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IoT enabled implementation of a smart energy management system for real-time monitoring and controlling

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Abstract The Pakistan power system faces a severe energy deficiency due to population growth. The Pakistan power system structure necessitates a smart load management system to address the mismanagement of load distribution that results in load shedding. A continuous power supply is essential for industrial and domestic sectors to enhance Pakistan's economy. Imported fuel presents a significant economic challenge in Pakistan. This system is designed to control and monitor load management utilizing Internet of Things (IoT)-based technology. The implementation of an IoT-based approach enhances system performance by upgrading conventional load management. This study analyzed effective energy management during peak hours. This system employs a smart energy management system to improve load shedding patterns. The system components include a power monitoring module, current sensor, transformer, Wi-Fi module, and relay module integrated with an Arduino-based microcontroller for monitoring and controlling load management. To model a virtual analysis a simulation based circuit diagram is design using Proteus Software. The implementation of this study improves energy transactions between utilities and consumers. In this study, a prototype was designed and implemented using Arduino, and sensors were employed to control and observe a smart load management system. This system utilizes a hypertext preprocessor for login webpage arrangement for IoT control and monitoring. The results indicate that the cumulative analysis for the implementation of this system automatically deactivates unnecessary loads during peak hours. This system can conserve energy during peak-hour intervals. The load parameters for current, voltage, and power were displayed on the LCD screen. The system automatically deactivates the load during harmonics in the power supply until normal conditions are restored. As compared to existing studies this system detects and switch the system during on and off peak hours without any human interaction.

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1 Introduction

The Artificial Intelligence help system to efficiently minimize the energy wastage, integration of smart grid with artificial intelligence is the innovative technology. This study analyzes the enhancement of energy with effective utilization. To employed this Artificial Intelligence based system use LSTM model to achieved the lowest Mean Absolute Error (MAE) with 0.1335 and Mean Squared Error (MSE) of 0.0497 [1]. A continuous supply of power without interruption plays a vital role in the country's economy. The smart distribution, control, and management of power generation are global requirements for implementing smart grid technology in power systems. A sustainable approach is required for implementation in a load management system. In this study, an energy model was designed using machine learning and the Internet of Things. The result elaborates the demand-side management parameters for controlling the load strategy [2].

Efficient energy management is one of the biggest challenges facing developing nations. Owing to the dense increase in population, there is a need to implement innovative technologies for energy security purposes. Conventional power systems need to be more advanced with IoT-based smart meter systems. The implementation of this advanced metering technology communicates between energy utilities and customers during the power transfer process. This system is a combination of two technologies: the Internet of Things and Artificial Intelligence. This study indicates that IoT- and AI-based smart meters are required for load management and load forecasting. As per consumer requirements, this study modeled the optimum solution for energy distribution using MATLAB [3]. This study is utilized to model and implement IoT-based energy observation and theft recognition using an Arduino microcontroller.

The microcontroller was centrally integrated with voltage and current sensors to monitor the load parameters. The primary purpose of implementing this innovative technology is to provide real-time parameters. This system can detect tempering by an unusual increase in current and voltage. On observing tempering automatically, a message refers to the relevant utility. The utilization of this technology enhances system stability and consumption calculations. The integration of the Arduino node MCU enables effective utilization to save energy for sustainable solutions [4].

Generation, transmission, distribution, and utilization are the main components of electrical power systems. Inefficiencies and load mismanagement are the main challenges in power systems. To overcome this problem, this project was designed for automatic load management between the main and standby transformers, using Arduino microcontrollers. This prototype was developed to enhance transformer performance, manage overloading, and ensure continual power supply. The method utilized in this study involves the integration of sensors with a microcontroller. This study facilitates IoT-based finding of irregular load conditions. When overloading is determined on the main transformer, the Arduino initiates a standby transformer to manage the load and reduce the thermal pressure on the device. The results of this study ensure reliable power distribution, and this system can increase the lifetime of transformers [5]. This study is related to a home automated system utilizing an Arduino Nano microcontroller integrated with Bluetooth devices to remotely manage house devices. This system can control different devices by automatically switching and observing the water level within a 130 m range using a web application. This technology is inspired by Internet of Things (IoT)-based technologies for controlling mechanisms via mobile applications. The sensors are employed in home applications to remotely switch equipment [6].

Global energy consumption is growing both domestically and industrially. The number of sustainable solar systems is increasing on the housing roofs of Dhaka, Bangladesh. Residential systems use light loads to generate power. The system used net metering to contribute to the national grid. Domestic consumers sell energy to power utilities to overcome their electricity expenditures. A mobile application is used to observe and control the mechanism using IoT-based technologies [7]. The global power sector has shifted towards renewable sustainable solutions. Conventional systems cause environmental problems and global warming worldwide. The smart power management system forecasts solar radiation for solar panels. Sensors employ Internet of Things technology to observe and control the equipment. The results of this study predict the stability and solar system integration of the grid. This study analyzed the utilization of IoT for smart innovative access to monitor the system [8]. However, conventional monitoring systems are ineffective and productive.

