Oorja: Real-Time Sustainable Power Monitoring System

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***Abstract* - The significant increase in energy demands in the last decade has led to unnecessary usage of energy. Though the environmental impact of overconsumption of energy is not immediately observed, they do cause power plants to generate more carbon emissions annually. An effective solution needs to be identified to address these issues. Real-time energy monitoring could have a positive impact on society and the environment while laying the groundwork for a sustainable future. This paper proposes 'Oorja' - a real-time sustainable power monitoring system, which is a cost-effective and visionary solution designed to enhance energy efficiency. It is built using an ESP32 microcontroller with a PZEM-004T sensor. It is IoT-enabled to provide real-time monitoring and analysis of power consumption through a web dashboard, mobile app, or a dedicated receiver. With extensive safety features, such as a glass fuse, a high-pitched alarm, and an automated power cut-off, the proposed system allows homes and businesses to optimize energy use and save expenses without sacrificing safety. These measures are designed to prevent electrical hazards. Additionally, it has a special debug mode that allows the user to quickly troubleshoot any minor faults without involving an expert. Results in this paper demonstrate the real-time performance of the proposed system with a variety of devices acting as loads.**

Keywords - Energy monitoring, Internet of Things (IoT), electrical safety, energy conservation, ESP32, PZEM-004T

I. INTRODUCTION

Electrical energy is regarded as the main force behind development and evolution in today's globe [1]. Over the past few years, as new technologies enhancing human lives have continued to be developed, there has been an increase in the demand for energy. The need for natural fuels, an exhaustible resource, surged in tandem with the rising demand for energy. There is a limited supply but a rising demand, which may cause major worldwide disruptions if it is not addressed sooner. Residents and businesses are therefore starting to look at the best ways to help de-escalate their electricity prices [2]. Real-time monitoring of power consumption is one way to reduce these costs by using the data to make educated judgements on managing the electrical devices that are being used. Customers can change their habits to save money if a technology that estimates power consumption is available.

Thus, an effective, affordable, and adaptable system is proposed in this paper, demonstrating the necessity to investigate and evaluate energy monitoring-based systems, particularly in view of the recent energy and climate crises. The Real-time Sustainable Power Monitoring System is an embedded system that uses an energy-efficient and reasonably priced sensor in conjunction with an IoT-enabled microcontroller to provide real-time analysis and monitoring.

It provides cost-effective and environment-friendly ways to consume energy efficiently while ensuring a sustainable future. The present work is divided into seven sections. Section II discusses the similar work available in the literature, concluding with the research gaps. Section III details the working of the proposed system, followed by section IV demonstrating the hardware details and software details of the proposed system. Section V details the special features of the proposed system. Section VI highlighting the real-world deployment scenario and Section VII concludes the proposed work along with its future prospects.

II. EXISTING SYSTEM

An analysis of previous research on smart energy meters showed that several studies addressed the design of smart energy meters with the goal of measuring energy consumption and ensuring a reliable method of power monitoring. In [3-5], DBMS and a GSM network are used as the foundation to give their clients information on how much energy they use. In [6], energy metering nodes connect with each other and the central node via Zigbee and transfer data to a central computer via GSM. Authors in [7] have suggested an automated energy meter that makes use of GSM technology. An ESP8266 based smart energy meter was proposed in [8], which computes the electricity bill automatically and without the need for outside assistance. In [9], IoT and WSNs were utilised to control building power in real time. Instead of treating energy usage as a fixed monthly expense, the authors of [10] provided a smart energy monitoring system that may assist users in managing and analyzing data at the device level.

The aforementioned systems available in the literature try to cater towards the same goal, i.e., sustainable energy usage, but lack in one or the other aspect. Certain systems lack flexibility, while for the others, electrical hazards were not a point of concern. Many of the proposed systems opted for GSM for connectivity. This makes the existing systems more expensive, bulky and inefficient when compared with the systems containing Wi-Fi. Many existing systems lacked the selection of an appropriate microprocessor and sensor combination that strikes a balance between energy efficiency and optimal performance.

III. PROPOSED SYSTEM OVERVIEW AND WORKING

The proposed system aims at monitoring the energy usage in homes and businesses in real time and hence allows the user to control the electrical devices remotely.

