

Automatic electric current detection and protection system based on IoT

Emelissa Norniza Nozarul^{1*}, Alias Masek¹ 

¹Universiti Tun Hussein Onn Malaysia

*Correspondence: E-mail: emelissanorniza0806@gmail.com

Abstract

Electrical safety is a crucial aspect of both domestic and commercial electrical systems, as failure to detect excessive current can cause equipment damage and increase the risk of fire. This project aims to design, develop, and test an IoT-based Automatic Electric Current Detection and Protection System to enhance electrical safety through real-time monitoring and automatic alerts. The system integrates current and power measurement sensors, an ESP32 microcontroller, protection mechanisms, an LCD display, and IoT notifications via Telegram. The threshold values are set at 1.9A for current and 20W for power. When these values are reached or exceeded, the system sends alert notifications on the LCD display and via Telegram to the user. Additionally, a servo motor automatically rotates to turn off the main circuit breaker (MCB) as a protective measure. The system design follows the Design Thinking approach, which includes phases such as empathy, problem definition, idea generation, prototype development, and testing. Functional and usability testing were carried out, with validation from four experts to assess the system's performance and suitability, including the display of threshold values on the LCD, load values when the switch is turned on, and notifications when thresholds are exceeded. Based on expert feedback, the addition of an auto-reclose function was suggested. The study results show that the system performs well, achieves the research objectives, and has potential for use as an electrical safety support system in future real-world applications.

Keywords: Automatic protection; Current detection system; Design thinking; Electrical safety; ESP32; Internet of Things (IoT)

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INTRODUCTION

Background

The increasing electricity consumption in the domestic and commercial sectors has caused wiring systems and Distribution Boards (DB) to operate close to the maximum design capacity. The growing number of high-power electrical appliances such as inverter air conditioners, water heaters, and motor-driven equipment has caused the load current to continuously rise, thereby increasing the risk of system failure if systematic current monitoring is not carried out. This situation becomes even more critical when users have no information regarding the actual current flowing in the main DB circuit.

In Malaysia, electrical safety remains a major issue. Data from the Fire and Rescue Department of Malaysia show that 3,172 of the 5,047 residential fires recorded between January and September 2024 (63%) were caused by electrical sources (Gimino, 2024). Many such incidents develop without any early warning because conventional protection devices only act after conditions reach dangerous levels. This scenario highlights the urgent need for an early monitoring system capable of detecting current changes before critical failure occurs.

In spite of the widespread use of protection components such as Miniature Circuit Breakers (MCBs) and fuses in DBs, these systems are reactive and do not provide any diagnostic information to the user. MCBs only disconnect the power when the current exceeds their rated value for a duration defined by their time-current characteristic (International Electrotechnical Commission [IEC], 2015), while internal damage to equipment or cables may have already occurred earlier. This lack of information makes it difficult for users to identify the root cause of electrical disturbances.

Additionally, short-term current surges can occur when motor-driven appliances and inductive loads such as refrigerators and water pumps start up. Although these surges last only a very short time, repeated surges may stress sensitive electronic components and shorten the lifespan of equipment. Conventional protection devices, however, are not designed to record or report such events to the user.

The absence of a real-time monitoring system in DBs also means users cannot directly monitor power usage patterns and current levels, a gap that IoT-enabled panelboards have only recently begun to address (Shaban & Alsharekh, 2022). Without this data, users are unaware that their electrical systems are operating near their safe limits, especially when multiple appliances are used simultaneously. This increases the risk of persistent overload, which could damage cable insulation and cause overheating.

From a maintenance perspective, the lack of historical current and power readings complicates the fault analysis process for technicians. Without historical data, troubleshooting must be performed manually and repeatedly, thereby increasing repair time and maintenance costs. A smart monitoring system could provide crucial supporting data for diagnostic and predictive maintenance purposes (Zonta et al., 2020).

Smart meters are being rolled out in Malaysia; they record electricity consumption at half-hourly intervals and transmit it automatically to the utility for monitoring and billing (Tenaga Nasional Berhad [TNB], n.d.). They are not designed to provide real-time current alarms or notifications of abnormal conditions within the user's DB. Therefore, smart meters cannot replace the need for specific current protection systems at the DB level.

The development of Internet of Things (IoT) technology has created new opportunities in the monitoring and safety of electrical systems. IoT enables sensor data to be transmitted in real time through wireless networks and accessed by users from any location (Al-Fuqaha et al., 2015). However, the use of IoT in domestic electrical safety monitoring is still at a low level and has not been fully exploited.

Previous studies have shown that IoT-based monitoring systems can deliver electrical measurements and notifications to users in real time (El-Khozondar et al., 2024; Shaban & Alsharekh, 2022). Applied to electrical safety, real-time notifications would allow users to take early action before damage becomes severe, thus reducing the risk of fire and equipment damage.

Previous Studies

Numerous studies have explored the integration of IoT-based systems for real-time monitoring and protection in electrical systems. Traditional protection mechanisms, such as MCB and RCCB, are often reactive and only respond once faults reach a critical point. This limitation has spurred the development of smarter systems that provide early detection and proactive protection.

