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Development of an Automatic Phase Selector for Nigerian Power Utility Customers

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Abstract: *Power utility customers in a developing country like Nigeria have constituted a habit of changing the electricity supply line from an unavailable or unstable phase to the most available or stable phase. The category of customers involved in this character are those on single phase power supply. However, this act is being carried out manually at the meter point using the cut-out fuses. This attitude results in phase unbalances, overheating electrical equipment including feeder pillars, transformer coils, network faults, and overall system instability. Thus, this paper presents the development of an Automatic Phase Selector for Nigerian Power Utility Customers. The device automatically selects an available phase from the three-phase power supply lines. The research comprises designing an automatic phase selector circuit, simulation of the designed circuit, programming code development in C- Language for the microcontroller, construction of the designed circuit, and carrying out tests on completed work done to ascertain the effectiveness of the developed system. The system operation involved a three-phase supply from the closest distribution network of the power utility company which is connected to a three-in-one gang switch while the switching ON and OFF of their static switches represent phase-off in an ideal situation. The operational results of this system are presented in the form of the truth table which indicates that the affected customer would not have a power supply only when the 3-phases are under voltage or overvoltage or unavailable. This implies that one of the three phases that meet the three criteria would be switched ON. A pure sine wave was used as input into the Optocoupler and the output waveform of the rectified pulsating signal is separately displayed. This output waveform is very clean and noiseless. Finally, the system when practically tested with an unbalanced three-phase supply, worked perfectly enhancing the flexibility of operating an Automatic Phase selector and hence avoiding manual switching of the phase selector which has been attributed to changing of cut-out fuses and associated stress as well as having a user-friendly phase selector.*

Keywords: *Cut-out Fuses, Distribution Networks, Phase Selector, Power Utility Customers, Programming Code, Truth Table.*

1. INTRODUCTION

As the growing residential population widens the gap between energy demand and supply, the rate of phase losses at the distribution level becomes higher, requiring much attention in securing a solution to this problem [1,2]. A permanent solution lies in the alternative use of renewable energy sources. This approach is not universally affordable, so it remains a constant yearning for a sufficient and efficient power supply.

In general, epileptic power supplies and electric power blackouts do not foster the development of the public and private sectors, as investors also worry about the viability of doing business in such countries, which hinders economic growth [2]. If the distribution companies do not have fixed phase available, then single phase loads may take three-phase power into the residence or where it is needed. Customer fuses called cut-out fuses are often replaced manually in the next available phase which of course is achievable by automation [2, 3]. Thus, an uninterruptible Phase Selector is designed to easily monitor, operate, and maintain constant electrical power in homes, hospitals, etc.

Generally, outages in the distribution network are about 70% on a phase off, while the other two phases are normal [3]. If three phases are available in the distribution network, automatic phase selection can be performed on critical loads in the event of a phase off on one of the phases. No backup power supply would be required as phase automatically switches in fraction of seconds such that the phase selection is not humanly noticeable. The primary objective of distribution companies is to provide continuous, efficient and reliable energy to consumers. If this objective is not met, unstable electricity supply tends to occur, which is evident in backwardness as found in developing countries such as Nigeria. Nigerians experiences power fluctuations, phase interruptions and even complete failures, which adversely affect economic development [2]. Most of the time, electrical equipment damage and downtime occurs in commercial and residential homes as a result of the epileptic nature of power supplies.

A mobile phone was used to select desired source of power from four different power generators. The Bluetooth module H5-5A was used for interaction between the device and the mobile application for load switching [2 - 4]. The device performs its designed function. However, the main limitations are the required human intervention (i.e. operating the phone to perform functions) and the limited range of Bluetooth to less than 100 meters.

To further speed up the operation of the system, [5] designed and implemented a PIC16F628 microcontroller-based phase selector. The process does not only produced smart and intelligent devices, but it also made them relatively cheap [5]. However, the microcontroller is permanently powered from one of the phases which is not always available due to the problem the device itself is trying to solve [6 - 16].

In another research work, purely electromagnetic devices such as contactors, overload protection relays, and timers were used; the method has never been adopted and the goal of the research was achieved [7]. It involves incorporation of timer switch (10 seconds) before the system start operation. Timer and socket are prone to separation when used in an environment with high vibration such as a generator house. Dust reduces the magnetizing strength of a contactor which in turn causes partial contact between supply and the load, these are however its observed limitations.

In this work, a transformerless voltage sensor would be used to provide supply input to the optocoupler that provides isolation for the microcontroller. An Optocoupler consists of an LED and a phototransistor whose conductivity is dependent on the intensity of the light radiated from the LED, the microcontroller is used for onward comparison and a bypass switch is incorporated in case the system fails. Users can switch between phases manually before technician intervention hence reduces downtime which has not been designed or used for this purpose prior to this design development. It entails three relays for switching operation and transistors that serves as switches between the microcontroller output and the relay. This designed automatic phase selector distinguishes itself from other transformer based power supply as power losses is negligible as a result of low current devices, no sound produced, and lower harmonic distortion.

2. MATERIALS AND METHOD

2.1 System Components Description

The materials adopted to achieve the aim of this project after a thorough review of their data sheets, the components include Microcontroller, Transistors, and DC relays.

i. **Microcontroller:** Microcontroller is a programmable very large scale integrated circuit (IC) that has the ability to execute numerous set of defined programs by the aid of set of predefined instructions. There are various types of Microcontroller available, a few are PIC Microcontroller which has a smaller instruction set of 35 and no internal oscillator which leads to slower operation, the 8051 microcontroller has 128 bytes of on-chip RAM for temporary data storage as against ATMega328PU that has 2kb, AVR Microcontroller is the most recent technology of Microcontroller with exceptional feature shown in Table 1.

