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Design and Implementation of Power Monitoring and Fault Protection System using ESP32 Microcontroller

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Abstract: Electrical power monitoring and fault protection are essential for ensuring the safety, reliability, and efficient operation of electrical appliances. Conventional electrical protection systems mainly depend on circuit breakers and fuses, which provide basic protection but do not offer continuous monitoring or remote access to electrical parameters. This paper presents the design and implementation of a Power Monitoring and Fault Protection System using an ESP32 microcontroller. The proposed system continuously monitors electrical parameters such as voltage, current, and power using voltage and current sensors. The sensed data is processed by the ESP32 microcontroller and displayed on a monitoring interface. The system identifies abnormal operating conditions such as overvoltage, undervoltage, and overcurrent by comparing measured values with predefined threshold limits. When a fault condition is detected, the controller activates a relay-based protection mechanism to disconnect the load and prevent potential damage to electrical appliances. An IoT-based monitoring facility using Wi-Fi enables remote observation of electrical parameters and fault conditions. The proposed system aims to provide a compact, cost-effective, and reliable solution for real-time electrical monitoring and automatic fault protection.

Keywords: ESP32, Power Monitoring, Fault Protection, Voltage Sensor, Current Sensor, Relay, Internet of Things (IoT), Overcurrent, Overvoltage.

I. INTRODUCTION

Electrical energy is widely used in residential, commercial, and industrial applications. The increasing use of electrical and electronic appliances has created a need for efficient power monitoring and protection systems. Voltage fluctuations, excessive current, short circuits, and abnormal power conditions can cause damage to electrical equipment and affect the reliability of electrical systems.

Traditional protection systems such as fuses and miniature circuit breakers (MCBs) provide protection against certain electrical faults. However, these systems generally do not provide real-time electrical parameter monitoring, continuous data recording, or remote fault notifications.

With the development of embedded systems and Internet of Things (IoT) technology, intelligent electrical monitoring systems can be developed to overcome these limitations. Microcontrollers provide the ability to collect sensor data, process electrical parameters, identify abnormal conditions, and control protection devices automatically.

The ESP32 microcontroller is selected for the proposed system because it provides processing capabilities, multiple input/output interfaces, analog-to-digital conversion, and built-in Wi-Fi connectivity. It enables integration of voltage and current sensors with a relay-based protection circuit and an IoT monitoring interface.

The proposed system uses voltage and current sensors to measure the electrical parameters of the connected load. The ESP32 processes the sensor readings and calculates the power consumption. If the measured parameters exceed predefined safety limits, the system identifies the fault and activates the relay to disconnect the load. The system also provides remote monitoring through wireless communication.

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The main objective of this work is to develop an intelligent power monitoring and fault protection system that combines real-time measurement, automatic fault detection, load isolation, and remote monitoring.

II. LITERATURE REVIEW

Smart Grid Protection Authors [1] (2026) investigated smart power monitoring and fault protection using ESP32, automated relay switching and cloud analytics. The study focused on real-time fault isolation and remote monitoring for intelligent energy management.

Dual-Line Fault System Authors [2] (2025) presented an ESP32-based fault detection system incorporating ZMPT101B voltage sensors, ACS712 current sensors and relay switching. The system focused on voltage and current fault detection with local display indication.

Chen and Lin [3] (2024) investigated web-based real-time telemetry and visualization using browser dashboards, Chart.js and WebSocket communication. Their approach supported dynamic visualization of electrical parameters.

IoT Fault Alert Authors [4] (2023) explored ESP32-based fault monitoring using Wi-Fi and the Blynk IoT platform. The approach focused on remote fault notifications and real-time system status monitoring.

Kumar and Patel [5] (2023) investigated IoT-based real-time power monitoring using ESP32. The system supported continuous transmission of RMS voltage, current and power measurements to cloud servers.

Mishra and Sundaram [6] (2022) investigated thermal monitoring and overheating protection using the DS18B20 digital temperature sensor. Their work focused on temperature-based protection and thermal threshold detection.

Hassan and Ibrahim [7] (2022) explored cloud-connected energy management systems incorporating real-time databases and automated CSV report generation for electrical parameter monitoring and historical data analysis.

