



## Design and Implementation of a 1.5 kVA Solar Powered Mobile Inverter

<sup>1</sup>Abubakar, I. N., <sup>2</sup>Idoko. J. A., <sup>3</sup>Dodo, U. A., <sup>4</sup>Umar, A., <sup>5</sup>Zarmai, J. T., <sup>6</sup>Abubakar. M., <sup>7</sup>Ndagi, U.

<sup>1,2,6,7</sup>Department of Electrical and Electronic Engineering,

Federal University of Technology, Minna

<sup>4</sup>Department of Electrical and Electronic Engineering,

Umar Ali Shinkafi Polytechnic, Sokoto State, Nigeria.

<sup>5</sup>Radial Circle Telecommunication Company Abuja, Nigeria.

<sup>3</sup>Department of Electrical and Computer Engineering,

Baze University, Abuja, Nigeria.

### ABSTRACT

*This paper focuses on the design and implementation of 1.5kVA 12V DC, 230V AC Solar-powered mobile inverter. The basic principle of operation is the conversion of 12V DC from a 200Ah Deep cycle battery using integrated circuits SG3524 and semiconductors at a frequency of 50Hz, into a 230V AC across the windings of a transformer. The battery was charged using solar panels via a charge controller. It incorporated a monitoring and supervisory circuit of microcontroller based (ATMEGA16) that employs a Liquid crystal display (LCD) and light emitting diodes to communicate the state of the inverter to the user. The results show that as soon as the load goes above 1500VA and the battery voltage goes below the preset threshold 12V DC the overload protecting circuitry attached to the system automatically shut down the system to prevent the inverter from being overloaded, a smaller transformer was used to energize and control the operation of the relays, which switched from the inverting mode to charging mode with battery monitor cut-off voltage 13.6V with its surge protection voltage above 250V. The system was successfully installed, tested and confirmed to deliver the required output. It also offers a better alternative to Public Power Supply from the utility companies such as the (Power Holding Company of Nigeria PHCN) as the case may be, generators as well as UPS considering its cost-effectiveness, noiselessness and ease of maintenance.*

### ARTICLE INFO

Article History

Received: February, 2020

Received in revised form: March, 2020

Accepted: May, 2020

Published online: June, 2020

### KEYWORDS

Power Inverter, Renewable Energy, Solar energy, DC to AC power

### INTRODUCTION

Renewable energy is the energy that exist freely and infinitely (do not run out of place) in nature (Oseni, 2012). Examples of renewable energy are solar energy, wind energy; nuclear energy etc. renewable energy researches are becoming more

popular due to depletion of conventional fossil fuel and its negative impact on environments (Abu-Rub, 2010). In our modern society today, electricity is the main source of power for our domestic consumption, industrial development, centres of learning and medical centres.



Hence, should be maintained for enhancement of productivity (Nwofe, 2014). In Nigeria, there is inadequate power supply from the Power generating stations to the consumers due to fault caused by failure of equipment, human factor, transmission and distribution mediums. Hence, these has led to unexpected interruption in power supply which causes loss of valuable information during data processing in computers, ineffectiveness of hospital equipment which sometimes leads to loss of lives and also in refineries, they suffer high cost of starting up the process plant after power interruption. To minimize this failures and interruption in electrical power has brought about the generation of an alternative source of energy such as fuel generator. Though, fuel generator produces the expected power but the negative side effects are unlimited such as; carbon monoxide gas released through the exhaust which is harmful to human health and also leads to depletion of the ozone layer, high cost of maintenance and fueling, loud noise, as well as bulkiness. Power inverters overcame these disadvantages by being less noisy, no cost of fuel, no air pollution, more efficient, low or no cost of maintenance of the system through the use of semiconductor power devices such as the Bipolar Transistor, Unipolar Transistor, Thyristor and particularly MOSFET to generate electricity in conjunction with a DC battery in few kilowatts. In this Paper a solar powered mobile inverter was designed and implemented.

