

Distributed Smart Socket System (DSSS) For Industrial Applications

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Abstract

Conventional electrical socket systems provide only basic power delivery and lack real-time monitoring, intelligent control, and safety awareness. This limitation often results in inefficient energy usage, difficulty in detecting abnormal load conditions, and increased risk of electrical faults. To address these challenges, this invention proposes a Distributed Smart Socket System (DSSS) for intelligent power monitoring and control using Internet of Things (IoT) technology. The DSSS employs a distributed architecture in which each smart socket unit independently monitors electrical parameters such as voltage, current, power, and energy consumption. Each socket is equipped with sensing modules, a relay-based load control mechanism, and an embedded controller to enable both remote and manual operation. A centralized master control unit wirelessly communicates with all socket units to collect real-time data and issue control commands. An integrated Human–Machine Interface (HMI) in the master unit displays socket-wise electrical parameters, load status, and system health in a user-friendly format. The system also supports detection of abnormal conditions such as overloads or excessive power consumption, thereby improving electrical safety and reliability. By distributing intelligence across socket units, the DSSS enhances scalability, energy efficiency, and operational control, making it suitable for smart homes, commercial buildings, laboratories, and industrial applications.

1. Introduction

The increased use of electrical and electronic devices in different environments has led to a high demand for efficient and intelligent energy management systems [1], [2], [5]. Electrical sockets are passive devices used to provide power to connected devices. However, they do not provide real-time power consumption information and do not monitor and control power consumption and safety [3], [11]. This has led to energy wastage and difficulties in identifying faulty loads and safety concerns [6], [14]. To address these challenges and improve power consumption and safety, this paper presents a Distributed Smart Socket System (DSSS) for real-time power monitoring and control using IoT technology [4], [7], [9].

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The proposed system uses a distributed system where smart sockets independently measure and monitor power consumption [8], [13]. Each smart socket unit independently measures and monitors various electrical parameters such as voltage, current, power consumption, and energy consumption [10], [12]. A centralized master control unit with a Human-Machine Interface (HMI) wirelessly connects to and collects data from all socket units [2], [7]. The proposed system is efficient and suitable for smart homes, laboratories, and industrial applications [5], [9], [15].

2. Literature Survey

The Internet of Things (IoT) and advancements in embedded technologies have helped to support modern-day energy monitoring and control systems [2], [7]. Several researches have been carried out to improve real-time electrical parameter monitoring, control, and optimization techniques [9], [11]. This section highlights some of the major methods that have already been developed to monitor and control electrical parameters with a focus on the research gap filled by the proposed Distributed Smart Socket System (DSSS).

2.1. IoT-Based Energy Monitoring Systems

IoT-based systems have been developed using voltage and current sensors with microcontrollers that enable real-time communication with cloud platforms or mobile applications [2], [11]. Such systems have improved access to remote data; however, most IoT-based systems have a centralized data collection approach that may not efficiently support data analysis for the socket level [9].

2.2. Smart Plug Technologies

Smart plug systems have been developed for remote control and basic monitoring capabilities using relay modules [1], [12]. Smart plugs are normally standalone systems; therefore, using such systems for a large-scale setup may prove to be expensive because there is a lack of coordination between multiple smart plug systems at a site level [13].

2.3. Distributed Embedded Monitoring Systems

Distributed monitoring systems consist of a number of sensor nodes connected to a controller node, which improves scalability and reliability since the load is shared among the members [8]. However, most of the existing systems have concentrated only on monitoring without integrating control, safety, and user interfaces into the system design [7].

2.4. Research Gap

Existing systems have concentrated on either centralized monitoring or individual device control, with very little emphasis on integrating the two. This has led to inflexibility, scalability issues, and a lack of safety features, which the proposed DSSS aims to address by integrating socket-level monitoring, centralized control, and safety features.

3. System Architecture

The Distributed Smart Socket System (DSSS) comprises a number of Smart Socket Units connected with a centralized unit called the Master Control Unit. Each smart socket works

independently and is connected wirelessly to the master unit. This creates a distributed system for monitoring and controlling smart sockets. This system is described in [5].

