Microcontroller-Based Switching for Cost-Effective Load Management and Industrial Automation

Dr. P. Karuppusamy

Professor, Department of Electrical and Electronics Engineering, Erode Sengunthar Engineering College, Tamil Nadu, India

Email: pkarrupusamyphd@gmail.com

Abstract

This study proposes a microcontroller-based switching system designed for cost-effective load management and industrial automation. Using a microcontroller such as Arduino or PIC, this system controls relay modules to manage various electrical loads efficiently. Real-time data from current and temperature sensors enable accurate load management, preventing overloads and improving power usage. The system automates load switching based on predefined schedules and real-time conditions, reducing energy consumption and operational costs. Safety is enhanced through overcurrent and temperature protection mechanisms, safeguarding equipment, and ensuring safe operations. Additionally, optional communication modules allow for remote monitoring and control, facilitating timely adjustments and interventions. This comprehensive approach to load management and automation proposes significant cost savings, improved efficiency, and improved safety and reliability in industrial settings.

Keywords: Microcontroller-Based Switching, Load Management, Industrial Automation, Arduino, Relay Modules, Real-Time Data, Energy Consumption Reduction.

DOI: https://doi.org/10.36548/jeea.2024.3.007
Received: 27.08.2024, received in revised form: 24.09.2024, accepted: 0810.2024, published: 18.10.2024

1. Introduction

In today's rapidly developing industrial landscape, the demand for efficient energy management and advanced automation solutions is higher than ever. Companies face constant pressure to reduce operational costs, improve production, and improve safety standards. One promising approach to address these challenges is through the use of microcontroller-based systems for load management and industrial automation [1]. These systems offer accurate control, real-time monitoring, and adaptive responses, making them perfect for industrial applications. By integrating sensors and communication modules, these systems manage electrical loads efficiently, ensuring optimal power usage and preventing overloads, which can lead to equipment damage and increased operational costs.

This study explores a microcontroller-based switching system designed specifically for cost-effective load management and industrial automation. The core of the system is a microcontroller, such as an Arduino, PIC, which controls relay modules to switch various loads like motors, lights. Sensors, including current and temperature sensors, feed real-time data to the microcontroller, enabling informed decisions about load management [2]. The system automates load switching based on real-time data and predefined schedules, avoiding peak hour costs and reducing energy consumption. Additionally, it incorporates overcurrent and temperature protection mechanisms to ensure safe operating conditions and prevent equipment damage. With optional communication modules, the system can be monitored and controlled remotely, allowing for timely involvement and further optimizing load management and operational efficiency. By implementing such a system, industries can significantly improve their load management practices, resulting in substantial cost savings, improved automation, and improved safety and consistency.

2. Literature Review

A range of studies have explored the use of microcontroller-based switching for cost-effective load management and industrial automation. P.M.E Hari Prasanth and Devi both highlight the potential of this technology in industrial automation, with P.M.E Hari Prasanth specifically focusing on the use of Arduino and IoT for remote operation of industrial appliances, and Devi discussing the use of the MCS-51 microcontroller and CAN protocol for monitoring and controlling large industrial areas [3][4]. Yadav extends this to the residential sector, proposing a load prioritization technique using the ATmega 2560 microcontroller to manage energy consumption [5]. Singh presents a novel switching strategy for single-fed asynchronous machines, which not only improves energy efficiency and conservation but also involves lower capital costs [6]. James Mbutu Gitonga presents the microcontroller-based ATS with sequential loading that effectively ensures reliable switching between utility and generator power, enhancing power management. This system's main advantage is its precise control and reliability, verified through simulations and prototype testing [7]. El Sayed F presents a microcontroller-based electronic circuit that efficiently switches between two voltage sources to mitigate power fluctuations, with a maximum load capacity of 60 amps. This system's main advantage is its ability to decrease voltage and power fluctuations automatically, as proven through testing [8]. G. Gnanavel describes about the MCS-51 microcontroller and CAN bus technology that allows single-person monitoring and control of industrial networks. Its main advantage is cost-effectiveness, applicable in industries, automobiles, and homes [4]. These studies collectively demonstrate the potential of microcontroller-based switching for cost-effective load management and industrial automation [9,10].

