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An Improved Microcontroller-Based Automatic Three-Phase Analyzer and Selector

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ABSTRACT

Automatic selection and change-over systems have been developed to reduce the risks involved in manual change-over process. While some of the designs switch to any available phase, others switch to the phase with maximum voltage, regardless of the value of the supplied voltage. Other designs which consider the need to avoid both undesirable voltages make the selection range fixed in the code which controls the switching mechanism, thereby not allowing the flexibility in changing the range for switching to meet environmental needs. This work seeks to design an improved microcontroller-based automatic three-phase analyzer and selector with a keypad for setting the switching range for switching. The analysis was achieved by developing a C++ program using the Arduino Integrated Development Environment (IDE) and simulating the system with Proteus Professional Application. The system includes the phase sensing unit, the processing unit and the switching unit. Serial monitor results show that voltages from all three phases may not always be equal, so the system selects the best phase, based on the preset range, to ensure adequate power supply at all times. The preset switching range, which is entered with the keypad, is saved to the Electronically Erasable Programmable Read Only Memory (EEPROM) of the Arduino Nano microcontroller. When no phase supplies voltage within the preset range, the system switches the load to alternative power supply, if there is any. This system will prevent undesirable voltage supplies and save cost whenever there is need to change the switching range to meet environmental requirement.

Keywords: Automatic, Change-over System, Keypad, Step-down Transformer, Switching Range

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1. INTRODUCTION

The high demand for electricity for industrial, commercial and domestic use calls for the need to prevent any interruption in power supply, to avoid economic losses, which can adversely affect the standard of living and way of life. According to Islam (2017), power instability and phase failure poses a serious challenge to most developing and under developed countries. Sreekanth and Ganesh (2017) noted that power interruption in distribution lines is about 70% caused by single phase faults when the other two phases are in normal condition. It is therefore, necessary to automate phase control and selection. An automated phase control and selection system is a system which analyzes all available phases and selects the best phase to be supplied to the house, factory or building where such a device is installed. Such system eliminates the time taken to manually change from one phase to another or from grid power to generator or inverter. It is mainly used to protect and safe life and properties.

With the importance and advancement of control systems in engineering, various designs have been developed to solve the problems associated with frequent phase failure in electricity generation system especially in countries such as Nigeria. The Network for Electricity Consumers Advocacy of Nigeria, NECAN, decried the high level of electricity related accidents leading to the deaths of many Nigerians and loss of property in 2017 and reported that about 366 Nigerians were said to have died through electrocutions and property valued at several hundreds of millions of Naira lost (Ewepu, 2018).

The use of microcontrollers to automate home appliances and protect them from electrical damage has gained wide attention in recent years (Orike & Enoch, 2019). Existing designs that use microcontroller to automate the selection and switching processes have a fixed range of values for switching for example, 160 – 220V, 200 – 220V etc. which is coded directly at design time. Supposing a consumer who has installed a 180-200V change-over device wants to configure the device to allow lower values for switching, say 110-220V, which can be safely used to power most laptops, there will be need to reprogram the microcontroller. If reprogramming of the microcontroller cannot be done as at the time needed, the user will therefore be left with no option than to replace the existing device with another device that has a favourable range for switching.

This work seeks to design, construct and implement an improved automatic three-phase analyzer and selector with flexibility in changing the switching range of the device through the use of a keypad.

The objectives of this work are to:

i. Analyze the implication of attaching fixed switching ranges on automatic three phase selector.
ii. Design an improved system that will optimize cost and enhance flexibility by incorporating a selection keypad.
iii. Simulate the system using Arduino IDE and Proteus Professional applications.
iv. Implement the entire system as a single unit.

In the work of Ezema *et al*. (2012), a 3-phase automatic change over with generator control mechanism was designed to select between two available sources of power giving preference to one out of the two sources. This system focused mainly on automatically changing over from mains to generator and from generator to mains. It paid little attention to phase selection from the available phases of the three phase supply.