The accurate implementation of IoT technologies is required for innovative solutions. The IoT overcomes these challenges by providing an efficient monitoring system [9]. Analogous devices have been transformed into digital devices for innovative technology implementation. This study examined the utilization of digital home device control. Internet of Things (IoT) is an invention in the technology to operate equipment using Wi-Fi. This system includes regulators, transformers, and bridge rectifiers along with the Arduino microcontroller [10]. The IoT based management and observation is main component for industrial. This study present smart meters for current, voltage phase difference to determine power factor. The energy consumption measured by the current, voltage, frequency and power and Arduino based microcontroller is implemented to observe the load connected to the grid. In this prototype application is designed for observe the grid connected loads [11]. The wastage of power owing to the uncontrolled utilization of load is a major challenge worldwide. This study considers IoT-based automatic load management for rooms. The experimental methodology was designed using a passive infrared sensor integrated with an Arduino and other supporting devices for control. The results of this study demonstrated power savings on mobile phone applications, such as Blynk. The passive infrared sensor senses motion to actuate the load [12].

The development of innovative technologies in this study contributes to the implementation of IoT-based power-consumption monitoring. An LCD display was utilized in this project to monitor the energy parameters. The methodology utilized in this study is a quantitative method that implements the equipment implemented in this study with sensors and Arduino Uno microcontrollers. This research is inspired by innovative IoT-based technology for webpage monitoring and actuating. The testing and validation outcomes showed a 0.19% error percentage in the designed system. This system displays and stores energy parameters for real-time monitoring of multiple power sources [13].The advancement of home automation technologies is continuously improving globally. This study aims to utilize Arduino with a Bluetooth module to design a home-automated system. The transaction of data between mobile devices and Arduino wirelessly manages domestic devices. This study focuses on a simple and economical system that uses Bluetooth to handle home appliances [14].

Global energy requirements have increased, and there is a need to implement renewable sources to overcome this challenge. The United Nations' sustainable goals and the Paris Climate Change Agreement deliberate concerns over energy consumption. Mismanagement occurs in the Pakistani electrical power distribution system. This study examined the energy management, distribution, and safety features of power systems. The method used in this study utilizes current and voltage sensors to observe the power parameters. The microcontroller actuates the relay in the case of overloading, and warns the consumer and power utility [15]. This study is utilized to design an IoT-based energy-observing system to reduce energy wastage. It is necessary to implement an effective energy consumption using a sensor. Deployment of this system to integrate the Arduino with a wireless sensor network. The wireless network collects data from the sensor and transmits these parameters to the cloud system. Two parameters, voltage and current, were monitored. This system used an Arduino-based microcontroller ESP8266 Wi-Fi module. Thingview was used to observe and manage the data for load management [16].

Smart grids are an innovative option to be implemented to reduce energy wastage and peak-hour demand. Domestic and industrial needs to implement smart energy meters and plugs. In this study, a fog computing system mechanism is proposed for a load management system using IoT, smart meters, and plug technologies. This smart plug determines the real-time peak value of the power factor, frequency, current, and voltage. This parameter transacts to smart meter via Zigbee network. The smart meters employed were Raspberry Pi and Arduino-based microcontrollers. The tests and validations were performed in the laboratory. The outcome demonstrated 97% accuracy with 30% power savings captured via a smart meter and plug [17]. IoT-based innovative technologies are growing owing to economic issues, and these devices can be accessed remotely. These technologies are useful for education, projects, energy tracking systems, transport systems, and so on [18].A solar-based sustainable system has been implemented across the globe. Efficient observation and load management provide an optimum solution for enhancing the stability of the system. In this study, a solar-based load management system was considered for real-time data transactions from solar panels, batteries, and other equipment parameters, using an IoT-based system.

This system was implemented to observe the cost-effective proficiency of the solar system to consumers. Arduino NodeMCU is utilized for this sustainable approach [19]. New technologies have been implemented for energy optimization for domestic purposes. The automation system employed Bluetooth and Wi-Fi to control home equipment. This study examined the installation of a load management system in domestic settings to provide a sustainable solution. The designed prototype indicated the power distribution and management of domestic control [20]. The power observation for 3 phase electrical power requires the calculation and control of the energy at each phase. This study examines the 3 phase power control and observes its parameters using a mobile application.

The components, including sensors, LCD, and mobile phones, can control the system using the Blynk application. The test and validation demonstrate the voltage, energy, current, frequency, and power parameters required to measure the error ratio in this prototype [21].An innovative technology energy management system is utilized for automation to accurately determine the energy consumption. This system is economical and cost-effective for industrial and domestic applications. This system is integrated with IoT technology and employs a light-dependent resistor to sense the light intensity for switching automatically.The parameters that need to be observed are power, current, and voltage. The Arduino NodeMCU transfers data to the server for Android applications. The implementation outcome was obtained to manage the street light operation automatically to reduce energy wastage [22]. Energy deficiencies are a major challenge in emerging countries. This study determines an economical and stable system that can be implemented in the form of a small prototype. The pulse-width modulation controller is utilized to make the prototype more effective for energy savings. The battery storage system was integrated into the system to provide an external supply. An Arduino board was employed with sensors to control the system. The testing of this project shows a real-time energy management system for an extra energy-efficient system [23].

Conventional meters are manually read by meter readers and bills are delivered manually to consumers. In this conventional system, there are accuracy problems due to the manual system. The implementation of digital IoT-based technology can overcome these challenges. The Arduino, along with voltage and current transformers, was utilized to measure the parameters. The user can pay bills using smartphones and pages [24]. Energy saving is one of the biggest challenges worldwide. Load monitoring and control are required to save power. IoT-based technology is proposed in this study for an optimal energy-saving solution [25]. The power requirements increase owing to an increase in the population. The objective of this study is to provide an optimum solution for energy saving. This study focuses on Arduino with the Global System for Mobile Communications for meter calculation and stores the energy consumption in watts [26].

