Three-phase Voltage Imbalance Protection System

Sreehari Sharma S[1], Salins SS[2], Sreejith S[3]

[1]Student, Department of Electrical and Electronics Engineering, College of Engineering Attingal
[2,3]Assistant Professor, Department of Electrical and Electronics Engineering, College of Engineering Attingal

Abstract
Voltage imbalance condition often causes issues in the operation of three-phase electrical equipment. It results in overheating, improper operation, or performance-related issues. The system proposed here was developed to protect the three-phase rectifier used in a DC Machines lab with 30kW capacity from the voltage imbalance. It was developed as a simple and low-cost system that can effectively satisfy the intention. It continuously compares the supply voltage levels using voltage sensors and stops the power supply if there is a significant difference in the phase voltage levels. It will display the phase voltage levels in the liquid crystal display and also will give an alert using the buzzer. This system was successfully implemented and tested and can be used to protect other three-phase equipment as well.

Keywords: Voltage Imbalance, Protection, Three-phase, Rectifier

1. Introduction

Often the unbalanced voltage supply affects the operations of three-phase equipment such as motors and three-phase rectifiers [1]. Even if there are no issues on the supplier side, unbalanced loading conditions can lead to voltage unbalance conditions [2]. Though we generally use MCBs as a protective measure for electrical equipment it cannot protect against voltage imbalance. The unbalanced voltage conditions can cause overheating issues and can also affect the performance of the equipment. If the voltage differences are larger, the diodes connected to those phases with lower voltage can remain reverse biased. This system was designed to protect a three-phase 30kW rectifier against voltage imbalance conditions. The implementation was done using an Arduino UNO so that with minor modifications we can add voltage imbalance protection to the system. It is a cost-effective and simple protective system against voltage imbalance conditions. It can also be utilized in other places where we have to protect three-phase equipment from voltage unbalances.

2. Proposed System

A. Components Used

The following are the components used in the system:

- Arduino UNO
- ZMPT101B
- LCD I2C

- 5v Single Channel Relay
- Piezo Buzzer

The Arduino Uno is a low-cost development board based on the Atmega328p microcontroller. It can operate with very low power consumption. It can read both digital and analog values and can give digital and PWM signal outputs. Fig.1 shows a pinout diagram of Arduino UNO.

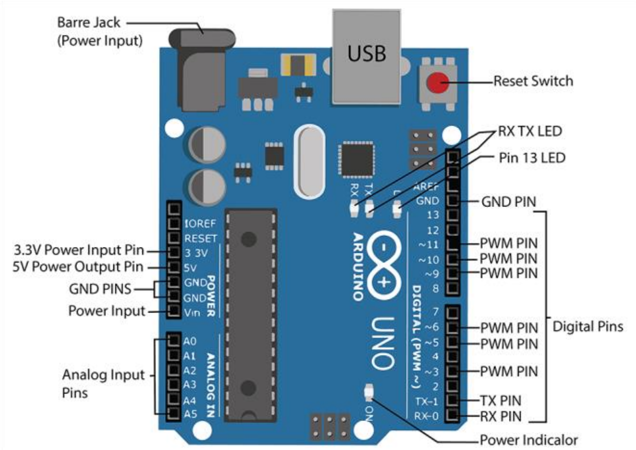

Figure 3: Pinout diagram of Arduino UNO

ZMPT101B is an analog AC voltage sensor with a voltage transformer in it. It can measure AC Single Phase voltages up to 250V. Fig.2 shows the pinout diagram of ZMPT101B.

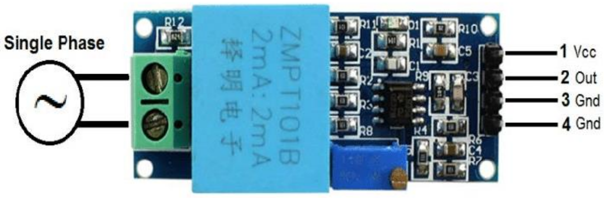

Figure 2: Pinout diagram of ZMPT101B

LCD I2C consists of a typical Liquid Crystal Display and an I2C LCD Adapter. The advantage of using LCD I2C is that the connections are made simpler as it requires only four pins to be connected.
Fig.3 shows the pinout diagram of LCD I2C.

