American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-13, Issue-7, pp-01-09
www.ajer.org
Research Paper Open Access

Development of A 110 V Auxiliary DC Supply Unit for the Nigerian Power System Protection

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ABSTRACT: *This work developed a 110 V direct current (DC) auxiliary supply unit for power system protection application in Nigeria. Piece-wise design and analysis of the transformation circuit, rectification and filtration circuits and feedback and protection control circuits were carried out. The assembly and installation of the various designed circuits and components were done through soldering, connectors and links. Simulations were done via Proteus application to evaluate output of the developed system. The auxiliary supply unit developed was also experimentally tested to ascertain its performance and the results obtained were compared with the simulation results. The fully developed system was also taken to utility infrastructure and subjected to real-time testing. The results from the work showed that the developed unit operated appropriately, producing the desired DC voltage outputs for smooth running of the protection scheme of the Nigerian electricity supply system. The simulated and experimental outputs for the transformer were 110 and 112.5 VAC; rectifier outputs were 154.9 and 159.1 VDC; filtered outputs were 154 and 159 VDC and the controlled outputs were 111.1 and 125 VDC. The variations in the outputs were within the tolerance limits. These results are indications that the system developed exhibited operational characteristics that are suitable for the Nigerian electricity system operation. The developed auxiliary supply unit satisfactorily produced the DC voltage signal suitable for the effective and efficient performance of power system protection scheme.*
KEYWORDS: *Auxiliary supply, Controlled Rectification, DC, Protection system, Nigeria*

Date of Submission: 25-06-2024 Date of acceptance: 04-07-2024

I. INTRODUCTION

One of the major problems of the electricity supply system in Nigeria is frequent breakdown of essential components such as transformers, high voltage distribution boards among others [1]. [2], [3], [4]. These components are responsible for smooth and efficient running of the electricity supply system and their frequent damage or downtime as a result of occurrence of faults or other forms of disturbances is a potential threat to the sustainable socio-economic and industrial growth of any nation including Nigeria. Therefore, to protect these components against the devastating effect of faults or other disturbances in the Nigerian power network that is characteristically overburdened due to geometrically growing electrical energy demand instigated by persistently rising population and industrialization, there is the need for a robust and an efficient system in this regard. A key device that is triggered into action to prevent loss of power system components in the event of faults or other disturbances is known as auxiliary supply. An auxiliary supply is a direct current (DC) supply unit that aids the overall functionality of the protection system whose primary goal is to isolate faults and/or faulty parts of the power circuit and thereby, preventing loss of important circuit elements including transformers and high voltage distribution boards [5].

The auxiliary supply, by the Nigerian electricity utility standards, is either 30 V or 110 V DC. A 30 V DC auxiliary supply is usually employed for small-size equipment and small coverage areas. A 110 V DV auxiliary supply on the other hand is usually deployed for large-size equipment and large coverage areas. According to [6], the unavailability of this sensitive electrical unit normally creates a serious bottleneck during power system operation. It can lead to loss of lives and properties, loss of vital equipment such as transformers and distribution panels, poor and erratic power supply and high unit cost of energy in Nigeria. Hence, the importance of this electrical unit to the overall functionality of the Nigerian electricity supply system cannot be over-emphasized; as it action enables protection system to perform on/off and trip functions.

The problem of DC failure in the electricity supply system in Nigeria has been keenly noticed and confirmed for over a period of about 34 years and still persists till today [7]. The recent technological advancement leading to improved design of circuit breakers, transformers and all other associated equipment has even worsened the situation. In the obsolete design of relays and circuit breakers, half-wave rectification is usually employed to achieve DC supply. Nowadays, where the design is solid-state electronics and microprocessor based, a near perfect DC supply is required for the smooth operations of the relays and breakers, otherwise they will burn out. A standard over-current, earth-fault and over-current solid-state electronics and microprocessor-based relay costs a fortune in recent times, thereby further increasing the running costs of the electricity supply utility in addition to its being scarcely available. This further leads to delay in restoration of supply and loss of equipment, lives and properties among others [8]. Hence, for smooth and effective operation of the protection scheme for enhanced running of the Nigerian electricity supply system at large, the availability of economic and reliable auxiliary supply is imperative.