Fig. 1 shows the block diagram of the proposed power monitoring system. The proposed system is built around an ESP32 microcontroller connected with a PZEM-004T sensor and an active low relay.

Being cost-effective and user-friendly, Blynk 2.0 is the IOT server of choice. With reference to Section II, Table I presents a parametric comparison of the proposed system with the functionally similar existing systems in papers [3] to [10].

TABLE I. COMPARISON OF PROPOSED SYSTEM WITH THE EXISTING SYSTEMS

Parameter	Existing Systems	Proposed System
Technology Used	GSM , Arduino, Raspberry Pi	ESP32, Wi-Fi provisioning
User friendly	No	Yes
Wireless Control	Few [7,9]	Yes (hardware and software)
Troubleshooting	Not available	Available (further discussed in Section V)
Safety Features	None	Buzzer, Fuse, Notifications
Weight	Bulky [due to GSM and Raspberry Pi]	Light
Scalability	Difficult	Easy

Although being a prototype, the proposed system is designed to sustain real-life load and designed with ease of use in mind. The web dashboard, combined with its unique Debug Mode (refer to Section V), provides an easy way to incorporate user feedback. Furthermore, unlike other existing systems, which are rigid in structure, Oorja is easily scalable. With just a few changes in the dashboard and a few OTA updates, it can easily be used to add multiple nodes.

As shown in Fig.1. The proposed system contains two circuits, one for the transmitter and one for the receiver.

A. Transmitter Unit

The transmitter is the heart of the complete operation performed by the proposed system. Fig. 2 shows the circuit diagram of the transmitter implemented in the proposed system. The transmitter serves a dual purpose: as a power socket for AC devices as well as a multimeter. It takes the mains supply from any socket and routes it to the connected appliance plugged into the transmitter's socket via the PZEM-004T sensor. The sensor then measures the current through the appliance, the voltage drop across it with the frequency, the power drawn by the appliance and the power factor. The sensor then feeds these readings into the ESP32 via the Rx and Tx terminals, where the data is interpreted. This data is then sent to the Blynk IoT server using the internal Wi-Fi provisioning.

Fig. 3. displays the actual hardware of the transmitter. As depicted in Fig. 3, each LED acts as an indicator of a specific function, namely Wi-Fi connection, connection to the IoT server and the power status. The transmitter device also has a socket where any AC device to be monitored can be plugged in.