#### REVIEW OF RELATED WORKS

With the advancement in technology and development towards the alternative source of power supply, design and construction of an inverter has achieved high efficiency, noiseless, portability, cheap and pollution free (Bayar, 2013). The earliest back-up power (inverter) was motor-generator, which was developed to serve the

need during World War II (Cherp, 2013). A popular brand of that era was red - line which is still around till today. The output waveform fits a wide variety of application but it was inefficient (Bayar, 2013).

In the early 1960s solid state transistor replaced the mechanical vibrators. The first advantage of this type of inverter was that, it was not a motor-generator. But its unregulated square wave design could operate only a resistive load and it could not operate reactive load. Such as fan, blender, micro wave oven (Marquardt, *et al.*, 2010).

In the early 1980s there were two companies manufacturing back-up power supply. They were heart interface and GTO electronic. They used Field Effect transistors (FETs) (Zhang *et al.*, 2008). Back-up power types can be broadly categorized as mechanical or electronic. The mechanical types are the early motor-generator, which consists of a DC motor that powers an AC generator (Wang *et al.*, 2009). Al-Salaymeh *et al.* (2010) proposed a design of PV system to produce energy for basic domestic needs. The proposed design studies the feasibility of utilizing PV systems in a standard residential apartment in Amman city in Jordan to conduct energy and economic calculations. It was found that the calculated payback period was higher in a standalone as compared to grid electricity. To decrease payback period, a grid-connected PV system was suggested. The output results of this study show that installation of PV system in a residential flat in Jordan may not be economically rewarding owing to the high cost of PV system compared to the cost grid electricity.

Nur, *et al.*, (2016), research work was based on design and implementation of a push-pull Inverter for photovoltaic Portable Lamp. The Focus was to implement a Push-Pull Inverter which is used to power a 3W LED lamp with the help of a 12V battery. A 10W solar panel was used with a 12V battery to power the lamp. The Proposed

load of the LED lamp was 3W which was built around a 555 timer IC. The challenge of this research work was that there is no power rating is determined for the inverter. Li *et al.* (2012) studied a grid-connected PV system installed in an institutional building in Hong Kong. The analysis was based on two years measured data made in output energy generated were systematically recorded and analyzed. It was found that with feed-in-

tariff schemes, high electricity selling price can shorten the payback period for grid-connected PV system to a reasonable time period that is much less than the life span of the installation. This paper exploits the gaps in the review to design a more reliable and stable system. The PV system was solely designed as a backup to the supply from the national grid. By so doing, constant supply of electricity is ensured.

## DESIGN AND IMPLEMENTATION

### Introduction

The functional block diagram that represents the stages of the 1.5 kVA solar inverter is as shown in Figure 1.

