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# Design and Construction of an IoT-Based Three-Phase Electric Motor Monitoring and Protection Device

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**ABSTRACT**

Three-phase induction motors are widely used in industry as the main drive for pumps, compressors, and conveyors, yet they remain vulnerable to overcurrent, voltage unbalance, and overheating that can shorten their service life. Conventional protection devices such as thermal overload relays and circuit breakers operate locally and do not provide real-time condition information to operators. This study designs and builds an Internet of Things (IoT)-based monitoring and protection device for three-phase electric motors that can observe motor conditions in real time and respond automatically to disturbances. The hardware uses an ESP32 S3 microcontroller, three PZEM-004T sensors to measure voltage, current, power, frequency and power factor, and three MLX90614 non-contact infrared sensors to measure motor temperature. Protection is executed through a solid-state relay coupled to a contactor, while monitoring data are displayed locally on a 3.5-inch TFT screen and remotely through the Blynk IoT platform and Telegram notifications. Testing shows that the prototype trips automatically when the current exceeds the setting value and when the voltage deviation between phases exceeds 2%, with an average trip response time of 354.4 ms, while normal operating conditions do not trigger false trips. Comparison against a standard measuring instrument shows a maximum measurement error of 1.67%. These results indicate that the proposed system is accurate, responsive, and suitable for improving the safety and reliability of three-phase motor operation.



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## 1. INTRODUCTION

Three-phase induction motors are the most widely used type of electric motor in industrial equipment for generating rotational mechanical power, such as in pumps, compressors, *conveyors*, and various production machines [1]. This type of motor is favored for its high efficiency, robust construction, and ability to operate over long periods. However, during operation, three-phase electric motors are susceptible to electrical disturbances such as overcurrent and voltage unbalance between phases [2], [3], [4], which may affect motor performance and reliability. Excessive temperature rise may also occur during motor operation; however, in the present prototype, temperature measurement is implemented as a monitoring parameter and is not included as an automatic protection criterion. The automatic protection function developed and evaluated in this study is specifically limited to overcurrent and voltage unbalance conditions.

Conventional motor protection systems commonly employ protection devices such as thermal overload relays (TOR) and miniature circuit breakers (MCB), while contactors are primarily used as switching and control devices [5], [6]. TOR provides protection against prolonged overcurrent conditions, whereas an MCB provides protection against excessive current and short-circuit conditions. The contactor, in contrast, performs the switching function and can be controlled by a protection circuit to disconnect the motor from the power supply. These conventional arrangements generally provide limited real-time information regarding the electrical condition of the motor to the operator. Therefore, integrating monitoring, automatic protection control, and IoT-based notification can improve the ability to identify and respond to motor disturbances. The development of *Internet of Things* (IoT) technology opens up opportunities to integrate electrical monitoring systems with the internet, allowing parameters such as current, voltage, power, and motor temperature to be monitored remotely via a *smartphone* or computer [7].

Several previous studies have addressed IoT-based monitoring and protection of three-phase electric motors. Gunawan and Sahar [8] developed an Arduino-based system for overcurrent and over/under-voltage protection and monitoring, although it was not fully integrated with a cloud-based IoT platform. Puspita and Darmawan [5] showed that the use of a *thermal overload relay* effectively protects motors from overload, but the approach remains conventional and lacks remote monitoring features. Sawidin et al. [9] developed a three-phase motor control system with phase-failure protection based on a *Zelio smart relay* that operates reliably, yet is not equipped with IoT-based monitoring capability. Meanwhile, Motlagh et al. [10] emphasized that IoT technology offers substantial opportunities in the energy sector, particularly for *real-time* and efficient monitoring and management of electrical systems. Based on this review, it can be concluded that research on the protection and monitoring of electric motors is generally still conducted separately, indicating the need for a system capable of integrating both functions within a single IoT-based platform.