A survey of literature has shown that many works have been done on different forms of auxiliary supply system. [9] worked on design of power converters using soft-switching full-bridge rectifier for alternating current distribution system applications. [10] designed a DC power supply system using buck circuit with applications restricted to 5-50 V. [11] developed a DC to DC converter for application in the second stage of alternating current to direct current telecommunication power supply system. [12] implemented an auxiliary supply system which adopts loop control method using virtual impedance to reduce current circulation effect. The work provided certain theoretical basis according to China standard. [13] designed backup power supply system which is a version of an auxiliary supply for high-speed maglev automobiles powered by linear-synchronous traction motors. [14] researched into the auxiliary power supply system needs in relation to the China electric multiple unit, with interest on maintenance and servicing to guarantee safety operation of the auxiliary supply system. Going by the literature surveyed, varieties of auxiliary supply systems have been developed with different requirements and applications in diverse areas of human endeavours. However, applications specific to the Nigerian electricity supply system are relatively elusive.

Therefore, the goal of this work was to develop a 110 V auxiliary tripping unit for protection application in the Nigerian electricity supply system using locally sourced and replaceable materials. The remaining parts of the paper are organized as follows: Section 2 dealt with the design of the auxiliary supply. Section 3 provided the implemented auxiliary supply unit and the results of tests conducted on the unit. Section 4 gave the conclusion and suggestion for further work.

II. MATERIALSAND METHODS

2.1. The Overview of the System Design

The basic structure of the 110 V auxiliary DC supply unit developed in this work is presented in the block diagram of Figure 1. The 220 V AC input to the system was transformed to a 110 V AC output via a stepped down transformer. The 110 V AC output signal was then applied to the bridge rectifier; the use of which prevented the need for a centre-tap transformer.

The bridge rectifier converted the 110 V AC output signal into uni-directional signal which was subjected to filtration through capacitors to remove the ripples present. The silicon-controlled rectifier (SCR) was connected end-to-end with the rectifier card and regulates the voltage and current outputs reaching the connected load and the battery that serves as back-up for the load. The protection and control unit receive feedback from the load and in the event that the desired voltage and current signals are not reaching the load, the unit triggers into action to regulate the operation of the SCR through the combined efforts of the connected resistors and thyristors to produce the desired signals for the right operation of the load. The positive terminal of the battery is connected to the contactor end while the negative terminal is connected to negative side of the filter. The contactor acts to isolate the source, load and battery during power supply failure, fault or maintenance exercise. The voltmeter and ammeter respectively monitor the voltage and current for smooth and effective system operation. The red, yellow and green light emitting diode (LED) indicators depict the status of the system under different conditions. The red, yellow and green LEDs indicate earth fault, continuous battery charging and fully-charged battery conditions respectively.

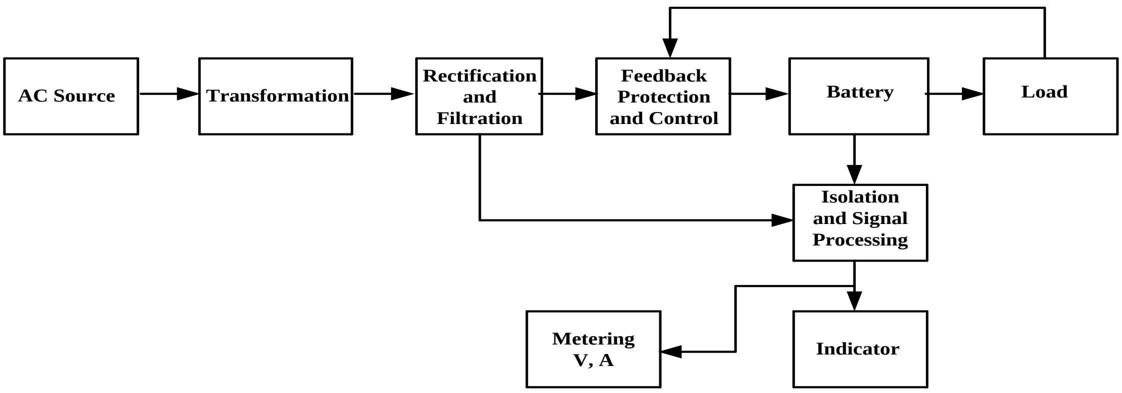


Fig. 1. The block diagram of the developed 110 V auxiliary DC power supply

2.2. System Design

The overall designed circuit for the 110 V auxiliary DC supply unit developed in this work is shown in Figure 2. The analysis of each sub-unit of the system is provided in the subsections.