One relevant study by El-Khozondar et al. (2024) developed a low-cost ESP32-based energy monitoring system that delivers consumption data to users in real time through WhatsApp and the Blynk platform. Although their study focused on energy management, the concept of providing users with real-time updates is also highly relevant to the field of electrical safety.

In the realm of electrical measurement, Modbus RTU is a widely used serial communication protocol for metering modules such as the PZEM-004T. The Modbus serial line specification defines a master-slave protocol in which each RTU frame is protected by a cyclic redundancy check (CRC) (Modbus Organization, 2006). Its simplicity and multi-vendor support make it suitable for integrating measurement modules with IoT platforms in residential electrical safety systems.

Despite advancements in IoT and energy monitoring, the systems reviewed above focus mainly on energy usage monitoring and load management (El-Khozondar et al., 2024; Shaban & Alsharekh, 2022), while conventional devices provide only basic protection. Few solutions combine real-time detection, automatic protection, and data storage in a single package, which points to the need for more integrated solutions that offer both detection and automatic response for better electrical safety.

The absence of early detection in conventional protection systems has resulted in significant safety risks. Citing U.S. Fire Administration data, Thakur et al. (2023) reported that arc faults were the heat source in 82% of electrical fires in residential buildings in the United States, a hazard that can be mitigated through early detection. Similarly, most residential fires in Malaysia are attributed to electrical sources (Gimino, 2024). These findings demonstrate the need for systems that can detect and alert users about electrical faults before they escalate into major hazards.

The development of smart distribution panels that offer real-time load monitoring and forecasting has been a significant step forward in energy management. Shaban and Alsharekh (2022) introduced an IoT-enabled low-voltage distribution panelboard that provides real-time load monitoring and household-level load forecasting. While such systems are effective for managing energy demand, they focus more on demand-side management than on electrical safety, with fault detection mentioned only as a possible future extension. For residential

applications, there is a need for simpler, low-cost systems focused on providing early warnings and protection against electrical hazards.

KNX, an international standard for home and building automation, supports numerous functions, including lighting, climate control, and energy management, and is promoted as a means of reducing energy use and operating costs (KNX Association, n.d.). However, the complexity and installation cost of full building automation systems can make them less practical for homeowners who only seek affordable and easy-to-use electrical safety solutions. This highlights the need for more practical, low-cost systems aimed at ensuring electrical safety in smaller-scale applications.

Research Gap

Real-time notifications are crucial in modern electrical protection systems, as conventional protection systems such as MCB and RCCB typically only act once the conditions reach a level that triggers a trip. Therefore, Telegram notifications serve as an early warning mechanism by providing users with information about the condition of the electrical circuit before it reaches a critical state. This approach aligns with the concept of smart monitoring, which emphasizes immediate information delivery to support timely decision-making (El-Khozondar et al., 2024).

For electrical monitoring systems, communication between microcontrollers and electrical measurement modules often uses industrial protocols such as Modbus RTU over serial lines (e.g., RS-485). Modbus RTU provides a simple communication structure while ensuring communication integrity through CRC validation, making it suitable for transmitting electrical parameters accurately (Modbus Organization, 2006).

An electrical safety system must remain stable even during power interruptions or resets. Therefore, critical settings such as warning thresholds should be stored in non-volatile memory. Within the ESP32 ecosystem, the Non-Volatile Storage (NVS) library stores key-value data in flash memory so that configuration data remain available after power loss or system restart, reducing the need for repeated manual configuration (Espressif Systems, n.d.).

Although several smart systems have been introduced for energy monitoring (El-Khozondar et al., 2024; Shaban & Alsharekh, 2022), the integration of real-time monitoring, automatic protection, historical data storage, and smart notifications in a single low-cost device remains uncommon.

The absence of effective early detection systems continues to contribute to electrical accidents caused by overloads, electrical arcing, and unstable voltages. These limitations demonstrate the need for an affordable and integrated monitoring system capable of providing continuous current monitoring, automatic protection, historical data logging, and real-time user notifications (Thakur et al., 2023).

METHODS

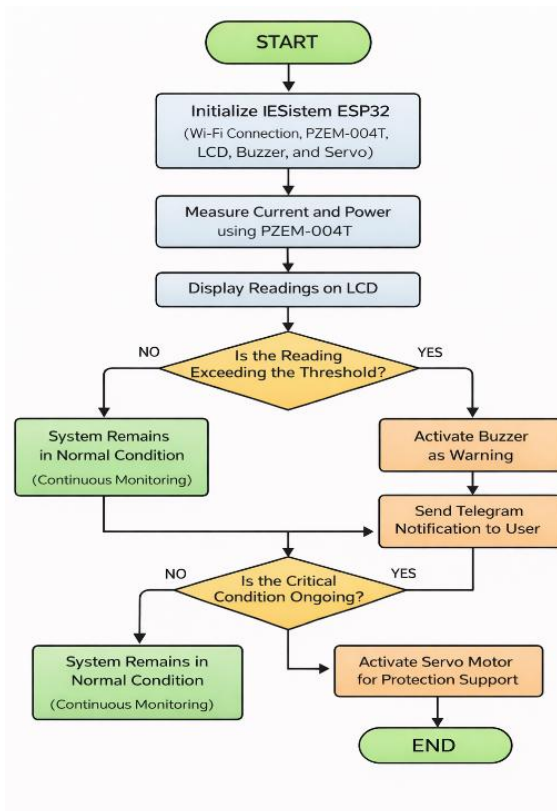
Materials

The following materials were used in the prototype of the Automatic Electric Current Detection and Protection System based on the Internet of Things (IoT):

