# Design of 3 Phase Motor Control System Using PLC with Raspberry Pi Based on Internet of Things (IoT) System

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*Abstract*— *PLC is currently widely used as a control component in a large control system. Based on the cost efficiency and the equipment used, the control was designed using the Raspberry Pi for Internet of Things (IoT) system. One of the IoT systems is to use a web server as an interface between the user and the machine. PLC can function as a PLC Master that controls the work of the PLC Slave. In the design of automation systems in a building using two Slave PLCs each as motor control for elevator and star-delta starting motor control used for industrial machines. The simulation shows that communication between the web server from Raspberry Pi to the PLC can be done and synchronous between one command to another. The simulation results on the PLC Master working system can work well and efficiently. The results of the voltage and current on the motor are quite stable and in accordance with the standards of the motor value itself.*

*Keywords*— *PLC, Raspberry Pi, Web server, Control System.*

## I. INTRODUCTION

According to research that has been done by P.Vivekanandan, D.L.rakrak, J.Anitha [1] that building management systems are made by implementing security in industry by combining PLCs with SCADA systems as controls. This makes it possible to carry out processes with many inputs and also various outputs on the system. SCADA functions for communication between the operator and the machine or device. However, this SCADA system requires several PCs and additional components other than PLC as communication and monitoring media on the system.

A simpler system as communication between the user and the system or device is needed in today's industry. According to research that has been done by Abhijeet S. Punpale and P. B. Borole [2] that control systems can rely on the Internet of Things (IoT). By relying on IoT control can be done remotely using a web server. The device that support this IoT system is the Raspberry Pi. By relying on this system the costs incurred are also efficient because there is no need to add many devices.

Control system using internet requires a website as control system interface. Website is controlled by a computer or server that keeps on running every day so that the access control system can work every time it is needed which is commonly referred to as a web server [3].

Based on the research that has been done by Naveen S, et al [4] that the Raspberry Pi can be connected to various electronic components or equipment such as cameras, RFID readers, relays, and including control equipment others such as PLC.

Website is a collection of pages that are used to display text information, still or motion pictures, animation, sound and or a combination of both static and dynamic that form a series of interrelated buildings where each is connected with networks. HTML (Hypertext Markup Language) is one of the formats used in making documents and applications that run on web pages [5].

In any industry induction motors have an important role because motor is simple and rough in construction. The advantage of induction motors is that they are strong and can operate in any environmental conditions. By implementing a control system for motor work, induction motors can be used efficiently in a variety of applications [6].

Based on the research above, the main control system design with PLC was made for motors used in a building with a web server interface using Raspberry Pi.

## II. RESEARCH METHODOLOGY

PLC Master functions as the main control located in the control room of a building that controls the PLC Slave to be active and work according to their respective functions. Figure 1 is a diagram of the control system design.
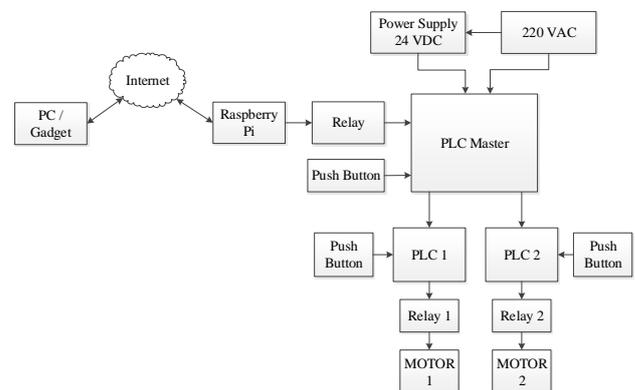


Figure 1. Control System Diagram

### A. Raspberry Pi and Web Server

Main control system is designed using the Raspberry Pi as the main input of control. Raspberry Pi is a component that has its own operating system, that is used in this design is Raspbian. Input from the web server is a display button to provide a signal to the output port on the Raspberry Pi to activate the relay. The relay functions to activate the connected PLC Master input port.