Ashish *et al*. (2015) designed a phase selector with options for a solar inverter and generator supply input. This work allowed for multiple power sources but had no way of indicating the power source or voltage value of the three phases. It considered the availability of power and not necessarily the amount or quality of power available.

Ezirim *et al*. (2015) designed an automatic phase selector using contactors of three poles with rating 50Hz, 240volts each and relay with a contact of a current carrying capacity of 5amps and 240volts at 50Hz. The phase selector system designed in this work was focused only on the availability of phases and not the voltage present in these phases. It failed to solve the challenges of phase drop as it will still supply a low phase irrespective of higher phases being present. This system was dependent on logic gates and not the use of a microcontroller.

Ajith *et al*. (2017) constructed an automatic three-phase selector with power factor improvement. This system was designed to function as an automatic phase selector and also as a device to evaluate how effectively electric power in a power system is being used. The system had no set switching range thus selection was based on the highest phase available. If the voltages of the three phases should fall below the voltage required by the load, one of such voltages will be selected and supplied to the load. This could cause damage to electrical appliances.

In the model designed by Himadri and Sayan (2016), uninterrupted AC mains supply was achieved by an automatic change-over of the load from the missing phase to the next available phase. This work only considered availability of phase and not the actual voltage supplied by the selected phase.

Lawal *et al*. (2017) used a PIC16F628 microcontroller in the design of a three-phase voltage selector. Although this work was able to achieve the functions of a three-phase selector, the switching range of selection is set at 180-220V

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thus not enabling flexibility in range selection except by reprogramming the system.

Ofualagba and Udoha (2017) worked on the design and simulation of automatic phase selector and change-over switch for three-phase supply. This design was able to provide a graphic display of the voltages available, but failed to solve the challenge of over voltage supply as the microcontroller chooses the highest phase available which might be higher than required.

2. MATERIALS AND METHODS

According to Lawal *et al.* (2017), power system automation includes the several processes associated with power generation and delivery. Data obtained from the data acquisition stage of power system automation could be used locally within the device obtaining it, transferred to another device in a substation, or transmitted from the substation to one or several databases for interpretation, analysis, or use by operators, engineers, planners, and administration (Ajith *et al.*, 2017).

The system described in this work is designed using the Arduino Nano development board with an ATMega328 microcontroller, an LCD screen which is used to display the voltage levels of the three phases and the active phase in use, a 4x3 keypad which helps the user to preset the switching range and switching relays which respond to the signals sent by the microcontroller. The entire system is designed to printed circuit board and cased as a single unit.

The complete hardware block diagram (as shown in Fig. 1) consists of the following:

i. Phase Sensing Unit
   - 220/9V Step-down transformers
   - Rectifying circuits
   - Voltage Dividers
   - LM7805 Voltage Regulator

ii. Processing Unit
   - Arduino Nano ATMega328P
   - 4x3 Keypad
   - 16x2 Liquid Crystal Display

iii. Switching Unit
   - Switching Relays
   - Isolation Diodes
   - Transistors

iv. Inductive Load.

