Design and Construction of a 3-Phase Protective Device for Voltage Variation of Induction Motor

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Abstract

Protection of equipment and properties is of great importance to government, organization and individuals. This brought about the concept of design and construction of overvoltage, under voltage and single phasing protective device which will be capable of protecting all connected appliances as well as prevention of fire outbreak during abnormal power supply, since all fault cannot be humanly observed. This paper is aimed at providing a solution to the problem of voltage variation (under and over voltage). The protection of three phase induction motors is to start and stop the motor automatically in case of any fault. The circuit will take full control of the motor and it will protect the motor from several faults such as over voltage and under voltage. In addition, under specified range (190-250V) the circuit can also protect induction motor from single phasing which is also a major fault in power system. Herein, microcontroller AT MEGA 382 Arduino Kit was used as the principal driver of the project. From the results obtained, the device is cost effective and reliable and also capable of protecting induction motor from under/over voltage as well as single phasing problems.

Keywords*:* *Protection, induction motor, abnormal power supply, under and over voltage, microcontroller*

1. INTRODUCTION

Protection of equipment and properties is of great importance to government, organizations and individuals. This brought about the concept of design and construction of over voltage, under voltage and single phasing protective device which will be capable of protecting all connected appliances as well as prevention of fire outbreak during abnormal power supply, since all faults cannot be humanly observed [1].

Induction motor or asynchronous motor is an AC electric motor in which the rotor torque produced is caused by electromagnetic induction from the stator winding of the magnetic field [2]. The type of winding found in induction motors rotor is Squirrel cage rotor. It's the most widely used for appliances, industrial control and automation. And often refer to as the workhorse of the motion industry because of its robustness, reliable, low cost, high efficiency and durability. Three-phase induction motors are widely used in industrial drives and single-phase induction motors are widely used for smaller loads especially in domestic appliances, such as washing machines [3].

This paper is aimed at designing a three phase Induction motors protection scheme to start and stop the motor automatically in case of any fault. The circuit will take full control of the motor and it will protect the motor from faults such as over voltage and under voltage and the circuit will switch on the motor under safety conditions and also protects Induction motor from single phasing which is also a major fault. The circuit will be fully controlled by the microcontroller and the microcontrollers will continuously monitor the voltages of the three phase and if the voltages goes abnormal then it will switch off the motor until they are normal.

In this project, the microcontroller AT MEGA 382 Arduino kit was used as the principal driver of the project. Today, this versatile device can be found in a variety of control applications such as TVs, VCRs, CD players, microwave ovens, automotive engines e.t.c. [4]. A Microcontroller unit (MCU) uses microprocessor as its central processing unit (CPU) and it incorporates memory, timing reference, I/O peripherals etc., on same chip. Limited computational capabilities and enhanced I/O are special features [4].

2.0 LITERATURE REVIEW

Electrical energy is a form of energy that can easily be converted to other forms and vice-versa [1]. An electric power system consists of generation, transmission and distribution system. The transmission and distribution systems are amongst the final stages of power transfer to the consumers, the electric power should be available instantly at the correct voltage and frequency [1].

However, the electric power system in Nigeria often experience power interruption and fluctuation due to system disturbance. In other to avoid this problem, it is required to design a system that would allow certain range of voltage suitable for the smooth running of the equipment and also switches it off from the supply in the event of overvoltage and/or under voltage, overheating and detect phase loss on the distribution line [5].

2.1 Review of Previous Works

[6] designed and constructed an over voltage and under voltage protection scheme using a tap selector method. The method involved movement of parts and suffers problems associated with mechanical device such as noise, wear and tears, slow switching time, e.t.c. The method is not suitable for this task because of its limitations.

[7] carried out review on the established principles and the advanced aspects of the selection and application of protective relays in the overall protection in power systems, multifunctional of some numerical devices used for power distribution and industrial systems, and there after addressed some of the key issues of concerns in the selection, coordination, as well as setting and testing of smart relays and systems.