The Raspberry Pi output component is a relay. Activating the relay is processed on a web server. Users can provide input to the Raspberry Pi by accessing the web. If the input from the web is to enable GPIO output 23 then the port will provide a voltage to Relay A of 5 VDC. In accordance with the working principle of the relay that is when the coil on the relay gets a voltage, then the condition of the relay that was previously NO (Normally Open) will become NC (Normally Close). Also for input condition from the web for GPIO output 24. If the GPIO output is active, it gives a voltage of 5 VDC to Relay B. Relay changes the condition from a NO condition to an NC condition.

To create a display on a web server using HTML (Hypertext Markup Language). This language makes it possible to make the display of text and other functions that want to display on the web. Communication between the web and Raspberry Pi is by inserting HTML file of the web display into the Raspberry Pi programming. Raspberry Pi programming using Python.

*B. PLC Master*

The system on the PLC Master is processed using the CX-Programmer software. This software is Omron's software that functions to program PLCs using ladder diagrams. Ladder diagrams contain logic that applies normally open (NO) and normally close (NC) conditions as input and process conditions. As for the output on the ladder diagram in the form of a coil.

PLC Master input can be obtained from Relay A, Relay B, and push buttons that are used as manual input on the system. The output of PLC Master is Relay 1 and Relay 2 along with their respective indicators to activate the PLC Slave. There is input for emergency condition with buzzer as the output for alarm. The schematic circuit of main control system can be seen in Figure 2.
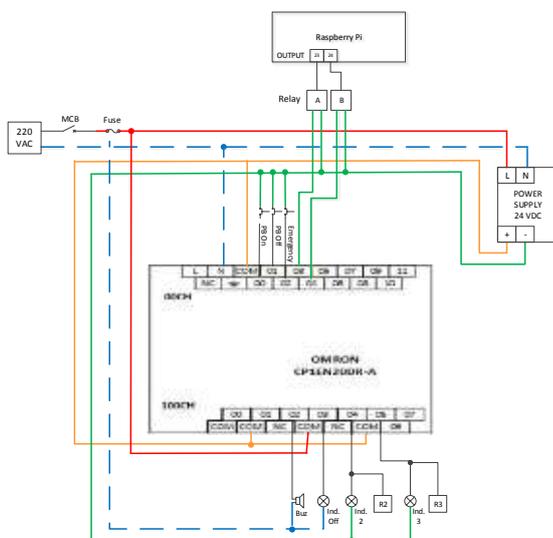

Figure 2. Main Control System Schematic Circuit

*C. PLC 1*

Figure 3 is a schematic circuit of PLC 1 which is a control system for elevator work. The motor can rotate in two directions, i.e. forward (clockwise) and reverse (counter clockwise). The forward motor rotation is obtained by connecting line R to terminal U, line S to terminal V, and line T to terminal W. Reverse motor rotation is obtained by exchanging one of the two line phases, for example line R with terminal V, line S with terminal U, and line T with terminal W [7].
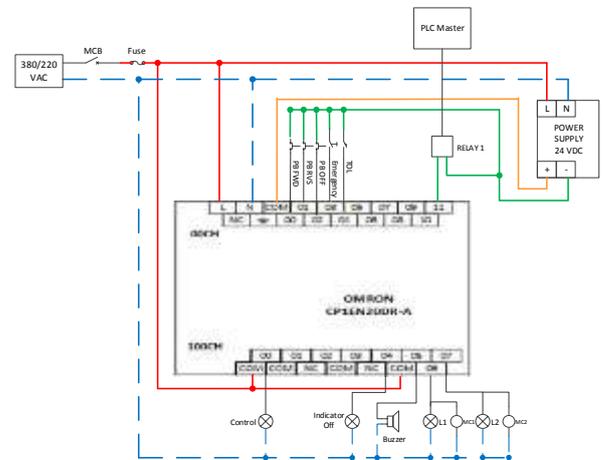

Figure 3. PLC 1 Schematic Circuit

The output components used in this system are indicator lamp, buzzer, and magnetic contactors. Magnetic contactors are used to regulate the work of 3 phase motor.

