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The Future of Energy: How Smart Meters are Reshaping Consumption and Conservation

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Abstract

By offering real-time data on electricity consumption, smart electric meters are revolutionizing energy management by empowering customers and utilities to make educated decisions about energy conservation and use. These meters are compatible with cutting-edge features including outage monitoring, demand response programs, and smooth integration of renewable energy sources. In addition to optimizing energy use and lowering costs, this also improves grid dependability and helps create a more sustainable energy future. But there are drawbacks to smart meter adoption as well, such as privacy worries over precise usage data and cybersecurity threats because of their networked nature. Smart meters can completely transform the energy industry and open the door to more economical, sustainable, and efficient energy management, notwithstanding these obstacles. They optimize energy use, lower expenses, and improve grid dependability by providing accurate, current information. Smart meters enable utility providers to respond to faults or outages more quickly and manage demand more effectively. By encouraging customers to use energy more efficiently during off-peak hours, they promote dynamic pricing models that assist stabilize the power system and lessen the need for extra energy production.

Keywords: Consumption monitoring, real-time data, remote monitoring, energy management, Internet of things

INTRODUCTION

The introduction of Internet of Things (IoT) technology in smart electric meters is a major leap in how we manage and track energy use. Traditional meters only measure how much electricity is used, but smart meters are more advanced, with sensors, communication tools, and computing capabilities. These IoT smart meters offer a wide range of features that completely change how electricity is monitored, controlled, and used.

These smart meters use sensors and control devices connected through special communication networks. They collect real-time data on energy consumption, allow remote monitoring and control of electricity use, and help manage things like demand response programs. This study will explain how smart meters work, the two main types of communication technologies used, Radio Frequency (RF) and Power Line Carrier (PLC), and the latest advancements in these technologies. It will also look at the status of smart grid projects around the world, focusing on policies, goals, and what is coming.

We will explore the key benefits and features of IoT-enabled smart meters, and their impact on

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consumers, energy suppliers, and the entire energy system. These meters can help integrate renewable energy sources, optimize energy use, and improve the efficiency of the grid. However, there are challenges, like concerns about data privacy, cybersecurity, and compatibility between different systems.

Another important development is the growing use of LED lighting and how it is opening the potential for Free-Space Optical (FSO) communication. Unlike traditional Radio Frequency (RF) communication, LED-based wireless networks offer benefits like faster data speeds, better security, lower energy use, and easy integration into daily life. Since these systems use visible light, which is widely available and unregulated, they provide a promising and efficient alternative for future communication systems [1–5].

Finally, traditional power grids are being transformed into smart grids (SGs) to address problems like energy wastage, increased demand, and security. Unlike old grids, which only send energy in one direction, smart grids allow for two-way energy flow between energy providers and consumers, improving the efficiency and management of energy across generation, distribution, and consumption.

Smart meters and the move to smart grids offer great potential for making energy use more efficient, sustainable, and secure, while also opening the door for new technologies like FSO communication to further enhance the energy ecosystem [7–10].

SYSTEM ARCHITECTURE

The block diagram of the system is shown in Figure 1.

Components of the Block Diagram

ESP32 Microcontroller

The ESP32 is a highly versatile microcontroller with built-in Wi-Fi and Bluetooth capabilities, making it perfect for IoT applications. It is a dual-core processor that can handle complex tasks, such as data processing, communication, and managing multiple devices simultaneously. In this system, the ESP32 serves as the central controller, gathering data from the voltage and current sensors, managing communication between the components, and performing actions like controlling other devices.

ZMPT101B Voltage Sensor

The ZMPT101B is a voltage sensor designed to monitor AC voltage. It outputs a voltage that corresponds to the measured mains voltage level. By using this sensor, the ESP32 can gather data on the voltage levels of the system and process this information for monitoring purposes or trigger specific actions when the voltage exceeds preset limits.

