International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** III **Month of publication:** March 2025

DOI: https://doi.org/10.22214/ijraset.2025.67952

Prioritized Power Distribution System

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Abstract: This paper presents a prioritized power distribution system utilizing the ESP32 microcontroller to enhance efficiency and reliability in electrical load management. By implementing IoT technology, the system monitors key parameters such as voltage and current, allowing for real-time adjustments based on demand and priority levels. The implementation of algorithms prioritizes critical loads during peak times or outages, minimizing downtime and preventing overloads. The ESP32's wireless communication capabilities enable seamless data transmission to a centralized platform for effective analysis and decision-making. Additionally, it notify users of anomalies, improving responsiveness. Overall, this innovative solution aims to optimize power distribution networks, reduce energy management costs, and enhance infrastructure reliability.
Keywords: ESP32, Power Distribution, IoT Load Management, Real-Time Monitoring, Wireless Communication, Energy Efficiency

I. INTRODUCTION

The demand for reliable and efficient power distribution systems has never been more critical as global energy consumption continues to rise. Traditional power distribution networks often face challenges such as aging infrastructure, increased load demands, and the need for enhanced monitoring capabilities. In this context, the integration of advanced technologies, particularly those associated with the Internet of Things (IoT), offers promising solutions to improve operational efficiency and reliability. The ESP32 microcontroller has emerged as a leading candidate for IoT applications due to its robust features, including built-in Wi-Fi and Bluetooth connectivity, low power consumption, and dual-core processing capabilities. These attributes make it ideal for real-time data acquisition and control in power distribution systems. By leveraging the ESP32, utility providers can implement smart monitoring solutions that continuously track critical parameters such as voltage, current, temperature, and load conditions. One of the most significant advancements in power distribution is the concept of prioritized load management. This approach involves dynamically adjusting power distribution based on predefined criteria to ensure that essential services remain operational during peak demand periods or system stress.

Load shedding strategies can be employed to temporarily disconnect non-essential loads, thereby preserving the integrity of critical infrastructure. This paper discusses the development and implementation of an ESP32-based prioritized power distribution system. It outlines the methodologies for real-time monitoring, data processing, communication protocols, and automated control actions that enhance energy efficiency and reliability. By harnessing the capabilities of the ESP32, this system not only addresses immediate operational challenges but also contributes to the long-term sustainability of electrical infrastructure in an increasingly energy-conscious world.[1]

II. LITERATURE SURVEY

The concept of a Prioritized Power Distribution System (PPDS) emerges as a solution to efficiently manage electrical loads during power shortages, ensuring critical appliances receive uninterrupted power. Existing research explores various techniques for intelligent power distribution, including demand-side management, smart grids, and IoT-based monitoring systems. Studies have demonstrated the effectiveness of priority-based load shedding in preventing system overload and optimizing available power resources.

IoT-enabled power management systems using ESP32, and cloud-based control interfaces have been widely explored to facilitate remote monitoring and automation. Prior research also highlights the role of renewable energy integration and real-time voltage sensing in enhancing system resilience. However, challenges such as dynamic load adjustments, seamless transition between power sources, and user-defined priority settings remain key areas of exploration. The proposed PPDS implements ESP32, a web-based UI, ensuring efficient power distribution with real-time monitoring and user-configurable relay prioritization, addressing gaps in traditional load management systems.[3]

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue III Mar 2025- Available at www.ijraset.com

III. SYSTEM DESIGN

A. Hardware Overview

The hardware design of the multifunctional agricultural manipulator consists of several components, each serving a specific role in automating agricultural tasks. The key hardware elements include:

1) Microcontrollers (ESP32/8266 and Arduino): The ESP32/8266 is used for wireless communication and image processing via an attached camera, while the Arduino handles real-time control of the actuators and sensors. This dual-controller setup allows for parallel processing, ensuring that the system remains responsive and efficient.[1]
2) Relay: Relays are a crucial component in the prioritized power distribution system, enabling control over the power supply to light bulbs based on the system's load management strategy. Depending on the required switching speed and load capacity, either electromechanical or solid-state relays can be utilized. These relays are connected to the GPIO pins of the ESP32 microcontroller, which allows for precise control over specific light bulbs according to their priority settings. When the ESP32 sends a signal to a relay, it can turn the corresponding light bulb on or off, effectively managing power distribution. It is important to ensure that the relays are rated for the voltage of the light bulbs being controlled, typically either 120V or 230V AC. This rating is crucial for safe operation, as using a relay with an inappropriate voltage rating can lead to failures or hazards. The control interface between the ESP32 and the relays allows for flexible and dynamic management of electrical loads, making it an essential aspect of the overall system design.[2]
3) Voltage Meter: A The voltage meter measures real-time voltage levels, providing the ESP32 with feedback on connected load power consumption. It communicates with the microcontroller via analog input or digital protocols like I2C/SPI. Data from the meter enables dynamic relay state adjustments based on current load conditions, optimizing power distribution. [3]
4) Light Bulbs: The LED bulbs are preferred for the prioritized power distribution system due to their energy efficiency and longevity compared to incandescent bulbs. The wattage of these bulbs must align with the relay specifications and overall power budget. By controlling the light bulbs through relays based on priority settings, the system can effectively manage energy usage while ensuring critical loads receive power when needed. [4]
5) LED strips: LED strips are an essential component of the Prioritized Power Distribution System (PPDS), serving as visual indicators of power allocation and priority-based switching. Compared to traditional lighting solutions, LED strips offer lower power consumption, higher efficiency, and longer lifespan, making them ideal for real-time status representation. The wattage and voltage ratings of the LED strips must be compatible with the relay specifications and overall power supply to ensure seamless operation. By integrating LED strips with relays, the system dynamically reflects priority-based power distribution, visually indicating which loads are active under different power conditions. This enhances user awareness and facilitates better energy management.[4]

B. Working of power distribution

The prioritized power distribution system is designed to efficiently manage electrical loads by leveraging the capabilities of the ESP32 microcontroller, relays, voltage meters, and light bulbs. This innovative solution aims to optimize energy usage while ensuring that critical loads receive necessary power during peak demand periods or outages. The mechanism behind this system involves several key components working in harmony to achieve optimal performance.

1) System Initialization: Upon powering up, the ESP32 microcontroller initializes all connected components, including relays and the voltage meter. It establishes communication protocols and configures GPIO pins for controlling relays and receiving data from the voltage meter. The system then enters a monitoring state, ready to assess load conditions and prioritize power distribution based on predefined criteria.[5]
2) Real-Time Monitoring: The voltage meter continuously measures the voltage levels of connected loads, providing real-time data to the ESP32. This information is crucial for understanding current power consumption and detecting any fluctuations in voltage that may indicate overload conditions. The ESP32 processes this data to maintain an accurate overview of the system's electrical
3) Priority-Based Control Logic: The ESP32 implements a control algorithm that determines which loads (light bulbs) should receive power based on their assigned priority levels. Critical loads are given precedence, ensuring they remain powered during high-demand situations. The microcontroller evaluates the voltage meter data and makes decisions to activate or deactivate relays accordingly, optimizing energy distribution.

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4) Relay Activation and Load Management: Based on the control logic, the ESP32 sends signals to the relays to switch specific light bulbs on or off. When a critical load is detected or voltage levels exceed safe limits, the system can deactivate non-essential loads to prevent overloads and maintain stable operation. This dynamic management allows for efficient use of available power while meeting demand.
5) Feedback Loop for Optimization: The system operates in a continuous feedback loop, where real-time data from the voltage meter informs the ESP32's decisions regarding relay states. If changes in load conditions occur, such as an increase in demand or a drop in voltage, the ESP32 recalibrates its control strategy to ensure optimal performance. This adaptive mechanism enhances overall energy efficiency and reliability in power distribution.[7]

IV. CONTROL SYSTEM

The control system for the prioritized power distribution system is designed to efficiently manage electrical loads based on their priority levels. This system leverages the capabilities of the ESP32 microcontroller, relays, voltage meters, and light bulbs to create a responsive and effective energy management solution.

The Prioritized Power Distribution System (PPDS) utilizes a priority management algorithm to categorize loads, such as light bulbs, based on their importance. Critical loads are given higher priority to ensure they remain powered during peak demand or outages, while non-essential loads can be temporarily disconnected to optimize energy usage. This algorithm is embedded within the ESP32 firmware, which continuously analyzes real-time voltage data from the voltage sensor to make informed relay activation decisions. Additionally, the system features a user interface that allows operators to monitor system performance and manually adjust priority settings if necessary.

