American Journal of Engineering Research (AJER) 2016
American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-5, Issue-2, pp-125-135
www.ajer.org
Research Paper Open Access

Development of A Cost Effective 2.5kva Uninterruptible Power Supply System

Olanrewaju Lateef Kadir[1], Okechi Onuoha[2], Nnaemeka Chiemezie Onuekwusi[3], Ufuoma Onochoja[4], Chikwelu Nonso Udezue[5]
[1,2,4,5](Projects Development Institute (PRODA), Nigeria)
[3](Federal University of Technology, Owerri (FUTO), Nigeria)

ABSTRACT : *This paper is on the detailed development of a cost effective Uninterruptible Power Supply (UPS) system for domestic use. The UPS serves as a standby / backup power supply unit for power supply from the main commercial supply line. In this paper, an easy to implement block diagram showing all the important units of the UPS system is given. Detailed design showing all calculations and considerations were also included in this work. Also, a simple cost analysis showing the cost of producing this system from the scratch and also the cost of a similar product in Nigeria is also shown.*

The UPS consists of charge a controlling section, an inverting section, an automatic change-over / switching section a transformation and a load section. The battery is charged through a rectifier. The rectified DC output was achieved using a bridge rectifier and a voltage regulator. The change-over was done by an electric relay whose function is to establish connection between the load and either the mains or the batteries.

Keywords - *zener diode; automatic change over; oscillator; national grid; low reluctance; battery bank*

I. INTRODUCTION

The importance of electrical power supply cannot be over-emphasized. It provides lightings during the day to indoor areas and to entire surrounding at night. The tasks of generating and distributing uninterruptible power in developing countries seem to be impossible to solve by their governments. As a result, individuals, business centers, companies are trying to solve this problem on their own. One of the methods used in solving this is the use of mechanical generating plant which is usually called generator. The use of generators as alternatives has limitations. These limitations include: high cost of operation and maintenance; it causes a lot of environmental pollution; it produces a lot of noise; and most mechanical generators are bulky.

Another method used in solving the problem is the uninterruptible power supply (UPS). The UPS derives its power from energy stored in a battery. The UPS is a better alternative than the generator in terms of noise, environmental pollution and size.

The aim of this article is develop an easy to operate 2.5kVA uninterruptible power supply that will generate power from battery. UPS is an electronic system or circuit that changes direct current (DC) stored in a battery to alternating current (AC). It is used to supply continuous power to the load connected to its output socket. The battery(s) will be charged by a rectifier circuit which consists of a transformer, a bridge rectifier, a filter and a voltage regulator. In view of erratic power, the UPS serves as a main to the household appliances or load connected to it.

The article contains four sections. After this introductory section, section two explains the individual functions of all the components of the circuit and how they operate. This section also discusses the circuit design calculations and description. Testing and performance evaluation are presented in section three and conclusions and recommendations are drawn in section four.