[8] designed and simulated automatic phase selector and changeover switch for 3-Phase power supply. It provided means of switching supply from one phase of AC mains to another in the case of phase failure. It is also capable of changing over the load to generator in the even that all the phases are down. When the supply is restored back, the circuit can sense the restoration of any or all the three phases of the mains and changeover without any notice of power outage. The work is an improvement on the existing electromechanical devices use for this purpose over the years. They made used of 1- of - 4 analogue multiplexers (CD4052), analogue to digital converter (ADC0804), AT89C51 microcontroller and relay switches to archived the work.

[9] designed and constructed an under/over voltage protector for three phase induction motor and discrete component were used and comparator as the driver. In my work, single phasing was considered and Arduino Atmega 328 UN O was used as the microcontroller which is the brain of the circuit.

[10] designed and constructed a digital phase selector he also made use of Arduino microcontroller but fail to include the overheating and single phase failure protection. His design switches when there is failure in any of the phases considering the voltage range for the safety of the equipment.

3.0 METHODOLOGY

Based on the program written into the microcontroller, it's prime use is to protect the motor from voltage violation and single phasing and the circuit will automatically on/off the motor. Microcontroller send signal to the relay connected to the starter of induction motor for it to start/stop operation. The block diagram of automatic voltage control of induction motor using microcontroller is shown in the Fig. 1 below.

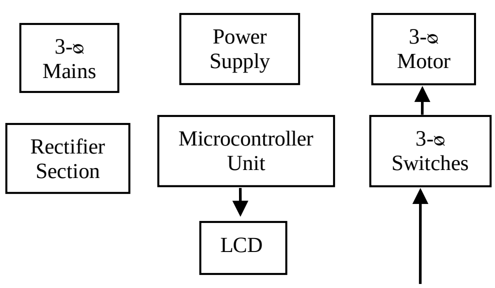

Figure 1: Block Diagram of the Circuit

3.1 Modification on the Existing Design

The improvement in this design is that, single phasing was considered and Arduino Atmega 328 UN O was used as the microcontroller to serve as the brain of the circuit for the detection of over and under voltages. The design is economical, easier and is more efficient.

3.1.1 Arduino board

Arduino is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software. It can be used to sense the environment by receiving input from a variety of sensors and can affect its surroundings by controlling lights, motors, and other actuators. Arduino projects can be stand-alone or they can communicate with software on running on a computer (e.g. Flash, Processing, MaxMSP).

It includes 6 to 10-bit analogue inputs and can be used for ultra-inexpensive data acquisition. The Arduino Uno is based on the ATmega 328 that consist of 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analogue inputs, a 16 MHz ceramic resonator, a USB connection, a power jack and a reset button. It contains everything needed to support the microcontroller where just simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.

The ADC feature of Arduino Uno depends from the ATmega 328 microcontroller itself. It contains 10-bit successive approximation ADC. The operation of translating an analogue voltage value into different levels is what we call Analogue to Digital Conversion. This project needs the signal from pulse width modulation (PWM), which is a powerful way of controlling analogue circuits and systems, using the digital outputs of microprocessors. Defining the term, we can say that PWM is the way we control a digital signal simulating an analogue one, by means of altering its state and the frequency. The choice of this micro-controller is usually the availability and the required functionality. The ATmega328 is a suitable choice for the following reasons:

i. It is readily available in Nigeria electronics stores
ii. It has analogy to digital inputs.
iii. It has 24/35 I/O pins with individual control and high current source/sink for LED drive.

Figure 2 shows the Arduino board used in this project.

