IJAAR PUBLISHING®

Engineering Research Journal | ISSN: **2782-8212**
Vol. 3, Issue 8 (August, 2023) | www.ijaar.org/erj

MICROCONTROLLER-BASED AUTOMATIC THREE-PHASE LOAD BALANCING SYSTEM

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ABSTRACT

Unbalanced load distribution in a three-phase system causes faults and eventual breakdown of the distribution system due to damage to the critical components such as the distribution transformer. To mitigate the effects of unbalanced load distribution, a microcontroller-based automatic three-phase load balancing system was designed and simulated in this paper. The system performs measurement, monitoring, protection, and control functions to balance the load and avoid power loss and damage to the distribution transformer. The system design and simulation were carried out using Proteus 8 Computer Aided Design (CAD) software. The simulation results showed satisfactory performance of the system and demonstrated that the system was able to balance the load distribution and indicate when the system is critically unbalanced or well-balanced on the Liquid Crystal Display (LCD) unit. The use of microcontroller-based load balancing systems is recommended to improve the performance and longevity of three-phase distribution systems.

This study presents the design and simulation of an automatic three-phase load-balancing system. Unbalanced load distribution in three-phase systems can cause damage to distribution transformers and result in power loss. To address this issue, a microcontroller-based system was designed and simulated to balance the load on a three-phase distribution network. The system uses voltage and current sensors to measure loads on each phase and control the switching of loads to balance the system. In the event of short-circuits, Undervoltage or overvoltage, the system disconnects the loads to prevent further damage. The system includes a dsPIC33FJ32MC202 microcontroller, switching relays, voltage and current sensors, and a liquid crystal display (LCD) unit. The LCDs' real-time phase power, load percentage, and unbalance index of the distribution system. Results showed that the system performs satisfactorily and can be used to improve energy efficiency and prevent damage in three-phase distribution systems.

Keywords: Microcontroller, Distribution system, Load balancing system

Published *08/08/2023*
Balami, M.I. & Muhammad, U. (2023). Microcontroller-Based Automatic Three-Phase Load Balancing System. *Engineering Research Journal*, 3(8), 25-35.

INTRODUCTION

The use of three-phase four-wire systems for power distribution is common in many countries, including Nigeria, where standard phase voltage of 230V and 415V phase-to-phase voltage is employed. In a distribution system, single-phase residential loads are connected to the single-phase lines while three-phase residential and industrial loads, such as three-phase induction motors, are connected across all three phases and the neutral (1). This can lead to uneven distribution of loads in the three-phase distribution system, causing unbalanced voltage and current, which can lead to power loss and damage to the distribution transformer.

Unbalanced loads can cause secondary voltage imbalances, additional transformer losses, and high neutral currents, significantly reducing the life of a transformer (2). Therefore, it is important to design and implement systems capable of minimizing or eliminating unbalance in the distribution system (3). Traditional techniques employed in low-voltage distribution systems to reduce the three-phase unbalance rate include reactive power compensation and load transfer (4). However, these methods may not always provide a complete solution to the problem (5).

In this paper, we present a design for an automatic three-phase load-balancing system using a microcontroller. This system performs measurement, monitoring, protection and control functions and thus helps in energy saving an improvement over other literatures (6) (7). The basic working principle of this system is the use of voltage and current sensors to perform measurements of the loads in each phase of the three-phase distribution system and perform control functions through switching of the load units to balance the load. In the event of short-circuit on the lines, Undervoltage and overvoltage, this system disconnects the loads from the distribution network to avoid further damage to the system or load. The major components used in this design include a dsPIC33FJ32MC202 microcontroller, switching relays, voltage and current sensors, and a liquid crystal display (LCD) unit. The LCDs are the real-time phase power, load percentage, and unbalance index of the distribution system. The simulation results obtained from the design showed satisfactory performance of the system, demonstrating its potential to effectively balance loads in a three-phase distribution system.

