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Smart Energy Data Acquisition and Automatic Protection System using Raspberry Pi

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Abstract— **There are several limitations in conventional domestic energy monitoring systems, including the lack of real-time measurement, limited fault detection, absence of continuous energy data logging, and limited remote monitoring capabilities. To address these issues, this paper presents a Smart Energy Monitoring and Protection System using Raspberry Pi. The proposed system uses a ZMPT101B voltage sensor and an ACS712 current sensor to measure electrical parameters, while an ADS1115 analog-to-digital converter interfaces the sensor outputs with the Raspberry Pi. The system calculates voltage, current, approximate power, and accumulated energy consumption in real time. A relay-based protection mechanism automatically disconnects the connected load during abnormal conditions such as under-voltage, over-voltage, over-current, over-power, and zero-voltage or sensor-fault conditions. The measured data and fault events are stored using an SQLite database and displayed through a Flask-based web dashboard, enabling local monitoring through a laptop or mobile device connected to the same network. In addition, the system provides reports, CSV data export, PDF saving, and Telegram-based notifications. The proposed system provides a low-cost and modular solution for real-time energy monitoring, automatic protection, and data management, making it suitable for homes, laboratories, small offices, and other small-load electrical installations. The developed prototype demonstrates the integration of IoT-based monitoring, electrical protection, data logging, and web-based visualization using a Raspberry Pi.**

Keyword—Raspberry Pi, IoT, Energy Monitoring, ZMPT101B, ACS712, ADS1115, Relay Protection, Flask, SQLite, Smart Energy Management.

I INTRODUCTION

The increasing use of electrical appliances and electronic equipment has created a need for reliable and efficient energy monitoring and protection systems. Conventional electrical monitoring methods mainly depend on manual observation and traditional protection devices, which may not provide continuous information about voltage, current, power and energy consumption. With the development of embedded systems and IoT technologies, real-time electrical monitoring and automatic protection can be integrated into a single system. Embedded systems are designed to perform specific functions and are widely used in monitoring, control and protection applications. Raspberry Pi provides a compact and flexible platform for implementing such applications. In the proposed system, the Raspberry Pi is used as the main controller to

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acquire and process electrical measurements. A ZMPT101B voltage sensor is used for AC voltage measurement, while an ACS712 current sensor is used for load-current measurement. Since the Raspberry Pi does not provide built-in analog inputs, an ADS1115 analog-to-digital converter is used to interface the sensors with the controller. embedded systems are designed to perform specific functions and are widely used in monitoring, control and protection applications.

Raspberry Pi provides a compact and flexible platform for implementing such applications. In the proposed system, the Raspberry Pi is used as the main controller to acquire and process electrical measurements A ZMPT101B voltage sensor is used for AC voltage measurement, while an ACS712 current sensor is used for load-current measurement. Since the Raspberry Pi does not provide built-in analog inputs, an ADS1115 analog-to-digital converter is used to interface the sensors with the controller. The proposed system continuously monitors electrical parameters and calculates approximate power and accumulated energy consumption. A relay-based protection mechanism disconnects the connected load when abnormal conditions such as under-voltage, over-voltage, over-current or over-power are detected. The measured data and fault events are stored in an SQLite database and displayed through a Flask web dashboard, providing real-time monitoring and historical information to the user. Thus, the proposed Raspberry Pi-based system combines real-time energy monitoring, automatic protection, data logging and web-based monitoring in a low-cost and modular platform. The system can be used for homes, laboratories, small offices and other small-load electrical installations.

The system is designed to provide continuous observation of electrical conditions and to respond to abnormal operating states without requiring constant manual intervention. The protection logic evaluates the measured parameters against predefined operating limits and controls the relay accordingly. A recovery delay is incorporated to avoid unnecessary repeated switching when the measured values temporarily return to the safe range. The monitoring application further supports storage and presentation of electrical data for analysis. Voltage, current, power and energy values can be recorded at regular intervals, while fault events are maintained separately for identifying abnormal operating conditions. The web-based interface provides dashboard information, reports and alert details, allowing users to observe both current and previously recorded system conditions. The proposed system also provides additional communication and reporting capabilities through Telegram notifications, CSV data export and report generation. These features improve the accessibility of the monitored information and help the user review energy consumption and protection events. The modular design allows the monitoring and protection functions to be extended for different small-load electrical applications.

