

Advanced Energy Metering and Automated Control System

Banniswara Reddy Akula^{1,*}, Sanjeeva Sunilkumar Jillela², Harshavardhan Reddy Tadipathri³, Sivakumar Selvaraj⁴

Abstract

In this paper need for energy efficiency especially combining smart metering with control of load and prepaid billing becomes insistent. An ESP32-based Advanced Energy Metering and Automated Load Control System is presented in this paper taking advantage of an IoT-capable smart meters, real-time data analytics, motion detector-based automation scheduling, Real-time clock (RTC) module-enabled scheduling, and GSM based prepaid billing notifications. The central controller, responsible for real-time energy monitoring, automated load control, and wireless communication, is the ESP32 microcontroller. A prepaid billing method will maintain the system, allowing consumers to add money on their electricity credits and have the balance deducted as they use. GSM module will send SMS notifications to users about balance updates, low credit warnings, and disconnection alerts after the balance ends. Accurate time-based load scheduling is needed, the RTC module is responsible for doing that. Also, occupancy is sensed, and load switching is done to avoid unnecessary power consumption by motion sensors. The ESP32 gets data from sensors and smart meters. It changes power use based on plans and how much energy is used. Users can add money to pre-paid accounts, watch energy use, and control devices using a web dashboard. Tests show better control of power, improved energy use, and saving money. The ESP32 offers a cheap way to track usage, set pre-paid prices, time actions smartly, and act based on motion.

Keywords: 4-channel relay, ESP32, energy meter, GSM module, RTC (real time clock) module

INTRODUCTION

Good energy systems are needed because the demand for power is increasing worldwide. Old methods often fail to provide real-time information and control, causing energy waste. With the ESP32 chip, which can connect devices for load control, smart tuning, and live power tracking, this system offers a smart energy watch and load control system. By obtaining and analyzing power use data, users can better control loads using a web or phone application [1]. This cheap and easy-to-scale technology helps improve green energy use across many types of work. One of the biggest issues facing today's commercial, industrial, and residential infrastructure is the management of power consumption and energy usage. High costs and unaccounted consumption are common problems for traditional energy metering and billing systems, which are prone to inaccuracies, delays, and inefficiencies, resulting in excessive energy wastage.

Owing to the growing global energy demand and escalating energy prices, effective energy management has emerged as a necessity for both

*Author for Correspondence

Banniswara Reddy Akula

E-mail: vtu27033@veltech.edu.in

¹⁻³Student, Department of Electrical and Electronics Engineering, Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, Avadi, Chennai, Tamil Nadu, India

⁴Professor, Department of Electrical and Electronics Engineering, Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, Avadi, Chennai, Tamil Nadu, India

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homes and industries [2]. Conventional metering and billing do not have enough accuracy; bills are generated with a delay, and energy power is distributed through ineffective channels, leading to excessive energy usage and increased operational overhead. Moreover, manual meter reading and postpaid billing systems can cause billing discrepancies, delayed payments, and unauthorized energy usage [3]. Modern smart energy management systems use advanced algorithms to optimize energy consumption and generation in real time, taking into consideration the existing smart grid infrastructure and energy market conditions. Electric power has become essential to human survival and advancement. In addition to the requirement of increased supply to match the growing demand, the digitization of energy distribution is also essential to improve people's standard of living. The inefficiency of traditional meter reading by human operators prevents the full satisfaction of future residential development needs. Therefore, there is an increased demand for automatic meter reading (AMR) systems, which electronically collect meter readings, and their applications are growing in industrial, commercial, and utility environments.

EXISTING WORK

Figure 1 represents the existing system. In this existing system, the AC supply is given to the energy meter, the energy meter can note the meter readings, that is connected to microcontroller. The microcontroller is interconnected to 2 channel relay, and the relay operates the loads. In this existing system only can measure the voltage and current ant units of the house in the energy meter and with the growing demand for electricity and improved energy management, energy metering has become an important practice. It assists in understanding use patterns, recognizing overuse, and implementing strategies to improve energy use. This paper discusses various energy metering practices and the role of energy metering in enhancing energy efficiency. This system cannot have a prepaid billing system. To overcome this, an advanced energy metering and load control system for a time scheduling system was proposed [4].

