FUNAI Journal of Science & Technology,
2(1), 2016, 85-102

DESIGN AND IMPLEMENTATION OF OFF-GRID SOLAR INVERTER FOR RESIDENTIAL APPLICATION

O.D.Oyedum[1],*A.L.Onyechekwa[2], B.M. Olomiyesan[3] and J.A.Ezenwora[4]
[1,2,4]Physics Department, Federal University of Technology, Minna,Niger State, Nigeria.
[3]Examination Development Department, National Examinations Council (NECO), Minna, Niger State, Nigeria.

(Received 14 May, 2016; Revised 3 August 2016; Accepted:11 August, 2016)

Abstract

Renewable energy sources have been identified as a potential solution to shortage in power generation especially in the developing countries of the world. The desire for alternative and clean energy has induced a rapid growth in the number of solar power buildings across the globe. Photovoltaic module generates direct current which cannot be used directly by many home appliances, so there is need for an inverter. This study presents the design and implementation of 500 VA solar inverter to aid provision of home electricity need through solar energy, especially in rural areas where access to the national grid is not available. The oscillator circuit of the inverter consists of a SG3524 integrated circuit and two NPN transistor drivers powered directly by a 12V battery through a switch. The actual construction was done on a veroboard and enclosed in a metal casing. The testing of the solar inverter system was carried out in the month of July, using a tilted solar module. The result of the study shows that the inverter functions efficiently with 12V deep cycle battery with threshold capacity rating of 62 AH which can sustain steady output of 220-240 V to external load for more than four hours.

Keywords: *Solar panel, inverter, oscillator, circuit, current and voltage*

*Corresponding author's e-mail: dejioje@yahoo.com

1. Introduction

The lack of electricity in many communities, especially in the developing countries of the world is a source of great concern. The source of the problem varies from shortage in power generation to limited grid expansion.

Almost 33% of the world's populations live without usable electrical power (Osama and Egon, 2007).In Nigeria, electricity supply exceeds demand all the time, hence many rural communities remain without access to the national grid while those connected experience epileptic power supply. The fact that the recent past has been at an all time low with regard to power supply in Nigeria cannot be overemphasized. Government effort to revive the power sector with more funds has not been successful. Many businesses are completely or virtually grounded due to the epileptic nature of power supply. Homes and corporate organisations in Nigeria now, more than ever before, largely depend on generators to provide electricity, and the cost to the economy is very huge and growing. For instance, 70% of all generators and spares made in the United Kingdom end up in Nigeria (Okechukwu, 2008). The desire for alternative and clean energy has induced a rapid growth in the number of solar power buildings across the globe. The environmental impact of electricity generation, particularly the greenhouse effect is also another important reason for exploring photovoltaics as alternative source of electricity. Present evidence suggests that "effective" CO_2 levels will double by 2030, causing global warming of 1-4°C (Honsberg and Browden, 2009). The photovoltaic module is the generator required for the conversion of solar energy to electrical energy. PV module generates direct current which cannot be used directly by many home appliances, so there is need for an inverter which is an electrical device that converts direct current (DC) to alternating current (AC); the converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching and control circuits. Solar inverter is the major electronic component that is required in solar power system. As a tropical country, Nigeria is blessed with abundant sunshine all year round; solar energy can be properly harnessed to meet the ever growing demand for good and efficient power supply. Hence, this work aims at designing an inverter to:

i. aid provision of home electricity need through solar energy, especially in rural areas where access to the national grid is not available; and
ii. serve as a backup power system in homes, especially when there is power outage.

2. Materials and Methods

2.1 The inverter circuit design and implementation

The functional diagram in Fig. 1 below illustrates the units that are involved in the design and implementation of the solar charging inverter, while Fig. 2 shows the comprehensive circuit diagram of the inverter.

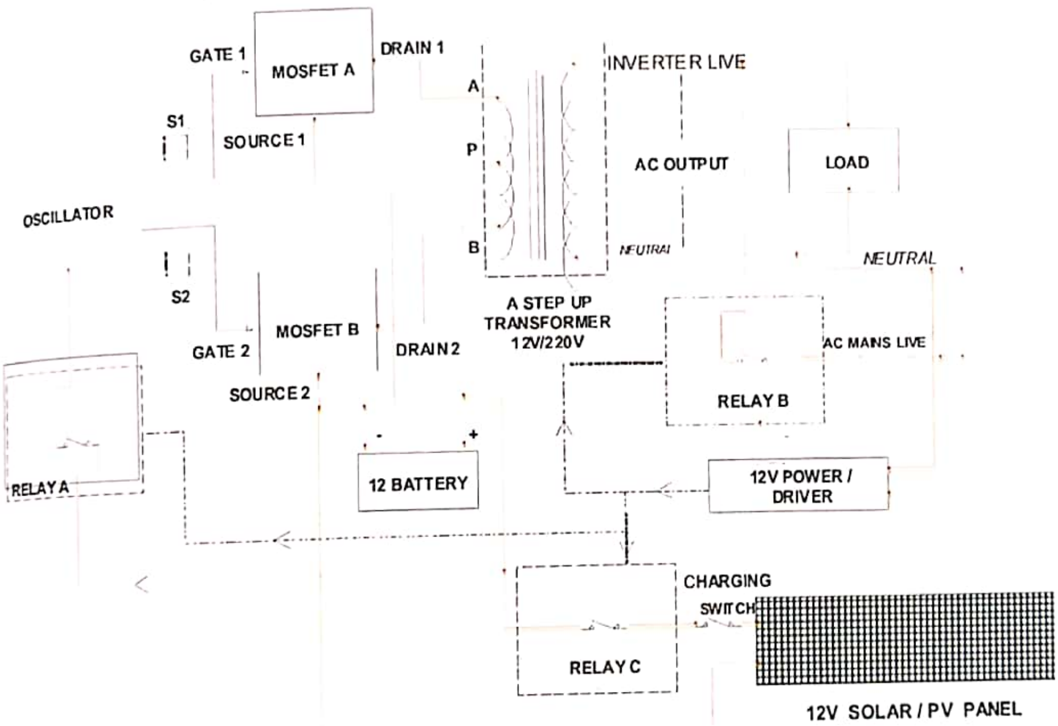

Fig. 1: The functional diagram of the inverter

The units are listed as follows:

(I) Oscillator, MOSFET A/B (ii) Step-up transformer (iii) Relay circuit A, B and C, (iv) 12 V power supply/driver (v) 12 V solar/ PV panel (vi) 12 V battery (vii) Load

2.2. The load

The inverter is rated at 500 VA. The power factor of Watt to VA for inverters is approximately 0.7 (Schwartz, 2003). Therefore, the power output is obtained as 500 VA × 0.7 = 350 W.