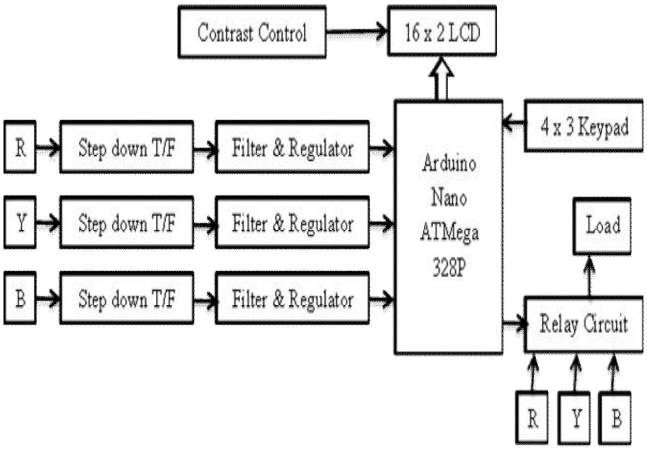

Fig. 1: Hardware Block Diagram

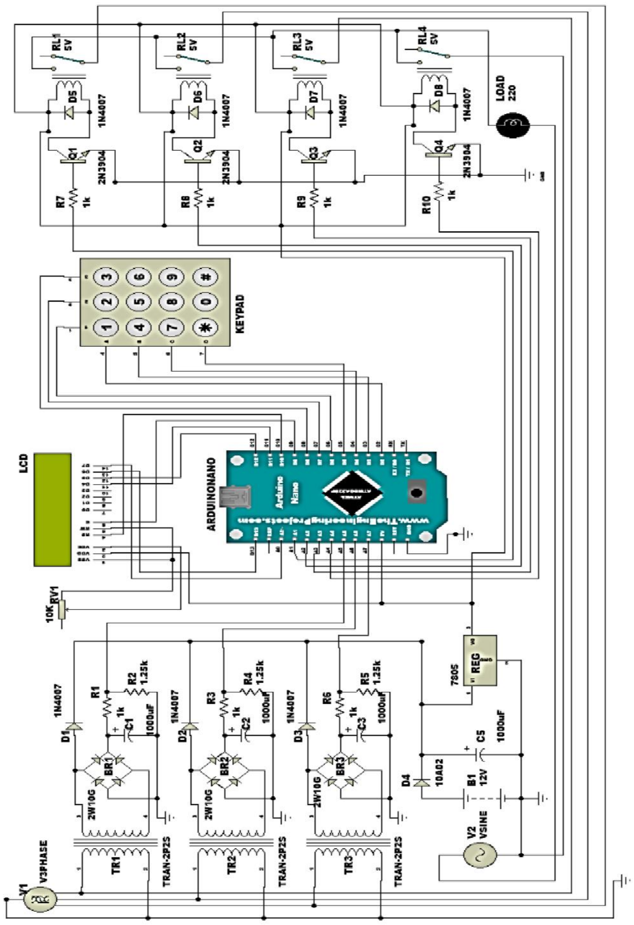

Fig. 2: Circuit Diagram

The phase sensing unit receives the 50Hz A.C. input from the three-phase supply through three step-down transformers, each sensing one of the phases. The received A.C. voltage is stepped down to 9V using a 220/9V transformer on each phase. The stepped down voltage is rectified using a full wave bridge rectifier and further filtered to remove ripples. A voltage divider circuit is used to convert the 9V output from transformer to 5V which is the optimum input voltage requirement for the operation of the Arduino Nano microcontroller. Also, the output of each transformer is fed to the LM8705 voltage regulator to ensure that a maximum of 5V is supplied to power-on the Arduino Nano. The microcontroller interprets the data it receives from the phase sensing unit and the user keypad, processes the data and issues signals to the switching unit. The switching unit switches the load to the selected phase. The keypad is used to preset the switching range. This preset value is saved to the EEPROM of the Arduino Nano and it becomes the default range for switching until it is reset by the user.

The software which controls the automatic three phase analyzer and selector was written in C++ language using the Arduino Integrated Development Environment (IDE). This IDE serves as the compiler which converts the C++ code to machine code. The software was designed such that voltage value from each phase of the mains supply which was received and interpreted by the microcontroller in bytes was converted back to 220V by mapping each phase value.

The system was simulated using Proteus Professional Application to represent the actual components with miniature components. The three-phase transformer was replaced with three single-phase transformers. The 16-pin LCD display was replaced with a 14-pin LM016L display. The Arduino Nano was powered from the outputs of the secondary terminals of the transformers and the backup DC supply which is represented by a 12V battery, B1. The input to the Arduino Nano 5V was regulated by an LM7805 regulator. V1 represents a three-phase supply while V2 represents the backup or alternative supply. The three single-phase transformers are represented as TR1, TR2 and TR3 respectively. The program written for the system was exported as compiled machine codes to the Arduino component using the Arduino IDE.

The design calculations and equations for the various components are as shown in (1) – (7).