Table 1: ATMega328 PU features

S/N	Parameter	Value
1	CPU type	8bit AVR
2	Performance	20MIPS at 20Hz
3	Maximum CPU speed	20 MHz
4	Flash Memory	32kb
5	SRAM	2KB
6	EEPROM	1KB
7	Pin Count	28
8	Maximum I/O pins	23

ii. **Transistor as Switch:** A transistor is a semiconductor device that performs the function of amplification and can also be used as a switch, for this project, it was employed for switching negative signals on the relays based on the output of the microcontroller.

iii. **Relay:** A 12V 10A relay is selected. The relay is driven by the transistor. If two or three phases are live, the load will be connected to the phase that is ON only and automatically select the next available phase in the event of phase-off without interruption.
The relay consists of 3 pins, namely;
NC = Normally close

NO = Normally Open
COM = Common

For this project implementation, only NO and COM are of use. Each phase of the supply is connected to normally open (NO) and the load is connected to common COM. When there is any phase available, the common (COM) leg will switch from a normally closed (NC) to a normally open (NO) hence supply is restored to the load. This switching action will happen within a fraction of a second, so there will not be an interruption.

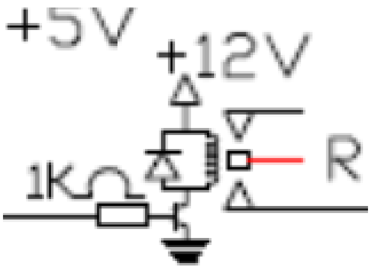

Figure1a: Red phase transistor as a Switch

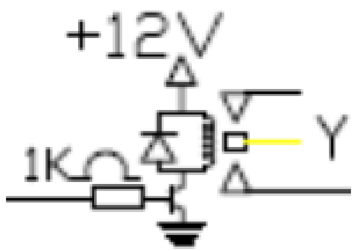

Figure 1b: Yellow phase transistor as a switch

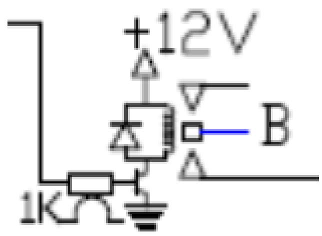

Figure 1c: Blue phase transistor as a Switch

2.2 Methodology

2.2.1 Development of block diagram and flowchart

The circuit diagram shows the interconnection of each component that makes up the phase selector, the block diagram shows the summary of the designed circuit in block form and the flowchart is a graphical or pictorial representation of the algorithm (step-by-step procedure of achieving the phase selection by the ATMega328PU).

i. **System block diagram:** The system block diagram is displayed in Figure 2. The block comprises several sections that make up the system. The section includes a Phase Filter and Regulator, Battery, Crystal Oscillator, Microcontroller (ATMega328PU), Phase Driver, Relay Buzzer, and LCD