2.2.1. AC Input/Transformer Unit

The primary side of the transformer was connected to 220 V AC supply as delineated in Figure 2 and the input stepped down to 110 V AC output which was equivalent to ratio of 2:1. The desired current output from the 5 kVA transformer selected for the design based on the requirement, the input current to the transformer was determined from equation (1).

$$\frac{V_1}{V_2} = \frac{I_2}{I_1} \tag{1}$$

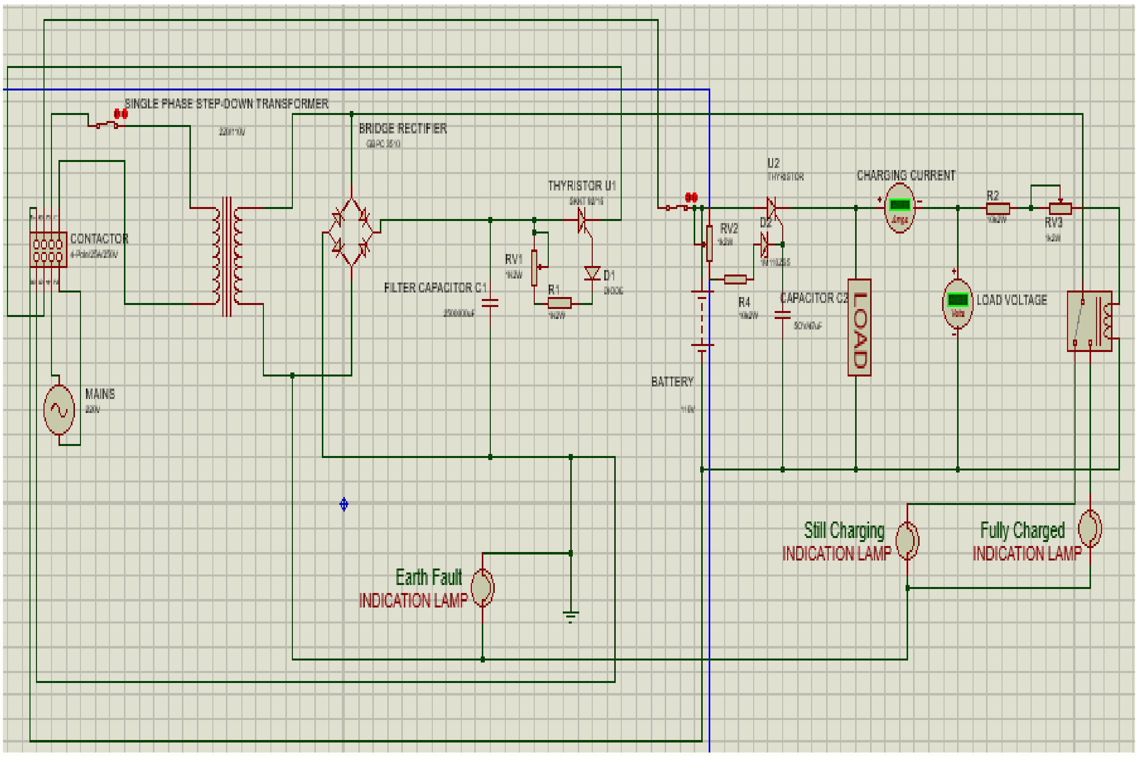


Fig. 2. circuit diagram of the Auxiliary DC Tripping Circuit

Where V1 is the desired input (primary) voltage, V2 is the desired output (secondary) voltage, I1 is the input (primary) current and I2 is the output (secondary) current.

The use of V1, V2 and I2 as 220 V, 110 V and 25 A respectively in equation (1) gave I1 as 13 A. Hence, with I1 and I2 known, the winding sizes of the primary and secondary sides of the transformer were determined. The primary and secondary currents of 13 and 25 A require 1.5 and 2.5 mm2 copper conductors respectively for the continuous rating from the IEEE wiring regulations. Input and output isolations in the event of input supply failure were achieved with the use of a 4-pole, 220 V direct on-line AC contactor. This design choice prevents the battery bank from draining into the circuit.