Singh and Singh [8] (2022) compared ACS712 Hall-effect current sensors with shunt-resistor-based current measurement techniques, emphasizing galvanic isolation, sensitivity, linearity and calibration.

Al-Otaibi and Al-Badi [9] (2022) investigated solid-state relay control and overload response mechanisms for automatic load disconnection under abnormal electrical operating conditions.

Alvarez and Martinez [10] (2022) explored dual-core task scheduling using ESP32 and FreeRTOS. Their approach focused on separating time-critical sensor acquisition tasks from wireless communication tasks.

Das and Babu [11] (2022) investigated ZMPT101B voltage sensor signal conditioning, DC offset compensation and RMS voltage calculation for microcontrollerbased electrical monitoring systems.

Verma and Roy [12] (2022) investigated automated load disconnection and fault event logging using microcontrollerbased protection systems. Their work focused on fault detection, automatic switching and timestamped event recording.

III. PROBLEM DEFINITION AND OBJECTIVES

A. Problem Definition

Electrical appliances may be exposed to abnormal voltage and current conditions. Conventional protection devices provide basic interruption but may not offer detailed real-time measurements or remote indication of a fault. An embedded monitoring system is therefore proposed to measure electrical parameters, identify abnormal conditions, and initiate load isolation while communicating the system status to the user.

B. Objectives

1. To design a sensor-based electrical monitoring circuit for measuring AC supply voltage and load current and computing RMS voltage, RMS current and electrical power using a microcontroller.
2. To implement a threshold-based fault detection algorithm for identifying overvoltage, undervoltage and overcurrent conditions and automatically disconnecting the load using a relay driver circuit.

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3. To implement a Wi-Fi-enabled monitoring interface for real-time transmission of electrical parameters and fault notifications, along with local display of measurements and fault status.
4. To develop a compact PCB-based protection system incorporating electrical isolation, appropriate creepage and clearance distances, and evaluate its measurement accuracy, fault detection accuracy and load disconnection response time.

IV. MATHEMATICAL FRAMEWORK

A. RMS Voltage and Current

For sampled AC waveforms, RMS voltage and current are estimated from a finite set of samples v[k] and i[k] over N samples per 20 ms cycle:

$$V_{RMS} = \sqrt{\frac{1}{N}\sum_{k=1}^{N} v^2[k]}, \quad I_{RMS} = \sqrt{\frac{1}{N}\sum_{k=1}^{N} i^2[k]} \tag{1}$$

True RMS Formulations:

$$V_{RMS} = 230\ \text{V}, \quad I_{RMS} = 2\ \text{A} \tag{2}$$

Active Real Power & Power Factor:

$$P = V_{RMS} \times I_{RMS}, \quad P = 230 \times 2 = 460\ \text{W} \tag{3}$$

Dynamic Energy Accumulation:

$$E = \sum \left(\frac{P \times \Delta t}{3.6 \times 10^6} \right) \text{[kWh]} \tag{4}$$

$$E = \sum \left(\frac{460 \times 0.02}{3.6 \times 10^6} \right) = 0.00000255\ \text{[kWh]} \tag{5}$$