MATERIALS AND METHODS

The system was designed using Proteus 8 Computer Aided Design (CAD) software. The microcontroller used in this design was dsPIC33FJ32MC202 and the current and voltage sensors employed were ACS758ECB-200B-PFF-T and a voltage divider network respectively. The relay switching unit consisted of ULN2803 as the relay driver and relays for switching the loads. The power supply unit was designed using a switching mode power supply (SMPS) circuit with a full wave bridge rectifier (DF10M) and a 10µf 450V capacitor as an input filter. The output of the power supply unit consisted of 5V for the microcontroller and LCD, and 12V for the relay switching unit. The design simulation was carried out using the Proteus 8 CAD software and the results were obtained and analyzed. The system was designed using a dsPIC33FJ32MC202 microcontroller, switching relays, voltage and current sensors, and a liquid crystal display (LCD) unit. The system performs measurements of the loads in each phase of the three-phase distribution system and controls the load units to balance the load. In the event of short-circuit on the lines, Undervoltage, and overvoltage, the system disconnects the loads from the distribution network to avoid further damage. The LCDs' real-time phase power, load percentage, and unbalance index of the distribution system.

The system consisted of eight functional blocks: a power supply unit (PSU), power measurement unit (PMU), relay switching unit (RSU), voltage and current sensors, dsPIC33FJ32MC202 microcontroller, switching relays, liquid crystal display (LCD) unit, and a bridge rectifier as shown in Figure 1.

The PSU was designed using a switching mode power supply (SMPS) for its high efficiency and lightweight. The PMU used the ACS758ECB-200B-PFF-T current sensor and a voltage divider network for voltage sensing and measurement. The RSU consisted of relays and relay drivers (ULN2803) to connect, disconnect or redistribute load to the three-phase distribution network. The system was tested using six loads of 150W, 200W, 350W, 400W, 500W and 600W.

The simulation results showed that the system was able to balance the load distribution and indicate when the system is critically unbalanced or well-balanced on the LCD unit.

A software flowchart algorithm was developed using the MPLAB X IDE and written in C programming language to control the microcontroller and perform the measurement, monitoring, protection, and control functions. The algorithm includes initialization, measurement, data processing, and control functions.

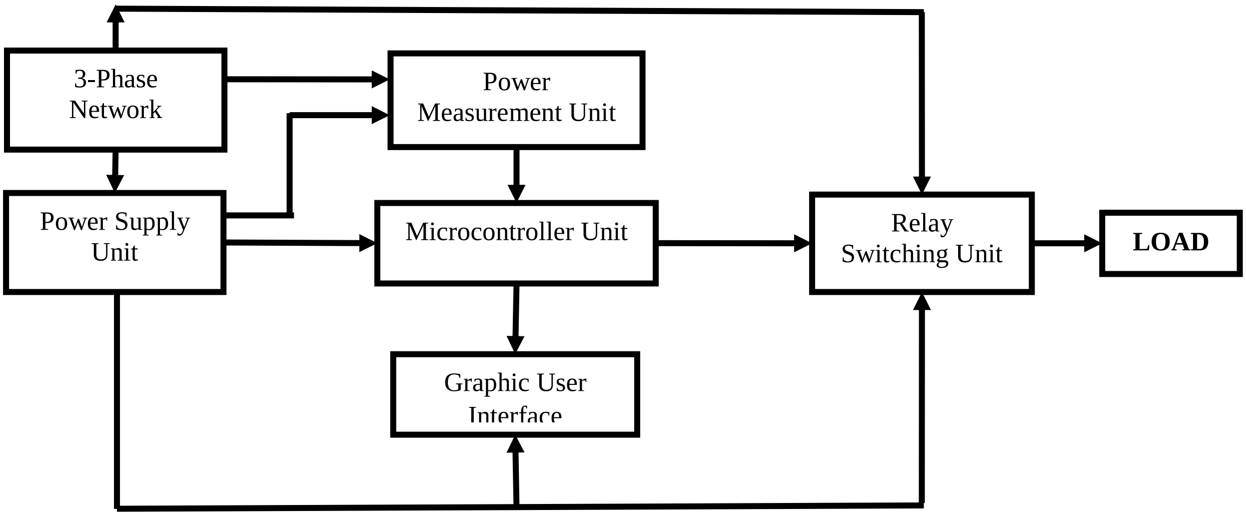


Figure 1: Block Diagram of the Three Phase Load Balancing System

Power Supply Unit:

