

Smart Load Balancing using Load Sharing Technique

Gayathri.L¹, Chandrashekhar K²

¹²DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

¹²RAO BAHADUR Y. MAHABALESWARAPPA ENGINEERING COLLEGE

Abstract - The Smart Load Balancing using Load Sharing Techniques project is developed to improve the efficiency and reliability of electrical power distribution systems. The system uses an Arduino microcontroller as the main control unit to monitor and manage electrical loads automatically. A PZEM-004T module is used to measure important electrical parameters such as voltage, current, power, and energy consumption in real time. Current sensors continuously monitor the load conditions on different supply lines. For demonstration, 100 W and 200 W bulbs are used as electrical loads. Under normal conditions, power is supplied through the primary line. When an overload condition is detected, the controller automatically shifts a portion of the load to an available line through relay switching. This helps maintain balanced load distribution and prevents damage caused by excessive loading. A temperature sensor is incorporated to monitor overheating conditions and improve system safety. If the temperature exceeds the preset limit, a buzzer alert is generated to warn the user. An LCD display provides real-time information about system parameters and operating status. The integration of a NodeMCU module enables IoT-based remote monitoring through the internet. The proposed system reduces manual intervention, improves protection, and enhances the overall performance of electrical distribution networks. It provides a practical, reliable, and cost-effective solution for intelligent load management applications.

Key Words: Load Balancing, Power Distribution, Arduino Microcontroller, Real-Time Monitoring, IoT (Internet of Things).

1. INTRODUCTION (Size 11, Times New roman)

The increasing demand for electrical energy and the rapid expansion of industrial, commercial, and residential power systems have made efficient load management an essential requirement for modern electrical distribution networks. Uneven distribution of electrical loads among different supply lines can lead to voltage imbalance, excessive power losses, transformer overloading, reduced equipment life, and deterioration of overall power quality. As electrical loads continuously vary with consumer demand, maintaining balanced load distribution has become a major challenge for ensuring reliable and uninterrupted power supply [1], [3].

Recent advancements in embedded systems and Internet of Things (IoT) technologies have enabled the development of intelligent monitoring and automation solutions for power distribution systems. Embedded controllers provide real-time processing and automatic control capabilities, while IoT

platforms facilitate remote monitoring, data acquisition, and system supervision through wireless communication. These technologies improve operational efficiency by continuously monitoring electrical parameters, enabling quick fault detection, reducing manual intervention, and supporting effective decision-making [5], [6].

In this work, a smart load management system is developed using an Arduino-based controller integrated with a NodeMCU module for IoT-enabled monitoring. The system continuously measures important electrical parameters such as voltage, current, and temperature using appropriate sensors. Based on the monitored conditions, the controller automatically distributes the electrical load between multiple supply lines to prevent overload conditions and ensure balanced operation. The NodeMCU module enables real-time remote monitoring of system parameters, allowing users to supervise the system from any location. In addition, thermal protection and automatic load-sharing mechanisms improve system safety, reliability, and operational performance. The proposed system provides a simple, economical, and practical solution for intelligent electrical load management suitable for industrial, commercial, and small-scale power distribution applications [3], [6], [10].

The remainder of this paper is organized as follows. Section 2 presents the literature review of existing load management techniques. Section 3 describes the proposed methodology and system design. Section 4 discusses the hardware and software implementation. Section 5 presents the experimental results and discussion, while Section 6 concludes the paper and outlines future research directions.

2. LITERATURE REVIEW

Weckx *et al.* [1] proposed a smart load balancing technique using electric vehicle (EV) chargers and photovoltaic (PV) inverters in unbalanced distribution grids. Their system dynamically transferred power between phases to reduce voltage imbalance and feeder losses while improving voltage regulation. The proposed controller also supported renewable energy integration without requiring complex communication infrastructure.

Czarnecki *et al.* [2] investigated unbalanced power conditions in four-wire electrical systems and presented various reactive power compensation techniques. Their study demonstrated that proper compensation significantly reduces voltage fluctuations, improves power quality, and enhances transmission efficiency by minimizing reactive power losses.

Singh *et al.* [3] developed a three-phase load balancing system using a Distribution Static Compensator (DSTATCOM). The proposed method continuously monitored load conditions and

dynamically compensated reactive power, resulting in improved voltage regulation, harmonic reduction, enhanced power factor, and balanced current distribution.

Siti *et al.* [4] introduced a fuzzy logic-based load balancing technique combined with Newton–Raphson optimization for secondary distribution networks. Their intelligent optimization algorithm redistributed electrical loads automatically, minimized phase imbalance, improved power quality, and enhanced system reliability.