II. DESIGN METHODOLOGY

1.1 Block Diagram of an uninterruptible Power Supply

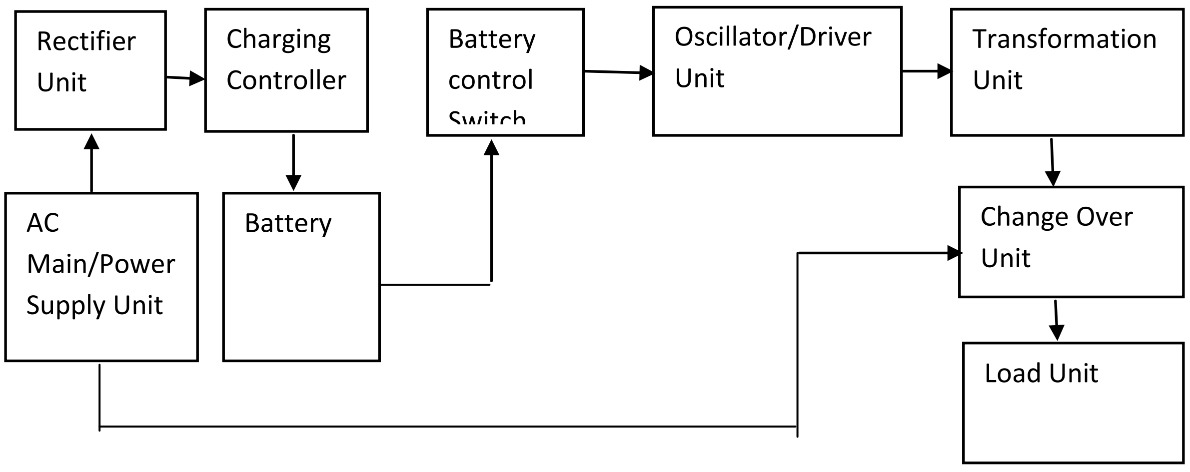

Fig. 1.1: Block Diagram of an Uninterruptible Power Supply

Figure 1.1 shows the block diagram of a UPS. This diagram was used in the design calculation.

1.2 Load Unit

The load unit is the output unit of the UPS. This is where all the electrical power consuming appliances are connected to the UPS. This unit makes use of a socket outlet. A voltmeter may be included in the output to display the output voltage.

1.3 Change-Over Unit

At the changeover unit is a relay switch (RL_1) that was incorporated at the output of the UPS to switch the source of power supply to the output from either the battery or the supply mains (national grid).

1.4 Transformation Unit

In this section of the design, a 24/240V step-up transformer (T_1) was used. The transformer has a centre tap which was connected to the positive terminal of the battery. Figure 1.2 shows the circuit diagram for the 24/220V transformation unit together with the driver, changeover and load units.

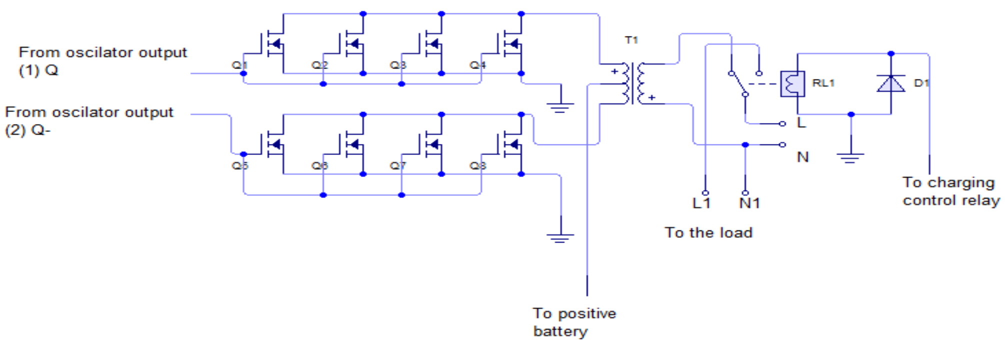

Fig. 1.2: Circuit Diagram for a 24/240V Transformation/Change-over/Load Unit

1.4.1 Determination of the number of turns of coil on each side of T_1 windings

Power rating of T_1 was 2.5kVA. The volt per turn is given by

$$E_t = 4.44\ fB_{max}\ A = \frac{V_p}{N_p} = \frac{V_s}{N_s} \qquad (1.1)$$

Where
E_t is volt per turn, f is the frequency in *Hertz*, B_{max}, is the maximum flux density in *tesla*, A is the lamination core area in m^2, V_p (in volt) is the primary side voltage, N_p is the number of turns on the primary side, V_s (in volt) is the secondary side voltage, N_s is the number of turns on the secondary side.
The size of the transformer core must be determined based on the transformer total power. The area of the core should at least have the value according to the equation 1.2. Therefore the area of lamination of transformer T_1 is given as

$$A = \sqrt{power \ (Watt)}cm^2 \qquad (1.2)$$

$$A = \sqrt{power \ (Watt)} \times 10^{-4} m^2 \qquad (1.3)$$

$$A = \sqrt{IV \cos\theta} \times 10^{-4} m^2 \qquad (1.4)$$

Where
Cosɵ is the power factor.
Choosing a power factor of 0.8 and maximum flux density of lamination to be 1.2 Tesla, the volt per turn is obtained using equations 3.1 and 3.4.