2 MATERIALS AND METHODS

2.1 Hardware setup

Microcontroller: In this study, Wi-Fi microcontroller ESP8266 was used to monitor and control the electrical gadgets. The microcontroller collects all data from the sensor and controls the load. This system is integrated with a Wi-Fi module to monitor parameters via a web application. This microcontroller includes various analog and numeric input and output ports.

2.1.1 PZEM Module

The PZEM module has multiple functions and features to measure power, voltage, current, and energy parameters. Current and voltage sensors were integrated into the module to monitor the parameters. An ACS712ELCTR-05B-T sensor was used to measure the current flow in the circuit.

2.1.2 LCD Module

The LCD screen shows the electrical parameters for the system. The parameters measured by the sensors integrated with the load management system.

Figure 1. Microcontroller

Table 1. Microcontroller Specifications

Technical Specification	Parameters
Operating Voltage	3.3 V
Digital I/O Pins	11
Analog Input Pins	1 (3.2 V max)
Clock Speed	80/160 MHz
Flash	16 MB
Size	34.2 x 25.6 mm
Weight	3 g

Table 2. PZEM Module Specifications

Technical Specification	Parameters
Working voltage	80 260VAC
Current measurement	0 – 100 A
Rated power	22kW
Operating frequency	45-65Hz
Measurement accuracy	1.0 grade
Working voltage	80 260VAC
Current measurement	0 – 100 A

2.1.3 Four channel relay
A control relay module is an electrical switch that is worked by an electromagnet that can be switch as per the instruction received the microcontroller.

2.1.4 Current Sensor
The current sensor ACS712 is utilized to measure the current parameters in the electric circuit. This system uses current sensor to control the load of energy system.

Figure 2. PZEM module with current sensor

Table 3. Current specifications

Technical Specification	Parameters
Voltage	4.4 – 6.6 V
Rated power	22kW
Frequency	80 kHz
Temperature range	-39 0 C – 84 0 C

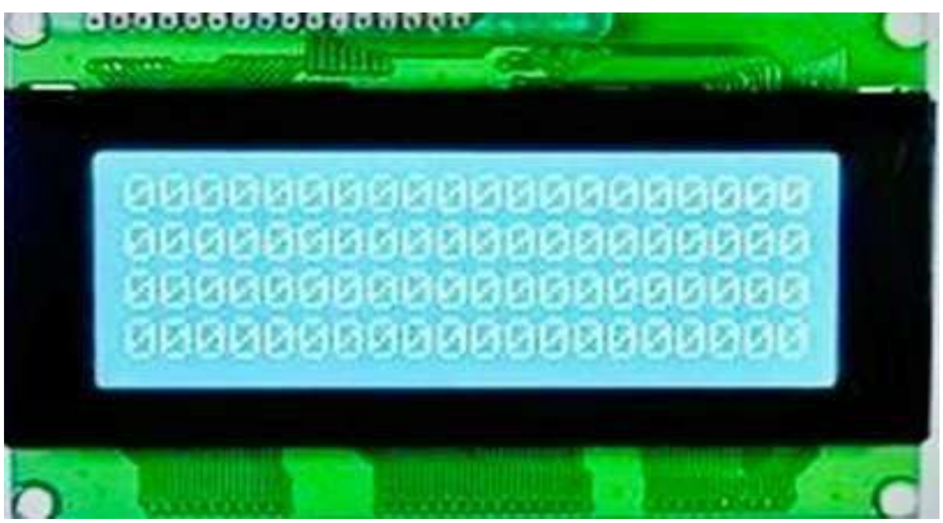

Figure 3. LCD

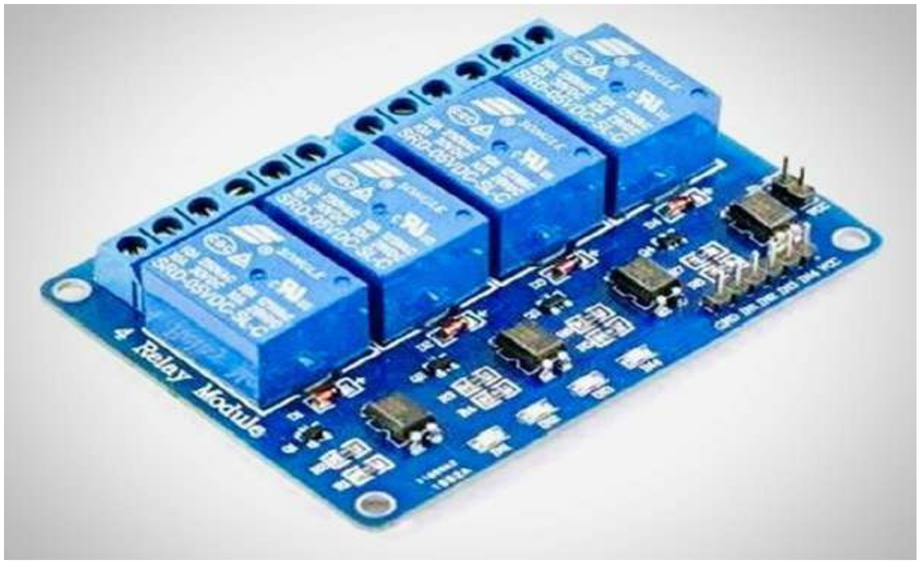

Figure 4. Four Channel Relay

The hardware setup was designed to monitor parameters such as current, voltage, and frequency of the load. The Arduino setup was utilized for switching the load during peak hours. The four-channel relay was integrated with an Arduino to operate the load. This integration switches on and off to address the peak hours. The Wi-Fi module is a sink with a system that monitors parameters using web applications. The hardware architecture is shown in figure 5.