The power supply unit was designed using a switching mode power supply (SMPS) due to its lightweight and high efficiency compared to the linear power supply. The output of the power supply consists of 5V for the microcontroller, LCD, and current sensor, and 12V for the RSU. The block and circuit diagrams of the PSU are shown in Figure 2 and Figure 3 respectively. The input is from the mains supply of the distribution system, which is rectified and filtered using a bridge rectifier and input filter capacitor. Equation (1) was used to determine the maximum input current. The design specifications, DF10M full wave bridge rectifier (BR1) with a peak reverse voltage of 700V and current delivery of 1A was selected for the input rectifier while a 10µf 450V capacitor was chosen for the dc input capacitor based on Equation (2) while Equation (3) was used to determine the switching MOSFET for the PSU. UC3842 was used as the switching IC, and the transformer core was EI28 based on the recommendations of (8).

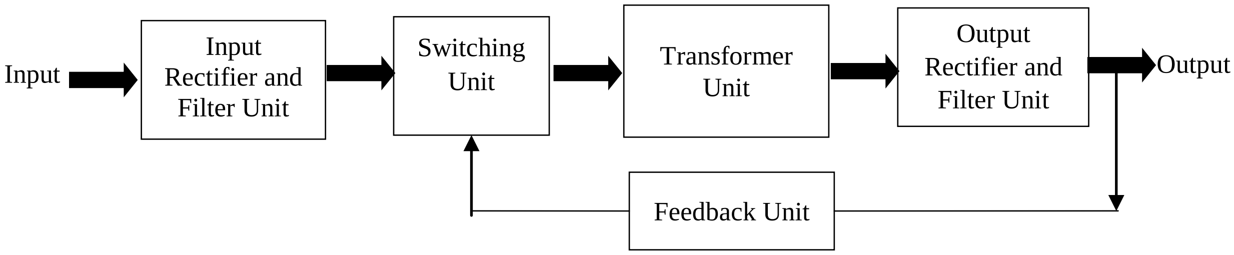


