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DESIGN AND CONSTRUCTION OF AN AUTOMATIC PHASE FAILURE DETECTION SYSTEM FOR A THREE-PHASE MOTOR

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ABSTRACT

This project work Design and Construction of an Automatic Phase Failure Detection System for a Three Phase Moto was successfully done. The constructed system used PIC Microcontroller to sense the present of phase failure by comparing the rated voltage values with the current line voltage. The system is stripped off whenever there is presence of phase failure.. From the results, it is observed that the results are satisfactory, reliable, gives quick response, cost effective and highly versatile with the ability of the system to switch off the load when any of the phase voltage is lower than the set (rated) threshold as well as when there is phase outage.

Keywords: *Design, Construction, Automatic, Detection System, Three-Phase Motor.*

INTRODUCTION

An electrical motor is an electromechanical device that converts electrical energy into mechanical energy. In the case of three-phase AC (Alternating Current) operation, the most widely used motor is a 3 phase induction motor, as this type of motor does not require an additional starting device. These types of motors are known as self-starting induction motors. The three phase induction motors are simple in construction, rugged, low cost and easy to maintain. They run at a constant speed from no-load to the full load. Therefore, these motors are frequently used in industries to drive loads. But, the three phase induction motor generally suffers from under voltage, overvoltage, overheating, phase loss and phase reversal problems (Ovbiagele *et al.*, 2019). This operating condition affects the overall efficiency and working conditions of the motor thereby resulting into different fault conditions such as shutdown which result into industrial production losses.

Phase loss is the operation of a three phase motor on only two phases to due to the loss of voltage on one phase. Phase loss is the maximum condition of voltage unbalance. This occurs when one fuse blows, when there is a mechanical failure within the equipment, a broken power line, open supply transformer winding, or a lightning strike (Ezema, 2012). Three-phase motors must be connected to a nominal voltage to function properly. If for any reason any of the phases that supply the motor are disconnected, the motor continues to operate with the remaining two phases. This is called phase failure or single phasing (Ezema, 2012). If a three-phase motor is operating and loses one of the phases, the motor will continue to operate at a reduced speed and experience vibrations. The current will also increase considerably in the remaining phases, causing an internal heating of the motor components. If the motor is not disconnected quickly, it will break down as a result of this increase in temperature. This failure can be harmful even if it occurs when the engine is not in operation because, depending on the load, sometimes the engine is able to start even when only two phases are connected. **Phase failure can also occur due to** faulty cables that supply the motor, broken connection terminals due to vibrations or aging. It also occurs through connection terminals that are not properly tightened; one of the fuses of the three-phase circuit opens; the starter contactor is damaged or rusty and leaves an open phase and so on.

This work is aimed at monitoring and sensing of the voltage status of the three phase induction motor such that if there is a phase loss, the proposed system automatically stops the motor from running or prevent it from starting until when the monitored phase voltage is equal to the rated supply voltage.

LITERATURE REVIEW

Ofualagba and Udoha (2017) implemented an automatic phase selector and changeover circuit consisted of three transformers T1, T2 and T3 which were connected to each phase from the public utility supply. The output of the transformers was rectified, regulated and fed to feed into the Atmega328 PU Microcontroller Unit for onward comparison and processing. The programmed logic resident in the ROM of the Microcontroller unit does all the processing of the Direct Current (DC) voltage and passed the signal for the phase with the healthiest available phase (most stable, safe and available). The processed signal was sent to the respective pin which actuated/triggered the switching circuit interfaced with it to feed the load without any notice of power outage. .The research was based on providing uninterrupted power supply for household usage. There was no provision for other 3-phase equipment and no feedback mechanism such audio or wireless means of alarming incorporated in the design.

Denishet al., (2019) designed an Automatic Phase Sequence and Overload Protection using PIC Microcontroller. Single phase was taken from three phase supply for voltage and current measurement. Three phase supply was given as input to phase sequence detector module to check the phase sequence. Then the measured voltage, current and checked phase sequence was given to ADC pins of PIC 16F877A. Using the C-program dumped in PIC 16F877A, it compared the measured parameters with the predefined ranges used in the program and displays voltage and current values in the LCD as well as sent the signal to relay according to the results of comparison of the measured parameters.