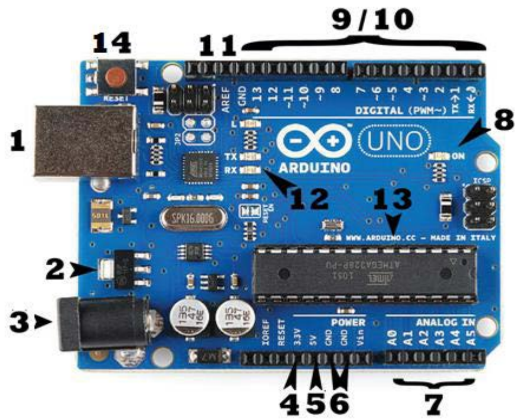

Figure 2: Arduino Board

3.1.2 Power supply

The power supply unit is the unit that energizes all other unit in the design at a fixed voltage. The fixed voltage supplies the switching unit and microcontroller while the unbalanced voltage from the three phases into the analog to digital converter for voltage comparison.

Power supply converts AC to DC. In this design, 12V DC is required for switching unit and 5V DC for the microcontroller unit. Rectification is process of converting AC to DC and it consists of the following components;

i. Step down transformer
ii. Rectifier
iii. Filter
iv. Voltage regulator

Other components designed in detailed here in includes; relay, transistor and liquid crystal display (LCD).

3.2 Under and Over Voltage Scenarios

Under voltage fault is simulated by reducing the maximum voltage on all three phases by a certain percentage when the motor is running under normal condition. In this project if the voltage level fell below 190V, it is said to be undervoltage.

When the motor is operating at normal condition with load, the three phase voltage are increased by a certain percentage. In this case if the voltage is above 250V, it is said to be overvoltage.

3.3 Single Phasing

The single phasing fault is a worst condition of unbalanced case. This fault is simulated by keeping any one of the phase voltage at 0V.

3.4 Design Procedures

All the components used in the proposed protection system were design as follows;

3.4.1 Transistor Design

This is a three terminal, three-layer device formed by adding a second P or N region to a P-N junction diode. With two n- region and one P region, two junctions are formed and it is known as NPN transistor. The common emitter configuration for an NPN transistor is generally use in switching application.

When a transistor is used as a switch, it must be fully ON. In the fully ON state, the voltage across the transistor is almost zero and the transistor is said to be saturated because it cannot pass any more collector current Ic. The output device switched by the transistor is usually called the load. The power developed in a switching transistor is very small.

In the OFF state: Power $=I_c \times V_{ce}$ ...(1)

But, when $I_c = 0$, so the power is zero

In the ON state: From Eqn. (1),

Power $= I_c \times V_{ce}$, but V_{ce} is zero

This means that the transistor is not in the active region. The important rating in switching circuits are the maximum collector current I_c (max) and the minimum current gain H_{fe} (minimum). The procedure below explains how to choose a suitable switching transistor.

i. The transistor's maximum collector current I_c (max) must be greater than the load current.
ii. The transistor's minimum current gain H_{fe} (min) must be at least five times the load current divided by the maximum output current from the microcontroller.
iii. Choose a transistor which meets these requirement, and make a note of its properties I_c(max) and H_{fe}(min).
iv. Calculate an approximate value for the base resistor,

$$R_b=0.2 \times R_l \times H_{fe} \quad \ldots(2)$$

v. Then choose the nearest standard value for the base resistor

vi. Finally, remember that if the load is a motor, relay coil and diode are required.

Figure 3 depicts a transistor acting as switch.

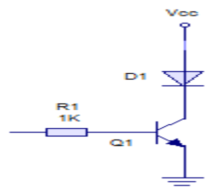

Figure 3: Transistor Switch

3.4.2. Relay Analysis

Relay is an electromagnetic device which is used to isolate two circuit electrically and connect them magnetically. They are very useful devices and allow one circuit to switch another while they are completely separated. They are often used to interface an electronic circuit (working at a low voltage) to an electrical circuit which works at high voltage. For example, in this project a 12V relay is use to switch a 240V AC main circuit. In a basic relay, there are three contactors: normally open (NO), normally close (NC) and common (COM). At no input state, the COM is connected to NC. When the operating voltage is applied the relay coil get energized and the COM changes contact to NO.