PROPOSED SYSTEM

Figure 2 shows that the system uses an ESP32 chip to save energy and track power usage. It shows real-time data, helps pay bills, and controls power loads using wireless options. The ESP32 chip powers the system, taking readings from the meter and using them to manage bills, time, and power loads.

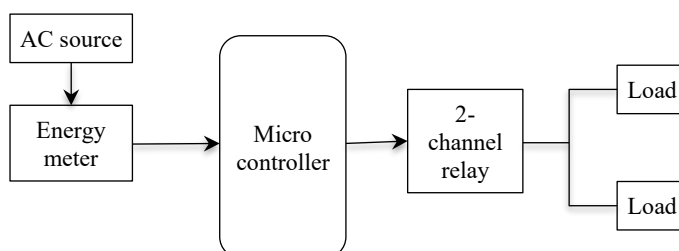


Figure 1. Existing system block diagram of smart energy meter system.

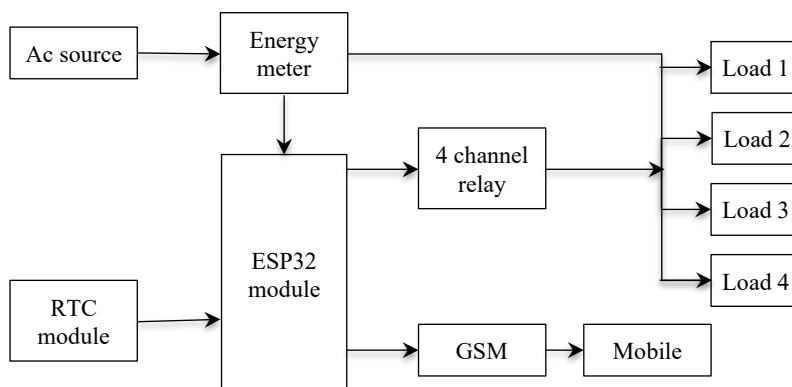


Figure 2. Proposed system of advanced energy metering and load control system.

One of the main components of this system is prepaid billing using GSM. Users pay for energy before using it. As they use power, units are cut. The GSM sends SMS alerts about balances, low credits, and auto power off if credits are used. This solves postpaid problems, such as late payments and bill fights. The system also has a real-time clock for controlling the appliances. Users can set times for device use and shut off when busy or not needed to save energy [5].

Initially, an AC supply is provided to the energy meter, and the center microcontroller is connected. The energy meter is interconnected with the loads and microcontroller. The microcontroller is the core of the system, and relay should operate the loads. When the energy bill is generated, the amount should be automatically reduced, and this is called postpaid billing. The proposed system prepaid paid billing, and the message notification should be sent to the user through the GSM module. In this system, scheduling is performed, and to improve efficiency, the system incorporates an automation mechanism driven by motion sensors. A PIR sensor detects people in a room and turns the lights on or off. It also performs this function for other devices. This saves power when no one is present. Relay parts help in this setup, allowing users to control things with rules. These rules use weight, movement, or time, making power use good [6].

The proposed automatic energy metering system incorporates several new and innovative features that offer advanced advantages over current energy monitoring techniques. The two-way communication system depicts the cost, and the system is intuitive to manage and scale. The pay-as-you-go concept is a more practical approach to handling our energy use, placing real-time data gathering and automated management under one roof when contrasted with a conventional one-way meter. The system can send you instant alerts, schedule your home appliance on at different times, and help monitor your energy use, allowing you to use energy in the most efficient & effective way. In addition, utilizing a prepaid metering system negated the need for monthly bill calculations and manual disconnections. By enabling the use of renewable sources like solar or wind to offset some or all of power use, an ingenious load-administration scheme must be in place to scale up to a future power system [7]. This gives you real-time, granular details relating to energy outputs, manage payments when your household energy habits change, and thereby helps you to integrating the power you make more effectively with the grid, rather than letting it all go to waste. Overall, the proposed ESP32-based Advanced Energy Meter and Automatic Load Control System is a scalable, cost-effective, and intelligent real-time energy monitoring, billing pre-paid automatic management of electrical loads solution which allows users to remotely monitor, control and schedule appliances for specific times and/or energy costs. Powered by IoT, GSM Connectivity, RTC scheduling, and motion-based automation, both commercial and residential consumers can reduce their energy costs with real-time, two-way communication energy consumption.