2.2 Software Setup

The proposed system uses following programming setups: Arduino IDE: To achieve an efficient energy management system, the Arduino Integrated Development Environment (IDE) software was utilized to write and upload the programming. In the software design, instructions and values were set to obtain the defined results. Figure 6 shows the Arduino IDE program, which shows the real parameters of the equipment.

For the web structure development Hypertext Preprocessor(PHP) utilized for we application. The Hypertext Markup Language(HTML) codes are utilized in arrangement with numerous web structures. The main objective of PHP is to permit web developer to generate the pages dynamically. The figure 7 shows the display of the energy management system. This system uses PHP language to control the system. As displayed over the page is showing three signs of current, voltage and frequency and additionally noticing three kinds of parameters which the green button shows the peak hour's initiation and red button shows the deactivation of peak hours.

The design and circuit simulation were done with proteus. The figure 8 is the schematic design of using proteus software. The components are placed in the schematic diagram that shows the flow of the load management system. Figure demonstrates all the internal parts.

2.3 Methodology

The proposed methodology includes an Arduino UNO 4 channel relay, Wi-Fi module, current and potential sensor, transformer, transistor, and diode to manage the energy that is connected to the load. The energy parameters received from the sensors stored in the IoT-based cloud system PZEM sensor were utilized to measure the current and voltage via the energy source, and then the information was transferred to the microcontroller. These parameters demonstrate on the LCD screen and web portal via IoT based technology.

For the schematic diagram for the hardware setup shown in figure 9, where hardware components including sensors, Arduino, Relay, Wi-Fi module, LCD display, buzzer and load are employed with a power source. The

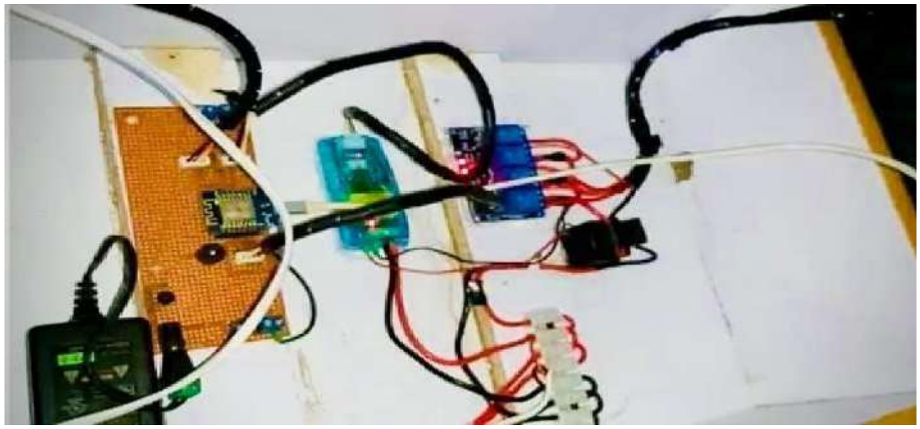

Figure 5. Experimental Setup

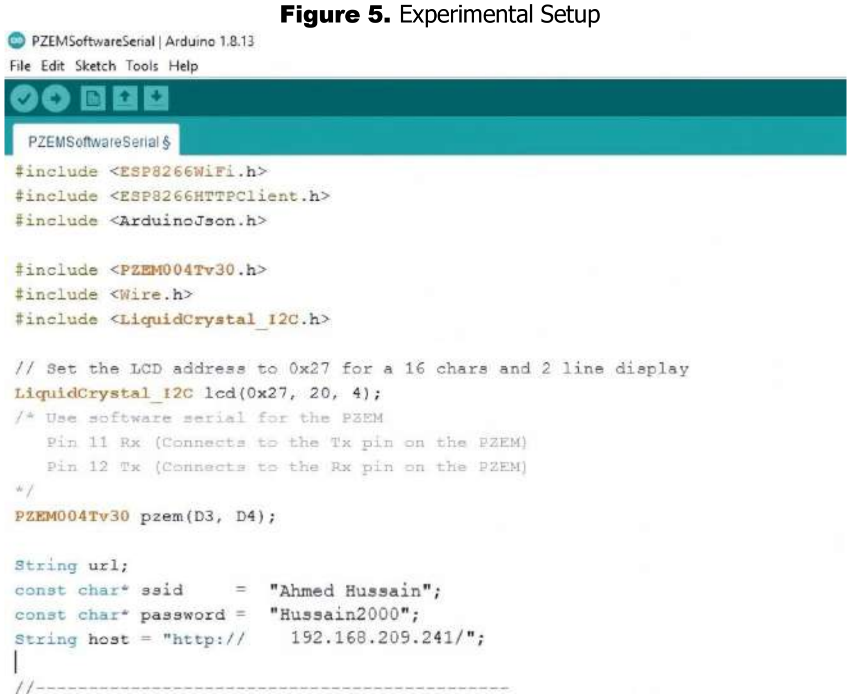

Figure 6. Software Setup

hardware schematic was designed using a fritzing software tool for the facility analysis.

Figure 10 shows the hardware flow of energy management system. The hardware setup is connected to three loads: primary, necessary, and luxury. The symbol indicates the connected load status. The current sensor PZEM module provides current, voltage, and frequency parameters to the Arduino-based microcontroller. The LED integrated with the microcontroller also indicates the load status for the peak hours. The relays are integrated with a microcontroller for peak hours switching, the buzzer indicates the peak hours, and the hardware is synchronized with the Hypertext Preprocessor (PHP) web page for parameters based on the Internet of Things.