In a related research, Alamain (2018) implemented a control system for identification of phase failure and detection of unbalanced phase sequence of induction motor using Atmega328 microcontroller. Three phase voltage was tapped using transformers; rectified and regulated. The regulated voltage was fed to the microcontroller ADC pins. To detect the phase sequence, Operational Amplifier (Op Amp) was used to convert sine wave to square waveform and compared the sequence and send the state of sequence as logic bit (0 or 1) to the computer. In case of any fault in phase sequence, the controller cutoff the power and LCD display message (Sequence abnormal).The major weakness of this design was the complexity involves with using software for phase sequence detection and the inability of the system to provide viable means of alerting and feedback system in case of any fault on the phases.

Tanjil Sarker *et al.*, (2017) designed a Global System for Mobile communication (GSM) & microcontroller based three phase fault analysis system. The three phase fault detector and analysis system was designed based on GSM and PIC Microcontroller. The PIC Microcontroller device was interfaced with GSM module that enables alerting the operators on any fault detected on any of the phases.GSM technology was utilized as a means of feedback and for alerting operators about any fault on the phases. It required

GSM network; which is not available in some locations. This was seen as the major system limitation.

Ovbiagele *et al.*,(2019) designed and constructed a microcontroller based fault detection and protection of three phase induction motor using various protection schemes. The values of voltage and current of the motor and the problems occurring in the motor were monitored and detected by the microcontroller and the warning signals are displayed on the LCD. The motor tripped off if any fault occurred

METHODOLOGY

Proposed System Block Diagram

The work is implemented using the proposed system block diagram shown in Fig.1

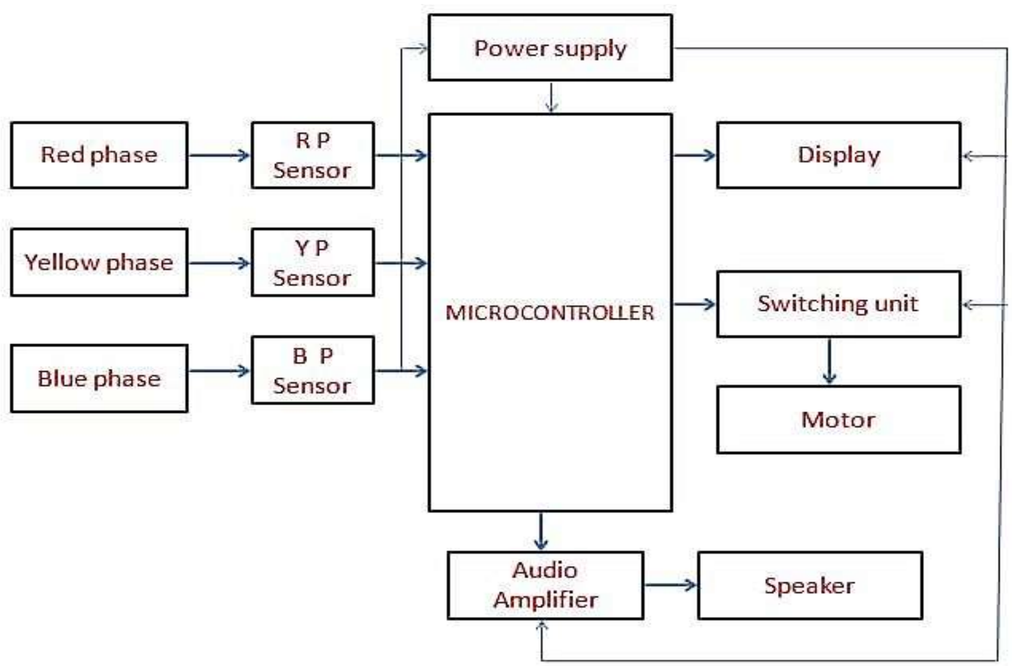

Fig. 1: System Block Diagram

The various components and their design parameters are explained in the following sub sections.

Power Supply Design

The power supply unit is designed to supply 12V, 5V and 3.3V. The power supply has components such as a step down transformer, a bridge rectifier, a filter capacitor and a voltage regulator.