Similar efforts have also been reported in the international literature. Ciancetta et al. [11] developed a low-cost IoT sensor network for monitoring the mechanical power of three-phase induction motors using an indirect measuring method, while Shukla et al. [12] demonstrated *real-time* monitoring of motor current, temperature, vibration, and humidity using an ESP32-based web server. Ioannides et al. [13] reviewed the broader application of IoT-based control for induction machines in electric-drive and renewable-energy conversion systems, underlining the growing role of IoT in industrial motor management. On the protection side, Dawood et al. [14] proposed a detailed classification scheme capable of detecting fifteen types of single-phasing-related faults in three-phase motors, and Bibeyen et al. [15] implemented an IoT-based control system that regulates voltage, current, temperature, and vibration for industrial induction motors while keeping communication latency below 100 ms. Methodologically closest to the present work, Syawali and Meliala [16] developed an IoT-based three-phase induction motor monitoring system using PZEM-004T sensors, while Musyafiq et al. [17] developed an IoT-based control, monitoring, and protection system for three-phase induction motors using PZEM-004T sensors and a Blynk platform. These studies demonstrate the feasibility of integrating electrical measurement and IoT-based monitoring. However, the present study focuses on integrating real-time multiparameter electrical monitoring, temperature monitoring, automatic protection against two specific electrical disturbances—*overcurrent* and *voltage unbalance*—and dual remote notification through Blynk and Telegram within a single prototype. The system is further evaluated quantitatively in terms of measurement accuracy and protection response time.

Based on these problems and research gaps, and building upon prior work on the design of an IoT-based automated electrical installation protection system [18], this paper proposes the design and construction of an IoT-based monitoring and protection device for three-phase electric motors that integrates the measurement of electrical parameters (voltage, current, power, frequency, and power factor) using a PZEM-004T sensor on each phase with non-contact measurement of the motor surface temperature using an MLX90614 sensor. Data are processed by an ESP32 S3 DEVKITC 1 microcontroller and displayed locally on a TFT screen as well as remotely through the Blynk platform and Telegram notifications. Automatic protection is carried out through a *solid state relay* (SSR) connected to a contactor to interrupt the power supply whenever an *overcurrent* condition or voltage imbalance (*voltage unbalance*) occurs. The novelty of this research lies in the full integration of multi-parameter monitoring, automatic protection against two types of disturbances, and dual notification (Blynk and Telegram) within a single prototype that has been quantitatively tested for measurement accuracy and protection response time.

## 2. METHOD

### 2.1. Research Type and Approach

This study adopts an *engineering design* approach followed by experimental testing. The research stages include the design of hardware and software, integration of sensors with the microcontroller, implementation of internet-based communication, and performance testing of the device to determine the measurement accuracy and reliability of the protection system.

### 2.2. Tools and Materials

The main hardware used consists of an ESP32 S3 DEVKITC 1 microcontroller, chosen for its built-in WiFi connectivity and three PZEM-004T sensor modules for measuring voltage, active power, apparent power, reactive power, power factor, energy, and frequency on each phase (R, S, T); three MLX90614 non-contact infrared temperature sensors; a DS3231 RTC module for timekeeping; a 3.5-inch ILI9488 TFT screen as the local interface; a three-phase *solid state relay* (SSR); a contactor; and a 0.18 kW three-phase electric motor as the test object. The software used includes the Arduino IDE for microcontroller programming, the Blynk IoT platform as the remote monitoring interface, as previously applied in various similar IoT-based monitoring systems [22], and a Telegram bot for automatic disturbance notification.

### 2.3. System Design

The system design is illustrated in the block diagram in Figure 1. The three-phase power supply is fed to the motor as the main load. The electrical conditions and motor temperature are monitored by the PZEM-004T and MLX90614 sensors, and the data are then sent to the ESP32 microcontroller via serial (UART) and I2C communication. The microcontroller evaluates whether the data indicate a normal or an abnormal condition based on predetermined threshold (*setting*) values. When an abnormal condition occurs, the microcontroller sends a signal to the protection system (SSR and contactor) to interrupt the power supply to the motor. The monitoring data are then transmitted via the WiFi module to the IoT platform so that they can be accessed remotely by the user.

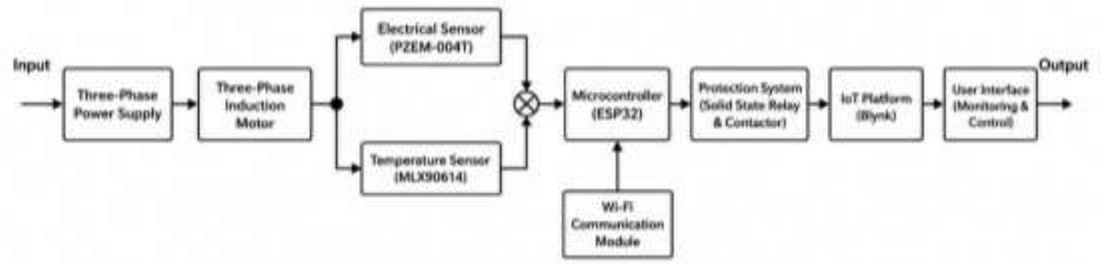


Figure 1. Block diagram of the three-phase electric motor monitoring and protection system