The proposed system is developed to provide a practical approach for combining electrical measurement and protection functions within a single embedded platform. By integrating the sensing unit, analog-to-digital conversion, Raspberry Pi controller, relay interface, database and web application, the system can perform monitoring and protection without requiring separate monitoring equipment.

The modular structure also permits individual components and software functions to be modified or extended according to the application requirements. Overall, the Smart Energy Monitoring and Protection System Using Raspberry Pi provide an integrated solution for monitoring electrical parameters, recording energy-related information and protecting connected loads from predefined abnormal conditions. The combination of real-time monitoring, automatic load disconnection, historical data storage and web-based visualization makes the system suitable as a prototype for intelligent electrical energy management and protection.

The implementation of the proposed system provides a centralized platform for electrical parameter measurement, protection and information management. The Raspberry Pi processes the sensor data and coordinates the operation of the monitoring application and relay control. The stored information can be used to analyse energy consumption and identify previously recorded abnormal conditions. This approach reduces the dependence on continuous manual monitoring and provides users with accessible information about the electrical system. The proposed Smart Energy Monitoring and Protection System Using Raspberry Pi therefore focus on integrating monitoring, automatic load protection, data storage and web-based visualization into a single system. The developed prototype demonstrates the practical use of an embedded computing platform for real-time electrical monitoring and protection, with scope for further development in energy management and remote monitoring applications.

The system architecture is organized into sensing, processing, protection, storage and visualization units. The sensing unit acquires voltage and current information, while the Raspberry Pi processes the converted signals and determines the operating condition of the connected load. The protection unit operates the relay according to the detected condition, whereas the database and web interface manage and present the recorded information.

The integration of these units provides a unified platform for observing electrical parameters and responding to abnormal conditions. The recorded data also provides a basis for reviewing energy consumption and protection events over time.

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Thus, the proposed system demonstrates the application of Raspberry Pi-based embedded technology for intelligent energy monitoring and electrical load protection. The system architecture is organized into sensing, processing, protection, storage, and visualization units. The sensing unit acquires voltage and current information through the ZMPT101B and ACS712 sensors, while the Raspberry Pi processes the converted signals and determines the operating condition of the connected load.

The protection unit operates the relay according to detected abnormal conditions, while the SQLite database stores measurement and fault information and the Flask-based web interface presents the recorded data to the user. This integration provides a unified platform for real-time electrical monitoring, automatic load protection, data storage, and web-based visualization, demonstrating the practical application of Raspberry Pi technology for intelligent energy monitoring and electrical protection.

The proposed system is designed to improve the reliability and accessibility of electrical monitoring by combining real-time measurement with automatic protection and data management. By continuously observing voltage, current, power and energy consumption, the system can provide useful information about the connected load and identify abnormal operating conditions. The stored measurements and fault records can further assist users in analysing system performance and energy usage. This integrated approach makes the system a practical and modular solution for real-time energy monitoring and protection using Raspberry Pi.

II Related Work

Several approaches have been proposed for improving electrical energy monitoring and protection. Conventional energy monitoring systems have limitations in providing continuous measurement, fault detection and accessible energy consumption information. Smart metering and embedded systems have therefore been explored to improve monitoring and control of electrical loads. Some systems use wireless communication technologies such as GSM to transmit electrical meter readings and provide remote monitoring.

Relay-based control has also been incorporated to disconnect the power supply to the load during abnormal conditions, helping to address problems associated with voltage fluctuations and electrical faults. Other approaches interface analogue energy meters with digital circuits and LCD displays to provide users with real-time meter readings and billing information.