3.4.3 Power Supply

The power section consists of the transformer section, rectifier section and the filter section. The design of the power supply was achieved using a 240/12V, 50Hz, 500mA stepdown transformer. Voltage of 12V is required by relay and 5V to the microcontroller (Arduino) and the liquid crystal display (LCD).

a) Transformer Calculation

The transformer used is 240V A.C voltage which is step down to 12V A.C using a center tap transformer. The resultant output is given by;

$$V_{peak} = \sqrt{2} V_{rms} \quad \ldots(3)$$

Since, $V_{rms} = 12V$, $\gg V_{peak} = \sqrt{2} \times 12V$

$$V_{peak} = 16.97V$$

Power rating of the transformer is given as; $S = 12 \times 500 = 6VA$

b) Rectifier Design

Rectification is the process of converting AC voltage into DC voltage which is achieved by the arrangement of a diode rectifier circuit. IN4007 is used for rectification. There are three basic rectifier circuit; the half wave and full wave bridge rectifier. In this project, a full wave center tap rectifier was employed because of its high efficiency in AC ripple elimination.

$V_{dc} = (2/\prod) \times V_{peak}$ …(4)

But, $V_{peak} = 16.97V$, $\gg V_{dc} = (2/\prod) \times 16.97$

$V_{dc} = 10.80V$

c) Filter Design

The different types of filters are the resistor and capacitor. It is preferable to choose a filtering capacitor that will hold the peak to peak ripple at approximately 10% of the peak voltage. From the values gotten, it is calculated as:

$V_{ripple} = 0.1V_{peak}$ …(5)

But, $V_{peak} = 16.97V$, $\gg V_{ripple}=0.1\times16.97$

$V_{ripple}=1.697V$

Also, $C = I/2fV_{ripple}$ …(6)

where, I is current taken by the load

f is the frequency of the supply

C is the capacitance of the filtering capacitor

Since $V_{ripple}=1.697V$ and $f = 50Hz$

$\gg C= 0.17/2\times50\times1.69$

$C=1801.7\mu f$

From this calculation, a capacitor of 2200µf was chosen.

d) Voltage Regulator

A voltage regulator regulates the input voltage to a fixed output voltage. The circuit component used in the implementation of the microcontroller and the liquid crystal display require 5V D.C voltage. LM7805 (+5V) is chosen to provide up to 1000mA load circuit. Figure 4 shows the block diagram of the voltage regulator while Table 1 shows its characteristics as obtained from the data sheet.

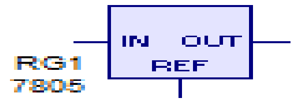

Figure 4: Voltage Regulator

Table1: Datasheet Specification for LM7805 [11]

	LM7805			
Characteristic	**Min**	**Typical**	**Max**	**Units**
Output voltage(Vo)	4.8	5.0	5.2	V
Input voltage(unless stated)	7.5	10	20	V
Dropout voltage	-	2.0	-	V
Load regulation(ΔVo)		2.0	50	mV
Line regulation(ΔVo)		3.0	50	mV
Peak output current at 25℃		2.4		A

e) Limiting Resistor

Limiting resistor can be obtained from ohm's law relations as in Eqn. (7) below.

V= IR …(7)

Therefore, R= V/I

LED can operate between the range of 1.8 - 2.2V DC forward operation, with a maximum current of 20mA.

16 – 18mA current was suggested for smooth operation of the LED.

The LED resistance can be obtained from Eqn. (8)

R=Vs-Vz/Iz …(8)

But Iz = 20mA, ≫ R=12-2.2/20mA = 490Ω.

The closest standard resistor value is 1kΩ.

f) Transistor Switch Driver Circuit

The voltage through the relay contact is rated 12V, with coil requirement is to switch 12V DC and resistance of 1kΩ. The circuit arrangement is as shown in Fig. 5.

