Intelligent Power Socket

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***Abstract*—**This paper presents the development of a smart socket designed to monitor and control household energy consumption through the Internet of Things (IoT). The system integrates an ESP32 microcontroller, sensors, and an MQTT-based communication protocol to enable real-time energy monitoring and remote control of connected appliances. An intuitive web-based interface allows users to access and manage energy data efficiently. The system was tested under various conditions to evaluate its accuracy, reliability, and scalability. Results demonstrate the smart socket's potential for enhancing energy efficiency and facilitating sustainable energy practices in residential settings.

***Keywords*—**smart socket, Internet of Things (IoT), energy measurement, remote control, smart home.

I. Introduction

The growing emphasis on energy conservation and sustainable practices has highlighted the need for efficient household energy management systems. Residential electricity consumption accounts for a significant proportion of global energy use, and the ability to monitor and control appliances in real time is essential for reducing energy waste and optimizing consumption patterns [1][2]. Traditional energy monitoring systems, while effective, often lack accessibility and user-friendliness, limiting their adoption in everyday households. Advances in IoT technology provide a solution by enabling connected devices to gather, transmit, and analyze data seamlessly, empowering users to make informed energy-saving decisions [3].

Smart sockets represent an innovative application of IoT in energy management, offering a versatile and cost-effective solution for monitoring and controlling electrical appliances. By integrating real-time energy monitoring, remote control, and automation capabilities, smart sockets help users optimize their energy consumption and contribute to sustainability goals. Recent studies have demonstrated the effectiveness of IoT-enabled devices in reducing energy waste and enhancing user engagement in energy management [4][5]. However, challenges such as scalability, data reliability, and integration with existing systems remain significant barriers to widespread adoption.

This paper introduces a smart socket system designed to address these challenges. The system utilizes an ESP32 microcontroller as its core, incorporating sensors to measure energy consumption and an MQTT-based communication protocol for efficient data transmission. The system is complemented by a web-based interface that enables users to monitor energy usage and control appliances remotely. By combining cost-effective hardware with intuitive software, the proposed smart socket aims to provide an accessible solution for real-time energy management in residential environments.

II. Integration

The integration of sensors and the ESP module significantly enhances the smart socket's functionality by providing comprehensive monitoring and control capabilities. A key component in this integration is the current sensor, specifically the ACS712 -30A Hall effect current sensor, which measures the current and power consumption of devices connected to the smart sockets [2]. This data is crucial for users to monitor and manage their energy usage effectively, preventing wastage and promoting energy efficiency. Additionally, the NodeMCU, which is based on the ESP8266-12E Wi-Fi module, acts as the central control unit, facilitating

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remote control and automation of the smart sockets [2]. This module processes data received from the server and allows users to interact with their smart sockets through a web interface, providing a seamless user experience. Furthermore, the integration of the relay module, activated by the NodeMCU, enables the physical control of the power supply to connected devices, allowing them to be turned on or off remotely. This feature, combined with the ESP module's ability to control sockets even when their physical switches are off, highlights the system's robustness and flexibility. To maximize the smart socket's potential, further emphasis should be placed on expanding its scalability and enhancing user accessibility through advanced smartphone applications. This comprehensive integration of sensors and ESP modules not only augments the smart socket's functionality but also underscores the importance of innovation in creating energy-efficient and user-friendly smart home solutions.

In the smart socket system, MQTT (Message Queuing Telemetry Transport) plays a pivotal role in facilitating communication between devices, leveraging its lightweight and efficient design to operate effectively in resource-constrained environments such as those involving smart home devices. The protocol's publish-subscribe architecture simplifies the communication process, allowing the smart sockets to not only send but also receive messages from a central control unit like the NodeMCU, which orchestrates the system's operations. This design ensures that the smart socket can efficiently manage its power usage and maintain reliable connections even when network conditions are less than ideal, further enhancing the system's overall efficiency and reliability. Given these capabilities, MQTT is particularly well-suited for smart socket systems, ensuring seamless and robust communication that is crucial for real-time monitoring and control of home appliances. This underscores the necessity for adopting MQTT in environments where efficient and reliable communication is paramount, especially as smart home technologies continue to evolve and demand more sophisticated connectivity solutions.

