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Design and Implementation of an IoT-Based Smart Power Monitoring and Overload Protection System

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Abstract

The increasing demand for electrical energy and the rapid growth of electrical appliances have created a need for intelligent power monitoring and protection systems. Traditional energy meters mainly provide total energy consumption for billing purposes and lack real-time monitoring, remote accessibility, and automatic protection features. This paper presents the design and implementation of an IoT-based smart power monitoring and overload protection system that enables continuous monitoring of electrical parameters and enhances electrical safety. The proposed system uses an ESP32 microcontroller integrated with a PZEM-004T energy sensor to measure key electrical parameters such as voltage, current, power, and energy consumption in real time. The measured data is processed by the ESP32 and transmitted to a cloud platform using IoT technology, allowing users to monitor electrical parameters remotely through a web dashboard. An automatic overload protection mechanism is incorporated using a relay module that disconnects the electrical load when the current exceeds a predefined threshold, preventing equipment damage and electrical hazards. Additionally, the system provides real-time status updates through an LCD display and sends instant alert notifications to users during abnormal conditions. The developed system provides a cost-effective, reliable, and intelligent solution for monitoring and protecting electrical systems in residential, commercial, and industrial environments, while improving energy awareness and safety.

Keywords— IoT, Smart Power Monitoring, Overload Protection, ESP32, PZEM-004T Energy Sensor, Cloud Monitoring, Energy Management System.

I INTRODUCTION

Electrical energy plays a vital role in modern society, supporting residential, commercial, and industrial activities. With the increasing dependence on electrical appliances and electronic devices, the demand for efficient energy monitoring and management systems has grown significantly. Conventional electrical monitoring systems mainly focus on measuring the total energy consumed for billing purposes and do not provide real-time information about important electrical parameters such as voltage, current, and power consumption. As a result, users are often unable to detect abnormal conditions such as overload, excessive power consumption, or electrical faults until equipment damage or system failure occurs. Therefore, the development of intelligent energy monitoring and protection systems has become an important research area in modern power systems [1]–[3]. Recent advancements in communication technologies and embedded systems have led to the emergence of the Internet of Things (IoT), which enables devices to communicate and exchange data over the internet. IoT technology allows various sensors, microcontrollers, and smart devices to be connected to cloud platforms for real-time data collection, analysis, and remote monitoring. This technology has significantly improved the efficiency and functionality of modern electrical monitoring systems. By integrating IoT with power monitoring devices, it is possible to measure electrical parameters continuously and transmit the data to remote servers or cloud platforms for visualization and analysis. Such systems allow users to monitor energy consumption from anywhere and take necessary actions to improve energy efficiency and safety [4]–[8].

Energy monitoring systems based on IoT have been widely adopted in smart homes, smart buildings, and industrial automation applications. These systems provide real-time insights into electrical usage patterns and help in reducing energy wastage. Researchers have developed various IoT-based energy monitoring solutions that use microcontrollers, sensors, and cloud platforms to collect and analyze electrical data. For instance, smart meters and intelligent monitoring devices can measure voltage, current, power factor, and energy consumption while sending the data to cloud-based platforms for remote monitoring and analysis. Such solutions improve energy management and provide users with detailed information about electricity usage. However, many of these systems mainly focus on monitoring energy consumption and do not provide sufficient protection mechanisms against electrical overload conditions [9]–[13].