V. BLOCK DIAGRAM

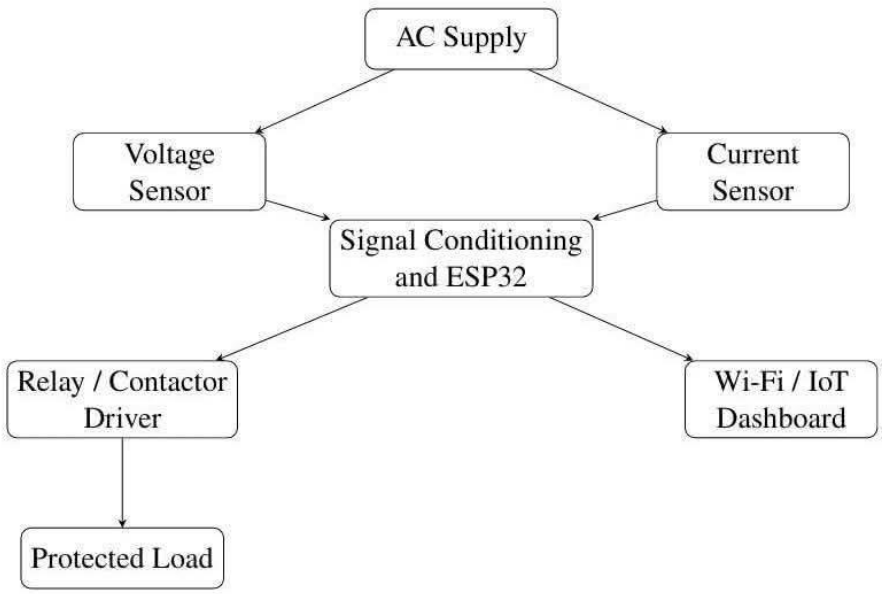

Fig. 1 Functional block diagram of the proposed power monitoring and fault protection system.

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VI. PROPOSED METHODOLOGY

A. System Architecture

The proposed system contains an AC input section, voltage and current sensing circuits, signal-conditioning circuits, an ESP32 microcontroller, a relay driver, a display, and a Wi-Fi monitoring interface. The sensors provide measurement signals to the controller. The ESP32 calculates electrical parameters and evaluates the fault conditions. The relay driver receives a control signal when the protection logic determines that the load must be isolated.

B. Hardware Components

- ESP32 microcontroller: Acts as the central processing unit. It samples sensor outputs, calculates electrical quantities, evaluates threshold conditions, controls the relay driver, and communicates with the IoT platform.
- ZMPT101B voltage sensor: Provides an isolated, scaled signal corresponding to the measured AC voltage. Its output requires appropriate calibration and conditioning before connection to the ESP32 ADC.
- ACS712 current sensor: Uses the Hall-effect principle to provide an analog output related to the current passing through its conductor. The sensor output is calibrated to estimate load current.
- Relay and driver: The driver interfaces the ESP32 control signal to the relay coil. The relay contacts are selected and rated for the intended load and fault environment. A relay module alone must not be assumed to safely interrupt high short-circuit currents.
- Display and indicators: An LCD or OLED can display voltage, current, power, and system state. A buzzer or LED can provide local fault indication.
- IoT interface: The ESP32 Wi-Fi connection can publish measurement values and fault status to a dashboard or server for remote observation and logging.

VII. SENSOR INTERFACING AND DATA ACQUISITION

The voltage and current sensors are connected to separate analog input channels through suitable signal-conditioning circuits. The ESP32 ADC accepts only low-voltage signals within its specified input range. Therefore, the sensor outputs must be checked to ensure that they never exceed the permitted ADC voltage, including during transients. The sampling routine collects multiple samples over a defined measurement window.

Before calculating RMS values, the firmware estimates and removes the sensor's DC offset. Calibration factors are then applied to convert ADC readings into engineering units. Calibration should be performed using suitable reference instruments over the intended measurement range. For real-power calculation, voltage and current samples must be synchronized sufficiently to preserve their phase relationship.

The measurement update rate should balance response time, noise rejection, and processor workload. The system can use averaging or digital filtering to reduce measurement noise. The selected sampling window and filter parameters should be documented during testing.

VIII. FAULT DETECTION AND PROTECTION

The fault-detection algorithm repeatedly compares the measured RMS voltage and current against predefined limits. If voltage exceeds the upper threshold, an overvoltage condition is recorded. If voltage falls below the lower threshold, an undervoltage condition is recorded. If current exceeds the permitted value, an overcurrent condition is recorded.

When a fault is confirmed, the ESP32 changes the system state to protection mode, activates the relay driver, updates the local indication, and sends the fault status to the IoT interface. The firmware should use a defined recovery procedure so that the load is not reconnected until the fault has cleared and a safe reset condition is satisfied.

A microcontroller and relay are not substitutes for a properly rated fuse, MCB, RCD, or other required protective equipment. Short-circuit currents can rise faster and reach levels beyond the capability of a small relay or softwarecontrolled system. The prototype must include appropriately rated upstream protection and be tested using safe, isolated, current-limited test arrangements.