COMPONENTS AND ITS SPECIFICATIONS

1. NodeMCU (ESP32)
2. 4-Channel Relay Module
3. RTC (Real Time Clock) module
4. GSM (Global System Mobile Communication)
5. Energy Meter

NodeMCU (ESP32) A tiny, inexpensive, and open-source Wi-Fi microcontroller board intended for IoT applications is the NodeMCU ESP32 (Figure 3). It is built around the CH340 USB converter chip and ESP32 Wi-Fi transceiver module. These are a few of its attributes: Wi-Fi: 802.11, 2.4 GHz Wi-Fi with an on-board antenna and integrated TCP/IP Programmable via the Arduino IDE, it has interpreters to execute commands in languages like LUA GPIO: 17 GPIO, 11 of which are functional Chipset: Tensilica L106 32-bit CPU with ESP32EX core Wi-Fi SoC USB: Has a reset button and a micro USB port. Compatibility: Works with Python and the Arduino IDE A tiny, inexpensive, open-source Wi-Fi microcontroller board intended for Internet of Things applications is the Node-MCU ESP32 [8].



Figure 3. NodeMCU (ESP32).



Figure 4. Channel relay module.

Specifications

Operating voltage -3 V to 5 V

Input voltage-5 V

Wi-Fi (802.11 b/g/n)

4 GHz Wi-Fi and Bluetooth Combo

Inbuilt Wi-Fi module with range of 50 to 100 meters

Channel Relay Module

The adaptable 4-channel isolated relay module (Figure 4), known as 4 Channel Relay Module, is made to be easily controlled by a wide range of microcontrollers, including NodeMCU ESP8266 and more. A wide range of appliances and equipment with high current requirements can be effectively handled by it, thanks to its maximum contact capacities of AC 230 V 10 A and DC 30 V 10 A. This 4-channel relay is used to connect various loads, such as fans, bulbs, and ACs [9].

Specifications

The supply Voltage was 3.75 V, 6 V the max contact voltage of the relay was 230 V AC, 30 V DC

RTC (Real Time Clock) module

A real-time clock (RTC) module (Figure 5) is a standalone timekeeping device that continues to keep time and date when the main microcontroller or system is powered off. RTCs differ from the regular timers found within a microcontroller system, as RTCs keep the time rather uniquely powered by a small backup battery (like a CR2032) or a supercapacitor. RTCs are very useful for applications that require better timekeeping, such as data logging, scheduling, automation, or low-power IoT devices [10].

Specifications

- Operating voltage—5 V
- Maximum current—15 mA
- Battery backup—CR2032

GSM (Global System Mobile Communication

ESP32 microcontroller can be equipped with a GSM (Global System for Mobile Communications) module (Figure 6) which uses a cellular network to connect to the cloud for calls, SMS and the Internet (GPRS/3G/4G/5G). GSM modules are widely used in IoT applications, including remote monitoring, smart agriculture, GPS, and emergency alert systems [11].



Figure 5. RTC (real time clock) module.



Figure 6. GSM (global system mobile communication).

Specifications

- SIM900A
- Network—2G/3G/4G
- Communication—UART
- Supply voltage—3.3 V to 4.2 V

Energy Meter

The energy meter (Figure 7) is a tool that measures the electrical energy usage in homes, industries, or embedded systems. Energy meters provide a range of information, such as voltage, current, power (watts), power factor, and energy consumption (kWh). Energy meters can interface with ESP32 for IoT-based energy monitoring, automation, and smart grid applications.

Specifications

- Frequency—50 Hz
- Rated voltage—230 V
- Max current rating—30 Amps
- Current circuit at rated current— <1 A
- Voltage circuit at rated current— <1 W/4 VA

RESULTS AND DISCUSSION

The IoT-based advanced home automation system (Figure 8(a) and (b)) using Node-MCU ESP32 successfully controls household appliances such as lights and fans remotely through a Blynk app.