### 2.4. Hardware Design

The prototype *wiring* design in Figure 2 shows the connection pattern between components. Each phase (R, S, T) has a current sensor in the form of a *current transformer* (CT) connected to its respective PZEM-004T module, while voltage measurement is performed by connecting the voltage input of the PZEM-004T module directly to the power source. Three MLX90614 sensors are directed at the surface of the cables leading to the motor terminals to monitor temperature non-contact. All sensor modules are connected to the ESP32 S3 via UART and I2C lines. The control signal from the ESP32 is forwarded to the SSR, which controls the contactor as the main circuit breaker for the power supply to the motor.

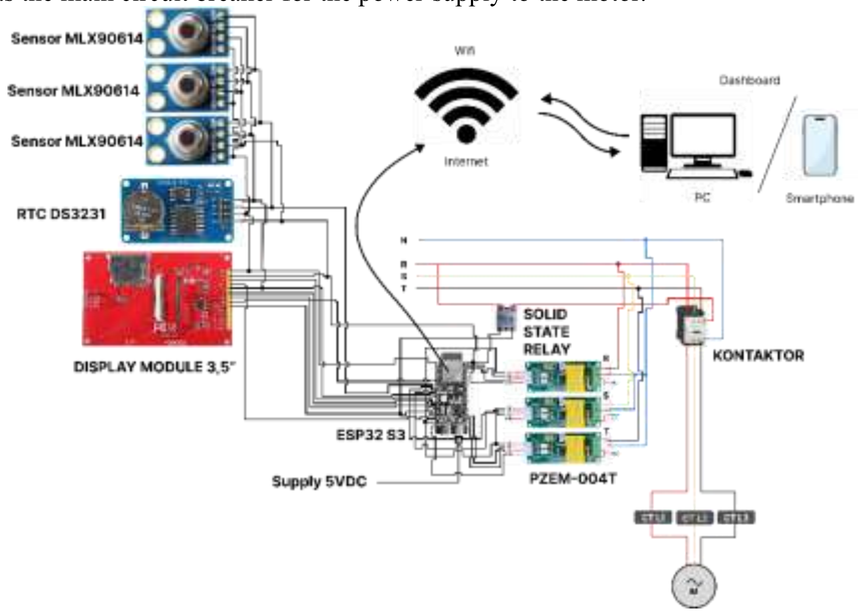


Figure 2. *Wiring* design of the three-phase electric motor monitoring and protection prototype

### 2.5. Testing Procedure

Testing was carried out in four stages. *First*, each component (microcontroller, PZEM-004T sensor, MLX90614 sensor, TFT screen, RTC, and SSR) was tested to ensure that all devices functioned normally. *Second*, *overcurrent* protection testing was performed by gradually lowering the protection current *setting* to observe the relay *trip* response under current conditions below and above the *setting* value. *Third, voltage-*

*unbalance* protection testing was performed under balanced and unbalanced three-phase voltage conditions using a 2% unbalance threshold based on SPLN D5.004-1:2012. The voltage-unbalance percentage was calculated from the three-phase voltage measurements using the average phase voltage as the reference. First, the average phase voltage was calculated as

$$\mathrm{V}avg = \frac{(V_R + V_S + V_T)}{3} \quad (1)$$

The voltage unbalance was then determined from the maximum deviation of the individual phase voltage from the average voltage using

$$Voltage\ Unbalance\ (\%) = \left| \frac{max(|V_R - V_avg|, |V_S - V_avg|, |V_T - V_avg|)}{V_avg} \right| \times 100\% \quad (2)$$

where $V_R, V_S$, and $V_T$ represent the measured RMS voltages of phases R, S, and T, respectively. A voltage-unbalance limit of 2% was adopted as the protection threshold based on SPLN D5.004-1:2012. Therefore, the protection system identifies a voltage-unbalance disturbance when the calculated deviation reaches or exceeds the 2% threshold.