Considering AC voltage of 220 V, the current expected to flow through the load is obtained as 1.6 A by using equation 1. This current value is of great importance in the design and construction processes.

$$(I) = \frac{Power}{Voltage} \quad (1)$$

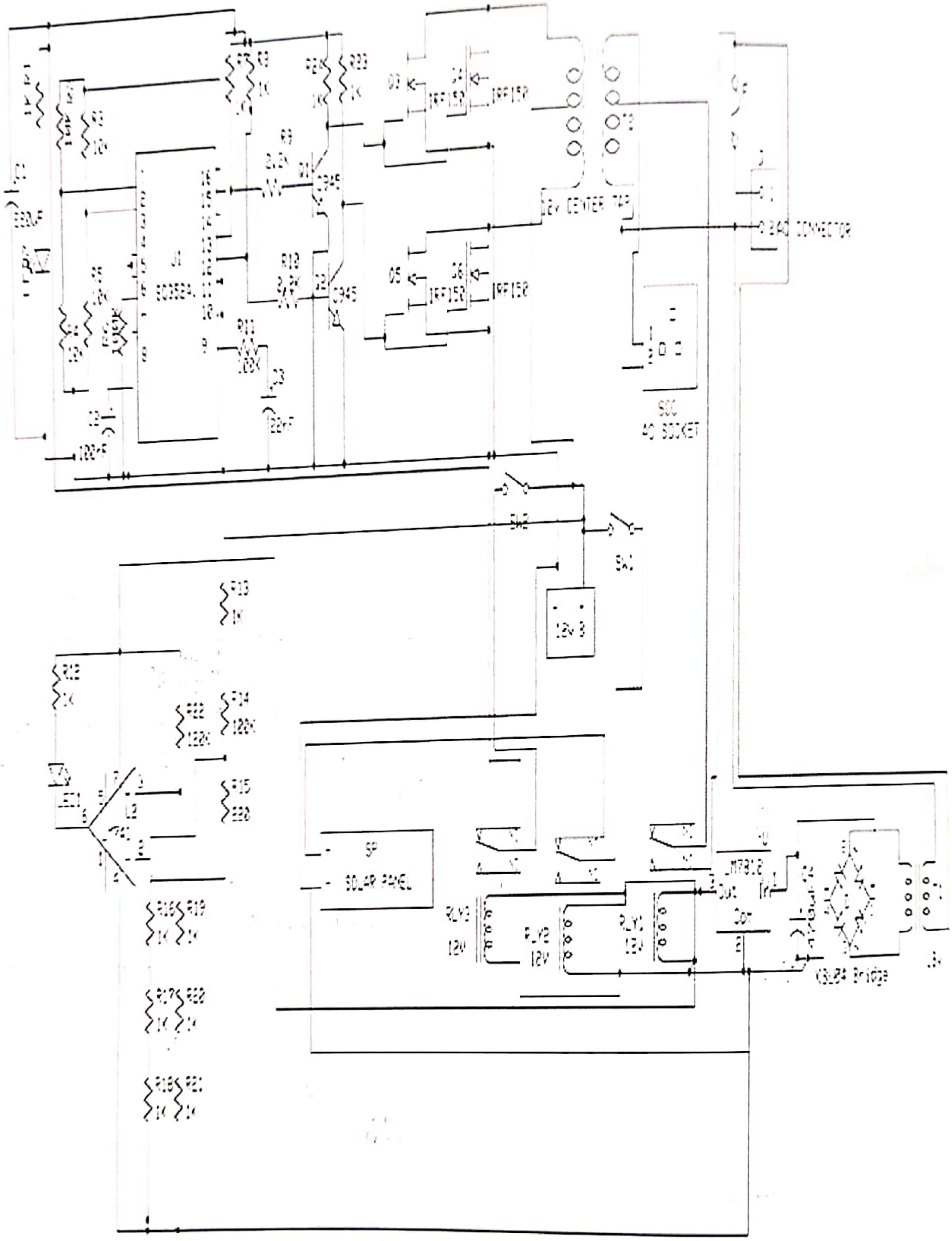

Fig. 1: The functional diagram of the inverter

2.3. The step-up transformer

The step-up transformer is specially designed for the project. It is slightly rated above 500 VA to withstand power surge and the primary coil is powered by a 12 V battery source. Moreover, the secondary coil is designed with respect to the maximum current (1.6 A) expected to flow through the load. The two coils are usually constructed with a ratio that is determined by the intended voltages across them using the mathematical relationship between the two coils of a step-up transformer given as:

$$\frac{V_P}{V_S} = \frac{I_S}{I_P} = \frac{N_P}{N_S} \quad (2)$$

where;

V_P = Voltage across the primary coil = 12 V,

V_S = Voltage across the secondary coil = 220 V,

I_S = Current across the secondary coil = 1.6 A,

I_P =Current across the primary coil,

N_S = Number of turns of the secondary coil and;

N_P = number of turns of the primary coil.

Using the above equation, the current across the primary coil was calculated to be 29.32 A. Conventionally, the primary turns of low power inverter is usually 30; hence the number of turns in the secondary coil was determined as 550 turns.

2.4. The oscillator

The oscillator circuit consists of a SG3524 integrated circuit and two NPN transistor drivers as shown in Fig. 2. The circuit is directly powered by the 12 V battery through a switch (inverter switch). A LED power indicator shows the presence of current flow in the circuit. The LED used is rated 2.3 V 10 mA with a resistance of 1000 Ω as obtained from Kirchoff's law.This oscillator circuit was constructed using specification from the manufacturer's datasheet as shown in Fig. 3.

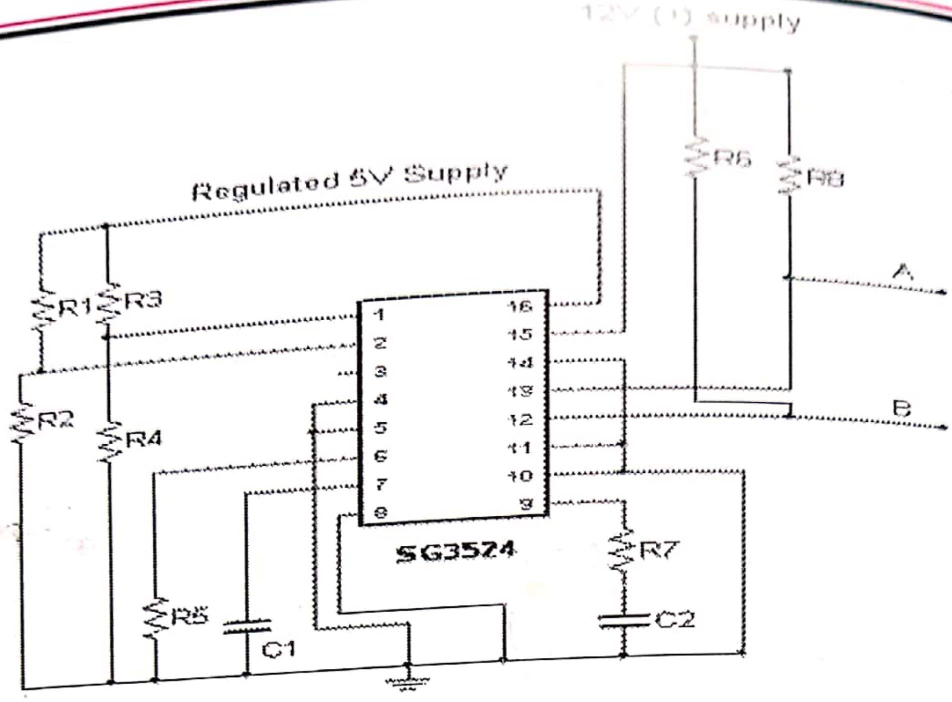

Fig. 3: The SG3524 circuit

Pins 1 and 2 are adjusted to similar voltage of 2.5 V. R_1, R_2, R_3 and R_4 are rated 10 kΩ each. R_1/R_2 and R_3/R_4 form potential dividers that apply regulated 2.5 V to both pins 1 and 2. Pin 3 is not connected. Pins 4 and 5 are grounded. R_5 and C_1 determine the operating frequency of the oscillator. The design frequency is 50 Hz (for normal AC mains of 220-240 V). Choosing C_1 to be 0.1 μF and using eqn 3, R_5 is obtained as 236 kΩ (ST Microelectronics, 2000).