- The ESP32 microcontroller was selected due to its robust technical features, including 5V DC power supply, 3.3V input/output voltage, 448 Kbyte ROM, 520 Kbyte SRAM, and 16 Kbyte RTC SRAM. It is equipped with a Dual-Core CPU (Tensilica Xtensa LX6, 32-bit), Wi-Fi, Bluetooth, and 30 pins for various connections.
- PZEM-004T current and power sensors are used to measure current and power flowing through the system. The readings are displayed on an LCD screen for real-time visualization and are stored for further analysis.
- A servo motor is used to activate the circuit breaker (MCB) and disconnect the current when a fault, such as an overload, is detected.
- The relay is employed to control the power supply and ensure automatic disconnection when an electrical fault occurs.
- The buzzer is used as a safety feature that provides an audible alert when the current exceeds the preset threshold, signaling to the user that there is an issue.

- The system integrates Telegram notifications to alert users about critical current and power readings. A Telegram bot is used to send real-time alerts directly to the user's mobile device when abnormalities are detected.
- The system uses Internet of Things (IoT) technology, allowing users to monitor and control the electrical system remotely. The system is connected to the internet via Wi-Fi, enabling real-time monitoring and sending notifications.
- The junction box is used to protect the electronic components in the Automatic Electric Current Detection and Protection System from risks such as physical damage, dust, water, and direct contact, ensuring the components are safely enclosed and organized.
- The LCD 20x4 serves as a local user interface, displaying real-time electrical measurement data, including system warning status. It uses the I2C protocol, which simplifies connections by requiring only two communication lines, reducing wiring complexity.
- Threshold in the electric monitoring system refers to a set limit for parameters like current or power. When the reading exceeds this threshold, the system detects the abnormal condition and activates warning functions such as a buzzer, servo movement, or sends notifications via Telegram.
- The methodology used the Design Thinking model consists of five main phases: Empathize, Define, Ideate, Prototype, and Test. Each phase is structured to ensure that the system development is user-oriented, has clear requirements, generates testable prototypes, and undergoes systematic functionality testing. Overall, this methodology provides a solid foundation for the development of an electrical safety support system in the DB that not only works from a technical perspective but is also easy to understand and use by the target users (Brown, 2008; Dym et al., 2005; Razzouk & Shute, 2012), as shown in Figure 1.

Figure 1
Research Methodology Flowchart



Empathize Phase

The Empathize phase focuses on understanding users' problems with electrical system safety. Observations were made on existing protection systems in distribution boards (DB) and safety incidents like overloads. Findings

revealed that most users lack real-time data on current and power flow, and conventional protection devices such as MCB and RCCB only react after a fault occurs, providing no early warning. This leads to users being unaware of risks until they escalate.

Respondents agreed on the need for a smart system that can detect abnormal current and power, provide early warnings, and automatically disconnect the power. They also suggested adding an LCD display to show current and power data and real-time notifications, which are specified in Table 1.

Table 1

Results From Unstructured Interview With the Assistant Laboratory Engineer, FPTV

Question	Answer
How do you usually solve electrical faults, such as short circuits?	By checking the DB directly and turning each switch on/off one by one.
In your opinion, is it difficult or easy to locate the cause of a short circuit or electrical equipment failure?	It is quite difficult in the lab because each switch and load needs to be checked one by one.
Is the existing protection system (such as MCB/fuse) sufficient in terms of safety and user information?	The existing system is quite limited because we struggle to get early information and identify the cause of the fault.
In your opinion, is there a need for a smart system that can detect: • Abnormal current and power • Provide early warnings • Automatically disconnect power Is it necessary for homes or small industries/domestic wiring?	Yes, this system is very much needed, especially in homes or small industries that rely on electrical equipment daily. • A system that ensures user safety. • A system that provides notifications no matter where we are.
What additional features do you think are needed to complete and assist non-technical users?	• An LCD display that shows current and power usage. • Users can receive notifications and real-time displays for current, power, and incoming load.

For Question 1, the respondent explained that electrical faults, such as short circuits, are usually addressed manually by inspecting the distribution board (DB) and turning switches on/off one by one, relying on physical checks and user experience.

Question 2 revealed that identifying the cause of faults is challenging, especially in lab settings, as each switch and load needs to be checked, which is time-consuming and difficult for non-technical users.