*Fourth*, accuracy testing was performed by comparing the parameter values displayed by the system against the values measured with a standard measuring instrument (multimeter), calculated using the following relative error (*error*) equation.

$$\text{Error (\%)} = |(Xp - Xm) / Xm| \times 100\% \quad (3)$$

where *Xp* is the parameter value shown on the prototype display and *Xm* is the value measured with the standard measuring instrument. In addition, the protection response time (*trip* duration) was recorded from the moment a disturbance was detected until the relay interrupted the power supply, in order to determine the operating characteristics of the protection relay implemented in the system.

## 3. RESULTS AND DISCUSSION

### 3.1. Prototype Realization

The IoT-based monitoring and protection prototype for three-phase electric motors that was built is shown in Figure 3. All components, namely the MCB, contactor, SSR, PZEM-004T sensors, ESP32 S3 microcontroller, and TFT screen, are neatly mounted inside a single 3D-printed *case*. Placing the TFT screen at the front allows the user to read electrical parameters directly, while the power and protection components are placed inside to remain safe from direct contact.

Figure 3. Physical realization of the three-phase electric motor monitoring and protection prototype

### 3.2. Component Testing

Initial testing of all components (ESP32 S3 microcontroller, three PZEM-004T modules, ILI9488 TFT screen, DS3231 RTC, SSR, and MLX90614 temperature sensor) showed that all modules could power on correctly with the available supply and functioned according to their specifications, so that all components were deemed suitable for use in the subsequent system integration stage.

### 3.3. Overcurrent Protection Testing

*Overcurrent* protection testing was carried out with a nominal motor current of 0.421 A/phase. Under normal conditions with a *setting* value of 0.5 A, the system did not *trip* because the measured current (0.412–0.435 A) remained below the *setting* value. When the *setting* value was lowered to 0.3 A, the system successfully *tripped* in every test because the actual current (0.405–0.439 A) exceeded that *setting* value, as summarized in Table 1. This result is consistent with the operating principle of overcurrent relays, which command a *trip* as soon as the measured current exceeds the specified *setting* value [23].

Table 1. Overcurrent protection test results

| Condition | Current Setting (A) | Measured Current Range (A) | Status |
|---|---|---|---|
| **Normal (below setting)** | 0.5 | 0,434 ; 0,417 ; 0,413 | No trip |
| **Overcurrent (above setting)** | 0.3 | 0,436 ; 0,417 ; 0,409 | Trip |

### 3.4. Voltage Unbalance Protection Testing

Voltage-unbalance protection testing was carried out with a deviation threshold of 2%. Under relatively balanced voltage conditions, the measured deviation ranged from 1.23% to 1.45%, so the system did not *trip*. Conversely, under unbalanced voltage conditions with a deviation of 2.00% to 2.21%, the system successfully detected the disturbance and *tripped* in every test, as summarized in Table 2. These results show that the system can accurately distinguish between normal conditions and disturbance conditions without any *false trip*.

Table 2. Voltage unbalance protection test results

| Condition | Measured Voltage Deviation (%) | Status |
|---|---|---|
| **Balanced voltage** | 1.23 – 1.45 | No trip |
| **Unbalanced voltage** | 2.00 – 2.21 | Trip |

The protection response time was evaluated through five repeated tests under voltage-unbalance conditions. The measured trip durations ranged from 280 ms to 511 ms, with an average response time of 354.4 ms. Because the program logic directly commands a *trip* as soon as the *setting* value is exceeded, without any intentional time delay, the protection relay in this system falls under the category of an *instantaneous relay*, unlike a *definite time relay* or an *inverse time relay*, both of which require an intentional operating time delay [23]

This response time is considerably faster than the phase-failure, *overcurrent*, and overheating protection response times of 4.03 s, 8.47 s, and 3.64 s, respectively, reported by Musyafiq et al. [17] for a comparable PZEM-004T-based three-phase motor protection system, and it is consistent with the sub-second response achievable through solid-state switching, as demonstrated in the single-phasing protection scheme of Dawood et al. [14].

### 3.5. Measurement Accuracy Analysis

The accuracy comparison of voltage and current measurements between the prototype and the standard measuring instrument is presented in Figure 4. The measured values from the prototype show close agreement with the reference instrument across phases R, S, and T. The average measurement error was 0.33% for current and 0.67% for voltage, indicating that the PZEM-004T sensors provided sufficiently accurate measurements for the protection and monitoring functions implemented in this prototype.