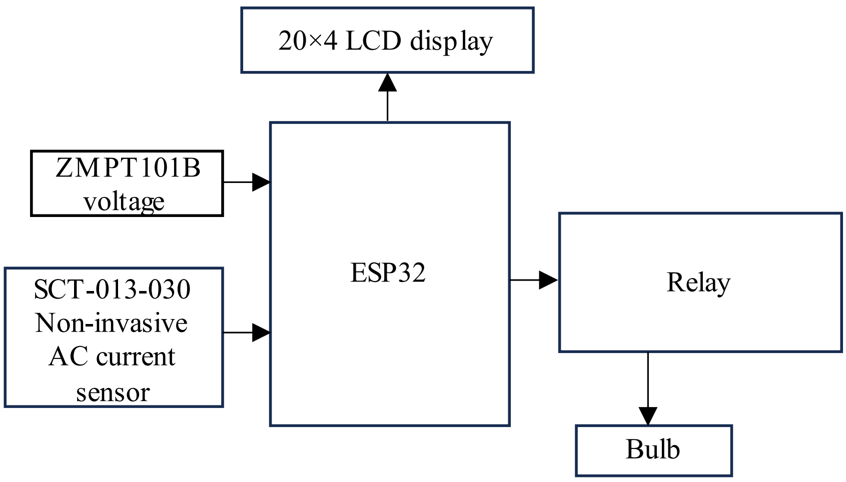

Figure 1. Block diagram of IoT based intelligent energy metering system.

SCT-013-030 Non-invasive Current Sensor

The SCT-013-030 is a non-invasive current sensor that measures AC current without needing to directly connect to the wire. It works by using a current transformer to detect the current flowing through the conductor. This sensor sends the current measurements to the ESP32, enabling it to track real-time current usage and, if needed, make decisions like activating or deactivating devices based on current conditions.

LCD Display

The LCD display offers a visual interface for users to view essential data like voltage and current measurements. The ESP32 communicates with the LCD to update and display the information in real-time. This makes it easy for users to monitor system performance and make informed decisions, such as turning devices on or off based on the data being presented.

Relay

A relay is a switch that can be controlled by the ESP32 to turn devices on or off. The ESP32 sends a signal to the relay, which can then open or close the circuit, controlling external devices such as lamps or appliances. In this system, the relay works as an output component, enabling automated or manual control based on the system's inputs, such as when the voltage or current readings surpass set thresholds.

These components work together to form a smart energy monitoring and control system. The ESP32 processes data from the voltage and current sensors and sends real-time information to the LCD display. The relay then enables actions like turning devices on or off based on the system's readings, allowing for efficient energy management and automation.

OPERATIONAL OVERVIEW

ESP32 reads voltage and current data from the ZMPT101B sensor and the SCT-013-030 sensor. It processes this data to calculate key parameters like energy consumption and to detect any deviations in voltage or current levels. TheESP32 provides users with real-time energy consumption information by communicating with an LCD screen to display data. Additionally, ESP32 controls the relay to turn the lamp on and off according to predetermined conditions or user instructions. For example, it can automatically turn off the light if the current exceeds a certain level to prevent overcharging. Overall, this system allows monitoring of electricity consumption and contributes to energy efficiency and safety by providing control over connected loads.

IMPLEMENTATION DETAILS

Implementing a power system using an ESP32 microcontroller involves several important steps. First, ESP32 needs to be installed with the necessary tools and libraries to ensure communication with sensors and output devices and to establish Wi-Fi communication. Once installed, the ZMPT101B sensor and SCT-013-030 sensor are integrated into the ESP32 and connected to the input pin to capture actual voltage and time data. The microcontroller then processes this data, calculates parameters such as power consumption and detects abnormal voltage or current levels.

In addition, logic is normally applied to control the relay according to preset values or user commands, allowing the connected load to be changed. The ESP32 provides users with real-time information on energy consumption by communicating with an LCD screen to display data. During the application process, tests and calibrations were carried out to ensure accurate and reliable measurements. After testing, the system can be integrated and installed at the desired location, allowing effective monitoring of electricity consumption and control of connected loads, contributing to energy efficiency and security.