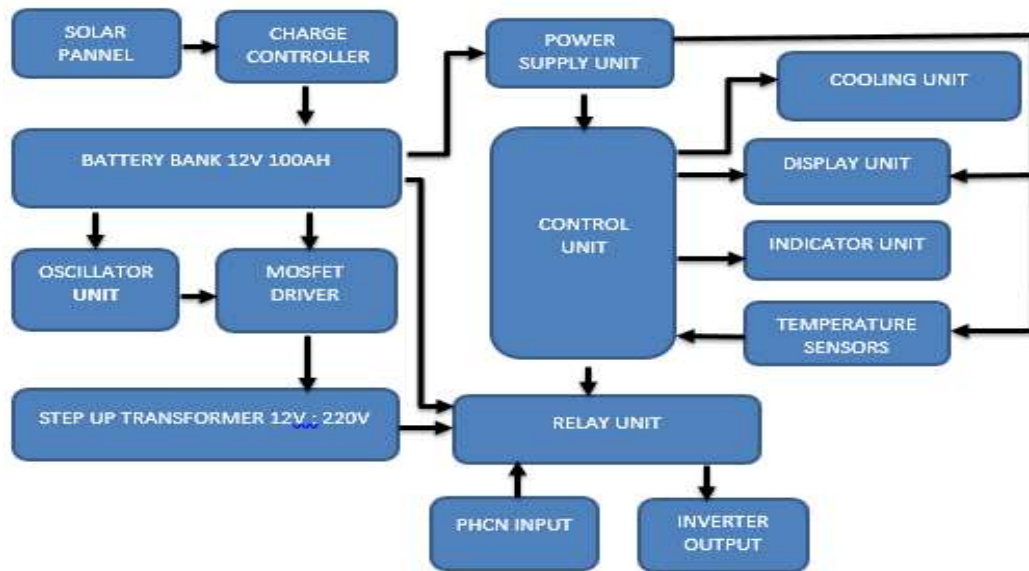


Figure 1: Functional Block Diagram of the 1.5kVA Solar Powered Inverter

The block diagram in Figure 4 comprises the oscillator stage which is responsible for generating the sine wave, the MOSFET driver for driving the required current through the transformer, relay unit for switching between the inverter output and PHCN supply. The charge controller controls the charging rate from the solar panel to the battery bank, the control unit made of AVR microcontroller to perform

monitoring and control operation. The display unit which display information of the activities, the temperature sensors that monitor the temperature of the MOSFETs and the power transformer should in case of fault and the cooling fan. In what follows, the design calculation and specification leading to the final circuit are presented.

### Power Supply Unit

The power supply unit is needed to power the electronics component used that operate on 5V DC. It basically consists of a 7805, a 3 pin fixed positive output type monolithic voltage regulators with built-in overcurrent limit circuit and built-in thermal overload protection circuit. It regulates the 12V battery to a steady 5V with the ability to drive 1000mA which was used to power the microcontroller, the temperature sensors and the LCD display. A 470uF electrolytic capacitor was connected to the output of

the regulator so as to smoothen the signal and remove any noise that may be caused by the regulator due to the process of regulation. A 100k variable resistor was connected between the 12V battery and the ground so as to measure the battery voltage, the wiper of the 100K variable resistor was connected to the ADC input of the microcontroller which convert the analog signal into a digital signal. The circuit diagram of the power supply unit is presented in figure 2.

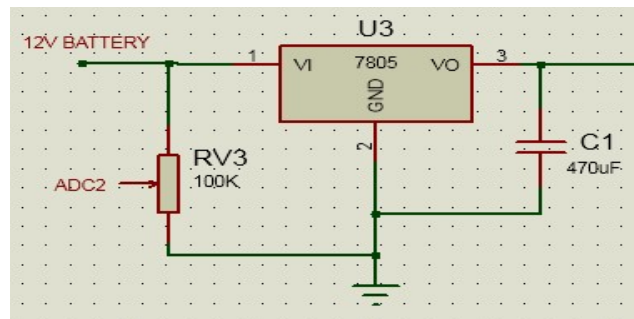


Figure 2: The Power Supply Unit

### The Relay Unit

Array of relays were used as shown in figure 3.3, A 12V 10A relay was used for the switching of oscillator and the cooling fan i.e. RL1 and RL2, 12V 30A relay was used for switching the input and output device i.e. RL3-8. An electro mechanical relay was used; all the relays are normally close mode relay. The output relay (RL7) is normally close at the inverter ON i.e. it used to supply source to the inverter through the battery when the mains AC supply is OFF. On the event of power supply from the mains, it switches OFF the inverter. Input relays is use

to control the charging circuit and AC output voltage. Immediately there is supply of the voltage from the mains, the normally closed one of the relay depending on the level of the input voltage. At the same time, it makes the circuit with the output transformer winding which now turn to be the primary coil through transformation, drop the voltage to 12V at the secondary (center tap/primary coil when AC is not used). The 12V AC is supply to the MOSFETs and MOSFETs serves as the rectifier that charges the battery.

