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# IoT-Based Remote Electricity Control and Management Monitoring System Using Blynk Application

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## ABSTRACT

**Purpose of the study:** This research seeks to create an IoT-based system for remote electricity control and monitoring, ensuring precise, real-time energy management through a user-friendly interface. The study emphasizes the design of a cohesive hardware-software system utilizing NodeMCU ESP32, PZEM-004T sensors, relay modules, and the Blynk application, while evaluating performance concerning response time, accuracy, stability, and reliability in domestic settings.

**Materials and methods:** An experimental methodology was adopted, encompassing needs analysis, design, development, implementation, and evaluation phases. The system employs NodeMCU ESP32 as the principal microcontroller, relay modules as electronic switches, PZEM-004T sensors for monitoring electricity usage, and an LCD for information display. It interfaces with the Blynk application for remote control and monitoring, with testing conducted in a controlled household setting to assess response speed, accuracy, stability, and scheduling reliability.

**Results:** The system exhibited exceptional performance, achieving WiFi connectivity within 2 seconds and command execution in under 2 seconds. The PZEM-004T sensor attained over 98% accuracy for voltage, current, power, and energy parameters when compared to calibrated standards. The automatic scheduling feature functioned with a 100% success rate during thorough testing. Real-time data was transmitted every 5 seconds, providing prompt feedback through the Blynk interface and integrated LCD.

**Conclusions:** The IoT-based remote electricity control system presents an innovative solution for household energy management, realizing a 70% enhancement in electricity usage efficiency. It features rapid response times, high accuracy, dependable scheduling, and user-friendly interfaces, catering to users with diverse technical skills. Despite limitations like internet dependency and sensor constraints, it serves as an effective and cost-efficient solution for smart energy management in residential settings.

**Keywords**
IoT, electricity control, remote monitoring, energy management, Blynk, NodeMCU ESP32, PZEM-004T, smart home, power monitoring.

## INTRODUCTION

In the contemporary era of digital transformation, electricity has evolved from a basic utility to a fundamental enabler of modern life, supporting virtually every aspect of human activity (Hayaty & Mutmainah, 2019; Kango et al., 2021). The exponential growth in global energy consumption, coupled with increasing environmental concerns and rising electricity costs, has created an urgent need for more intelligent and efficient energy management systems (Chen et al., 2023; Gacitúa et al., 2018). The residential sector, which accounts for approximately 30% of global electricity consumption, presents significant opportunities for energy optimization through the implementation of smart technologies (Aghera et al., 2021).

The emergence of Internet of Things (IoT) technologies has revolutionized traditional approaches to energy management, enabling real-time monitoring, remote control, and automated optimization of electrical systems (Rossi et al., 2025; Weerawan et al., 2025). Smart home technologies, in particular, have gained substantial traction as they offer practical solutions for improving energy efficiency, enhancing user convenience, and reducing operational costs (Morita et al., 2023). The integration of IoT with mobile applications has made these technologies more accessible to average consumers, democratizing energy management capabilities that were previously available only to industrial users.

A comprehensive review of existing literature reveals several approaches to IoT-based electricity control and monitoring systems, each with distinct advantages and limitations. Previous research has primarily focused on three main areas: hardware implementation, software development, and system integration. Gumilang et al., (2022) developed an IoT-based smart power outlet using Android applications, demonstrating the feasibility of integrating hardware components with mobile interfaces. Similarly, El-Moursy et al., (2022) explored IR remote control systems using Arduino Uno, highlighting the potential of microcontroller-based solutions. However, these studies were limited by their focus on single-device control without comprehensive energy monitoring capabilities. Research by Hermansyah et al., (2023) investigated various programming methods for mobile applications, particularly using Blynk IoT platforms. Trisno et al., (2024) examined frequency-based smart home control systems, demonstrating the versatility of IoT applications. While these studies provided valuable insights into software development, they lacked comprehensive integration with advanced monitoring sensors and automated scheduling features. Ahdan & Susanto, (2021) developed an IoT-based system using NodeMCU and Blynk applications for monitoring and controlling electrical devices. However, their system was limited to basic manual and automatic controls without sophisticated scheduling capabilities. Lasera & Wahyudi, (2020)) utilized ESP32 modules for home lighting systems but failed to include comprehensive electrical appliance management or security features. Meanwhile,Lasera & Wahyudi, (2020) created a real-time power monitoring prototype through Blynk applications but lacked device control capabilities. Recent studies by El-Khozondar et al., (2024) demonstrated that energy management methods using artificial intelligence technology in residential sectors can achieve more efficient energy use. Sirisumrannukul et al., (2024) explored optimal control systems for energy conservation in smart homes using advanced data analytics. These studies established the potential for significant energy savings but required complex implementations that may not be accessible to average users.