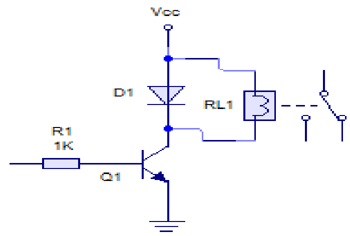

Figure 5: Transistor Switch Driver

3.4.4 Over and Under Voltage Design

Using the equation, $V_{out} = \left(\frac{R_2}{R_1+R_2}\right)(V_{in})$ …(9)

But V_{in}=11.24/2 = 5.62V

Choosing 4.7kΩ as the resistors value, the overvoltage value can be obtained using voltage divider as;

>> $V_{out} = \left(\frac{4.7}{4.7+4.7}\right)(5.62)$ = 26.414/9.4 =2.81V

For the under voltage, V_{in}=8.55/2 = 4.275V

Therefore, using voltage divider also,

$V_{out} = \left(\frac{R_2}{R_1+R_2}\right)(V_{in})$ …(10)

>> Vout = $\left(\frac{4.7}{4.7+4.7}\right)(4.275)$ = 2.14V

3.5 Implementation

The designed components were selected based on the calculation above and tested individually off board to ensure better performance. The components were later mounted on bread board. The connection was cross checked before being tested. The results being obtained were purely operational. It was thus at this junction that the three variable resistors of each power supply monitor unit were varied to observe the response of the relays and was observed to the approximate. The tested circuit was then transferred to the PC board for soldering. The soldering process were carefully followed such that the PC board surface and the component lead were cleaned before heating. The overall circuit diagram of the system is as show in Fig. 6.