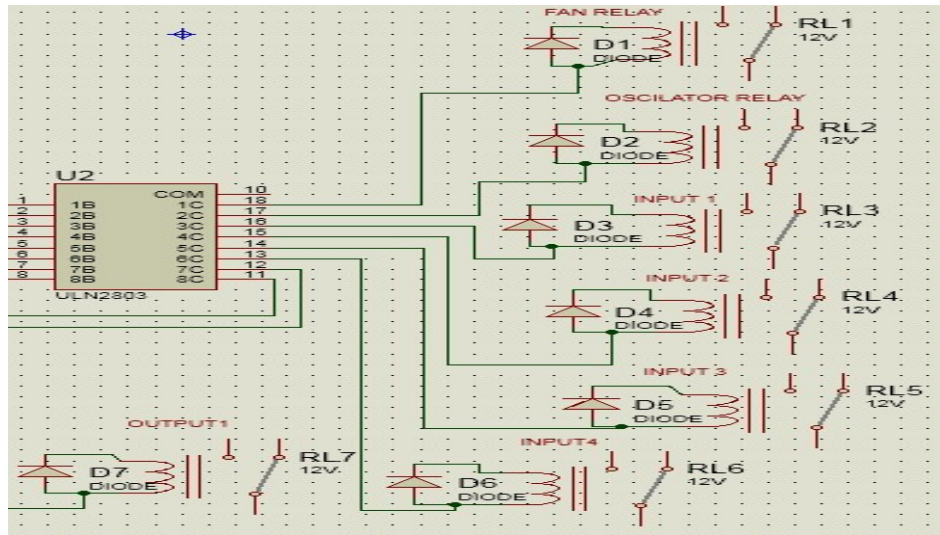


Figure 3: The Relay Unit

### The Relay Driver Unit

A ULN2803 relay driver was employed to drive the arrays of relay since the microcontroller can only drive 5V and the relays require a 12V DC to function, this driver contains eight Darlington transistors with common emitters and integral suppression diodes for inductive loads. The driver features a peak load current rating of 600mA (500mA continuous) and can withstand up to 50V. The microcontroller switches the driver from its input which is 5V and the driver switches each relay from its output which is 12V.

### Battery Charging Unit

This section discusses the battery charging circuit using the connected solar panel. For a 1.5kVA inverter to operate for one hour at maximum load, the required current is given in equation (1).

$$I = \frac{\text{rated power}}{\text{battery voltage}} \quad (1)$$

Assuming a power factor of 0.8

$$\text{Thus } \frac{1500 \times 0.8}{12} \text{ Therefore } I = 100A$$

(since the battery is 12V)

Hence, using a battery of 200AH, the time duration will be  $200/100 \times 1\text{hr}$

= 2 hours

(approximately)

### Oscillator Stage

The conversion of DC energy from the battery to AC energy of a specified frequency is done in this stage. It is an electronic source of alternating current or voltage having sine, square, saw tooth or pulse width. According to the definition/explanation above, it can be deduced that the oscillating stage is where the main idea of inverter lies. The oscillator used in this design was pulse width modulation regulator control (SG3524). This was chosen because of its reliability and availability of some essential components in its circuitry to implement single ended or push-pull switching regulator. Included in the circuit is an oscillator, voltage reference, a pulse width modulator, error amplifier, overload protection circuitry and output drivers. The IC has 16 pin dual-in-line-dips as shown in Figure 4, dual alternating output switches, current limiting and shut down circuitry, voltage stability.

### Frequency Configuration of the Oscillator

As stated above, SG3524 requires external synchronization for the designer to

vary the pulse duration derived and consequently the frequency. The formula

generated from the manufacturer of SG3524 for pulse duration is given as:  
 $T = 1.1 RC$  (where T is in microsecond.) (2)

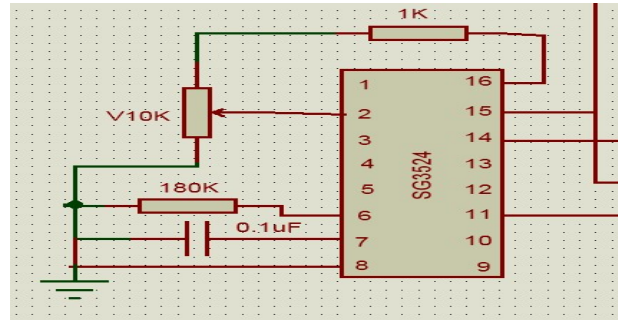


Figure 4: Circuit Diagram of the Oscillator

### MOSFET Design Calculation

A voltage level of 5V was fed from preamplifier to the switching MOSFET that makes  $V_{GS} = 0$  at self-bias. Thus, the gate current can be obtained as:

$$I_G = \frac{V_H - V_{GS}}{R_b} \quad (3)$$

Where,  $V_{GS}$  is the gate to source voltage,  $V_H$  is the preamplifier voltage level, and  $R_b$  is the gate resistor. Thus,

$$I_G = \frac{5 - 0}{100} = \frac{5}{100} = 0.05 \text{ Amp}$$

If  $V_G = 5V$  at  $V_H$

Therefore: Drain Current  
=  $D_i$

$$\text{Since drain current} = \frac{V_{DD}}{R_D}$$

$R_D$  = the reactance of the coil of the transformer.