Filtering Capacitor Design

The peak voltage = $V_{peak} = V_s \times \sqrt{2}$ … (1)

V_s =R.M.S value of the transformer secondary winding = 12V

$V_{peak} = \sqrt{2} \times 12 = 16.97V$ … (2)

The DC value of the rectified voltage is given by

$V_{dc} = \frac{2}{\pi} V_{peak} = \frac{2}{\pi} \times 16.97 = 10.80V$ … (3)

Maximum load current is given by

$I_m = \sqrt{2} \times I_{R.M.S} = \sqrt{2} \times 300mA = 0.4242A$ … (4)

$I_{R.M.S} = 2A$ = Transformer secondary output current

Average load current;

$I_{dc} = \frac{2}{\pi} I_m = \frac{2}{\pi} \times 2.83 = 0.2700A$ … (5)

It is preferable to use a filtering capacitor that will hold the peak ripple voltage at approximately 1%

$V_{ripple} = 0.01 \times V_{dc} = 0.01 \times 10.80 = 0.106V$ … (6)

The shunt capacitor value C_1 is obtained from the relation given by

$C_1 = \frac{I_{dc}}{F \times V_{ripple} \times 4\sqrt{3}} = \frac{1.80}{50 \times 0.106 \times 4\sqrt{3}} = \frac{0.2700}{37.41229} = 0.00721\mu F$ …. (7)

From the E series for capacitors available for commercial purchase, the rated capacitance for C_1 is not available. Hence, available capacitor of 1000uf will be used for the rating of C_1

Design of 5V Power Supply

This power supply will be used to power the microcontroller, the LCD, the temperature sensor and the buzzer alarm. A 5V constant voltage regulator LM7805 was used to deliver the required 5V.

Design of 12V Power Supply

The 12V power supply will be derived from the central power supply shown in Fig. 2. A 12V constant voltage regulator called LM7812 was used to deliver the required 12V

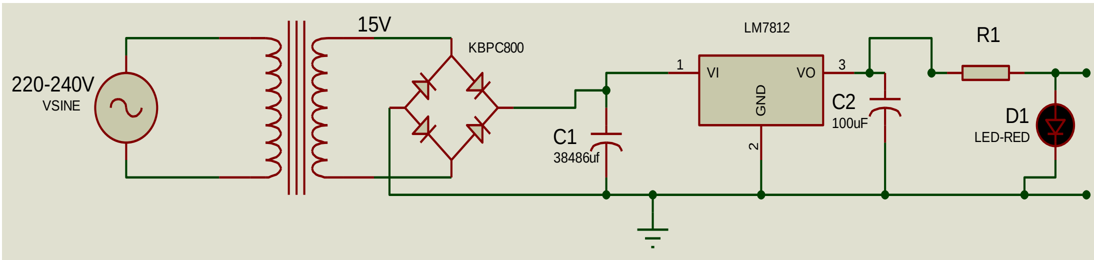

Fig.2: 12V Power Supply Circuit

The capacitor C_2 is used for post filtering after regulation, its value is suitably chosen as 100µf. The protection resistor rating for the red LED is designed using the KVL relation around closed loop between C_2, R_1 and D_1 of Fig. 2 as follows

$$V = V_D + I_D R_1 \qquad \ldots (8)$$

Where V is the source voltage of the red LED = 12V

V_D Is the voltage consumed by the LED from its data sheet specification $= 2V$

I_D = Current consumed by the LED from its data sheet specification = $20mA$

$$R_1 = \frac{V - V_D}{I_D} = \frac{12-2}{20mA} = \frac{10}{20} = 500\ ohms \qquad \ldots (9)$$

But 510ohm resistor was used in the implementation since 500 ohms resistor was not available

Design of 3.3V Power Supply

The 3.3V power supply was obtained through LM317 variable voltage regulator Using the formula for maximum output voltage ($V_{o\ max}$) required from the LM317 adjustable voltage regulator, the ratings of resistor R_2 of Fig. 3. is determined.

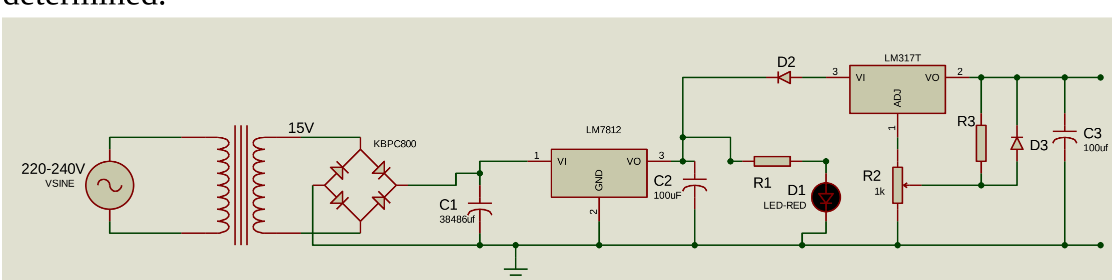

Fig. 3: 3.3V Supply

$$V_{o\,max} = V_{ref}\left(1 + \frac{R_2}{R_3}\right) \quad \ldots (10)$$

$V_{ref} = LM317$ Reference, voltage $= 1.25V$

since we need an output of 4.2V from LM317, then $V_{o\,max}$ will be equated to the required output voltage.

