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Design and Build an IoT-Based 3-Phase Electric Motor Protection System

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ABSTRACT

Keywords
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IoT
ESP32

The current condition of industries is very dependent on 3 phase electric motors as the production driver of the industry. Because using an electric motor can reduce pollution and is easy to maintain. However, 3 phase electric motors also need maintenance so that they are always ready to be used when needed 3-phase motor maintenance consists off: (1) 3 phase electric motors are always kept clean, because if dirt gets into the 3-phase electric motor it will disrupt its performance. (2) The control system of a 3-phase electric motor must always be maintained in good condition, if there is damage it must be replaced immediately. (3) A protection system for the 3-phase electric motor must be provided so that the 3-phase electric motor does not experience damage that could disrupt the production process.

1. Introduction

3-phase induction motors are the induction motors that are most widely used today, especially for industrial purposes, because these motors are often made with large power. If a problem occurs with the motor, the safety system will work to disconnect the motor from the system so that the motor stops operating[1].

In field conditions, 3-phase induction motors are often used for very long periods, so it is necessary to have a protection system that can maintain the lifetime or age of 3-phase induction motors to minimize damage. Unbalance voltage which results in single phasing interference in a 3-phase induction motor can be considered one of the worst conditions that can occur. This condition occurs when one of the phases of the motor is disconnected so that only two phases remain operational. This can cause various serious problems with the motorbike, both in terms of performance as well as reliability. Damage to motors due to single-phasing can include decreased torque, increased current, and increased motor temperature. The load and voltage imbalance that occurs can result in excessive tension on the phases that are still operating, while the disconnected phases do not receive sufficient voltage. This can cause overheating of motor components such as the stator and bearings, which in turn can reduce the operational life of the motor and even cause permanent damage. In the case of unbalanced voltage, it is important to immediately overcome single-phasing disturbances in 3-phase induction motors to prevent more serious damage[2].

The consideration for using a three-phase induction motor is because it has a simple construction that is easy to maintain, relatively constant rotation with changes in load, low cost, high reliability, and has a good power factor. However, when operating a three-phase motor, problems often occur such as phase imbalance, excessive voltage, overload, and overheating. Insufficient voltage supply will cause an increase in motor current. Overvoltage will cause insulation breakdown voltage and overcurrent will cause the windings on the motor to heat. Temperature affects the life of the motor, if the motor continues to have high temperatures it will cause damage to the motor windings. As a result of long-lasting high heat, the life of the motor will be short because the insulation on the coil is damaged, and the rotation and torque on the motor will also decrease, which can result in damage to the motor. In addition, the faster the rotation of the three-phase motor, the greater the voltage and current. Monitoring the voltage and current of three-phase motors needs to be done so that the motor's performance is in good condition and when a disturbance occurs it can be detected as early as possible. Monitoring the voltage and current of three-phase motors is usually still done manually. Manual measurements using direct measuring instruments are considered less flexible. The engineer approaches the three-phase motor and brings measuring instruments to measure the voltage and current of the three-phase motor. This work has the risk of human error and is ineffective [3].

2. The Proposed Method

2.1. Induction motors

Induction motors are the simplest type of electric motor, have strong construction, and have different KVA sizes. An induction motor is a motor that is supplied with alternating current to the stator directly and to the rotor with an effect or transformer from the stator. It is called an induction motor because the current flowing in the rotor is not obtained from a particular source but rather the current is induced due to the relative difference between the rotation of the rotor shaft and the rotating field that occurs in the stator. This rotating field is the basic principle of a 3-phase induction motor, while a single-phase induction motor does not produce a rotating field [4]. Induction motors work based on electromagnetic induction from the stator coil to the rotor coil. If the stator coil of a 3-phase induction motor is connected to a 3-phase voltage source, the stator coil will produce a rotating magnetic field. The lines of flux force induced from the stator coil will cut the rotor coil, causing an electromotive force (emf) or induced voltage to arise. Because the rotor conductor (coil) is a closed circuit, current will flow in the rotor coil. The rotor coil that carries this current is in the flux line of force originating from the stator coil so that the rotor coil will experience Lorentz force which causes a torque that tends to move the rotor following the direction of movement of the stator-induced field [5]. If a three-phase voltage source is connected to the stator terminal, a current will arise in the voltage coil (stator) which produces flux. The flux in the stator is usually constant, the speed of the stator rotating field can be written using the following formula:

$$NS = 120 \times \frac{f}{p} \tag{1}$$

Where:

f = Voltage source frequency (Hz).

p = Number of pairs of poles.

NS = Synchronous rotation speed of the stator magnetic field. [5]

The stator rotating field will cut the conductor rod. As a result, an induced voltage (emf) arises in the motor coil:

$$E2S = 4{,}44\ f_2 N_2 O_m \ \text{(for one phase)} \tag{2}$$

Where:

$E2S$ = induced voltage when the rotor rotates (volts)

f_2 = motor frequency (H1)

N_2 = Number of motor windings

O_m = Maximum flux (Weber)[4]

Because the rotor coil is a closed circuit, the emf (E) will produce an induced current (I). The presence of current (I) in the magnetic field will cause a force (F) on the rotor. If the initial couple generated by the force (F") on the rotor is large enough to support the load, the rotor will rotate in the direction of the stator rotating field. That the rotor conductor rod is cut by the stator rotating field means that the induced voltage requires a relative difference between the stator rotating field speed (Ns) and the rotor rotation speed (Nr). The difference between the stator field speed (Ns) and the rotor rotation speed (Nr) is called slip, expressed by:

$$S = \frac{Ns-Nr}{Ns}\ x\ 100\% \tag{3}$$

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If $Ns = Nr$ it means that the voltage is not induced and the current does not flow in the rotor coil, thus it does not produce a couple. The motor coupling will be generated if $Ns < Nr$. [4]

The power flow in a three-phase induction motor must be calculated according to a predetermined formula. The total input power to the stator coil of an induction motor is expressed by:

$$P_{in}\sqrt{3} \times VL \times I \times PF \quad (4)$$

$$I = \frac{P}{V} \times \sqrt{3} \times PF \quad (5)$$

Where:

VL = Source Voltage (Volts)

I = Source Current (Ampere)

PF = Induction Motor Power Factor.