The Arduino integrate with sensors to automatically switch the extra load. This system operation comprises of automatic energy control by using microcontroller integrated with current sensor to save the energy during peak hours. The sensors interconnect with controller for the parameter comparison. The proteus virtual reality software is used to model the energy flow of the project.

3 Calculations

This equation is used to calculate the demand:

Figure 7. Web Structure

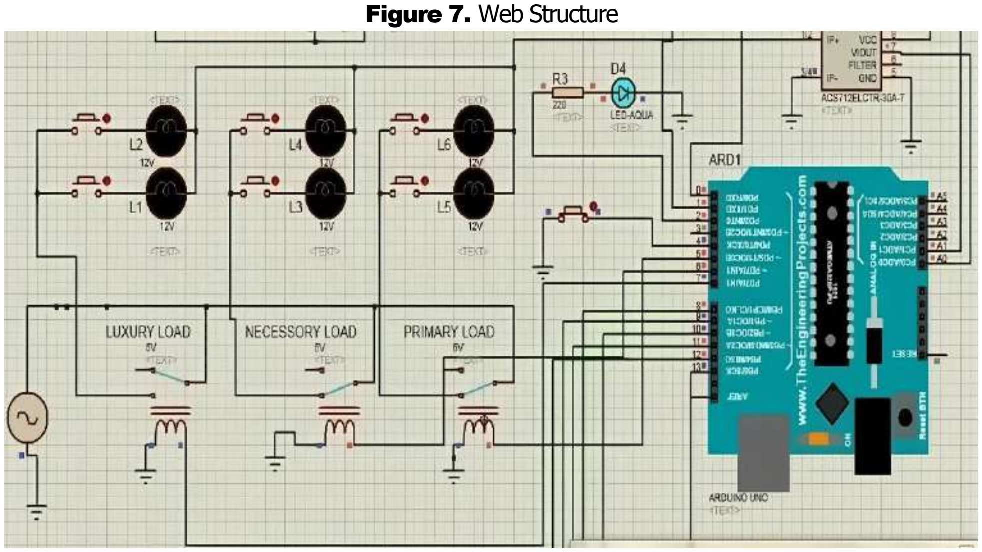

Figure 8. Schematic of the energy management system

$$P_{load} = P_{supply} \tag{1}$$

Where:

P_{load} is the complete load demand.

P_{supply} is the accessible power supply.

Given:

$$P_{load} = 80\,\text{MW} \quad \text{(total power consumed by all loads)}$$

$$P_{supply} = 100\,\text{MW} \quad \text{(available power supply)}$$

Now, we want to find the optimum alteration (ΔP_{load}) to diminish the difference between P_{load} and P_{supply}:

$$P_{load} - P_{supply} \tag{2}$$

Minimize:

$$|80 - 100| = 20\,\text{MW}$$

This objective function essentially reduces the difference, which is equivalent to 20 MW.

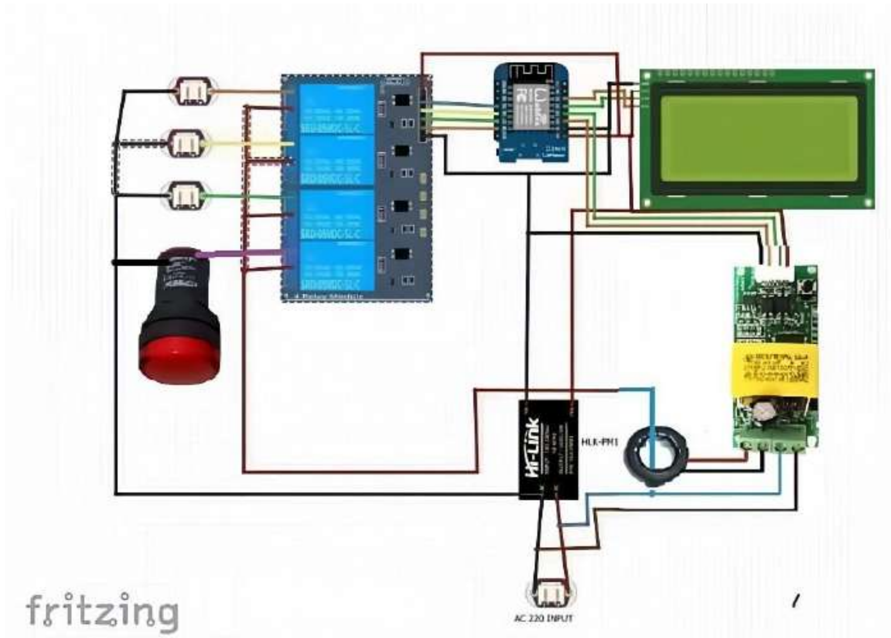

Figure 9. Schematic layout of energy management system

3.1 Peak Hours Calculations

Consider a scenario where a service organization needs to manage the power load during a peak period.

- Total power supply during the peak period: $P_{\text{supply}} = 100\,\text{MW}$
- Total power demand (initial load) during the peak period: $P_{\text{load}} = 120\,\text{MW}$

The objective is to optimize the load and reduce P_{load} to match P_{supply} while minimizing the cost of load shedding. We introduce a cost factor for shedding load.