3. Methodology

3.1 Block Diagram

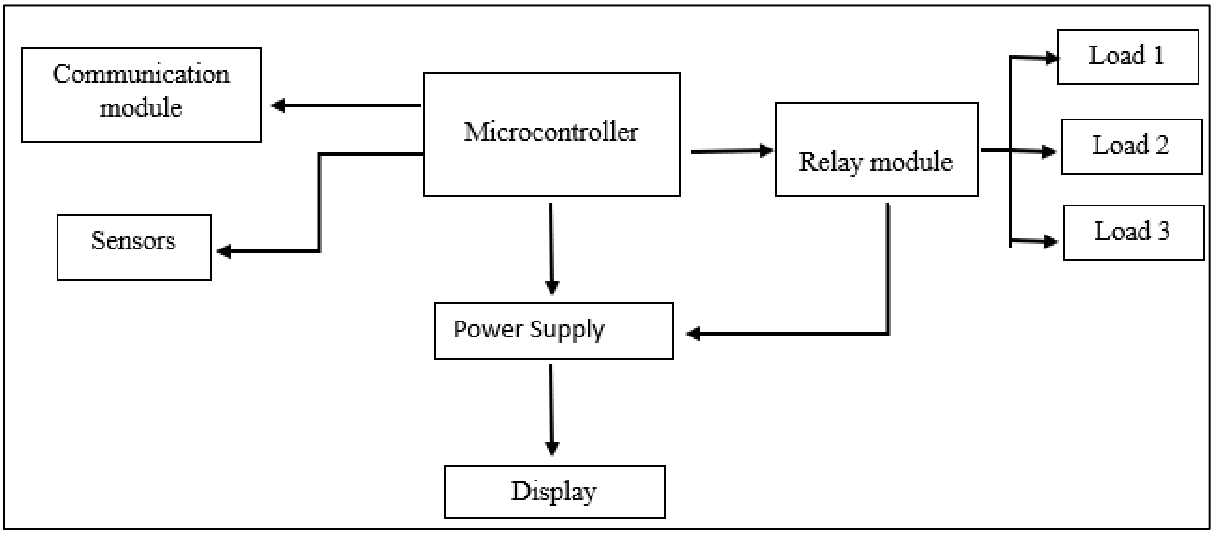

Figure 1. Block Diagram of Microcontroller-Based Switching for Load Management and Industrial Automation

The microcontroller is the central part of the system (Figure 1), controlling the relays based on sensor inputs and predefined logic. The Relay module is used to interface between the microcontroller and the high-power loads, allowing the microcontroller to safely switch them on and off. Loads are the devices being controlled (e.g., motors, lights). Sensors provide real-time data to the microcontroller (e.g., current sensors for monitoring load, and temperature sensors for monitoring environmental conditions). The power supply delivers the necessary power to the microcontroller, relays, and other components. Switches are used for manual controls for user interference. Display (LED) shows real-time status, sensor readings, and other relevant information. and communication module enables remote monitoring and control.

3.2 Implementation

Flowchart

The flowchart (Figure 2) illustrates the operational flow of the proposed system,

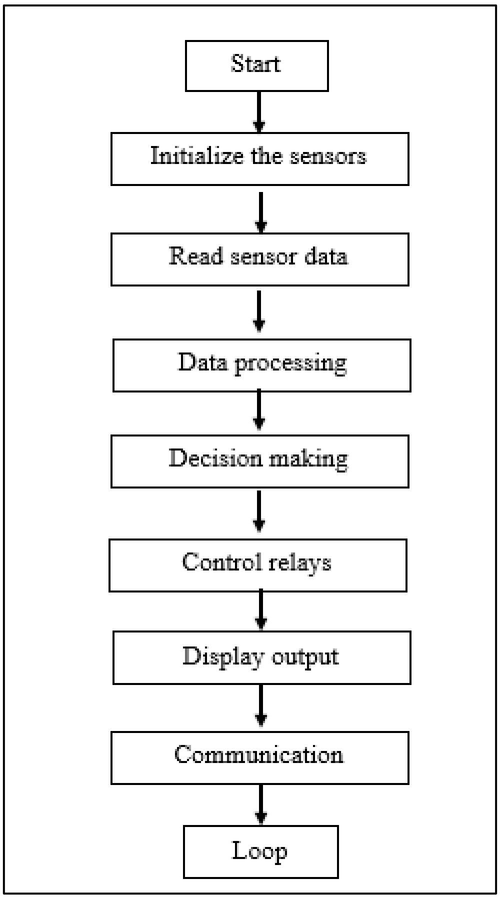

Figure 2. Flowchart of Microcontroller-Based Switching for Load Management and Industrial Automation

Step 1: Initialize the microcontroller and all connected peripheral device**.**

Step 2: Set up and initialize the sensor inputs and relay outputs.