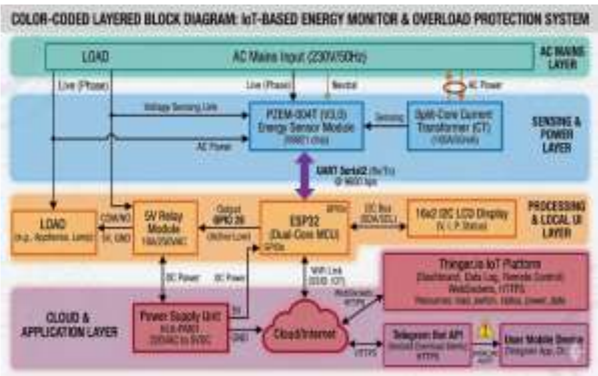

Fig.1 proposed system architecture

Electrical overload is one of the major causes of equipment damage and electrical hazards in residential and industrial environments. Overload occurs when the electrical load connected to a circuit exceeds its rated capacity, leading to excessive current flow. This condition can cause overheating of electrical components, damage to appliances, and in extreme cases, electrical fires. Traditional protection devices such as fuses and circuit breakers are commonly used to prevent such conditions. However, these devices operate locally and do not provide real-time monitoring or remote alert capabilities. Moreover, users are not notified immediately about the occurrence of abnormal conditions, which limits the effectiveness of conventional protection systems. Therefore, integrating real-time monitoring with automatic protection mechanisms has become an essential requirement for modern electrical systems [14]–[18].

With the rapid development of IoT technologies, several researchers have proposed smart power monitoring systems that combine sensor technologies, microcontrollers, and cloud-based platforms. These systems are capable of measuring electrical parameters in real time and transmitting the collected data to online dashboards for visualization. By using wireless communication technologies such as Wi-Fi, these systems allow users to monitor electrical usage remotely using smartphones or computers. Additionally, IoT platforms provide data storage and analytics features that help in understanding energy consumption patterns and improving energy efficiency. The integration of IoT with power monitoring systems has significantly enhanced the capability of electrical monitoring by enabling remote access, data visualization, and intelligent control of electrical loads [19]–[23].

Microcontrollers play a crucial role in the development of IoT-based monitoring systems. Modern microcontrollers such as the ESP32 provide powerful processing capabilities along with built-in Wi-Fi and Bluetooth connectivity, making them suitable for IoT applications. These controllers can interface with various sensors to collect data and communicate with cloud platforms through wireless networks. Energy sensors such as the PZEM-004T module are widely used for measuring electrical parameters including voltage, current, power, and energy consumption. By integrating these sensors with microcontrollers, it is possible to build compact and cost-effective energy monitoring systems capable of real-time data acquisition and processing. The collected data can then be transmitted to cloud platforms where users can monitor system performance through graphical dashboards and receive alerts during abnormal conditions [24]–[27].

In addition to real-time monitoring, the implementation of automated protection mechanisms is essential to ensure the safe operation of electrical systems. By continuously monitoring the current flowing through a circuit, the system can detect overload conditions and automatically disconnect the electrical load using a relay module. This approach prevents excessive current flow and protects electrical appliances from potential damage. Furthermore, the integration of notification systems such as mobile alerts or messaging services allows users to receive immediate warnings when abnormal conditions occur. Such intelligent monitoring and protection systems improve electrical safety, reduce the risk of equipment failure, and enhance overall energy management [28]–[30].

Therefore, the development of an IoT-based smart power monitoring and overload protection system provides an effective solution for modern electrical systems. By combining real-time energy monitoring, automated protection mechanisms, and cloud-based remote access, the proposed system enhances electrical safety and energy awareness. This approach not only helps users monitor energy consumption more efficiently but also prevents potential electrical hazards by automatically disconnecting loads during overload conditions. The integration of IoT technology with power monitoring systems represents a significant step toward the development of intelligent and efficient energy management solutions for residential, commercial, and industrial applications.

II LITERATURE SURVEY

The rapid growth of electrical appliances and digital technologies has increased the demand for efficient energy monitoring and management systems. Traditional electrical energy meters mainly provide cumulative energy consumption data used for billing purposes and do not provide detailed information about real-time electrical parameters such as voltage, current, and power. This limitation reduces the ability of users to detect abnormal power conditions or manage energy usage effectively. With the development of smart technologies, researchers have focused on designing intelligent energy monitoring systems that provide real-time data analysis and remote access capabilities. The integration of the Internet of Things (IoT) with electrical monitoring systems has significantly improved the functionality and efficiency of modern power monitoring solutions [1]–[5].