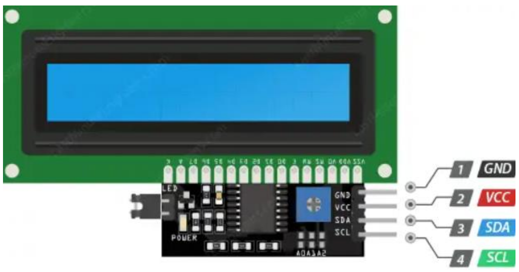

Figure 3: Pinout diagram of LCD I2C

The 5V Single Channel Relay is commonly used for switching purposes in IoT. It can handle up to 10A at 250V AC. Fig.4 shows the pinout diagram of the 5v Relay Module.

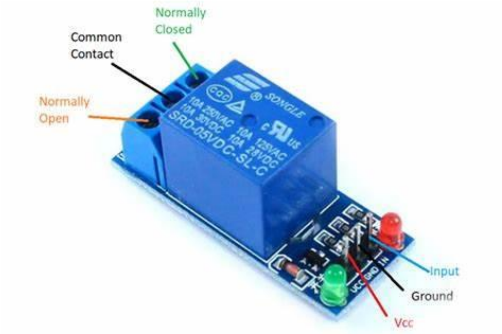

Figure 4: Pinout diagram of Relay Module

Piezo Buzzer is used for creating a beep sound in order to give alarms in different situations.
Fig.5 shows the pinout diagram of a 5v piezo buzzer.

Figure 5: Pinout diagram of the piezo buzzer

3. 30kW Rectifier

A. Overall Working: The rectifier operates using a three-phase power supply and has a maximum output power capacity of 30kW. The output is adjusted to 220v DC but can be adjusted between 180v to 240v DC. Fig. 6 shows the rectifier for which the protection system was designed.


Figure 6: Three-phase rectifier

It is connected to the power supply using a three-phase three-pole MCB. Just after the MCB there is a three-phase contactor. The protection system was added to this part. After the contactor, a delta-wye transformer and an autotransformer are provided for voltage adjustments. The output is fed to a three-phase full bridge rectifier circuit. Fig.7 shows a three-phase full bridge rectifier.

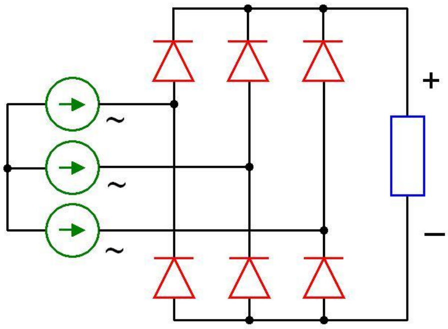

Figure 7: Three-phase full bridge rectifier

B. Working of Three-Phase Contactor: The contactor is nothing but an electrically operated switch used for switching an electrical power circuit. They are generally designed to handle high-power applications. Fig.8 shows the wiring diagram of a typical contactor.

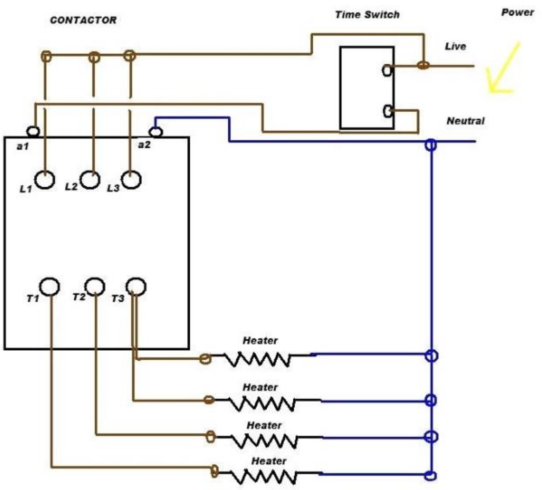

Figure 8: Wiring diagram of contactor

The contactor has three pairs of terminals for connecting three phases (T1-L1, T2-L2, T3-L3), apart from these three pairs it has another pair of terminals **a1** and **a2**. It is used to excite the electromagnet which turns the contactor into the ON position.