$$E_t = 1.1913 \ volt / turn$$

The expected output voltage of T_1 is 240V.
Secondary voltage V_s of T_1 is 240V
The number of turns in the secondary winding (N_s) is obtained using equations 1.5

$$N_s = \frac{V_s}{E_t} turns \qquad (1.5)$$

$$N_s \approx 202 \ turns$$

Also, the numbers of turns in the primary winding (N_p) is given as in equation 1.6

$$N_p = \frac{V_p}{E_t} turns \qquad (1.6)$$

$$N_p \approx 20 \ turns$$

1.4.2 Coil Gauge Required for T_1

Recall,

$$Power \ (VA) = IV \qquad (1.7)$$

Power rating of T_1 is 2500VA, assuming 90% efficiency. Then the input rating is given by

$$P_i = \frac{P_{out}}{eff} \qquad (1.8)$$

Where P_i is the input power, P_{out} is the output power and *eff* is the efficiency.

Voltage on the secondary side is 240V, thus, current I_s in the secondary side of T_1 is

$$I_s = \frac{P_{out}}{V_s}$$

$$I_s = 10.42 \ Amperes$$

From the America Wire Gauge (AWG), Gauge 11 will be sufficient for the secondary coil.
Voltage on the primary side is 24V, thus primary current, I_p

$$I_p = \frac{P_i}{V_p}$$

$$I_p = 115.7\ Amperes$$

From AWG, Gauge 1 will be sufficient for primary side.

1.5 Oscillator Unit

The oscillator unit makes use of an IC (CD4047) configured in a-stable multi-vibrator for pulse generation of 50Hz duration. This is shown in Figure 1.3

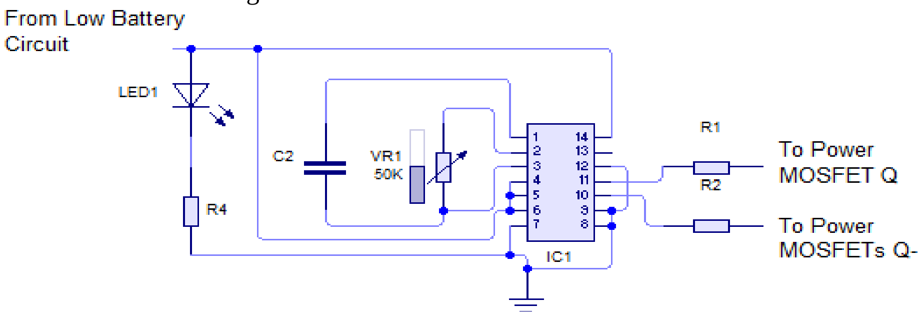

Fig. 1.3: Oscillator Circuit

The configuration is such that pins 4, 5, 6 and 14 were connected to V_{cc} while pins 7, 8, 9 and 12 were connected to the ground. The VR_1, and C_2 network will determine the frequency of oscillator which is 50Hz. Pin 10 and pin 11 are the output (Q) and complementary output (Q-) respectively and this results in the separation of signal into two separate channels. Each channel was connected to the gates of two separate power MOSFETs channel. Each channel of the MOSFETs was then connected to the ends of the primary side of T_1.
The IC is to be provided with a constant voltage from the battery through a voltage regulator IC 7812.
The LED_1 is to indicate when the inverter is working. R_1 and R_2 serve as limiting resistor to limit the current entering the gates of the MOSFETs.
The period T of the oscillator is given by

$$T = 4.4 VR_1 C_2 (\sec s) \qquad (1.10)$$

and

$$T = \frac{1}{f}$$

$$f = \frac{1}{4.4 VR_1 C_2}$$

Where
f is frequency which in this case is *50Hz*. Choosing C_2 to be *100nf*, VR_1 was obtained to be equal to *45.5k Ω* from equation 1.10
From the manufacturer data sheet, when the voltage at pin 14 is 12V, the voltage and current output at pin 10 and pin 11 of IC 4047CD are 5.6V and 50mA.

