Design And Develoment Of A System For Monitoring Voltage, Current And Temperature As Well As Overcurrent And Overheating Protection For Single Phase Motors Based On The Internet *Of Things*

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***Abstract*— Single-phase induction motors used in practical activities at the Electrical Engineering Vocational Education Laboratory (PVTE), Universitas Sultan Ageng Tirtayasa, are potentially exposed to overcurrent and overheating faults. Motor condition monitoring is still performed manually using conventional measuring instruments, so an automatic fault warning system is not yet available. This study aims to design and test an Internet of Things (IoT)-based monitoring and protection system to monitor motor voltage, current, and temperature in real time and automatically disconnect the electrical supply when abnormal conditions occur. The system uses an ESP32 as the controller, PZEM-004T to measure voltage and current, DS18B20 to detect temperature, a Solid State Relay (SSR) as the protection actuator, a 20×4 LCD (Liquid Crystal Display) as the local display, and a Telegram Bot for remote notification. System testing was conducted using black-box testing, covering protection success, sensor accuracy, notification delivery, response time, and LCD display. The results showed a 100% protection success rate, with average response times of 0.30 s for overcurrent and 0.42 s for overheating. The relative errors of the voltage, current, and temperature sensors were 1.14%, 3.26%, and 1.00%, respectively, all below the 5% tolerance. Telegram notifications were successfully delivered in 100% of the tests, with an average delivery time of 1.66 s. The system is considered feasible as an automatic monitoring and protection solution for single-phase induction motors in an educational laboratory environment.**

Keywords*— *IoT, monitoring motor, single-phase induction motor, overcurrent, automatic protection.

I. INTRODUCTION

Single-phase induction motors are widely used in household equipment, small-scale industry, and electrical engineering practical activities because of their simple construction, low maintenance cost, and ease of operation. This type of motor generally uses Class B insulation with a maximum winding operating temperature of 130°C [1]. Therefore, an unmonitored temperature increase can accelerate insulation degradation and shorten motor service life. The temperature sensor used in this study measures the motor surface temperature rather than the internal winding temperature; therefore, the protection threshold is set below the insulation-class limit to allow earlier detection of overheating faults. In practical applications, continuous monitoring of motor operating conditions is important to identify abnormal changes in electrical and thermal parameters at an early stage. Monitoring voltage, current, and temperature simultaneously can provide a more comprehensive overview of the motor's operating condition. In addition, integrating monitoring with an automatic protection mechanism can reduce the risk of motor damage caused by prolonged abnormal operating conditions.

Based on observations at the Electrical Engineering Vocational Education Laboratory (PVTE), Universitas Sultan Ageng Tirtayasa, a 220 VAC/50 Hz/125 W single-phase induction motor is used as a load in Electrical Measurement Practicum Module 5 (Energy Consumption), with 12 sessions or approximately 18 hours of use per semester by 24 student subgroups. This usage intensity is consistent with the frequency of motor faults reported by PVTE Laboratory Assistants, consisting of three overcurrent events and five to eight overheating events during one semester. These events were still detected manually through direct observation and multimeter measurements, without an automatic warning mechanism capable of responding rapidly to abnormal conditions. This indicates that conventional monitoring methods are not sufficient to accommodate the relatively high This condition is reinforced by information from the Head of the PVTE Laboratory that the existing protection consists of an MCB (Miniature Circuit Breaker) and a basic thermal overload relay, which operate independently without being connected to a monitoring system. Meanwhile, motor maintenance is performed only once every three months, so the motor condition between maintenance schedules is not continuously monitored. The absence of integration between detection and protection functions can contribute to delayed fault handling [2]. Motor overheating is generally triggered by a combination of overload, inadequate ventilation, and unstable supply voltage, which ultimately increases stator current above its nominal value [3], [4]. Previous studies have shown that integrating Internet of Things (IoT) technology into motor monitoring systems can support predictive maintenance and improve monitoring effectiveness compared with conventional methods [5], [6], [7]. However, most reported systems focus on monitoring and do not include an automatic protection mechanism directly integrated with sensor readings, so preventive action still depends on the operator's manual response.

In contrast, this study designs a system that integrates monitoring and protection functions into a single ESP32-based microcontroller system. Motor voltage and current are measured using a PZEM-004T sensor, while motor surface temperature is monitored using a DS18B20 sensor. The three parameters are displayed locally on an LCD and transmitted as notifications through Telegram, while the protection action is implemented by automatically disconnecting the load using a Solid State Relay (SSR) when the current or temperature exceeds the specified threshold. Thus, the system is designed to reduce the time gap between fault occurrence and fault detection, which has been a major weakness of manual monitoring methods in the PVTE Laboratory.