To enhance responsiveness and maintenance efficiency, alerts or notifications can be integrated to inform users about anomalies or required actions, ensuring proactive system management.[8]

A. Task Automation

1) Energy Efficiency Optimization: By continuously analyzing load conditions and making real-time adjustments, the system optimizes energy usage across connected devices. This task automation not only reduces energy waste but also contributes to cost savings by ensuring that power is allocated efficiently based on actual demand.
2) Automated Alerts and Notifications: The system can be programmed to send automated alerts or notifications to users in case of critical events, such as excessive power consumption or relay failures. This feature enhances responsiveness and facilitates timely maintenance actions, ensuring the reliability of the power distribution system.
3) Scheduled Load Shedding: The system can be programmed to automatically shed loads during peak demand periods or at specific times of the day. This task automation helps to balance the load on the electrical grid, reducing the strain on power generation and distribution infrastructure.[9]

V. IMPLEMENTATION AND PROTOTYPE

In order to effectively control power distribution based on current conditions, the Prioritized Power Distribution System (PPDS) integrates ESP32, relays, voltage sensors, LED strips, and light bulbs. The Main Power Mode and Secondary Power Mode are the two power supply modes that the system is intended to operate in.

With the help of a voltage sensor and a priority management algorithm, the ESP32 microcontroller continuously checks voltage levels and adjusts relays as necessary. A web-based user interface (UI) that lets users adjust priority levels and track system performance[9]

LED strips in the prototype show power distribution according to priority settings, simulating a reduced-scale power distribution network. A 4-channel relay module, a 2-channel relay module, an ESP32, an emergency light circuit, two 6V batteries (for a total of 12V), and indicator bulbs are all part of the arrangement. There are two modes of operation for the system: Main Power Mode, in which all loads are kept active, and Secondary Power Mode, in which the priority management algorithm governs power distribution.

Relays can have their priorities dynamically assigned by the user through the user interface (UI), guaranteeing effective energy allocation and the absence of duplicate priorities. This prototype is a scalable solution for smart energy distribution since it successfully illustrates priority-based load control, intelligent power management, and real-time monitoring. The two operational scenarios that follow serve as examples of the implementation:

Fig. 1 System Working with Main Power Supply

1) System Working with Main Power Supply – Since the primary power supply is operational in this mode, all loads continue to be powered. The fact that the LED strips and bulbs are completely lit shows that power is freely flowing to all of the devices that are connected. All priority levels are guaranteed a continuous power supply since the relays stay ON.

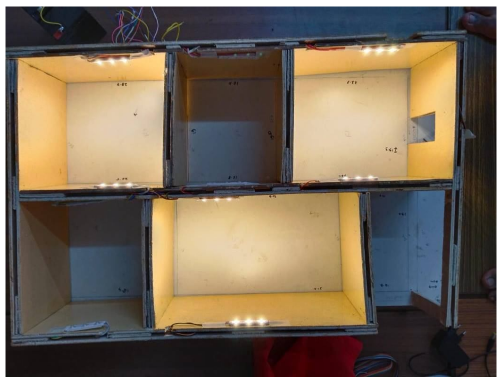

Fig. 1 System Working with Secondary Power Supply

2) System Working with Secondary Power Supply – The priority-based algorithm optimizes energy consumption by turning off non-essential loads and only activating the most crucial loads when the system transitions to secondary power. Depending on the priority settings, the LED strips clearly show which loads are still on. In order to ensure efficient power distribution, the ESP32 dynamically modifies relay operations in accordance with user-defined priorities.

This prototype is a scalable and workable solution for smart energy distribution since it successfully demonstrates priority-based load control, intelligent power management, and real-time monitoring..[10]

VI. CONCLUSIONS

An effective and clever power management system that guarantees the best possible energy use amid power fluctuations is demonstrated by the Prioritized Power Distribution System (PPDS). Real-time monitoring and dynamic priority-based load control are made possible by the system's integration of ESP32, relays, voltage sensors, and a user interface. Especially in times of power outages, the capacity to distinguish between important and non-essential loads guarantees that vital equipment always have power.

Two operating modes—Main Power Mode and Secondary Power Mode where power distribution is dynamically modified based on priority settings are successfully shown by the prototype. By using LED strips and indication lamps, power distribution is clearly shown visually, increasing user awareness. The system is a viable option for homes, businesses, and smart energy grids due to its scalability, automation, and remote control features.

To sum up, the PPDS improves power efficiency, lowers wasteful energy use, and guarantees smooth power distribution during blackouts. To further maximize performance and dependability, future improvements might use renewable energy, AI-based predictive analytics, and cutting-edge wireless connectivity technology.