Regarding Question 3, the respondent noted that existing protection systems, like MCB or fuses, lack early warning features and do not provide sufficient information to users, making it difficult to quickly identify the cause of faults.

In Question 4, the respondent agreed on the need for a smart system that can detect abnormal current and power, offer early warnings, and automatically disconnect power, especially for homes or small industries using electrical equipment daily. This system would enhance safety and allow users to receive notifications even when not on-site.

Finally, for Question 5, the respondent suggested adding an LCD display for showing current and power usage, along with real-time notifications for incoming load, which would help non-technical users easily understand the system's status and receive timely alerts.

Define Phase

This phase aims to define the main problem based on the findings from the Empathize phase. The key issue identified is the lack of a real-time current and power monitoring system, as well as the absence of an early warning system to notify users before an electrical failure occurs. Therefore, the problem statement for this project is the need to develop an automatic electric current detection and protection system that continuously monitors current and power, provides early warnings to users, and supports existing protection systems without replacing them entirely. which are specified in Table 2.

Table 2
Results From Unstructured Interview - Answers and Issues

Question	Answer	Issue Identified
How do you usually solve electrical faults, such as short circuits?	By checking the DB directly and turning each switch on/off one by one.	Manual process of fault detection in DB, slow and dependent on experience.
In your opinion, is it difficult or easy to locate the cause of a short circuit or electrical equipment failure?	It is quite difficult in the lab because each switch and load needs to be checked one by one.	Difficulty in identifying faults, especially in lab environments where each switch and load must be checked one by one.
Is the existing protection system (such as MCB/fuse) sufficient in terms of safety and user information?	The existing system is quite limited because we struggle to get early information and identify the cause of the fault.	Existing protection systems are limited in providing user information and early fault detection.
In your opinion, is there a need for a smart system that can detect: • Abnormal current and power • Provide early warnings • Automatically disconnect power Is it necessary for homes or small industries/domestic wiring?	Yes, this system is very much needed, especially in homes or small industries that rely on electrical equipment daily. • A system that ensures user safety. • A system that provides notifications no matter where we are.	Need for a smart system with features like abnormal current detection, early warnings, and automatic power disconnection.
What additional features do you think are needed to complete and assist non-technical users?	• An LCD display that shows current and power usage. • Users can receive notifications and real-time displays for current, power, and incoming load.	Lack of user-friendly features for non-technical users.

Based on Table 2, the interview results show that electrical fault detection, such as short circuits, still relies heavily on manual methods, like checking the DB and turning switches on/off one by one, which is time-consuming and challenging in environments like laboratories. Respondents also stated that existing protection systems, like MCB/fuses, are limited as they do not provide early information or help users quickly identify the cause of faults. Respondents agreed that a smart system capable of detecting abnormal current and power, providing early warnings, and automatically disconnecting power is crucial, especially for homes and small industries. Additionally, features such as an LCD display and real-time notifications were suggested to help non-technical users understand the electrical load status and receive alerts from anywhere..

Ideate Phase

This phase focuses on generating ideas to solve the identified problems. Key solutions considered for the development of a smart electrical current monitoring and protection system include using the PZEM-004T power sensor to measure current and power, the ESP32 microcontroller as the system's control center, and IoT technology to send alert notifications via Telegram. These solutions were chosen for their practicality, cost-effectiveness, and suitability for domestic and small-scale applications. These are specified in Table 3.

Table 3
Ideas and Idea Selection

Problem	Idea
Manual fault detection in DB with on/off switches; slow and relies on experience.	Develop a current and power monitoring system using the PZEM-004T sensor to automatically detect abnormalities without manual checks.

Problem	Idea
Difficulty in identifying faults (especially in a lab, checking each switch).	Use the ESP32 microcontroller to process real-time current and power readings to quickly and systematically identify faults.
Existing protection systems are limited in providing information.	Provide a support system that displays current and power information, as well as normal/abnormal status to give early information to users (via an LCD display)
Need for a smart system (abnormal detection, early warnings, auto cut-off).	Develop an IoT-based smart system that detects abnormal current and power, gives early warnings, and automatically activates protection mechanisms. (IoT sends Telegram alerts + activates automatic protection).
Lack of user-friendly features for non-technical users	Provide an LCD display and Telegram notifications to help non-technical users understand the system's status and receive real-time alerts.

Based on the interview findings, several main issues were identified, such as the manual process of fault detection in the DB, the difficulty of identifying faults in certain environments, the limitations of existing protection systems in providing early information, and the need for a smart system capable of real-time monitoring, early warnings, and automatic power disconnection. Additional features like an LCD display and real-time notifications were suggested to make the system more user-friendly, especially for non-technical users.

Design specifications serve as benchmarks or guidelines that outline the characteristics of a design to be implemented. This section is crucial in ensuring that the development process runs smoothly and meets user requirements. The following key features are emphasized in the development of this project:

- Flexibility
- Durability
- Cost

For flexibility the design of the Automatic Electric Current Detection and Protection System based on IoT is tailored to meet user requirements, making it easy to use and apply in real-world environments such as homes or small industries. The system is designed for installation near the Distribution Board (DB) without interfering with the existing protection system. Additionally, it provides flexibility in monitoring by displaying real-time current and power readings on an LCD, while also sending notifications via Telegram, allowing users to monitor their electrical system from different locations.