- Cost per MW of load shedding: PKR 100,000 per MW

3.1.1 Objective Function

Minimize the cost of load shedding, C, which is the product of the load shed (ΔP_{load}) and the cost per MW of load shedding:

$$C = 100,000 \times \Delta P_{\text{load}} \tag{3}$$

3.1.2 Constraints

1. The load shed (ΔP_{load}) cannot exceed the initial load (P_{load}) since the load cannot be negative:

$$\Delta P_{\text{load}} \leq P_{\text{load}}$$

2. The adjusted load ($P_{\text{load}} - \Delta P_{\text{load}}$) should equal the power supply:

$$P_{\text{load}} - \Delta P_{\text{load}} = P_{\text{supply}}$$

Calculating the difference between the initial load and supply:

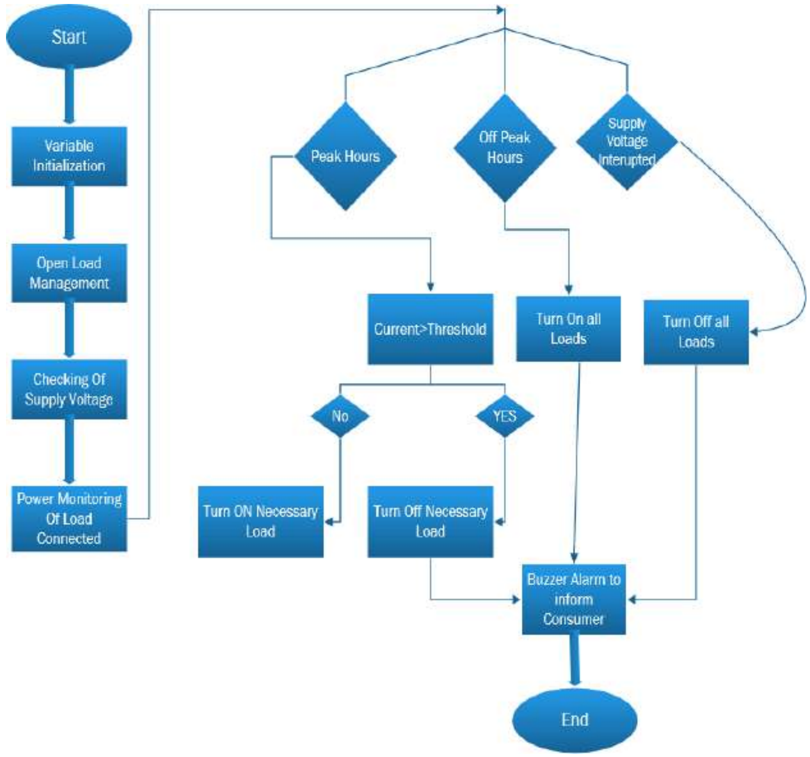

Figure 10. Hardware flow of energy management system

$$\Delta P_{\text{load}} = P_{\text{load}} - P_{\text{supply}} = 120\,\text{MW} - 100\,\text{MW} = 20\,\text{MW}$$

Calculating the cost of load shedding:

$$C = 100,000 \times 20 = \text{PKR } 2{,}000{,}000$$

Table 4. Load Management Peak Hours

No of Consumers	Load Current Range (A)	Total Load Current without Control System (A)	Total Load Current with Control System (A)
1-1500	1-2	3000	3000
1501-3500	3-5	5000	5000
3501-6500	7-10	8000	8000
6501-9939	10-25	25000	14000

The figure 11 and 12 shows the characteristics curves for the peak hour and electricity breakdown for the mathematical data collections.

4 RESULTS AND DISCUSSION

In the result phase, the microcontroller and sensors functioned properly. The system works proficiently and manages the load during peak hours. The main purpose of this prototype is to minimize energy wastage during the peak hours. Furthermore, the system is inspired by the latest IoT-based technology for monitoring and controlling energy management via web applications and webpages.

4.1 Login webpage

Fig. 13 shows the login page for the control and monitoring of the prototype. This login can be used in any web browser. This login page is inspired by the latest technology Internet of Things (IoT).