Step 3: Read the data from the sensors (Current, voltage and temperature)

Step 4: Analyse the data which is from the sensors to determine the environmental status and conditions of the load

Step 5: Compare the sensor readings with the predefined threshold to decide turn on or off the specific load to cost effective management

Step 6: Activate or deactivate the relays based on the decision

Step 7: Display the current status of the system, conditions of the load and sensor readings on display unit

Step 8: Send the current status and receive the control commands through the communication module

Step 9: Repeat the process

The above process reduced power consumption by switching off non-essential loads during peak times. Improved energy efficiency by monitoring and controlling loads in real-time, and reduced the cost due to lower electricity usage. Improved the automated control of industrial processes and reduced the need for manual involvement.

3.3 Hardware Connection

The system (Figure 3) consists of a power supply connected to the microcontroller (Arduino ESP 8266), with sensors interfacing over its analog/digital input pins and relays linked to its digital output pins. A display unit is connected through appropriate communication pins (I2C/SPI), allowing for visual feedback. User interface components, including buttons and LEDs, are connected to various input/output pins to enable communication. Additionally, an optional communication module can be integrated through the serial pins for extended connectivity.

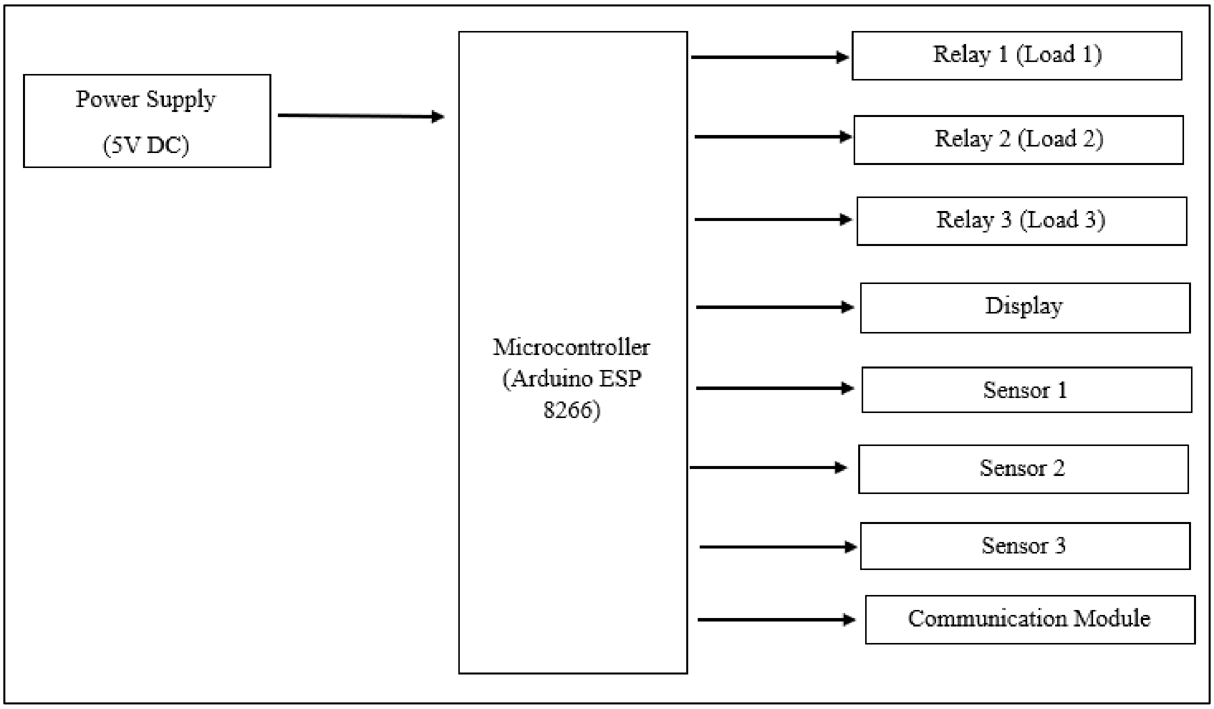

Figure 3. Hardware Connections

The output of the microcontroller-based switching system for cost-effective load management and industrial automation can be considered into various types, including real-time data displays, control actions, and communication feedback. The output of the real-time data display includes sensor readings (current, voltage, temp), system status (active and idle loads), and the energy consumed.