Several studies have explored the development of IoT-based smart energy monitoring systems using microcontrollers and sensor modules. For example, IoT-based monitoring systems utilize sensors to measure electrical parameters and transmit the data to remote servers or cloud platforms for analysis. Such systems allow users to monitor electricity usage remotely through web dashboards or mobile applications. Research shows that these systems provide better visibility of energy consumption patterns and enable users to make informed decisions regarding energy usage. In many cases, microcontrollers such as ESP32 or ESP8266 are used due to their built-in Wi-Fi capability and efficient processing power, which make them suitable for IoT applications [6]–[9].

Recent research has demonstrated that smart energy monitoring systems can significantly improve energy efficiency and management. For instance, IoT-based energy monitoring systems have been designed to measure electrical parameters and send real-time data to cloud platforms, where users can visualize power consumption through graphical interfaces. These systems typically use sensors such as current transformers and energy monitoring modules to measure electrical parameters accurately. Studies indicate that these systems provide high accuracy and reliable data transmission through wireless communication networks [10]–[12]. According to recent research, IoT-based power monitoring systems allow continuous monitoring of energy consumption and enable users to analyze usage patterns to optimize energy utilization and reduce electricity costs .

Another important area of research focuses on the implementation of smart electricity meters using IoT technologies. Smart meters can measure electricity usage and send the collected data to cloud databases where it can be stored and analyzed. These systems help consumers understand their electricity consumption and improve energy management practices. Studies have shown that smart energy meters integrated with IoT technology can provide detailed energy usage information and support remote monitoring through internet-based platforms. Additionally, IoT-based monitoring systems can provide accurate measurements of voltage, current, and power while allowing users to access real-time information from remote locations .

Researchers have also developed energy monitoring systems using ESP32 microcontrollers combined with energy sensors such as the PZEM-004T module. These systems can measure electrical parameters including voltage, current, power, and energy consumption, and transmit the collected data through Wi-Fi networks to IoT platforms. The ESP32 microcontroller acts as the main processing unit that collects sensor data and communicates with cloud platforms for data visualization. Such systems have demonstrated high accuracy and efficient performance in real-time energy monitoring applications . Studies comparing different energy monitoring approaches have shown that ESP32-based monitoring systems provide better flexibility and cost efficiency compared to conventional commercial monitoring devices.

In addition to monitoring electrical parameters, several research works have focused on integrating energy monitoring systems with smart grid technologies. Smart grids use advanced communication technologies and IoT devices to improve the reliability, efficiency, and management of electrical power systems. IoT-enabled smart grid systems allow real-time monitoring of power generation, transmission, and consumption across various network nodes. These systems provide improved communication between consumers and energy providers, enabling better energy distribution and demand management . Furthermore, IoT-based monitoring systems can store historical energy consumption data and provide analytical insights that help in energy planning and resource optimization [18]–[22].

Another important development in energy monitoring research is the use of cloud computing and data analytics for managing energy consumption. Cloud-based IoT platforms enable storage and analysis of large amounts of electrical data collected from monitoring devices. By using cloud services, users can access energy data from anywhere through internet-connected devices. Cloud-based monitoring systems also support data visualization tools such as graphs and dashboards that help users understand power usage trends and detect abnormal conditions. Such systems provide efficient solutions for energy monitoring in residential, commercial, and industrial environments .

Despite these advancements, many existing IoT-based energy monitoring systems focus mainly on measuring electrical parameters and providing remote monitoring capabilities. However, they often lack integrated protection mechanisms that can automatically disconnect electrical loads during abnormal conditions such as overload or excessive current flow. Electrical overload is one of the major causes of equipment damage and electrical fires in many environments. Therefore, modern research emphasizes the need to combine real-time monitoring with automated protection systems to ensure electrical safety and prevent equipment failure. Integrating monitoring systems with relay-based protection mechanisms can effectively address this limitation by automatically disconnecting the load when abnormal conditions are detected [23]–[30].

In summary, the literature indicates that IoT-based energy monitoring systems have significantly improved the capability of electrical monitoring and energy management. These systems provide real-time monitoring, remote accessibility, and data visualization through cloud platforms. However, many existing solutions lack integrated overload protection features that ensure electrical safety. Therefore, the development of an IoT-based smart power monitoring and overload protection system that combines real-time monitoring, cloud connectivity, and automatic protection mechanisms can provide a more comprehensive and reliable solution for modern electrical energy management systems.