$$f = \frac{1.18}{R_5 C_1} \quad (3)$$

C_2 and R_7 are 0.001 μF and 10 kΩ, respectively (with reference to the datasheet of SG3524). Pins 12 and 13 (points A and B) are the outputs of the device. They were loaded with 1kΩ resistors (R_6 and R_8) because of their open collector nature. These outputs are associated with corresponding NPN transistor amplifiers/drivers. They are used for driving the MOSFET circuit.

2.5. MOSFET switching stage

This unit involves two circuits of two parallel IRFP150N MOSFETs each. This circuit is designed to switch the primary coil of the transformer to the ground. Therefore, it is designed to withstand the expected 29.32 A current flow in coil. An IRFP150N MOSFET has a maximum current rating of 42 A. Each pair of MOSFETS is connected to a common drain and a common source (i.e. in parallel) and is equivalent to one MOSFET with the drain current equal to the sum of the two drain currents. Therefore, the resultant maximum current rating of the two IRFP150N MOSFETs in parallel is 42 × 2 =84A.

2.6. The 12 V power supply

This unit was incorporated into the design to switch three electric relays in case any user is tempted to plug the solar inverter to the AC mains. Otherwise this circuit remains inactive when it is used as a stand-alone inverter in locations that are not connected to the national grid. The power relay circuit is shown in Fig. 4.

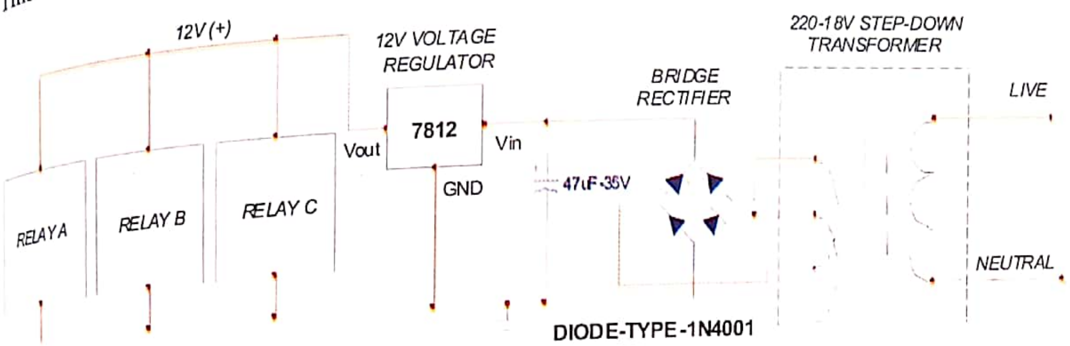

Fig. 4: The power circuit with three relays

2.7. Battery charging

The battery can be charged through the following:

- Normal AC mains
- Solar/PV panel

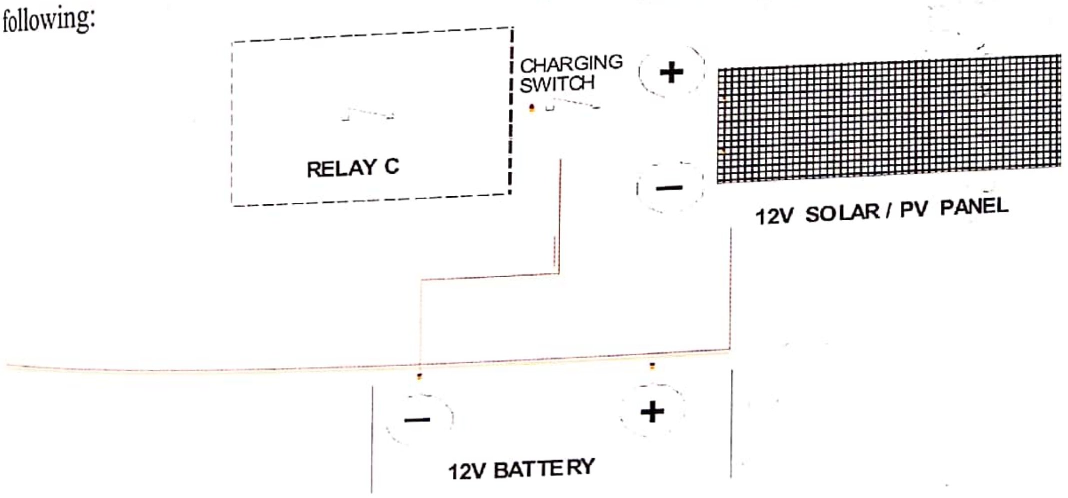

Fig. 5: The solar/PV battery charging circuit

2.8. Charging with AC mains

The most important facts about the process are that:

i. The transformer works in step-up mode (12 to 220 V) when the inverter is in use and step-down during charging (220-12 V).

ii. The body diodes of the power MOSETs act like single directional devices and form a center-tapped full-wave rectifier with the transformer.

ii. The charging current is about the design value for the primary coil (29.32 A).

2.9. Solar/PV charging

The circuit is controlled by a charging switch as shown in Fig. 5. Relay C opens the circuit whenever the battery is being charged through the AC mains, otherwise it is closed during solar/PV charging.

2.10. Battery level indicator circuit

A fully charged battery is indicated by the LED1 light turning ON otherwise it is OFF, indicating that the battery is not fully charged. Charges flow from area of potential to areas of low potential. This principle was used in connecting with the operational amplifier used in the circuit. Operational amplifiers can be used as comparators. The amplifier used is Lm741.

2.11. Circuit construction

This project involves practical implementation of the designed circuit as a working hardware. The first step involves verifying the workability of some parts and components of the circuit on the breadboard, using a temporary circuit connection. Subsequently, the actual construction was done on a veroboard. The required electronic components were carefully connected and joined together (using a soldering lead) according to the circuit diagram. The breakdown of the complete circuit during the design analysis was of great importance in the construction, as each circuit unit was implemented one after the other. Thereafter, all the units were joined together as a single working circuit. All joints were held in position with a soldering lead. The power supply unit was particularly handled with great care in order to avoid damage to some components like the MOSFETs. After the construction, the power units were properly checked for short circuit and unwanted bridges.