Setting R_3 as 220 ohm, then equation 2 becomes

$$1.25 \times \left(1 + \frac{R_2}{220}\right) = 4.2 = 1.25 + \frac{1.250R_2}{220} \quad \ldots (11)$$

$$924 = 275 + 1.250R_2 \quad \ldots (12)$$

$$924 - 275 = 649 = 1.25R_2 \quad \ldots (13)$$

$$\frac{649}{1.25} = R_2 = 519.2 \quad \ldots (14)$$

$$R_2 = 519.2 \text{ Ohms} \quad \ldots (15)$$

From the data sheet for four color band resistors available commercially, Ohmic value 1k Ohms for R_2 was used since the exact value cannot be gotten.

Power Supply Design for phase sensing

The power supply is aimed at supplying a maximum of 6Vdc to the analog pin of the microcontroller for sensing the presence of voltage at a constant current of at least 40mA.

Design of LCD Constant Voltage Dividers

The voltage divider configuration made up of R7 and R8 are required to supply an output voltage of 0.5V (in accordance to the data sheet) to the LCD for powering the background light contrast as shown in Fig. 4

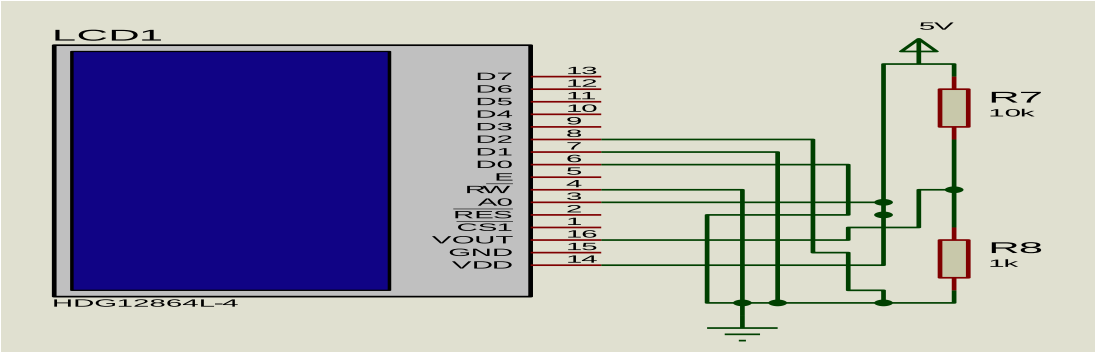

Fig. 4: LCD circuitry with Constant Dividers

$$V_{OUT} = \frac{R_8}{R_8 + R_7} \times V_{CC} = 0.5 = \frac{1000}{1000 + R_7} \times 5 \quad \dots (16)$$

Note, R_8 was set as 1000 Ohms for convenience in calculating R_7

$$5000 = 500 + 0.5R_7 \quad \dots (17)$$

$$5000 - 500 = 0.5R_7 = 4500 \quad \dots (18)$$

$$R_7 = \frac{4500}{0.5} = 9000\ Ohms \quad \dots (19)$$

But 10000 Ohm resistor was used with reference to the E series table data sheet for commercially available resistors

Design of Microcontroller Oscillatory Circuit

This unit is responsible for determining the frequency of operation of the microcontroller. The crystal oscillator C_1 has three types as shown in Table I. The crystal oscillator chosen determines the range of selection for C_2 and C_3. The circuitry is shown in Fig. 5