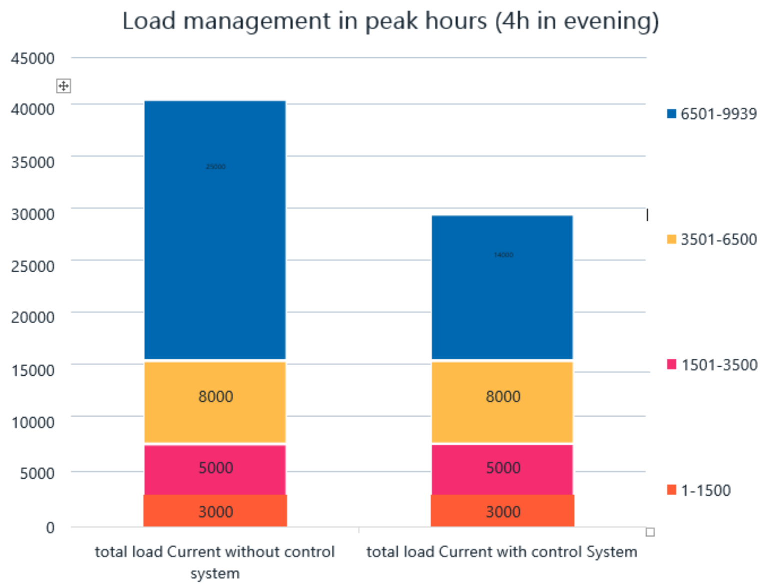

Figure 11. Characteristics curve both with and without a control system

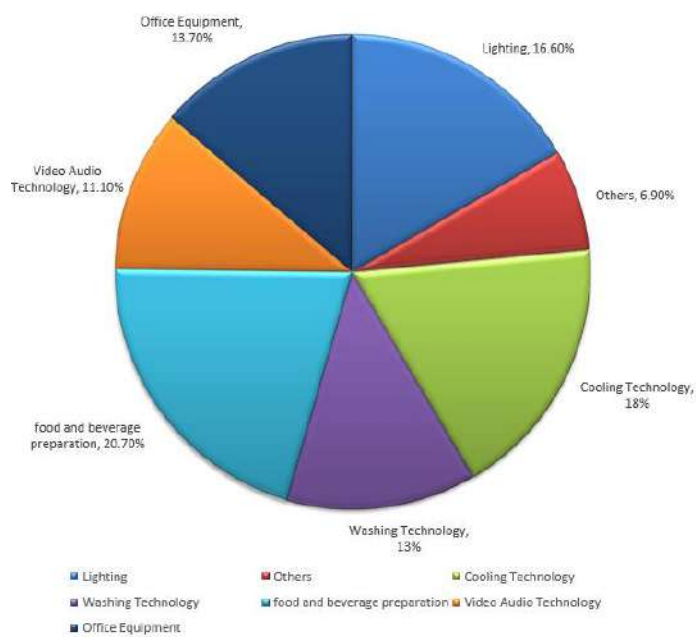

Figure 12. Breakdown in Electricity consumption in household

4.2 Web application result

The web results after the login page, shown in figure 14, show the real frequency, current, and voltage parameters for the prototype. The results for the voltage parameters shows 221 voltage and current were 1.3 Ampere, frequency 49.9 Hz and the power 287.3 watt. These parameters are used for off-peak hours.

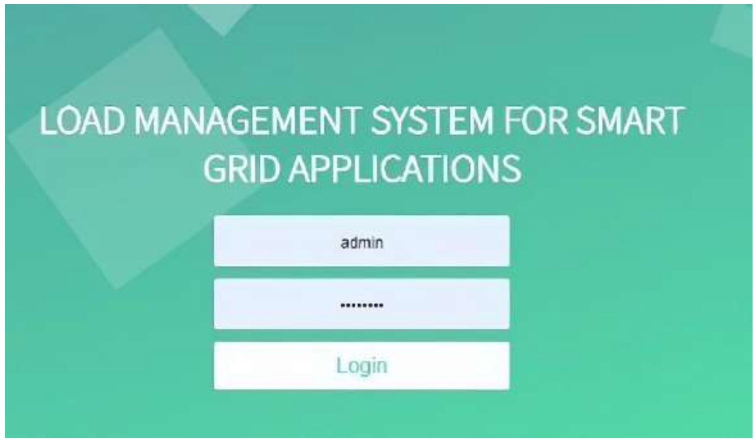

Figure 13. Web page

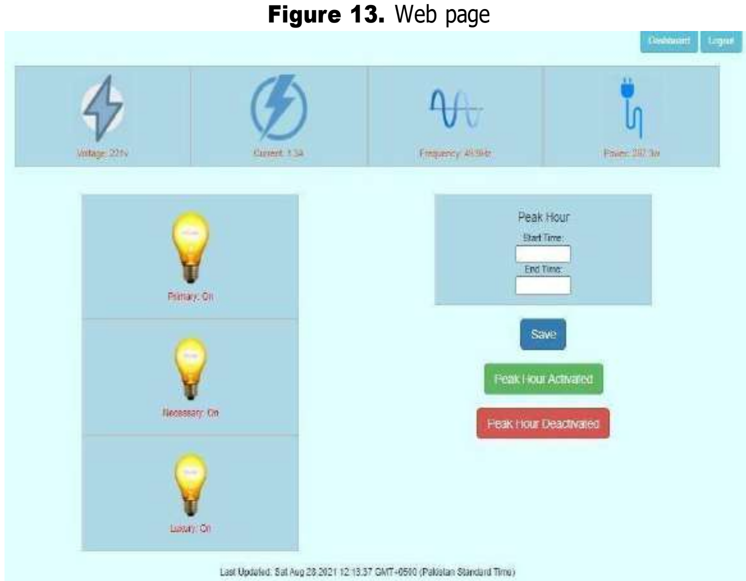

Figure 14. Web portal interface

4.3 Off peak hours' consumptions

During normal hours, all primary, necessary, and luxury loads are connected, as shown in the ON state, and will display the readings of the voltage, current, power, frequency, and display off-peak hours on the LCD as well as web portal, as shown in figure 15 and 16.

The hardware connection diagram of the surveillance setup for the peak hours is shown in figure 17. All the hardware components were connected in a schematic diagram. This system uses Proteus software to analyze and design parameters. During this analysis, all primary, necessary, and luxury loads were on due to off-peak.

Figure 15. Hardware results off peak hours

Figure 16. Web results off peak hours

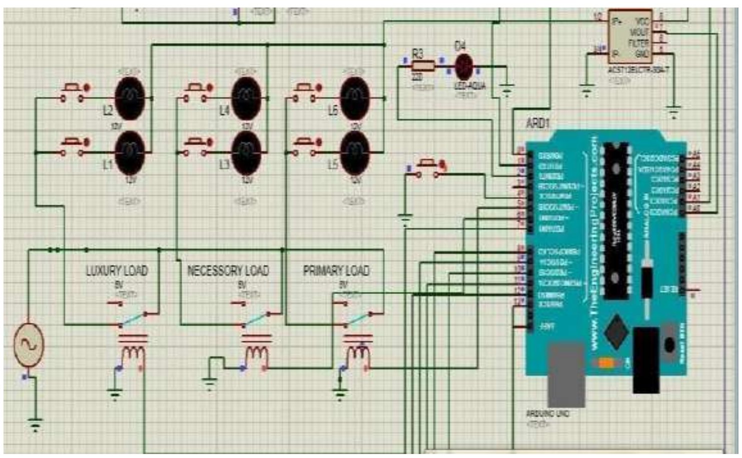

Figure 17. Off peak hours' connection diagram

4.4 On peak hours' consumptions

During the peak hour, all necessary and luxury loads are connected in the OFF state and will display the readings of the voltage, current, power, frequency, and additionally display peak hours on the LCD as well as the web portal, as shown in figure 18 and 19.