Next is durability: the prototype is designed with durability in mind, ensuring that the components used are suitable for continuous use. Key components such as the ESP32, PZEM-004T sensor, buzzer, LCD, and connecting modules are selected for their durability and long-term stable operation. Components are securely installed, and protective enclosures such as junction boxes are used to shield the circuitry from dust, physical contact, and environmental damage. Durability is essential to maintain the consistent operation of the monitoring and warning functions.

Lastly, the cost of developing the IoT-based Automatic Electric Current Detection and Protection System is reasonable and affordable, making it suitable for application in homes or small industries. The selection of components like the ESP32, PZEM-004T, LCD, and buzzer balances cost and quality to ensure that the system performs optimally while remaining affordable.

The table below shows the estimated cost of the components used in the development of this project. Additionally, the overall cost of the system aligns with its intended functions, including real-time monitoring, early warning, and IoT notifications.

Table 4
Estimated Cost and Components

Component	Estimated Cost (RM)
Current Sensor	7.90
Microcontroller (ESP32)	39.00
LCD & Arduino I2C I2C	27.00
Servo Motor	20.45
Buzzer	5.00

Component	Estimated Cost (RM)
Accessories	11.00
Enclosure & Wiring	25.00
100A PZEM 004T	50.01
MB102 Power Supply	5.00
USB Male to Male	4.00
Total	RM194.36

Prototype Development Phase

The prototype development phase involves several steps to ensure smooth construction. Important aspects to focus on include:

1. Model Sketches
2. Materials and Components
3. Control Circuit Design

Figure 2 shows the block diagram of the entire system on hardware, while Figure 3 shows the block diagram of the system on the prototype software.

Figure 2

Block Diagram of the Entire System on Hardware

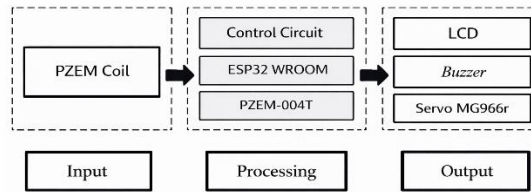
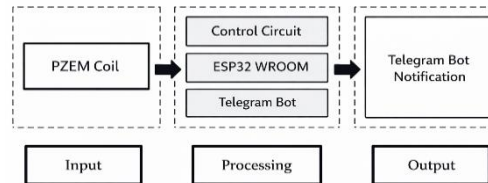
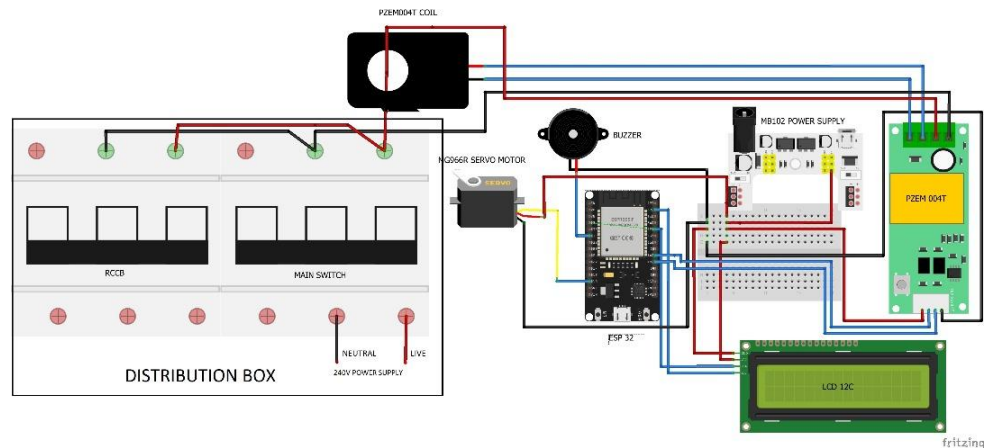


Figure 3

Block Diagram of the Prototype Software



The physical design was created using the Fritzing electronic design automation tool, following the block diagram. Fritzing was used to generate an in-depth schematic diagram and layout, demonstrating the actual components involved in the system and their interconnections. The design provided precise information on the positioning of components such as sensors, relays, and the microcontroller, as well as the wiring required to connect them. This design not only supported the assembly of the prototype but also ensured that the configurations and connections were optimized for stable performance. By integrating both logical and physical design steps, a comprehensive system model was built, laying the foundation for successful prototype assembly and testing, as depicted in Figure 4.