Figure 2: Block Diagram of the Power Supply Unit

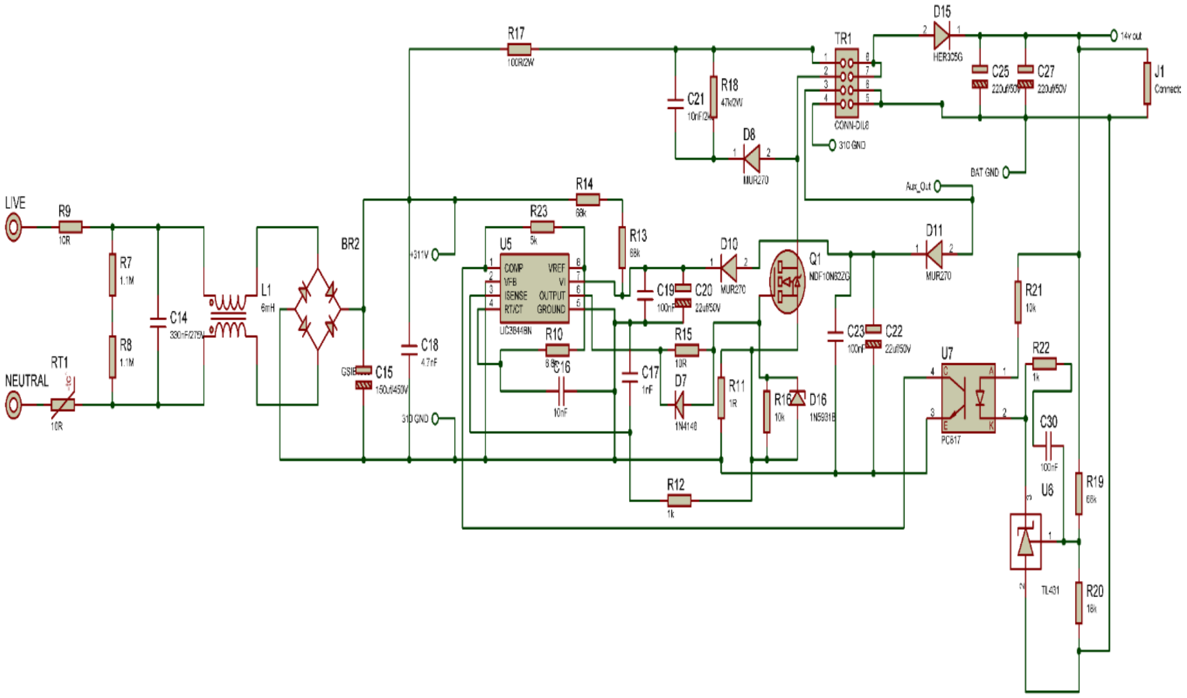


Figure 3: Circuit Diagram of Power Supply Unit

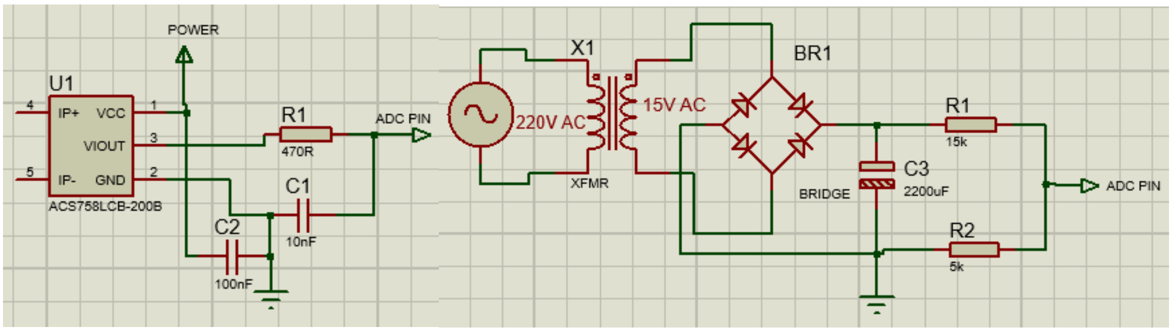
$$I_{in\,(rms)} = I_{in\,(peak)} \times \sqrt{\frac{D_{max}}{3}} = 2 \times \sqrt{\frac{0.44}{3}} = 0.77A \qquad (1)$$

$$C_{in} = C_6 = \frac{2 \times P_{in} \times T_d}{\left(V_{in\,(max)}\sqrt{2}\right)^2 - \left(V_{in\,(min)}\sqrt{2}\right)^2} \qquad (2)$$

$$V_{ds} = V_{dc\,(\max)} + V_{ref} + V_{leakage} + V_{Spike} \qquad (3)$$

Power Measurement Unit:

The power measurement unit uses ACS758ECB-200B-PFF-T for current sensing and measurement (9)and a voltage divider network for voltage sensing and measurement (10). The current sensor has a current sensitivity of 10mV/A and can measure up to 200A current. For voltage measurement, every single phase of the distribution network is rectified using a bridge rectifier and then filtered. A voltage divider network was provided to calibrate the input voltage from a maximum of 500V dc (500√2V AC). Figure 4 depicts the power measurement circuits.