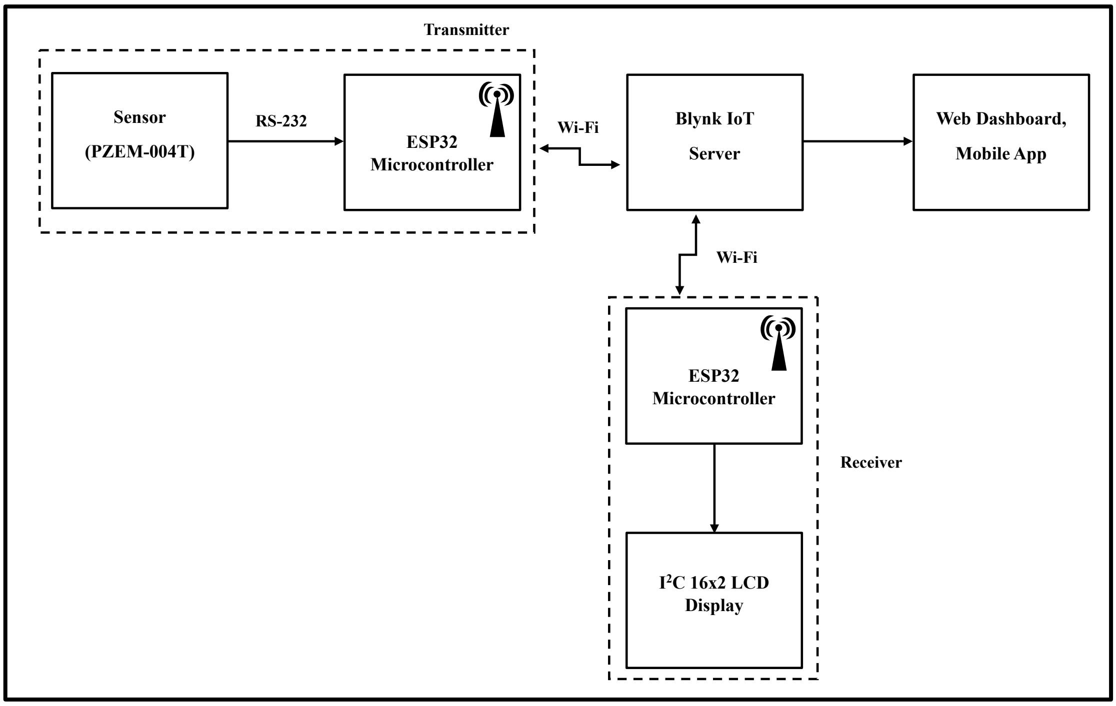


Fig.1. Block diagram of the proposed system

B. Receiver Unit

The receiver consists of an ESP32 for processing the data received from the transmitter, and two 16x2 I2C LCDs for display. The data received from the transmitter circuit is processed, interpreted and displayed on the LCDs using the I2C communication bus. Also, it connects to the Blynk IoT server via internal Wi-Fi provisioning. Fig. 4 shows the circuit diagram of the receiver in the proposed system.