2.2.2. Rectification Unit

The bridge rectifier employed in the circuit of Figure 2 aided the conversion of the AC to DC signal. The rectifier possesses four terminals; two of the terminals are the AC input while the other two terminals are for the DC output. The AC input and the DC output were determined by using an AVO meter. The GBPC 3510 bridge rectifier was selected from the surge electronics datasheet [15]. The choice of this rectifier was due to electrical features, having a voltage range of 50 to 1000 V and current rating of 35 A which are suitable for the auxiliary DC supply developed in this work.

2.2.3. Filtration and Silicon Controlled Rectification

The mathematical model employed to determine the size of the capacitor required for the filtering function in the circuit of Figure 2 is given by equation (2).

$$C = \frac{I}{2 \times f \times V_{pp}} \qquad (2)$$

Where C is the capacitance, I is the load current, f is the frequency of the supply and Vpp is the maximum output ripple voltage allowed.

Using I, f and Vpp as 25 A, 50 Hz and 1 V respectively, the value of C was determined as 250000 µF. This capacitance was employed since it only allows 1 V as maximum output ripple voltage that could be present in the final DC output of the developed auxiliary supply unit.

The thyristor SKKT 92/16 was selected from the Semikron electronics datasheet for the controlled rectification [16]. This was due to its suitability for the auxiliary supply unit developed in this work as a result of its appropriate electrical features, having voltage rating of 1200 V, gate current rating of 150 mA maximum at 3 V and forward conduction current of 92 A. The thyristor worked as controlled rectifier and it was connected in series with the positive terminal of the capacitor (filter) as shown in Figure 2. The thyristor gate requires 3 V for its firing. Resistors of 1.2 kΩ were connected across the thyristor to for voltage divider circuit to produce the required 3 V.

2.2.4. Relay and Charging Control Indicator

Relay was used as the charge controller. The relay was programmed in two ways; normally close (NC) and normally open (NO). The normally closed controls the still charging indicator of the battery while the normally open controls the full charge indicator. The interconnection of the relay as deployed in this work was shown in Figure 2.

2.2.5. Control Card and Method of Connection.

A printed circuit board (PCB) was designed according to the overall circuit design in Figure 2. The PCB was one-side layer. The plain copper board was first cleaned with a sand paper before it was immersed in the etchant at the atmospheric temperature. Soldering was done from the back after layout of components and soft drilling. The control card was etched using etching liquid chemical meant for the purpose. The copper layer was properly cleaned before components layout and soldering commenced. The soldering was checked for dry joints and partial contacts. Components such as the transformer, AC direct on-line contactor, thyristor block, fuses and their holders, overcurrent miniature circuit breaker and the bridge rectifier were mounted separately on the inner base plate of the system developed. Connecting wires which needed to be connected to the control card were simply brought and soldered to the control card.

Charge level monitor relay was directly soldered to the control card. Other items such as indication lamps were wired from the control card and taken to the door of the panel where the lamps were installed. On the door also is installed, the OFF and ON switch with mains availability indicator on it. The door was labelled for all those items installed on it. The body of the panel was perforated to aid effective cooling to prolong the lifespan of the installed internal components.

2.3. Simulation and Testing of the Developed System

Prior to the full implementation of the auxiliary DC supply developed in this work, simulation of the design was conducted using Proteus simulation software to preview the outputs from the system which is very vital for the satisfactory operation of protection system. After the full implementation of the work, the system was experimentally tested in the Applied Electricity Laboratory of the Department of Electrical and Electronics Engineering, College of Engineering, Federal University of Agriculture, Abeokuta, Ogun State, Nigeria to ascertain its performance in real time and compare the results with the simulation outputs. The experimental testing process of the developed system is shown in Figure 3. Further testing of the system was done at Eleweran 1 x 15 MVA, 33/11 kV injection station, Abeokuta, Ogun State, Nigeria to validate its effectively. Figure 4 shows when the system was connected to a battery bank at the injection station for performance testing.