RESULT

The smart electric system presented in this study helps monitor and manage electricity effectively by combining the latest technology with a user-friendly web interface. The hardware of a smart electric meter is shown in Figure 2. It shows the basic structure of the measuring device, which includes several major components. This includes a fully equipped measuring device, a powerful microcontroller for data processing and analysis, a wireless communication module for connecting without a fixed connection (such as Wi-Fi) and secure storage for storing user data. Figure 2 shows how these components are tightly integrated into the measuring device, ensuring reliability and efficiency in use.

The user interface of the smart electric meter is presented through a dynamic and user-friendly webpage (Figure 3), accessible via any web-enabled device. The interface offers a wealth of features to users, empowering them with real-time insights into their electricity usage patterns. Users can visualize their consumption data through interactive charts and graphs, track trends over time, and set personalized energy-saving goals. The webpage interface also facilitates remote monitoring and control, allowing users to adjust settings, receive alerts for abnormal usage, and remotely manage connected devices for optimized energy efficiency.

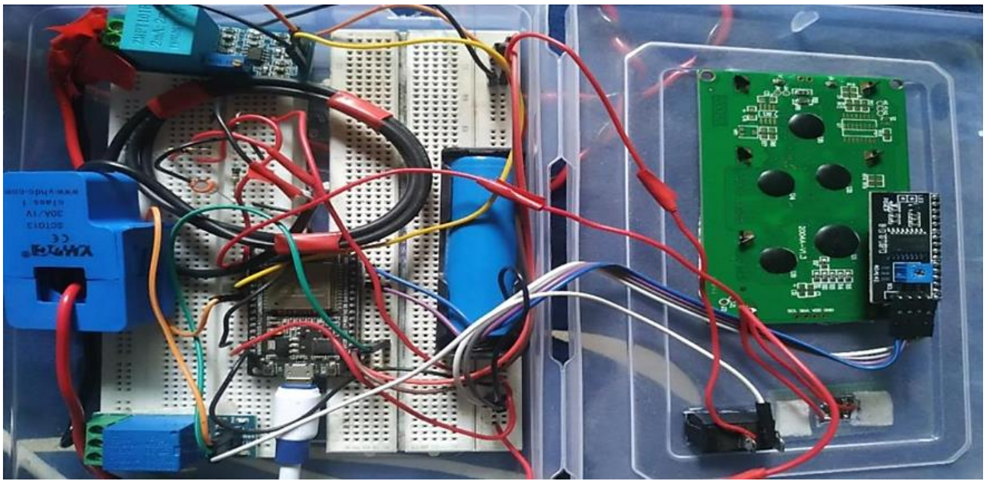

Figure 2. Hardware system of smart electric meter.