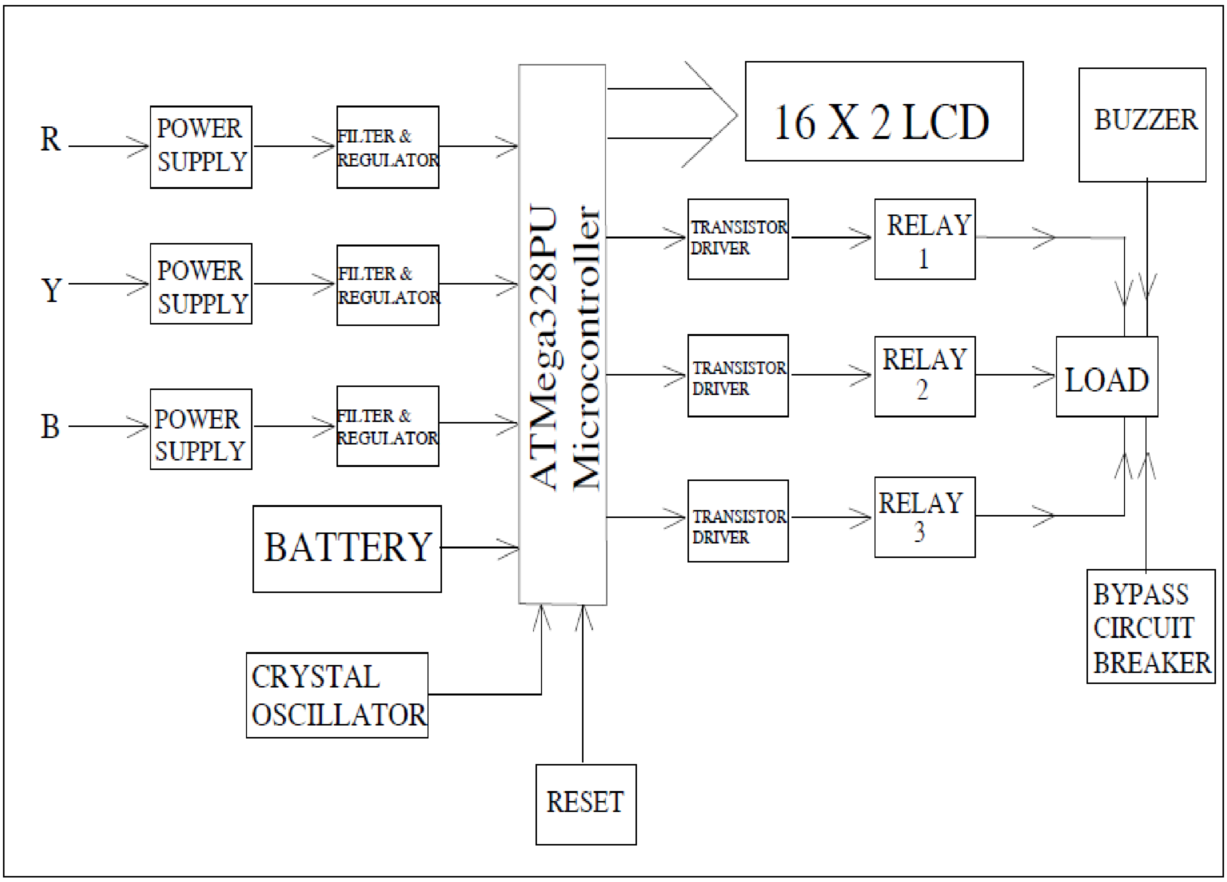

Figure 2: Block diagram of an automatic phase selector

ii. System flowchart: The Flowchart of the proposed system is shown in Figure 3. It simply illustrates the operational procedure of the proposed Automatic Phase Selector.

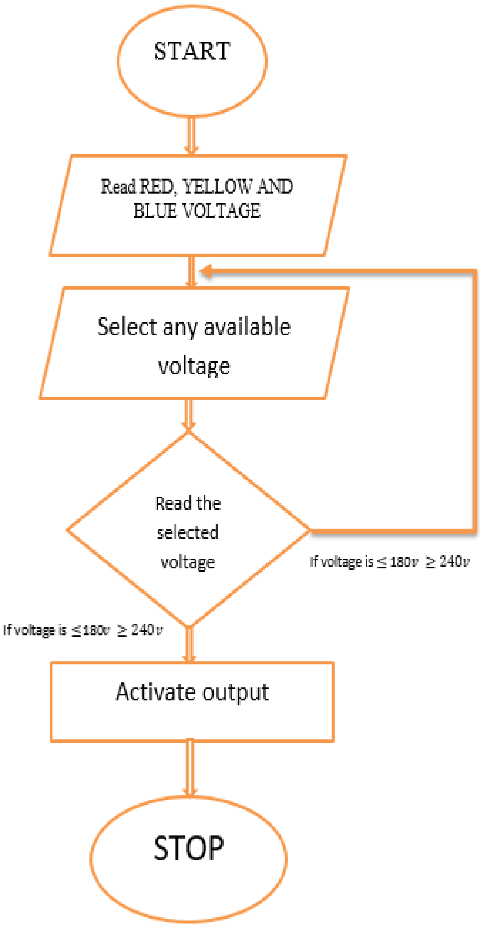

Figure 3: Flowchart of an automatic phase selector

2.2.2 Circuit design

The Automatic phase selector design is divided into three stages; Transformerless AC voltage sensor stage, Isolation stage, Sensing stage, and Switching stage.

i. Transformerless AC voltage sensor: This stage is possible by application of the good old voltage divider rule. It consists of two resistors connected in series as shown in Figure 4:

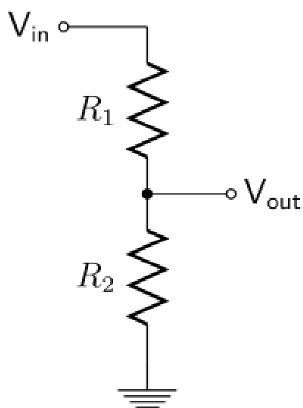

Figure 4: Voltage divider

It is recalled that:

$$Vout = \frac{Vin \times R2}{R1+R2} \quad (1)$$

Where,

V_{in} = 220v

V_{out} = 5v (desired)

R_1 = 220kΩ (selected)

R_2= Unknow

Applying voltage divider method;

$$R2 = \frac{V2 \times R2}{V1} \quad (2)$$

$$R2 = \frac{5 \times 220k\Omega}{220v}$$

$$R2 = 5k \quad (3)$$

Substituting equation (3) into equation (1),

$$Vout = \frac{220 \times 5k\Omega}{220k\Omega + 5k\Omega} = \frac{1100}{225}$$

$$Vout = 4.88v$$

The dropped voltage is rectified to DC by the bridge rectifier to serve as input to the Optocoupler.

ii. Voltage Divider Simulation:

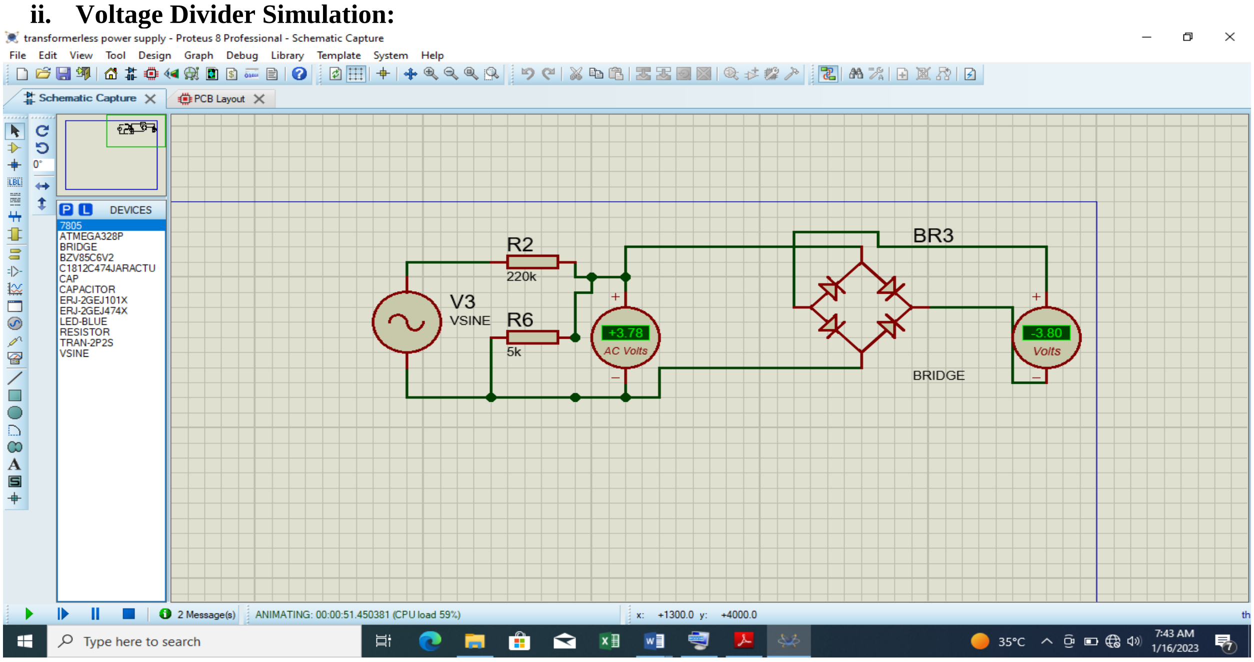

Figure 5: Resistor as voltage divider simulation

Diode :

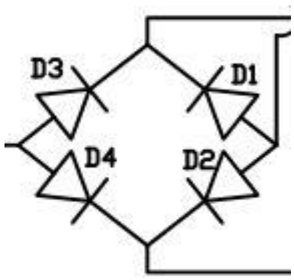

Figure 6: Bridge rectifier

$$peak\ inverse\ voltage = 2 \times Vrms$$

$$= 2 \times 5 = 10V$$

IN4007 was selected since it can operate within the calculated voltage range.

iii. **Optocoupler:** An optocoupler is a photo switch that provides isolation between two different supplies. PC817 is selected for its ruggedness (it handles handle high voltage input) compared to other phototransistors and it is readily available. The PC817 returns the always high (5v) input to the Microcontroller to a low state (0v) for inward comparison, the higher the light emitted on the internal resistor of PC817, the lower conductivity to the microcontroller which hence allows for achievement voltage level comparison and not just availability.

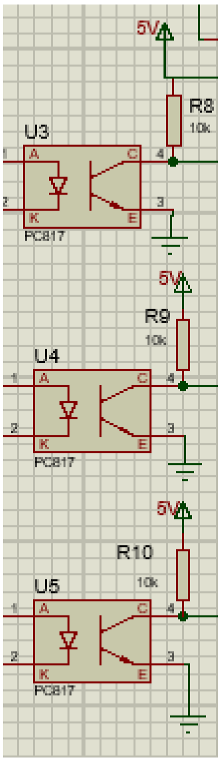

Figure 7: Optocoupler

iv. **Sensing stage:** This is the brain of the system, input pins for the voltage sensors are pin 4, pin 5, pin 6, and the output pins are pin 13, pin 16, and pin 18. Pin 20 is the VCC while pin 22, is the ground. Pins 21, 22, 23, 24, and 25 are connected to the LCD. Pin 11 is connected to the buzzer and the push button is connected with a 1k resistor in series to pin 1 for resetting the Microcontroller when necessary. Crystal oscillator boosts the speed of operation of the microcontroller, and it is connected between pin 9 and 10.

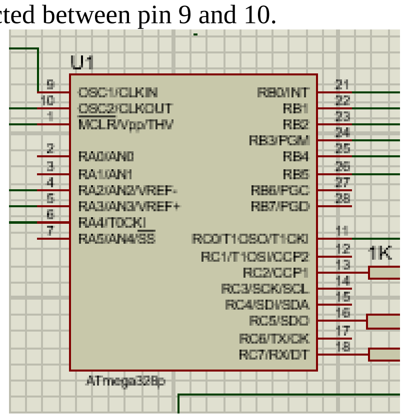

Figure 8: ATMega328PU

v. **Switching Stage:** This stage comprises of two (2) sections; Transistors and Relays.

vi. **Transistor as a Switch:** For this design, transistors (BC547) were used as a switch. The output from ATMega 328PU pin is connected to the base of the transistor but to limit the rate of current, resistor is required.

vii. **Determination of Base Resistor**

It is essential to recall the expressions in Equations (4) and (5)