Based on the above description, this study aims to design and evaluate the performance of an IoT-based monitoring and protection system for a single-phase induction motor that can monitor voltage, current, and temperature in real time, automatically disconnect the load under overcurrent and overheating conditions, and transmit motor condition data remotely through Telegram. The contribution of this study lies in the comprehensive integration of data acquisition, remote notification, and protection action into a single ESP32-based system, thereby reducing the delay between fault detection and protective action compared with the conventional protection system currently used in the PVTE.

II. MATERIALS AND METHODS

A. *Theoretical Basis*

The theoretical basis of this study covers single-phase induction motors, electrical and temperature parameters, sensors, the ESP32 microcontroller, protection systems, and IoT technology for remote monitoring. Previous studies are reviewed to compare the methods, components, and approaches used in related research. These references support the selection of components and monitoring methods relevant to the proposed system. Furthermore, the review identifies limitations in previous studies and establishes the theoretical foundation for designing an IoT-based monitoring and protection system for a single-phase induction motor.

a) Single Phase Inducrion Motor and Insulation System

A single-phase induction motor is an alternating-current electrical machine that operates based on electromagnetic induction, in which the magnetic field generated in the stator winding induces current in the rotor and produces electromagnetic torque that rotates the motor shaft [8]. This type of motor is widely used in low- to medium-power equipment such as water pumps, fans, and washing machines because of its simple construction and ability to operate directly from commonly available single-phase electrical supplies in households and small industries [9]. Like other electrical machines, single-phase induction motors remain vulnerable to operational faults such as overcurrent and overheating, which are the main concerns of this study.

b) Overcurrent and Overheating Faults in Induction Motors

Based on the discussion above, this study aims to design and evaluate an IoT-based monitoring and protection system for a single-phase induction motor. The system monitors voltage, current, and temperature in real time, disconnects the load under overcurrent and overheating conditions, and transmits motor data through Telegram. Its main contribution is integrating monitoring, remote notification, and protection functions into an ESP32-based system to improve fault response compared with conventional protection in the PVTE Laboratory. The system is evaluated based on sensor accuracy, protection success rate, response time, notification delivery, and display consistency to support safer motor operation during laboratory practical activities and improve the reliability of motor condition monitoring.

Prolonged overcurrent conditions can subsequently cause overheating because an increase in current above the rated value results in greater heat generation in the stator winding due to the increase in I^2R power losses. This indicates that overcurrent and overheating are not completely independent faults but are related through a cause-and-effect relationship. In addition to excessive current, overheating can also be caused by inadequate cooling ventilation and prolonged continuous motor operation. In line with this condition, NEMA MG 1-2009 states that temperature rise beyond the insulation class limit can accelerate the degradation of insulation materials and shorten motor service life. In this study, the motor uses Class B insulation with a maximum winding temperature of 130 °C. Therefore, the temperature protection threshold is set below this limit because the sensor used measures the motor surface temperature rather than the internal winding temperature. Early detection of these two conditions therefore forms the basis for designing the monitoring and protection system in this study. Monitoring these parameters simultaneously allows changes in the motor's electrical and thermal conditions to be observed during operation. The current and temperature measurements can also provide complementary information for identifying abnormal operating conditions. Therefore, continuous monitoring combined with automatic protection is important to minimize the risk of prolonged faults and potential motor damage.

c) Internet of Things for Motor Monitoring

Internet of Things (IoT) is a technology that enables devices around people to connect to each other through the internet, allowing them to exchange data and be controlled automatically with minimal human involvement [10], [11]. The application of IoT in motor monitoring systems allows electrical and thermal parameters to be monitored in real time and accessed remotely, enabling protective actions to be taken more quickly than manual supervision based on periodic inspections. This approach is consistent with the study in [12], which designed an ESP32-based electrical energy monitoring and control system using a PZEM-004T sensor, where remote on/off control could be performed in real time under emergency conditions. This study adopts a similar principle; however, the ESP32 microcontroller serves both as the data processing unit and as the WiFi connectivity provider, allowing sensor data acquisition, notification delivery, and protection command execution to operate within a single integrated system without requiring an additional communication module.

d) Monitoring Sensors

The PZEM-004T is a sensor module for measuring voltage, current, power, power factor, and energy, communicating with a microcontroller through a TTL serial interface [13]. It uses a current transformer (CT) with available measurement ranges of 10 A and 100 A, making it suitable for small- to medium-power motors. Its real-time measurement capability supports continuous voltage and current monitoring, while integration with the ESP32 enables continuous data acquisition and provides electrical parameter data for evaluating motor operating conditions.