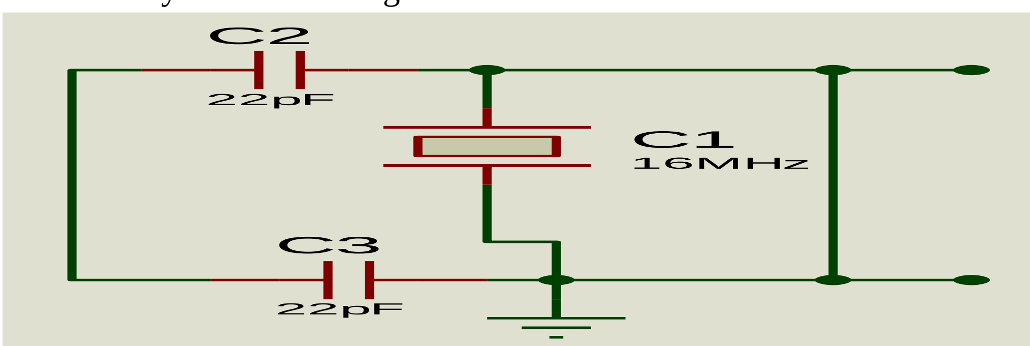

Figure 5: Oscillatory Circuitry for Microcontroller.

A 16MHz high speed crystal oscillator was used as C_1 and the rating of C_2 and C_3 were chosen in accordance to the ranges specified in Table. I with reference to the value of C_1.

Table.1: Crystal Oscillator Capacitors and their Frequencies

Types of Crystal Oscillator	Frequency (Hz)	C1 (F)	C2 (F)
Low Power	32k	33p	33p
LP	200k	15p	15p
Ceramic Resonator	200k	26-68p	26-68p

XT	1.0M	15p	15p
	4M	15p	15p
High Speed Crystal	8M	15-33p	15-33p
	20M	15-33p	15-33

Internal frequency of operation of the microcontroller and period of machine cycle needed to execute an instruction is computed below

$$F_{internal} = \frac{F_{Quartz}}{2} = \frac{16MHz}{2} = 8MHz \qquad \ldots (20)$$

$$T = \frac{1}{F_{Internal}} = \frac{1}{8} = 0.125\mu s \qquad \ldots (21)$$

$F_{internal}$ = Internal clock frequency of microcontroller
T = Period or machine cycle for executing an instruction
F_{quartz} = Frequency of crystal quartz

Flow Chat Design for Source Code Implementation and the Complete Proposed System Circuit

The flowchart for the proposed system and the circuit diagram implemented in this work are shown in Figs.6 and 7