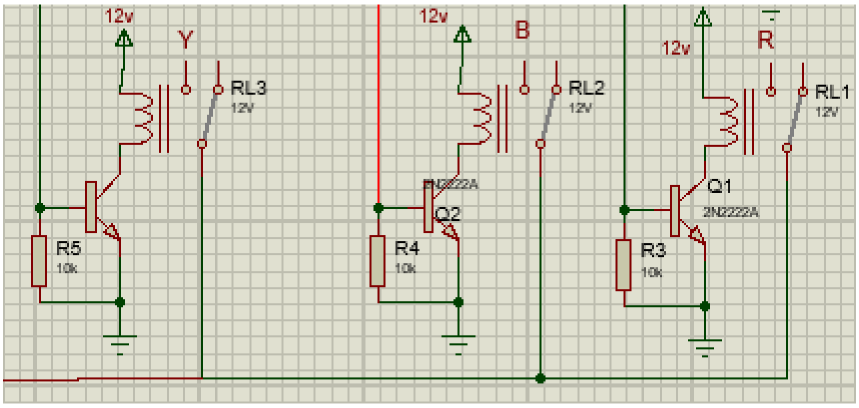

Figure 9: Switching stage

$$\frac{Ic}{Ib} = \beta \tag{4}$$

$$Ic = \frac{Vc}{R} \tag{5}$$

This imply that, $Ic = \frac{12}{173}$

$$Ic = 0.07A \equiv 7mA$$

And

$$Ib = \frac{Ic}{\beta}$$

$$Ib = \frac{0.07}{30}$$

Which imply that, $I_b = 0.002 \times 2 = 0.004\ A$.
Also,

$$R = \frac{Vcc - Vbe}{Ibe} \tag{6}$$

Imply that, $R = \frac{5-0.7}{0.004}$

$$R = 1075\Omega \equiv 1K\Omega$$

Therefore,

R13 = R14 = R15 = 1kΩ

viii. **Relay Switching:** A 12V 10A relay is selected. The relay is driven by the transistor. If two or three phases are live, the load will be connected to the phase that is ON only and automatically select the next available phase in the event of phase-off without interruption. The relay consists of 3 pins, namely;
NC = Normally close
NO = Normally Open
COM = Common

For this research implementation, only NO and COM are of use. Each supply phase is connected to normally open (NO) and the load is connected to common COM. When any phase is available, the common (COM) leg will switch from normally closed (NC) to normally open (NO) hence supply is restored to the load as seen in the figure below. This switching action will happen within fraction of seconds, so there will not be interruption.

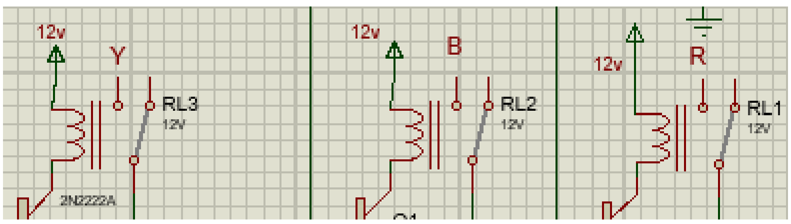

Figure 10: Relay

2.3 Circuit Construction

2.3.1 Printed circuit board (PCB) development

The brain of this device (ATMega328PU) is a very sensitive Microcontroller that any form of interference causes it malfunction. This interference includes flying jumper wire in the circuit hence to avoid this problem, Printed Circuit Board (PCB) was best and it as well makes the circuit neat as seen in the figure 11.

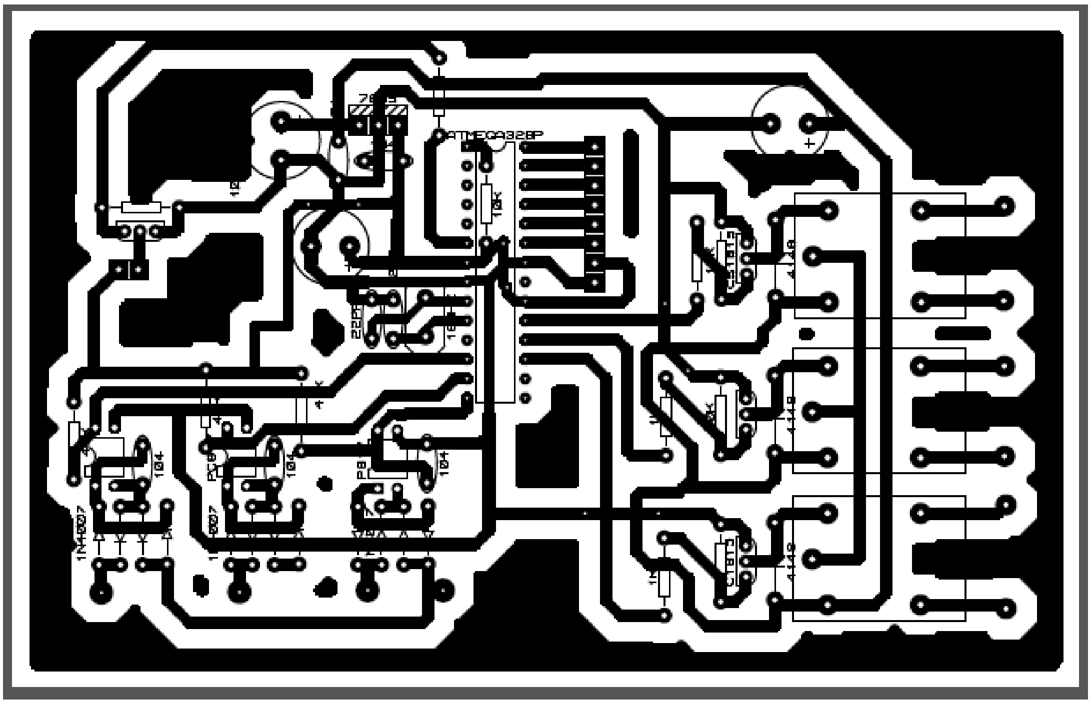

Figure 11: PCB design

2.3.2 Component mounting

The designed components were carefully placed in the boreholes as printed on the PCB. The figure below shows what the circuit looks like after implementation.