VII. ACKNOWLEDGMENT

For the resources and technical assistance required to construct the Prioritized Power Distribution System (PPDS), the authors would like to sincerely thank Vivekanand Education Society's Polytechnic. We would like to express our gratitude to our mentors, instructors, and coworkers for their invaluable advice, helpful criticism, and support during the project. A special appreciation goes out to the ESP32 developers and contributors, as well as to other open-source platforms that were essential to the system's successful deployment. Finally, we would like to thank our family and friends for their unwavering encouragement and support during the research and development stage.

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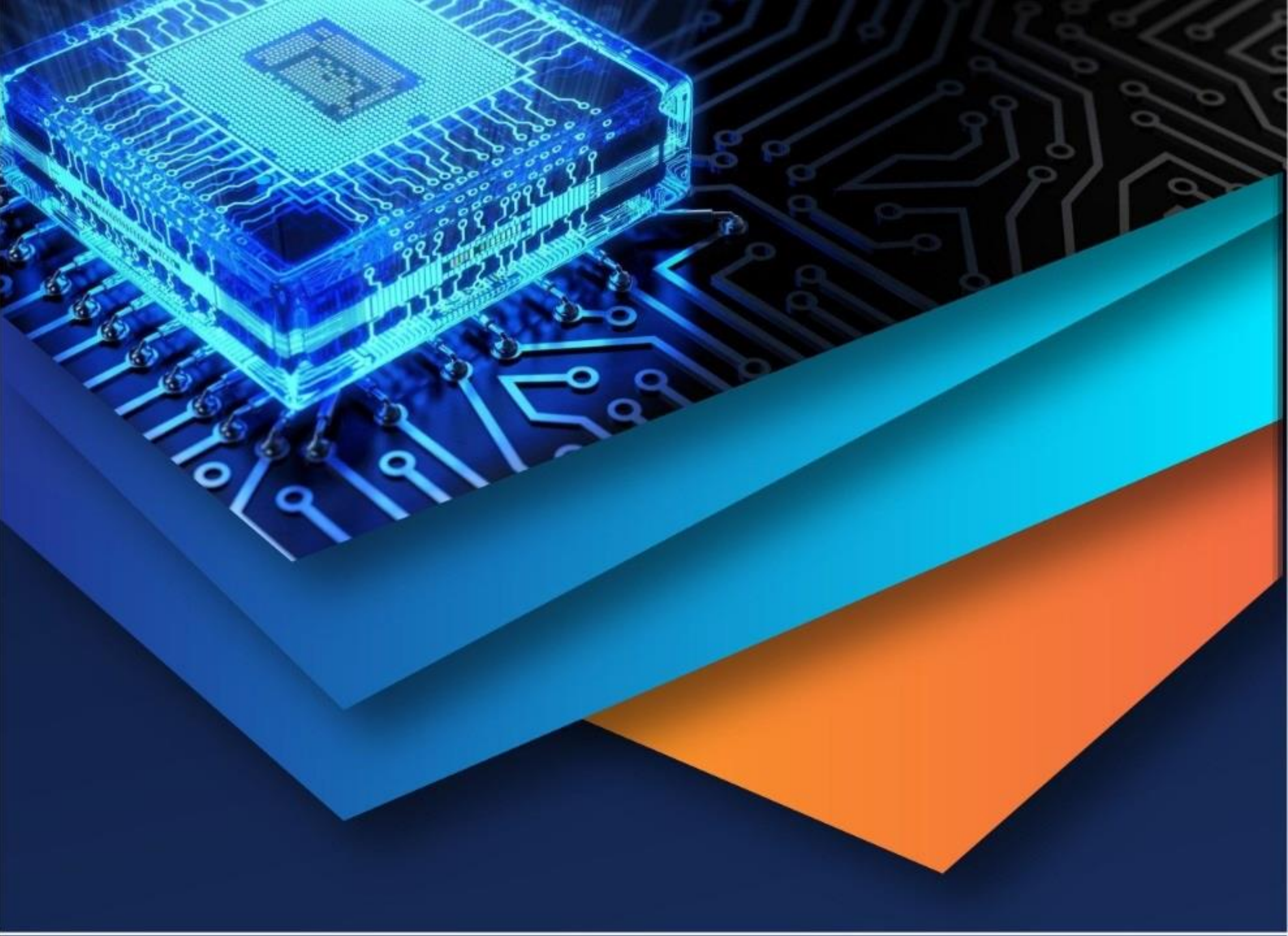

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