The DS18B20 is a digital temperature sensor that uses the 1-Wire communication protocol, allowing data transmission and power supply through a single cable line, with a measurement range of −10 °C to +85 °C and an accuracy of ±0.5 °C [14]. Each sensor unit has a unique 64-bit identification code, allowing individual identification when multiple sensors are connected to the same communication line. These characteristics are considered in selecting the DS18B20 for this study, as the sensor provides sufficient accuracy for detecting increases in the motor surface temperature in real time without requiring a complex additional interface circuit.

e) Protection System

A Solid-State Relay (SSR) is an electronic switch that controls electrical loads using semiconductor components such as MOSFETs, triacs, or thyristors, without mechanical moving parts found in electromechanical relays [15]. This characteristic enables high-speed switching without electrical arcing and provides greater operational durability than conventional relays. In this study, the SSR serves as the main actuator to automatically disconnect the motor power supply when the measured current or temperature exceeds the predetermined threshold. This automatic disconnection helps prevent prolonged exposure to abnormal operating conditions. Therefore, the SSR plays an important role in improving the responsiveness of the motor protection system.

f) Telegram Bot as a Remote Monitoring Medium

Telegram provides a *chatbot* feature through the Telegram Bot API, which enables microcontroller-based devices to send and receive messages automatically without manual intervention. In this study, the integration of the ESP32 with the Telegram Bot API is utilized to send real-time notifications of motor conditions to users, particularly when *overcurrent* or *overheating* conditions occur, while also serving as a remote monitoring channel that complements the local display on the LCD. Through this mechanism, users can continue to monitor the motor condition and receive warnings even when they are not physically present in the.

B. Research Flow

This study employed an engineering method based on the Waterfall model, which consists of requirements analysis, design, implementation, and testing [16]. The research began with problem identification through direct observation and interviews with the Head and Laboratory Assistant at the PVTE Laboratory to determine existing conditions and system requirements. The next stage involved designing the hardware architecture, software logic, and protection algorithm, followed by hardware assembly and software implementation. System testing evaluated monitoring functions, sensor accuracy, and protection performance. Finally, the results were analyzed to determine whether the system met the predefined success criteria. The evaluation also identified potential limitations and areas requiring improvement. These findings provide a basis for assessing the system's suitability for laboratory use. The research flow is illustrated in Fig. 1.

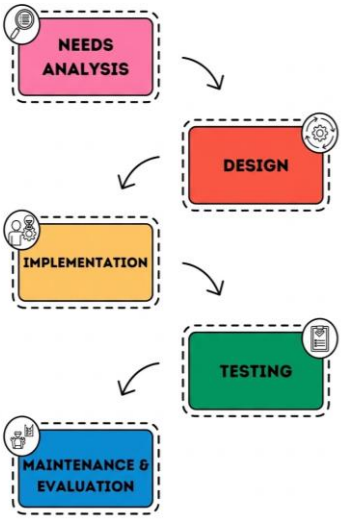


Fig 1. Waterfall Research Model [16]

C. System Architecture Design

The designed system places the ESP32 microcontroller as the main controller that integrates all sensors, actuators, and communication media. The PZEM-004T sensor measures the motor's electrical parameters, including voltage, current, power, energy, frequency, and power factor, while the DS18B20 sensor continuously measures the motor surface temperature. Both data are processed by the ESP32 and then displayed locally on a 20×4 LCD and transmitted as remote notifications through the Telegram Bot. If the processed data indicate that the motor current or temperature exceeds the predetermined threshold, the ESP32 activates the Solid-State Relay (SSR) to automatically disconnect the power supply to the motor. With this architecture, data acquisition, notification, and protection functions operate within a single closed-loop control cycle without manual intervention. The block diagram illustrating the relationship between these components is presented in Fig. 2.

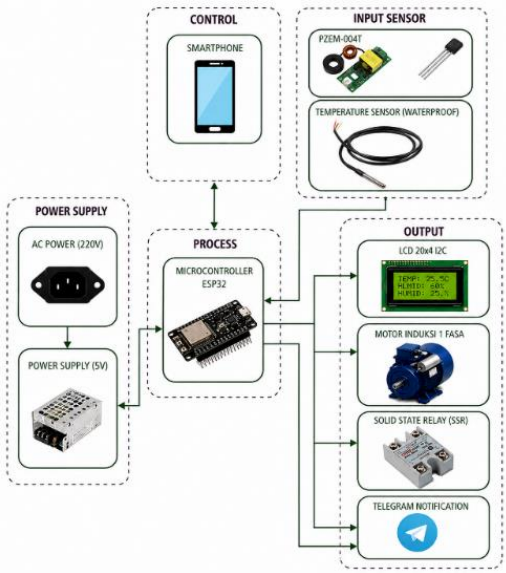


Fig 2. Block Diagram of the Motor Monitoring and Protection System

The overcurrent protection threshold was set at 115% of the motor's *Full Load Ampere* (FLA), corresponding to >0.78 A from an FLA of 0.68 A, while the overheating protection threshold was set at a surface temperature of >80 °C. These threshold values were selected to provide sufficient sensitivity for detecting mild fault conditions while preventing *false trips* during normal motor operation.