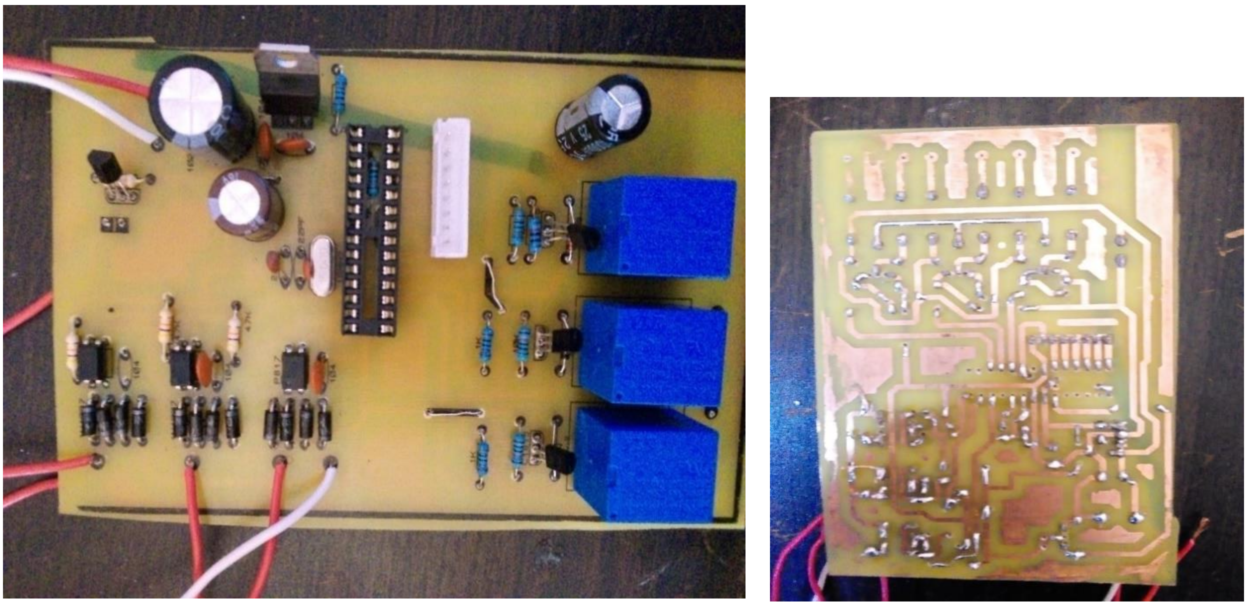

Figure 12: Designed circuit

2.4 Circuit Test and System Operation

2.4.1 Continuity test

A continuity test is a technique used to verify the flow of currents in a circuit between two or more paths. A continuity test was carried out to identify open circuit faults on components that are expected to be continuous; and short circuit faults for components or paths that are not expected to contact.

2.4.2 Resistivity test

These are tests carried out on all resistors found in the designed circuit to ensure their value is maintained hence normal flow of current through the circuit. The equipment used to carry out this test is a multimeter.

2.4.3 Frequency test

The frequency of the output was tested and confirmed at 50 Hz. This test is significant as a variation higher than ±0.05% is disastrous to any load in Nigeria. The equipment used to verify the frequency is a Frequency Meter.

2.4.4 System operation

The power supply consists of two resistors used as voltage dividers to drop the 220VAC to 5VAC, rectified to 5VDC to serve as input to the optocoupler; the optocoupler was introduced because Integrated Circuit such as ATmeg328PU malfunction as a result of interference due to presence of ripples in converted AC signals. The ATmeg328PU, being the brain of the system receives 5V DC signal from the optocoupler, process it, and gives an output with the best voltage level. For safe and efficient switching operation, transistors with relays were incorporated to serve the purpose of the switch. The buzzer beeps when the switching operation is done by the system

