WWW.IJRPR.COM

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Design, Construction and Implementation of 1KVA Inverter

***Adewumi Hope Kofoworola*[1], *Awodele Mojoyinola Kofoworola*[1] *Abiodun Ayodele Joshua*[2], *Ajiboye Joseph Olumide*[1], *Oyeshola Hakeem Olayinka**[1], *Dauda Basit Gbolahan*[1], *Olatunji Abdulateef Ayomide*[1], *Akintoyinbo Timileyin James*[1], *Agboola Abdul-Hakiim*[1], *Adedeji Kowiyu Omotayo*[1]**

[1] Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria

[2] Lead City University, Ibadan, Oyo State, Nigeria

***Email:** hooyeshola@lautech.edu.ng

DOI : https://doi.org/10.55248/gengpi.5.1124.3222

ABSTRACT

This inverter was designed and constructed to be powered with 12v battery. it converts the raw Direct Current (DC) solar power that is produced by the solar panels into Alternating Current (AC) power that comes out of the wall sockets outlet. It serves as noiseless back-up and reliable power supply to most appliances. It works effectively and produce direct current only when the battery was charged. It is a 1KVA modify sine wave inverter which means that load equal or above the power rating should for no reason be loaded to this device in order to avoid overload which can result system breakdown.

KEYWORDS: Design, Construction, Implementation, Inverter.

1.0 INTRODUCTION

Electricity plays a very important role in our daily activities especially in our technological and social economy growth [1,2]. Some countries remain underdeveloped due to their inability to provide uninterrupted power supply for the growth of their society [3-5]. It has been recorded in literature that the burning of natural resources for energy can create smoke, cause acid rain and pollute water and air [6-7]. Carbon dioxide (CO_2), a leading greenhouse gas is also produced in the case of burning fuels [8-10]. There is need to make use of the solar power which uses only the power of the sun as its fuel [11]. The energy from the sun is free and readily accessible in most part of the world [12]. It creates no harmful by product and contributes actively to the reduction of global warming[13]. Basically, solar power source makes it possible to provide a clean reliable and quality supply of alternative electricity free of surges or sags which could be found in the line voltage frequency (50Hz) [11,14]. This paper aims at creating a 1000walts power source which can be utilized as a regular power source for private individuals in the office or home. It involves the design and construction of a 1KVA hybrid solar PV (photovoltaic) system which involves a solar panel, battery and inverter. Furthermore, as a consumer is generating his or her own electricity, they also will benefit from a reduction in their electricity bills.

2.0 DESCRIPTION OF COMPONENTS USED

2.1 IRFP 250N MOSFET (power transistor):

This transistor is in charge of producing the power in the inverter. It does this by producing power and sending a signal to the transformer, which then raises the voltage to a level where the signal can support the inverter's required power. The transformer: there are two types of transformer used for the construction of the inverter, H bridge and push pull transformers are the two types of transformers utilized in the construction of the inverter; however, the H bridge type is thought to be the most dependable. The inverter's transformer was severely damaged; the coil gauges were 16 and 24 [15].

2.2 Light Emitting Diode (LED):

This inverter contains two LEDs for indication purposes. The first shows that the inverter is operating, and the second shows that the inverter is charging the battery. Both LEDs are positioned in the charging portion of the inverter [16,17].

2.3 The Relay:

The relay which has two parts, the normally connected part and the open load part is used in the inverter's charging section to cut off the battery's charging when it reaches its full charge. When the battery is charging, the relay remains in the normally connected part until it claps and moves to the open circuit part, which is when the battery stops charging[18].

2.4 Resistors and Capacitors:

There are a variety of types, sizes, and functions for resistors and capacitors. Capacitors are used to hold charges and filter signals, whereas resistors are used to impede signals travelling in a specific direction [19,20].

2.5 The Battery:

The battery is a two-terminal device that provides DC supply to the inverter section when the AC mains is not available. This DC is then converter into 220V AC supply and output at the inverter output socket [21].

It is pertinent to state that lead-acid batteries used in automobiles are very good for this purpose as they provide good quality power for a long duration and can be recharged once the power stored in them are consumed. The backup time provide by the inverter depends on the battery type and its current capacity [22].