D. Hardware Design

The hardware design was developed by integrating several main components to build the monitoring and protection system for a single-phase induction motor. The components included the ESP32, PZEM-004T, DS18B20, LCD, and SSR, each designed to perform its respective function within the system.

a) ESP 32

The ESP32 functions as the central controller, reading all sensor data, processing the measurements to determine the motor operating status, controlling SSR actuation, and transmitting data to the Telegram Bot via a Wi-Fi connection. All components are powered by an adapter that converts 220 V AC to 5 V DC to provide a stable supply for the ESP32, LCD, and sensors.

b) PZEM-004T

This sensor is used to measure the motor's voltage and current and is connected to the ESP32 through TTL serial communication. It was selected because it uses a current transformer (CT) as the measurement element, allowing installation without permanently interrupting the motor's electrical circuit, while providing data output that is directly compatible with the microcontroller without requiring additional signal-conditioning circuitry.

c) DS18B20

The DS18B20 sensor was installed on the motor surface (housing) to continuously monitor temperature increases caused by excessive loading. Surface installation was selected because it is non-invasive to the motor's internal structure, although the measured temperature is physically lower than the winding hotspot temperature due to the thermal gradient through the insulation layer and motor frame. The temperature data obtained from the sensor are then compared with the overheating protection threshold established in the system architecture design to determine SSR activation.

d) Solid State Relay (SSR)

The SSR functions as the protection actuator that automatically disconnects the power supply to the motor when the ESP32 detects that the current or temperature exceeds the predetermined threshold. The SSR was selected due to its high switching speed and lack of mechanical moving parts, allowing the load to be disconnected almost immediately when an abnormal condition is detected.

e) LCD 20x4

The LCD is used as a local display medium to show the motor voltage, current, temperature, and protection status in real time, allowing motor condition information to remain accessible at the device location even when an internet connection is unavailable. This function also provides immediate visual feedback during system operation and testing.

E. Software Design

The system algorithm begins with the initialization of the ESP32 and all sensor modules, followed by connection to the Wi-Fi network. Once connected, the system periodically reads data from the PZEM-004T and DS18B20, then processes the data to determine the motor operating status. The processed data are displayed on the LCD and transmitted to the Telegram Bot, while the evaluation of current and temperature thresholds is used to determine the protection response. If the conditions remain within normal limits, the program repeats the sensor reading cycle; otherwise, when an abnormal condition is detected, the system activates the SSR and sends a warning notification before returning to the data reading cycle. The algorithm flow is illustrated in Fig. 3.

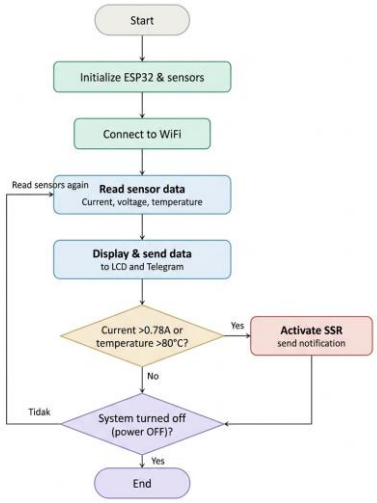


Fig 3. System Program Flowchart

F. Design Algorithm

The current protection threshold was determined based on the Full Load Ampere (FLA) of the IMP MW-125 motor, which is 0.68 A according to the nameplate data, with the overcurrent threshold set at 115% FLA or 0.78 A, referring to the NEMA MG-1 standard. The temperature threshold was set at 80 °C on the motor surface, below the 130 °C hotspot limit for Class B insulation according to NEMA MG-1, considering that the DS18B20 measures surface temperature, which is lower than the internal winding temperature due to the thermal gradient. This safety margin was selected to prevent false trips under normal operating conditions while ensuring overheating faults are detected before reaching the critical insulation limit.

The protection logic is designed to operate in a *fail-fast* manner, disconnecting the electrical supply immediately without a time-delay (*debounce*) mechanism when the current or temperature exceeds the predetermined threshold. This approach was selected because the 0.78 A overcurrent threshold still provides sufficient margin above the IMP MW-125 motor starting current of 0.68–0.71 A based on the test results, thereby reducing the risk of *false trips* during motor startup. The system is considered to be in a normal condition when both current

and temperature remain below their respective thresholds and enters a fault condition when either parameter exceeds its limit. Under a fault condition, the SSR disconnects the power supply to the motor, while the ESP32 sends a warning notification containing the fault type and motor status through the Telegram Bot.