Tsikalakis *et al.* [5] proposed a centralized control strategy for optimizing microgrid operation under varying load conditions. Their controller effectively coordinated distributed energy resources, improved load sharing, maintained voltage stability, and reduced operational losses in smart microgrids.

Bollen *et al.* [6] presented advanced signal processing techniques for detecting power quality disturbances such as harmonics, voltage sags, interruptions, and load imbalance. Their research demonstrated that intelligent monitoring significantly improves fault diagnosis, protection capability, and real-time system performance.

Lopes *et al.* [7] proposed coordinated control strategies for islanded microgrids to improve voltage regulation, load sharing, renewable energy integration, and operational stability. Their framework enhanced system reliability while reducing power interruptions and improving energy management.

Akagi *et al.* [8] introduced instantaneous power theory for power conditioning applications. Their work focused on harmonic compensation, reactive power control, and active power filtering to improve power quality under unbalanced and nonlinear loading conditions.

Loh *et al.* [9] proposed advanced control strategies for grid-connected inverters operating under unbalanced voltage conditions. Their approach ensured stable power injection, reduced harmonic distortion, improved inverter efficiency, and enhanced renewable energy integration into modern electrical networks.

Abu-Siada *et al.* [10] developed a transformer condition monitoring system for unbalanced loading conditions. Their intelligent monitoring technique continuously analyzed transformer operating parameters to detect abnormal conditions, thereby improving reliability, reducing maintenance costs, and extending transformer life.

From the literature survey, it is evident that most existing approaches focus on power quality improvement, reactive power compensation, and sophisticated control strategies using advanced power electronic devices. However, many of these systems involve complex algorithms, expensive hardware, and high implementation costs. The proposed Arduino and NodeMCU-based smart load management system provides a simple, economical, and IoT-enabled solution that offers automatic load balancing, continuous monitoring, remote supervision, and improved operational reliability, making it suitable for practical industrial and commercial applications.

3.METHODOLOGY

The proposed smart load management system is designed to monitor electrical parameters continuously and automatically distribute electrical loads between multiple supply lines to ensure safe and efficient operation. The system integrates an Arduino Uno microcontroller, sensing modules, relay-based load control, and NodeMCU for IoT-based remote monitoring. The overall methodology consists of five major stages: data acquisition, parameter processing, decision making, load control, and remote monitoring.

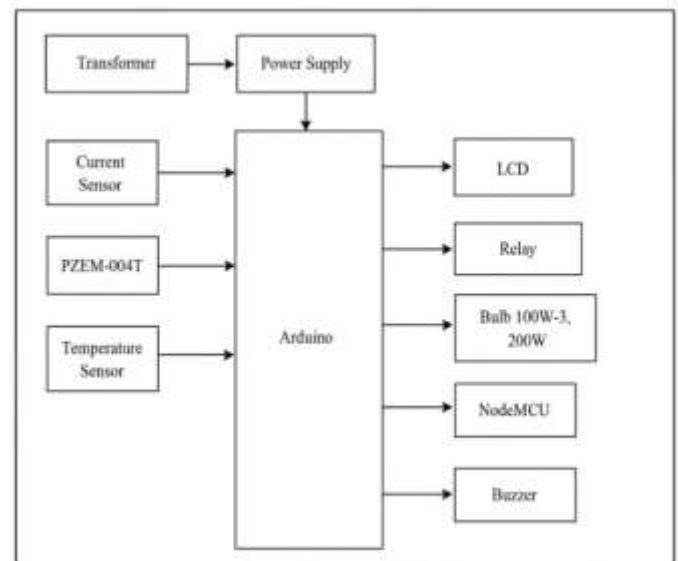


Fig 1: Block diagram

3.1 System Architecture

The proposed system consists of a regulated power supply, Arduino Uno, PZEM-004T voltage and power monitoring module, ACS712 current sensor, DS18B20 temperature sensor, relay module, LCD display, buzzer, and NodeMCU communication module. The sensors continuously measure voltage, current, power, and temperature of the connected electrical loads. These measurements are transmitted to the Arduino controller, which processes the sensor data according to the programmed control algorithm.

The Arduino compares the measured values with predefined threshold limits. If all parameters remain within the safe operating range, the connected loads continue to operate normally. When an overload or excessive temperature condition is detected, the controller automatically disconnects or transfers the load through the relay module to maintain balanced load distribution and protect the electrical system. Simultaneously, the LCD displays the measured electrical parameters, while the buzzer provides an audible warning to notify the user of abnormal operating conditions.