Therefore, the reactance of the coil must be known.

Since L (inductance) is not noted

$$\therefore X_L = \frac{V}{I}, V = 12 \text{ and } I = ?$$

$$\text{Targeted power rating} = 1.5 \text{ KW} = P = IV$$

$$1500 = 12 \times I$$

Assuming 0.8 power factor

$$\frac{1500 \times 0.8}{12} \quad \text{Therefore } I = 100A$$

The IRF150 has capacity of 40Amp; therefore, the MOSFET should be arranged in parallel to compensate for the current.

$$\text{If } X_L = \frac{V}{I} = \frac{12}{100} = 0.12 \Omega$$

At 50Hz the reactance of the coil was noted to be  $0.12 \Omega$ . Hence,  $R_D = 0.12 \Omega$

$$\text{Drain current} = D_i = \frac{V_{DD}}{R_D} = \frac{12}{0.12} = 100 \text{ Amps}$$

The arrangement of three (3) IRF150 in parallel will give total of 120A and the full load actually require 100A which is the reason why three MOSFET are connected in parallel to form the H-Bridge.

### Transformer Design

The transformer used here is a step-up transformer from 12V to 230 V AC. The physical basis of a transformer is mutual induction between two circuit linked by a common magnetic flux generated corresponding to the input power to the transformer. The bidirectional transformer was used at the output stage of the entire design of 1.5kVA inverter, to be able to realized 220V from the input of transformer of 12V AC signal at the MOSFET end. This step-up center tapped transformer steps up 12V AC from the output of the inverter unit to the desired 220 V AC.

### Transformer Design Calculation

The transformer calculation was carried out on the assumption that there is no power loss. This however applies to an ideal case. Assuming no power loss, the

rated power of the inverter is equal to the output power. Thus recall that input current = 100A,

Let  $E_s$  = Emf of secondary side of the transformer = 220V

$E_p$  = Emf of primary side of the transformer = 12V

$N_s$  = number of turns in secondary side of the transformer = 580 turns

$N_p$  = number of turns in primary side of the transformer = ?

Also, transformer ratio (K) is given as in (4).

$$K = \frac{E_s}{E_p} = \frac{N_s}{N_p} \quad (4)$$

$$\frac{230}{12} = 19.2 = K$$

Given that the number of turns of the secondary side ( $N_s$ ) = 580 turns

To find  $N_p$  i.e. number of turns in primary side

Given  $E_p = 12V$ ,  $E_s = 220V$

$$\frac{E_p}{E_s} = \frac{N_p}{N_s}$$

$$N_p = \frac{E_p}{E_s} \times N_s = \frac{12}{220} \times 580 = 30 \text{ turns}$$

To achieve the impedance of the coil the parameters are noted:

Secondary coil turns = 580 turns

Primary coil turns = 30 turns

Secondary Voltage = 220V

Primary Voltage = 12V

Secondary current = ?

Primary current = 100A

The secondary current obtained by the current that runs through the source to the drain of the MOSFET. This help in powering the transformer, because the transformer is the  $R_L$  (Load resistor of the MOSFET).

$\therefore I_s$  (primary current) is given by transformer ratio:

$$\frac{I_p}{I_s} = \frac{V_s}{V_p} = I_p = \frac{12 \times 100}{220} = 5.45A$$

$\therefore$  Secondary current = 5.45A

Power efficiency = power input = power output

$$\text{Power efficiency} = 12 \times 100 = 220 \times 5.45$$

$$= 1200W$$

Which is the same as  $1200 / 0.8(\text{PF}) = 1500VA$

$$\text{If primary reactance } X_{sr} = \frac{V}{I} = \frac{12}{100} = 0.12$$

$\therefore$  Inductance of the primary coil

$$X_L = 2\pi fL$$

$$= 0.12$$

$$= 2 \times 3.142 \times 50 \times L$$

$$L = \frac{X_L}{2\pi f} = \frac{0.12}{2 \times 3.142 \times 50}$$

$$L = 0.382 \times 10^{-3}H$$

Inductance of the primary coil

$$X_L = \frac{220}{5.45} = 40.37\Omega$$

$$X_L = 2\pi fL$$

$$X_L = 2 \times 3.142 \times 50 \times L$$

$$L = \frac{40.37}{2 \times 3.142 \times 50}$$

$$L = 0.128H$$

Therefore, the resonant factor (Q) =  $\frac{\omega L}{R_{dc}}$

Where  $R_{dc}$  = dc pure resistivity

DC resistivity for secondary coil is  $1.6\Omega$

DC resistivity for primary coil =  $2.5\Omega$

$$\frac{2\pi fL}{R_{dc}} = Q - \text{for primary coil}$$

$$\frac{2 \times 3.142 \times 50 \times 0.382 \times 10^{-3}}{1.6}$$

$$= 0.075$$

$$Q \text{ factor for secondary coil} = \frac{2 \times 3.142 \times 0.128 \times 50}{2.5}$$

$$= 16.09$$

Hence, impedance for secondary coils,

$$R = Q \times X_L$$

$$R = 0.075 \times 0.072$$

$$R = 0.0054\Omega$$

Impedance for primary coil

$$= Q \times X_L$$

$$= 16.09 \times 0.12$$

$$= 1.93 \Omega$$

### Power Switching MOSFET

The insulated gate of the MOSFET further reduces substantially the gate current, in which the gate current is less than one Pico ampere (pA). On the design, the MOSFET received 5V alternating voltage. Therefore, to OFF the MOSFET completely, the MOSFET gate was negatively biased to

avoid the damage of the component, because without the negative bias, the MOSFET will not completely OFF before the arrival of the other pulses which might damage the MOSFET. In addition, 22KΩ resistor connected between the gate and the

source to completely turn OFF the MOSFET. In addition, diodes were connected across the drain of the MOSFET to avoid surge at reverse direction, which might also damage the MOSFET.

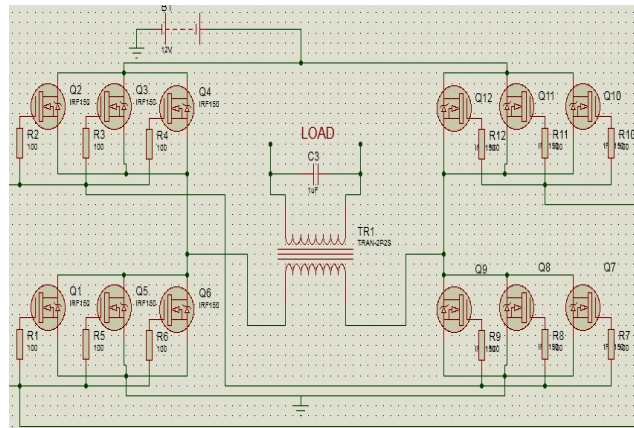


Figure 5: Circuit Configuration of the MOSFET

#### Control Unit

This unit is made up of AVR microcontroller ATMEGA16 which perform the control function of the solar inverter, it monitors the two temperature sensor, monitor both the AC and DC voltage level, perform the switching of the relays, control the cooling fan and oscillator, display all necessary information on the LCD.

#### Display Unit

This unit is made of a 16 by 2 liquid crystal Display (LCD), this is a basic 16 character by 2-line display. Black text on Green/Blue background. It functions as an interface between the user and the inverter system and utilizes the extremely common HD44780 parallel interface chipset. This unit shows the output of all activities of the inverter and the LCD is responsible for this display. Figure 6 shows the LCD connection to the microcontroller.