2.6 The AC Mains Supply:

The AC input supplies a 220V AC, 50Hz from the public supply. This is connected to the charger circuit where it is rectified to DC voltage and through the relay switch to the output of the inverter to bypass the inverter when there is public electric power supply while the battery is charging [21].

2.7 The Oscillator:

This section uses a pulse width modulator PWM IC SG 3524 to generate the 50Hz frequency required to generate AC supply by the inverter [23]. The relationship between the frequency, resistance and capacitance has been given below as;

$$\text{Frequency, } F = \frac{1}{1.1 \times C_T R_T}$$

Where: C_T= Timer Capacitor

R_T= Fixed resistor

The battery supply is connected to the IC SG 3524 through the inverter ON/OFF switch. The flip-flop converts the incoming signal into signals with changing polarity such that in a two-signal with changing polarity, the first is positive while the seconds is negative and vice versa. This process is repeated 50times per seconds to give an alternating signal with 50Hz frequency at the output of SG3524. This alternating signal is known as “MOS Drive Signal”[21].

2.8 The AC Mains Sensor:

This inverter uses a 0 – 18V/1 Amp triggering transformer and a regulator to sense the AC mains supply. When the AC mains supply is available, this supply is given to the primary winding of the triggering transformer to give 18V AC supply at the secondary winding. It is then rectified by bridge rectifier and input to filter capacitors which covert the 18V supply to 12V DC supply. The 12V supply stays constant even when there is a change in the AC mains supply and the inverter is informed about the availability of the AC mains supply [21].

2.9 The Inverter Transformer:

The transformer used for this project has a center tapping which divides the primary into two equal section. This center-tapping is connected to the positive terminal of the battery. Two ends of the primary are connected to the negative terminal of the battery through switches S1 and S2. These switches S1 and S2 are turned ON/OFF alternatively to generate current in the primary coil. When the switch S1 is closed and S2 id opened, the current flows in the first part of the primary winding and the EMF is induced in the secondary winding. When the switch S2 is closed and S1 is opened, the current flows in the second part of the primary winding and the EMF of opposite polarity is induced in the secondary winding. Thus, if the switches S1 and S2 are alternatively opened and closed at constant rate, then the output from the secondary winding is a square wave of the frequency at which the switches S1 and S2 are opened and closed. The transformer is said to be connected in “push-pull-mode” [21, 24].

2.10 The Battery Charger:

When the inverter section receives AC mains supply, it stops operation but the charger section in the inverter starts its operation. In this mode, the inverter transformer works as a step down transformer and output 12V at its secondary winding. During the charging, MOSFET transistors at the output section works as rectifier with the drain working as the cathode while the source S receives negative supply from the battery [23]. The center-tapping is connected to the positive supply and the positive terminal of the battery and the MOSFET source S is connected to the negative terminal with a shunt resistance. Thus, when the inverter receives AC mains supply, inverter transformer and MOSFET together work as a charger and charge the battery [21, 23, 25].

2.11 The Change Over:

This section is used to switch ON the inverter when the AC mains supply is OFF and to switch OFF the inverter when the AC mains supply returns (ON). During changeover, when the inverter receives AC mains supply, it stops drawing the battery supply and the AC mains supply at the inverter input is directly sent to the inverter output socket. This is done using a once, two-pole relay [26].

2.12 Inverter Ac Output:

The AC output gives a 220V AC, 50Hz either directly from the input when the AC mains supply is available or from the inverter circuit action on the battery when the AC mains supply is not available [27]. Computers and other household appliances are connected to this output.

2.13 Protections:

The AC input to this device was fused with a 5Amp fuse to protect the transformer as well as the rectifying circuit in case of over voltage, and high current which could flow into the transformer [27].

2.14 Indicators:

Three indicators are connected to the front of the inverter; a Red colour shows that the inverter is charging as well as delivering a 220V AC from its output terminal and Green colour indicates that the inverter is discharging from the battery [21].

2.15 Switch:

A switch is connected to the front of the inverter. The red switch controls the AC voltage input output of the inverter [28].