2.12. Casing construction

Metal casing of gauge 16 was chosen. The metal was bent into shape and size suitable to accommodate the circuit. The casing is also perforated linearly in order to allow ventilation and improve the heat sink. Fig. 6 below shows a diagrammatic sketch of the inverter casing.

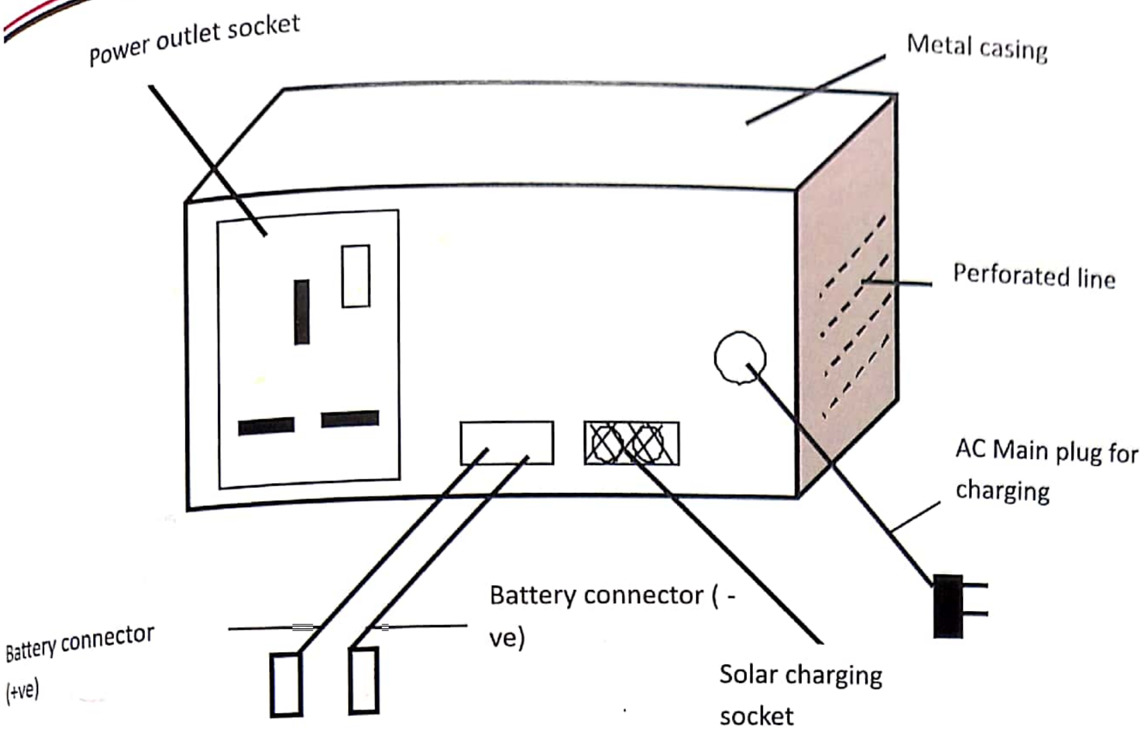

Fig. 6: Casing of the inverter

2.13. Testing

Testing the solar inverter system was carried out with adequate precautions. This test was carried out in the month of July, 2011 using a suspended panel on top of a roof. The module tilt angle was 9° (Minna has coordinates 9°37′ N, 6°30′ E). Tilted modules perform better by 47% than the flat module (Olopade and Sanusi, 2008). The following steps were taken to connect different units of the system (as shown in Plate I below).

i. The inverter and the solar panel switches were put off to break the circuit.

ii. The red cable from the solar inverter system was firmly connected to the positive terminal of the battery and the black was also connected to the negative terminal.

iii. The next step was the connection of solar panel. The red cable of the solar charging input was connected to the positive terminal of the panel while the corresponding black cable was connected to the negative terminal of the panel and the panel was exposed to sunlight.

It was observed that the battery was being charged by the solar panel and was monitored between 9:30am and 3:30pm.

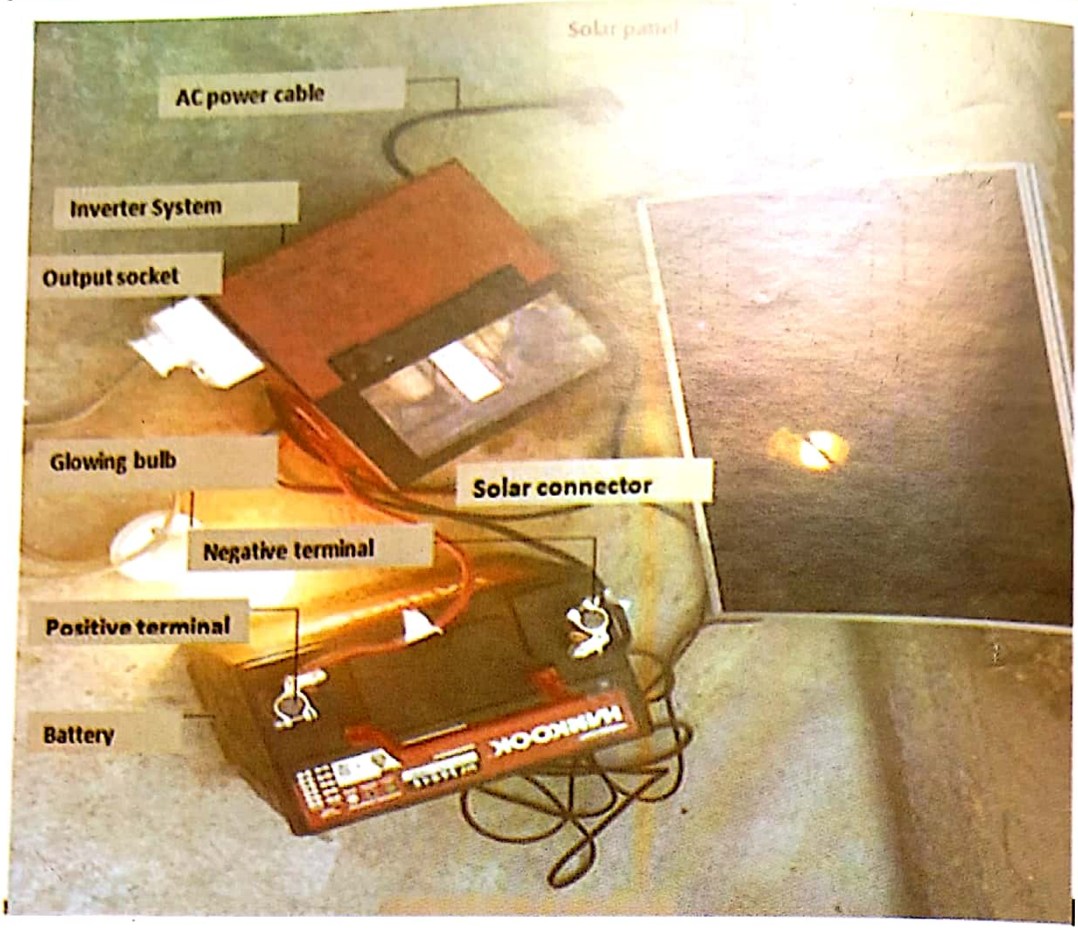

Plate I: The overall construction layout

Figure 7 shows the block diagram of performance measurement layout of the inverter. Measurement of current and voltage were done with the multimeter placed in series and parallel respectively for each case.

i. Testing Load on the system: The output socket of the inverter was first switched off. The solar charger switch was also switched off (to avoid damaging the solar panel) and the inverter switch was turned on which was confirmed by the LED indicator. A 60 W bulb (representing a load less than 350 W) was connected and the output socket was switched on. It was observed that the system powered it with full brightness.

ii. The performance of the inverter was further tested using three separate batteries of 12 volts 55 AH, 12 volts 63 AH and 12 volts 75 AH as storage media. Input/output voltages as well as input/output currents were measured under different circuit conditions using a multimeter.