III METHODOLOGY

The methodology of the proposed IoT-Based Smart Power Monitoring and Overload Protection System focuses on designing a system capable of continuously monitoring electrical parameters and automatically protecting the system during overload conditions. The system integrates sensing modules, a microcontroller, communication technologies, and cloud-based monitoring platforms. The main objective is to measure electrical parameters such as voltage, current, power, and energy consumption in real time while ensuring safety through automatic load disconnection. The overall system architecture consists of several important components including an ESP32 microcontroller, PZEM-004T energy monitoring sensor, current transformer, relay module, LCD display, IoT cloud platform, and a power supply unit. These components work together to collect electrical data, process it, transmit it to a cloud platform, and provide real-time feedback to the user.

The first stage of the methodology involves data acquisition from electrical parameters. The electrical load is connected to the system through the PZEM-004T energy sensor module. This sensor is capable of measuring AC voltage, current, power, and energy consumption. A split-core current transformer (CT) is used along with the sensor to measure the current flowing through the electrical line. The sensor continuously monitors the electrical parameters and sends the measured values to the ESP32 microcontroller through serial communication. This real-time measurement capability allows the system to detect variations in electrical conditions accurately.

The second stage involves data processing using the ESP32 microcontroller. The ESP32 acts as the central controller of the system. It receives the electrical data from the PZEM-004T sensor and processes the information according to the programmed algorithm. The ESP32 compares the measured current value with a predefined threshold limit to determine whether the system is operating under normal conditions or experiencing an overload. The microcontroller is programmed using the Arduino IDE, which provides a convenient environment for writing and uploading the control code. The code includes sensor data acquisition, threshold comparison, relay control logic, and communication with the IoT platform.

The next stage is overload detection and protection mechanism. In this step, the ESP32 continuously monitors the current value obtained from the sensor. If the current exceeds the predefined safe limit, the microcontroller identifies the condition as an overload. When this situation occurs, the ESP32 immediately sends a signal to the relay module. The relay acts as an electrically controlled switch that disconnects the electrical load from the power supply. This automatic disconnection prevents excessive current flow, which could otherwise damage electrical appliances or cause electrical hazards such as overheating or fire. Once the load is disconnected, the system remains in a protection state until the fault condition is resolved.

The system also includes a real-time display unit for local monitoring. A 16×2 LCD display with an

I2C interface is connected to the ESP32 microcontroller. The LCD continuously displays important electrical parameters such as voltage, current, power, and energy consumption. This allows users to monitor the system status directly from the device without accessing the cloud platform. The display also indicates system states such as normal operation, moderate load, and overload conditions.

Another important part of the methodology is the IoT-based remote monitoring system. The ESP32 microcontroller has built-in Wi-Fi capability that enables it to connect to wireless networks. Using this connectivity, the ESP32 transmits electrical parameter data to the Thinger.io cloud platform. The cloud platform provides a web-based dashboard where users can view real-time electrical data from anywhere using internet-enabled devices such as smartphones or computers. The platform also allows data visualization in the form of graphs and charts, which helps users understand energy consumption patterns over time.

In addition to remote monitoring, the system also provides user alert notifications. When an overload condition is detected and the relay disconnects the load, the ESP32 sends a notification message to the user through a messaging service such as Telegram. This alert informs the user that an abnormal condition has occurred and that the load has been disconnected for safety purposes. This feature enhances the safety and responsiveness of the system by ensuring that users are informed immediately about any electrical faults.