3.0 PRINCIPLE OF OPERATION

An inverter uses an oscillator to convert a DC battery voltage into an AC voltage signal. The AC signal is then amplified by a booster integrated circuit (IC) to a higher voltage that can drive a power transistor, which raises the inverter's power level. The voltage, which is twelve volts, is sent to a transformer, which raises the voltage level from twelve to approximately 220v [29].

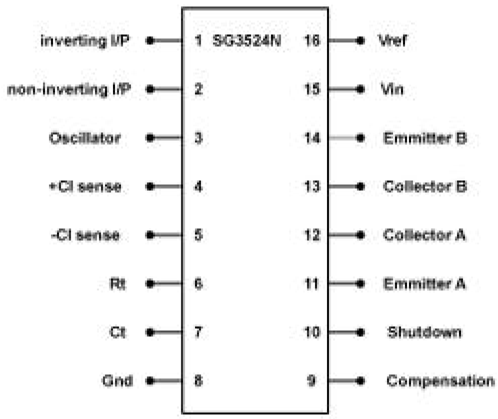

Figure 1: Diagram showing Pin configuration of SG3524 PWM IC

Vin for the PWM IC (12volts) is taken from the battery source.

Pin 16 outputs a constant +5V and used to set the voltage reference of 2.5V for the pulse-width control through voltage divider resistors to pin1.

Pin1 and pin2 works as the feedback control input from the Opt-coupler stage connected to the load output to automatically adjust the output voltage using pin 16 voltage reference as its reference voltage to either increasing the width or reducing the width of the PWM to keep the output load voltage stable.

Pin 11 and pin 14 is the output of the PWM

Pin 6 and 7 is used to set the output frequency of the PWM using the formula from the datasheet.

1.15T = RC ------------------------------------ (1) Single output

1.15T = 2RC ---------------------------------- (2) Double output

$\frac{1}{T}$ = F -- (3) frequency of 50Hz

Therefore,

$F = \frac{1.15}{2 \times R_T C_T} = 50Hz$

Where;

$C_T = 0.1\mu F$

Substituting C_T and making R_T subject

$R_T = \frac{1.12}{2FC}$ -- (4)

$R_T = 15{,}000\ \Omega = 15K\ \Omega$

Therefore, a fixed resistor of 100 KΩ and a variable resistor of 50 KΩ are considered.

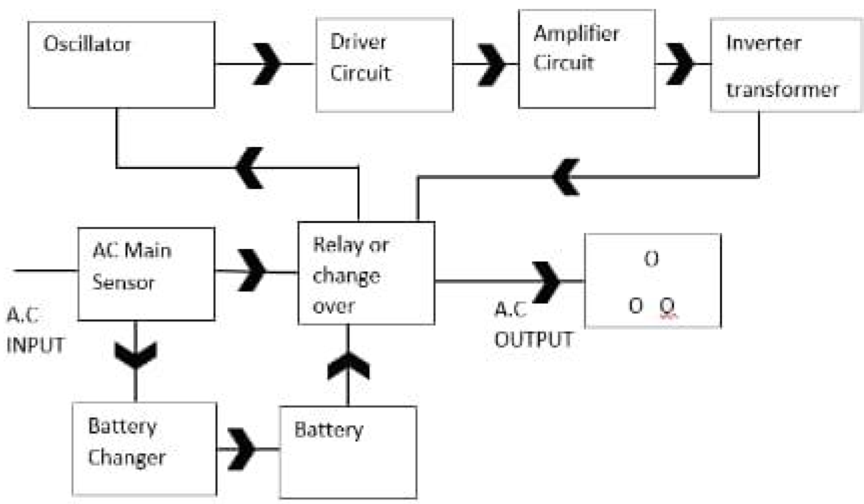

Figure 2: Block diagram for DC-AC power inverter

In Figure 2, energy is obtained from the mains/generator. The source is connected to the inverter where the output of the charge controller goes to the battery. If the inverter is connected to the mains/generator, it supplies directly to the load while the remaining energy is fed to the battery. The battery tends to supply the load if the energy gotten from the mains/generator is no longer available. The inverter also includes an integrated AC charger controller that manages battery charging from the mains or generator.