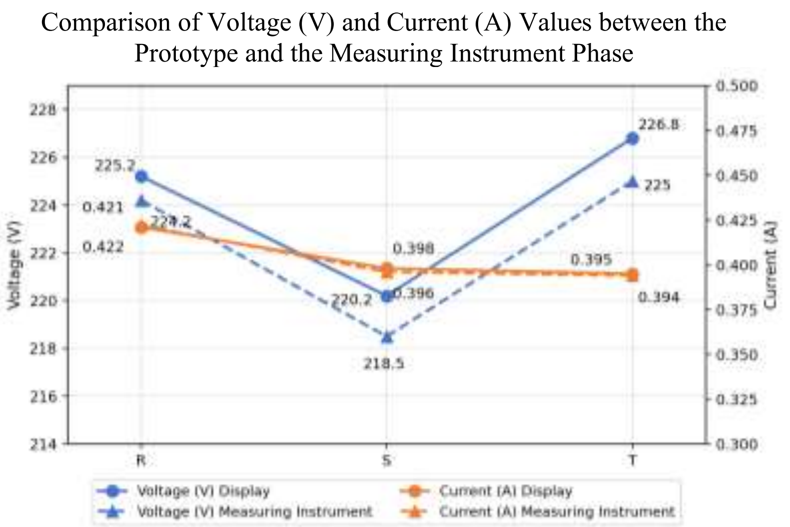

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Figure 4. Comparison of voltage and current values between the prototype and the measuring instrument

A summary of the accuracy test results for all parameters is presented in Table 3. Parameters measured directly by the sensor (current, voltage, and frequency) show a smaller *error* than parameters obtained through calculation (active power, apparent power, and reactive power), because errors in the current, voltage, and power-factor quantities can accumulate through the multiplication process. Nevertheless, the largest *error* obtained, namely for active power on phase R at 1.67%, remains well below the 2% threshold, so that the PZEM-004T and MLX90614 sensors are deemed suitable for monitoring the electrical parameters of three-phase motors. This level of accuracy compares favorably with related IoT-based motor monitoring systems reported in the literature, such as the indirect mechanical-power estimation method of Ciancetta et al. [11], which achieved a relative error within 8%, and the voltage, current, and temperature monitoring system of Syawali and Meliala [16], which reported errors ranging from 0.1% to 11.7% depending on the phase and parameter measured.

Table 3. Summary of measurement error for electrical and temperature parameters

| Parameter | Average Error (%) | Maximum Error (%) |
|---|---|---|
| Current | 0.33 | 0.51 |
| Voltage | 0.67 | 0.80 |
| Active power | 1.07 | 1.67 |
| Apparent power | 0.52 | 0.69 |
| Reactive power | 0.57 | 0.92 |
| Power factor | 0.18 | 0.53 |
| Frequency | 0.00 | 0.00 |
| Temperature | 0.55 | 1.23 |

### 3.6. IoT Monitoring Interface

In addition to being displayed on the local TFT screen, all electrical parameters can also be monitored remotely through the Blynk *dashboard*, as shown in Figure 5, via either the web or *mobile* application. Motor status data (normal/*overcurrent* and balanced/unbalanced) are displayed in *real time* together with a relay *reset* control option. As a complement, the system also sends automatic notifications via a Telegram bot every time a *trip* condition occurs, containing information on system status, electrical parameter values at the moment of the disturbance, and an explanation of the *trip* cause, so that users can obtain disturbance information proactively through *push notifications* without having to open the Blynk application or check the TFT screen directly. This approach to remote notification and *dashboarding* is consistent with the application of IoT platforms in various similar electrical equipment monitoring and control systems reported previously [24], [25], [26].