4. Protection System Block Diagram

The protection system that has been designed using Arduino UNO monitors the voltage levels and operates the contactor accordingly. The measured voltage levels are shown in the LCD display and the buzzer is activated if there is a voltage imbalance condition. Fig.9 shows the overall block diagram of the system.

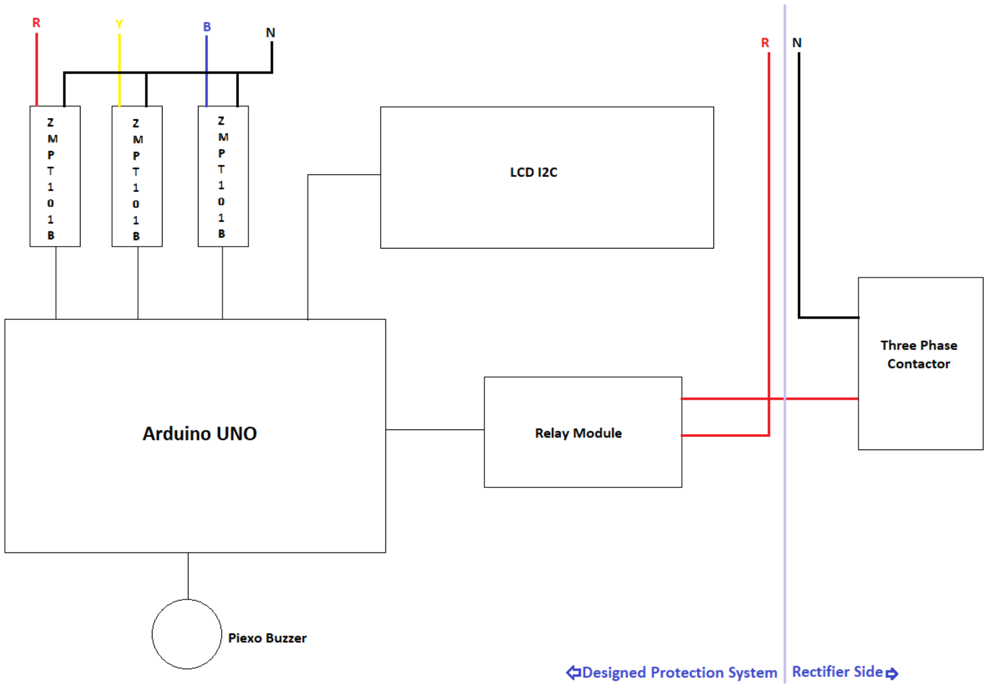

Figure 9: Overall block diagram

5. Working

The Arduino UNO measures the phase voltages using the ZMPT101B voltage sensors continuously. The rectifier is supposed to be connected to a power supply within the 240+/- 5V range. Arduino will first verify whether the measured phase voltages are within this limit. Secondly, Arduino compares the differences between phase voltages, and differences up to 3 volts are neglected. If any of the two conditions is not satisfied Arduino will turn the 5v relay module to OFF position. This will de-excite the coil of electromagnet within the contactor of the rectifier unit and will stop the power supply to the delta-wye transformer, hence the power supply to the full bridge rectifier is also stopped. After cutting off the power supply to the rectifier, the buzzer is activated for 5 seconds and it again monitors the voltage conditions. If both conditions are satisfied the relay is turned on and the electromagnet of the contactor is energized allowing the power to flow towards the full bridge rectifier through the transformers. Fig.10 shows the flowchart representing the operation of the protection system.