Also, the inverter circuitry makes use of SG3524 PWM IC whose function is to produce the oscillating signal that controls the ON/OFF switching of eight MOSFETs connected in parallel to a center-tapped transformer. This setup switches 12V DC from the battery through the transformer's windings to generate a 220V AC output at 50Hz, suitable for powering computers and other household appliances with a maximum power rating of 1000 VA.

3.1 Soft-Start

The soft start section is a charging delay circuit. After a power cut, when the AC supply returns, i.e. when the inverter switch from the battery mode to AC mains mode (i.e. charging mode), the charging process is not started immediately. The charging starts after a small delay of about 6 seconds.

The compensation pins 9 and reference pin 16 are used for the soft start circuit. This helps to prevent overshoot of the output at start. It uses a resistor and a capacitor charging circuit to introduce the delay. The time delay can be obtained thus,

T = RC

For time delay of $T = \frac{1}{F} = \frac{1}{50} = 20ms$

Assuming Capacitor value of 4.7Ωf

$R = \frac{T}{C} = 4255.3\ \Omega$

To get a higher time value, 4700Ω is considered. This will give 22ms delay.

3.2 MOSFET Driver

The MOSFET stage conducts/switches the necessary load current through the step up/step down power transformer

i. The MOSFET uses in the switching step up stage are the IRFP 250N N-channel.

ii. A fixed resistor of 10KΩ is connected between the gates and sourced to aid fast switching by discharging any residual static charge at the gate.

iii. During charging, the diodes in the MOSFET transistors acts as a rectifier to the AC voltage from the step down power transformer with an external filter capacitor to charge the battery.

3.3 Datasheet of IRFP 250N

Drain to source breakdown voltage BVDSS = 100V

Gate to source voltage (cut-off) = 4V

Gate to source breakdown voltage = 20V

Drain current (continuous) = 41A

Drain to source resistance r_{DSS}= 0.055Ω

Power Dissipation PD = 230Watts

A total of 6 MOSFET is considered with half of the number function for half the design period.

The maximum output of the MOSFET is given as;

Maximum Output-power = Watts x efficiency x total number of parallel MOSFET

Number of parallel MOSFET =3 (three)

Worse case Efficiency of each MOSFET = 80% of 250watts = 200watts.

Max. Output-power of MOSFET = 200 x 3 = 600watts

Power factor of inverter = 0.9

The watts of 1KVA inverter = 1000 x 0.9 = 900watts

Therefore, Total Wattage of MOSFET = Maximum Wattage of 1KVA inverter

3.4 Battery Indicators

At low 9.5volts, the inverter is design to shut down. This arrangement involves the use of comparator IC and zener diode as the reference input terminal to the op-amp IC. The second input to the op-amp IC is connected from a voltage divider network from the positive terminal of the battery. The output from the op-amp is feed to an SCR transistor to short down the inverter when the battery goes below 9.5volts. At full battery status of 14.5volts, the monitor circuit shuts down. In this case, the output from the op-amp is feed to a Bi-stable mode input of a 555 timer IC to stop the charging process when the battery goes above 14.5volts.

4.0 DESIGN CIRCUIT OF THE 1KVA INVERTER

The circuit design of the inverter was done using a Proteus 8 software simulation.