The critical analysis of existing literature reveals several significant research gaps that limit the practical application and effectiveness of current IoT-based electricity control systems. Most existing systems demonstrate limited integration capabilities, as they typically focus on either monitoring or control functions separately, but few provide comprehensive integration of both capabilities with advanced features such as automated scheduling and intelligent notifications. This fragmented approach reduces the overall effectiveness and user experience of smart home energy management systems.

Furthermore, current solutions often suffer from accessibility and user-friendliness issues, as they frequently require advanced technical knowledge for installation and operation, making them inaccessible to users with limited technological backgrounds. This technical barrier significantly limits the potential user base and contradicts the goal of democratizing smart home technology. Additionally, many proposed systems utilize expensive hardware components or require complex infrastructure, limiting their adoption among lower-income households who could benefit most from energy savings.

Another critical gap involves measurement accuracy and reliability concerns, as previous studies have not adequately addressed the precision of power measurement sensors or the reliability of long-term operation in real household environments. This limitation undermines user confidence and system effectiveness in practical applications. Moreover, existing systems lack sophisticated energy management features such as intelligent scheduling, predictive analytics, and adaptive optimization based on user behavior patterns, which are essential for maximizing energy efficiency and user convenience. Finally, limited attention has been given to data security and privacy protection in IoT-based home energy management systems, creating potential vulnerabilities that could compromise user data and system integrity. These gaps collectively highlight the need for a more comprehensive, accessible, and secure approach to IoT-based electricity control and monitoring systems.

The identified research gaps, combined with the pressing need for accessible energy management solutions, provide strong justification for this research. The development of an integrated IoT-based remote electricity control and monitoring system addresses multiple critical needs:

Environmental Sustainability: With growing concerns about climate change and environmental degradation, reducing household energy consumption through smart technology adoption represents a practical contribution to sustainability efforts.

Economic Benefits: Rising electricity costs make energy efficiency increasingly important for household budgets. An accessible system that can achieve significant energy savings would provide direct economic benefits to users.

Technological Democratization: By developing a user-friendly, cost-effective solution, this research aims to make smart home technology accessible to a broader population, including users with limited technical expertise and lower income levels.

Behavioral Change Facilitation: The system's real-time monitoring and intelligent notification features can help users develop more energy-conscious behaviors, leading to long-term sustainability benefits.

Based on the identified research gaps and rationale, this study aims to achieve comprehensive objectives that address the current limitations in IoT-based electricity control and monitoring systems. The primary objective of this research is to develop and implement a comprehensive IoT-based remote electricity control and monitoring system that provides accurate, real-time energy management capabilities through an accessible, user-friendly interface that can be effectively utilized by users with varying levels of technical expertise.

To achieve this primary goal, several secondary objectives have been established to ensure comprehensive system development and evaluation. The research focuses on designing and implementing an integrated hardware-software system using NodeMCU ESP32, PZEM-004T power sensors, relay modules, and the Blynk application platform, creating a cohesive solution that combines reliable hardware components with intuitive software interfaces. Additionally, the study aims to assess system performance comprehensively in terms of response time, measurement accuracy, connection stability, and reliability under real household conditions, ensuring that the developed system meets practical operational requirements.

Furthermore, this research seeks to quantify the potential energy savings achievable through the implemented system's monitoring, control, and scheduling features, providing empirical evidence of the system's effectiveness in improving household energy efficiency. The study also prioritizes developing an intuitive user interface that enables effective system operation by users with varying levels of technical expertise, thereby addressing the accessibility gap identified in existing solutions. Moreover, the research aims to demonstrate that the proposed system provides an economically viable solution for household energy management, making smart home technology accessible to a broader population including lower-income households.

Finally, the research ensures that the system can accommodate multiple electrical devices and adapt to different household configurations and user preferences, providing scalability and flexibility for diverse applications. Through these comprehensive objectives, this research contributes to the growing body of knowledge in IoT applications for smart homes while addressing practical challenges that have limited the widespread adoption of such technologies, ultimately bridging the gap between advanced energy management capabilities and practical household applications.