(a) Current Measurement Circuit (b) Voltage Measurement Circuit

Figure 4: Power Measurement Circuit

Relay Switching Unit:

The switching unit consists mainly of relays and relay drivers. The relays make and break contacts to connect the load to the distribution network, balance the load on the distribution network, or disconnect the load from the three-phase distribution network. The relay driver used in this research was ULN2803. ULN2803 is a high-voltage and high-current eight NPN Darlington pair transistor array and is mainly used to drive relays and other high-current loads. The relay switching unit also includes protection features such as overvoltage, under-voltage, and short-circuit protection. Figure 5 depicts the relay switching unit.

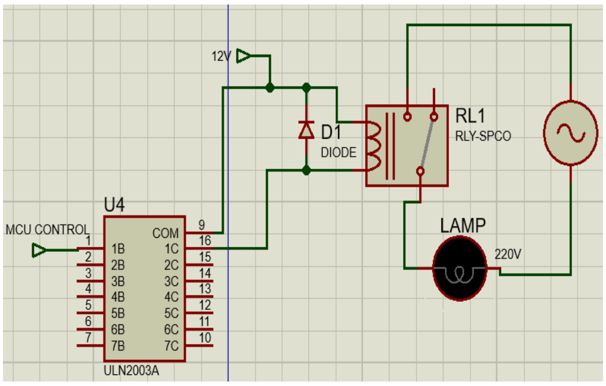


Figure 5: Circuit Diagram of Switching Unit

LCD Unit:

The LCD unit is used to display real-time phase power, load percentage, and unbalance index of the distribution system. It is connected to the microcontroller, which updates the display with the current measurements and status of the system.

Microcontroller Unit

The Microcontroller used in this project was dsPIC33FJ32MC202.The dsPIC33FJ32MC202 is a 44-pin 16-bit microcontroller from Microchip as shown in Figure 6. Based on the size of the memory, number of interface pins and processing speed (11), the microcontroller was selected.

The microcontroller takes data from the Power Measurement Unit (PMU), processes the data and performs the required control and redistribution functions. The monitoring operation of the microcontroller unit is taken from the data from the PMU using Equations 4 to 10.

To determine the current drawn by each load on the distribution system, Equation (4) is used while Equation (5) is used by the microcontroller to determine the phase voltage. The percentage of the load on each of the phase of the distribution network is determined using equation (6)

$$\text{Load Current } (\mathrm{I_L}) = \mathrm{ADC_1} \times 0.12210012210012210012210012210012 \qquad ---(4)$$

$$Phase\ Voltage\ \left(V_{phase}\right) = ADC_2 \times 0.17440240512781758233085538601365 \qquad ---(5)$$

ADC_1 is the value of the analog-to-digital converter read by the microcontroller from the current sensor while $ADC_2$is the value of the analog-to-digital converter read by the microcontroller from the voltage sensor. The multiplication of the Load current and phase voltage gives the total power drawn by the load connected to the distribution network.

$$\%\ Phase\ Load = \frac{Phase\ Load}{Total\ Load} \times 100 \qquad ------(6)$$

In compliance with the European Standard EN 50160 [15], the voltage unbalance ratio (VUR) and the phasing unbalance index (PUI) of the current will be determined and the result will be used to perform control and protection action.

$$Voltage\ Unbalance\ Ratio\ (VUR) = \frac{Maximum\ deviation\ from\ the\ means\ of\ the\ three\ phase\ voltages}{mean\ of\ the\ three\ phase\ voltages} \times 100\%$$

$$VUR = \frac{Max\ \left|V_{avg} - V_R\right|, \left|V_{avg} - V_B\right|, \left|V_{avg} - V_Y\right|}{V_{avg}} \times 100\% \qquad [7]$$

Where V_{avg} is the mean voltage of the three phase voltages, V_R is the line voltage on the red phase, V_B is the line voltage on the blue phase and V_Y is the line voltage on the yellow phase.