Figure 7. Energy meter.

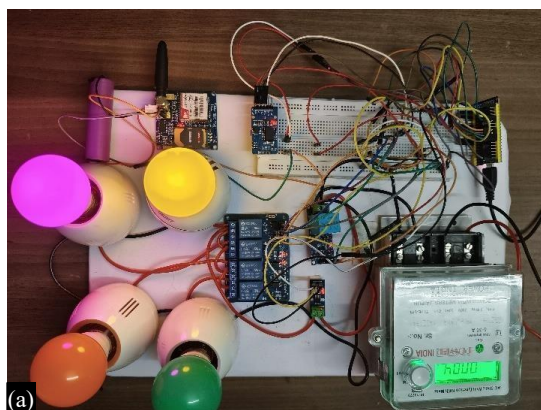


Figure 8. (a) Lights 1 and 2 are ON during daytime.

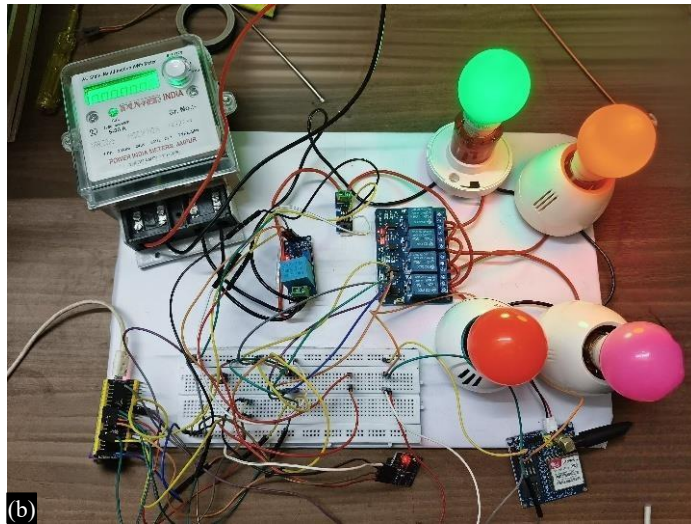


Figure 8. (b) Lights 3 and 4 are ON during nighttime.

The system shows quick response time, allowing users to operate devices from the Wi-Fi range and access them.

This framework highlights the development of Node-MCU ESP8266 in low-cost energy efficiency remotely control improving comfort and effectiveness, but it depends intensely on steady wi-fi network and reduce human effort, easy to operate and safety.

RELATED WORK

Many studies have examined IoT-based energy metering and load control systems. In [2], a real-time energy metering system was realized on a smart meter with cloud-based analytics that allowed users to analyze their energy consumption habits; however, it did not have load control automation. In [12], a motion-sensing method was incorporated into smart lighting systems for energy efficiency.

Although the method was effective for reducing energy for lighting control, there was little mention of a more complete load management method for multiple appliances. In [13], a different but related time-based scheduling system was developed for home appliances with a Raspberry Pi; this solution was effective for an energy cost reduction purpose but was more costly and complex than a microcontroller solution. Our proposed system builds on previous work completed to demonstrate an energy metering, energy saving, and scheduling system that utilizes a low-cost ESP32 based architecture. Finally, these methods yield a complete and scalable energy management strategy suitable for residential and industrial settings.

CONCLUSION

This study presents an intelligent energy management system that utilizes IoT technologies to improve energy efficiency. The proposed system features energy metering, motion-based load control, and scheduling, which improves energy efficiency and saves money for the user. The results of this study indicate that both automated scheduling and motion-based control significantly reduce energy consumption without compromising user experience.

The system provides a cost-effective and scalable energy management solution for various environments, such as smart homes, office environments, and industrial applications. Future work will include integrating machine learning algorithms for predictive energy management; improving the accuracy of the sensors used in the system; and extending the system beyond energy management to encompass industrial applications. Equipping the system with edge computing capabilities on the ESP32 would improve real-time decision-making and possibly reduce reliance on cloud computing.

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