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IoT Based Smart Power and Load Management System

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Abstract— **The escalating electricity demand in Pakistan and other developing nations presents significant challenges for distribution systems. To address this issue, utilities often resort to load shedding practices. However, despite urging consumers to reduce their load during peak hours through monthly bill notifications, compliance remains low due to either unwillingness or lack of awareness. The manual process of reminding consumers about peak hours and manually managing high loads during peak and off-peak periods is both inconvenient and laborious. In response to these challenges, this study focuses on implementing a time-controlled automated load management system. The primary objective is to enable automatic switching ON/OFF of various consumer loads at specific intervals. This system eliminates the need for manual load switching based on time, while also providing control and monitoring capabilities for electrical devices using the Internet of Things (IoT) concept. The implementation utilizes an ESP-32 device based on the Blynk framework, integrating sensors and smartphones to create a functional prototype. Through the Blynk framework-installed smartphones, users can interact with the system's server, which responds to their requests. Our development efforts have resulted in an IoT-based load management system, empowering users to utilize their electrical load at full capacity during normal hours. However, during peak hours, load consumption is automatically restricted through IoT technology. The IoT application facilitates wireless monitoring and control of the load, enhancing convenience and efficiency.**

Index Terms— **Load Management, IoT, Smart Power**

I. Introduction

THE power generation, management, and control systems in Pakistan are predominantly outdated, lacking proper load management capabilities. Furthermore, the current peak hour system proves to be ineffective. Implementing a comprehensive smart grid system would be highly beneficial in addressing these challenges by effectively managing electricity theft, minimizing power loss, and controlling other associated losses. Pakistan's energy requirements are increasing, placing mounting pressure on energy resources and distribution networks [1]. Pakistan's energy sector is facing a crisis due to inadequate energy production to meet growing demand [2]. Factors such as debt recycling, financial conditions, and limited energy supplies contribute to this problem. The reliance on natural gas and oil as the primary energy sources, with over 80% dependency, exacerbates the issue. Insufficient production from hydroelectric and coal resources leads to energy shortages and inadequate electricity generation [3]. Power theft poses a significant challenge in Pakistan, leading to substantial financial losses in the power sector. Distribution companies (DISCOs) conduct regular inspections to detect illegal connections visually. However, tracking the methods used for theft is difficult due to the various techniques employed. Estimates suggest that power theft costs Pakistan billions to tens of billions of dollars annually [4]. This large-scale theft, coupled with energy shortages and default on payment of electricity bills, contributes to the ongoing crisis in the power sector. Resolving these issues is crucial for bringing about a visible change in the sector [5]. In [6] their study, presented a system that utilizes IoT technology, specifically the implementation of a Wi-Fi module ESP01, to establish a connection between users and the utility. This system effectively restricts the load that an individual user can connect, resulting in a limitation of the overall connected load for a larger area. By enabling users to operate essential loads during load shedding, this approach successfully mitigates the potential discomfort caused by complete power cuts. In [7] a study conducted on an innovative approach was proposed to directly prevent electricity theft from the distribution line by maintaining a low frequency. The system adjusts the frequency of electricity to a range between 6Hz and 7Hz on the distribution side. At the consumer end, an authorized meter is utilized to convert the frequency back to the standard 50Hz. Many other researches also used Wi-Fi, Li-Fi or light based solution for different healthcare and biomedical applications [8, 9]. In [10] the researchers argues that electrical shortages in Pakistan are the primary cause of the country's socioeconomic failure. He attributes these shortages to institutional and governance shortcomings and suggests the need for a better policy to resolve the energy crisis. The researchers in [11] used the ARIMA model to predict electricity consumption in Pakistan, considering seasonal temperature variations until 2020. Their findings indicate that as temperature rises, electricity consumption also increases, with the highest demand of 6785.6 GWh expected in July 2020. In [12] assessed Pakistan's current energy scenario, examining various aspects such as supplies, consumption, reserves, power generation, and demand-supply dynamics. They concluded that conventional resources are insufficient to meet the rising energy demands and advocated for the adoption of renewable energy solutions. Researcher proposed in [13] several strategies to address energy shortfalls, including analysing the impact of energy imports on bridging the supply-demand gap. They also discussed planned projects like gas pipelines and LNG imports, emphasizing the need for infrastructure development based on renewable energy sources. In [14] the scientist provided a comprehensive overview of Pakistan's energy industry, covering its history, achievements, energy reserves, electricity generation/consumption, and renewable energy potential. They highlighted the reasons behind the energy crisis and explored potential solutions. The researchers in [15] conducted a study on the benchmarking and regulation of electricity distribution businesses in Pakistan. Using stochastic frontier analysis, they estimated the cost effectiveness and efficiency of government-owned power distribution corporations. Their findings revealed an average efficiency of 72.5 percent in this sector, highlighting the urgent need for action to reduce losses and improve service quality. The study in [16] employed Holt-Winter and Auto regressive Integrated Moving Average (ARIMA) models to predict power consumption by sector. They concluded that without adequate measures, the gap between electricity supply and demand will continue to widen. Their findings suggested that the residential sector would eventually have the highest demand. They proposed ideas to address the supply-demand gap permanently.