G. Testing Procedure

System testing was conducted using two complementary approaches. Black-box testing was used to validate that each main system function—monitoring, protection, Telegram notification, and LCD display—operated according to the specified requirements by evaluating the correspondence between inputs and outputs without directly examining the program structure [17]. This approach was complemented by quantitative testing involving sensor calibration, response time measurement, and protection success rate calculations, ensuring that system validation covered both functional and numerical aspectsk.

The testing was conducted using a single-phase induction motor, IMP MW-125 (220 V/50 Hz/125 W, FLA 0.68 A, Class B insulation), as the main research object, equipped with an ESP32, PZEM-004T, DS18B20, SSR, LCD, and Telegram Bot as part of the tested system. To simulate overcurrent conditions without risking damage to the main motor, a One Cool OC-115N vacuum pump (230 V/50–60 Hz, ¼ HP) was used as a controlled test load, with its operating current consistently exceeding the protection threshold. As reference measuring instruments, a digital multimeter was used for voltage, a clamp meter for current, and a digital thermometer for temperature.

The tested parameters included voltage, current, temperature, response time, and protection success rate. Sensor accuracy was evaluated by comparing PZEM-004T and DS18B20 readings with standard instruments over five repetitions. Monitoring tests verified LCD and Telegram data consistency with sensor readings. Overcurrent and overheating tests were each performed five times using a vacuum pump and controlled heating to assess the SSR's ability to disconnect the power supply. Telegram testing verified message delivery within ≤5 seconds of fault detection, while LCD testing compared displayed values with actual sensor readings.

H. Data Analysis

Sensor accuracy was analyzed using the percentage of relative error between the sensor reading and the value obtained from the standard measuring instrument, calculated using the following equation:

$$\text{Persentase Kesalahan (\%)} = \left| \frac{\text{Nilai Sensor} - \text{Nilai Standar}}{\text{Nilai Standar}} \right| \times 100 \quad (1)$$

The measurement was considered accurate when the relative error was within the tolerance limit of ≤5%, referring to the criteria applied in [18]. In testing the PZEM-004T sensor in the IoT-based motor monitoring and protection system, the measured voltage and current values were compared with those obtained from standard measuring instruments to determine the relative error.

The protection success rate is calculated by dividing the number of successful tests by the total number of tests:

$$\text{Keberhasilan Proteksi (\%)} = \left(\frac{\text{Jumlah Pengujian yang Berhasil}}{\text{Jumlah Total Pengujian}} \right) \times 100 \quad (2)$$

The system was considered to have passed the test if all *overcurrent* and *overheating* tests successfully triggered the SSR to disconnect the power supply according to the predetermined thresholds.

The system response time was calculated as the difference between the SSR actuation time ($t_{aktuasi}$) and the time when the abnormal condition was detected by the sensor ($t_{deteksi}$):

$$t_{respons} = t_{aktuasi} - t_{deteksi} \quad (3)$$

The representative value was obtained from the average of five test repetitions:

$$\bar{t} = \frac{t_1 + t_2 + t_3 + t_4 + t_5}{5} \quad (4)$$

The response time tolerance was set at ≤1 second for SSR actuation and ≤5 seconds for Telegram notification delivery, referring to the criteria for detection and protection actuation speed in microcontroller-based systems applied in similar systems [19]. All test results were subsequently compared with the reference values obtained from standard measuring instruments to assess the consistency and reliability of the developed monitoring and protection system.

III. RESULTS AND DISCUSSION

A. Implementation of the Monitoring and Protection System

The designed IoT-based monitoring and protection system for a single-phase induction motor was successfully implemented and directly tested on an IMP MW-125 single-phase induction motor (220 V/50 Hz/125 W, FLA 0.68 A) at the PVTE Laboratory. The ESP32, PZEM-004T, DS18B20, SSR, 20×4 LCD, and Telegram Bot communication module were integrated into a single operating system according to the architecture described in the Method section. The system was tested using a *black-box testing* approach, evaluating five main functional aspects: protection success, sensor accuracy, Telegram notification reliability, system response time, and LCD display consistency. The results of these five aspects are presented sequentially in the following subsections Fig. 4 and Table 1:



Fig 4. 20×4 LCD Display Under Normal Operating Conditions

TABLE 1. PROTECTION SUCCESS TEST RESULTS

Parameter	Treshold Value	Number Of Test	Succesful Test	Success Rate
Overcurrent	> 0,78 A	5	5	100%
Overheating	> 80 °C	5	5	100%

The SSR-based protection system proved to operate reliably as a protection actuator, consistent with the principle that an effective microcontroller-based protection system should be capable of detecting abnormal conditions and responding rapidly [1]. The 115% FLA overcurrent protection threshold was selected because it better suits the characteristics of the low-power motor used in this study (FLA 0.68 A) than the 150% FLA threshold commonly recommended in industrial motor protection standards, making the system more sensitive to mild overload conditions without causing false trips during normal operating current (0.68–0.71 A).