$$R_1 = \frac{V_{out} - V_{GS}}{I_{max}} \qquad (1.11)$$

Where V_{out} at pin 10 and pin 11 of IC 4047CD are *5.6V*, $V_{GS} = 0$ and I_{max}=*50mA*. From equation 1.11, $R_1 = R_2 = 100\Omega$

$$V_{cc1} = V_{LED1} + I_{LED1} R_4 \qquad (1.12)$$

Where V_{cc1}=12V (from R_{g1}), V_{LED1}=2V and I_{LED1}=10mA (from manufacturer specification). From equation 1.12 R4 was computed to be 1kΩ

1.6 Driver Unit

This section makes use of power MOSFETs IRFP250N. The MOSFETs has a maximum current (I_M) and voltage of 30A and 200V respectively. Each output of the oscillator was connected to each channel of the MOSFETs which resulted in the channels being alternatively ON and OFF. The required number of power MOSFETs, N_m, was obtained using equation 1.8.

$$N_m = \frac{I_p}{I_m} \qquad (1.13)$$

Hence 4 MOSFETs can safely handle the expected primary current but 6 MOSFETs was recommended for higher reliability.

1.7 Battery Control Switch Unit

This unit is used to disconnect the battery from the inverting section whenever there is power supply from the national grid. This unit makes use of relay switch.

1.8 Charging Controller

The charging controller is used to protect the battery from over drainage and over charging. The charging controller consists of low battery voltage trip unit and charging control unit.

1.8.1 Low Battery Control Circuit

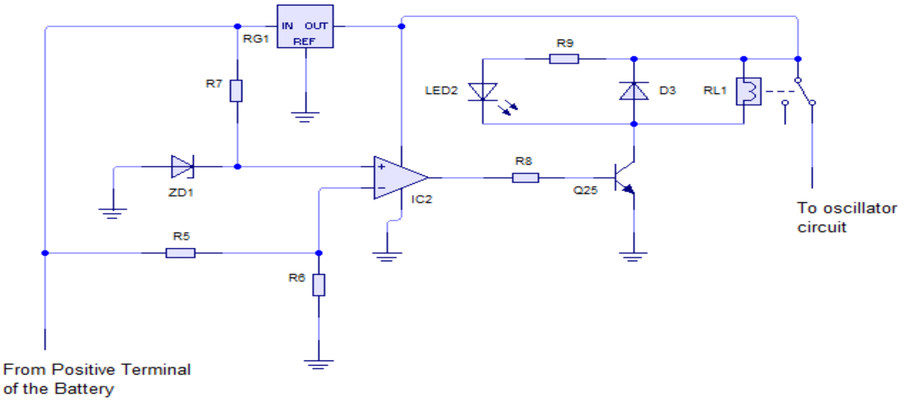

Fig. 1.4: Low Battery Voltage Trip Circuit

The low battery voltage trip is required to disconnect the battery from the output when its voltage has dropped to certain level. This is to ensure that the battery is not over drained by the UPS. Figure 2.4 shows the circuit diagram for low voltage battery trip.

This unit makes use of LM324 comparator (IC_2) and zener diode Z_{D1}

Pin 1 is the output terminal.

Pin 2 is the non-inverting terminal.

Pin 3 is the inverting terminal.

Pin 2 of the op-amp is set to a constant voltage of +10V by Z_{D1}, while pin 3 is set to 9V through potential divider formed by R_5 and R_6.

As the battery voltage is discharging, the voltage at pin 3 will be reducing. When the voltage at pin 3 becomes lower than the voltage at pin 2, it results to a high voltage at pin 1 which will bias the transistor Q_{25} through resistor R_8. This triggers the relay connected to it thereby disconnecting the battery from oscillator.

