, then for motor rotation direction control (FWD pin) is connected to the PLC digital output at address 100.00. The encoder is connected to the motor shaft directly and the frequency reading value will be read by the PLC digital input address 00, the data read by the counter is frequency data, because the encoder has a PPR (Pulse Per Revolution) value of 400, to get the speed value in RPS units the frequency value will be divided by 400 first, finally to get the speed value in RPM, the RPS speed value must be multiplied by 60. For the ladder diagram program, it is the same as in the previous experiment but for this experiment it is added with the encoder reading and how to convert it. The measurement results can be seen in Table 8.

Table 8. Results of measurements of Open Loop Control Encoder Reading PLC

No	Digital (hex) / RPM Setting Point	Frequency (Hz)	Encoder Speed (RPS)	Encoder Speed (RPM)	Error (%)
1	100	618	1.545	92.7	7.3
2	1000	6644	16.61	996.6	0.34

From the results of open loop control measurements by directly reading the speed output to the PLC, an error of 7.3% was obtained for the 100 RPM setting point and an error of 0.34% for the 1000 RPM setting point, so it can be said that the speed reading with the encoder is quite accurate.

4.2.8 Close Loop Control data measurement has been carried out

This measurement aims to obtain motor speed output data from close loop control by reading the output speed value with an encoder connected to the PLC through a reading method using a high speed counter, then the value becomes a feedback correction value to improve the output speed according to the setting point value that has been determined using PID control.

Next, find the constant value of the PID using the Ziegler - Nichols method to determine the values of Kp, Ti, and Td using the system response curve model in Figure 14.

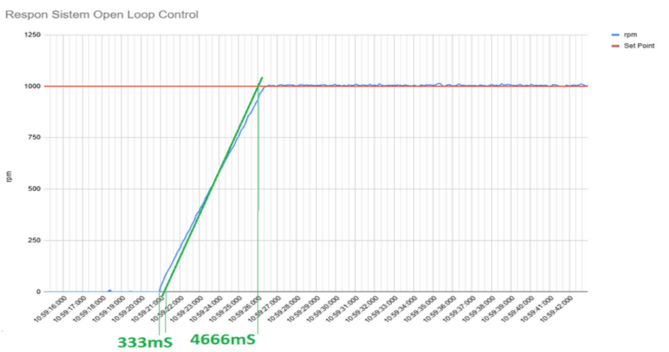

Figure 14. System Response Curve

Based on the curve in Figure 14, the Dead Time (L) value = 333 mS and the Delay Time (T) value = 4666 mS are obtained. To calculate the PID constant, Equations 4, 5, and 6 are used.

constant P = 1.2 T/ L …………………..(4)

= 1.2 (4666/333)

= 1.2 * 14.01201201201201

= **16.81441441441441**

constant Ti = 2 * L …………………………(5)

= 2 * 333

= **666 mS = 0.666 S**

constant Td = 0.5 * L ………………………(6)

= 0.5 * 333

= **166.5 mS = 0.1665 S**

After obtaining the PID constant value, it is then entered into the PLC program. The system response results can be seen in Figure 15. Measurements are made with a setting point at a value of 1000 rpm.

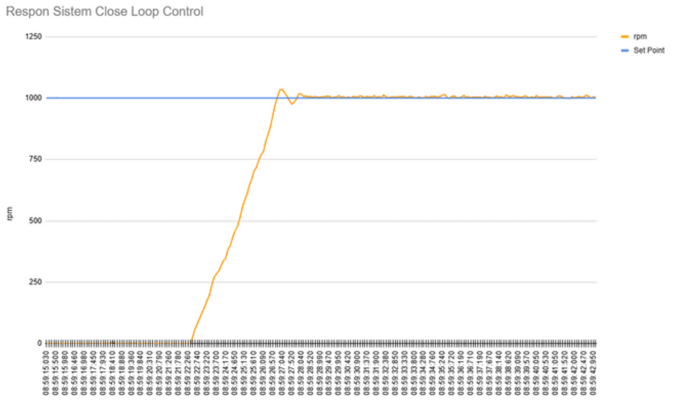

Figure 15. Closed Loop System Response Curve

From the results of the close loop control measurement by directly reading the speed output to the PLC by adding a PID controller, a rise time of 1 second was obtained which was faster than using open loop control with overshoot until the settling time had a time of 1 second.

5. Conclusion

From several measurements/tests that have been carried out using both open loop control and close loop control, the motor speed output can actually be in accordance with the input setting point that has been inputted because the 3 phase inverter module already has a PID controller, it can be seen in the open loop output when the acceleration motor selects a good system response with a rise time of 6 seconds to reach the target speed of 1000 RPM, by adding a PID controller to the PLC, it can be seen that the PLC PID controller will be in series with the internal control of the inverter module. The PID parameter value is entered with KP = 17, Ti = 666 mS, Td = 166 mS, then the system response output has a faster acceleration response of 1 second than open loop control with overshoot time until the settling time reaches 1 second.

In this study, each module is designed to be a practical trainer, so that in the future, using this study, several student practical materials can be designed that can increase student knowledge about 3-phase motor control using PLC and inverter, in addition, with several industrial control parts such as PLC, analog modules, HMI, inverters, and 3-phase motors, the learning process becomes more practical and allows for deeper exploration of concepts. Students or learners can easily observe, operate, and understand the working principles of PLC and other devices. This helps improve the ability to grasp and understand concepts in the world of industry and automation.

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