Microcontroller-based systems combined with communication modules have also been developed for wireless transmission of electrical data. These systems acquire meter readings and transmit the information to a central monitoring unit, reducing the need for manual meter reading. Wireless Energy Meter systems further demonstrate the use of communication technologies for transmitting electrical measurements to a server, where the data can be monitored and analysed. The proposed Smart Energy Monitoring and Protection System Using Raspberry Pi extend these concepts by integrating electrical sensing, automatic load protection, data storage and web-based monitoring into a single platform.

The system uses ZMPT101B and ACS712 sensors with an ADS1115 ADC for voltage and current measurement, while Raspberry Pi performs data processing and relay control. The measured parameters and fault events are stored in SQLite and presented through a Flask-based dashboard, providing real-time monitoring and historical stored in SQLite and presented through a Flask-based dashboard, providing real-time monitoring and historical information. Thus, the proposed system combines monitoring, protection and data management in a modular Raspberry Pi-based platform.

III Proposed Method

The proposed Smart Energy Data Acquisition and Automatic Protection System Using Raspberry Pi is developed by integrating voltage sensing, current sensing, data acquisition, processing, monitoring and automatic protection techniques. Initially, the AC supply voltage and load current are measured using the ZMPT101B voltage sensor and ACS712 current sensor, respectively. The analog outputs generated by these sensors are connected to the ADS1115 16-bit Analog-to-Digital Converter (ADC), which converts the analog signals into digital data because the Raspberry Pi Zero 2 W does not have built-in analog input channels.

The digital data acquired by the ADS1115 is transmitted to the Raspberry Pi through the I2C communication interface. The Raspberry Pi processes the received data and calculates the electrical parameters, including voltage, current, power and energy consumption. These measured and calculated parameters are continuously updated and displayed on a 16×2 LCD and a web-based monitoring dashboard.



Fig. 1. Graphical Representation of Smart Energy Data Acquisition and Automatic Protection System Using Raspberry Pi.

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The overall graphical representation of the proposed system architecture, illustrating the integration of voltage and current sensors, ADS1115 ADC, Raspberry Pi, LCD display, web-based monitoring dashboard, database, relay module and automatic protection features, is shown in Fig. 1.

A Raspberry Pi-controlled relay automatically disconnects the load when voltage, current or power exceeds predefined safety limits, protecting connected equipment from electrical faults. A recovery delay mechanism is incorporated to ensure that the electrical parameters remain within the safe operating range before reconnecting the load. Fault events and electrical measurements are stored in an SQLite database for historical analysis and report generation.

Additionally, a Flask-based web application provides real-time monitoring, data visualization and access to stored reports through connected devices. Remote fault notifications are implemented using Telegram to inform users about abnormal operating conditions.

The overall methodology integrates sensing, analog-to-digital conversion, data processing, automatic relay control, local display, database management and remote monitoring to achieve an efficient and low-cost smart energy data acquisition and automatic protection system.

3.1 SMART METER

The proposed Smart Energy Data Acquisition and Automatic Protection System Using Raspberry Pi monitors electrical parameters and provides automatic load protection. A ZMPT101B voltage sensor and ACS712 current sensor measure the supply voltage and load current, respectively. The ADS1115 ADC converts the analog signals into digital data for processing by the Raspberry Pi.

The system monitors voltage, current, power and energy, displaying readings on a 16×2 LCD and web dashboard. SQLite stores measurement and fault data, while a relay disconnects the load during abnormal conditions. Telegram sends remote fault alerts.

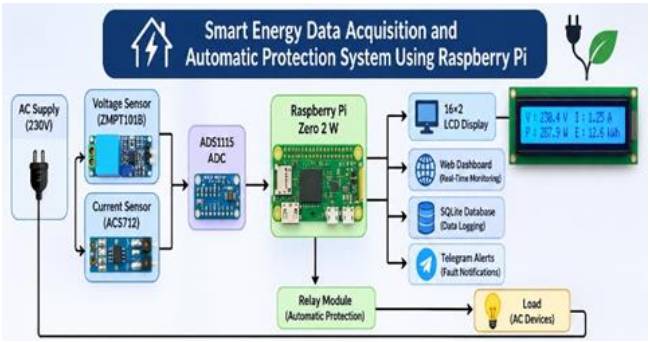


Fig. 2. Block Diagram of Proposed Raspberry Pi-Based Smart Energy Meter.