2.1 Transformer Inductance for Simulation

Transformation ratio is given by:

$$\frac{L_s}{L_p} = \left(\frac{V_s}{V_p}\right)^2 \qquad (1)$$

Where:

Ls = Inductance at the secondary windings of the transformer

Lp = Inductance at the primary windings of the transformer (1H)

Vs = Voltage at the secondary windings of the transformer (9V)

Vp = Voltage at the secondary windings of the transformer (220)

Ls is therefore calculated as:

$$\frac{L_s}{1} = \left(\frac{9}{220}\right)^2$$

L_s = 1.674mH

2.2 Calculation for Filter Capacitors

Full Wave Rectification is given as:

$$C = \frac{I_{dc}}{4\sqrt{3}\, f \gamma V_{ip}} \qquad (2)$$

Where:

f = frequency of voltage at transformer primary

γ = Ripple factor (in this case, we desire a ripple factor of at most 1%)

V_{ip}=Voltage at transformer primary = 220V

I_{dc} = D.C current = 0.5A

V_{ra}= Voltage at point of rectification = 9V

$$C = \frac{0.5}{4\sqrt{3} \times 50 \times 0.01 \times 220}$$

C1 = C2 = C3 = C4 = 1000µF

2.3 Calculation for Voltage Dividers

By voltage divider rule, the values of R_1 and R_2 are determined as follows:

$$R_2 = \frac{(R_1 * V_i)}{(V_m - V_i)} \quad (3)$$

Choosing $R_1 = R_3 = R_5 = 1k\Omega$

$$R_2 = \frac{(1 * 5k)}{(9-5)} = 1.25k\Omega$$

$R_2 = R_4 = R_6 = 1.25k\Omega$

2.4 Calculation for Base Resistors

$$I_B = \frac{V_B - V_{BE}}{R_B} \quad (4)$$

Where:

V_B = Transistor base voltage = 5V
V_{BE} = voltage drop between the emitter and base terminals for silicon devices (since the input characteristics of an NPN transistor are of a forward biased diode). $V_{BE} = 0.7$

Note: Each Arduino pin has an inbuilt resistor of 1K. Therefore, applying Ohm's law

$$I_B = \frac{V}{R} \quad (5)$$

$$I_B = \frac{5}{1000}$$

$$I_B = 5mA$$

Substituting value for I_B in (4) we have:

$$0.005 = \frac{(5-0.7)}{R_B}$$

$R_B = 860\Omega$.

Since the closest standard value is 1K, hence:

R7 = R8 = R9 = R10 = 1K

2.4 Methods

The following methods/principles were applied in order to achieve the design goal.

i. Analog to Digital Conversion:

$$PH_{\_N} = \text{analogRead}(POW_{\_N}) \quad (6)$$

ii. Mapping:

$$PHASE_{\_N} = \text{map}(PH_{\_N}, 0, 1023, 0, 220) \quad (7)$$

Where:

$POW_{\_N}$ = Phase supply
$PH_{\_N}$ = Variable name allocated to store input voltage equivalent values (0 – 1023)
$PHASE_{\_N}$ = Variable name allocated to store mapped phase values (0 – 220)
N = 1, 2, and 3, corresponding to the three-phase supply.

The values of $PHASE_{\_N}$ are compared against a switching range which is preset using the 4x3 keypad and the best phase corresponding to the selected switching range is supplied to the load (building). The LCD is used to indicate the selected phase, showing the voltage values of such phase. Switching of the relays is controlled by sending a HIGH signal to the digital pin to which the relay is connected.

3. RESULTS AND DISCUSSION

Several results were obtained from the simulation of the system developed in this research. These tests were carried out in order to ensure proper functionality of each circuit component, and to effectively monitor the response and voltage values supplied by the three phases. At first, the serial monitor results were generated to observe the behaviour of the 3-Phase supply. The results were tabulated in Table 1.