3.4 Software Module

The web interface is a user-friendly platform that displays data from the hardware module. It uses standard web technologies like HTML, CSS, and JavaScript to create a responsive and communicative dashboard. The hardware module (Arduino ESP8266) collects data from sensors, relays and processes it, then sends it to the web server. The web interface then repossesses this data and presents it to the user in an understandable format.

3.5 Implementation

The ESP8266 connects to Wi-Fi and sends data to the web server using an HTTP POST request. The data is sent in JSON format. The web server is set up using Node.js to receive data from the ESP8266. The Node.js server listens to the incoming POST requests on a specific endpoint (/data). After receiving data, it stores the latest readings and makes them available through another endpoint (/data). The server can store this data in a MySQL database and also keep it in memory for fast access. The server also provides endpoints to serve this data to the web interface after the request. Here HTML is used to generate the normal web page. It describes elements like headings, paragraphs, tables, forms, and other items needed for the user interface. HTML is used to organize and display the data through elements such as <div>, <span>, <p>, <table>, and <canvas> (for charts). The HTML page is loaded by the user's browser. It contains JavaScript. The JavaScript periodically sends AJAX GET requests to the endpoint (/data). The HTML page gets the data from the server using JavaScript and updates the displayed values every 5 seconds. The coding is depicted in Figure 4 below.

```
<!DOCTYPE html>
<html lang="en">
<head>
    <meta charset="UTF-8">
    <meta name="viewport" content="width=device-width, initial-scale=1.0">
    <title>Load Management Dashboard</title>
    <link rel="stylesheet" href="styles.css">
</head>
<body>
    <div class="dashboard">
        <h1>Load Management Dashboard</h1>
        <div class="status-panel">
            <h2>System Status</h2>
            <p><strong>Current Load:</strong> <span id="current-load">15.2 A</span></p>
            <p><strong>Voltage:</strong> <span id="voltage">220 V</span></p>
            <p><strong>Temperature:</strong> <span id="temperature">35°C</span></p>
            <p><strong>Total Energy Consumption:</strong> <span id="total-energy">150 kWh</span></p>
        </div>
        <div class="loads-panel">
            <h2>Load Control</h2>
            <p><strong>Active Loads:</strong> <span id="active-loads">Motor1, Light1</span></p>
            <p><strong>Idle Loads:</strong> <span id="idle-loads">Motor2, Light2</span></p>
            <div class="control-buttons">
                <button onclick="toggleLoad('Light2')">Turn on Light2</button>
                <button onclick="toggleLoad('Motor1')">Turn off Motor1</button>
                <button onclick="adjustThreshold()">Adjust Overcurrent Threshold</button>
            </div>
        </div>
        <div class="alert-panel">
            <h2>Alerts</h2>
            <p id="alert-message">Overcurrent detected in Motor2. Action Taken: Motor2 deactivated.</p>
        </div>
    </div>
    <script src="script.js"></script>
</body>
</html>
```

Figure 4. Coding

4. Result and Discussion

In this experiment, the electrical loads were monitored and managed to ensure optimal performance and safety. The initial measurements showed a current load of 15.2 A, a voltage of 220 V, and a temperature of 35°C, with total energy consumption at 150 kWh (Figure 5).

Motor1 and Light1 were active, while Motor2 and Light2 were idle. Control actions enabled turning on Light2, turning off Motor1, and adjusting the overcurrent threshold. An overcurrent in Motor2 was detected and it was automatically deactivated to prevent damage. This demonstrated effective load management through real-time monitoring, control actions, and automated safety responses.