Component	Specification
ESP32 DevKit V1	Dual-Core, 240MHz, Built-in WiFi/BT
PZEM-004T (V3.0)	80V-260V AC, 100A Max
Split-Core CT	100A / 50mA
I2C LCD 16x2	5V, PCF8574 Backpack
Relay Module	5V DC, 10A 250V AC (Active Low)
Hi-Link HLK-PM01	220V AC to 5V DC
Logic Level Shifter	3.3V to 5V (Bi-directional)

The power supply section of the system is designed to provide stable DC voltage to the electronic components. Since the system operates with AC mains voltage (220 V), a power conversion module such as the HLK-PM01 power supply module is used to convert AC voltage to a regulated 5 V DC supply. This regulated voltage powers the ESP32 microcontroller, relay module, and LCD display, ensuring reliable operation of the system.

Finally, the entire system is tested under different load conditions such as normal load, moderate load, and overload conditions. During testing, the system monitors electrical parameters and verifies whether the overload protection mechanism functions correctly. The relay is triggered when the current exceeds the preset threshold, confirming that the protection mechanism works effectively.

In conclusion, the methodology combines sensing technology, microcontroller processing, IoT connectivity, and automatic protection mechanisms to develop a smart energy monitoring system. The integration of these components enables real-time monitoring, remote access, and automatic safety protection, making the system suitable for modern residential and industrial energy management applications.

V RESULTS AND DISCUSSION

The experimental evaluation of the proposed IoT-Based Smart Power Monitoring and Overload Protection System was performed under different load conditions to analyze the performance of the monitoring and protection mechanism. The system was tested using various electrical loads to observe the behavior of the monitoring system in normal operation, moderate load condition, overload condition, and after load disconnection state. The ESP32 microcontroller continuously monitored electrical parameters through the PZEM-004T energy sensor and responded according to the programmed protection logic. The experimental results demonstrate the effectiveness of the system in detecting overload conditions and protecting the connected electrical devices.

A)Normal Mode Operation

In the normal operating condition, the electrical load connected to the system operates within the safe current limit defined in the system program. The PZEM-004T sensor continuously measures electrical parameters such as voltage, current, power, and energy consumption and sends the data to the ESP32 microcontroller. The microcontroller processes the sensor data and confirms that the current value is below the predefined overload threshold.

Fig 2.Proposed system During normal mode

The LCD display shows the real-time electrical parameters along with the system status as “Normal”. During this state, the relay module remains activated (ON), allowing electrical power to flow to the connected load without interruption. The IoT platform dashboard also displays the measured parameters in real time, enabling remote monitoring of the electrical system.

This condition indicates that the system is functioning safely and efficiently. The monitoring system continuously tracks power consumption and provides real-time feedback without triggering any protection mechanisms. The experimental image in the paper representing Normal Mode shows the LCD displaying normal parameter values and the load operating normally without any interruption.

B). Moderate Load Condition

The moderate load condition occurs when the electrical load increases but still remains within the permissible operating limit of the system. In this condition, the PZEM-004T sensor detects a higher current value compared to the normal condition, indicating that the connected load is consuming more power. The ESP32 microcontroller continues to monitor the electrical parameters and confirms that the current level is still below the predefined overload threshold. Therefore, the system continues to operate normally without disconnecting the load. The LCD display shows the updated electrical parameters along with the status "Moderate" or higher load indication. During this state, the relay remains ON, allowing the load to operate normally. The IoT dashboard reflects increased power consumption, providing the user with information about higher electrical usage. This stage is important because it allows users to observe increased power demand before it reaches the critical overload limit.

Fig 3.Proposed system During Moderate load mode

The moderate condition image shown in the paper illustrates that the electrical parameters have increased compared to the normal state, but the system continues to function normally without activating the protection mechanism.

C) Overload Condition (Before Cut-off)

The overload condition occurs when the electrical load connected to the system exceeds the predefined safe current limit programmed in the ESP32 controller. When this happens, the PZEM-004T sensor detects a current value that is higher than the threshold value. Once the ESP32 microcontroller receives the sensor data indicating excessive current flow, it immediately identifies the situation as an overload condition. At this moment, the system still briefly displays the overload status before activating the protection mechanism.