The NodeMCU module receives processed data from the Arduino through serial communication and transmits the information to the IoT platform (ThingSpeak) using Wi-Fi connectivity. This enables users to remotely monitor the operating status of the system in real time.

3.2 Working Procedure

The operation of the proposed system is carried out in the following sequence:

Step 1: The power supply unit converts the AC mains voltage into a regulated 5 V DC supply required by the Arduino controller, sensors, NodeMCU, LCD, and relay module.

Step 2: The PZEM-004T module continuously measures the supply voltage, current, power, and energy consumption, while the ACS712 current sensor provides additional current measurement for overload detection. Simultaneously, the DS18B20 sensor monitors the operating temperature of the system.

Step 3: The Arduino Uno collects sensor data through its analog and digital input pins and processes the measurements using the embedded control program developed in the Arduino IDE.

Step 4: The controller compares the measured values with predefined threshold limits. During normal operating conditions, the loads remain connected and the measured parameters are displayed on the LCD.

Step 5: If the measured current exceeds the allowable limit or the temperature rises beyond the safe operating range, the Arduino activates the relay module to disconnect or redistribute the electrical load. At the same time, the buzzer generates an audible warning indicating the fault condition.

Step 6: The processed electrical parameters are transmitted from the Arduino to the NodeMCU through UART serial communication. The NodeMCU uploads the data to the ThingSpeak cloud platform via Wi-Fi, enabling real-time remote monitoring and analysis.

Step 7: The monitoring process repeats continuously, ensuring automatic load balancing, overload protection, temperature monitoring, and uninterrupted supervision of the electrical distribution system.

3.3 Control Algorithm

The proposed control algorithm operates according to the following logic:

1. Initialize the Arduino controller, sensors, LCD, relay module, buzzer, and NodeMCU.
2. Continuously acquire voltage, current, power, energy, and temperature measurements.
3. Display all measured parameters on the LCD screen.
4. Compare sensor values with predefined threshold limits.
5. If all parameters remain within safe limits, continue normal operation.
6. If overload or overheating is detected, activate the relay module to disconnect or shift the load and activate the buzzer for fault indication.
7. Transmit all measured parameters to the ThingSpeak cloud using the NodeMCU for remote monitoring.
8. Repeat the monitoring and control cycle continuously until the system is switched off.

The proposed methodology provides an intelligent, low-cost, and IoT-enabled solution for automatic load management. By combining continuous parameter monitoring, automatic relay

control, thermal protection, and cloud-based remote supervision, the system improves power distribution reliability, enhances electrical safety, minimizes manual intervention, and ensures efficient utilization of available electrical resources.

4. Results and Discussion



Fig 2: Project Model

The proposed smart load management system was successfully designed and implemented using an Arduino Uno, NodeMCU, relay module, and sensing circuits. Experimental testing confirmed that the system continuously monitored voltage, current, and temperature, and automatically controlled the connected loads based on the measured operating conditions.



Fig 3 :Implementation

Figure 2 and Figure 3 show the developed hardware prototype and its implementation. The relay module successfully switched the electrical loads, ensuring balanced load distribution and preventing overload conditions.



Fig 4: Load Balance Display



Fig 5.: Voltage display

Figure 4 and Figure 5 demonstrate the real-time monitoring of load status and supply voltage through the LCD display. The measured voltage was approximately 220.7 V, indicating accurate sensing and stable system performance.



Fig 6 remote monitoring

Figure 6 shows the IoT dashboard used for remote monitoring. The NodeMCU successfully transmitted real-time electrical parameters, including voltage, current, power, and temperature, to the cloud platform. The dashboard also enabled remote monitoring of the system, improving accessibility and operational efficiency.

Overall, the experimental results demonstrate that the proposed system provides effective automatic load balancing, real-time parameter monitoring, overload protection, and IoT-based remote supervision. The developed prototype offers a reliable and cost-effective solution for intelligent electrical load management.

5. Conclusion and Future Scope

The proposed Arduino-based smart load management system was successfully designed, implemented, and tested. The system effectively integrates the Arduino Uno, NodeMCU, current and temperature sensors, relay modules, and IoT technology to achieve automatic load balancing and system protection. Real-time monitoring of voltage, current, power, and temperature enables efficient load management, while relay-based switching prevents overload conditions and improves system reliability. The IoT integration facilitates remote monitoring, enhancing user accessibility and overall operational efficiency. The experimental results demonstrate that the proposed system is a reliable and cost-effective solution for intelligent electrical load management.