$$V_{avg} = \frac{V_R + V_B + V_Y}{3} \qquad [8]$$

When the voltage unbalance ratio (VUR) exceeds 2% as specified in NE 50160 standard, the balance action will be initiated. Also, the phasing unbalance index (PUI) of not more than 10% is used as condition to perform balance in the loads of the three-phase distribution network. The calculation to determine the phasing unbalance index (PUI) is given as:

$$\text{phasing unbalance index (PUI)} = \frac{Maximum\ deviation\ from\ the\ means\ of\ the\ current\ in\ three\ phase\ voltages}{mean\ of\ the\ three\ phase\ currents} \times 100\%$$

$$PUI = \frac{Max\ \left|I_{avg} - I_R\right|, \left|I_{avg} - I\right|, \left|I_{avg} - I_Y\right|}{I_{avg}} \times 100\% \qquad [9]$$

Where I_{avg} is the mean current of the three-phase distribution system while I_R, I_B, and I_Y are the line current in the red, blue and yellow phases respectively.

$$I_{avg} = \frac{I_R + I_B + I_Y}{3} \qquad [10]$$

The maximum acceptable rate of imbalance current is 10%. Where exceeding this ratio leads to an increased temperature of the transformer windings and that will affect the life span of the transformer. Also exceeds the maximum value of PUI, leads to increase the losses of windings and active power, and thus reducing the efficiency

Software Flowchart Algorithm:

The software flowchart algorithm was developed using the MPLAB X IDE and written in C programming language. It controls the microcontroller to perform the measurement, monitoring, protection, and control functions. The algorithm includes initialization, measurement, data processing, and control functions. The initialization function sets up the microcontroller and its peripherals, while the measurement function continuously measures the voltage and current to determine the power on each of the three phases.

RESULTS

The circuit was simulated using Proteus 8 CAD software to ensure compliance with the designed specifications. The simulation results were analyzed and the following observations were made:

When no load was connected, the screen displayed a welcome message and the thesis topic, and the phase unbalance index (PUI) was 0, as well as the percentage load on each of the phases.

When only one load was connected, the load was automatically connected to the red phase (Phase 1) indicating a critical phase unbalance index of 200%.

When two loads were connected, the system automatically distributed the load to two phases with a PUI of 100%.

When three loads were connected, the system automatically distributed the load to the three phases with a PUI of 33%.

When five loads were connected, the loads were automatically distributed among the three phases with a PUI of 8%, indicating a balanced system.

From these results, it can be seen that the system effectively balances the load distribution among the three phases, and indicates when the system is critically unbalanced or well-balanced. This shows that the simulation works according to design specifications.

The results obtained showed satisfactory performance of the designed system.

The circuit was simulated using Proteus 8 CAD software and the results showed that the system was able to balance the load distribution and indicate when the system is critically unbalanced or well-balanced on the LCD unit. The simulation was conducted using six loads of 150W, 200W, 350W, 400W, 500W and 600W. When only one load was connected, the system displayed a phase unbalance index of 200% indicating that only one phase was loaded, thus the system was critically unbalanced. When two or three loads were connected, the system automatically distributed the load to the corresponding number of phases and displayed the phase load percentage and phase unbalance index. When five loads were connected, the system distributed the load among the three phases with a phase unbalance index of 8%, indicating that the system was well-balanced. The simulation results were consistent with the design specifications.

The system was designed and simulated using Proteus 8 CAD software. The system was tested using six loads of 150W, 200W, 350W, 400W, 500W and 600W. The simulation results showed that when no load was connected, the system displayed 0% load and 0% phase unbalance index (PUI) on the LCD unit. When one load was connected, the load was automatically connected to one phase, resulting in a PUI of 200% indicating a critically unbalanced system.