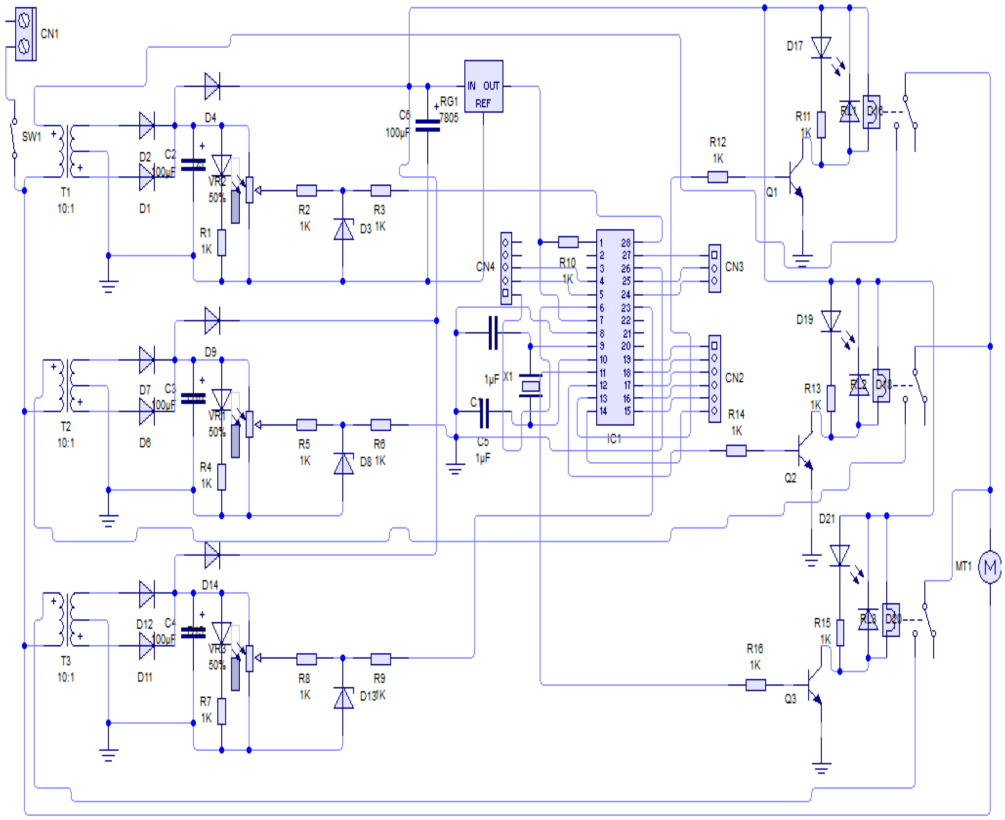

Figure 6: Overall Circuit Diagram of the Protection System

4.0 TEST RESULTS AND DISCUSSIONS

The components used for the implementation of this project were tested on breadboard for better performance, and were later transferred to the printed circuit board (PCB) and soldered. The heat applied during soldering was just moderate to avoid damage of the PCB and the components since most of the components have low heat resistance. The test equipment includes;

- Breadboard: To assemble and test individual components
- Digital multi meter: To measure voltage, current, resistance and continuity.
- VARIAC: To obtain a variable AC supply.
- Oscilloscope: To monitor all the signal shapes.

The test was done on each section that make up the circuit to ensure satisfactory and the efficiency of the microcontroller digital based protective device for induction motor. This section present the results obtained from the various measurements taken on the different tasks carried out. The discussion of the result obtained follows after every table.

4.1 Test on Power Supply Unit (PSU)

The effect of varying the input voltage on the monitor voltage (Unregulated Voltage) and the regulated voltage were tested and tabulated as shown in Table2 below.

Table 2: Result obtained for the power supply unit

Transformer	**Theoretical Voltage(V)**	**Measured Voltage(V)**
Input voltage	240	232
Output voltage	12.0	11.80
Rectifier		
Input voltage	12.0	11.80
Output voltage	10.79	10.60
Filter		
Output voltage		10.02

LM7805		
Input Voltage	Range 7.5-20	10.02
Output voltage	Range 4.8-5.2	5.09

The above result is for the power supply at no-load. A center tap transformer of 12V×2 was used. In practice, the output voltage falls as the load current increases.

4.2 Switching Unit Test

The switching unit which comprises of transistor BC547 and a relay was tested to the efficiency of the component. Low voltage was applied to the base of the transistor which gives a high output and when a high voltage was applied it gives a low output. The test was carried out on the three phases and the relay and transistor was ensured to be working in a normal condition. The result for the under and over voltage test is tabulated as shown in Table 3 below.

Table 3: Under and Over Voltage Test Results

Parameter	**Theoretical Voltage(V)**	**Measured Voltage(V)**
Under voltage	190	240
Over voltage	250	240

The result of the test shown in the table above was gotten after the program have been written. The induction motor will stop running if any of the phase (i.e RED, YELLOW, OR BLUE) is below the stated voltage range 190-250V is under voltage and above is over voltage which is sense by the microcontroller and the display on the liquid crystal display(LCD) and if the voltage of the phases is within the range the induction keeps running without any interruption.

4.4 Discussion of Results

The overall test was carried out to ascertain the efficiency of the system. After each unit have been tested separately, it is then coupled together and tested. The RED, YELLOW and BLUE phases and their neutral which are lumped together were connected to the AC 3-φ power supply VARIAC and output of the relay (i.e the common of each phase was connected to the induction motor) and a multi meter was also connected to the VARIAC to know the voltage value. The AC 3-φ power supply VARIAC was powered and the aim of the project was achieved successfully.

5.0 CONCLUSION

In this work, the design of a 3-φ under and over voltage protection device for induction motor was achieved. The protector was incorporated with a sensing unit which is microcontroller (ATmega 382), such that the device only works the voltage is within the specific voltage for the design which between 190-250V. The system shuts down for input voltages outside the range of 190 to 250volts and continues operation for voltage within and in the limit.

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