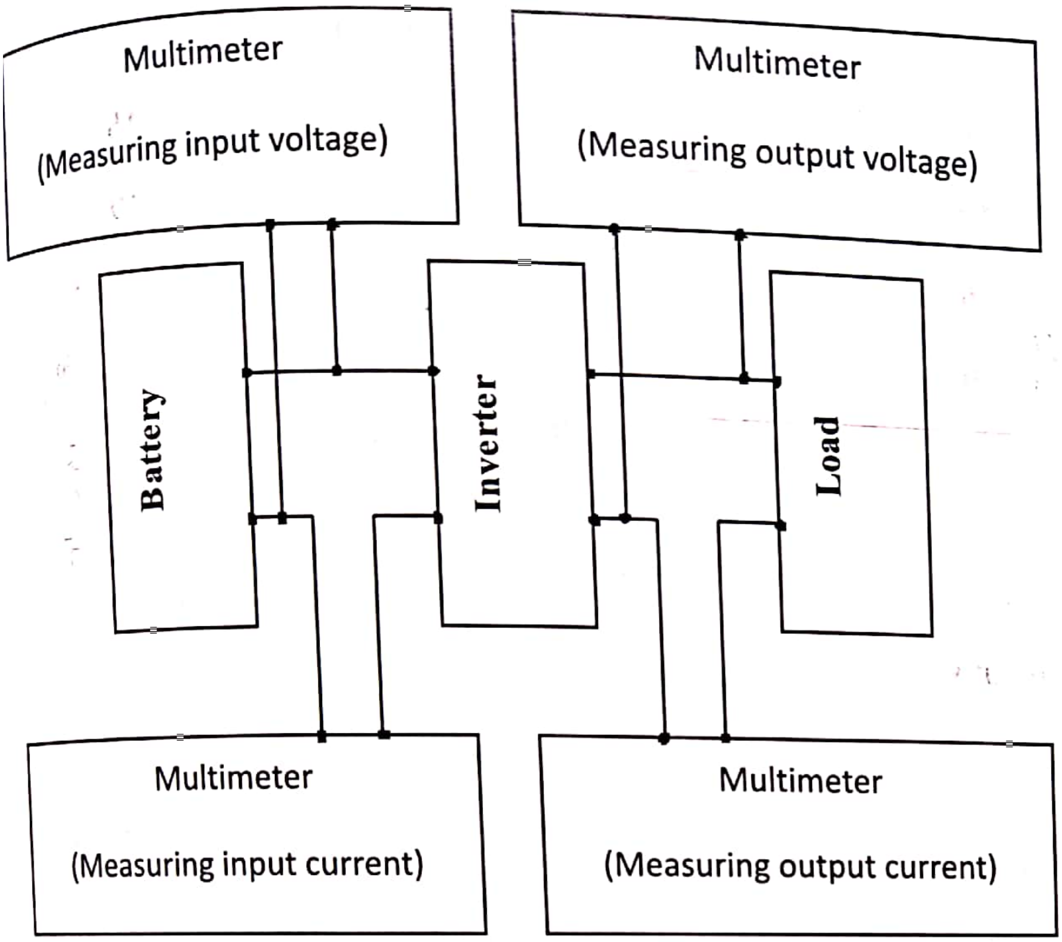

Fig. 7: Block diagram oflayout for performance measurement

The observed wave output is a modified sine wave.

3. Results and Discussion

Results of the performance test are shown in Figs 8-15 for the cases of 12 volts feed batteries of 55 and 62 AH. All the vertical primary axes in Figs 11-12 represent the effect of the 100 W load when connected to the output of the inverter while the secondary vertical axes represent the effect when a load of 60 W was connected.

3.1. Input and output voltage and current for different loads using 12 volts 55 AH battery

Figures 8 and 9 illustrate the results obtained for different input voltage and current using a 55 AH battery. The measurements were made for about 60 minutes. Input voltage here implies inverter input relative to the battery.

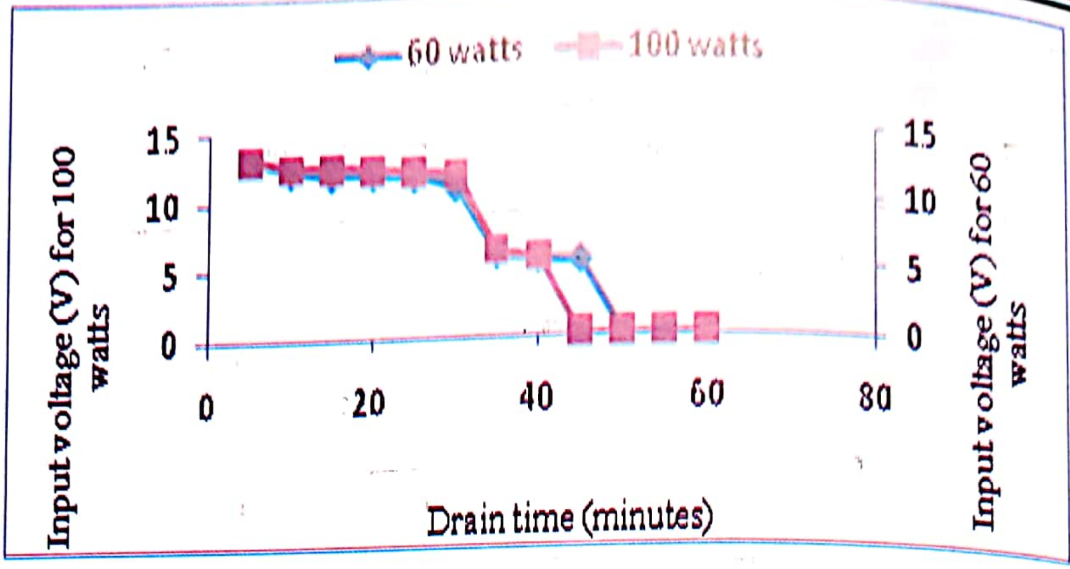

Fig. 8: Input voltage using 12 volts, 55 AH battery with 60 W and 100 W loads.