At pin 2, the inverting terminal,

$$V_{R6} = \frac{R_6 \times V_{cc2}}{R_5 + R_6} \qquad (1.14)$$

Where

V_{cc2} is the battery voltage

V_{R6} is the voltage across the inverting terminal set to 9V by potential divider formed by resistor R_5 and R_6.
Using equation 3.14, $R_5 = R_6 = 1k\Omega$
At pin 3 (non-inverting terminal), the zener diode Z_{D1}, is set to a voltage of 10V.

$$V_{cc2} = R_7 I_{ZD1} + V_{ZD1} \qquad (1.15)$$

Where V_{ZD1} is the zener diode voltage, 10V and I_{ZD1} is the zener diode current, 10mA. R_7 is obtained to be $1k\Omega$
The transistor C1815 (Q_{25}) has the following specifications from the data sheet.
$I_{cmax} = 0.5A$, $V_{BEmax} = 5V$, $\beta = 100$
Output voltage of the op-amp = $0.9 \times V_{cc3}$
Where V_{cc3} is the voltage regulator's output voltage supplied to power the op-amp.
Output at pin 1 = $0.9 \times 12 = 10.8V$
Thus, $V_{BB} = 0.9V_{cc3} \times 10.8$

$$R_8 = \frac{V_{BB} - V_{BE}}{I_B} \qquad (1.16)$$

and

$$I_B = \frac{I_C}{\beta} \qquad (1.17)$$

For LED_2

$$R_9 = \frac{V_{CC1} - V_{LED}}{I_{LED}} \qquad (1.18)$$

Where $V_{cc1} = 12V$, $V_{LED2} = 2V$ *and* $I_{LED2} = 10mA$. From equations 1.16, 1.17 and 1.18, R_8 *and* R_9 are obtained to be $2k\Omega$ *and* $1k\Omega$ respectively
Diode D_3 is IN4007. It has a peak voltage of 50V and a maximum current of 7A; it can safely protect the relay from inverse voltage.

1.8.2 Charging Controller Unit

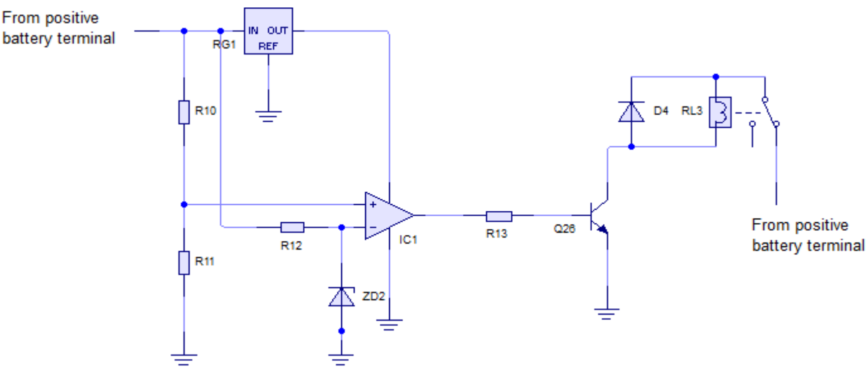

Fig. 1.5: Charging controller circuit

This stage is designed to prevent the battery from overvoltage charging. Figure 1.5 shows the circuit diagram for charging controller unit. Two fully charged batteries were connected in series giving a total voltage of 24V. IC_3 was used as a comparator in the charging controller unit. The inverting terminal was fixed at a constant voltage of 12V through zener diode Z_{D2}.

Thus,

$$R_{12} = \frac{V_{CC2} - V_{ZD2}}{I_{ZD2}} \qquad (1.19)$$

Where V_{cc2} is the batteries voltage, $V_{ZD2} = 12V$, $I_{ZD2} = 10mA$. R_{12} is obtained to be $1.2k\Omega$
Once the batteries are fully charged, the voltage across the non-inverting terminal is higher than that of the inverting terminal, this will triggers the transistor Q_{26} connected to it. This disconnects the batteries from the charging source. The charging source is reconnected when the voltage at the inverting terminal is higher than the voltage at the non-inverting terminal. The non-inverting terminal is therefore set to 14V through potential divider formed by R_{10} and R_{11}.
Then,