To find the output power value, you must calculate the mechanical power with the rotational power. To get the mechanical power value, you must calculate the air gap power value (P_{AG}). The following is the formula for calculating the air gap power value:

$$P_{AG} = 3 \times |I|^2 \times Z_F \quad (6)$$

Where:

P_{AG} = Air Gap Power (Watts)

I = Stator Current (Ampere)

Z_F = Parallel Impedance (Ohm)

After getting the air gap power results, you can calculate the mechanical power value. The following is the formula for calculating the mechanical power value:

$$P_{CONV} = P_{AG}\,(1 - S) \quad (7)$$

Where:

P_{CONV} = Mechanical Power (Watts)

S = Slip

To calculate rotational power, it can be expressed using the formula:

$$P_{ROT} = P_{NL} - 3\,|I_{NL}|^2 R \quad (8)$$

Where:

P_{ROT} = Rotational Power (Watts)

P_{NL} = Power at no-load test (Watt)

I_{NL} = Current at no-load test (Ampere)

R = Stator Resistance (Ohm)

After calculating the rotational power and mechanical power, we can calculate the output power of the electric motor. The calculation of the output power of an electric motor can be expressed as[6]:

$$P_{OUT} = P_{CONV} - P_{ROT} \quad (9)$$

Where:

P_{OUT} = Output Power (Watts)

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2.2. Internet Of Things (IoT)

The Internet of Things better known as IoT is a concept that aims to expand the benefits of continuously connected internet connectivity. The term Internet of Things was originally suggested by Kevin Ashton in 1999 and became famous through the Auto-ID Center at MIT. Capabilities such as data sharing, remote control, and so on, also apply to objects in the real world. Meanwhile, "Things" in the word IoT refers to subjects controlled by the internet. For example, the use of online transportation, e-commerce, online ticket ordering, controlling and managing equipment using sensors, all of which are connected to local and global networks and are always active. The Internet of Things refers to objects that can be uniquely identified as virtual representations in an Internet-based structure[7].

The Internet of Things is one of the inventions that was developed because it has advantages in terms of functionality and supports work without the help of cables or only via a network. The Internet of Things usually abbreviated as IoT is a concept or program in which an object can send or transmit data over a network without the help of computer devices or assistance from humans. IoT implementation itself is not limited to one particular field. IoT has made a significant contribution from small-scale applications to large-scale applications, one of which is in the world of education[8].

2.3. Contactor

Contactors are electrical equipment that works based on the principle of electromagnetic induction. In the contactor there is a winding which, when an electric current flows through it, a magnetic field will arise in the iron core, which will make the contacts attracted by the magnetic force that arises. The contacts on the contactor include:

- The NO (Normally Open) auxiliary contact will close
- The NC (Normally Close) auxiliary contact will open
- The main contact is used for the power circuit
- Auxiliary contacts are used for control circuits

In an electromagnetic contactor, there is a main coil contained in an iron core. The short circuit coil functions as a vibration damper when the two iron cores are attached to each other. If the main coil is energized, a magnetic field will arise in the iron core which will attract the iron core of the short-circuit coil which is coupled to the main contact and auxiliary contact of the contactor[9].

2.4. Mini Circuit Breaker (MCB)

MCB (Mini Circuit Breaker) is a component of a home or company electrical installation whose job is to limit electric current, besides functioning as a protection system in electrical installations if a short circuit or short circuit occurs and if an overload occurs. The working principle of an MCB is that when there is overcurrent, the overcurrent will produce heat in the bimetal, at that time the bimetal will bend, breaking the MCB contact or what is usually called a trip. (Suranto, 2022)

Every load above 100 A must be equipped with a fuse, and the current capacity of the MCB cannot be compared with the breaking capacity of the fuse. Bimetals included in overcurrent protectors usually work at a temperature of 2500 C when the room temperature rises. One way to overcome this problem is to reduce the load. By reducing the load in this way, it means that the amount of heat produced will be reduced[10].

2.5. MLX90614 Temperature Sensor

The MLX90614 temperature sensor is a sensor used to measure the temperature of an object by utilizing infrared wave radiation from the reflection of an object. To detect the temperature of an object, the sensor is placed at a distance of 1-10 cm. Because the closer the sensor is to the object, the more accurate the temperature reading of the object is. The temperature sensor also has an error in reading of 0.76%[11].

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2.6. ESP32 Module

ESP32 is the name of a microcontroller designed by a company based in Shanghai, China, namely Espressif Systems. The ESP32 offers a standalone WiFi network solution as a bridge from an existing microcontroller to a WiFi network, the ESP32 uses a dual-core system running on the Xtensa LX16 instructions. The ESP32 has a faster CPU core and Wi-Fi, more GPIOs, and support for Bluetooth 4.2, as well as low power consumption, making it very suitable for creating several Internet of Things-based electronics projects[12].

2.7. PZEM-004T Module

The PZEM-004T module is a module that can measure several electrical variables at once, such as voltage, current, power, and energy. Apart from that, this sensor can display these measurements directly on the LCD (voltage, current, power, and energy). This sensor is a complete form of a collection of previous conventional sensors which are generally separated from one another[7].