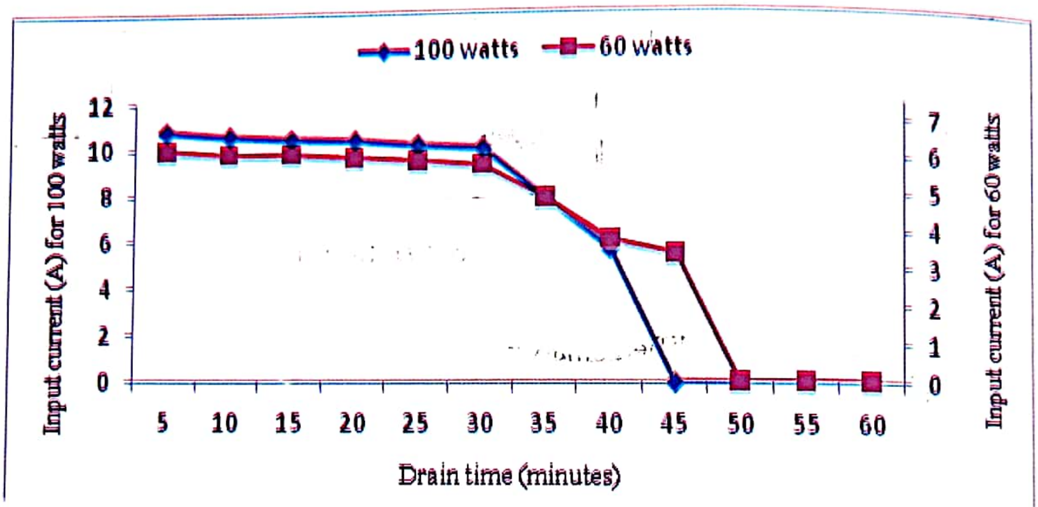

Fig. 9: Input current using 12 volts, 55 AH battery with 60 W and 100 W loads.

Figure 8 shows that the input voltage dropped from an initial voltage of 13.1 volts to 5.5 and 5.7 volts in about 40 minutes when a load of 60 and 100 watt, respectively were connected to the inverter output. Thereafter, the battery was completely drained at about 45 and 50 minutes for the 100 and 60 watt load respectively.The same trend was observed for the corresponding input current measured using the same loads and battery as shown in Figure 9. The results show that the battery could not withstand the load for more than 40 and 50 minutes respectively for the 60 watt and 100 watt load. Also, the battery could not withstand a constant drain of about 6 A (under 60 W load) or 10 A (under 100 W load) for more than 30 minutes and was completely drained in less than 50 minutes. Fig. 10 and 11 present the results obtained for an output voltage and current using a battery of 55 AH measurement made for about 60 minutes.

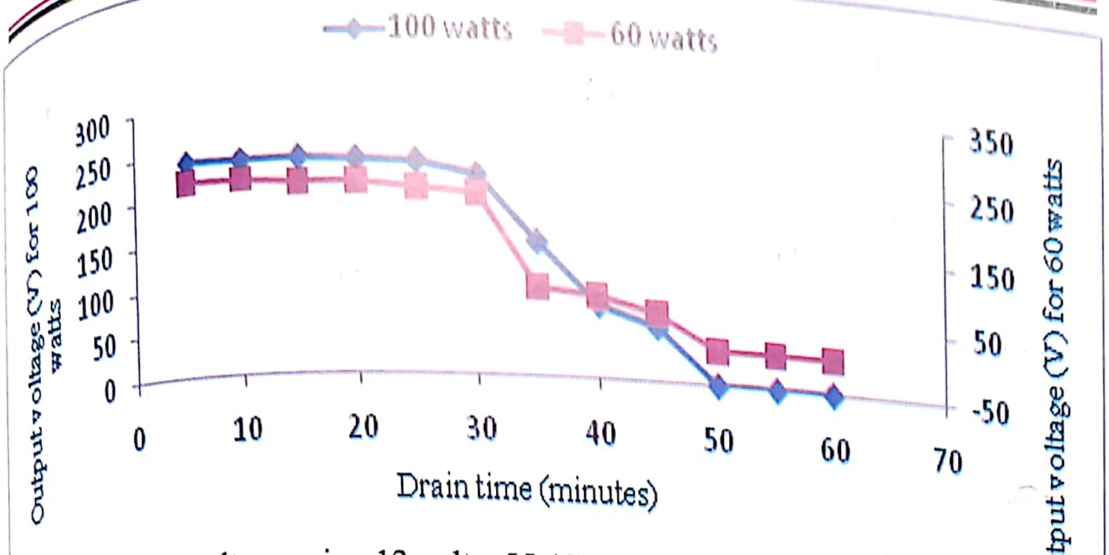

Fig. 10: Output voltage using 12 volts, 55 AH battery with 60 W and 100 W loads.

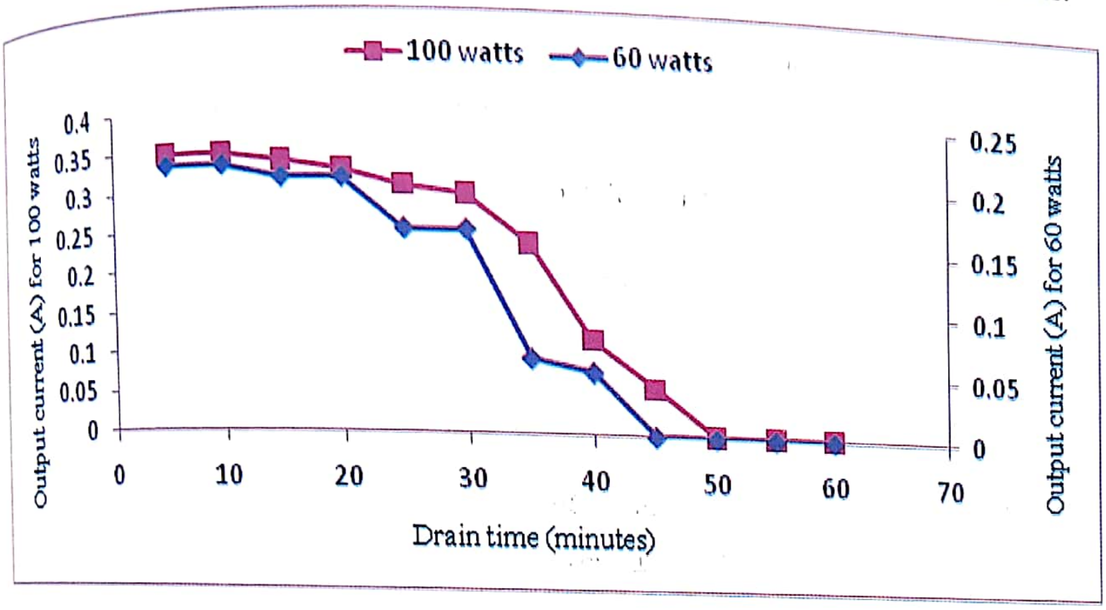

Fig. 11: Output current using 12 volts, 55 AH battery with 60 W and 100 W loads.