When two or three loads were connected, the system automatically distributed the load among the three phases and displayed the percentage of load and PUI on the LCD unit. When five loads were connected, the system distributed the load among the three phases resulting in a PUI of 8% and a maximum load percentage difference of 6%, indicating a balanced system.

The simulation results showed that the system functioned according to the design specifications, balancing the load system and indicating when the system is critically unbalanced or well-balanced on the LCD unit.

DISCUSSION

The simulation results of the microcontroller-based automatic three-phase load balancing system showed that the system is capable of balancing the load on the three-phase distribution network. When no loads were connected, the system displayed a phase unbalance index of 0% and no load on any of the phases (Figure 6). When one load was connected, the system automatically connected it to one phase, resulting in a critical system unbalance with a maximum phase unbalance index of 200% (Figure 7). However, when two or more loads were connected, the system distributed them evenly among the three phases, resulting in a well-balanced system with a phase unbalance index below 10% (Figures 8 and 9).

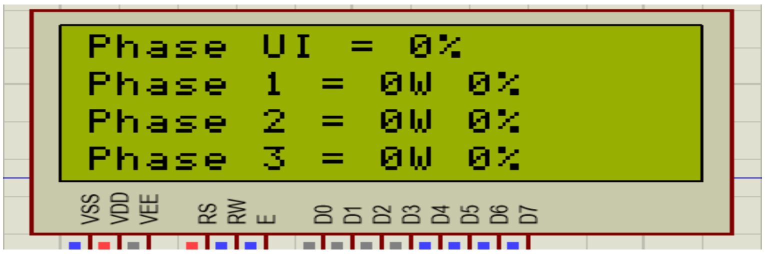
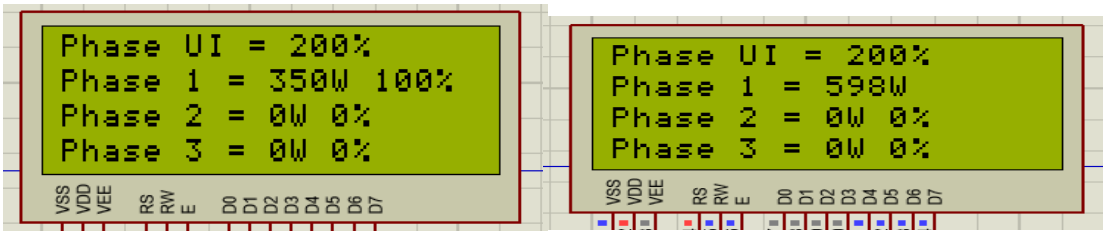

Phase UI = 0%
Phase 1 = 0W 0%
Phase 2 = 0W 0%
Phase 3 = 0W 0%

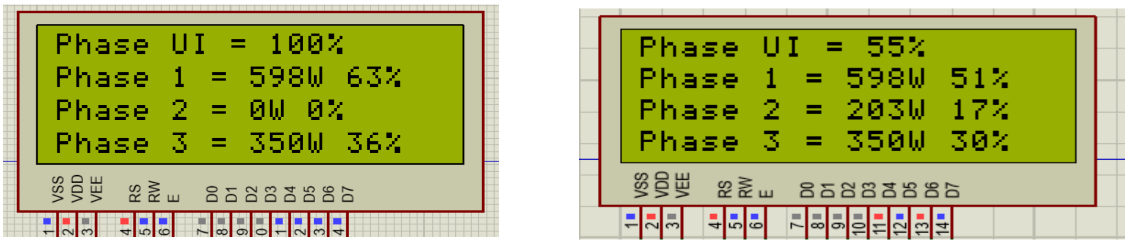
Figure 6: Display showing none of the Phases were loaded and 0% Phase UI


Phase UI = 200%
Phase 1 = 350W 100%
Phase 2 = 0W 0%
Phase 3 = 0W 0%

Phase UI = 200%
Phase 1 = 598W
Phase 2 = 0W 0%
Phase 3 = 0W 0%

Figure 7: Simulation showing only one phase loaded with critical system unbalance