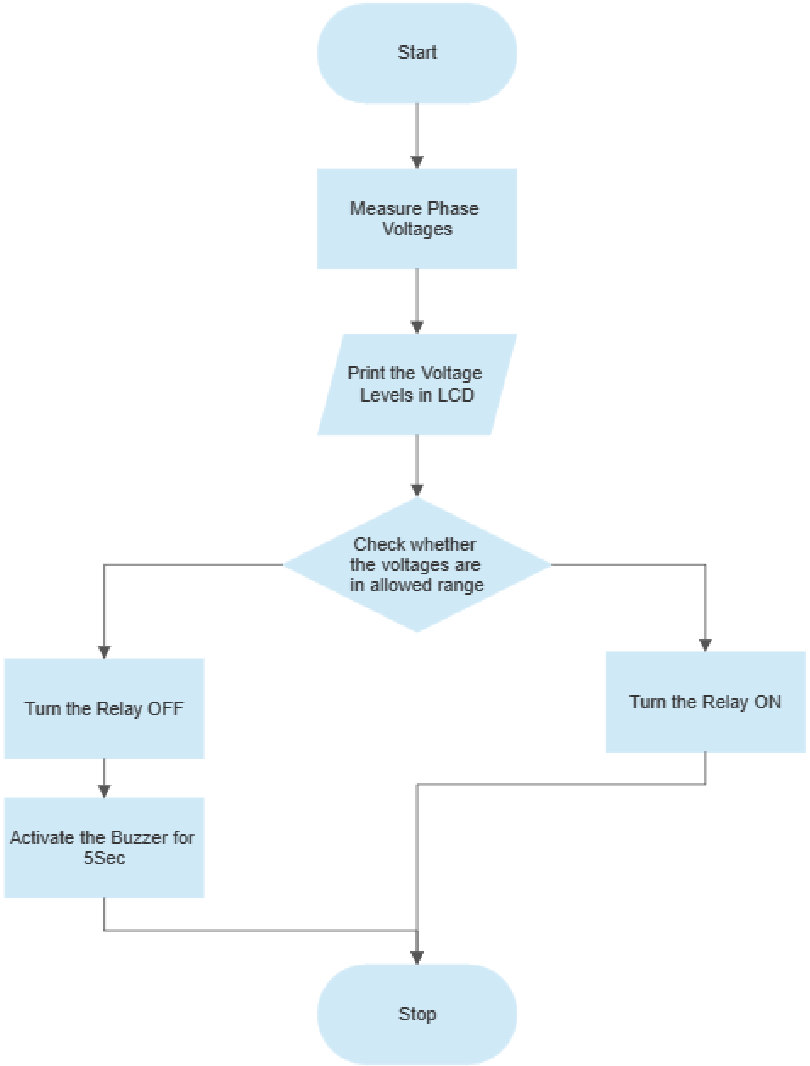

Figure 10: Flow chart of the operation

6. Test Results

The protection system was evaluated under different voltage conditions by using external auto transformers and rheostats in series to the rectifier unit. The rectifier was left unloaded during the testing phase. Table.1 shows the results of the testing.

Table 1: Phase Voltage Levels and Contactor State

	R Phase Voltage	**Y Phase Voltage**	**B Phase Voltage**	**Contactor State**
Test 1	236	235	235	ON
Test 2	240	228	238	OFF
Test 3	230	228	227	OFF
Test 4	238	237	238.5	ON

Fig.11 shows the experimental setup using an external auto transformer and rheostats.

Figure 11: Experimental Setup

7. Conclusion

The intent of designing this system was to protect the three-phase rectifier from unbalanced voltage conditions without major modifications to the existing setup and to do it in a cost-effective way. The test results have proved that the system has achieved the expected parameters and performed all the operations as expected. The system also has a good potential for further development and can also be used to protect other three-phase electrical equipment as well. With certain modifications, the system can measure energy consumption as well.

8. References

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