Figure 4*Diagram of the Overall Circuit Prototype Using the Fritzing Application*

- The overall circuit for the IoT-based Automatic Electric Current Detection and Protection System prototype was developed to illustrate the complete arrangement of components, wiring connections, and system operations.
- The circuit was designed using the Fritzing software, which helped the researcher visually understand the component connections and the flow of operations more clearly.
- The schematic layout ensured that components were installed correctly and safely before the actual prototype construction began.
- The main 240VAC supply from the Distribution Box (DB) is routed through existing safety devices, such as the RCCB and main switch, before reaching the load.
- For current monitoring, a current transformer (CT coil) is used and installed on the Live path to detect the current flowing to the load. This CT coil is connected to the PZEM-004T module for real-time current and power measurement.
- The PZEM-004T module is connected to the ESP32 microcontroller via a data communication link. The ESP32 processes the current and power readings, compares them with predefined thresholds, and determines whether the system is in a normal or abnormal state.
- The processed data is used to control output devices and send information to the user.
- The I2C LCD is connected to the ESP32 for real-time display of current and power readings. A buzzer is used as a local sound alarm, activated when readings exceed set thresholds.
- The system also supports IoT functionality, where the ESP32 sends warning notifications to users via the Telegram app using a Wi-Fi connection, allowing the user to receive alerts even when away from the system.
- A servo motor is used as a protective mechanism, activated based on the system's control logic when current levels reach critical and persistent thresholds.
- The MB102 power supply module is used to provide the necessary DC voltage to the ESP32 and related components, ensuring a stable power supply to the system.
- All components in the system are connected to the same ground (GND) to ensure stable system operation and prevent reading interference.

Overall, the schematic provides a detailed representation of the system's operation, component arrangement, and wiring, facilitating the prototype development process and simplifying testing and maintenance tasks.

Testing Phase

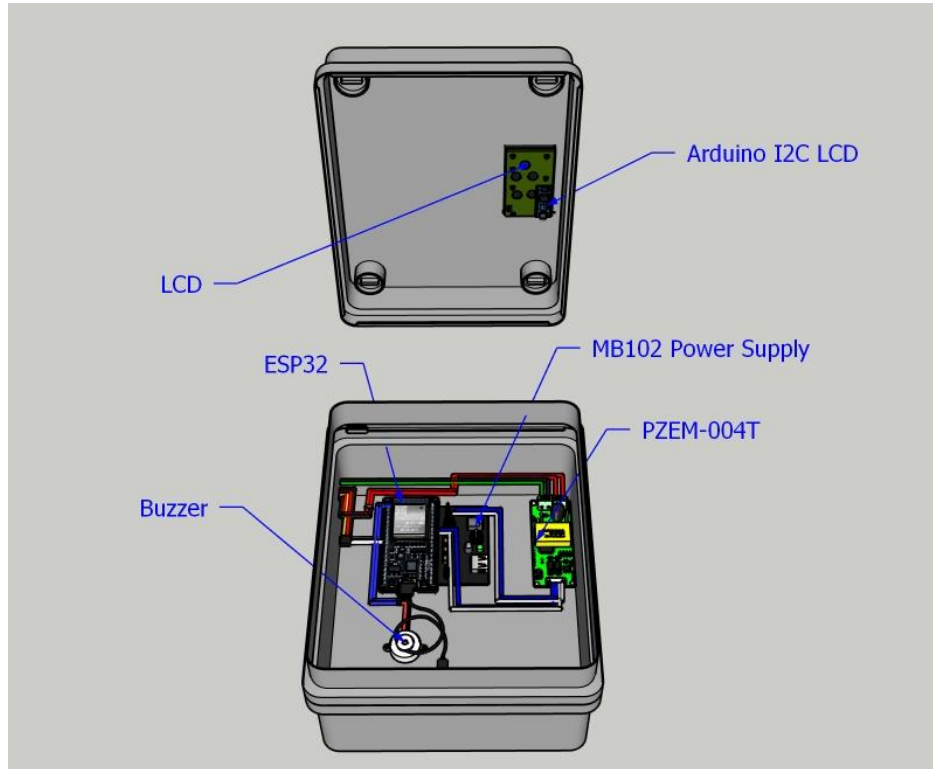
The Test phase involves evaluating the functionality and effectiveness of the system prototype. Testing is performed under both normal and abnormal conditions to ensure the system can detect current anomalies and activate the warning and protection mechanisms properly.

Any weaknesses identified during testing are used to improve the control logic and operational stability. This process is iterative until the system reaches satisfactory functionality.

Once the circuit development for the entire prototype is completed, testing is conducted to ensure that the inputs and outputs function as intended. Two key aspects tested are the prototype circuit and the functionality of the components. Figure 5 is the visualization of the internal elements of the prototype.

Figure 5

Three-Dimensional Diagram of the Prototype



- The circuit testing phase is carried out on the entire prototype circuit to ensure that all connections are made safely and correctly. This test also aims to ensure that the components and cables used are not damaged and are in good condition. The testing is done using two methods: visual inspection and continuity testing.³ The filling time of the drinker can vary according to the water pressure.
- The visual inspection test is conducted by performing a visual check on each input and output circuit connection. The inspection ensures that the wiring connections are correct, neat, and safe for use, and that there is no obvious physical damage such as frayed wires, loose connections, burnt components, or damaged terminals. Table 5 shows the results of the visual inspection.