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Table 1: Serial Monitor Results for Typical Phase Voltages

S/No	Phase 1 (V)	Phase 2 (V)	Phase 3 (V)
1.	179	220	220
2.	180	220	220
3.	179	207	206
4.	179	194	193
5.	180	182	180
6.	180	170	180
7.	180	180	168
8.	180	179	158
9.	179	179	148
10.	180	179	180
11.	179	179	168
12.	180	180	179
13.	179	179	168
14.	180	180	179
15.	180	179	168
16.	180	180	158
17.	180	179	139
18.	180	179	139
19.	179	180	130
20.	180	169	179

On setting the switching range to 180 – 220V, Fig. 3 shows the switching on of relay R1 which indicates Phase 1 with a voltage value of 199V was active. However, the virtual terminal results in Table 2 show that at SNo1 the system started with 199V, 220V and 220V for Phase 1, Phase 2 and Phase 3 respectively. As expected, the best value (220V) from the available phases was chosen. At S/No 4, the available values were 199V, 195V and 199V for Phase 1, Phase 2 and Phase 3 respectively. Phase 2 appeared to supply the least voltage at that point but it was still maintained as the active phase. This was in accordance to the desire to avoid unnecessary switching of the relays which could be dangerous to the switching elements or even cause some form of noise pollution. Similar observations are made at S/No 5 and S/No 14. The voltage of Phase 2 (171V) at S/No 6 dropped below the lower limit of the desired switching range. At this point, the system chose the next best value from the available phases. As a result, Phase 1 with voltage of 199V was switched on.

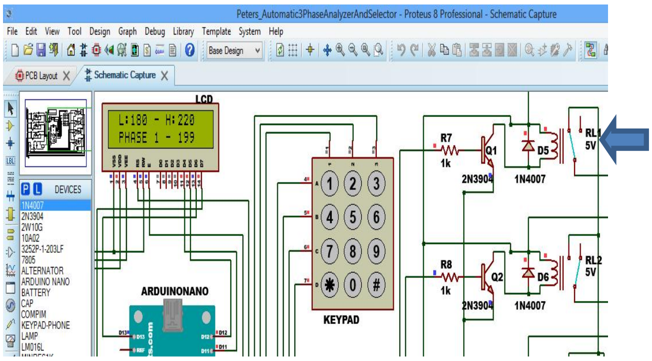

Fig. 3: Switching Range Preset to 180 – 220V

Table 2: Serial Monitor Results for Switching Range (180 – 220V)

S/No	Phase 1 (V)	Phase 2 (V)	Phase 3 (V)	Active Phase
1.	199	220	220	2
2.	199	220	220	2
3.	199	207	207	2
4.	199	195	199	2
5.	199	183	199	2
6.	199	171	191	1
7.	199	199	187	1
8.	199	199	175	1
9.	199	199	164	1
10	199	199	154	1
11	199	199	145	1
12	198	199	140	1
13	199	199	140	1
14	199	198	140	1

In Fig. 4, the switching range was set to 200V – 220V and it was observed that the system used Phase 2 as the active phase. At S/No 6 in Table 3, the available voltages on Phase 1, Phase 2 and Phase 3 were 189V, 190V and 193V respectively which none of the voltages was within the desired switching range. Hence, the system did not choose any of the phases from the public supply rather, the relay for the alternative or backup supply was switched on.

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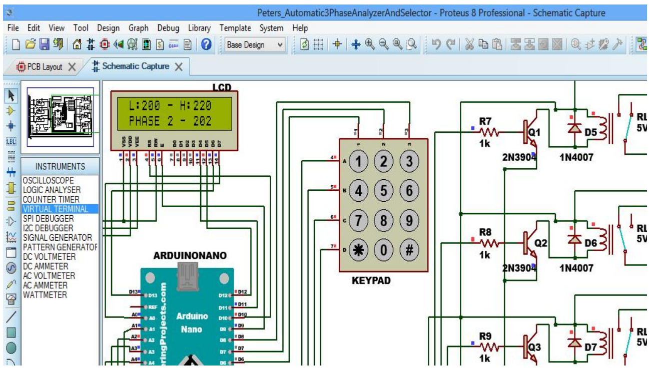