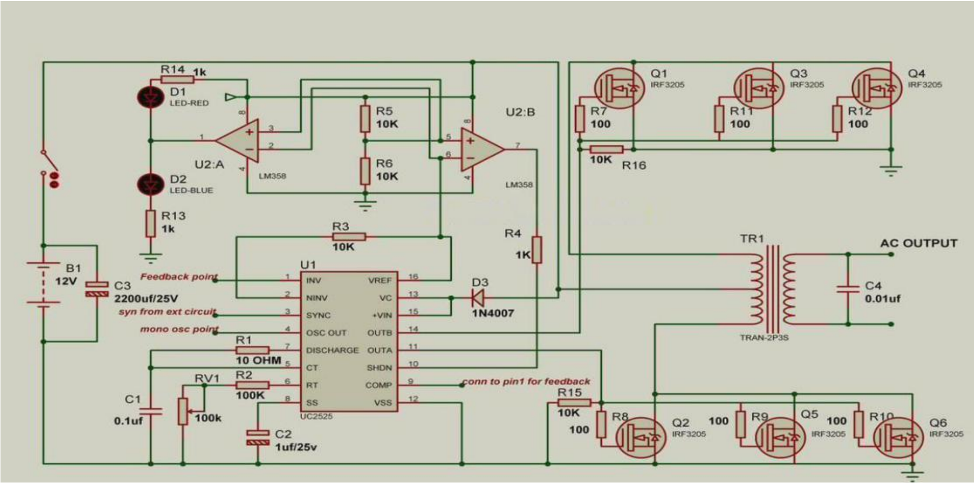

FIGURE 2: SOFTWARE SIMULATION DESIGN CIRCUIT OF THE 1KVA INVERTER

5.0 CONSTRUCTION OF THE INVERTER

The construction of an inverter is divided into three (3) basic stages which are; The input stage, The driver stage and The output stage

5.1 The Input Stage:

The first stage which is the input stage consists of rectifier, the oscillator and the transistor. The rectifier converts the alternating current which comes from the output transformer into direct current for the purpose of charging the battery and this is done by the use of diodes. The oscillation transistor amplifies the output current from the IC to a current which can be carried or accommodated by the MOSFETs in the stage (drive stage).

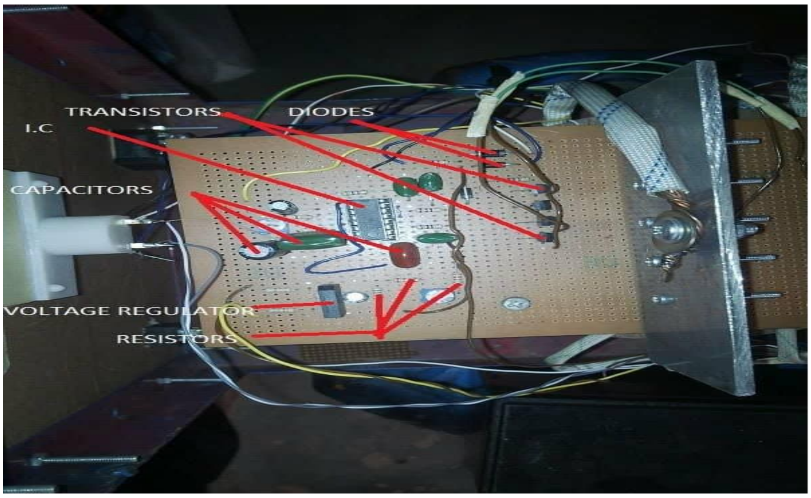

Figure 2: The input stage

5.2The Drive Stage

The drive stage is made up of basically the MOSFETs. The MOSFETs helps amplify the current to a much higher level and the number of MOSFETs used determines the amount of current that can be drawn from the inverter when charging the battery and when used to power appliances in the homes. It also determines the rating of the inverter, whether it will be a 1KVA inverter or a 5KVA inverter and so on.

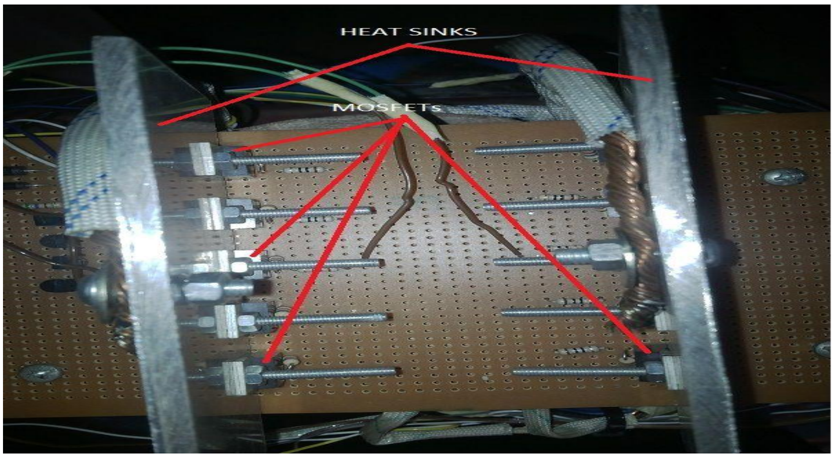

FIGURE 3: The drive stage

5.3 The Output Stage

The output stage is made up of the relays and transformer. The relays are basically incorporated here as a switching device which switches between power supply and inverter i.e., when there is power supply, the relays sense the power and switches off the inverter while switching to supply power from PHCN. It also does this when power supply goes off. The transformer, as the name implies, transforms the 12V DC which comes from the battery into 220V. The transformer also, to a large extent, determines the rating of the inverter.