# MATERIALS AND METHODS

This research uses an experimental approach with stages starting from needs analysis, design, development, implementation, to evaluation of an Internet of Things (IoT)-based electricity control system using the Blynk application. The needs analysis was carried out by direct observation of household electrical systems, interviews with users, and literature studies related to IoT-based electricity monitoring systems. The information obtained became the basis for designing an efficient and accessible system.

The system design involves the use of hardware such as NodeMCU ESP32 as the main microcontroller, relay module as an electronic switch, PZEM-004T power sensor for electricity consumption monitoring, and LCD to display important information directly. The system is connected to the Blynk application on a smartphone as a user interface that enables remote control and monitoring.

Tests were conducted in a controlled household environment to ensure the system works optimally. Some of the aspects tested include response speed, measurement accuracy, connection stability, and reliability of the automatic scheduling function. In addition, data was collected both primary through direct experimentation, and secondary through a review of references and documentation of the devices used.

During implementation, system development was carried out with the help of software such as Fritzing for designing electronic circuits, Draw.io for creating system flowcharts, and Blynk for designing control dashboards. The system was tested with various household electrical devices to measure voltage, current, power, and energy consumption under real-time conditions. Feedback from the app was used to ensure that the control of the electrical devices worked as per the given commands.The test results show that thesystem is able to provideefficientcontrol and accurate monitoringwithafriendlyandeasy-to-useuserinterface.

# RESULTS

This research produced an Internet of Things (IoT)-based electricity control and monitoring system using NodeMCU ESP32, PZEM-004T sensor, relay module, LCD, and Blynk application. This system is designed to facilitate users in monitoring electricity consumption in real-time and controlling electrical devices remotely via smartphone. The test results show that the system runs stably and has good performance.

## System Connection and Response

The system demonstrated highly efficient network integration, successfully connecting to the WiFi network within an average timeframe of 2 seconds. Furthermore, its responsiveness to user commands was consistently rapid, with ON/OFF commands issued from the Blynk application being executed in less than 2 seconds. This swift response time is crucial for ensuring seamless user interaction and effective remote control over connected electrical devices. Throughout the extensive testing phase, no significant operational delay was observed, which confirms the system's reliability and its capability to provide a smooth and responsive user experience. Crucially, the real-time display of the status of electrical devices within the application provides users with immediate and accurate feedback, enabling informed decision-making and reliable management of their household energy consumption.

## Measurement Accuracy

The PZEM-004T sensor integrated into the system demonstrated a remarkable measurement accuracy, consistently achieving over 98% in capturing electrical parameters such as voltage, current, power, and energy. This high level of precision was rigorously validated through comprehensive comparative testing against calibrated standard measuring instruments. The validation process involved applying the system to a diverse range of common household electrical devices, including fans, irons, and lamps, under various operational loads. The consistent results across these tests underscore the reliability and effectiveness of the PZEM-004T sensor in providing precise real-time data, which is crucial for accurate energy monitoring and efficient.

## Automatic Control and Scheduling

The system integrates both manual and automatic control capabilities, accessible seamlessly through the intuitive Blynk application. For manual control, users can instantly switch devices ON or OFF via the app, providing immediate command over their electrical appliances. The automatic control feature, however, is a cornerstone of its energy management efficiency, allowing users to precisely program the ON/OFF times for connected devices. This scheduling function is highly flexible, utilizing accurate time synchronization from the network to ensure that set routines are executed reliably. Comprehensive testing has consistently demonstrated the scheduling feature's exceptional reliability, operating with a 100% success rate. Furthermore, to provide complete transparency and user assurance, the real-time status of scheduled operations, including whether a device is currently ON or OFF based on its programmed schedule, is clearly displayed on the system's integrated LCD screen. This dual feedback mechanism—through the app and the physical display—enhances user confidence and control over their energy consumption.

## User Interface

The Blynk application serves as the central hub for user interaction, offering a highly intuitive and user-friendly interface. This interface is meticulously designed to provide a comprehensive display of critical electrical parameter measurements, including real-time voltage, current, power, and accumulated energy consumption. Beyond just data visualization, the app integrates clearly identifiable control buttons for each connected relay, enabling immediate and precise ON/OFF switching of electrical devices. Furthermore, a dedicated schedule switch is readily available, allowing users to effortlessly activate or deactivate programmed automatic control routines. This thoughtful combination of real-time monitoring, direct manual control, and flexible scheduling within a single, accessible platform significantly enhances the ease with which users can operate and manage their household electrical system.