Table 5

Results of Visual Inspection Testing

Circuit Type	Circuit Condition (Good/Not)	Items Checked
Power supply circuit	Good	240VAC connection to DB, connection to socket, DC supply connection (MB102)
Current/power measurement circuit	Good	CT coil connection to Live path, PZEM-004T module connection, TX/RX to ESP32
LCD display circuit (I2C)	Good	VCC, GND, SDA, SCL; clear and stable display
Buzzer circuit (warning)	Good	Control pin connection, VCC, and GND; buzzer not loose
Servo motor MG996R circuit	Good	Signal, VCC, GND; servo installation neat
IoT connection circuit	Good	ESP32 can connect to WiFi and Telegram configuration

The visual inspection testing results show that all circuit connections are in good condition and comply with the designed circuit configuration. Next, we will continue with the continuity test as in Table 6.

Table 6
Results of Continuity Testing

Circuit Type	Circuit Condition (Good/Not)	Items Tested
Wiring from DB to switch/socket	Good	Live, Neutral, and Earth connected correctly to terminals
DC supply circuit	Good	VCC and GND connections on breadboard/MB102 stable
PZEM-004T and ESP32 connection	Good	TX/RX connected, no short
LCD I2C and ESP32 connection	Good	SDA/SCL connected, no break
Buzzer connection	Good	Output pin and ground connected
Servo connection	Good	Signal, VCC, and GND connected

The continuity test results show that all connections have good continuity, confirming that the circuits are connected correctly and safely. Next, we continue with the component functionality test as shown in Table 7.

Table 7
Results of Component Functionality Testing

Component	Functioning (Yes/No)	Observations
Power supply / MB102	Yes	Stable DC voltage output
ESP32	Yes	Functions and can upload code
PZEM-004T + CT coil	Yes	Voltage (V), current (A), power (W), frequency (Hz), and energy (kWh) readings displayed
LCD I2C	Yes	Displays voltage (V), current (A), power (W), frequency (Hz), and energy (kWh) clearly
Buzzer	Yes	Sounds when readings exceed the threshold
Servo MG996R	Yes	Moves according to system commands
WiFi + Telegram	Yes	Notifications successfully sent

The results show that all components function properly as require.

- The output readings obtained from the PZEM-004T are evaluated through the Serial Monitor in the Arduino IDE and the LCD display. The displayed readings include parameters such as the current and power being used by the load.
- The LCD display serves to show real-time current and power readings, allowing users to easily monitor the system's status. The LCD display is updated in real-time according to the readings received from the PZEM-004T.
- The buzzer is used as a local sound warning when the current or power readings exceed the set threshold. In normal conditions, the buzzer remains inactive. However, when the readings exceed the threshold, the buzzer will sound as an early warning to the user.
- The servo motor is used as a protection mechanism when the readings exceed a certain threshold according to the system's control logic. The servo will move to a predetermined angle to execute protection actions (e.g., trip switch/trigger mechanism).

- This system also tests the output of Telegram notifications to ensure users receive warnings even when far from the DB location. Notifications are sent when abnormal current/power readings are detected, and warning messages are displayed in the Telegram app.

RESULTS AND DISCUSSION

Results

The system was successfully tested under both normal and abnormal conditions to assess its functionality and effectiveness. The results obtained from various testing methods provided insights into the performance and reliability of the system.

Circuit Testing was performed to ensure all connections were made properly and that there were no physical or electrical faults in the system. The Visual Inspection confirmed that all components, including wires and connections, were correctly installed and secure. This process ensured that no physical damage, such as loose wires or burnt components, was present. Additionally, the Continuity Testing was carried out using a multimeter to verify that all circuits were properly connected and that there were no interruptions or shorts. The results indicated that all wiring was intact and functioning as expected.

The Component Functionality of the system was thoroughly tested. The power supply module (MB102), ESP32 microcontroller, PZEM-004T sensor, LCD display, buzzer, servo motor, and IoT connectivity were all assessed. All components performed as expected, with the system accurately measuring electrical parameters such as voltage, current, power, frequency, and energy. These measurements were displayed on the LCD in real-time, confirming that the system was capable of monitoring and displaying the data as designed.

The Warning Systems within the prototype were also tested. The Buzzer was triggered when the current or power exceeded preset thresholds, providing an audible alert to indicate an anomaly. In addition, the Servo Motor was activated when the system detected critical conditions, serving as a visual cue for the protection mechanism to engage. These features ensured that the system provided timely alerts for abnormal conditions, enhancing its effectiveness.

In terms of IoT Notifications, the system successfully sent real-time alerts through Telegram. When the measured electrical parameters exceeded predefined limits, the system sent notifications to users, allowing them to take immediate action even from remote locations. This capability ensured that users could monitor the system and respond promptly to any potential risks, even when they were not physically present near the system.

The Power Supply was stable throughout the testing phase. The MB102 power supply module consistently delivered the required DC voltage to the ESP32 and other components. This ensured that the system operated continuously without interruptions, providing a reliable power source for the various modules used in the system.