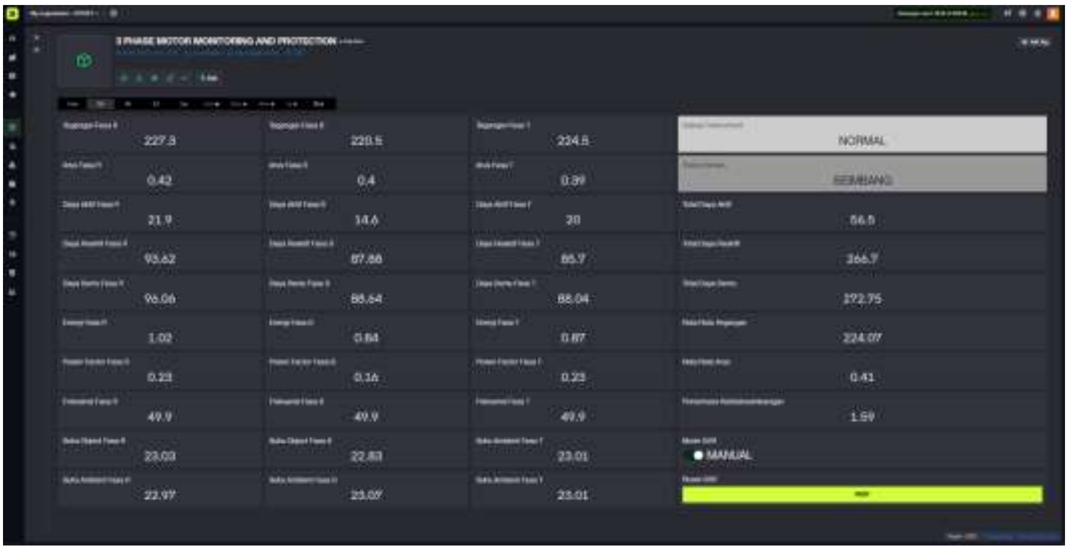


Figure 5. Monitoring dashboard display on the Blynk platform

Beyond the remote *dashboard*, the local TFT screen itself provides a dedicated *trip* display that is triggered automatically whenever the protection system disconnects the motor. Figure 6 shows a representative example of the local display when a *trip* occurs due to a *voltage unbalance* condition. The screen presents the *trip* timestamp, the identified cause of the disturbance, the instantaneous voltage and current values on phases R, S, and T at the moment of the *trip*, the calculated unbalance percentage together with the measured *trip* duration, the object and ambient temperatures recorded by the three MLX90614 sensors, and step-by-step instructions for resetting the system once the cause of the disturbance has been resolved. In the example shown, the system detected a voltage deviation of 2.00% between phases, exceeding the 2% threshold, and responded with a *trip* within 325 ms, consistent with the range reported in Section 3.4. Because the SSR is configured in a *latched* state after a *trip*, the motor remains disconnected and cannot restart automatically until the operator confirms that the disturbance has been cleared and performs a manual *reset*, either directly on the device, through the Blynk *dashboard*, or via the Telegram bot. This local *trip* display complements the remote monitoring interfaces described above by giving on-site personnel immediate, self-contained diagnostic information even when internet connectivity to the IoT platform is temporarily unavailable.


Figure 6. Example of the local display appearance when a *trip* occurs due to voltage unbalance

Overall, the test results across all aspects — from hardware integration, the accuracy of electrical and temperature parameter readings, the *real-time* monitoring display, to the protection performance against *overcurrent* and *voltage unbalance* disturbances — show that the prototype developed is able to address the problem of monitoring and protecting three-phase electric motors in an integrated manner. Some limitations that could guide further development include the small variation in *trip* duration caused by microcontroller processing time, as well as the opportunity to improve the accuracy of calculated parameters (active power, apparent power, and reactive power) through sensor calibration or improved data-reading algorithms.

## 4. CONCLUSION

This study successfully designed and built an IoT-based monitoring and protection prototype for three-phase electric motors that integrates multiparameter monitoring, automatic protection, and remote notification within a single system. The prototype uses an ESP32 S3 DEVKITC 1, PZEM-004T sensors for electrical parameter measurement, MLX90614 sensors for temperature monitoring, and an SSR-contactor switching system for motor disconnection. The prototype successfully provides real-time monitoring through the local TFT display and Blynk IoT platform, complemented by automatic disturbance notifications through Telegram. The automatic protection function was implemented for two electrical disturbance conditions, namely overcurrent and voltage unbalance. Overcurrent protection operated when the measured current exceeded the predetermined setting, while voltage-unbalance protection operated when the calculated voltage deviation reached or exceeded the 2% threshold based on SPLN D5.004-1:2012. The measurement accuracy results showed that all evaluated parameters had measurement errors below 2%, with the maximum error of 1.67% occurring in active power measurement. The voltage-unbalance protection was successfully demonstrated under both balanced and unbalanced conditions, while five repeated trip-duration tests produced an average response time of 354.4 ms. These results demonstrate that the proposed prototype can integrate multiparameter monitoring, automatic protection against two electrical disturbances, and dual IoT-based notification in a single three-phase motor monitoring system. Temperature measurement using the MLX90614 sensors was implemented as a monitoring function but was not included as an automatic protection criterion in

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the present prototype. Future development may incorporate temperature-based protection and historical data logging to further improve the protection and diagnostic capabilities of the system.

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