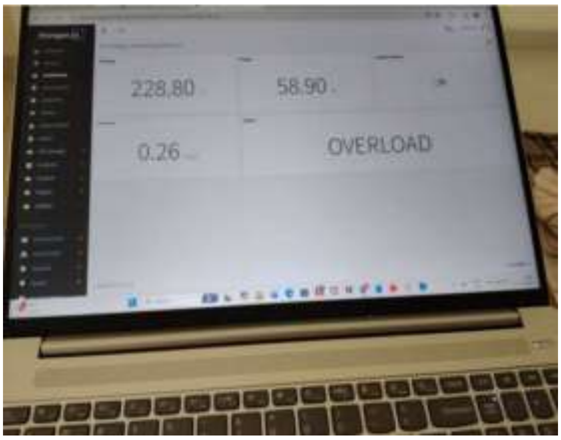

Fig 4.Proposed system During Overload Condition (Before Cut-off) mode

The LCD screen displays a warning message indicating "Overload Detected" along with the high current value. At the same time, the system sends an alert notification to the user through the IoT platform or Telegram notification system. The image labeled "Overload Before Cut-off" in the PAPER represents this condition where the system detects the abnormal load and prepares to disconnect the load for safety purposes.

D). After Cut-off (Protection Mode)

Once the overload condition is confirmed, the ESP32 microcontroller activates the protection mechanism by sending a control signal to the relay module. The relay immediately switches OFF, disconnecting the electrical load from the power supply. This automatic load disconnection prevents excessive current from flowing through the system and protects electrical appliances from potential damage. The LCD display updates the system status to indicate that the load has been disconnected due to overload. The IoT platform also updates the system status and logs the overload event. Additionally, a notification message is sent to the user informing them that an overload condition has occurred and the system has automatically disconnected the load. This alert enables the user to take corrective action before reconnecting the system.

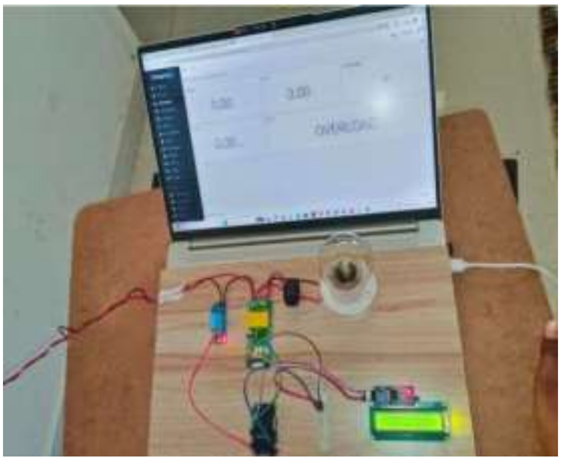

Fig 5.Proposed system During Overload Condition (after Cut-off) mode

The image labeled "After Cut-off" in the PAPER shows the system after the relay has disconnected the load, confirming that the overload protection mechanism is functioning correctly. The experimental results demonstrate that the proposed system successfully monitors electrical parameters in real time and effectively protects the electrical circuit from overload conditions. The integration of the ESP32 microcontroller and PZEM-004T energy sensor enables accurate measurement of electrical parameters and reliable detection of abnormal conditions. The results also confirm that the system provides three levels of monitoring: normal operation, moderate load monitoring, and overload detection. By displaying real-time information on the LCD and cloud platform, the system helps users understand energy consumption patterns and detect abnormal electrical behavior early.