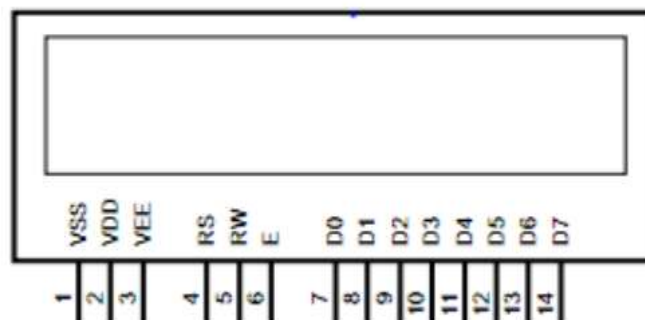


Figure 6: Liquid Crystal Display (LCD) (Abubakar, *et al.*, 2017)



### **Temperature Sensor**

Two temperature sensor was used in this project to serve as protection for the inverter, one is mounted on the MOSFETs and the other mounted on the transformer so as to detect fault or unwanted power loss.

### **CHASSIS FABRICATION**

The chassis was fabricated using an angle iron of 1.5 inches which provide strength and support for multidirectional forces. The chassis has a dimension of 32x12x14 inches (LxBxH) and was cover up with Acrylic glass. The picture of the chassis is shown in Plate I



Plate I. Project Chassis



Plate II. 80% Packaged work



Plate III. Complete Fully packaged work

## RESULTS

The result obtained from the constructed inverter were very satisfactory. The primary aim of obtaining a 1.5 kVA output capacity from the inverter was achieved and the uninterrupted constant supply of power achieved. Dual charging source was also achieved via solar panel and public utility supply. Some of the challenges faced include MOSFETs overheating, hence, the idea of heat sink to reduce the heating and the introduction of temperature sensor also help. Noise in the output transformer

was also reduced to the barest minimum, so vanish was applied to hold the coils more compact together to clear the noise and filter capacitor was also connected to the output.

### ***Inverter Test Result***

The inverter constructed was tested to ascertain the functionality of the units designed; including overload, full charging, low charging, and automatic changeover. The result of the inverter test is tabulated in Table 1.

**Table 1:** Inverter Test Result

Test	Results
Overload circuit	The inverter trips off when the applied load exceeds 1500VA.
Transformer	27V AC was obtained at the secondary after the stepped down process.
Battery full and low battery cut-off Circuit	The battery is fully charge at 13.4V DC and it cut-off the oscillating circuit once the battery voltage is 10Vdc.
Automatic Changeover	A smaller transformer was used to energize and control the operation of the relays, which switched from the inverting mode to charging mode.
Inverting Circuit test	12Vdc passed through the oscillator, which converted to an AC voltage
Surge Circuit	The inverter shutdown when the AC mains is more than 250V AC

### Battery Life Capacity Test

The negative and positive wires were connected to the battery terminals and the inverter switched ON, the output socket were loaded with some appliances and bulbs, the duration at which the inverter discharges under load condition depends on the total power of load connected to its

output terminal and the current rating of the battery connected to its input terminal. Bearing in mind that total load must not exceed 1500VA. For a 1400watt inverter using a 24V battery, 400Ampere hour to operate at maximum Load. Table 2 shows the result of the battery life capacity and this is graphically in Figure 7.

**Table 2:** Battery life capacity

Load	Time duration
350Watt	27 hours 43 minutes.
700Watt	14 hours 18 minutes.
1050watt	9 hours 14 minutes.
1400watt	7 hours 43 minutes.

### DISCUSSION OF THE INVERTER TEST RESULT

From Table 2, as the load goes above the 1500VA and the battery voltage goes below 12V DC the overload protecting circuit shutdown the system in order to prevent the inverter from being overloaded as well as increases the life span of the

battery, a smaller transformer was used to energize and control the operation of the relays, which was able to switch from the inverting mode to charging mode with battery monitoring cut-off voltage of 13.6 V and a surge protection voltage above 250V.