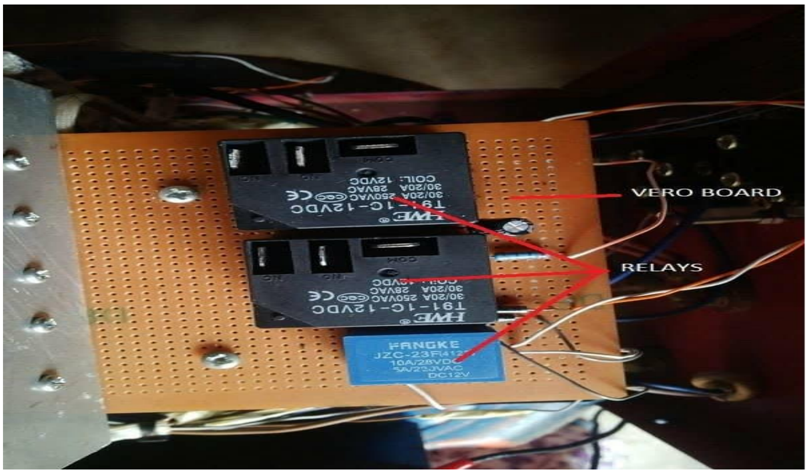

Plate 3: The output stage

6.0 THE CASING

These days, contests exist in the electronic industries, with each party attempting to outdo the others in some way. To this purpose, carefully designed packaging enhances a company's reputation while also adding a beautiful sheen. People place a lot of emphasis on the casing's shape and design without taking the contents into account. In this project, the case was constructed in a way that makes it simple to maintain and repair the components. The case has a screw-able cover, and provisions have been made for the circuit fittings or components.

The height of the casing is 200 mm, the base is 220 mm, and the length is 270 mm. A plain sheet of metal was bought to prepare the casing, and the specified dimensions were measured with the measuring tape. With the use of a scriber, the dimensions were drawn out, and then a cutting device sliced the metal to the marked dimensions. With a center punch and a drilling machine, the entire centers were punched out and drilled to the proper size. The metal was then bent using a vise, hammer, and other small tools, and the appropriate joints were then screwed together using screw nails to keep the casing in place.

The steel enclosure was then employed to house the entire machine. Positive and negative battery terminals, a power switch, a side handle, indicators, a circuit breaker, a fuse box, a DC fan, and an AC input/output point were all set in their designated slots and connected to the circuits that they belonged to. Each stage was carefully placed within the enclosure and attached after being earthed. The diagram of the casing is shown below:

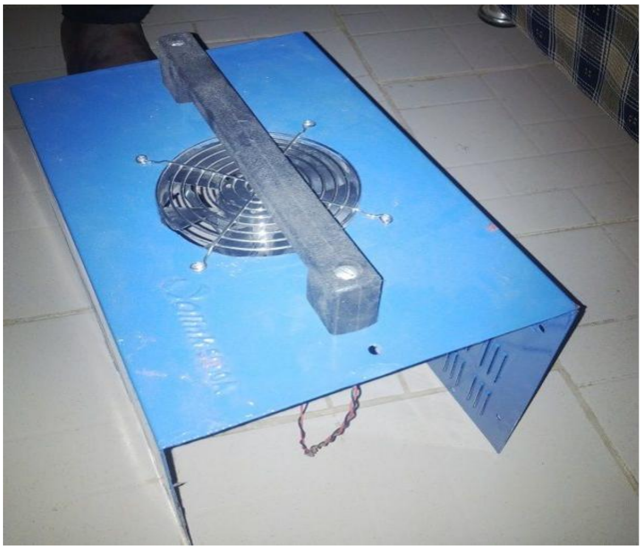

Plate 5: A diagram showing the constructed inverter casing

Plate 6a: Front view of an inverter

Plate 6b: Back view of an inverter

7.0 SYSTEM TESTING

Following the design and implementation phases, the system had to be tested for strength, effectiveness, and efficiency to see if the design needed to be modified. The components were examined using a digital multimeter (DMM) to make sure they were working properly and producing the correct data. All components were put through testing to make sure they met the requirements of the project's goal. The completed inverter system was then tested under load and no-load conditions.