B. Sensor Accuracy

The measurements were compared with standard measuring instruments over five repetitions for each parameter. The relative errors were calculated using Equation (1) and are presented in Table 2 and Fig. 5.

TABLE 2. SUMMARY OF SENSOR RELATIVE ERRORS

Parameter	Average Error (%)	Standard Deviation (%)	Tolerance Limit
Voltage (PZEM-004T)	1,14	0,39	≤5%
Current (PZEM-004T)	3,26	0,64	≤5%
Temperature (DS18B20)	1,00	1,37	≤5%

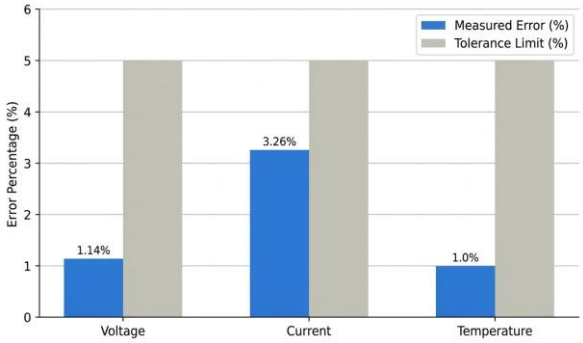


Fig 1. Average Relative Error and Standard Deviation for Each Sensor Parameter

All relative error values were below the 5% tolerance limit. The current measurement error (3.26%) was slightly higher than the PZEM-004T sensor datasheet specification (±0.5%), which was presumably caused by the measurement resolution in the low-current range (<1 A), fluctuations in the PLN grid voltage, and the tolerance of the reference measuring instrument. Compared with a similar study reporting voltage errors of 0.86–1.55% and current errors of 4.98–5.35% [19], the results of this study demonstrated comparable accuracy and even better performance in terms of the current parameter. These results indicate that the sensors provided sufficiently consistent measurements for real-time monitoring and protection of the single-phase induction motor under the tested operating conditions.

C. Monitoring System Test

Monitoring system testing was conducted to ensure that sensor data could be displayed and transmitted consistently through the monitoring media. Based on the sensor accuracy results in Table 2 and the LCD display test in Table 6, all voltage, current, and temperature parameters displayed on the LCD and transmitted via Telegram were consistent with the sensor readings. This indicates that the sensor data reading and transmission process through the ESP32 operated properly. Therefore, the monitoring system was able to provide real-time information on the motor condition as a basis for implementing the automatic protection function.

D. Overcurrent Protection Test

The overcurrent protection test was conducted five times by simulating an overload condition using a One Cool OC-115N vacuum pump as the test load, with the protection threshold set at >0.78 A (115% FLA). The test results are presented in the following Table 3:

TABLE 3. OVERCURRENT PROTECTION TESTING

Test	Measured Trip Current	Treshold	Status
1	1,31 A	>0,78 A	Succesful
2	1,30 A	>0,78 A	Succesful
3	1,33 A	>0,78 A	Succesful
4	1,00 A	>0,78 A	Succesful
5	1,30 A	>0,78 A	Succesful

All five trials successfully triggered the SSR to disconnect the power supply, with trip current values ranging from 1.00–1.33 A, all of which were above the predetermined threshold. The overcurrent protection success rate was 100% (5 out of 5 tests), as calculated using Equation (2). For comparison, the starting current of the IMP MW-125 motor recorded in a separate test ranged from 0.68–0.71 A, all below the protection threshold, indicating that the system did not experience false trips under normal operating conditions. The SSR response time to the overcurrent condition, calculated using Equation (3) and averaged over five measurements according to Equation (4), was 0.30 seconds, well below the specified tolerance of ≤1 second.

The 115% FLA protection threshold established in this study differs from the NEMA MG 1-2009 recommendation, which allows a threshold of up to 150% FLA. This difference was an intentional design decision: if the 150% FLA threshold (equivalent to 1.02 A) were applied, the lowest trip current recorded during testing (1.00 A) might not be detected as an overcurrent condition. Therefore, the 115% FLA threshold was selected to provide greater sensitivity in detecting mild overload conditions while maintaining sufficient margin above the normal starting current (0.68–0.71 A) to prevent false trips. This indicates that adjusting the protection threshold to the characteristics of a low-power motor is an important consideration and does not always require direct adoption of the maximum limit specified by the standard. Thus, the overcurrent protection system developed in this study demonstrated reliable and responsive operation under the operating conditions of the motor under investigation.