Wiring circuit for magnetic contactors can be seen in Figure 4, where two contactors are used. One magnetic contactor for forward motor rotation and one magnetic contactor for reverse motor rotation. In programming an interlock system is created. When the forward motor system runs, so the reverse system cannot be run even though the push button for the reverse input is pressed. Also for the reverse motor system runs, the forward system cannot be run even though the push button for the forward input is pressed.
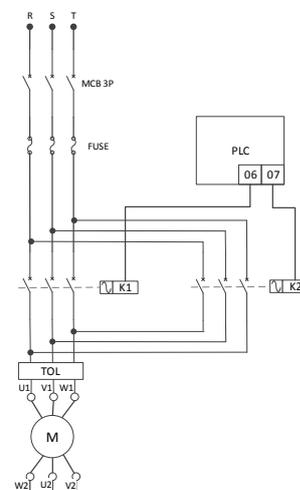

Figure 4. Forward-Reverse Wiring Circuit

The output from the magnetic contactor is connected to the thermal overload first before going to the motor. The function

of thermal overload is to read if there is excessive heat generated from the motor rotation, then the heat is converted into the amount of current by thermal overload.

The induction motor works based on the electromagnetic induction from the stator coil to the rotor coil. If a 3 phase voltage source is mounted on the stator coil, this will result in motor rotation [8]

### D. PLC 2

Figure 5 is a schematic circuit of PLC 2, which is a control system for starting industrial machinery. When the motor is connected star (Y), the starting current is only one third of the starting current in the delta (Δ) connection [9]. So that for the motor that need large power it is more effective to use this starting method because it will reduce the surge in starting current when the motor is turned on. Star-delta control systems using PLC systems are also more stable in the initial surge than manual control [10].
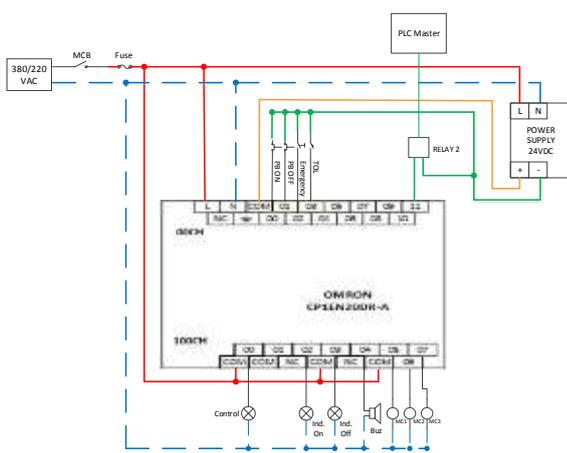


Figure 5. PLC Schematic Circuit 2

The output components of PLC 2 are indicator lamp, buzzer and magnetic contactors. Wiring circuit for magnetic contactors can be seen in Figure 6. There are three magnetic contactors are used, namely main contactor, star contactor, and delta contactor.
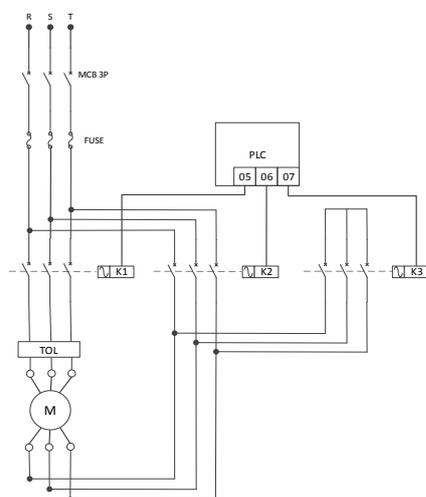


Figure 6. Star-Delta Wiring Circuit.

Programming on the PLC is designed to activate the main contactor and star contactor first for 10 seconds using a timer. Then the star contactor automatically turns off and switches to an active delta contactor. In this system the motor rotates stably under delta conditions. Push button off is used to turn off the motor.

The output from the contactor is also connected to the thermal overload before connected to motor. Thermal overload can read if there is excessive heat generated from the motor. The heat is converted into the amount of current by thermal overload if the thermal receives excess current then it will cut off contact and turn off the motor.

### III. RESULT AND DISSCUSSION

#### A. Raspberry Pi and Web Server

Raspberry Pi system can be tested through a web server that has been made. Figure 7 shows the web server testing during initial conditions where the relay is turned off. Testing is done by accessing the router's local IP address that is connected to the Raspberry Pi through a laptop. The display when the relay off is the display of the text "PLC is currently OFF".