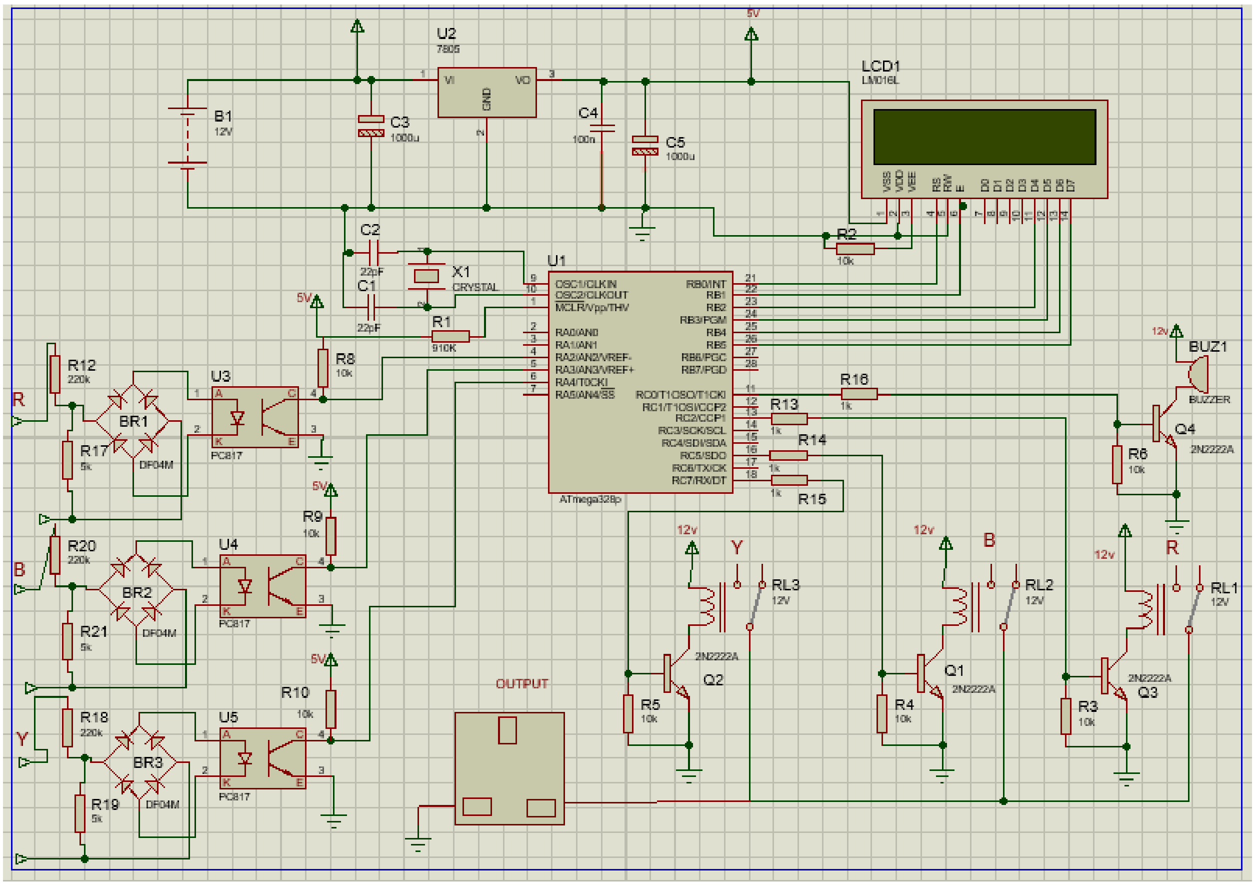

Figure 13: Circuit diagram of an automatic phase selector on proteus

3. RESULTS AND DISCUSSION

The system was tested with a three-phase supply system. The three-phase and neutral were connected to the input terminals of the device and the supply availability Indicator comes ON which tells that there is a power supply in the system. A static switch was pressed to supply voltage from the battery to the microcontroller as it is independent of the public supply. The Liquid Crystal Display (LCD) displays the voltage level on each phase and active phase (Output).

During the selection of the healthiest available phase, a buzzer sound would be heard to signal that there has been a change in the phase.

Later on, tests were carried out on case studies of power supply at various meter points. The results obtained in all the tests led to the generation of the truth table in Table 2. In the first scenario table 2, where the three phases met the three-parameter requirements, i.e. under voltage or overvoltage, or unavailable, the device will select the best of the three phases by considering the values of the parameters. The same thing applied to scenarios two, three, and five of Table 2. But, in scenarios four, six, and seven, where only one phase is on the power supply, the device will have no option but to select the phase with the availability of the power supply. The device will remain inactive with scenario eight (the last action in Table 2) where all three phases have no electricity supply. In this option, the customer will remain in darkness until the supply is restored. This summarily implies the operational results of this device are presented in the form of the truth table which indicates that the affected customer would not have a power supply only when the 3-phases are under voltage or overvoltage or unavailable.

During the scenario five where the yellow and blue phases are on supply and the red phase is on the outage. A challenge was encountered which involves the two phases of a power supply having “under voltages” due to neutral wire leakage to the ground in a 4 x 150 mm^2 armour cable containing the three phases at the feeder pillar section of the substation. During this scenario, the available voltage is extremely low to a level of 130V and with fluctuation in power supply. This time, the device's available option is to automatically trip off to await the arrival of a better power supply because the device sees the situation on the ground as a fault. Therefore, under-voltage becomes the performance metric with a great impact on present techniques.

Table 2: Truth table for the phase selector

S/N	Red	Yellow	Blue	Output
1	1	1	1	Select Red or Yellow or Blue
2	1	1	0	Select Red or Yellow
3	1	0	1	Select Red or Blue
4	1	0	0	Select Red
5	0	1	1	Select Yellow or Blue
6	0	1	0	Select Yellow
7	0	0	1	Select Blue
8	0	0	0	0