2.8. 5V Relay Module

A relay module is a device that operates based on electromagnetic principles to move the On to Off position or vice versa by utilizing electrical energy. The process of closing and opening the contractor occurs due to the magnetic induction effect that arises from the electric induction coil. The most basic difference between a relay and a switch is when it is moved from the On to Off position. The relay moves automatically using electric current, while the switch is done manually[13].

3. Method

3.1. Research Stage

In general, the research stages include:

1. Literature study stage

   This literature study was taken from several journals and also reference books which were used as a basis for processing existing data. This final project literature study includes the following:

   a. Study of 3-phase electric motor systems
   b. Contactor system study
   c. Mini circuit breaker (MCB) system study
   d. Study of MLX90614 temperature sensor system
   e. ESP32 module system study
   f. Study of Internet of Things (IoT) systems
   g. PZEM-004T module system study
   h. 5V relay module system study

2. Hardware design and manufacturing stage

   The design of this tool is adjusted to the function of the components that will be used so that it is ready to be realized.

3. System testing and analysis stage

   Test the system that has been thoroughly integrated and then carry out performance analysis according to its function.

To understand the flow of planning in this research, a research flow diagram or flowchart was created. The research flowchart can be seen in Figure 1.

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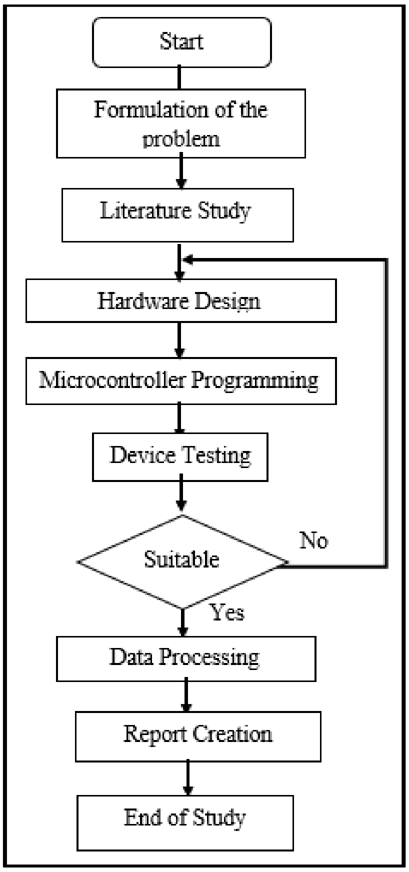

Figure 1. Flowchart

3.2. Circuit Block Diagram

Before designing hardware and software, it is necessary to design a system functional block in the form of a block diagram that explains the overall working system of this tool. The overall functional block of the system can be seen in the Figure 2.

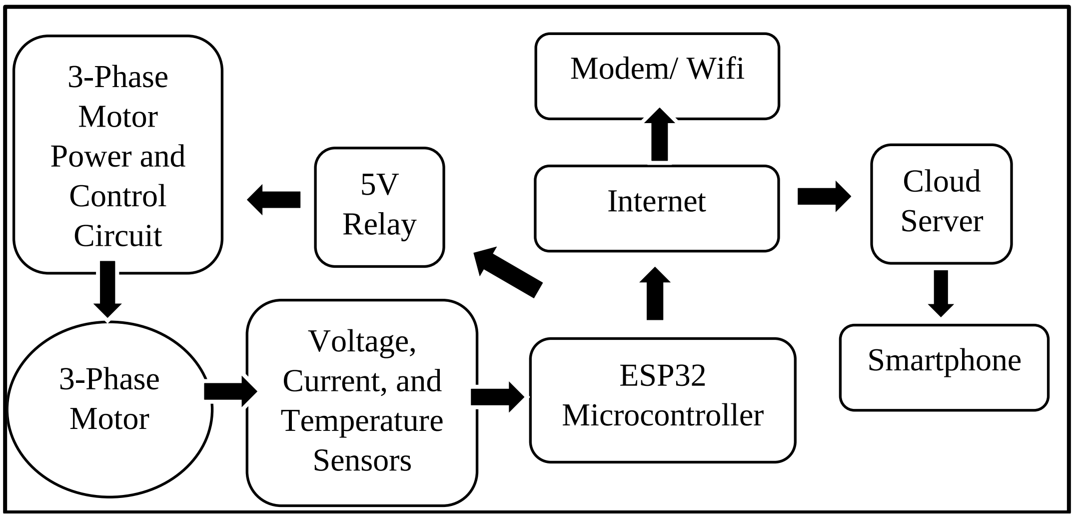

Figure 2. Circuit Block Diagram

The function of each block is as follows:

a) 3 phase motor: As a research object

b) 3 Phase motor circuit: To regulate and protect motor 3-phase

c) Voltage, current, temperature sensors: As a current, temperature and reading device voltage

d) ESP32 microcontroller: As the brain for managing the circuit and the sensor signal receiver is then sent to smartphones

e) 5V Relay: As a switch to control motor circuit 3-phase

f) Internet: As a global communications network Connect the microcontroller to the smartphone network

g) Modem/wifi: As an internet network provider for microcontroller

h) Cloud server: As a data sender via the platform computing on the internet to smartphones

i) Smartphone: As a recipient of data information already processed by a microcontroller

3.3. Circuit System Design

A. 3-Phase Electric Motor Power and Control Circuit

The control circuit and motor power circuit use a direct on line (DOL) circuit to make data retrieval easier. The control circuit is equipped with a single-phase MCB (Miniature Circuit Breaker) as control safety, 1 Off pushbutton as an off switch, a contactor for auxiliary contact for the control circuit, and Power. For the power circuit, only add 3 single-phase MCBs to protect the power circuit. The wiring diagram for the power and control circuit for a 3-phase electric motor can be seen in the figure 3