Figure 7. Relay Off Display

Then the test is done by entering the input of buttons that appear on the web. Each button functions to activate each output port programmed in the Raspberry Pi. As shown in Figure 8 is a web display when the relay is activated using each button.



Figure 8. Relay On Display

#### B. PLC MASTER

The PLC Master system is designed by making ladder

diagrams. Push button (PB) ON as an input is programmed to activate PLC 1 and PLC 2 addresses. Input NC contact of PB OFF and buzzer are installed in diagram next to the PB ON input contacts. This is intended if the PB OFF or buzzer is activated it can disconnect the PLC ON, PLC 1 and PLC 2 outputs. This is shown in Figure 9.


Figure 9. PB On Simulation

PB emergency as input functions to activate buzzer and turn off PLC 1 and PLC 2. Ladder diagrams are made with PB emergency as an input with buzzer as an output. The buzzer address is used as input in each line of PLC 1 and PLC 2. The output conditions for the emergency button function are shown in Figure 10.
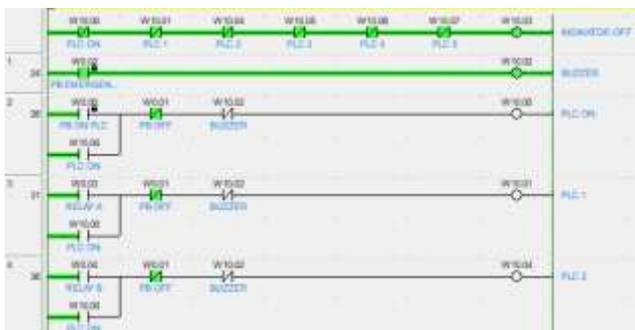

Figure 10. Emergency Button Simulation

Relay A functions as an input to activate PLC 1. If the relay condition is active it give a signal to the PLC 1 output address. This condition can be seen in Figure 11.
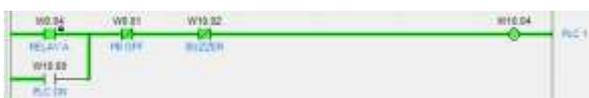

Figure 11. Condition of PLC 1 Active

Relay B as input from PLC 2. If the condition of relay B is active then the signal is given to the PLC 2 output address. This condition can be seen in Figure 12.
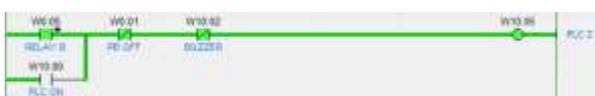

Figure 12. Condition of PLC 2 Active

*C. PLC 1*

The system on PLC 1 functions as a motor control system for the elevator. This applies a forward-reverse motor rotation work system. The ladder diagram of PLC 1 is shown in Figure 13.
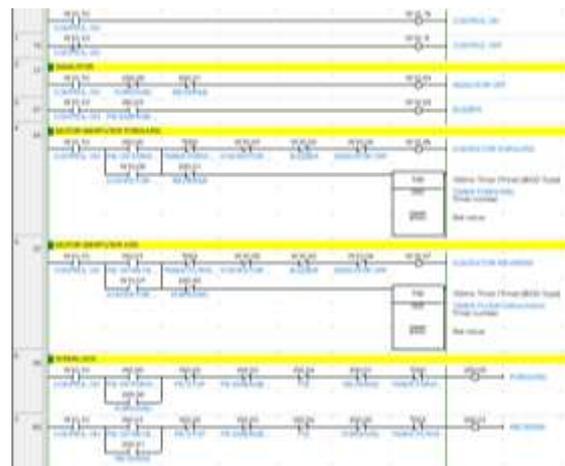

Figure 13. PLC Ladder Diagram 1

The testing of simulation result on PLC 1 are shown in Table 1. These conditions represent each given input.

TABLE 1. Simulation Result PLC 1

| Input | Output | | | | Motor |
|---|---|---|---|---|---|
| | Indicator Off | MC 1 and indicator | MC 2 and indicator | Buzzer | |
| Push button forward | OFF | ON | OFF | OFF | Forward |
| Push button reverse | OFF | OFF | ON | OFF | Reverse |
| Push button OFF | ON | OFF | OFF | OFF | OFF |
| Emergency button | ON | OFF | OFF | ON | OFF |
| Thermal overload | ON | OFF | OFF | OFF | OFF |

PLC 1 source voltage has been measured with a digital multimeter that is using a 3 phase voltage source. This is shown in Table 2.