$$R_{11} = \frac{R_{10} V_{OP^+}}{V_{CC2} - V_{OP^+}} \quad (1.20)$$

Where V_{cc2} is the batteries voltage, $V_{op}^+ = 14V$ and $R_{10} = 1k\Omega$. A resistor of $1k\Omega$ is obtained for R_{11}. Transistor Q_{26} (IC1815) has the following specifications: $I_{cmax} = 0.5A$, $V_{BEmax} = 0.7V$, $\beta = 100$

$$R_{13} = \frac{V_{BB} - V_{BE}}{I_B} \quad (1.21)$$

$$I_B = \frac{I_C}{\beta} \quad (1.22)$$

$$V_{BB} = V_{CC1} \times 0.9$$

A resistance of $2k\Omega$ is obtained for R_{13}
D_4 is a IN4007 diode with the following specification: Peak inverse voltage of 50V, and maximum current of 7A. The diodes were used as protector for the relays against the inverse voltage.

1.9 Rectifier Circuit

The rectifier circuit consists of transformer T_2, capacitor C_1 and a voltage regulator as shown in Figure 1.6

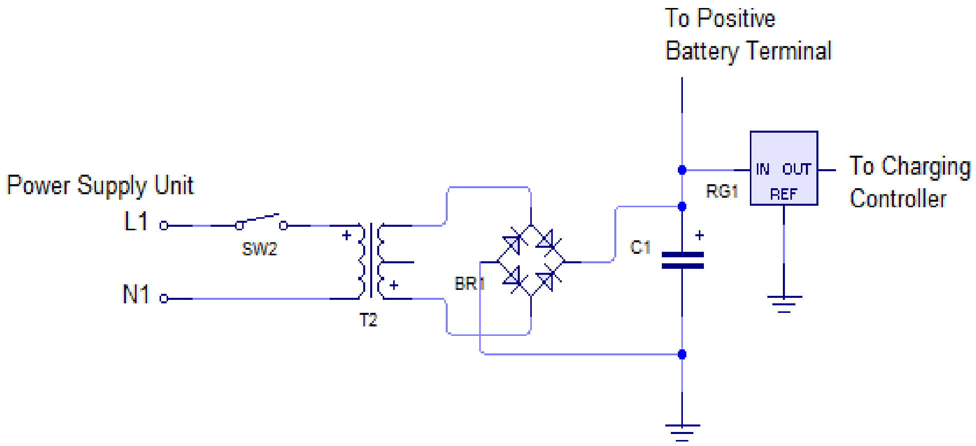

Fig. 1.6: Rectifier Circuit

T_2 is rated at 220/30V and the bridge rectifier consists of four diodes, D1 – D4 (IN4007). The diodes are used to convert the ac voltage available at the secondary of the power supply circuit to dc voltage. They have a peak inverse voltage of 100V, and a maximum current of 30Amperes which can safely handle 30V T_2. Capacitor C_1 is used to filter the ripples in the rectified voltage. The value of the capacitor depends on the load current and the degree of smoothing required. The capacitor is selected based on equation 1.23.

$$I_c = C\frac{dv_c}{dt} \qquad (1.23)$$

Where
C is the Capacitance of capacitor in Farad, dv_c is the ripples voltage (2V) produced by the rectifier and dt is the time between peaks of the input waveform.

$$t = \frac{1}{f} = \frac{1}{50} = 0.02 \text{ sec onds}$$

Where f is the frequency in Hertz.
The secondary current I_c of transformer T_2 is 6Amperes. From equation 1.23, C is obtained to be 6000µF
The voltage regulator, R_{G2} is 7815 IC with maximum output voltage of 15V. The output of the rectifier circuit is connected to the batteries for charging.

1.10 Power Supply/ AC Mains Unit
The power supply unit represent the input from the national grid. This unit is used to provide charging to the battery from the national supply grid. The AC input is rectified to the required output voltage to charge the battery through the rectifier circuit or unit. The UPS is made easy such that the supply from the national mains goes directly to the output when the supply main is available. A changeover is incorporated in the output to switch between supply from battery and supply mains from national grid without any noticeable interruption.