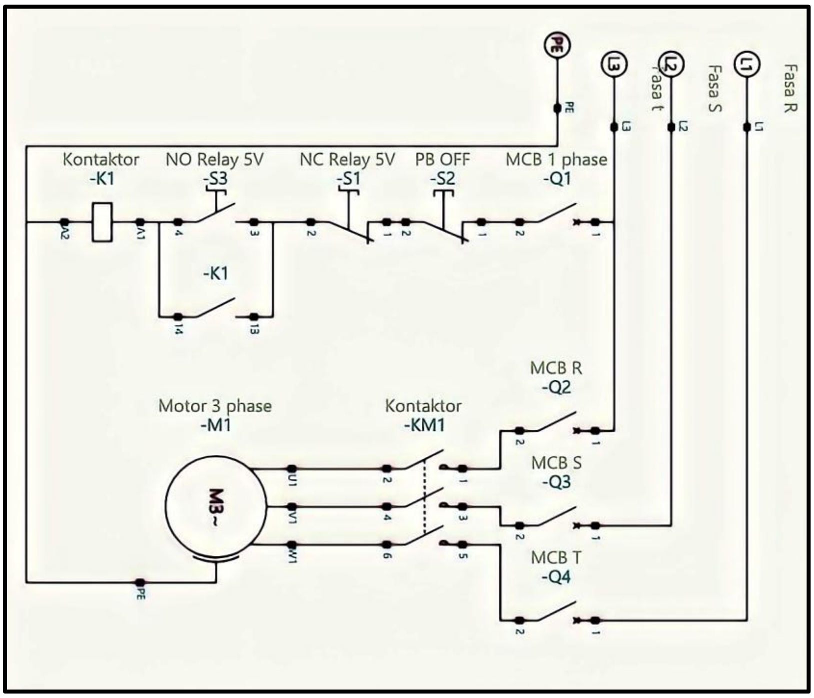

Figure 3. Wiring Diagram 3-Phase Electric Motor Power and Control Circuit

B. Microcontroller Circuit

This microcontroller circuit uses ESP32 as a circuit regulator, a PZEM sensor as a current and voltage reader from a 3-phase electric motor, and a 5V Relay as a switch to activate and deactivate the 3-phase electric motor. The microcontroller circuit wiring can be seen in the picture.

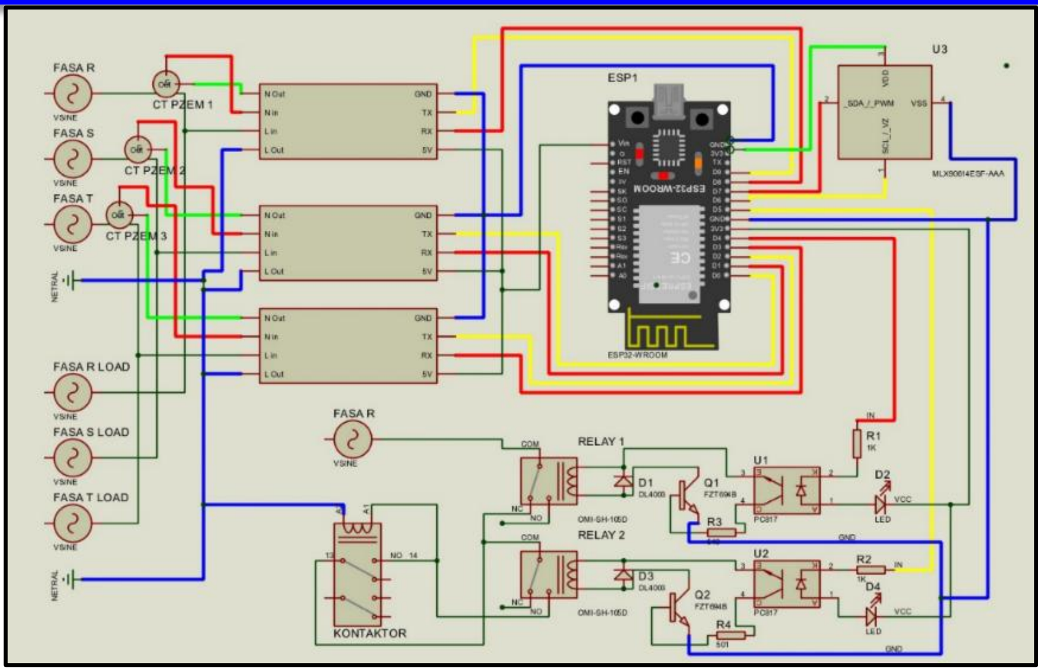

Figure 4. Wiring Diagram Microcontroller

4. Results and Discussion

In this chapter, we will discuss testing the system that has been created. The testing carried out aims to determine the performance of the tool that has been designed. The testing is carried out separately one component at a time and then tested as a whole.

Tests carried out include:

1) Testing 3 Phase Electric Motors
2) Contactor system testing
3) Mini Circuit Breaker (MCB) system testing
4) Testing the MLX90614 temperature sensor system
5) ESP32 Module system testing
6) Internet of Things (IoT) System Testing
7) Testing the PZEM-004T module system
8) Testing the 5 V relay module system
9) Overall circuit testing

4.1. 3-Phase Electric Motors Testing

A. Testing Purposes

Testing a 3-phase electric motor aims to determine the condition of the electric motor when it is connected to an inter-phase power source. If when connected to the power source the voltage between phases is less than 380 V and the phase and neutral voltage is less than 220 V, the electric motor is not suitable for use.