TABLE 2. PLC 1 Source Voltage

| Source Voltage | Voltage Measured |
|---|---|
| R-S Voltage | 397,2 Volt |
| R-T Voltage | 395,8 Volt |
| S-T Voltage | 396,6 Volt |

Furthermore, measurements are taken when the motor is running. The motor is star connection in this system. Table 3 shows the measured voltages and currents for the forward motor rotation.

TABLE 3. Measurement of Forward Motor Rotation

| Motor Terminal | Voltage Measured | Current Measured |
|---|---|---|
| Coil U1-U2 | 233,2 Volt | 1,66 Ampere |
| Coil V1-V2 | 233,5 Volt | 1,71 Ampere |
| Coil W1-W2 | 232,8 Volt | 1,71 Ampere |

When the motor is star connection, then the measured voltage at the coil is $V_{coil} = \frac{1}{\sqrt{3}} V_{line-line}$, while for current is $I_{coil} = I_{line-line}$ [7]. In accordance with these principles, when using a measured value for the voltage at each coil is:

$$V_{coil} = \frac{1}{\sqrt{3}} \text{ x } 396 \text{ Volt} = 228,64 \text{ Volt}$$

Then in accordance with the measurement that the

measured $V_{\text{line-lines}}$ approaching 380 Volt (ideal value) and $V_{\text{coil}}$ approaching 220 Volt (ideal values). Based on these calculations can also be seen the measured and calculated $V_{\text{coil}}$ results have almost the same value.

Table 4 shows measurements for reverse motor rotation. Measurements made are taking data voltage and current on each coil.

TABLE 4. Measurement of Reverse Motor Rotation

| Motor Terminal | Voltage Measured | Current Measured |
|---|---|---|
| U1-U2 Coil | 232,6 Volt | 1,67 Ampere |
| V1-V2 Coil | 233,4 Volt | 1,76 Ampere |
| W1-W2 Coil | 232,1 Volt | 1,62 Ampere |

In accordance with measurements that the voltage and current are not much different between the motor rotating forward and reverse. This value also shows that $V_{\text{coil}}$ when the motor is reverse is also approaching 220 Volt.

Calculation of the total current of the 3 phase motor can be expressed by the following formula [7]:

$$P = \sqrt{3}V.I.\cos\theta \qquad (1)$$

where:  P = Power (Watt)

V = Voltage (Volt)

I = Current (Ampere)

Cos θ = Power factor

The calculation of the current using an average voltage of 396 Volt, power 750 Watt, and cos θ on the motor 0.8 as follows:

$$I = \frac{750}{\sqrt{3}.396.0,8} = 1.37 \text{ Ampere}$$

The results of these calculations are close to the measured current value at each turn. This includes when the motor rotates forward or reverse.

### D. PLC 2

The system on PLC 2 functions as a motor control system for starting the motor. This applies a star-delta motor starting system. Ladder diagrams for PLC 2 are shown in Figure 14.
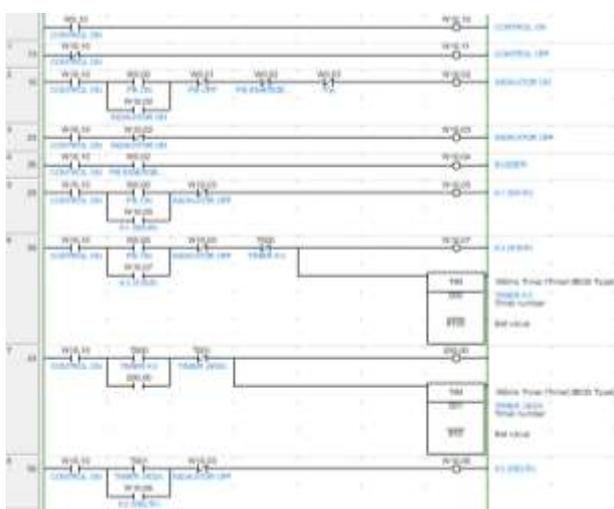


Figure 4. PLC Ladder Diagram 2

The input is from two push buttons and one emergency button. As for the output using an indicator lamp, buzzer, and

three magnetic contactors connected to a 3 phase 5.5 kWatt motor. A simulation testing is carried out in order to know the output that occurs at each given input as shown in Table 5.