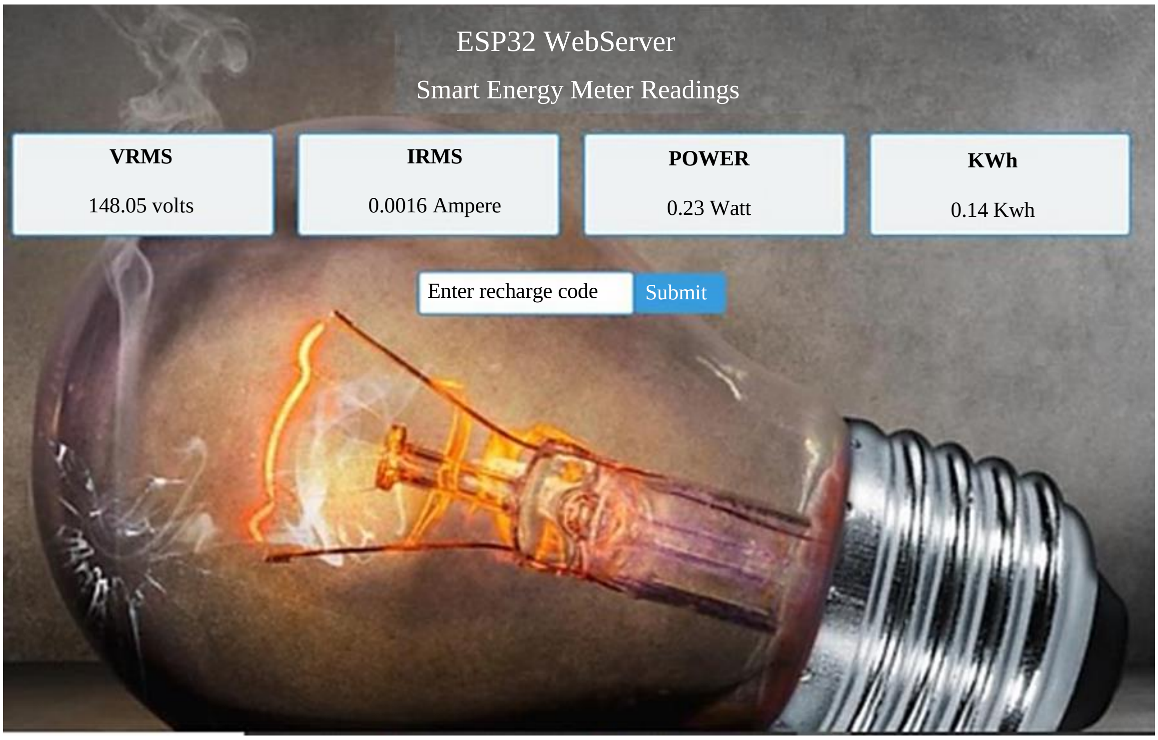

Figure 3. Webpage of the proposed system.

POTENTIAL APPLICATIONS

1. *Residential Energy Management:* Homeowners can use the system to monitor electricity consumption in real time, so they can detect energy-consuming devices and adjust their usage to reduce consumption and save on energy bills.
2. *Commercial and Industrial Monitoring:* Companies can use the system to monitor energy use in business and industry, ensuring efficient resource allocation and the development of high energy efficiency.
3. *Demand Response Programs:* Utilities can use data collected by smart meters to implement demand response programs that encourage consumers to reduce electricity use during peak demand to reduce the load on the electric grid.
4. *Renewable Energy Integration:* The system can facilitate the integration of renewable energy sources such as solar or wind power by providing real-time information on electricity consumption and production, allowing better management of distributed resources [6].
5. *Smart Grid Optimization:* By deploying smart meters on the electrical grid, utilities can gain insight into energy consumption and network performance, resulting in more efficient network management, more predictable maintenance, and greater reliability [7].
6. *Smart Grid IoT Applications:* As energy grids have grown and new energy technologies emerge, along with the rise of the Internet of Things (IoT), we are moving towards a concept called the *"energy internet"*. Over time, the *electrical power grid* has become the core of the energy system, connecting and managing how energy is generated, distributed, and used [8].

CONCLUSION

In conclusion, the implementation of a smart energy system using the ESP32 microcontroller and IoT technology represents a significant advancement in energy management and product control. The system offers a variety of applications that can be used in residential, commercial and industrial sectors, allowing real-time control of electricity consumption, response capacity, coordination of renewable energy sources and improvement of network performance. Smart metering systems contribute to energy efficiency, grid reliability and energy sustainability by providing consumers with information about how they use their energy and providing utilities with decision-making tools. In addition, the system can support functions such as electric vehicle management, remote energy control in off-grid areas and energy efficiency campaigns. With ever-increasing technological advances and increasing awareness of the importance of energy conservation, the use of solar energy systems is poised to play a significant role in shaping the future of energy, leading to more efficient, stable and sustainable energy

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