II. Research Gap

One notable research gap in Pakistan's energy sector pertains to the absence of comprehensive and efficient load management capabilities. As the demand for electricity continues to rise, the existing system for managing peak hour loads proves inadequate. The manual process of load switching based on time is burdensome and inconvenient, and compliance with load reduction during peak hours remains low due to unwillingness or lack of awareness among consumers. Introducing an IoT-based automated load management system holds great potential for overcoming these challenges and reducing power loss, energy theft, and associated losses. However, there exists a research gap concerning the evaluation of the effectiveness and feasibility of implementing such a system within the specific context of Pakistan. Further investigation is necessary to explore the viability and potential benefits of an IoT-based load management solution tailored to the country's energy landscape. Additionally, real time data processing of data also requires a processing system. Many real time applications-based systems have utilized signal processing techniques [17-20], parallel programming systems [21-23], supercomputers [24], or Field Programable Gate arrays [25-27]. However, due to utilization of these high-end systems, overall cost also increases [28]. Therefore, it is also important to propose low-cost system by utilizing low-cost control logic.

III. Our Contribution

- The implementation of an IoT-based time-controlled automated load management system that enables automatic switching ON/OFF various consumer loads at specific intervals.
- The proposal of a system that eliminates the need for manual load switching, while also providing control and monitoring capabilities for electrical devices using the Blynk framework.
- The development of a functional prototype of the system using an ESP-32 device based on the Blynk framework.
- The integration of sensors and smartphones to create an IoT-based load management system, enabling users to control and monitor their electrical loads at full capacity during normal hours, while automatically restricting load consumption during peak hours through IoT technology.
- The enhancement of communication and efficient management of demand and supply using the GSM module, which sends notifications to consumers' mobile phones regarding the specific timing of peak hours and potential overloading conditions.
- The provision of a user-friendly interface for controlling device loads and monitoring system status through the Blynk Application, which allows for seamless control over ESP-32 devices via the Internet.

IV. Methodology

Proposed methodology for implementing an IoT-based remote access load management system:

- The SP&LMS (Smart Power and Load Management System) was designed using various components including sensors, ESP-32, GSM Module, and the Blynk framework.
- A prototype of the system was developed, with the peak time set to 3 minutes and a watt threshold of less than 26 watts.
- The functionality of the Arduino Nano and ESP32 is contingent upon meeting these two conditions.
- The system includes four light bulbs, each consuming 12 watts of power.
- During peak times, the ZMCT103C current sensor measures the current value, while the 10-bit ZMPT101b voltage sensor measures the voltage in the circuit.
- The overall load operates below the threshold level during peak times.
- If the load exceeds the 26-watt threshold, an alarm notification is generated in the Blynk application, as well as an SMS notification via GSM.

- In response, Blynk automatically shuts off both the excessive load and restores the necessary load to normal operating conditions.
- The LCD screen continuously displays the voltage and power values connected to the Arduino Nano.
- Once connected to the Internet, the system owner can conveniently control and monitor the load status using a smartphone equipped with the Blynk application.
- Figure 1 shows the flow chart of the proposed study.