In the future, the system can be enhanced by integrating Artificial Intelligence (AI) and Machine Learning (ML) techniques for load prediction and intelligent decision-making. The proposed model can also be extended to three-phase power distribution and smart grid applications. Furthermore, the development of a dedicated mobile application and advanced cloud-based monitoring platform can provide remote control, real-time notifications, and improved system management.

REFERENCES

1. Weckx, S., & Driesen, J. (2015). *Load balancing with EV chargers and PV inverters in unbalanced distribution grids*. IEEE Transactions on Sustainable Energy, **6**(2), 635–643.
2. Czarnecki, L. S., & Haley, P. M. (2014). *Unbalanced power in four-wire systems and its reactive compensation*. IEEE Transactions on Power Delivery, **29**(1), 53–63.
3. Singh, R., & Singh, D. (2015). *Three-phase load balancing and harmonic reduction using distribution static compensator*. International Journal of Scientific and Research Publications, **5**(6).
4. Siti, M. W., Jimoh, A. A., & Nicolae, D. V. (2009). *Phase load balancing in the secondary distribution network using fuzzy logic and combinatorial optimization based on Newton–Raphson*. Electric Power Systems Research, **79**(2), 92–100.
5. Tsikalakis, A. G., & Hatziaargyriou, N. D. (2007). *Centralized control for optimizing microgrid operation*. IEEE Transactions on Energy Conversion, **23**(1), 241–248.
6. Bollen, M. H. J., & Gu, I. Y. H. (2006). *Signal Processing of Power Quality Disturbances*. Hoboken, NJ: Wiley-IEEE Press.
7. Lopes, J. P., Moreira, C. L., & Madureira, A. G. (2007). *Defining control strategies for microgrids islanded operation*. IEEE Transactions on Power Systems, **21**(2), 916–924.
8. Akagi, H., Watanabe, E. H., & Aredes, M. (2007). *Instantaneous Power Theory and Applications to Power Conditioning*. Hoboken, NJ: Wiley-IEEE Press.
9. Loh, P. C., & Blaabjerg, F. (2005). *Operation of grid-connected inverters under unbalanced voltage conditions*. IEEE Transactions on Industry Applications, **41**(5), 1295–1302.
10. Abu-Siada, A., & Islam, S. (2011). *A novel approach for transformer condition monitoring under unbalanced loading*. IEEE Transactions on Dielectrics and Electrical Insulation, **18**(2), 529–536.
11. Santoso, S., Beaty, H. W., & Dugan, R. C. (2012). *Electrical Power Systems Quality* (3rd ed.). New York, NY: McGraw-Hill.
12. Guerrero, J. M., Matas, J., de Vicuña, L. G., Castilla, M., & Miret, J. (2011). *Hierarchical control of droop-*

- controlled AC and DC microgrids*. IEEE Transactions on Industrial Electronics, **58**(1), 158–172.
13. Baran, M. E., & Wu, F. F. (1989). *Network reconfiguration in distribution systems for loss reduction and load balancing*. IEEE Transactions on Power Delivery, **4**(2), 1401–1407.
 14. Niknam, T., Narimani, M. R., & Jabbari, M. (2012). *Multi-objective optimal power flow in unbalanced distribution systems using heuristic optimization*. Applied Energy, **87**(9), 2899–2912.
 15. Falaghi, H., & Haghifam, M. (2009). *Distributed generation impact on distribution networks under unbalanced conditions*. International Journal of Electrical Power & Energy Systems, **31**(7–8), 371–378.
 16. Keane, A., & O'Malley, M. (2005). *Optimal allocation of distributed generation in distribution networks*. IEEE Transactions on Power Systems, **20**(3), 1641–1649.
 17. Goswami, S. K., & Basu, S. K. (1992). *A new algorithm for reconfiguration of distribution feeders for loss minimization*. IEEE Transactions on Power Delivery, **7**(3), 1484–1491.
 18. Kashem, M. A., & Jasmon, G. B. (2000). *Load balancing in distribution networks using heuristic methods*. Electric Power Systems Research, **55**(3), 171–179.
 19. Nazir, N., Racherla, P., & Almassalkhi, M. (2019). *Optimal multi-period dispatch of distributed energy resources in unbalanced distribution feeders*. IEEE Transactions on Power Systems.
 20. Chen, X., Dall'Anese, E., & Li, N. (2018). *Aggregate power flexibility in unbalanced distribution systems with distributed energy resources*. IEEE Transactions on Smart Grid.