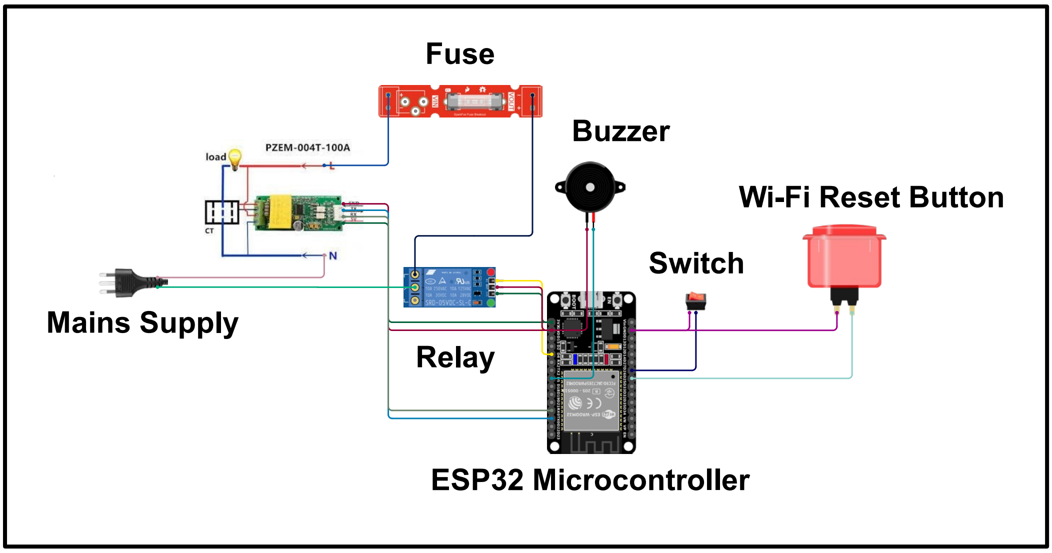


Fig. 2. Circuit diagram of transmitter unit

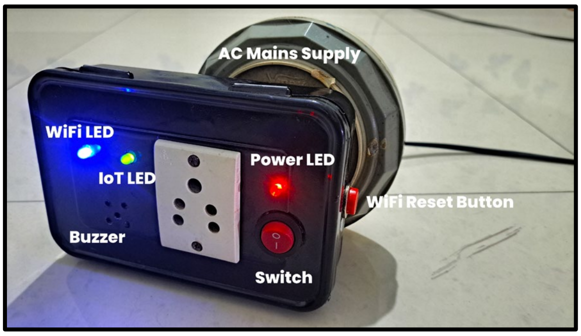


Fig. 3. Actual transmitter device

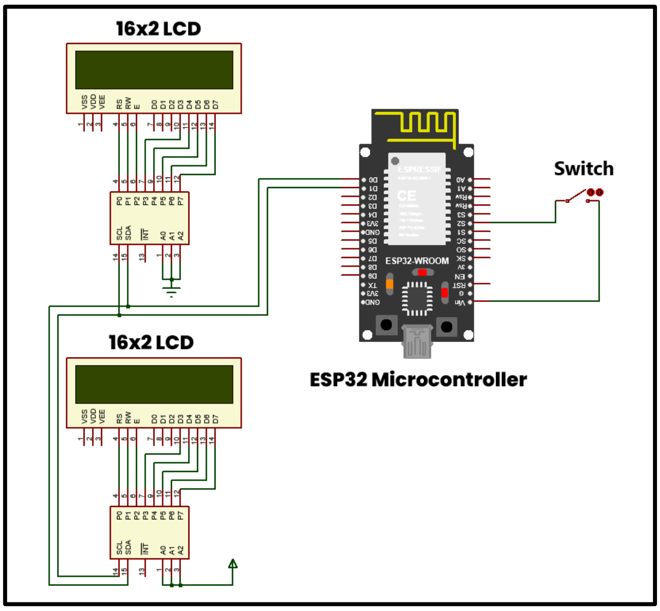


Fig. 4 Circuit diagram of receiver unit

C. Web Dashboard and Mobile App (Blynk IoT)

With the help of the Blynk IoT, intuitive smartphone app or web dashboard, we visualise as well as control the appliance on the go. Fig. 5 and 6 show the preview of Blynk IoT.

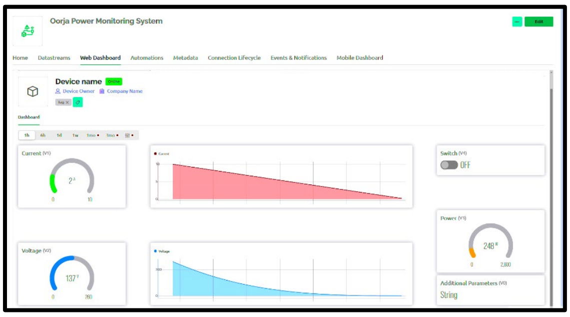


Fig. 5 Preview of Blynk IoT web board

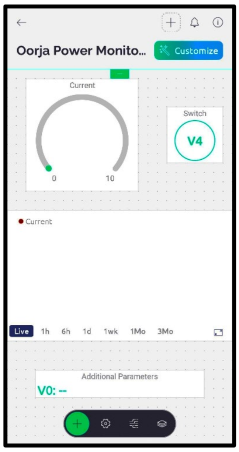


Fig. 6 Preview of Blynk IoT mobile app

Also, as shown in Fig. 4, the receiver can send the transmitter either an ON or an OFF signal using a switch wirelessly to switch the home appliance that is plugged in at the transmitter end. This switching feature is implemented using a 5V relay module.

IV. Hardware Description

This section provides an in-depth description of the significant hardware components that are the core of the proposed system.

A. PZEM_004T

It is a versatile AC power monitoring sensor, widely used in electrical consumption measurement systems [11]. The PZEM-004T energy monitor sensor can be used with IoT based systems. It features a TTL based serial communication interface. It is a perfect candidate for the proposed system as it includes measurement functions such as voltage, current and active power with power saving features. Fig. 7 shows the typical connections using PZEM-004T.

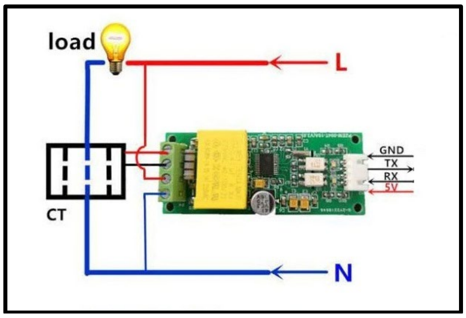


Fig. 7 PZEM-004T-100A Sensor Wiring diagram [11]

B. ESP32

The ESP32 is a line of low-cost, low-power (SoC) microcontrollers by Espressif Systems that has a dual-core processor, BLE and HT40 Wi-Fi for connectivity [12]. This particular microprocessor has been chosen owing to its 150 megabits data rate. Its processor, Xtensa, is a dual core 32-bit chip, running at 160 or 240 MHz. It comes with 448 kilobytes of ROM and 520 kilobytes of SRAM. Additionally, it has hardware accelerators for AES and SSL/TLS for security, while supporting multiple I/O options. Fig. 8 shows the ESP32 microcontroller development board.