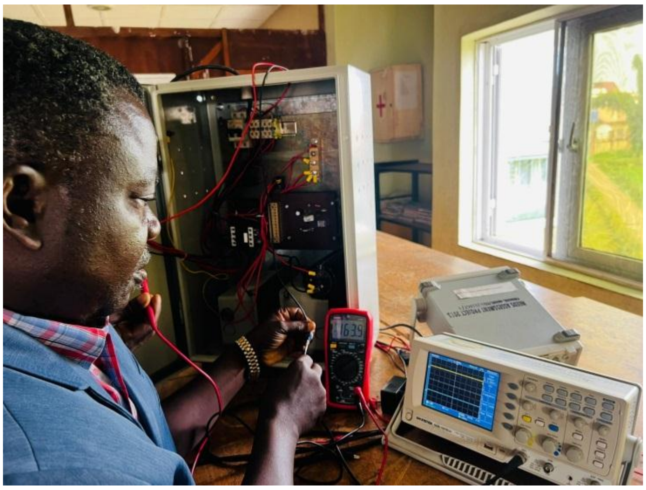


Fig. 3. Experimental testing of the developed auxiliary DC supply system

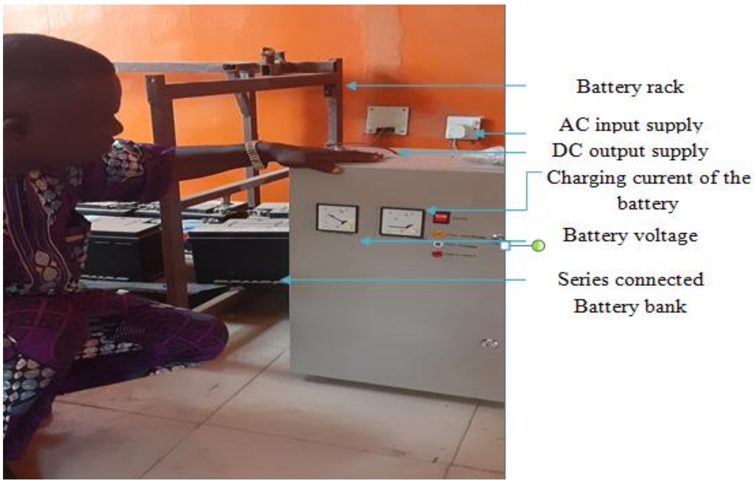
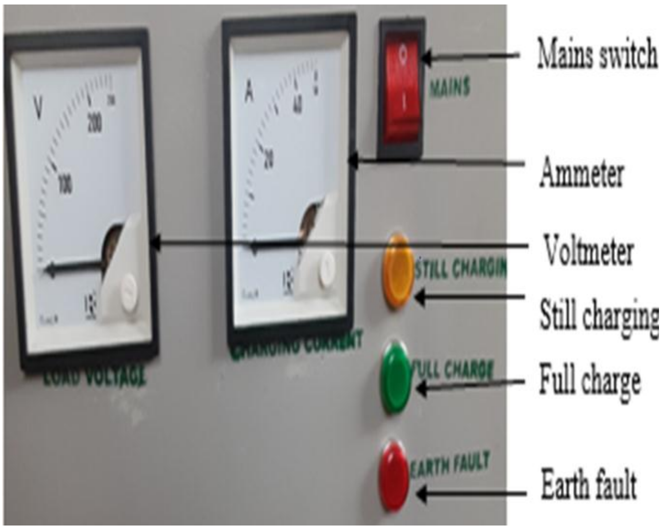


Fig. 4. Validation of the auxiliary DC supply system at the battery room of IBEDC 1 X 15 MVA, 33/11kV Injection Station, Eleweran