7.1 Testing of the Inverter System under No Load Condition

The inverter circuit was connected to the 12V sealed, rechargeable battery. The center-tapped transformer was linked to the battery's positive terminal, and the inverter circuit's overall ground was connected to the battery's negative terminal. The inverter was turned on, and the control circuit's variable resistor VR1 was changed until the output voltage of 220V was noted.

7.2 Testing of the Inverter under Load Condition

This test was carried out to make sure the inverter was operating as it should. The test assisted in determining the inverter's behavior under load conditions in terms of output voltage stability. The duration of discharge under load conditions is determined by the total power of the load connected to the inverter's output and the power rating of the battery connected to its input. It is important to ensure that the total load does not exceed 1000VA.

The duration at which the inverter discharges under load condition depends on the total power of the load connected to its output terminal and the power rating of the battery connected to its input terminal. Bearing in mind that total load must not exceed 1000Watts.

Discharge duration

(a) Battery power rating = 12volts, 75Ampere per hour

When total load = 100watts

Then duration = $\overline{}$
100

= 9hours

(b) Battery power rating = 12volts, 75Ampere per hour

When total load = 100watts

Then duration = $\overline{}$
200

= 4.5hours

(c) Battery power rating = 12voits, 75Ampere per hour

When total load = 300watts

Then duration = $\overline{}$
300

= 3hours

The inverter was tested on a section by section basis. The output voltage of the oscillator was obtained to be 4.24volts on each side with frequency set to approximately 50Hz. The other unit could not be tested until the final coupling had been done. The battery overcharging protection unit, low battery cut off unit, low and high voltage surge protection as well as the time delay units, feedback unit and the overload and short circuit protection unit were all tested by varying the potentiometer associated with each of them and observing the response through the displays. The list of various settings that were made is listed overleaf;

Table 1: Settings on the Inverter

Inverter output voltage	220volts
Inverter frequency	50Hz
Minimum battery voltage	10.0volts
Maximum loading capacity	700watts
Minimum A.C. input voltage	180V
Maximum A.C. input voltage	250V

After all the settings were done, the effect of loading was carried out on the INVERTER system and the load test results are as follows.

Table 2: Load Test

Power (watt)	**Voltage(volt)**	**Discharged duration**
100	230	9hours
200	230	4hours 30minutes
300	225	3hours
400	220	2hours 15minutes
500	220	1hour 50minutes
600	220	1hour 30minutes
700	220	1hour 20minutes
800	220	1hour 10mins
900	220	1hour

It was discovered that when the INVERTER was loaded, the output voltage initially to drop and then regulated itself back to 220V. This is due to the feedback action (automatic regulation action) of the IC, SG3524, used as the oscillator.

8.0 Conclusion

The construction of this project 1kVA, 220volts inverter at a 50Hz frequency was a gradual process from gathering of materials to testing of components. It is to be noted that the efficiency of this project depends on the power rating of the battery connected to the input and on the total power of the load connected to its output terminals. Thus, the inverter could deliver constant power for a calculated number of hours.

In view of the inconsistent and unreliable public power supply and high cost of electric power generators coupled with the high cost of maintenance, the inverter is found to offer a better constant additional power supply for a sustainable duration. It is noiseless, harmless, and cost effective. It is also a preferred power backup to a computer and other appliances because it switches automatically to the battery when the AC mains is not available. Thus, reduce system breakdown, prevent hard disk damages and data loss. In addition, the life span of the computers and other devices connected to either a standby or a continuous inverter is prolonged. The objective of the circuit was to invert power from low voltage DC sources to boost into AC power similar to one available in our wall socket for any load.