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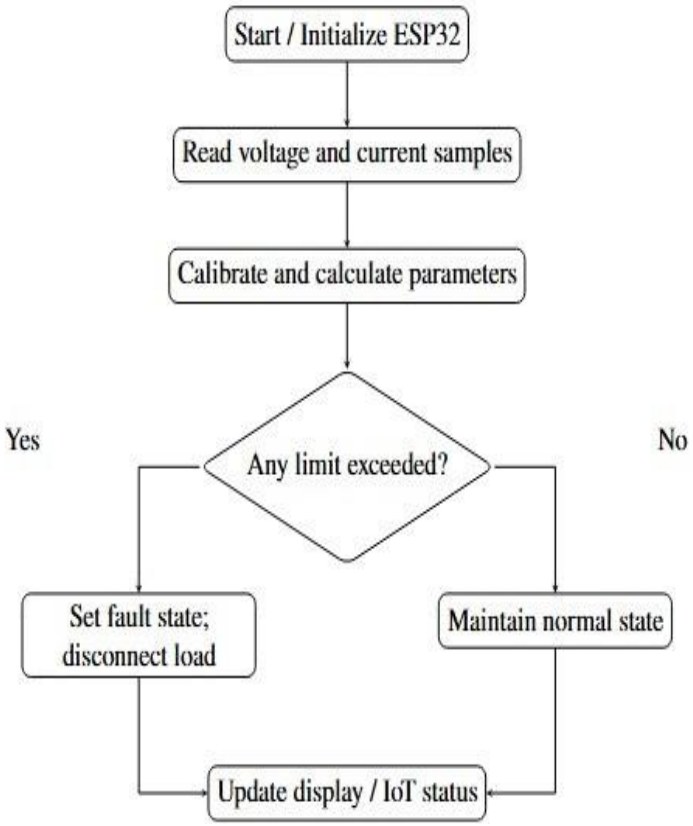

Fig. 2 Simplified measurement and fault-protection workflow. The implemented firmware should include separate normal, fault, and recovery states.

The system starts by initializing the ESP32, sensors, display, relay output, and Wi-Fi interface. It then acquires voltage and current samples, applies calibration, calculates RMS values and power, and updates the local and remote displays. The fault logic compares the measured values with the configured limits. Under normal conditions, monitoring continues. When a fault is confirmed, the controller commands load isolation and records or transmits the event. Restoration is allowed only after the fault condition is cleared and the defined reset procedure is completed.

IX. PCB DESIGN AND IMPLEMENTATION

The PCB integrates the ESP32 module, sensor interfaces, signal-conditioning components, low-voltage supply, relay driver, and display or communication connectors. Component placement should keep noisy switching paths away from sensitive analog measurement circuits. Grounding and routing should be planned to reduce interference in the sensor signals. Where the board interfaces with mains voltage, the high-voltage and low-voltage sections must be physically separated. Creepage and clearance distances, insulation barriers, enclosure design, fusing, connector ratings, and relay contact ratings must be selected according to applicable standards and the actual working voltage and pollution environment. The PCB should be reviewed by a qualified person before any mains-powered test.

Firmware modules can be organized into sensor acquisition, calibration, RMS and power calculation, fault evaluation, relay control, display update, and IoT communication. Each module should first be tested independently using safe simulated or low-voltage inputs before complete integration.

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X. FAULT DETECTION AND PROTECTION

The implemented decision sequence is shown below. Conditions are evaluated in priority order. The firmware automatically enables the relay when readings return to normal; it also commands ON below the supply-off threshold. This behavior must be reviewed before any deployment because it can permit unintended re-energization.

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TABLE I REPORTED FUNCTIONAL TEST RESULTS

headergray Condition (priority order)	Firmware state	Relay command
V < 50 V	SUPPLY OFF	ON
I ≥ 3 A	OVER CURRENT	OFF
V > 230 V	HIGH VOLTAGE	OFF
V < 200 V	LOW VOLTAGE	OFF
Otherwise	NORMAL	ON

The local display and alarm indicators are updated after each protection decision. Wireless telemetry is sent only when the Blynk connection is available. The two-second scheduled update is not a measured fault interruption time. A fail-safe reset policy, hysteresis, and independent timing validation are recommended.