TABLE 5. Simulation Result PLC 2

| Input | Output | | | | | | |
|---|---|---|---|---|---|---|---|
| | Indicator Off | Indicator On | Main MC | Star MC | Delta MC | Buzzer | Motor |
| Push button ON | OFF | ON | ON | ON (10 s) | ON (after 10 s) | OFF | ON |
| Push button OFF | ON | OFF | OFF | OFF | OFF | OFF | OFF |
| Emergency Button | ON | OFF | OFF | OFF | OFF | ON | OFF |
| Thermal overload | ON | OFF | OFF | OFF | OFF | OFF | OFF |

Data obtained from measuring the source voltage, also voltage and current measurement when the motor is in star and delta connection. The results of source voltage measurement can be seen in Table 6. The measured voltage is a line-to-line voltage or voltage between phases.

Table 6. PLC Source Voltage 2

| Source Voltage | Voltage Measured |
|---|---|
| R-S Voltage | 395,2 Volt |
| R-T Voltage | 397 Volt |
| S-T Voltage | 397 Volt |

Measurements are made when the motor is active. Table 7 and Table 8 show the measured voltages and currents for the motor star and delta conditions.

TABLE 7. Voltage Measurement

| Motor Terminal | Star Voltage Measured | Delta Voltage Measured |
|---|---|---|
| U1-U2 Coil | 226,2 Volt | 393,2 Volt |
| V1-V2 Coil | 226,5 Volt | 391,9 Volt |
| W1-W2 Coil | 224,8 Volt | 392,1 Volt |

TABLE 8. Current Measurement

| Motor Terminal | Star Current Measured | Delta Current Measured |
|---|---|---|
| U1 | 1,14 Ampere | 3,31 Ampere |
| V1 | 1,27 Ampere | 3,73 Ampere |
| W1 | 1,12 Ampere | 3,29 Ampere |
| U2 | 1,14 Ampere | 3,28 Ampere |
| V2 | 1,28 Ampere | 3,37 Ampere |
| W2 | 1,12 Ampere | 3,72 Ampere |

When the motor is delta connection, the measured voltage at the coil is the same as the measurement voltage, $V_{\text{coil}} = V_{\text{line-line}}$, while for the current is $I_{\text{coil}} = \frac{1}{\sqrt{3}} I_{\text{line-line}}$ [7].

In accordance with the measurement results, the measured voltage of the delta $V_{\text{coil}}$ value approaches $V_{\text{line-line}}$, where the ideal value is 380 Volt. As for $V_{\text{coil}}$ while motor have star connection, the calculations as follows:

$$V_{\text{coil}} \text{ star} = = \frac{1}{\sqrt{3}} \text{ x } 396 \text{ Volt} = 228.64 \text{ Volt}$$

Comparison between star and delta currents is 1: 3 [5], so according to the measured data it can be seen that the current when connected to a delta is greater than 3 times the current connected to the star. Calculation of the current using an average voltage of 396 Volt and cos θ on the motor 0.8 as follows:

$$I = 5500 / (\sqrt{3},396.0,8) = 10.02 \text{ Ampere}$$

## IV. CONCLUSION

Tests performed using software can be simulated according to the system design. Activation of the output port on the Raspberry Pi can be done from the web server interface. Web server is designed simply by displaying the features needed by the system, including the display of text and buttons.

The main control system using the CX-Programmer software can also be simulated well. This software supports simulating ladder diagrams that are made.

The control system on the Slave PLC can run well. PLCs can be utilized with various electrical control system requirements. Even PLCs can support control systems for AC components and DC components. PLC provides many convenient features in the control system, including counter and timer systems. Using a PLC also does not reduce the voltage or current to the output component. Based on the measurement results on each component of AC output, the value is close to 220/380 Volt and for DC output components the value is close to 24 Volt.

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