1.11 Battery Bank
A battery is an electrochemical device that converts electrical energy to chemical energy during charging and chemical energy back to electrical energy during discharging. A battery bank is needed in UPS design to store the energy when there is power supply from the national grid. Deep cycle battery type are recommended in UPS design because they are specifically designed for charge and discharge for a longer time. The battery should be large enough to store large amount of energy. Many sizes of batteries are available in the market, some includes: 12V/100A, 12V/150A and 12V/200A. The batteries can be connected in series to increase their voltage capacity or connected in parallel to increase their current capacity. The batteries used for this UPS are connected in series to produce 24V output.
Figure 1.7 shows the complete circuit diagram of the 2.5kVA UPS.

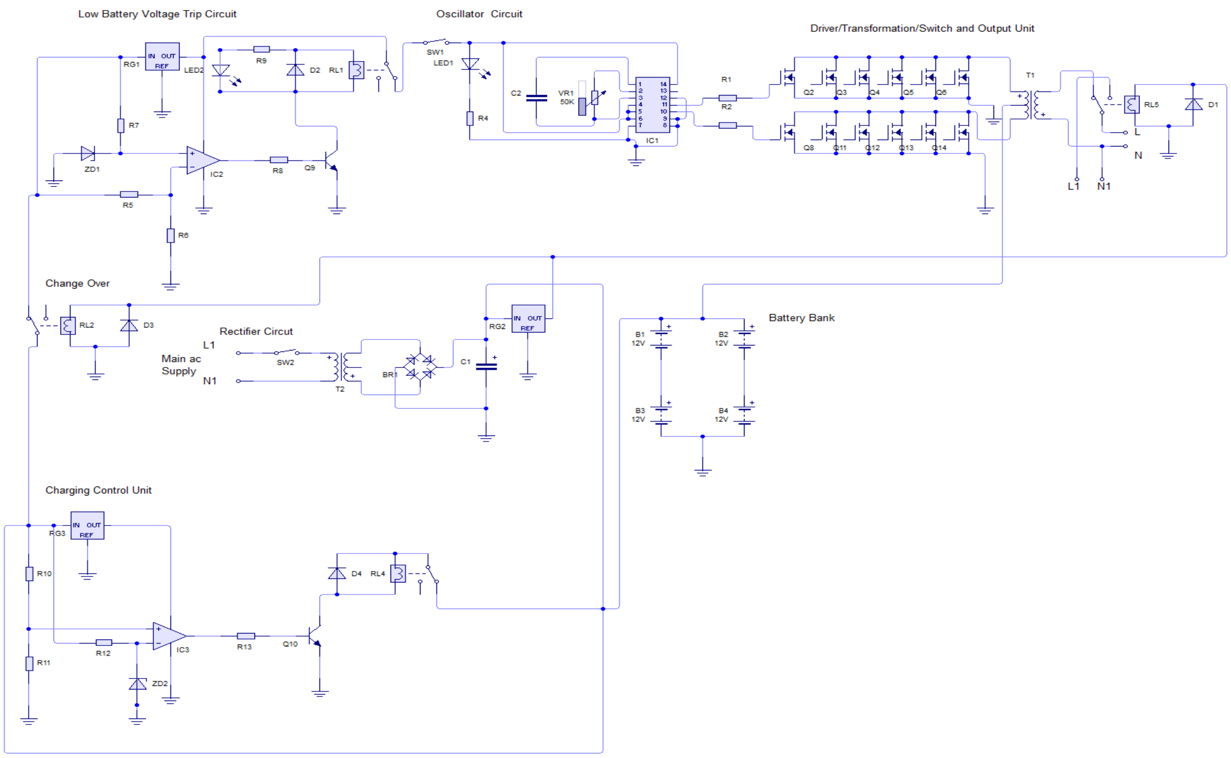

Fig. 1.7: Complete Circuit Diagram of Power Inverter

III. PERFORMANCE EVALUATION

The UPS was tested stage by stage. The system output voltage was measured at no load. Table 3.1 shows the expected and measured value.