XI. EXPERIMENTAL RESULTS AND DISCUSSION

The proposed design is intended to demonstrate continuous measurement of voltage and current, calculation of power, identification of abnormal operating conditions, and relay-based load isolation. The ESP32 also provides local status information and a path for remote monitoring through Wi-Fi. The prototype should be evaluated by comparing sensor measurements with calibrated reference instruments. Testing should include normal operating conditions and controlled low-voltage fault simulations. Important evaluation parameters include measurement error, repeatability, fault-detection time, relay response, false-trip behaviour, Wi-Fi availability, and event logging.

TABLE II REPORTED FUNCTIONAL TEST RESULTS

Test	Voltage (V)	Current (A)	Relay	Alarm
Normal	215–216.7	1.98–2.00	ON	OFF
Overcurrent	218.8–222	3.35–3.40	OFF	ON
Overvoltage	236	2.00	OFF	ON
Undervoltage	195	2.00	OFF	ON

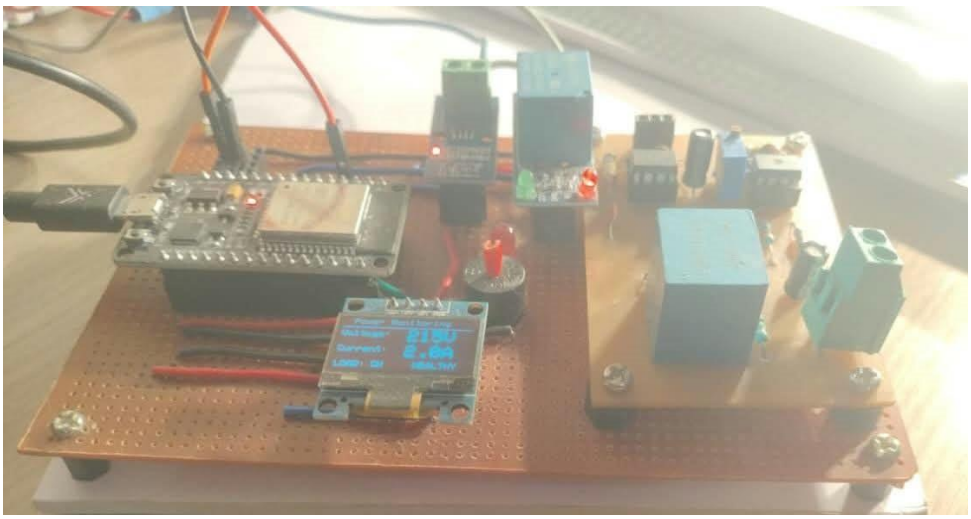

Fig. 3 Hardware Prototype during normal operation.

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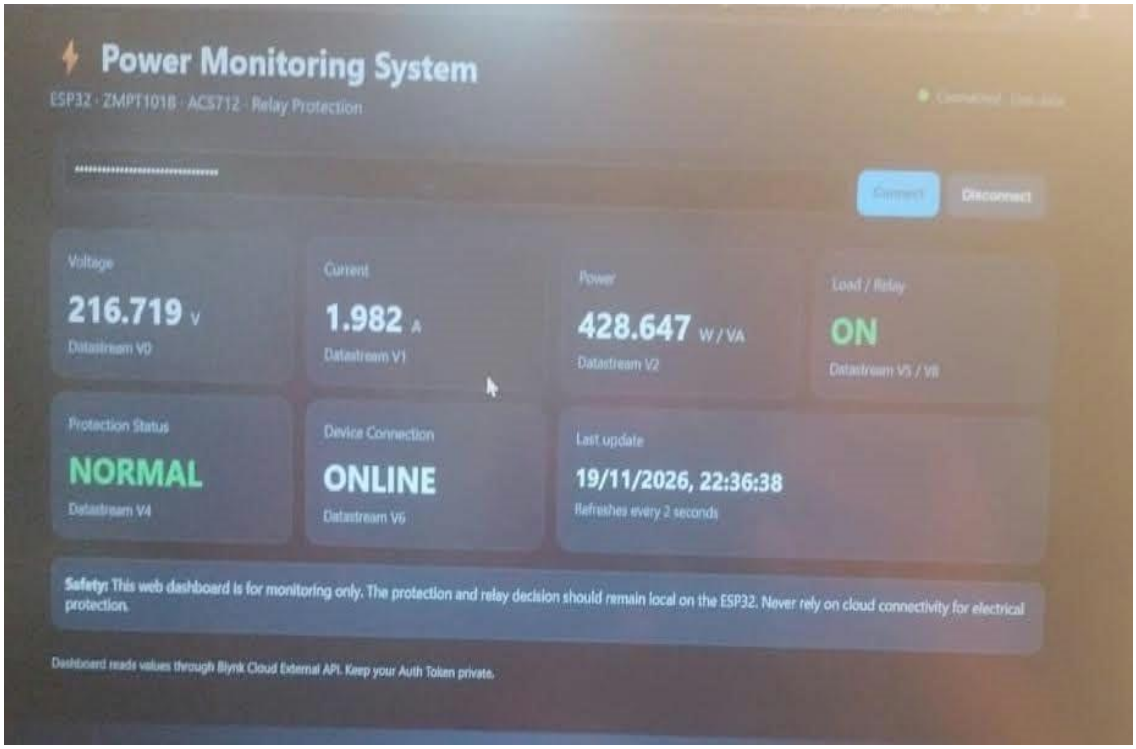