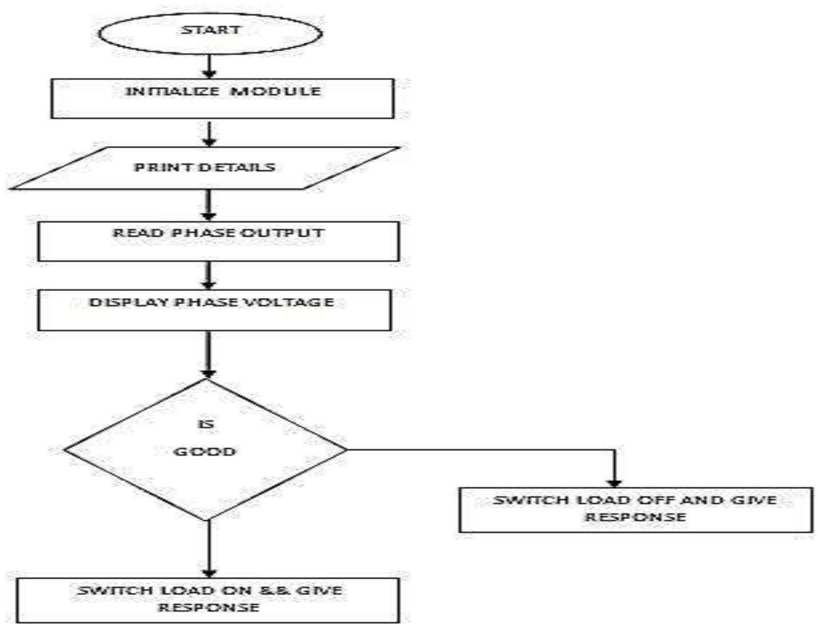

Fig. 6: System Flowchart

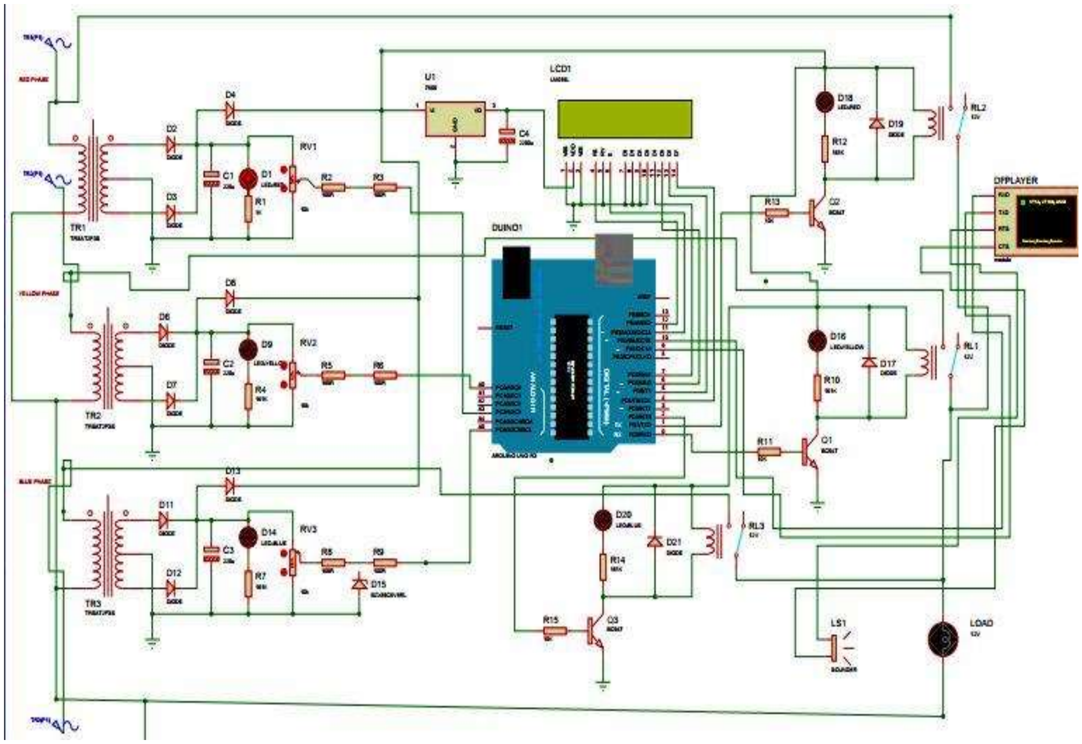

Fig. 7: Proposed System Circuit

RESULTS AND DISCUSSION

Results

The results obtained after the proposed system design implementation are shown the following subsections

Single Phasing Test

The single phasing protection is available; system was tested for it capability to trip OFF when one of the three phase power supply is not available as shown below in the Table II.

Table II: Single Phasing Test

S/N	Phase Voltage (V)	Three Phase Load
1.	Red, Yellow, Blue	ON
	Yellow, Red, Blue	ON
	Blue, Yellow, Red	ON
2.	X, Yellow, Blue (Red Fault)	OFF

Red, X, Blue (Yellow fault)	OFF
Red, Yellow, X (Blue Fault)	OFF

1. The protection system is ON or no tripping OFF the circuit when Red, Yellow and Blue phase's voltage values ranges between (≤190 and ≥240).
2. The protection system is tripping OFF the circuit. Whenever either Red or Yellow or Blue phase's voltage value is 0 - <190, the microcontroller identified one of the three phases is zero voltage value, then relay tripped OFF the circuit, showing on LCD: R PHASE FAIL or Y PHASE FAIL or B PHASE FAIL, for Red, Yellow and Blue phases respectively. as shown in Plate 1:

Discussion of Result:

The system was able to switch off the load when any of the phase voltage is lower than the set threshold as well as when there is phase outage. The audio player was performing as expected by sending an audio sound signifying phase failure and the LCD display was also satisfactory. By virtue of these tests and the results obtained, the implemented construction can be easily troubleshot if any abnormality arises. It can also be seen that three phase failure protection system can save life and also reduce stress encountered when a manual three phase failure protection system is used.

CONCLUSION

The Design and Construction of an Automatic Phase Failure Detection System for a 3-Phase Motor was successfully carried out. The implemented system used microcontroller to sense the present of phase failure by comparing the rated voltage values with the current line voltage. The system is stripped off whenever there is presence of phase failure. With the increasing rate of power failure disaster developing countries like Nigeria, this menace could be handled by implementation of this work in industries and workshops.

RECOMMENDATIONS

For further work on this topic, the following measures can be carried out to improve its functionality.

- The SMS function should be considered for alerting users remotely of system shutdown using Internet of Things (IoT) principles.
- Solar panel should be an alternative means for charging the battery

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Plate I