Figure 10 shows that the output voltage remained steady relatively between 240-220 volts and 240-215 volts until about 30 minutes for the loads of 60W and 100 W bulbs. From section 2.1.1, the design prediction shows that the output current must be in the order of 1.6 A or less at 220 V for the inverter to work efficiently. This was achieved in the first 30 and 40 minutes for the 60 and 100 watts load as shown in Fig 11. It then experienced a sharp drop in voltage from 220 volts to zero volts in about 50 minutes as shown in Fig 10. The same was also observed for the output current where the battery was completely drained of its charges in less than 50 minutes.

3.2 Input Voltage and current for different loads using 12 Volts 62AH battery

When driven by the 12 volts 62 AH battery the system sustained both 60 watt and 100 watt loads for more than one hour with input voltage to the inverter remaining almost steady at 12 volts and the inverter output voltage steady between 220-240 volts as shown in Figs. 12 and 13.

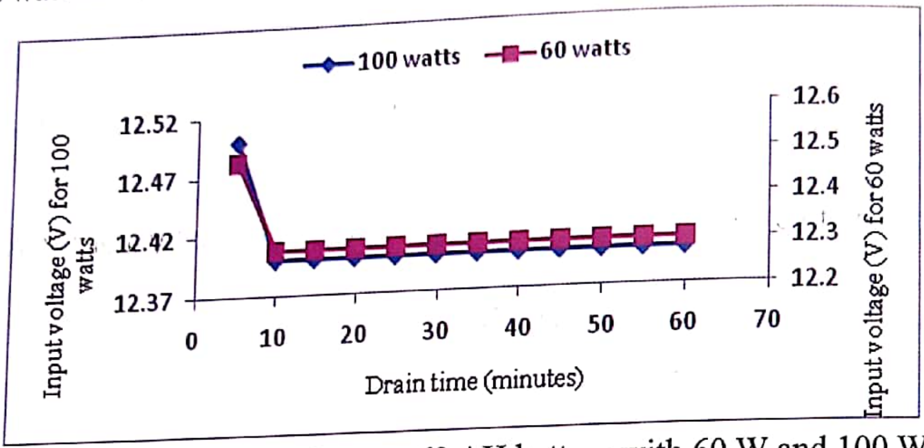

Fig. 12: Input voltage using 12 volts, 62 AH battery with 60 W and 100 W loads.

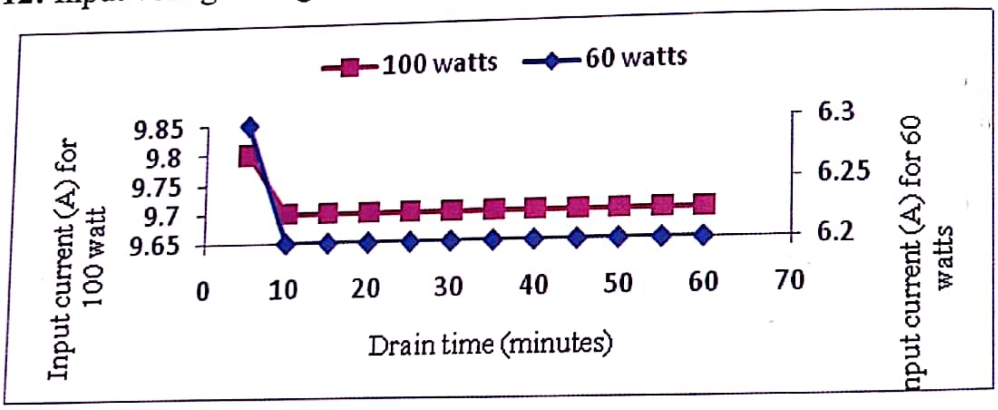

Fig. 13: Input current using 12 volts 62 AH battery with 60 W and 100 W loads.

Figure 13 shows that a steady current of about 6.2 A and 9.7 A was drawn from the 62 AH battery by the inverter for more than 1 hour when 60 watt and 100 watt loads were respectively connected. An input voltage of about 12.4 volts was maintained for both load conditions in the stated time duration. The results obtained for the output voltage and current when the system is driven by 62 AH battery are shown in Fig. 14 and 15.

From Fig. 14, it can be seen that although there was an initial fluctuation in output voltage using the 60 watts and 100 watts loads, the output voltage remained steady between 215 volts to 225 volts for more than 1 hour. Here the output current depends on the amount of load connected to the inverter, varying between 0.19 A and 0.24 A for the60 W load and more or less steady at 0.35 A for the 100 W load, as shown in Fig 15. By implication, if a larger load is connected, the system would require a larger battery bank to support the large amount of current drawn from the battery for the same period of time. These results show that there seems to be a threshold battery capacity for given load conditions. Thus, for the 55 AH battery, it was observed that:

i. The output voltage of 220 V delivered could not be sustained for loads exceeding 60 watts for a period of time more than 30 minutes, as shown in Figure 10.

ii. The brightness of the 60 W and 100 W bulbs became dim after 30 minutes.

iii. Between 30 and 40 minutes (Figure 8) input voltage of the inverter relative to the battery had dropped to less than 6 volts.

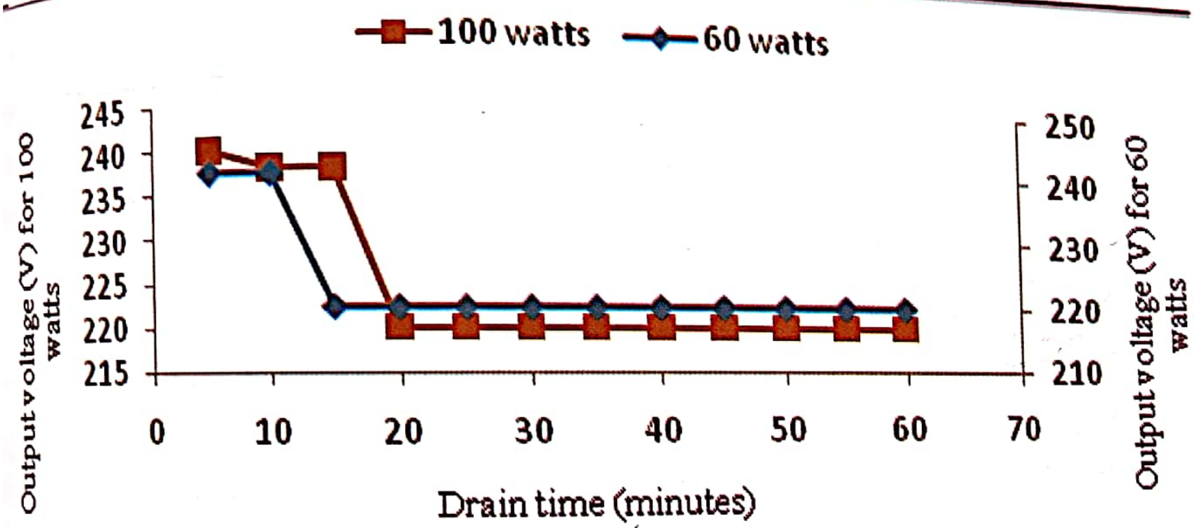

Fig. 14: Output voltage using 12 volts, 62 AH battery with 60 W and 100 W load.