Fig. 4 Normal-operation web dashboard.

The report describes normal dashboard readings of 216.719 V and 1.982 A, with the relay ON. The displayed power field is interpreted as apparent power because the listed firmware multiplies RMS quantities.

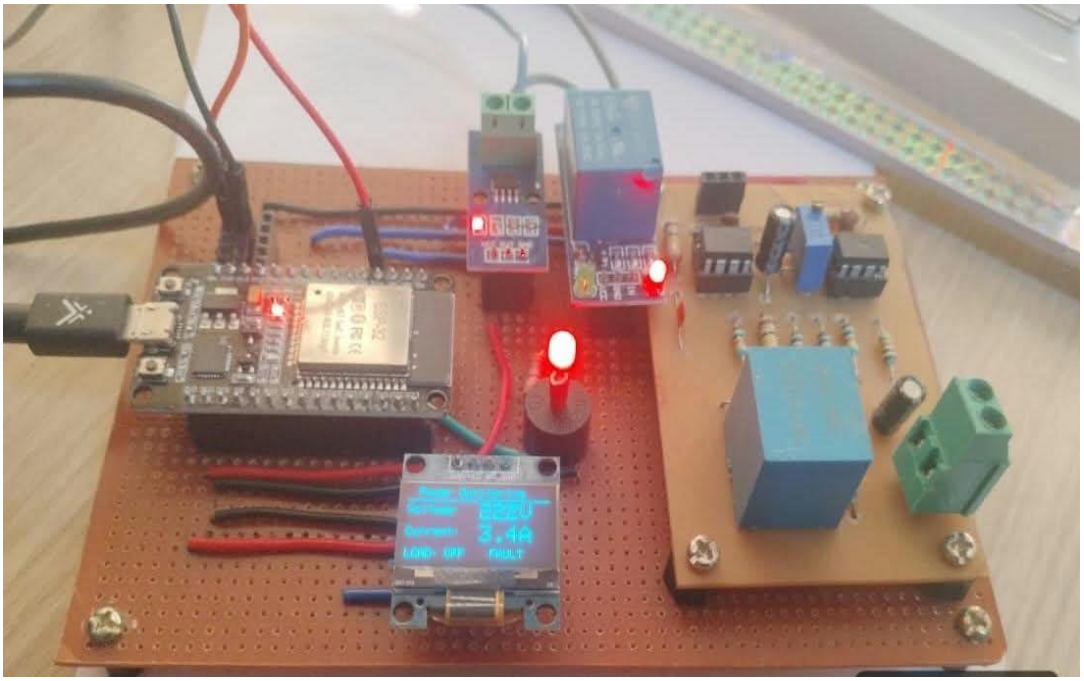

Fig. 5 Hardware overcurrent indication.