E. Overheating Protection Test

The overheating protection test was conducted using a similar method, consisting of five simulations of excessive heat conditions, with the protection threshold set at >80 °C on the motor surface. The test was conducted to determine the system's ability to detect temperature increases and provide a protective response when the motor temperature exceeded the predetermined limit. The test results were used to evaluate the success of the overheating protection function and the SSR response time in disconnecting the electrical supply. The test results are presented in the following Table 4:

TABLE 4. OVERHEATING PROTECTION TESTING

Test	Measured Trip Temperature	Threshold	Status
1	84,1 °C	>80 °C	Succesful
2	86,2 °C	>80 °C	Succesful
3	90,7 °C	>80 °C	Succesful
4	88,3 °C	>80 °C	Succesful
5	88,3 °C	>80 °C	Succesful

All five tests successfully triggered the SSR to disconnect the power supply, with trip temperatures ranging from 84.1–90.7 °C, consistently above the predetermined threshold. The overheating protection success rate reached 100% (5 out of 5 tests), with an average SSR response time of 0.42 seconds, slightly slower than the overcurrent response of 0.30 seconds, but still within the specified tolerance of ≤1 second. This difference in response time was likely influenced by the DS18B20 sensor conversion time required to measure the temperature before the data were processed by the system. The test results demonstrate that the system was able to detect temperature increases and consistently disconnect the power supply when the motor temperature exceeded the predetermined limit.

The 80 °C threshold was selected based on the motor surface temperature rather than the internal winding hotspot, considering that the DS18B20 sensor was installed on the motor housing. This value is above the motor's normal operating temperature (24–30 °C), preventing false trips under normal conditions while maintaining a safety margin of more than 50 °C below the 130 °C hotspot limit for Class B insulation according to NEMA MG-1. This is because the surface temperature is physically lower than the winding temperature due to the thermal gradient through the insulation layer and motor frame. The actual trip temperatures (84.1–90.7 °C), slightly above the 80 °C threshold, demonstrate that the protection system can detect abnormal conditions early without compromising motor reliability under normal operation.



Fig 4. LCD Display During Overheating Condition

F. Notifikasi Telegram Test

Notification testing was conducted to verify that the system could send timely alerts through the Telegram Bot when abnormal conditions were detected. A total of ten tests were performed, consisting of five overcurrent tests and five overheating tests. The test results are presented in the following Table 5, Fig 7, and Fig. 8:

TABLE 5. TELEGRAM NOTIFICATION TESTING

Notification Type	Test 1	Test 2	Test 3	Test 4	Test 5	Success
Overcurrent	✓	✓	✓	✓	✓	5/5
Overheating	✓	✓	✓	✓	✓	5/5

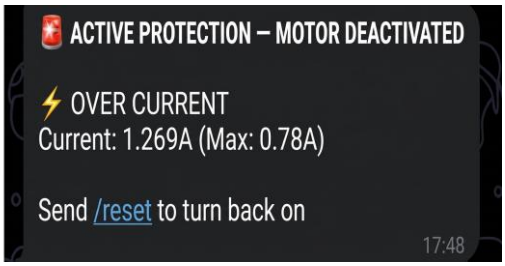


Fig. 3. Telegram Notification Under Overcurrent Condition

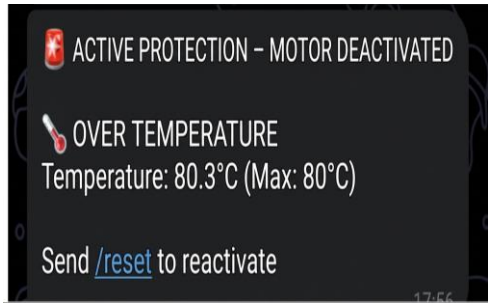


Fig. 2. Telegram Notification Under Overheating Condition

All ten notifications were successfully delivered, resulting in a notification delivery success rate of 100% (Equation (2)). The notification delivery time, calculated using Equations (3)–(4), averaged 1.66 seconds, well below the specified tolerance of ≤5 seconds. The received notifications contained information on the type of fault and the time of occurrence, enabling operators to monitor the motor condition directly without being physically present in the laboratory.

The consistent notification success across all test scenarios demonstrates that the integration of the ESP32 with the Telegram Bot API can function as a reliable remote communication channel for motor monitoring. With the delivery time well below the specified tolerance, delays in informing operators can be minimized, allowing follow-up actions in response to motor faults to be taken more quickly than with a manual monitoring scheme that relies on periodic inspections.

G. LCD Display Test

The 20×4 LCD display test was conducted to ensure that all parameters (voltage, current, temperature, and protection status) were displayed correctly and consistently with the actual sensor data. Each parameter was tested five times. The test results are presented in the following Table 6 :

TABLE 6. LCD DISPLAY TESTING

Displayed Data	Test Condition	Expected Result	Consistency (5x uji)
Voltage (V)	Normal Load	Matches Sensor Reading	5/5
Current (A)	Normal Load	Matches Sensor Reading	5/5
Temperature (°C)	Normal Operation	Matches Sensor Reading	5/5
Protection Status	Abnormal Condition	Warning message displayed	5/5

The test results showed that all displayed data corresponded to the actual sensor values in each repetition, including the protection status warning messages, which were displayed correctly when abnormal conditions were simulated. Therefore, the display consistency rate was recorded at 100%.