B. Testing Result

How to test a 3-phase electric motor by connecting the appropriate electrical voltage to the serial number of the 3-phase electric motor. 3-phase electric motors must also be connected to a star or delta when connecting to a 3-phase power source.

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Table 1. Electric Motor Testing

NO.	CONNECTED PHASE	CONDITION	
		NOT CONNECTED TO ELECTRICITY	CONNECTED TO ELECTRICITY
1	RN Phase	0,329 V	223,1 V
2	SN Phase	0,781 V	223,4 V
3	TN Phase	0,304 V	224,3 V
4	RS Phase	0,828 V	388,9 V
5	ST Phase	0,731 V	376,7 V
6	RT Phase	0,626 V	382,1 V

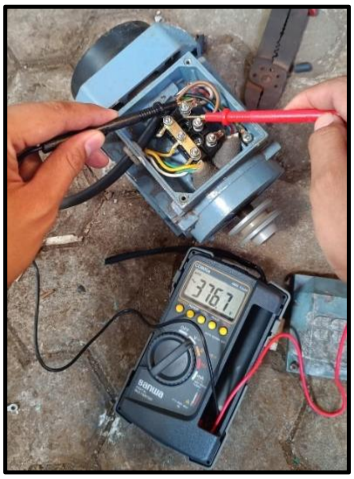

Figure 5. 3-Phase Electric Motor Testing

Table 1 shows the test results for a 3-phase electric motor if an electric voltage is applied and if it is not connected to an electricity source.

4.2. Contactor System Testing

A. Testing Purposes

Contactor testing aims to determine the condition of the contactor when connected to a 1-phase and 3-phase power source. When connected to 1 phase, the contactor auxiliary contact must be active, so that voltage appears at the NO auxiliary contact. When connected to 3 phases, the R, S, and T contact output voltage appears. If no voltage appears, than the contactor is not suitable for use.

B. Testing Result

The way to test this contactor is by connecting an AC voltage of 220 V to the main contact and coil. If the electricity source on the coil is connected, the contactor will open an electric current on the main contact and auxiliary contact.

Table 2. Contactor Testing

No.	Condition	R Phase	S Phase	T Phase	Help Contact
1.	Not Connected To Elecricity	0,329 V	0,781 V	0,304 V	0,201 V
2.	Connected To Electricity	223,5 V	223,7 V	224,9 V	223,2 V

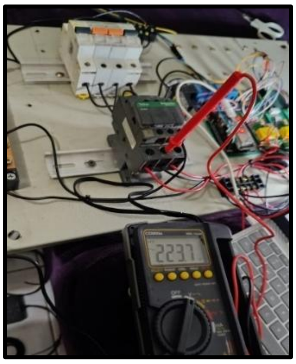

Figure 6. Contactor System Testing

Table 2 shows that if the coil is given a voltage of 220 V than the contactor will be connected and active, whereas if the coil is not given a voltage of 220 V than the contactor will not be connected.

4.3. Mini Circuit Breaker (MCB) Testing

A. Testing Purposes

MCB testing aims to determine the condition of the MCB when an electric voltage is applied. When the MCB output is activated, a voltage of not less than 220 V appears.

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However, if the input voltage and output voltage have a difference in value of more than 10 V, than the MCB is not suitable for use, because there is a voltage loss.

B. Testing Result

The way to test this MCB is by connecting a power source to the MCB, and then activating the MCB switch. If electric current does not flow to the MCB output than the MCB is declared damaged. And if there is an overload and short circuit but the MCB does not turn off the electric current, than the MCB is declared damaged.

Table 3. MCB Testing

No.	MCB Type	Condition	R Phase	S Phase	T Phase
1	1 Phase MCB	Not Connected	-	-	10,88 V
		Connected	-	-	224,5 V
2	3 Phase MCB	Not Connected	0,969 V	10,88 V	12,22 V
		Connected	226,4 V	228,5 V	227,9 V

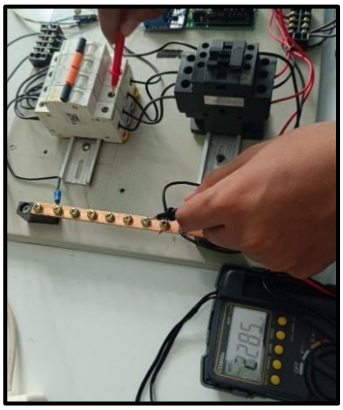

Figure 7. MCB Testing

Table 3 shows that if the MCB is supplied with electric current, it can withstand the electric current, so that it does not flow to other components before the MCB switch is activated. When the MCB is activated, the MCB function is active to protect against short circuits and overloads on the component, electric current also flows to other components.

4.4. MLX90614 Temperature Sensor Testing

A. Testing Purposes

Testing the MLX90614 temperature sensor aims to determine the accuracy of measuring the temperature of the target object and calculate the error value when collecting temperature data using an infrared thermometer which is compared with the temperature value that appears in the Arduino IDE software serial monitor.

B. Testing Result

The way to test this temperature sensor is by connecting a DC power source with a 5V voltage source to the temperature sensor. When the temperature sensor is active, point it at the object whose temperature you want to measure and send the results via the desired medium, for example, a cellphone or other device.

Table 4. MLX90614 Temperature Sensor Testing

No.	Object Name	Result	Comparative Value	Error
1	LED Lamp	33,56 °C	34,56 °C	1,00 °C
2	Ice	8,12 °C	6,75 °C	-1,37 °C

Figure 8. MLX90614 Testing

From table 4 it shows that the temperature sensor, if powered by a DC electric current, can read the temperature of the desired object. This comparative value uses a body temperature measuring instrument called an infrared thermometer. The error value for this temperature component is around 1.00 °C.