3.2 ENERGY METER

The proposed Smart Energy Data Acquisition and Automatic Protection System uses an electronic energy measurement technique based on Raspberry Pi. Unlike conventional electromechanical meters, the proposed system does not use rotating mechanical components. A ZMPT101B voltage sensor and ACS712 current sensor acquire the electrical parameters of the connected load. The ADS1115 ADC converts the analog signals into digital data, which is processed by the Raspberry Pi Zero 2 W. The system calculates voltage, current, power and energy consumption. The measured values are displayed through an LCD and web-based dashboard. Additionally, a relay provides automatic load disconnection during abnormal electrical conditions, improving system safety and reliability.

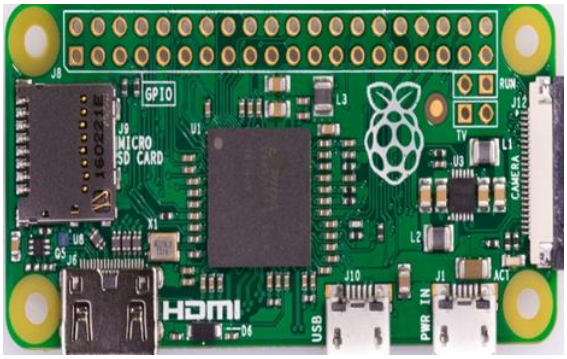


Fig. 3. Raspberry Pi-Based Electronic Energy Meter Structure.

IV. RESULT ANALYSIS

The developed Smart Energy Data Acquisition and Automatic Protection System Using Raspberry Pi provide real-time monitoring of electrical parameters and automatic load protection.

- The voltage and current sensors acquire electrical data from the connected load.
- The Raspberry Pi processes the data and calculates power and energy consumption.
- The LCD and web dashboard display the measured electrical parameters.
- The system stores energy readings and fault information in the database.
- The relay automatically disconnects the load during abnormal voltage and current conditions.
- Telegram notifications provide alerts during fault conditions.
- Historical reports help users analyse electricity consumption.

The results demonstrate that the proposed system integrates energy monitoring, data acquisition and automatic protection into a single low-cost platform, improving electrical safety and monitoring efficiency.

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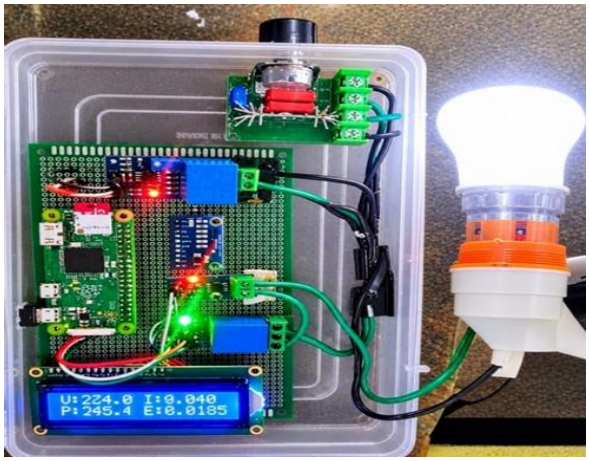


Figure 4. Circuit connection for Smart Energy Data Acquisition and Automatic Protection System Using Raspberry Pi