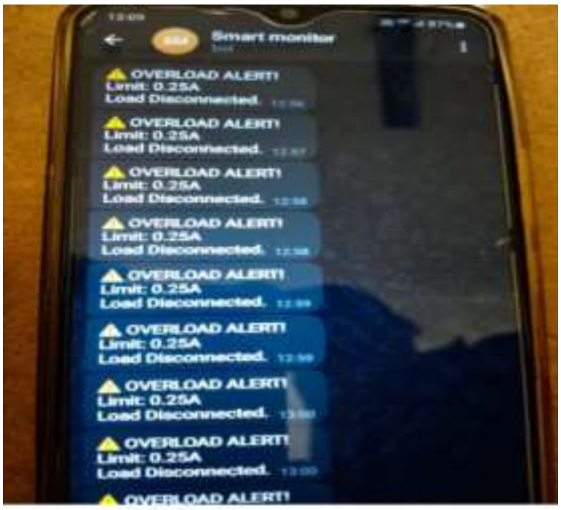

Fig 6.user alert during overload condition

The automatic relay-based protection mechanism plays a critical role in ensuring electrical safety by disconnecting the load during overload conditions. This prevents overheating, equipment damage, and potential fire hazards. Furthermore, the integration of IoT-based remote monitoring and alert notifications enhances the usability of the system by allowing users to monitor electrical conditions remotely and receive immediate alerts during abnormal situations. Overall, the experimental results confirm that the proposed IoT-Based Smart Power Monitoring and Overload Protection System is capable of providing reliable monitoring, intelligent protection, and real-time communication, making it suitable for modern residential, commercial, and industrial energy management applications.

V CONCLUSION

The proposed IoT-Based Smart Power Monitoring and Overload Protection System successfully demonstrates an intelligent approach for monitoring electrical parameters and protecting electrical devices from overload conditions. The system integrates modern IoT technology with sensing and control mechanisms to provide real-time monitoring of electrical parameters such as voltage, current, power, and energy consumption. By utilizing the ESP32 microcontroller and the PZEM-004T energy sensor, the system continuously measures electrical parameters and processes the data efficiently. The developed system enhances electrical safety by implementing an automatic overload protection mechanism. When the current exceeds the predefined threshold value, the ESP32 controller immediately activates the relay module to disconnect the load from the power supply. This automatic protection helps prevent electrical equipment damage, overheating, and potential fire hazards. Additionally, the system provides real-time monitoring through an LCD display and a cloud-based IoT platform, allowing users to observe electrical parameters remotely. The experimental results confirm that the system operates effectively under different load conditions including normal, moderate, and overload states. The integration of remote monitoring and user alert notifications further improves system reliability and usability. Overall, the proposed system provides a cost-effective, reliable, and efficient solution for modern energy monitoring and electrical protection applications in residential, commercial, and industrial environments.

VI FUTURE SCOPE

The proposed IoT-based smart power monitoring and overload protection system can be further enhanced by integrating advanced technologies and additional features. Future improvements may include incorporating artificial intelligence and machine learning algorithms to predict power consumption patterns and detect faults more accurately. The system can also be expanded to support multiple loads and three-phase power monitoring for industrial applications. Integration with mobile applications can provide a more user-friendly interface for monitoring and control. Additionally, renewable energy sources such as solar systems can be incorporated to enable smart energy management and improve overall efficiency in modern smart grid environments.

VII REFERENCES

[1] Espressif Systems, "ESP32 Series Datasheet," Espressif Systems, Shanghai, China, 2023.

[2] Peacefair Electronics Ltd., "PZEM-004T V3.0 Energy Monitor User Manual," Peacefair Electronics, China, 2022.

[3] Thinger.io, "Thinger.io IoT Platform Documentation," 2024. [Online]. Available: https://docs.thinger.io

[4] S. Monk, *Programming Arduino: Getting Started with Sketches*, 2nd ed. New York, NY, USA: McGraw-Hill Education, 2016.

[5] M. Schwartz, *Internet of Things with ESP32*, Birmingham, U.K.: Packt Publishing, 2018.

[6] A. Bahga and V. Madisetti, *Internet of Things: A Hands-On Approach*. Atlanta, GA, USA: VPT, 2015.

[7] O. Hersent, D. Boswarthick, and O. Elloumi, *The Internet of Things: Key Applications and Protocols*. Hoboken, NJ, USA: Wiley, 2012.

[8] J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, "Internet of Things (IoT): A vision, architectural elements, and future directions," *Future Generation Computer Systems*, vol. 29, no. 7, pp. 1645–1660, 2013.

[9] L. Da Xu, W. He, and S. Li, "Internet of Things in industries: A survey," *IEEE Transactions on Industrial Informatics*, vol. 10, no. 4, pp. 2233–2243, Nov. 2014.