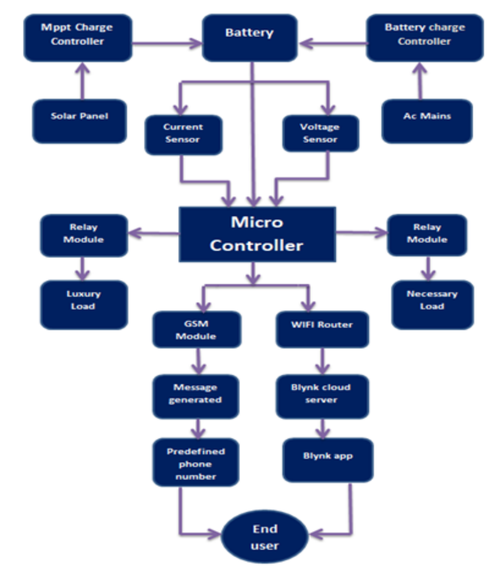

Figure 1. Flow chart of the proposed control scheme

V. Results and Discussion

A. Simulation

The proposed system offers a consumer-end installation solution that operates using renewable energy sources such as solar and wind, in conjunction with a battery backup. It incorporates an automatic power cutoff mechanism from the utility during peak hours to optimize energy usage. A current sensor serves as a continuous load current detection device. Figure 3 shows the proteus model of the proposed study. As peak hours commence and the load current surpasses the predefined range from the threshold level, the microcontroller (ESP-32) triggers a trip signal to the Blynk Application. This signal, in turn, deactivates the relay-connected heavy loads. During off-peak hours, the system generates notifications via Blynk and sends SMS alerts through GSM if a consumer intends to utilize heavy loads within this timeframe. This approach aids in demand and supply management, minimizing load shedding during peak hours. Furthermore, it facilitates low-cost tariffs for consumers and encourages the utilization of heavy loads during off-peak hours without disrupting power during high-cost tariff periods, supported by the usage time counter control integration.

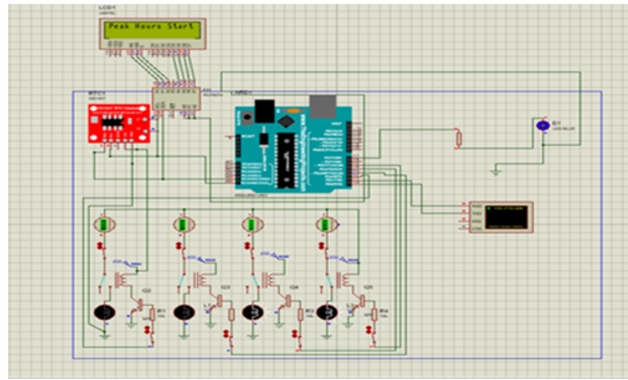

Figure 3. Proteus design of SLM device

The software development for this project is centered around an Android application, as the system operates based on IoT principles and wireless control. The chosen platform for control and monitoring purposes is the Blynk application, which serves as an IoT platform for iOS and Android smartphones, allowing seamless control over Arduino, Raspberry Pi, and ESP-32 devices via the Internet. Figure 4 shows the Blynk Framework.

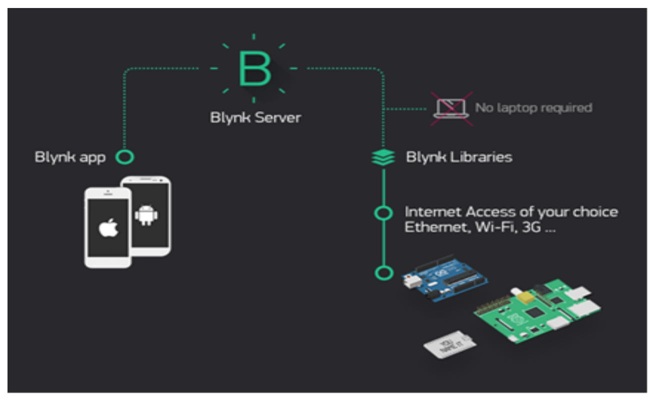

Figure 4. Illustrated Blynk Framework

The Blynk framework comprises three key components. Firstly, the Blynk App provides a user-friendly interface for creating visually appealing and functional interfaces for project control, utilizing a wide range of available widgets.