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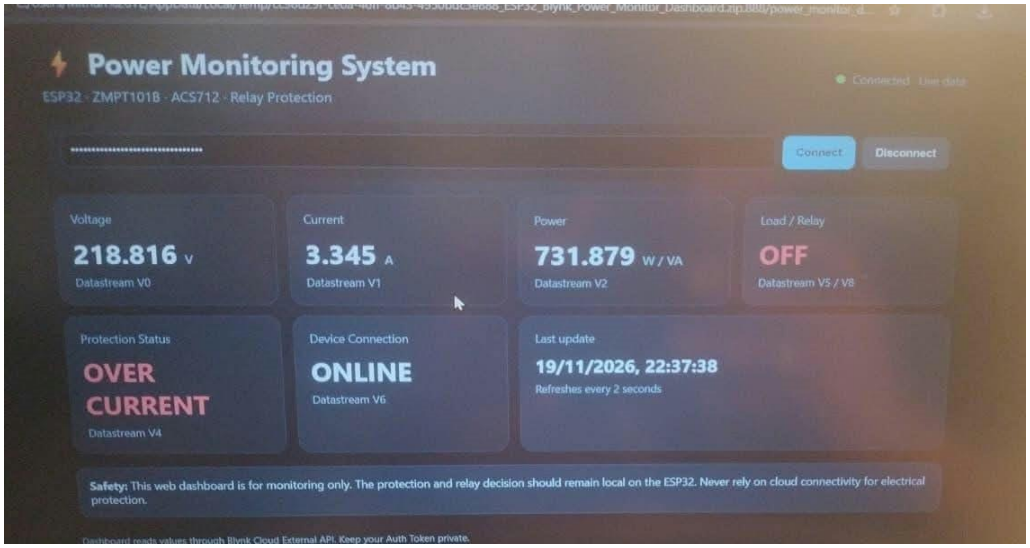

Fig. 6 Overcurrent dashboard.

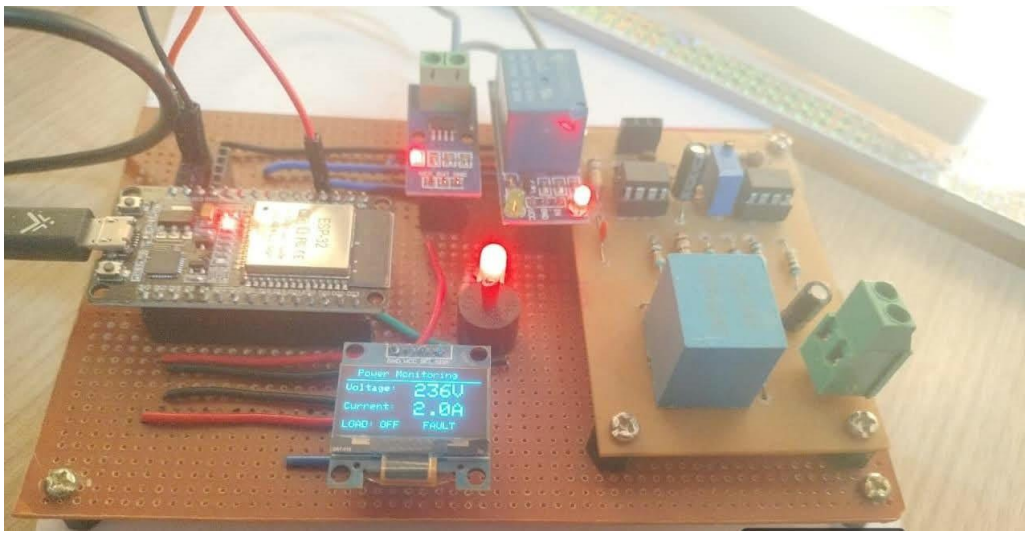

Fig. 7 Overvoltage test.