Fig. 4: Switching Range Preset to 200 – 220V

Table 3: Serial Monitor Results for Switching Range (200 – 220V)

S/No	Phase 1 (V)	Phase 2 (V)	Phase 3 (V)	Active Phase
1.	189	220	220	2
2.	189	220	220	2
3.	189	220	220	2
4.	189	215	215	2
5.	189	202	202	2
6.	189	190	193	Alternative
7.	189	189	189	Alternative
8.	189	189	189	Alternative
9.	189	189	189	Alternative
10	190	189	189	Alternative

The system when turned on was observed to select the "best" phase within the desired switching range. The selection and switching occurred simultaneously thus, there were no observable power cuts or interruption during switching and phase selection. The switching process occurred automatically without any need for manual changing of phases. The user can preset the range without the need to reprogram the microcontroller. This satisfies the objective of the system to automate the process of phase selection and change over. The automatic phase selection and switching is made possible through the use of the Arduino Nano microcontroller.

It was also observed that, with voltage range selection, phase switching only took place within the set range of voltages thereby protecting electrical appliances from over-voltage and under-voltage power supply. Unnecessary switching of the relays was also controlled by ensuring that the value on an active phase has gone outside the preset switching range before switching action was performed. Any successfully preset switching range was automatically saved to the Arduino Nano EEPROM and it served as the default switching range whenever the system was turned off and restarted. At initial installation, a default switching range of 180-220V was set through the program, until a new range was set. The microcontroller was also programmed to ensure that the user does not mistakenly input values higher than the 220V rating of the transformer used in the design in order avoid switching to a phase with over-voltage.

Automatic three phase voltage selector and change over devices come with different switching ranges example 180 – 200V, 180 – 220V etc. Some even allow the minimum voltage as low as 160V. In all these designs, the switching range is hard-coded and the user cannot easily change the range if needed.

Supposing the device is used in an environment where the optimum operating voltage of equipment should not go below 200V, and the switching range, at design, has already been programmed to select from 180 – 200V. In this case, the device will select any phase that generates voltage within that range. Typical example was observed in Table 3 at S/No 6 where the phase voltages were 199V, 171V and 191V for Phase 1, Phase 2 and Phase 3 respectively. At this point, Phase 1 which generated below the safe operating voltage of the equipment was selected thereby supplying under-voltage. If a fault exists that each of the three phases supply below 200V and at least, one of the phases supplies 180V and above, then the device will switch to the phase that meets up the switching range. As a result, the equipment will be selecting and allowing unsafe voltage. At the same point, the user cannot change the switching range to safeguard the equipment unless by reprogramming the microcontroller or replacement of the device with one that the switching range is from 200V and above.

However, instead of reprogramming the microcontroller or replacing the device, the user can preset the switching range at Startup depending on the load requirements. As observed in Table 3, the keypad was used to preset the switching range to 200 – 220V. At S/No 6, it was observed that the phase values were: 189V for Phase 1, 190V for Phase 2 and 193V for Phase 3. Here, no phase was selected because none of them could meet the requirement. By this, the equipment whose safe operating voltage is from 200V and above will be protected from under-voltage supply. This can also be used to avoid over-voltage supply. Once the setup is finished, no manual operations are required. Setup can be repeated as many times as desired and the setup values become the default settings on Startup.

4. CONCLUSION

From the results and observations made during implementation of the improved microcontroller-based automatic three phase voltage analyzer and selector, it can be seen that the system was capable of controlling the processes of phase change and voltage selection autonomously without any need for human supervision once the switching range has been set. It can also be seen that the system allows the user to preset a desired switching range for switching without having to reprogram the microcontroller or replace the entire device with one that would not allow some undesirable voltages in some operational areas. Hence, it reduces the cost of reprogramming the microcontroller or replacing an existing device to meet a desired switching range. This distinguishes this system from all other existing systems.

The system developed in this work has been able to satisfy the objectives of this research. It is important to note that the system, when mass produced, will be applicable in every home.

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