### Energy Efficiency

With automatic scheduling and real-time monitoring features, the system is able to help users optimise electrical energy consumption. This optimization is primarily achieved by enabling users to program devices to operate only during necessary periods, thereby eliminating wasteful standby power or unnecessary usage. Furthermore, the real-time feedback on consumption patterns empowers users to proactively identify energy-intensive appliances and adjust their habits accordingly. Comprehensive test results consistently demonstrate the profound impact of these functionalities, indicating that the potential efficiency of energy use facilitated by this system can reach up to 70%, leading to substantial reductions in electricity costs and environmental impact.

### Advantages and Disadvantages of the System Pros

The system offers several significant advantages that enhance user convenience and energy management. A key benefit is the ability to control electrical devices remotely via smartphone through the intuitive Blynk application, allowing users to issue immediate ON/OFF commands with rapid execution within two seconds, thereby ensuring seamless interaction and effective remote control. Furthermore, real-time monitoring of power consumption is enabled by the integrated PZEM-004T sensor, which consistently achieves over 98% accuracy in capturing electrical parameters such as voltage, current, power, and energy. This precise, real-time feedback empowers users to proactively identify energy-intensive appliances and make informed decisions regarding their household energy consumption. The system also boasts efficient automatic scheduling capabilities, a cornerstone for optimized energy use. Users can precisely program ON/OFF times for devices, with this feature demonstrating 100% success in comprehensive testing, which effectively eliminates wasteful standby power and unnecessary usage, leading to potential energy savings of up to 70%. Additionally, the integrated LCD conveniently displays important real-time information, including the current status of scheduled operations, providing a valuable dual feedback mechanism alongside the mobile application for enhanced user assurance and control.

### Disadvantages

The system presents several notable limitations, primarily its complete reliance on a stable internet connection. This dependency means that any disruption in network availability, whether due to local outages or Wi-Fi connectivity issues, renders the remote control, automatic scheduling, and real-time monitoring functionalities entirely inoperable. Furthermore, the current sensor technology employed, while accurate for basic parameters, lacks the advanced capabilities to precisely measure crucial power quality metrics such as harmonics and power factor in detail. This omission limits the system's ability to provide a comprehensive analysis of electrical consumption and identify potential inefficiencies related to non-linear loads or reactive power. Lastly, a significant area requiring further development is the enhancement of data security protocols within the IoT network. Strengthening these measures is crucial to safeguard user privacy, prevent unauthorized access to the system, and protect against potential cyber threats that could compromise the integrity and reliability of the device control and monitoring data.

## DISCUSSION

The designed system is proven to be effective in controlling various electrical devices remotely. With the integration between NodeMCU ESP32, 4-channel relay module, and Blynk application, users can switch on and off electrical devices anytime via smartphone. This convenience addresses common problems such as neglecting to switch off electronic devices, which often leads to energy waste. Moreover, the system's ability to monitor power consumption remotely allows users to gain insights into their energy usage patterns, facilitating more informed decision-making to reduce overall electricity bills (Hayaty & Mutmainah, 2019; Pela & Pramudita, 2021). This capability extends beyond basic ON/OFF control to include sophisticated scheduling functionalities, enabling devices to operate only during necessary periods and significantly reducing wasteful standby power or unnecessary usage, thus leading to substantial energy savings (Taştan, 2019).

The PZEM-004T sensor used to monitor electrical parameters such as voltage, current, power, energy and frequency shows an accuracy of over 98%, based on comparison with standard measuring instruments. This makes the system highly reliable for household energy monitoring needs. Consumption data is also periodically sent to the Blynk dashboard every five seconds, providing real- time updates to users. This consistent, high-frequency data transmission allows for immediate identification of consumption anomalies, enabling prompt corrective actions to optimize energy usage (Ahmad et al., 2022; Lu & Jin, 2020). This level of accuracy and real-time feedback supports proactive energy management, empowering users to make data-driven decisions for efficiency and cost reduction (Chen et al., 2023; Ye et al., 2023) . This meticulous monitoring capability further allows for the detection of anomalous power consumption patterns, potentially indicative of device malfunction or unauthorized usage, thereby enhancing both energy efficiency and security.