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4.5. ESP32 Module Testing

A. Testing Purposes

The ESP32 is a microcontroller. Testing the ESP32 module aims to determine the connectivity function of the ESP32 which is connected to a Wi-Fi network and can transmit the desired data stably and precisely. This ESP32 testing must be carried out properly to ensure the ESP32 functions properly in the circuit.

B. Testing Result

How to test the ESP32 microcontroller using a USB Type-C cable connected to a laptop or a 5 VDC voltage source. If the ESP32 indicator lights red, than the microcontroller is functioning properly. When sending data, the ESP32 indicator flashes red and blue, to inform that there is a program being sent to the ESP32.

Table 5. ESP32 Module Testing

NO.	Description	Value	Wifi Distance	Delay
1	1st Minute Temperature	31°C	3 meters	1 Minute
2	2nd Minute Temperature	32 °C	5 meters	2 Minute
3	3rd Minute Temperature	NaN °C	10 meters	

Table 5 shows that the ESP32 can transmit data with a WiFi network condition of a maximum of 5 meters from the circuit. ESP32 can send data to Blynk devices with a delay of 1 to 2 minutes depending on WiFi signal conditions.

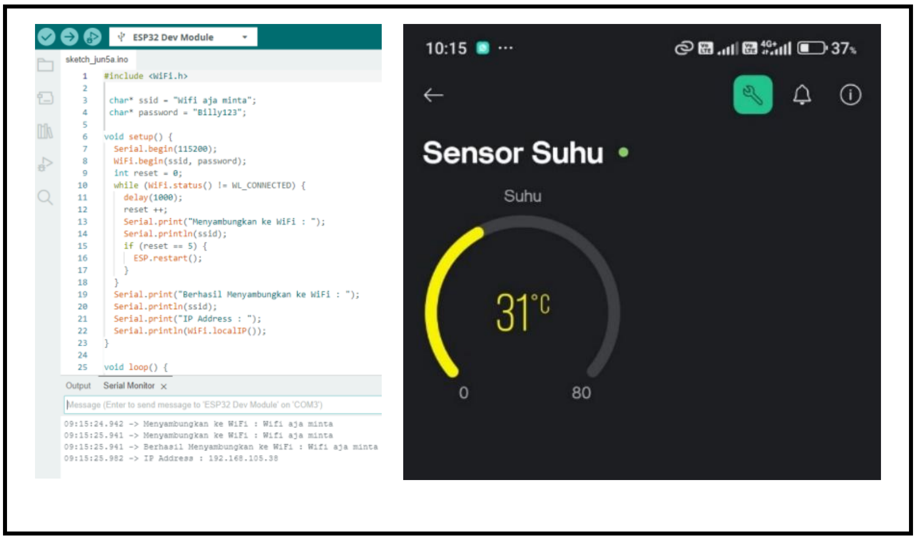

Figure 9. Microcontoroller ESP32 Module Conectivity Testing

4.6. Internet Of Things (IoT) System Testing

A. Testing Purposes

IoT (Internet of Things) is a software system used to control mobile phones via the Blynk application which sends data by the ESP32 microcontroller. Testing the Internet of Things (IoT) system aims to implement a circuit in the form of monitoring the required IoT-based data and evaluating Blynk in handling data from temperature sensors obtained from MLX90614 and voltage and current sensors obtained from PZEM.

B. Testing Result

How to test IoT by activating a programmed circuit. When the series is active, the items on Blynk (cellphone) must be active, as desired. If there is one item that cannot function as desired then there is a programming problem with the microcontroller.

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Table 6. Internet of Things (IoT) System Testing

No.	Description	Real Data	Blynk Data	Information
1	VR Voltage	226,2 V	226,10 V	2 minutes delay
2	VS Volatage	226,6 V	226,5 V	2 minutes delay
3	VT Volatage	226,4 V	226,3 V	2 minutes delay
4	IR Current	0,035 A	0,03 A	1,5 minutes delay
5.	IS Current	0,042 A	0,04 A	1,5 minutes delay
6.	IT Current	0,032 A	0,03 A	1,5 minutes delay
7.	Temperature	29,43 ^{0}C	29,43 ^{0}C	1 minutes delay

Table 6 shows that the information sent to the cellphone intermediary device has delays and error values. This condition exists because the software used also relies on internet signals. The weaker the internet signal, the longer the delay in sending information and the greater the error value displayed on the cellphone intermediary device.

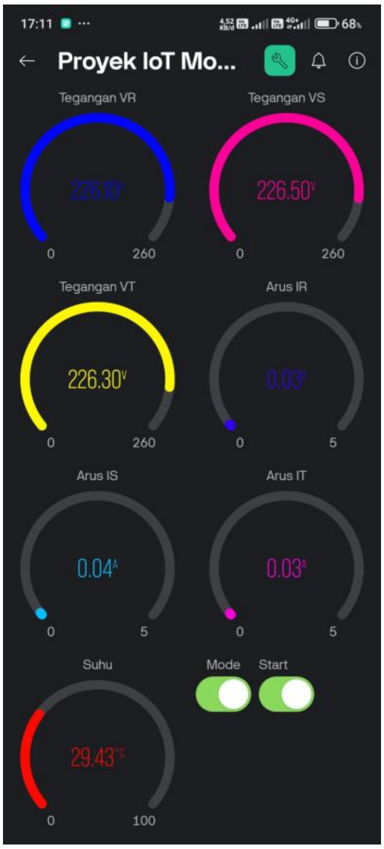

Figure 10. Internet of Things (IoT) System Testing

4.7. PZEM-004T System Module Testing

A. Testing Purposes

The PZEM-004T module is a sensor that reads electric voltage and electric current flowing in the circuit. System testing of the PZEM-004T Module aims to determine measurement accuracy and calculate error values between taking data from the avometer and the voltage and current values that appear in the Arduino IDE serial monitor software.