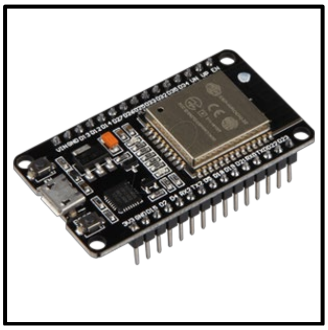


Fig. 8 ESP32 Microcontroller Development Board [12]

V. Proposed System Features

After analyzing the various shortcomings present in the available systems, Oorja is built-in with various safety and quality-of-life features as listed in the current section.

- *Wi-Fi provisioning:* In order to avoid being stuck with a hard-coded Wi-Fi AP to access the internet, Oorja is equipped with Wi-Fi provisioning, which can provide dynamic Wi-Fi for the ESP32 to connect to the server. Fig. 9 displays the working flowchart of the built-in Wi-Fi provisioning in Oorja.

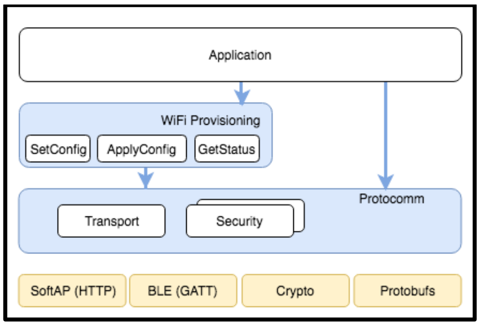


Fig. 9 Flowchart of Wi-Fi Provisioning [13]

- *Wireless control:* In order to toggle the transmitter from anywhere in the world, either the switch in the receiver or the virtual switch in the dashboard or the mobile app can be used.

- *State remembering:* Oorja uses its ROM to store the state of the relay and sync it with the IoT server as soon as it connects to it which prevents any malfunction in case of a power outage. For this, it utilises the "preferences.h" library.

- *Safety:* It comes equipped with a buzzer, which sounds loudly whenever any electrical malfunction is detected in the circuit. The circuit is equipped with a 10 A glass fuse and a system wherein Oorja sends a notification to the mobile app, notification in the mail, and via SMS about the malfunctioning.

- *Troubleshooting:* Oorja is revolutionary in being one of the only ones to provide an easy debugging experience in case of any malfunction. It comes with a system debug mode, which can be accessed by opening the lid of the transmitter and long-pressing the debug button until the debug LED starts glowing. Connect a USB-C data cable and open the serial monitor to look at the system. Fig. 10 features the debug LED and debug button on the ESP32 Dev Board.

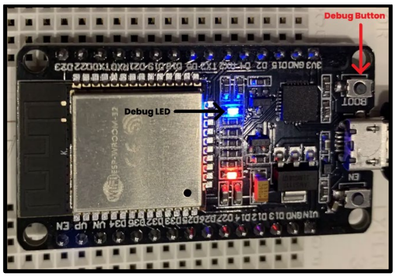


Fig. 10 Debug LED and button on ESP32 Development Board [14]

VI. Results and Discussions

In this section, the operation of the proposed IoT energy meter will be demonstrated in a typical household environment using real-world household appliances. The transmitter sends data to the IoT server every 2 seconds throughout the day. For testing purposes, the transmitter has been connected to the mains supply via an extension board and the load will be connected to the socket provided in the transmitter.

A. Load 1: Table Lamp

Fig. 11 Real-time view of the table lamp as a load

Fig. 12 Blynk IoT Web dashboard (Table lamp as a load)

B. Load 2: Mobile Charger

Fig. 13 Real-time view of the mobile charger as a load

Fig. 14 Blynk IoT Web dashboard (Mobile charger as a load)

C. Load 3: Glue Gun

Fig. 15 Real-time view of Glue Gun as a load

Fig. 16 Blynk IoT Web dashboard (Glue gun as a load)

Fig. 11, 13 and 15 show the real-time view of the appliance as the load when plugged into Oorja's Mains socket.