As shown in Figure 5 the Notifications generated at the beginning of Peak hours.

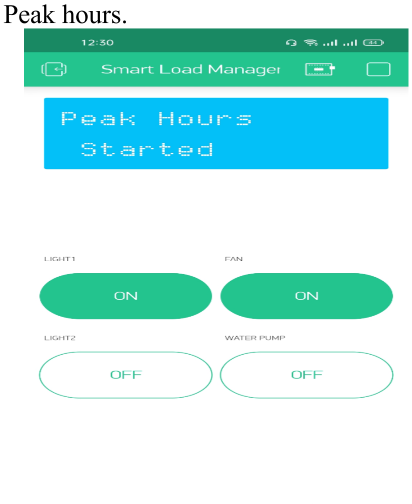

Figure 5. Blynk App User Interface

Secondly, the Blynk Server plays a crucial role in facilitating communication between the smartphone and the connected hardware. Users have the option to utilize the Blynk Cloud service or set up their private Blynk server locally. The open-source nature of the server allows it to handle many devices effortlessly, and it can even be deployed on a Raspberry Pi.

Lastly, the Blynk Libraries serve as a vital link enabling seamless communication between the server and a variety of popular hardware platforms. These libraries process incoming and outgoing commands, ensuring effective interaction between the smartphone and the hardware.

The GSM module serves a crucial role in this project by enabling the system to send notifications to consumers' mobile phones. It is utilized to signal the beginning and end of peak hours, allowing customers to be informed about the specific timing of these periods. Additionally, the GSM module is responsible for sending messages in the event of an overloading condition, providing timely warnings to the consumers as shown in Figure 6 and 7. This feature ensures that users are aware of any potential issues related to excessive load and allows them to take appropriate actions. By leveraging the capabilities of the GSM module, the system enhances communication and keeps customers well-informed about the operational status and conditions of their power usage.

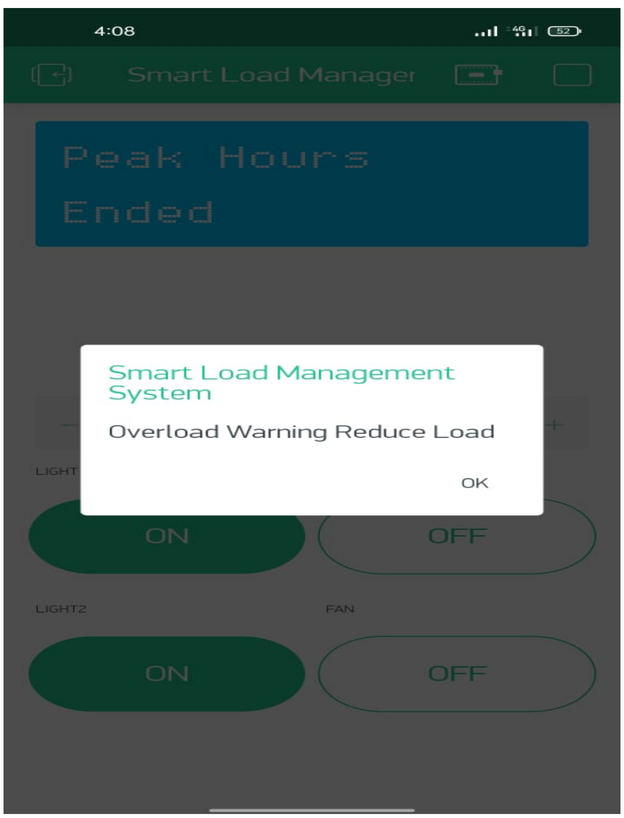

Figure 6. Overload Warning

Overall, the integration of the Blynk framework and the GSM module enhances the functionality and usability of the system, ensuring smooth wireless control and effective communication with the end users.