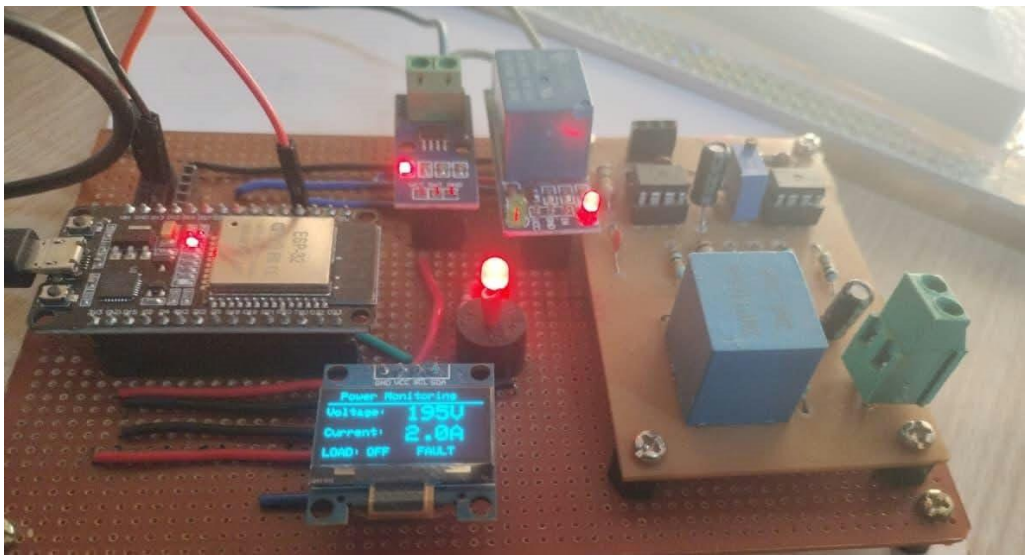

Fig. 8 Undervoltage test.

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The reported overvoltage and undervoltage tests show load disconnection at 236 V and 195 V respectively. The current values associated with fault events should be identified as pre-trip or captured event readings rather than assumed to represent sustained current after isolation.

XII. APPLICATION

The proposed system can be adapted for residential load monitoring, appliance protection, laboratory power monitoring, small commercial installations, and educational demonstrations of embedded power measurement and IoT-based fault indication. Its suitability for industrial or mains distribution use depends on validated ratings, certified protective components, enclosure design, and compliance testing.

XIII. CONCLUSION

The design of a power monitoring and fault protection system using an ESP32 microcontroller. The proposed architecture combines voltage and current sensing, electrical parameter calculation, threshold-based fault detection, relaycontrolled load isolation, local indication, and Wi-Fi-based remote monitoring. The controller processes the sensor readings and identifies overvoltage, undervoltage, and overcurrent conditions. When a fault is confirmed, the protection logic commands the relay driver to isolate the load and reports the event to the user. The design provides a foundation for an integrated embedded monitoring prototype. Future work includes completing PCB fabrication, calibrating the sensors, validating fault response under controlled conditions, improving event logging, and extending the system to additional electrical parameters or three-phase monitoring.

REFERENCES

[1]. Smart Grid Protection Authors, “Smart Power Cut Fault Protection and Energy Monitoring,” 2026.
[2]. Dual-Line Fault System Authors, “Smart Dual-Parallel Line Fault Detection with ESP32,” 2025.
[3]. K. L. Chen and Y. H. Lin, “Web-Based Real-Time Telemetry and Visualization,” 2024.
[4]. IoT Fault Alert Authors, “ESP32 and Blynk Real-Time Fault Monitoring,” 2023.
[5]. A. Kumar and S. R. Patel, “IoT-Based Real-Time Power Monitoring Using ESP32,” 2023.
[6]. R. K. Mishra and S. Sundaram, “Thermal Behavior and DS18B20 Overheating Protection,” 2022.
[7]. M. A. Hassan and N. K. Ibrahim, “Cloud-Connected Energy Management with CSV Audit Logging,” 2022.
[8]. G. Singh and P. K. Singh, “Comparison of ACS712 Hall Transducer and Shunt Resistor,” 2022.
[9]. F. Al-Otaibi and A. H. Al-Badi, “Solid-State Relay Control and Sub-Cycle Overload Response,” 2022.
[10]. T. R. Alvarez and G. Martinez, “Dual-Core Task Scheduling on ESP32 for IoT Edge Computing,” 2022.
[11]. D. C. Das and B. C. Babu, “ZMPT101B Voltage Sensor Conditioning and Offset Compensation,” 2022.
[12]. H. K. Verma and S. Roy, “Automated Load Disconnection and Fault Logging,” 2022.