The use of a microcontroller in this system allows for real-time monitoring and control of the load distribution, ensuring that the system remains balanced at all times. The use of current and voltage sensors also allows for accurate measurement of the loads on each phase, which is crucial in achieving accurate load balancing. Additionally, the use of relays and relay drivers in the switching unit ensures that the loads can be connected, disconnected, or redistributed as needed.



```
Phase UI = 100%
Phase 1 = 598W 63%
Phase 2 = 0W 0%
Phase 3 = 350W 36%
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Phase UI = 55%
Phase 1 = 598W 51%
Phase 2 = 203W 17%
Phase 3 = 350W 30%
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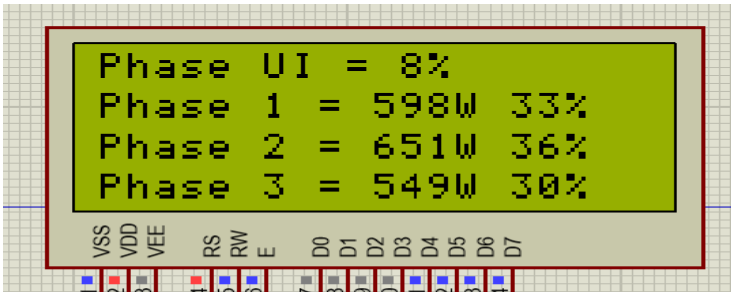
(a) Load Balance for two Load (b) Load Balance for 3 Loads

Figure 8: Balancing Function with Two and Three Loads Connected



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Phase UI = 8%
Phase 1 = 598W 33%
Phase 2 = 651W 36%
Phase 3 = 549W 30%
```

Figure 9: System Balanced with PUI of 8%

One of the main advantages of this system is that it can help to reduce power loss and damage to the three-phase distribution transformer caused by unbalanced loads. It also helps to improve the efficiency of the distribution system by ensuring that energy is delivered to the loads in a balanced manner. This can ultimately lead to cost savings for both the distribution company and the end users.

In conclusion, the microcontroller-based automatic three-phase load balancing system designed and simulated in this research has the potential to improve the efficiency and reliability of three-phase distribution systems by reducing the problems associated with unbalanced loads. It is recommended that this system be implemented in real-world distribution networks to achieve these benefits. Further research can be conducted to optimize the design and improve the performance of the system.

CONCLUSION

The study aimed to design and simulate an automatic three-phase load-balancing system using a microcontroller. The results of the simulation showed that the system performed well in balancing the load on the three-phase distribution network and indicated when the system was critically unbalanced or well-balanced. The use of a microcontroller for the control and redistribution of load on the distribution network helps to mitigate the problems associated with an unbalanced load on the distribution system. It is therefore recommended that this system be employed in distribution networks to reduce the problems associated with unbalanced loads. Future studies can focus on the implementation and testing of this system in a real-world scenario to further validate its effectiveness.

This study aimed to design and simulate a microcontroller-based automatic three-phase load balancing system to mitigate the effects of unbalanced load distribution in a three-phase system. The simulation results showed that the system was able to balance the load distribution and indicate when the system is critically unbalanced or well-balanced on the LCD unit. It is concluded that the use of microcontroller-based load balancing systems can improve the performance and longevity of a three-phase distribution system. It is recommended that this system be implemented in distribution networks to address the problem of unbalanced load distribution.

An automatic three-phase load balancing system was designed and simulated to mitigate the effects of unbalanced load in a three-phase distribution system. The system uses a microcontroller, switching relays, voltage and current sensors, and an LCD unit to perform the measurement, monitoring, protection and control functions. The system helps in energy saving and prevents damage to the distribution system.

Ethical Approval:

Not applicable.

Acknowledgements:

Not applicable.

Conflicts of Interest:

The authors declare no conflicts of interest.

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