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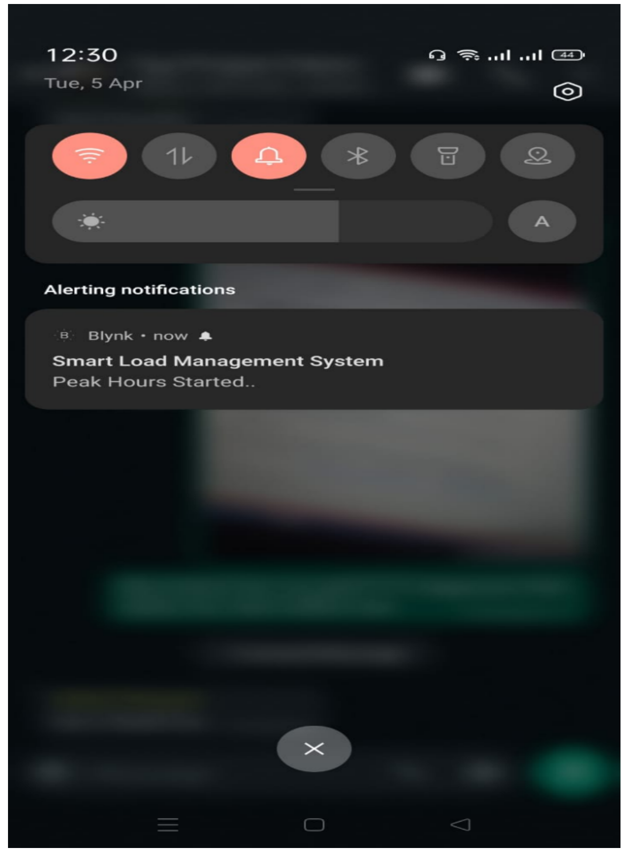

Figure 7. Peak Hour started message

B. Hardware Developed

A prototype load management system was developed and tested in a project-based scenario using three current sensors to measure the load currents of various types, including lighting, essential, and general loads. To ensure safe and practical performance, small current values were utilized for implementation, testing, and evaluation. The experiment involved connecting four 48W lamps to represent different load scenarios. During off-peak hours, these lamps could be turned on and off as desired. However, during peak hours, the usage of load was restricted to a specific limit. For testing the proposed design, a total limit of 26W was set. The LCD screen displayed the following outputs under different conditions.

Initially, the Blynk app received input, but no load was connected to the system. Subsequently, three lamps were connected to represent light, essential, and luxury loads, each drawing 100W of power. The load readings for these different load types are depicted in Figure 8.

After a certain time, interval, the ESP32 microcontroller sent an SMS notification to the user, requesting them to reduce the load within the limit as the peak time was about to begin. Another notification was sent 30 seconds later, informing the user that the peak time had started, and they should ensure their load remains within the limit to avoid a power outage.

These observations and notifications demonstrate the functionality and effectiveness of the load management system in regulating power consumption during peak and off-peak hours. The LCD screen and notifications serve as important visual and communicative elements in conveying the system status to the user.

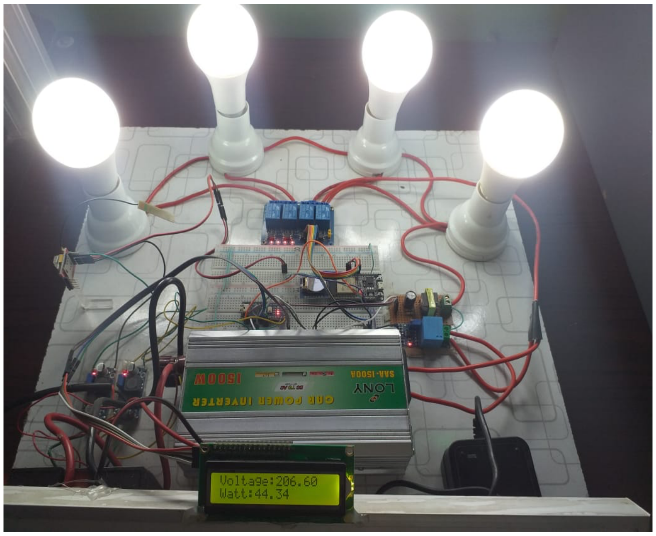

Figure 8. Hardware picture

When off-peak hours commence, the Arduino Nano triggers a signal to the connected LCD, indicating the end of the peak hour period. Simultaneously, the ESP-32 sends a signal to the mobile application, notifying users that the peak hour has concluded, and they are free to operate their devices according to their preferences. This approach encourages consumers to utilize heavy equipment during off-peak hours, thereby enabling utilities to achieve a balanced supply and demand during summer periods. Importantly, the control strategy ensures that devices are not switched off during off-peak hours, promoting uninterrupted usage and convenience for users.