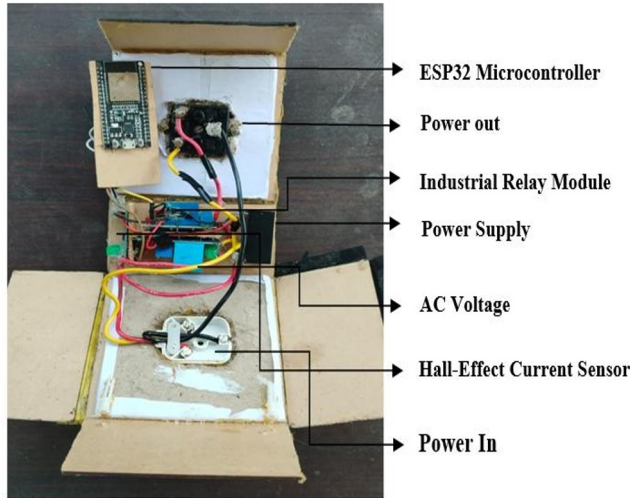


Fig. 1. Slave Box of DSSS

The Slave Box represents a smart socket unit for distributed sensing and control. Each slave box comprises a voltage sensor, current sensor, ESP32 microcontroller, relay module, and protection circuitry. The slave box constantly monitors and calculates power consumption and energy consumption. It wirelessly sends these calculated results to the master box and receives control signals from the master box. Additionally, the slave box comprises safety features such as overcurrent detection and automatic disconnection of the load. The working model of the Slave Box is shown in Fig.1.

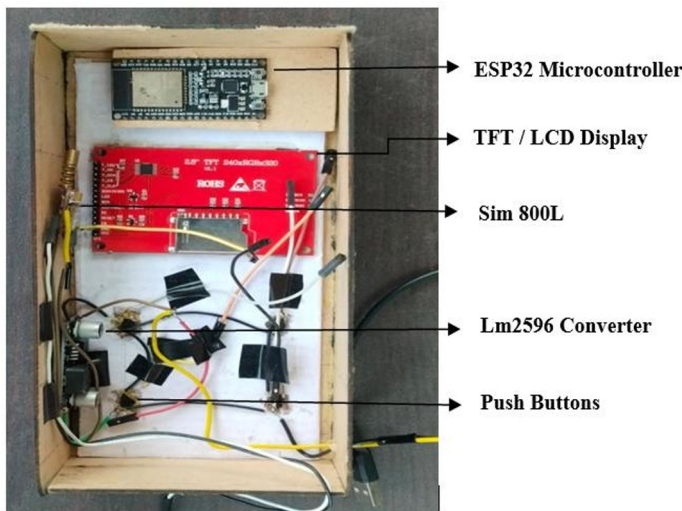


Fig. 2. Master Box of DSSS

The Master Box is the main control and monitoring unit of the Distributed Smart Socket System (DSSS) architecture. The Master Box contains an ESP32 module, a wireless communication module, and an HMI/TFT display unit for the purpose of visualization. The

Master Box receives all electrical parameters, i.e., voltage, current, power, and energy, from all the slave nodes of the DSSS. It also provides a feature for displaying all the electrical parameters in a user-friendly way. The Master Box also provides a feature for centralized control of all the electrical devices through an ON/OFF command sent to all the slave nodes. The model of the Master Box is shown in Fig. 2, which represents the centralized control and monitoring unit of the DSSS.

4. Methodology

The Distributed Smart Socket System (DSSS) is developed by following a modular architecture. This involves integrating smart socket units with a monitoring system [7], [11]. This methodology involves designing a system, integrating hardware, setting communication, processing, and safety implementation to ensure efficient system operation [10].

The system operates based on a distributed system configuration. Each smart socket operates independently with its own capabilities. Each smart socket node operates independently and sends signals to a controller for monitoring [5], [8]. This ensures flexibility and reliability of the system.

Each smart socket unit operates with a microcontroller and voltage and current sensors to measure current and voltage [2], [11]. A relay module is used to control the socket [6], [12]. Each smart socket unit also contains protection modules to ensure safety [10], [14]. The central unit contains a master controller, display interface, and a wireless communication module [7], [13]. Each smart socket unit operates independently and measures current and voltage. It then calculates power and energy consumption [9]. This ensures efficient system operation and reduces communication overhead. The smart socket unit then sends signals to the master controller for monitoring and logging [7].

This is achieved by the use of the Wi-Fi or ESP-NOW protocols, which enable the exchange of data between the nodes and the master unit [13]. The nodes are also assigned a unique ID, and the process of communication involves the transmission of data, control signals, and acknowledgement signals [2], [7].

The master controller is also used to display real-time data, including voltage, current, power, and load, using the HMI interface [4], [13]. The system also uses the button interface, which is convenient for the user [15].

Safety is another important aspect of the smart home network, which is achieved by the use of overcurrent, load disconnection, and short-circuit signals [10], [12]. The system disconnects the load and sends a signal to the master unit in case of any abnormality [14].