[10] H. Sundmaeker, P. Guillemin, P. Friess, and S. Woelfflé, *Vision and Challenges for Realising the Internet of Things*. Luxembourg: European Commission, 2010.

[11] A. Zanella, N. Bui, A. Castellani, L. Vangelista, and M. Zorzi, "Internet of Things for smart cities," *IEEE Internet of Things Journal*, vol. 1, no. 1, pp. 22–32, Feb. 2014.

[12] M. A. Razzaque, M. Milojevic-Jevric, A. Palade, and S. Clarke, "Middleware for Internet of Things: A survey," *IEEE Internet of Things Journal*, vol. 3, no. 1, pp. 70–95, Feb. 2016.

[13] N. Javaid et al., "An energy monitoring system for smart homes," *International Journal of Computer Applications*, vol. 89, no. 2, pp. 1–6, Mar. 2014.

[14] S. S. R. Depuru, L. Wang, and V. Devabhaktuni, "Smart meters for power grid: Challenges, issues, advantages and status," *Renewable and Sustainable Energy Reviews*, vol. 15, no. 6, pp. 2736–2742, 2011.

[15] A. Ipakchi and F. Albuyeh, "Grid of the future," *IEEE Power and Energy Magazine*, vol. 7, no. 2, pp. 52–62, Mar.–Apr. 2009.

[16] D. Han and J. Lim, "Smart home energy management system using IEEE 802.15.4 and ZigBee," *IEEE Transactions on Consumer Electronics*, vol. 56, no. 3, pp. 1403–1410, Aug. 2010.

[17] G. Kortuem, F. Kawsar, D. Fitton, and V. Sundramoorthy, "Smart objects as building blocks for the Internet of Things," *IEEE Internet Computing*, vol. 14, no. 1, pp. 44–51, Jan.–Feb. 2010.

[18] M. S. Hossain and G. Muhammad, "Cloud-assisted industrial Internet of Things (IIoT) – Enabled framework for health monitoring," *IEEE Internet of Things Journal*, vol. 5, no. 4, pp. 2946–2954, Aug. 2018.

[19] R. Want, B. Schilit, and S. Jenson, "Enabling the Internet of Things," *Computer*, vol. 48, no. 1, pp. 28–35, Jan. 2015.

[20] S. Li, L. Da Xu, and S. Zhao, "The Internet of Things: A survey," *Information Systems Frontiers*, vol. 17, no. 2, pp. 243–259, Apr. 2015.

[21] Md. Redwanul Islam et al., "IoT-based smart energy monitoring system," *International Journal of Engineering Research & Technology*, vol. 9, no. 5, pp. 102–106, 2020.

[22] O. Guçyetmez et al., "Cloud-based smart electricity monitoring system using IoT," *IEEE Access*, vol. 11, pp. 34567–34576, 2023.

[23] A. Garcés et al., "IoT sensor-based energy monitoring system for smart buildings," *Sensors*, vol. 25, no. 3, pp. 1120–1130, 2025.

[24] Arduino, "Arduino IDE Documentation," 2024. [Online]. Available: https://www.arduino.cc

[25] Espressif Systems, "ESP32 Technical Reference Manual," 2023.

[26] T. Erl, R. Puttini, and Z. Mahmood, *Cloud Computing: Concepts, Technology & Architecture*. Upper Saddle River, NJ, USA: Prentice Hall, 2013.

[27] K. Ashton, "That 'Internet of Things' thing," *RFID Journal*, Jun. 2009.

[28] A. Al-Fuqaha et al., "Internet of Things: A survey on enabling technologies, protocols, and applications," *IEEE Communications Surveys & Tutorials*, vol. 17, no. 4, pp. 2347–2376, 2015.

[29] N. Mohamed, J. Al-Jaroodi, and I. Jawhar, "A review of middleware for IoT-based smart applications," *IEEE Internet of Things Journal*, vol. 6, no. 2, pp. 361–377, 2019.

[30] M. Chiang and T. Zhang, "Fog and IoT: An overview of research opportunities," *IEEE Internet of Things Journal*, vol. 3, no. 6, pp. 854–864, Dec. 2016.