Fig. 12, 14 and 16 demonstrate a web dashboard reflecting the real-time values received from the transmitter. This includes voltage, current, frequency, power and power factor along with the graphs of current and voltage for studying the trends in daily electricity usage. The values illustrated in Fig. 12, 14 and 16 match very closely with the expected values according to each appliance's power rating.

D. Simulating Faults

When the values of sensors are intentionally inflated to simulate a state of short circuit (overcurrent, overvoltage), the safety features of the proposed system become evident. Fig. 17. Shows the notification that is received in the mail and the Blynk app in case of electrical malfunction to prevent further damage to components.

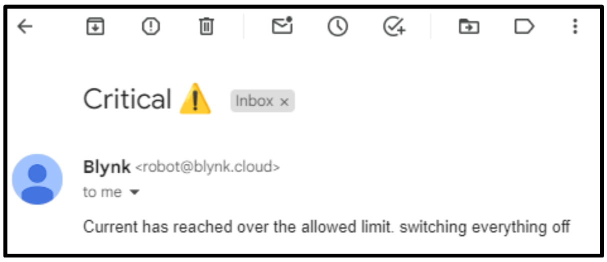
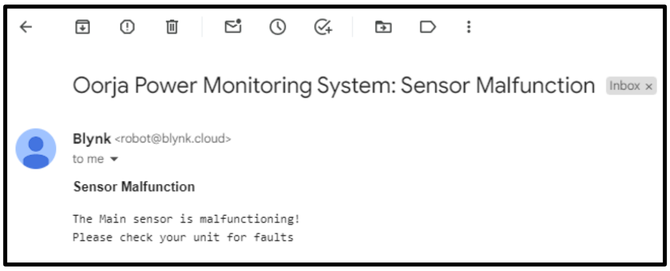


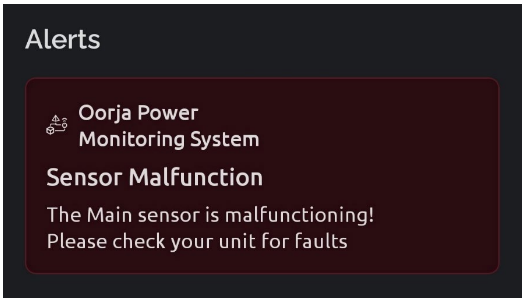
Fig. 17 Mail Notification in Case of Emergency

Afterwards, the sensor is removed from the transmitter in order to simulate a fault in the sensor itself and check it's fault detection as well as its ability to detect the difference between the fault in the sensor and the circuit.

Fig. 18. demonstrates the smart fault detection feature of the proposed system, which can detect the difference between an electrical wiring fault and a sensor issue and inform the user instantly to resolve the issue.



(a)



(b)

Fig. 18 Smart fault detection feature (a) Mail notification and, (b) Blynk App notification

VII. Conclusion and Future Scope

The design of an energy-efficient and cost-effective IoT-enabled energy monitoring system has been proposed. The system is suitable for energy monitoring and tracking applications. The sensor node is based on the high-performance and high-precision energy sensor PZEM-004T, and the ESP32 microprocessor perfectly complements the purpose of the proposed system. Test results show that the power supply monitoring system can accurately monitor voltage, current, power, frequency and power factor. While a few investigations in the existing literature focus on establishing systems that record service interference history, others measure wireless power. While research is being carried out on different electrical systems, the system and methodology proposed in this paper target all the issues already addressed in the literature in a more effective way, along with the provisioning of protection against electrical failures. The system proposed in this paper is easy to use and scalable as well. The CSV file generated by the mobile app of the past data of the sensor can be easily used to plot the values and connect with AI and ANN to monitor trends in energy consumption to optimize the usage.

However, the proposed system can be further optimized. It can be easily converted into a PCB to make its mass production and assembly quick and efficient. Also, the IoT server of choice, keeping future-proofing in mind, will be transitioned into AWS IoT-core, which has become an industry standard. Furthermore, future work could explore energy optimization strategies and address interoperability with existing smart grid technologies.

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