Finally, the DSSS prototype is tested for accuracy, reliability, and efficient communication by the application of different load conditions [9], [11]. The results of the test indicate that the system is stable, efficient, and reliable in its operation.

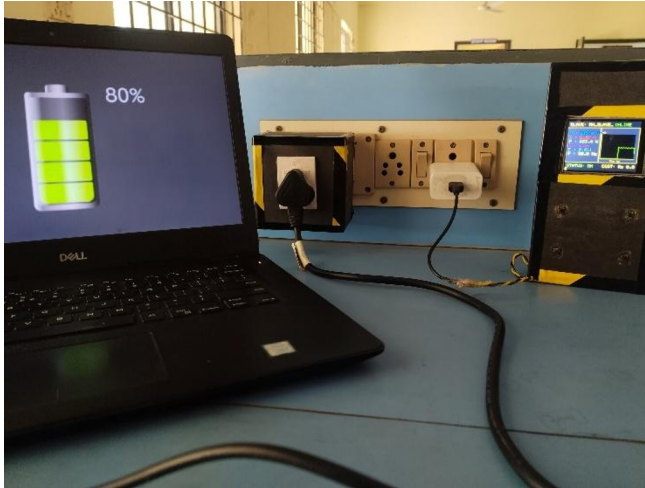


Fig. 3. Working Model of DSSS

As shown in the Fig.3, the final working model of the Distributed Smart Socket System (DSSS) shows the real-time monitoring and control of the electrical load. In this model, the laptop connected to the slave box is the load, and the system is continuously sensing the electrical parameters such as voltage, current, power, power factor, energy, and frequency. The master box is displaying the values of the electrical parameters along with the load condition, cost estimation, and the graphical representation.

5. Results and Discussion

The Distributed Smart Socket System (DSSS) prototype was implemented and tested under varying load conditions using lamps and small inductive load devices, as shown in Figure 1[7], [11]. The results have demonstrated that the smart socket unit is able to accurately measure the voltage, current, power, and energy consumption in real-time[13].



Fig.4. Output Display of Master Box of DSSS

As illustrated in Figure 4, the HMI display of the master unit displays the parameters, including voltage, current, power, power factor, energy, frequency, load status, cost estimation, and the graphical representation of the parameters. The master unit receives the data wirelessly from the slave unit connected to the socket unit, which is connected to the laptop load.

The wireless communication between the socket units and the master controller was stable with low latency[2]. The HMI display was able to provide the visualization of the parameters, and the relay-based load control was achieved with no significant delays.

The abnormal conditions were well handled by the system, where the overload detection led to the disconnection of the load. The system was set to operate at an overcurrent threshold of 2A with a response time of 500ms to 1 second. The distributed system was able to show the demonstration of its scalability feature [5], [8], where it was able to operate up to 3 to 5 nodes on the sockets.

PARAMETER	VALUE
Voltage Accuracy	$\pm 2\%$
Current Accuracy	$\pm 3\%$
Power Accuracy	$\pm 5\%$
Communication Latency	200–350 ms
Overload Response Time	<1 sec

Table.1. Quantitative Results

From the results obtained, it is evident that DSSS is able to provide accurate monitoring, communication, and control of the load while enhancing safety.

6. Conclusion

In this paper, the design and implementation of a Distributed Smart Socket System (DSSS) for smart energy monitoring and control was presented [4, 5]. The main advantage of using DSSS is that it does not follow a traditional centralized system for monitoring, unlike other systems. Instead, it is based on a distributed system, in which each socket is capable of operating individually, i.e., it can sense and control the load individually, but it is also capable of communicating with a centralized system, i.e., a master unit.

The combination of voltage and current sensing, relay-based control, wireless communication, and HMI-based visualization is also provided, which helps in the overall improvement of system performance [7, 13]. The DSSS is also capable of providing improved awareness of energy usage, improved electrical safety, and expansion capabilities [10, 14]. The DSSS is a cost-effective system for use in smart homes, laboratories, commercial buildings, and even industries.

The DSSS can also be improved further using cloud services, mobile applications, artificial intelligence, etc. The DSSS is also implemented as a prototype, and it is tested under operating conditions. The system was tested with up to 3–5 socket nodes, and no significant degradation in communication latency or performance was observed.

7. Future Advancements

The Distributed Smart Socket System DSSS can further be improved using advanced technologies for better smart functionalities. Cloud computing can be employed for storage of real-time data and energy trends for a long period of time. This would allow users to operate the Distributed Smart Socket System DSSS using a mobile or web app.

Artificial intelligence and machine learning can also be employed for predictive energy management. This would allow the Distributed Smart Socket System DSSS to evolve into an intelligent system for minimizing energy wastage.

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