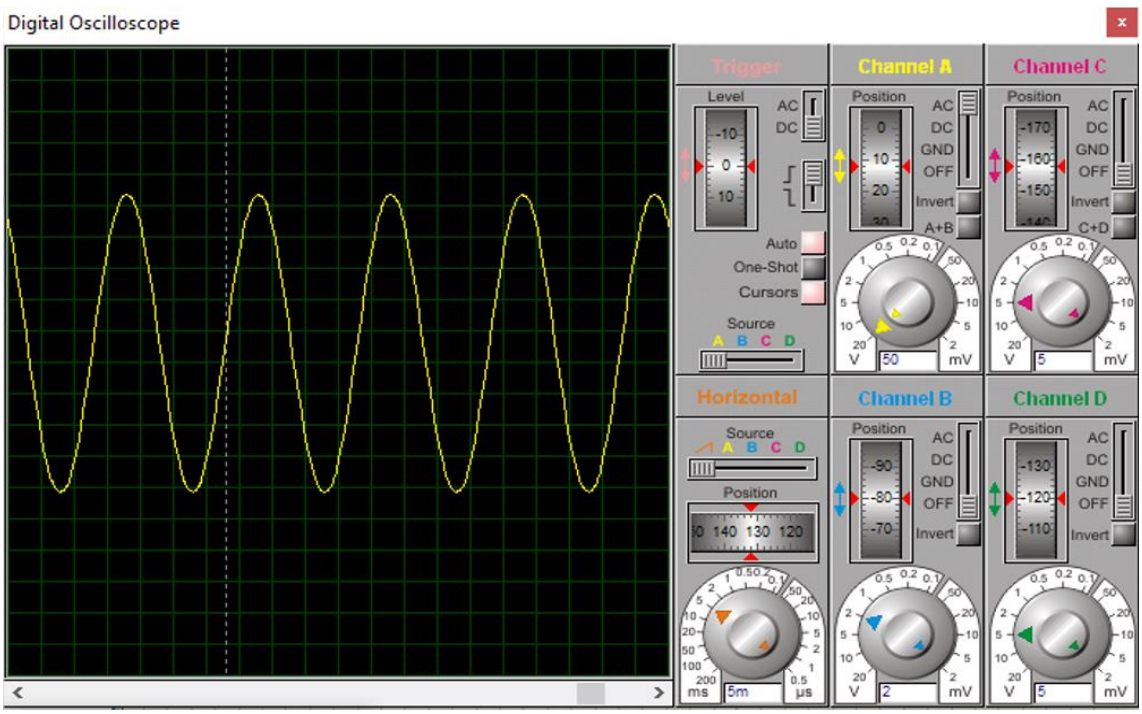

Figure 14: AC input measurement on the oscilloscope

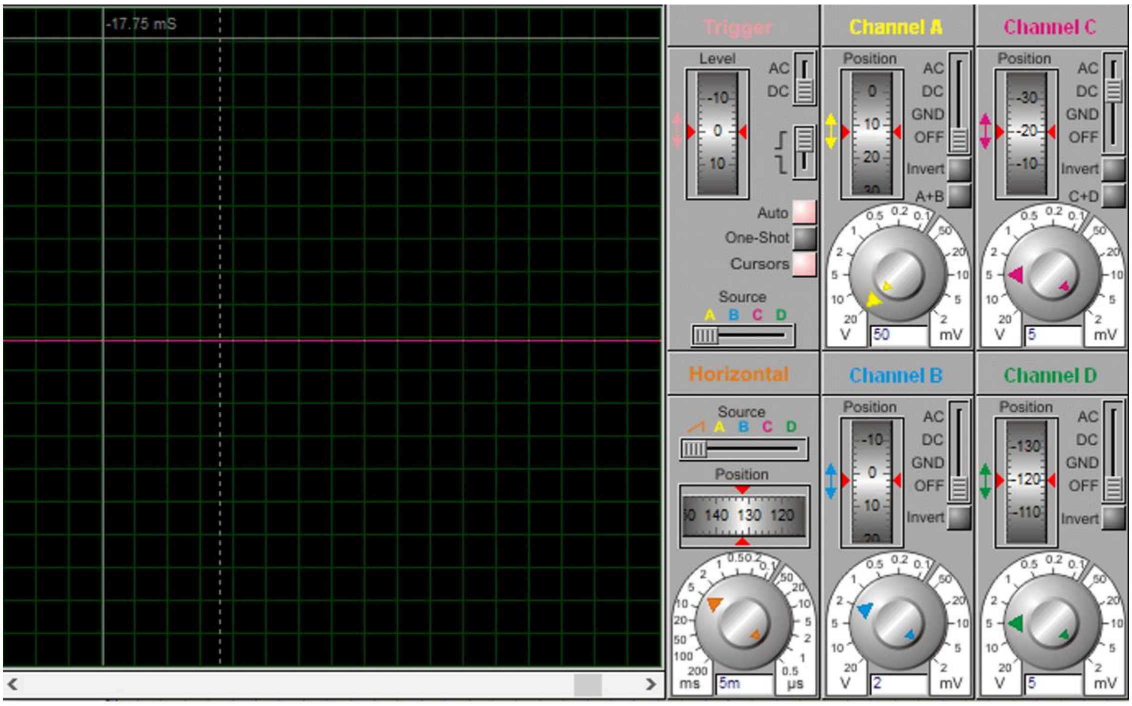

Figure 15: Rectified DC input measurement on the oscilloscope

The signal into the transformerless voltage sensor can be seen in Figure 8 which indicates that the system works perfectly as it was tested using a three-phase supply from the public transformer, the three phases were connected to 3 1gang switches, the switching ON and OFF of the static switches represent phase off in an ideal situation and the signal is a pure sine wave. The output waveform of the rectified pulsating digital signal is shown in Figure 10, the waveform is very clean and produces no noise.

4. CONCLUSION

An uninterruptible phase selector was designed, programmed, and constructed using components, materials, and tools that are locally sourced. The use of printed circuit boards (PCB) was employed in mounting the components for neatness sake. PVC casing was used for its lightweight and high resistance to ambient temperature compared to metal casing. The microcontroller is connected to the battery of 12V to make it isolated from the public supply. ATMega 328PU act on the input signal power from the power supply, compares the inputs, and activate the corresponding relay of the healthiest voltage. The operational results of this system are presented in the form of the truth table which indicates that the affected customer would not have a power supply only when the 3-phases are under voltage or overvoltage or unavailable. The novelty is the consideration of three parameters for phase switching i.e., under voltage, overvoltage, and phase loss. This implies that one of three phases that meet the three criteria would be switched ON. The novelty is the consideration of three parameters for phase switching i.e., under voltage, overvoltage, and phase loss.

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