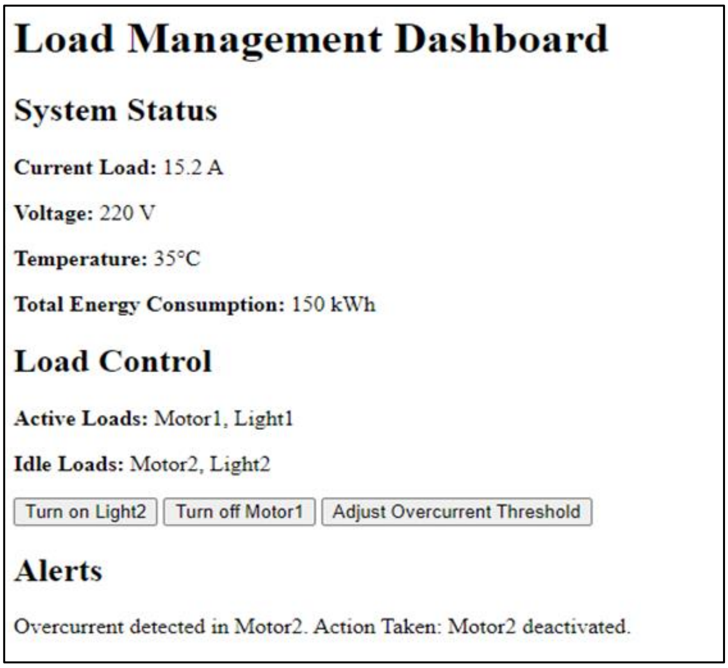

Figure 5. Initial Measurement

The LCD screen (Figure 6) displays key information such as current load, voltage, temperature, active loads, and alerts.

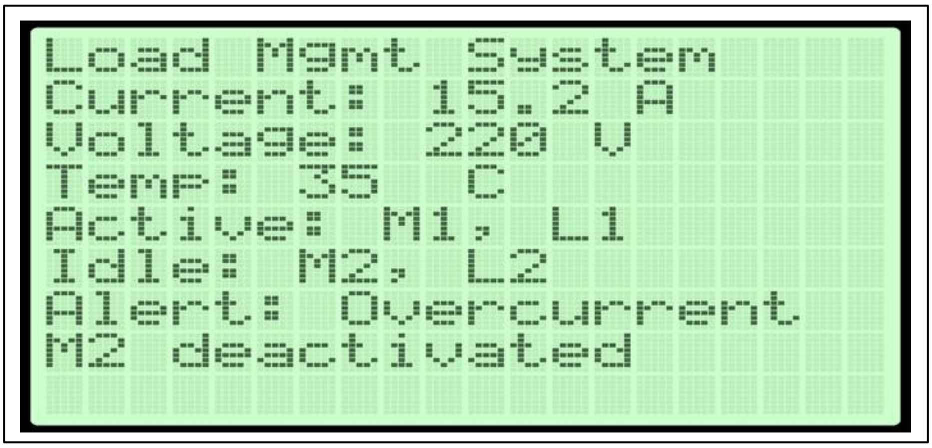

Figure 6. LCD Output

The displayed output on the microcontroller-based load management system is achieved through real-time data acquisition and processing. The Arduino ESP 8266 receives input from sensors. The sensors are connected to analog and digital pins, measuring current, voltage, and temperature. These readings are processed by the microcontroller, which then sends the values to the display unit through suitable communication protocols. The display shows the current system status, including active and idle loads. When an anomaly like an overcurrent is detected, the system generates an alert and takes corrective actions, such as deactivating specific loads (e.g., M2) to prevent damage. This information is updated on the display on time, providing users with clear and summarizing feedback on the system's performance and status.

5. Conclusion

The implementation of a microcontroller-based switching system for cost-effective load management and industrial automation offers a robust solution to modern industrial challenges. By using real-time sensor data, these systems manage electrical loads efficiently, improve power usage, and avoid overloads, thereby reducing operational costs and enhancing safety. The integration of communication modules allows for remote monitoring and control, adding flexibility and ease of management. The advancements in technology can further develop these systems by including more sophisticated sensors, IoT integration, and machine learning algorithms that can improve accuracy, sensitivity, and predictive capabilities. Additionally, integrating renewable energy sources like solar and wind can lead to more sustainable industrial practices. As these systems evolve, they will play an essential role in advancing industrial automation, energy efficiency, and smart manufacturing, making them crucial for future industrial operations.

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