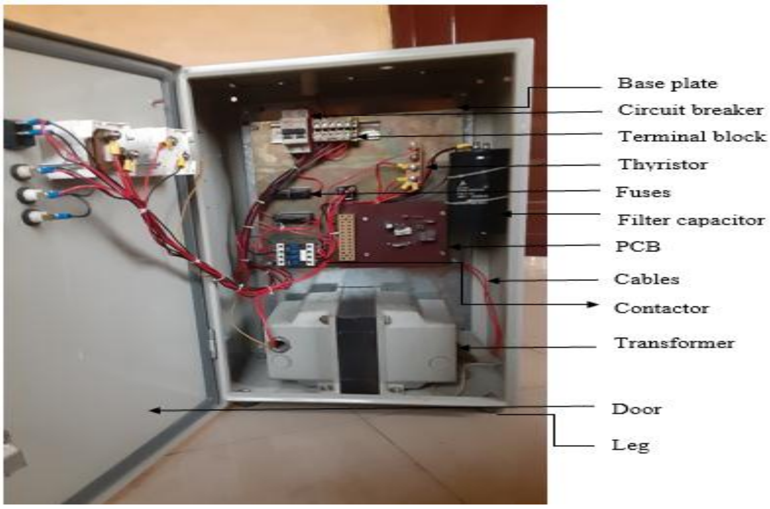
III. RESULTS AND DISCUSSION

3.1. The Developed Auxiliary DC Supply

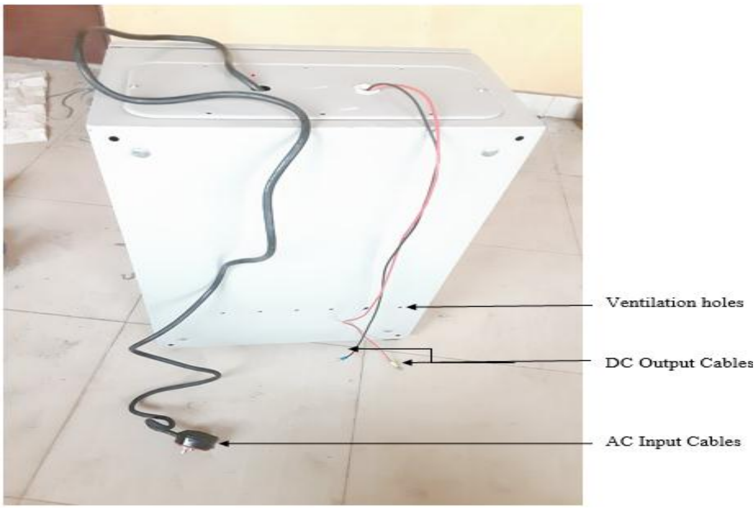
The fully developed 110 V auxiliary DC supply for electricity supply system protection application is presented in Figures 5a, b and c. Figure 5a shows the front view of the system containing the external components such as voltmeter, ammeter, mains switch and indicators responsible for different functions. Figure 5b depicts the internal connectivity between the various components making up the system. Figure 5c delineates the rear view of the system. This rear side has perforations for the heat dissipation to allow for cooling and durability of the system.



(a)



(b)



(c)

Fig. 5. The developed 110 V auxiliary DC supply system (a) Front view (b) Internal view (c) Rear view

3.2. Results of Simulation and Experimental Testing of the System

The output signals from the system during simulation and experimental testing as displayed on the oscilloscope are respectively shown in Figures 6 and 7 while the comparison of the results from simulation and experimental testing as measured from different sub-units is presented in Table 1. The output waveform in Figures 6 and 7 shows that the developed auxiliary supply produced approximately perfect DC output which is suitable for protection system operation during simulation and experimental testing. The simulation results of the system were observed to be close to the experimental testing results and analysis of the values presented in Table 1 indicated that the developed system has a performance accuracy of 99.52%. Hence, its performance is satisfactory for the operation of the protection system.

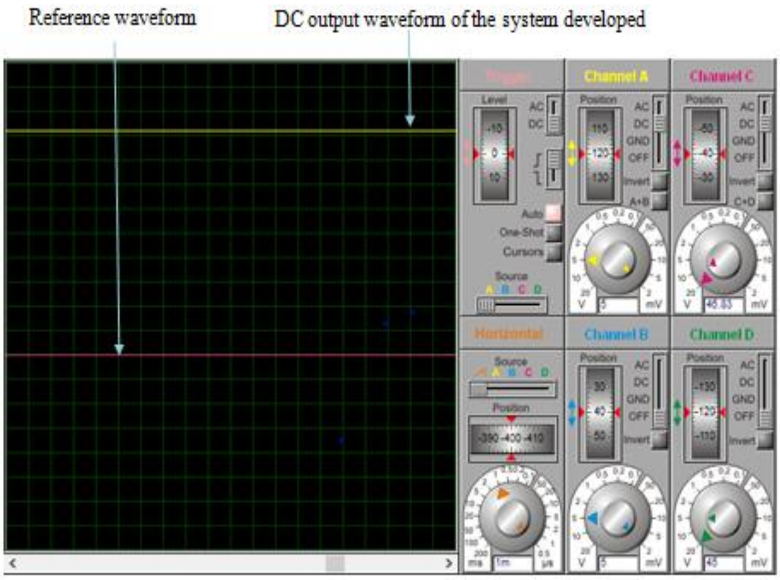


Fig. 6. Oscilloscope display of DC signal from the developed system during simulation using Proteus software