Overall, the system demonstrated efficiency in detecting abnormal conditions and activating the necessary protection mechanisms. The integration of IoT technology allowed for real-time monitoring and remote notifications, ensuring the system's usability in diverse environments. However, the testing revealed some limitations such as the potential need for more advanced power management features. Further testing in larger-scale systems or industrial settings would be beneficial to evaluate the robustness and adaptability of the system beyond residential or small industrial applications.

Discussion

The IoT-based automatic electrical current detection and protection system developed in this study addresses the key challenges identified during the initial stages of the project. The primary aim of the system was to monitor electrical parameters such as voltage, current, power, and frequency while delivering real-time alerts to users when abnormal conditions were detected. The system successfully achieved this objective, providing essential notifications and triggering protection mechanisms when necessary. By doing so, it offers a proactive approach to electrical safety, surpassing traditional protection devices such as MCBs and RCCBs that only operate after an issue arises (IEC, 2015; Thakur et al., 2023).

A significant advantage of this system is its continuous monitoring capability. The real-time data monitoring, coupled with alerts via IoT technology (specifically Telegram), ensures that users can act swiftly, even when they are not physically present near the electrical distribution board. This enhancement represents a notable improvement over conventional electrical protection systems, which only engage after the occurrence of a fault.

The ability to monitor data in real-time and receive alerts beforehand provides users with the opportunity to respond to potential issues before they escalate (El-Khozondar et al., 2024).

The system's design, which includes the integration of the PZEM-004T sensor and the ESP32 microcontroller, has proven to be an appropriate choice. The PZEM-004T sensor accurately measures electrical parameters and communicates efficiently with the ESP32. This setup facilitates the real-time display of data on an LCD and enables timely warnings through a buzzer and servo motor when thresholds are exceeded. The servo motor plays a critical role as a backup protection mechanism, triggering automatically when conditions reach a critical state, thus adding an extra layer of safety to the system.

Another key feature of the system is its flexibility, which allows it to cater to different user requirements. The combination of local and remote monitoring ensures that users can check the system's electrical status through the LCD and receive alerts through Telegram, providing continuous access to critical information. This dual approach makes the system user-friendly, even for individuals with limited technical knowledge. The simple interface and notification system allow non-technical users to easily interpret the electrical status of their electrical system (Brown & Wyatt, 2010).

However, there are some areas where the system can be improved. The current design is mainly intended for smaller-scale applications, such as residential homes or small industries. While it performs well in these environments, future work should focus on improving the scalability of the system to support larger commercial or industrial electrical systems. For larger setups, the system's power management features should be enhanced to handle higher loads, and more advanced fault detection mechanisms could be added.

Although the system provides real-time notifications through IoT, improvements in communication protocols could further enhance the reliability and security of these alerts. Ensuring that the system remains effective in situations where there are network disruptions is essential for critical applications. Furthermore, integrating advanced fault prediction capabilities could turn the system into a predictive maintenance tool, helping to detect issues before they occur (Zonta et al., 2020).

The components used in this system, such as the ESP32 and PZEM-004T, were selected due to their cost-effectiveness and suitability for the application. The relatively low cost, combined with the system's high functionality, ensures that it is accessible to a wide range of users, including homeowners and small businesses. Future development efforts should focus on expanding the system's capability to handle larger loads and adding predictive maintenance features to anticipate faults before they cause major damage (Zonta et al., 2020).

In conclusion, the IoT-based system effectively meets its objectives of providing real-time monitoring, automatic protection, and remote notifications. The system is particularly successful in small-scale applications, but future research should focus on scalability and the ability to predict faults to improve the system's usefulness in larger, more complex environments.

CONCLUSION

In this study, the IoT-based automatic electrical current detection and protection system successfully addressed the key challenges in electrical safety. The system was designed to continuously monitor essential electrical parameters such as current, voltage, power, and frequency while delivering real-time notifications to users when abnormal conditions arise. This proactive approach to electrical safety effectively surpasses traditional protection devices that only activate after the occurrence of a fault.

The integration of the PZEM-004T sensor and the ESP32 microcontroller proved to be an optimal choice, allowing for accurate measurements, efficient communication, and real-time data display. The system's flexibility, which supports both local and remote monitoring via IoT (Telegram), ensures users can monitor their electrical systems continuously, making it easy for both technical and non-technical users to interpret and act upon critical information.

However, while the system is well-suited for small-scale applications such as residential homes and small industries, future enhancements should focus on scalability, fault prediction, and handling larger loads for broader commercial and industrial use. Additionally, improving communication protocols and enhancing the reliability and security of notifications in case of network disruptions would further strengthen the system.

As a final point, the IoT-based system provides a reliable and efficient solution for electrical safety, offering real-time monitoring, protection, and notifications. As a result, it has the potential to be widely adopted, especially in smaller-scale environments. Further research and development are necessary to optimize the system for larger-

scale applications, with improvements in fault detection and predictive maintenance capabilities to increase its overall functionality and usability.

DECLARATIONS

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