These results indicate that the LCD functions as a reliable local monitoring medium, providing real-time information on the motor condition even without an internet connection. Therefore, the system remains functional for on-site monitoring in the event of a Wi-Fi network failure, complementing the remote notification function that depends on internet connectivity.

H. Overall Results And Discussion

All data displayed on the 20×4 LCD (voltage, current, temperature, and protection status) corresponded to the actual sensor values in each test, indicating that the LCD functioned properly as a local monitoring medium and remained functional even in the event of a network connection failure. A summary of the overall test results is presented in Table 7 and Fig 9.

TABLE 7. SUMMARY OF OVERALL SYSTEM TEST RESULTS

Testing Aspect	Target/ Tolerance	Result	Status
Protection success rate	100%	100%	Achieved
Voltage sensor error	≤5%	1,14%	Achieved
Current sensor error	≤5%	3,26%	Achieved
Temperature sensor error	≤5%	1,00%	Achieved
Telegram notification success rate	100%	100%	Achieved
SSR response time (*overcurrent*)	≤1 second	0,30 second	Achieved
SSR response time (*overheating*)	≤1 second	0,42 second	Achieved
Notification delivery time	≤5 second	1,66 second	Achieved
LCD display consistency	Matches sensor reading	100%	Achieved

Based on the table, all nine testing aspects established in the research methodology were successfully achieved, with the results falling within or even well below the specified tolerance limits. This indicates that the designed IoT-based monitoring and protection system for a single-phase induction motor functioned comprehensively according to the planned specifications, rather than only meeting certain aspects of the system.

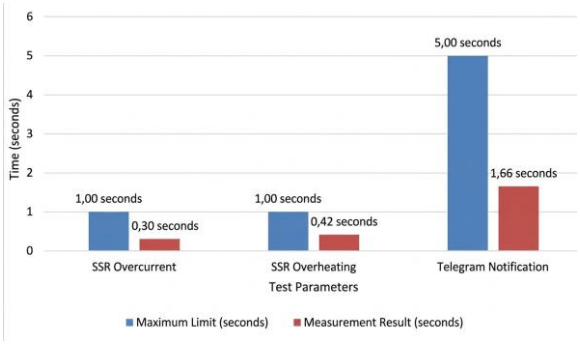


Fig 5. Comparison of SSR Response Times

In terms of novelty, this study differs from previous research by integrating three monitoring parameters (voltage, current, and temperature) with two types of automatic protection (overcurrent and overheating) using an SSR, complemented by Telegram Bot notifications and an LCD display. This integrated system was specifically implemented for a single-phase induction motor to support practical activities in an educational laboratory. This combination of functions has not been fully identified in the referenced comparative studies [19], [20], [21], which generally focus on only one or two aspects of monitoring or protection.

Regarding the research objectives established at the outset, all objectives were successfully achieved. The monitoring system operated with sensor errors below 5% across all three parameters, while the automatic protection system achieved a 100% success rate with a response time of less than 1 second. The integration of remote notifications was also successfully implemented, with a delivery time of less than 5 seconds. Overall, the system performance met all targets established in the research methodology.

Nevertheless, these results should be interpreted in consideration of several limitations of the study. Each parameter was tested with only five repetitions under relatively controlled laboratory conditions, so its representativeness of greater load variations or PLN grid disturbances under actual field conditions cannot yet be fully established. The reference measuring instruments used may also not have had official calibration certificates; therefore, the reported relative error values may include the inherent tolerance of the measuring instruments themselves. Furthermore, the 115% FLA overcurrent protection threshold was tested at only one load level, so its consistency under higher overload conditions requires further investigation, particularly for higher-power motors that may require additional delay or debounce mechanisms.

IV. Conclusion

The Internet of Things (IoT)-based monitoring and protection system for a single-phase induction motor was successfully designed to monitor voltage, current, and temperature in real time, with relative errors below 5%. The Solid-State Relay (SSR)-based protection system was able to disconnect the power supply during overcurrent and overheating conditions, achieving a 100% success rate with an average response time of less than 1 second. The integration of the Telegram Bot enabled remote monitoring and fault notifications, with a 100% notification delivery success rate and an average delivery time of 1.66 seconds. The system was considered feasible to support the safety of single-phase induction motors in educational laboratory practical activities. Future research is recommended to increase the number of test repetitions, evaluate the system under actual and long-term operating conditions, and investigate several overload threshold levels to assess the consistency of the protection response.

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