OUTPUT

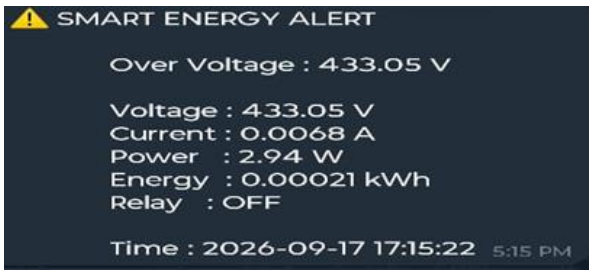


Figure 5. Telegram Notifications

The system monitors voltage, current, power, and energy consumption using sensors connected to the Raspberry Pi. When the voltage exceeds the configured limit, an over-voltage alert is generated and the relay automatically switches OFF. The dashboard displays real-time electrical parameters, relay status, and the alert timestamp.

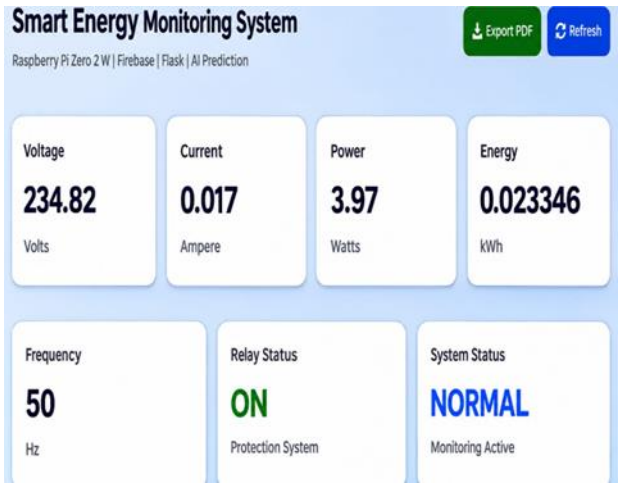


Figure 7. Website data display

The web-based dashboard displays real-time electrical parameters such as voltage, current, power, and energy consumption measured by the sensors. It shows relay ON/OFF status, fault alerts, and timestamps, allowing users to monitor the electrical system through a mobile or computer browser.

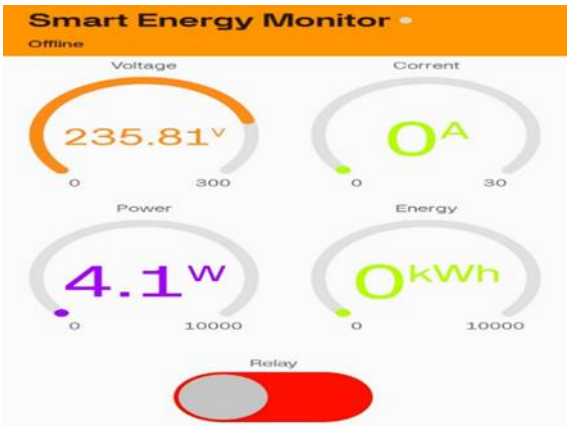


Figure 6. Blynk IoT Display (Normal voltage)

Blynk IoT is used to monitor electrical parameters such as voltage, current, power, and energy consumption through a mobile application. It provides real-time updates and notifications whenever abnormal electrical conditions are detected.

Advanced Data Analytics

The system analyses voltage, current, power and energy consumption. Stored data helps identify abnormal electrical conditions. The dashboard displays real-time readings and historical reports.

Additional Applications

The system can be extended for energy management, load monitoring and fault analysis. Its modular design supports future applications.

Remote Monitoring

Wi-Fi enables remote monitoring through a web dashboard. Telegram notifications alert users during abnormal electrical conditions.

V. CONCLUSION

This paper presents a Raspberry Pi-based Smart Energy Data Acquisition and Automatic Protection System for real-time monitoring of electrical parameters and energy consumption. The system measures voltage and current, calculates power and energy, and displays the readings through an LCD and web-based dashboard. It also provides automatic load disconnection during abnormal electrical conditions and sends fault alerts through Telegram. The stored data helps users analyse energy consumption and monitor electrical loads remotely. Thus, the proposed system improves energy monitoring, electrical safety and user convenience.

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