3.1 Output Voltage Test

Table 2.1: Output Voltage Test

	Expected Output Voltage (V)	Measured Output Voltage	Correlation (%)	Remarks
From Battery (Inverter Mode)	240	243.2	98.77	Satisfactory
From Commercial Main Supply	220	220	100	Satisfactory

3.2 Over-Drain Test

This test was carried out to prevent the batteries from too much draining i.e. to stop discharging when the voltage dropped to certain level. The system was powered ON and the oscillator output voltage was measured at different battery voltage. The result is as shown in Table 2.2.

Table 2.2: Over-drain Test

S/N	**Battery Voltage (V)**	**Oscillator Output (V)**	**System Output (V)**	**Remarks**
1	24	5.6	243.2	Satisfactory
2	22	5.6	223.5	Satisfactory
3	20	5.6	201.6	Satisfactory
4	18	5.6	182.4	Satisfactory
5	17	0.03	0	Satisfactory

3.3 Charging Test

This test was carried out in order to ensure that the charging current provided from the charging source does not overcharge the batteries. The results of the test is as shown in Table 2.3.

Table 2.3: Charging Test

S/N	Battery Voltage (V)	Indicator	
1	18	ON	The results obtained from the test were satisfactory.
2	20	ON	
3	22	ON	
4	24	ON	
5	26	OFF	

34 Output Power/Load Test

The duration of supply from the UPS when there is no supply from the national grid is a function of total power connected to its output or load unit and power rating or capacity of the battery. The battery capacity is 24V, 200Ampere hour (24V/200Ah). The UPS was tested with 1000W halogen bulbs. The discharge duration is as shown in Table 2.4.

Table 3.4: Output Power/Load Test

Power (Watt)	Output Voltage (V)	Duration (Hour)
1000	240	4hrs, 25 minutes
2000	240	2hrs, 15 minutes

3.5 Cost Implication

The development of this UPS is also cost effective. Table 2.5 shows the rough estimates of cost of different components used in the development of the UPS.

Table 2.5: Cost of Components of the Power Inverter

Components	Cost (₦)
Transformer T_1	25000
Transformer T_2	4500
Diodes and LED	500
Voltage regulators	500
Resistors	500
Capacitors	500
Relay switches	2000
FETs	2000
Integrated circuits and sockets	1500
Casing	5500
Sockets and plug	800
Switches	500
Meters	600
Connecting wires	4000
Miscellaneous	5000
TOTAL COST	**53400**

It will be observed that the total cost of the UPS (₦53,400) is less than the selling price of a similar UPS here in Nigeria. The least cost of a similar UPS system here in Nigeria costs at least ₦80,000. The cost of the UPS designed in this work will reduce significantly if the UPS is to be massively produced.

IV. CONCLUSIONS

From the tests carried out on the UPS, it can be resolved that the main objective has been achieved. The system's output voltage on NO LOAD was 243.2V when the battery voltage was 24V. From Table 3.2, the batteries stopped discharging when the voltage across them dropped below 18V. From Table 3.3, the charging stopped when the voltage of the series connected batteries was more than 24V, thereby facilitating a reliable and efficient use of the batteries. The UPS load/output test also showed that the UPS can carry 2000W (2500VA) successfully. Though the output voltage was seen reducing as more loads were connected, the duration of supply from the UPS depends on the power of the connected loads and the battery capacity. The duration can be increased by increasing the battery capacity.

REFERENCES

[1] Robert Boylestad, Louis Nashlsky "Electronic Devices and Circuit Theory, Seventh Edition, Prentice Hall, Upper Saddle River, New Jersey, 2003

[2] North Star Battery Operation Manual, 2009

[3] www.fairchildsemi.com

[4] Theraja B. L. and Theraja A. K. "A textbook of Electrical Technology", Vol 1, 21st Edition, S Chand & Company Limited, 2005.

[5] Paul Horowitz, "The Art of Electronics", Second Edition, Cambridge University Press, 2009

[6] David I. J and Nelms R. M, "Basic Engineering Circuit Design Analysis, Eight Edition, Published by John Winley and Sons, Inc, 2006

[7] www.epanorama.net