B. Testing Result

The way to test the PZEM-004T module is to provide a 5 VDC electrical voltage source to ensure that the PZEM-004T is still active. If the red indicator is on, than the PZEM-004T module is active. Then an AC voltage source is provided at the output of the PZEM-004T

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module, to read the current, voltage, power, and frequency flowing in the circuit. If one of them is not readable than there is an incorrect circuit connection to the PZEM-004T module.

Table 7. PZEM-004T System Module Testing

NO.	MEASUREMENT TYPE	R Phase	S Phase	T Phase	ERROR
1	Voltage	223,3 V	223,8 V	223,6 V	-4,2 V
2	Current	0,40 A	0,02 A	0,04 A	0,1 A

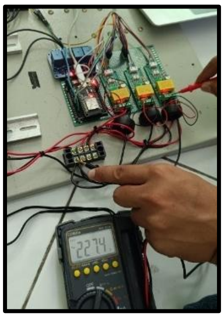

Figure 11. PZEM-004T System Module Testing

Table 7 shows that the PZEM-004T module can read the voltage, current, and power flowing in the 3-phase electric motor protection system circuit. The reading results will be sent to the microcontroller to be processed and sent to the cellphone device. The PZEM-004T module is also not completely correct in its current, voltage, and power readings. This module has error values for each type of measurement. Such as a voltage of -1.5 V and a current of 0.1 A.

4.8. 5V Relay Module System Testing

A. Testing Purposes

The 5V relay module is a DC relay that controls the circuit path with commands from the ESP32 microcontroller. The aim of testing the 5V relay module is to determine the condition and function of the relay in disconnecting electric current and connecting electric current when given a power source voltage and a signal from the ESP32 microcontroller.

B. Testing Result

The way to test the 5V relay module is to provide a 5 VDC electrical voltage source at the input voltage to ensure that the relay is still active. If the red indicator on the relay lights up than the relay is active and can be programmed. To ensure the relay is functioning, use the LED flip-flop program.

Table 8. 5V Relay Module System Testing

No.	Condition	NO Contact	NC Contact
1.	Without Voltage	0 V	0 V
2.	With Voltage (LOW Condition)	0 V	5,22 V
3.	With Voltage (HIGH Condition)	5,22 V	0 V

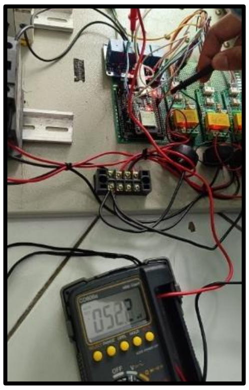

Figure 12. 5V Relay Module System Testing

From Table 8 it shows that this relay module requires a voltage of 5VDC for active conditions. When the 5V relay is active, it will become NC. However, when the condition is HIGH it will become NO and flow electric current to other components.

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4.9. Overall Circuit Testing

A. Testing Purposes

This circuit testing aims to ensure that the tools that have been designed and developed can function according to the specifications and needs that have been determined. Overall circuit testing to identify the advantages and disadvantages of the circuit system as a whole.

B. Testing Result

How to test this 3-phase electric motor protection circuit by providing a temperature above 500 C (Fire). If the electric motor turns off automatically than the circuit is working. And when given a temperature below 300 C (ice cubes), the electric motor will start again. The second test is by adjusting the electric voltage between phases. If one of the phases' voltage drops than the 3-phase electric motor circuit will turn off automatically. However, if the voltage returns to normal, the motor temperature will wait below 300 C and the motor will start again. If the temperature is below 300 C, the motor will start but the voltage between the phases is unstable so the motor will automatically turn off again.

Table 9. Overall Circuit Testing

NO.	CONDITION	TEMPERATURES	VR	VS	VT	Condition
1.	Motor On	55^0 C	222,3	222,5	223,5	Auto Shut Off
2.	Motor Off	15^0 C	221,7	222,4	222,8	Autu Shut On
3.	Motor On	37^0 C	180,1	222,3	223,5	Auto Shut Off
4.	Motor On	35^0 C	222,1	170,3	221,7	Auto Shut Off
5.	Motor On	38^0 C	222,1	221,5	160,7	Auto Shut Off

Table 9 shows how the 3-phase electric motor protection circuit works. If the temperature is above 500 C than the 3-phase electric motor turns off automatically. If the temperature is below 300 C than the 3-phase electric motor starts automatically. However, if the voltage in one of the phases is unstable, the motor will automatically stop. Temperature and electric voltage measurements are monitored from a cell phone.