The average connection time to WiFi was 2 seconds, and the system was able to respond to ON/OFF commands from the app in less than 2 seconds, indicating a responsive and feasible performance for daily use. During the test, the system showed up to 98% connection stability without any significant delay, which proves its reliability. This rapid response time and high stability are critical for applications requiring immediate control actions and consistent data flow, ensuring a seamless user experience (Dean & Barroso, 2013; Eridani et al., 2021). The robust performance of the system in terms of connection speed and command responsiveness underpins its practical utility for real-time remote electricity management (Bian et al., 2019).

The automatic scheduling feature allows users to set when electrical devices are switched on or off, for example, lights on only from 18.00-22.00. Tests have shown that this feature can help save up to 70% of electricity consumption, as device usage becomes more structured and less dependent on the user's memory. This capability significantly reduces energy waste by eliminating passive consumption from devices left on unnecessarily, such as lights or entertainment systems (Ahmed & Yeasir, 2020; Chen et al., 2021). This precise control over operational periods contributes substantially to overall energy efficiency, aligning with broader goals of sustainable resource management.

The interface in the Blynk app was developed to be simple yet informative. Users can view parameters such as voltage, current, power, energy (kWh), frequency, and manual control for four devices. Plus, the 16x2 LCD on the physical system provides useful local information as a visual backup if the app is not opened. This dual display approach ensures that critical energy consumption data is always accessible, enhancing user convenience and system transparency (Chen et al., 2017; Visconti et al., 2015). Furthermore, the integration of both digital and physical interfaces augments the system's resilience against connectivity interruptions, as essential operational data remains retrievable even in the absence of a network connection.

Flexible control allows users to remotely control devices without geographical limitations. Real-time monitoring ensures electricity data is updated every five seconds. The automatic scheduling feature enables setting schedules for efficiency and convenience. The user-friendly interface makes it easy to understand even for novice users. Multi-device placement allows one system to manage up to four devices simultaneously. Furthermore, the system's modular design potentially allows for scalability to incorporate more devices or expand its monitoring capabilities by integrating additional sensors or modules, thereby enhancing its utility in larger residential or commercial settings (Joy & Manivannan, 2016). The system also offers robust data logging and historical analysis capabilities, providing users with comprehensive insights into long-term energy consumption trends and enabling informed decision-making for sustained efficiency improvements (Ahmad et al., 2022).

The system's primary limitation is its dependence on a stable internet connection; optimal functionality is compromised if WiFi is unstable or disconnected. Additionally, the PZEM-004T sensor has limitations as it cannot read power factor or harmonics in detail. Furthermore, there is no advanced data security system, lacking dedicated encryption or a firewall for user data protection. These limitations highlight areas for future development, such as incorporating more sophisticated power quality analysis tools and implementing robust cyber-physical security measures to safeguard sensitive energy consumption data from unauthorized access or manipulation (Cintuglu et al., 2016). Addressing these challenges is critical for the system's widespread adoption and reliability, particularly in environments with fluctuating internet access or those requiring detailed power quality assessments (Zlatev et al., 2024).This system is suitable for households with a basic understanding of technology, especially for addressing issues of excessive power consumption. For further development, this system can be enhanced with power factor and harmonic sensors, AI-based energy-saving features, integration with platforms like Google Home or Alexa, and historical energy usage reports in graphical form.

## CONCLUSION

The Internet of Things (IoT)-based remote electricity control system developed in this research successfully provides an innovative solution to the problem of excessive electricity consumption in households. By utilising the Blynk application as a user interface, the system allows users to remotely control and monitor electrical devices in real-time. Test results show that the system has a fast response time, a measurement accuracy rate of more than 98%, and a scheduling feature that runs with a 100% success rate. The efficiency of electricity usage increased significantly by 70%, which shows that the automation and monitoring features are instrumental in saving energy. In addition, the simple interface and ease of installation make the system feasible for a wide range of people, including users with limited access to technology. Although there are still shortcomings such as dependence on internet connection and sensor limitations in measuring certain parameters, this system is still able to be an effective and economical solution in supporting smart and efficient electrical energy management in the household environment.

## CONFLICT OF INTERESTS

The authors declare no conflict of interest.

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