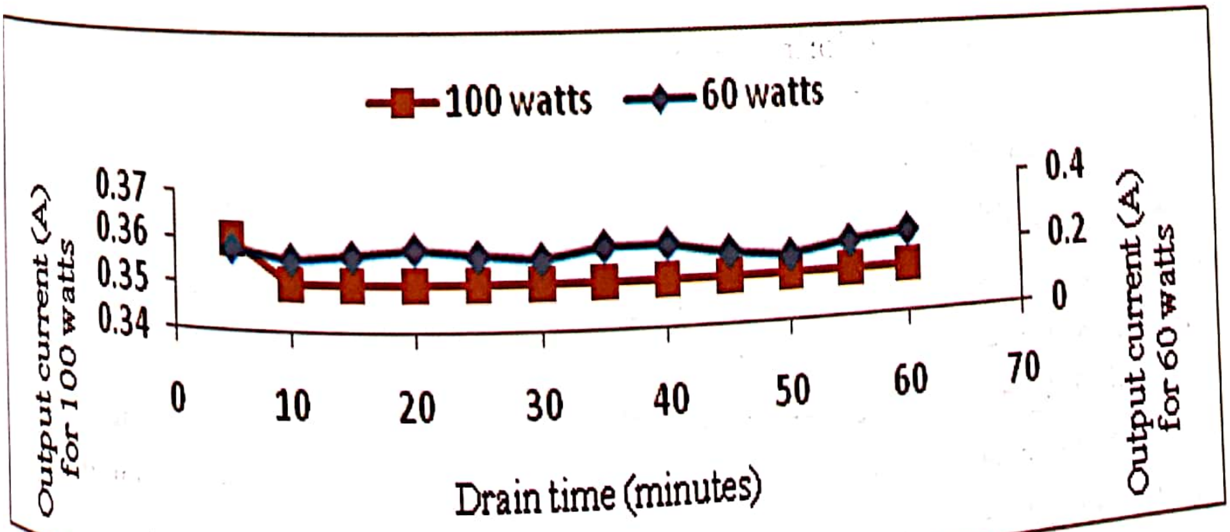

Fig. 15: Output current using 12 volts, 62 AH battery with 60 W and 100 W load

Roughly, it is estimated that for every 100 watts of the inverter load at 220-240 V, the inverter draws about 10 A at 12 V (DC) from the battery (Rigoli, 2011). From Fig 9, between 30 and 40 minutes, the input current had dropped to 5.7A which is far below the 10 A expected for a 100-watt load. A better trend was observed in Figs 14 and 15 where a constant voltage of about 12 V was delivered by the battery for more than 1 hour. Hence, 62 AH battery seems to be a threshold battery capacity for a load of 60 watts and above, as observed in the research work. Oyedum, Ugwuoke, Olomiyesan and Ibrahim (2014), investigated the use of poly-crystalline module for the design of photovoltaic systems in Minna and found that it suitable for use in Minna and its environment. Thus, poly-crystalline was used to charge the inverter. For the solar panel, an approximate average daily insolation of 700 Wm^{-2} for Ilorin was used (Olopade and Sanusi,2008). Ilorin (8.32^{0}N, 4.34^{0}E) has almost the same kind of weather condition as Minna. The Mitsubishi Electric solar panel of rate 110W, 12V has a DC current output of 6.43A in bright sunshine condition of about 1000Wm^{-2} solar irradiance, and the expected output is given as (Mitsubishi, 2010):

$$Expected\ output\ current = \left[\frac{700Wm^{-2}}{1000Wm^{-2}}\right] x$$

$$6.43A = 4.5A.$$

The measured current is 3.4A when a load of 100W was connected. If up to 10A current at 12V is desired in order to power the 100W load, according to Rigoli (2011), connecting four 110W Mitsubishi solar panels in parallel must be implemented. This gives 13.6A which is sufficient to drive the load and also charge the battery. The 3.4A was the measured charging current and was observed in rainy season month of July, when solar radiation is generally low in Minna due to high cloud cover. This output power obtained is relatively sufficient to power basic household devices such as:

i. Low power ceiling and standing fans with power rating ranging from 40-100 watts,
ii. TV and radio sets with power rating usually about 90 W,

The clipper used in some barbing salons with power in the range indicated in (I) above.

4. Conclusion

A DC-AC inverter system that uses solar rechargeable battery has been designed, implemented and characterised. It functions efficiently with deep cycle 12 volts battery with threshold capacity rating of 62 AH. This can sustain steady output of 220-240 volts to external load for more than 4 hours of steady use. The duration depends on the wattage of the load. It requires large diameter cables for input link to the inverter in order to withstand the large current drawn by the inverter when a load is connected to the output. For efficient solar energy conversion, a sealed deep cycle battery is recommended. MOSFETs of uniform specifications and power ratings were also used to implement the inverter circuit. The overall system design is a compact assembly that can take the place of electric generators currently used in most households by providing an environmental friendly back-up power to compensate for frequent power outages. Although the initial cost may be high for low income people, the long-term cost-effectiveness and benefits far more outweighs this disadvantage. The performance of the device is expected to improve in dry season when solar radiation is maximum in Minna.

References

Data Sheet Catalogue, (2000). Regulating Pulse Width Modulators. Available at: *http://www.Datasheetcatalog.Org/Datasheet/Stmicroelectronics/1431.Pdf*(Accessed on 15th October, 2009).

Honsberg, C. and Browden, S. (2009). Correlation of the Rise in Atmospheric Carbon-dioxide Concentration with the Rise in Average Temperature. Available at:http://pvcdrom.pveducation.org/INTRO/GREENHSE.HTM (Accessed on 6th October, 2010).Mitsubushi, (2010).Solar module specification. Mistsubuishi Electric solar panel.

Okechukwu, P.N. (2008). The Economic Cost of Blackouts. Available at:*http://www.nigeriavillagesquare.com/articles/okechukwu-peter-nwobu/the economic-cost-of-blackouts-2.html* (Accessed on 9th January, 2011).

Olopade, M. A. and Sanusi, Y.K. (2008). Solar Radiation Characteristics and the Performance of Photovoltaic (PV) Modules in a Tropical Station. *Journal ofScience Research and Development,* (2008 / 2009)11: 100-109.

Osama, O., and Egon, O. A. (2007). An Online Control Stretagy for DC Coupled HybridPower System. IEEE Power Engineering Society General Meeting, 1-8.

Oyedum, O.D., Ugwuoke, P. E., Olomiyesan, B.M. and Ibrahim, A.G. (2014). Performance Evaluation of Polycrystalline Silicon Module under Outdoor Conditions in North Central, Nigeria. *Nigeria Journal of Physics*, Special Edition, 37-42.

Rigoli, V. (2011). Fridge and Solar. Available at: *http://www.fridge-and-solar.net/amps.htm* [Accessed on 9th August, 2011].

STMicroelectronics,(2000). Regulating pulse width modulators. Available from:*http://www.datasheetcatalog.org/daasheet/stmicroelectronics/1431.pdf*(Accessed on 5th August, 2011).

Schwartz, J. (2003). Chasing the Elusive Power Factor. Available from: *http://investmentwatchblog.com/chasing-the-elusive-power-factor/* [Accessed on 12th April, 2010].