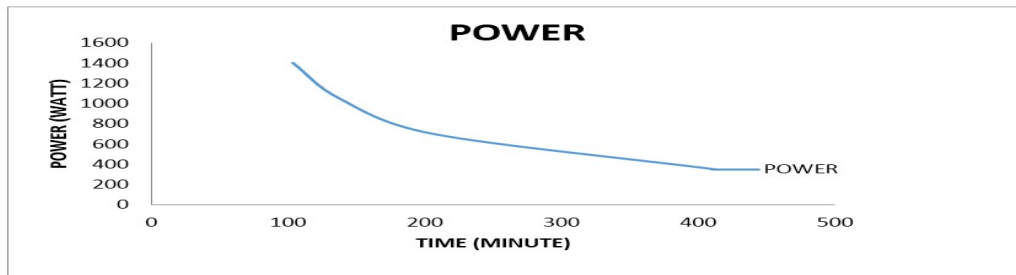


Figure 7: Graph showing the Relationship between Power and Time

### Discussion of Battery life Capacity Result

From Table 1 and graph in Figure 7. The load determines the working hours of the system, at applied load of 350watt the inverter backup for 27hours 43minutes, at applied load of 700watt the inverter backup for 14hours 18minutes, at applied load of 1050watt the inverter backup for 9hours 14minutes, while at maximum load and on battery fully charge, the operation time of the inverter will not exceed 7hour 43 minutes because of the current rating of the

battery. At a lower loading, the battery will last longer or another battery can be connected in parallel to increase amperes hour of the battery and the duration of the supply.

### CONCLUSION

This work was designed and constructed to provide an alternative means of power supply for domestic and commercial use. In addition, it aimed to provide solution to the erratic nature of



power supply in this country. This inverter can supply power to most household appliances for a period of time that is directly proportional to the ampere-hour rating of the battery. Finally, to achieve a longer time of power supply, battery banks and wider solar modules are recommended.

## REFERENCES

- Abubakar, I. N., Jacob, T., & Mustapha, B. M. (2017). Enhancement of Electrical Energy Transaction through the Development of a Prepaid Energy Meter using GSM Technology. *International Journal of Research Studies in Electrical and Electronics Engineering (IJRSEEE)*, 3(4), 10-18. DOI:- <http://dx.doi.org/10.20431/2454-9436.0304003>.
- Abu-Rub, H., Holtz, J., Rodriguez, J., and Ge, B. (2010). Medium-voltage multilevel converters – state of the art, challenges, and requirements in industrial applications. *IEEE Transactions on Industrial Electronics*, 57 (8), 2581–2596.
- Al-Salaymeh A., Al-Hamamre Z., & Abdelkader M.R.S. (2001). Technical and economical assessment of the utilization system in residential buildings: the case of Jogdan. *Energy conversion and management*, 51 (8), 1719-1726
- Bayar T. (2013). *Germany Must Manage Growth and Costs of Renewable Power*, IEA says Renewable Energy World. Com. Retrieved from <http://www.renewableenergyworld.com/rea/news/article/2013/05/8>
- Cherp, A., & Jewell, J. (2013). Energy security assessment framework and three case studies. *International Handbook of Energy Security*, 4, 146-173.
- Lai, J.-S. and Peng, F.Z. (1995). Multilevel converters-a new breed of power converters. Thirtieth IAS Annual Meeting, IAS'95, 2348–2356.
- Marquardt, R. (2010). Modular multilevel converter: A universal concept for HVDC-networks and extended dc-bus-applications. *International Power Electronics Conference*, 8, 502–507.
- Nur F.M., Chanuri C., Nurul I. R., Abadal-Salam T. H. & Ahmad M. O. (2016). Inverter Designs. *International Journal of Computing, Communications and Instrumentation Engineering (IJCCIE)* 3, 4, 2349-1469.
- Nwofe P.A. (2014). Utilization of solar and biomass energy- a panacea to energy sustainability in a developing economy. *International Journal of Energy and Environmental Research*, 2, (3), 10-19.
- Oseni, M.O., (2012). Improving households 'access to electricity and energy consumption pattern in Nigeria: Renewable energy alternative. *Renewable and Sustainable Energy Reviews*, 16, 39-67.
- Wang, C. and Li, Y. (2009). A survey on topologies of multilevel converters and study of two novel topologies. *IEEE 6th International Power Electronics and Motion Control Conference, IPEMC'09*, 2, 860–865.
- Zhang, F., Yang, S., Peng, F. Z., and Qian, Z. (2008). A zigzag cascaded multilevel inverter topology with self-voltage balancing. *Twenty-Third Annual IEEE Applied Power Electronics Conference and Exposition*, 1, (7), 1632–1635.