Figure 18. Web results peak hours

Figure 19. Web results peak hours

The hardware connection diagram of the surveillance setup for peak hours is shown in figure 20. All hardware components are connected in the schematic diagram. This system uses proteus software to analyze and design the parameters. During this analysis, all luxury loads were off owing to peak hour monitoring. The voltage, current, and power parameters were also analyzed in the subsequent operation of the surveillance system.

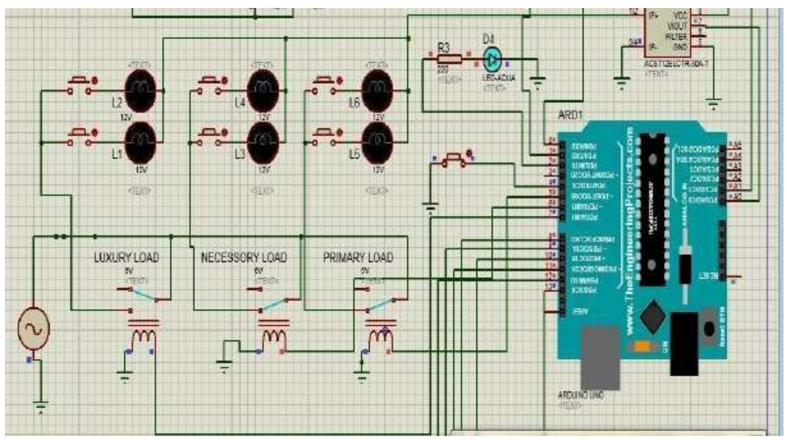

Figure 20. Peak hours' connection diagram

(IoT)-based controlling web page was designed to transmit, store, monitor, and control real-time parameters with three load connections. All hardware and simulation-based parameters were analyzed and matched. The proposed system was used to design and implement a load management system for residential, commercial, and industrial applications to control various loads. The implementation of this scheme reduce the physical human interface for energy systems. The construction of this automated system is a sustainable approach for energy scavenging. By application of this work can significantly control the production and observing of the conventional energy systems. Future work in relation to the performance of Arduino constructed load management systems can be implemented using a Raspberry PI controller instead of Arduino to improve the reliability of load management systems inspired by artificial intelligence and cloud computing integration. Furthermore, renewable power generation systems must be integrated with the system for sustainable solution.

5 CONCLUSION AND FUTURE WORK

The results show that automation and smart energy management systems inspired by the latest Internet of Things (IoT) systems are needed for implementation. Smart energy management can be an effective solution for saving power during peak hours. This study can be helpful in the implementation of the latest load-management systems. Three loads were considered in this study: necessary, primary, and luxury. The luxury load was automatically turned off during peak hours. This model was designed to improve the performance of the system by encouraging load between supply and demand and avoid unscheduled load shedding. The software application integrated development environment (IDE) was used to program Arduino. The simulation parameters were designed using Proteus software. The Arduino microcontroller was utilized for internet-based control and monitoring of the load management system. The WiFi-based microcontroller was utilized to monitor and communicate data between the microcontroller and web application. Current, voltage, and power sensors were integrated with a system to measure and control the system. The Internet of Things (IoT)-based controlling web page was designed to transmit, store, monitor, and control real-time parameters with three load connections. All hardware and simulation-based parameters were analyzed and matched. The proposed system was used to design and implement a load management system for residential, commercial, and industrial applications to control various loads. Future work in relation to the performance of Arduino constructed load management systems can be implemented using a Raspberry PI controller instead of Arduino to improve the reliability of load management systems inspired by artificial intelligence and cloud computing integration. Furthermore, renewable power generation systems must be integrated with the system for sustainable solution The results show that automation and smart energy management systems inspired by the latest Internet of Things (IoT) systems are needed for implementation. Smart energy management can be an effective solution for saving power during peak hours. This study can be helpful in the implementation of the latest load-management systems. Three loads were considered in this study: necessary, primary, and luxury. The luxury load was automatically turned off during peak hours. This model was designed to improve the performance of the system by encouraging users to reduce their power consumption during peak hours and shift their loads to off-peak hours to manage the load between supply and demand and avoid unscheduled load shedding. The software application integrated development environment (IDE) was used to program Arduino. The simulation parameters were designed using Proteus software. The Arduino microcontroller was utilized for internet-based control and monitoring of the load management system. The WiFi-based microcontroller was utilized to monitor and communicate data between the microcontroller and web application. Current, voltage, and power sensors were integrated with a system to measure and control the system. The Internet of Things

6 Author Contributions

Shujaat Ali: Technical and Material Support Supervision. **Syed Saad Ali:** Conceptualization, Hardware and Software development and editing. **Muzammil Ahmad Khan:** Data Analysis and Interpretation. **Muhammad Ahmed Hussain:** Design of study and Data collection. **Masroor Khan:** Interpretation of Data. **Hermain Fayyaz Karim:** Revision the work.

Compliance with Ethical Standards

It is hereby declared that none of the authors have any conflicts of interest. Moreover, consent was obtained from each author included in the study.

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