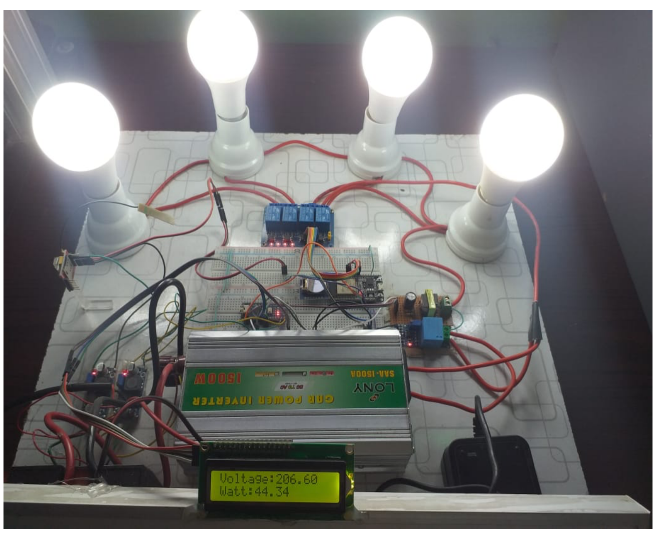

Figure 9. Hardware picture of project during off peak hours

The peak hour time is determined based on the current ongoing time, while the remaining duration is considered as the off-peak time. The system operates using renewable energy sources (solar and wind) in conjunction with a battery backup. To alert the user, notifications are generated at the beginning and end of the peak hour through the Blynk Application, and SMS notifications are also sent via GSM. When the peak hour starts, the luxury load is automatically shut down, and the other loads operate within the permissible limit of 26 watts. If a consumer exceeds this limit, an overloading SMS and notification will be generated, notifying the user about the excessive load.

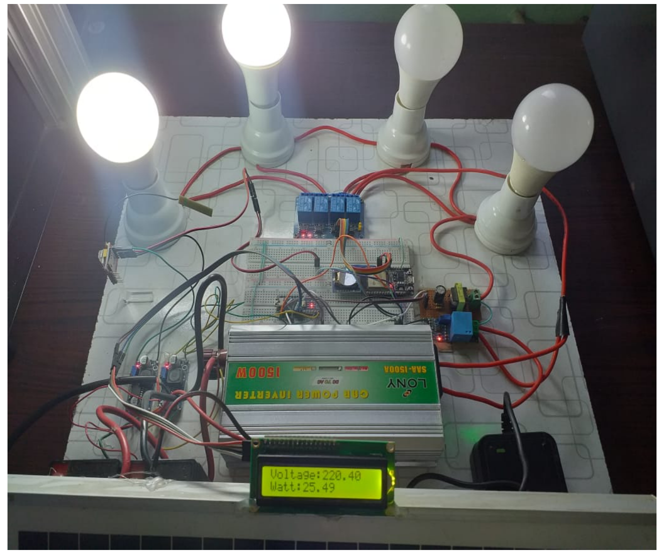

Figure 10. Hardware picture of project during peak hours

VI. Conclusion

The energy crisis in Pakistan has severe implications for socio-economic development. It requires innovative solutions and proactive policies to implement renewable energy sources and curb theft and default in payment of electricity bills. The proposed IoT-based time controlled automated load management system is an effective solution to manage power consumption during peak and off-peak hours. The integration of ESP-32, Blynk application, and GSM module enables wireless communication, automatic load switching, and effective monitoring and control of the system. Additionally, the system offers notifications to inform users about peak hours and potential overloading conditions, enhancing communication, and keeping users well-informed about their power usage. The prototype tested with three different types of loads showed effective load management during peak hours.

For future work, the study proposes integrating renewable energy sources, such as solar panels or wind turbines, to power the load management system. This will enable sustainable energy consumption and promote environmental conservation.

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