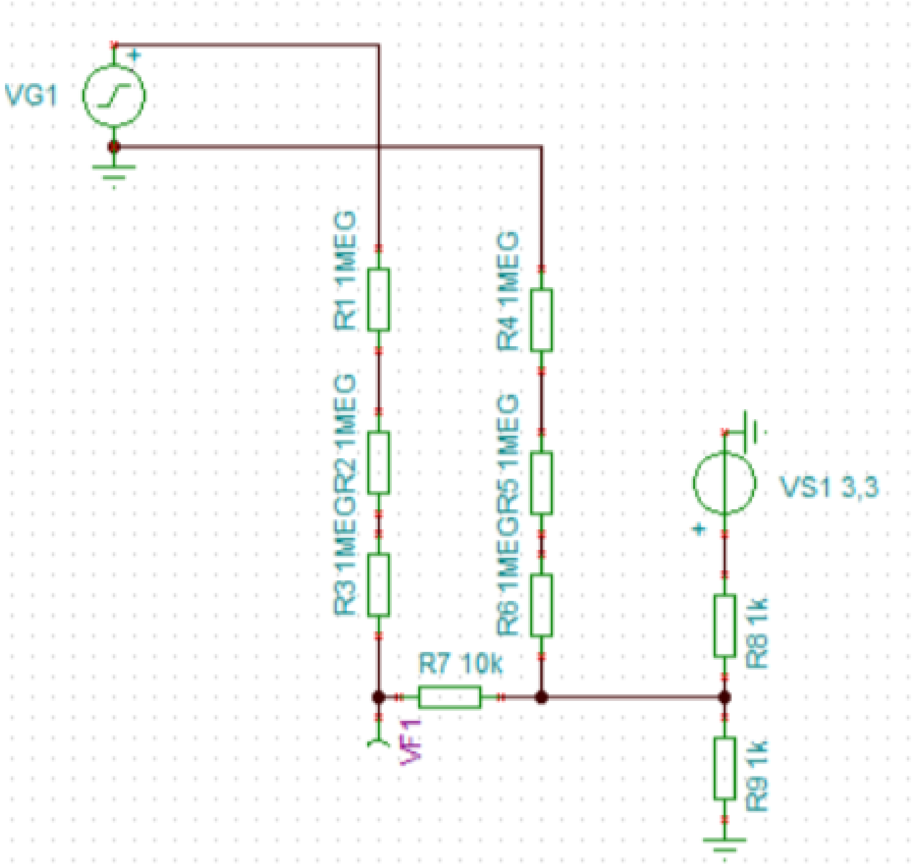

Fig. 1 Power circuit for voltage measurements

The smart socket's architecture was designed to balance compactness, cost-efficiency, and functionality. It integrates several key components: an ESP32C3 microcontroller for control and communication, an ACS712 sensor for current measurement, and voltage divider circuits for safe voltage monitoring. The system communicates with a centralized server using the MQTT protocol and presents real-time data to the user through a Node-RED dashboard. The final prototype integrates all hardware components into a custom-designed enclosure. The enclosure was produced using 3D printing to accommodate the PCB and other electronics. This design ensures the device is robust and suitable for household use.

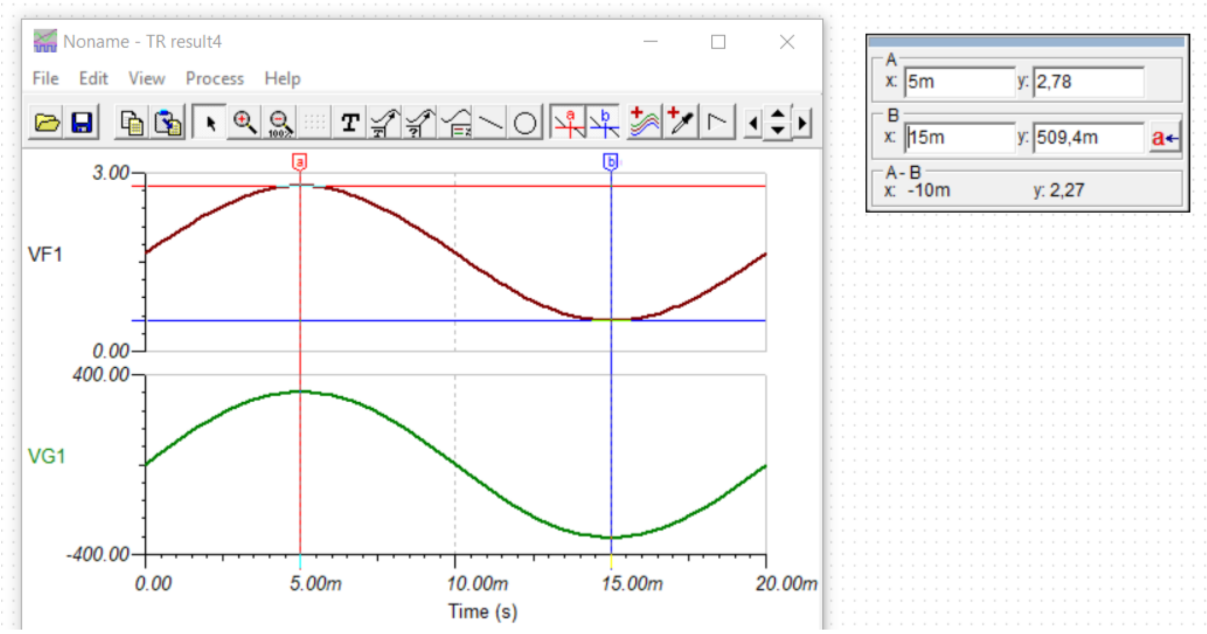

Fig. 2 Simulation of the power circuit for voltage measurements performance

Fig. 3 Final PCB of the device

III. Conclusion

The smart socket demonstrated reliable performance in monitoring and controlling energy consumption. The results validate the smart socket's potential as an effective tool for residential energy management. By combining real-time monitoring, remote control, and user-friendly interfaces, the system addresses key limitations of traditional energy management solutions. However, challenges such as integrating the system with existing home automation platforms and optimizing sensor performance under extreme conditions were identified during testing. Future work could focus on expanding the system's capabilities, such as adding machine learning algorithms for predictive energy analysis or integrating with renewable energy sources to further enhance sustainability. This study presents a smart socket system designed to empower users with real-time energy monitoring and control capabilities. By leveraging IoT technologies and cost-effective components, the system provides a scalable and user-friendly solution for optimizing household energy consumption. The successful implementation and testing of the smart socket underscore its potential to contribute to sustainable energy practices. Future research should explore expanding the system's functionality and integrating it with broader smart home ecosystems.

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