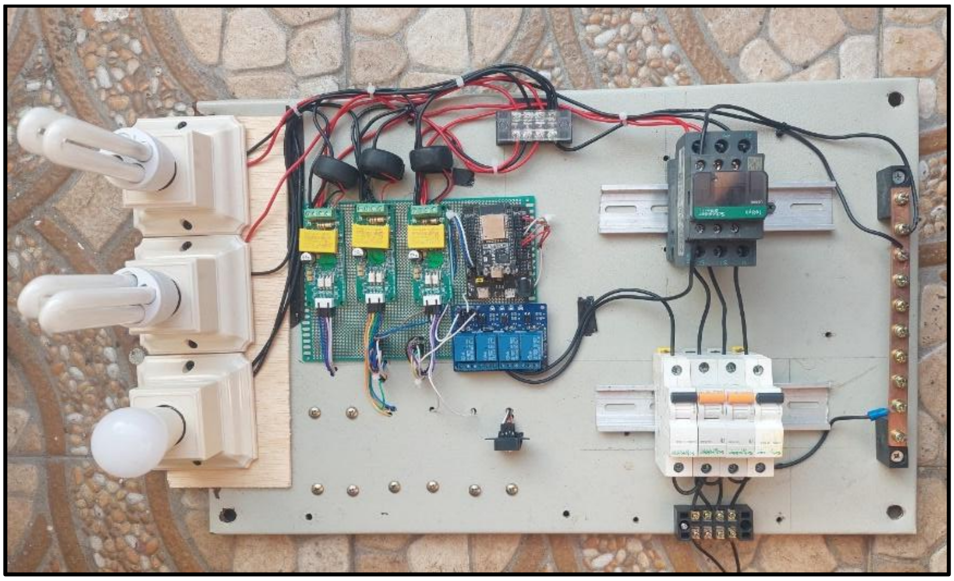

Figure 13. Overall Circuit Testing

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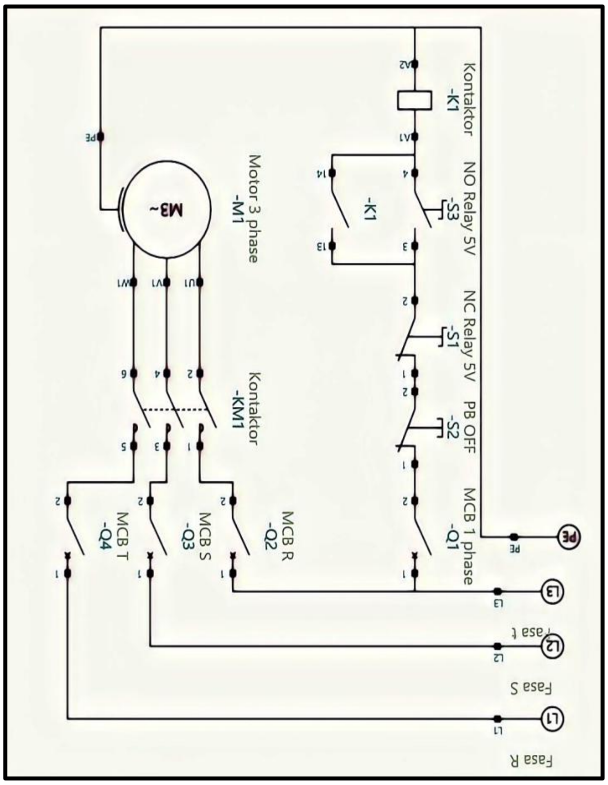

Figure 14. AC Component Circuit Schematic

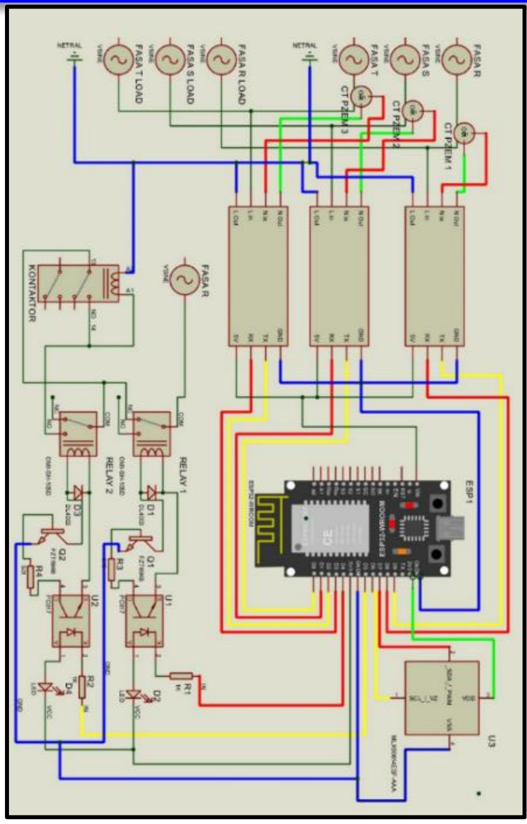

Figure 15. Microcontroller Component Circuit Schematic

5. Conclusion

5.1. Conclusion

Based on the results of discussion and testing from this research, it can be concluded that:

1. This 3-phase electric motor protection circuit is made using components including ESP32, PZEM-004T Sensor, MLX 90614 Temperature Sensor, and 5V relay module which are assembled to form a single DC component. Than the output from the relay is connected to the contactor which is protected by the MCB. The output of the PZEM-004T sensor is connected to a 3-phase electric motor.
2. The working principle of this electric motor protection system is to take data from temperature sensors and voltage sensors. The data received is transmitted to the mobile device for monitoring. If the circuit reads a temperature above 400 C, the electric motor will stop automatically. However, if the temperature drops to less than 300 C with a stable voltage condition of 220 V/380 V, the motor will automatically start. When one of the voltages is unstable (below 220 V/ 380 V) the electric motor will automatically stop.

5.2. Suggestion

Based on the cases that the author experienced while working on this series, the author suggests to future researchers:

1. Use a sensor that uses AC voltage, so it doesn't use DC voltage for the power source.
2. To use software applications that are real-time based, so that data delays are not too long to be monitored.
3. When using an electric motorbike for a long time, it is recommended to use additional safety measures such as TOR (Thermal Overload Relay) to protect against overloads. If you use a

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large-capacity electric motor, it is recommended to use a star delta control circuit, to reduce current spikes at the initial start.

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