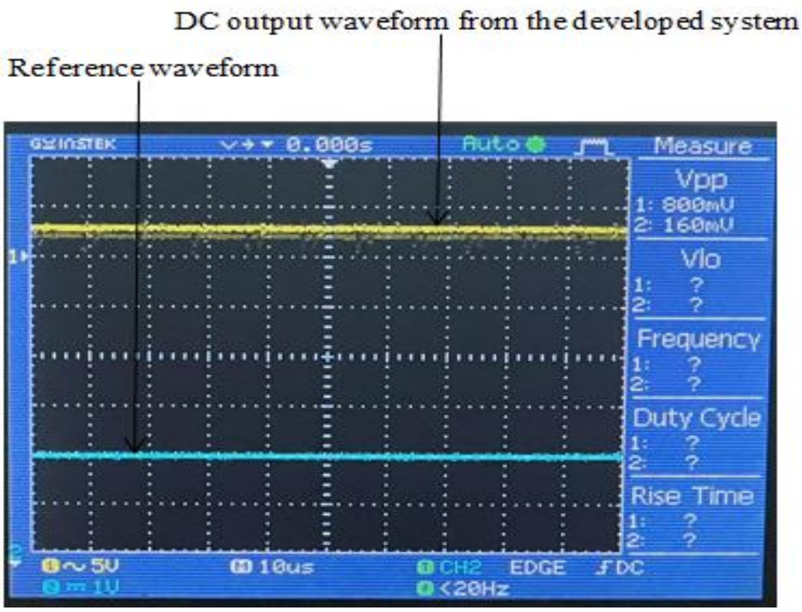


Fig. 7. Oscilloscope display of DC signal from the developed system during experimental testing

Table 1: Results of the simulation test and the system developed.

Location	Expected Output (Volts)	Simulated Output (Of The Designed Circuit System) (Volts)	Experimental Output (Developed System) (Volts)
AC Power Supply	220	220.0	225.0
Transformer Output (220/110) V	110	110.0	112.5
Rectifier Output	155	154.9	159.1
Filtered Output	155	154.0	159.1
Thyristor Output	110	111.1	125.0

More so, based on the International Electrotechnical Commission (IEC) Standard, the allowable limit for a DC Power Supply for tripping unit of a power system protection ranges from 85 to 127 V. Hence, the output of the power supply is expected to have a threshold of 85 to 127 V as the operating voltage range to enable the protection system to operate without damage. This standard is strictly adhered to by the typical user of an auxiliary supply system which is the Ibadan Electricity Distribution Company (IBEDC). The developed auxiliary DC supply system in this work, therefore, complied with the IEC standard, having a voltage of 111.1 and 125.0 V as the outputs from thyristor during simulation and experimental testing respectively as presented in Table 1. The result of further testing of the system developed at Eleweran injection station after an artificial fault was created revealed that the feeder in question tripped effectively. This shows that the developed system responded satisfactorily and triggered the protection devices for the feeder into action appropriately to de-escalate the fault occurrence.

IV. CONCLUSION

In the electricity business operations, the availability of a robust, reliable and efficient system that can aid prompt response of protection system in the event of unhealthy conditions such as fault is a necessity that must be accorded adequate attention to minimize to a very great extent the technical and economic losses that are associated with such events. In this work, a 110 V auxiliary supply system that ensures satisfactory operation of the tripping unit for smooth and effective running of electricity business in Nigeria was developed using locally sourced and replaceable materials. The various component parts of the system developed operated as desired during testing. The output from the overall system both in terms of signal quality and value complied with recommended standard for satisfactory performance of the Nigerian electricity supply system. Hence, the developed auxiliary DC supply unit could be suitably deployed for electricity business operation in Nigeria. As a suggestion for further improvement on the system developed, the use of microcontroller and other integrated circuits (ICs) can be adopted in place of the discrete passive components employed in the present design. The will facilitate more flexible design and operation as well as enhanced digitization of the system. Through the adoption of microcontroller and others ICs, more desired features such as smartness or intelligence can be introduced into system for improved operation.

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