REFERENCES

[1] Strielkowski, W., Civín, L., Tarkhanova, E., Tvaronavičienė, M., & Petrenko, Y. (2021). Renewable energy in the sustainable development of electrical power sector: A review. *Energies*, *14*(24), 8240.

[2] Røpke, I., Christensen, T. H., & Jensen, J. O. (2010). Information and communication technologies–A new round of household electrification. *Energy Policy*, *38*(4), 1764-1773.

[3] Okafor, E. E. (2008). Development crisis of power supply and implications for industrial sector in Nigeria. *Studies of Tribes and Tribals*, *6*(2), 83-92.

[4] Oyedepo, S. O. (2012). Energy and sustainable development in Nigeria: the way forward. *Energy, Sustainability and Society*, *2*, 1-17.

[5] Ibiene, D., Clinton, A., & Chinago, A. B. (2018). State of power supply in Nigeria, the way out. *International Journal of Development and Sustainability*, *7*(2), 435-447.

[6] Estrellan, C. R., & Iino, F. (2010). Toxic emissions from open burning. *Chemosphere*, *80*(3), 193-207.

[7] Crutzen, P. J., & Andreae, M. O. (1990). Biomass burning in the tropics: Impact on atmospheric chemistry and biogeochemical cycles. *science*, *250*(4988), 1669-1678.

[8] DeLuchi, M. A. (1991). *Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity: Main text* (Vol. 1). Center for Transportation Research, Argonne National Laboratory.

[9] Jiang, Z., Xiao, T., Kuznetsov, V. Á., & Edwards, P. Á. (2010). Turning carbon dioxide into fuel. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *368*(1923), 3343-3364.

[10] Paraschiv, S., & Paraschiv, L. S. (2020). Trends of carbon dioxide (CO2) emissions from fossil fuels combustion (coal, gas and oil) in the EU member states from 1960 to 2018. *Energy Reports*, *6*, 237-242.

[11] Glaser, P. E. (1968). Power from the sun: Its future. *Science*, *162*(3856), 857-861.

[12] Armaroli, N., & Balzani, V. (2007). The future of energy supply: challenges and opportunities. *Angewandte Chemie International Edition*, *46*(1-2), 52-66.

[13] Bose, B. K. (2010). Global warming: Energy, environmental pollution, and the impact of power electronics. *IEEE Industrial Electronics Magazine*, *4*(1), 6-17.

[14] OLADIMEJI, A. J. (2020). *Intergration of large Photovoltanic distributed generation into grid and the effect on power quality (Modelling Nigerian low voltage distribution Grid system 415V)* (Doctoral dissertation, College of science and Technology).

[15] Tastet, P., & Garnier, J. (1992). Heavy ions sensitivity of power MOSFETs. *IEEE transactions on nuclear science*, *39*(3), 357-361.

[16] Pinto, R. A., Cosetin, M. R., Campos, A., Dalla Costa, M. A., & Do Prado, R. N. (2011). Compact emergency lamp using power LEDs. *IEEE Transactions on Industrial Electronics*, *59*(4), 1728-1738.

[17] Kumar, A., Bijapur, A. A., Charitha, B., Kulkarni, K. R., & Natarajan, K. (2016, May). An IOT based smart inverter. In *2016 IEEE International Conference on Recent Trends in Electronics, Information & Communication Technology (RTEICT)* (pp. 1976-1980). IEEE.

[18] Barnett, G. (2017). *Vehicle battery fires: why they happen and how they happen*. SAE International.

[19] Sarjeant, W. J., Zirnheld, J., MacDougall, F. W., Bowers, J. S., Clark, N., Clelland, I. W., ... & Prymak, J. (1999). Capacitors—past, present, and future. In *Handbook of low and high dielectric constant materials and their applications* (pp. 423-491). Academic Press.

[20] Pallas-Areny, R., & Webster, J. G. (2012). *Sensors and signal conditioning*. John Wiley & Sons.

[21] Omitola, O. O., Olatinwo, S. O., & Oyedare, T. R. (2014). Design and Construction of 1KW (1000VA) Power Inverter. *Design and Construction of 1KW (1000VA) Power Inverter*, *5*(2), 1-13.

[22] May, G. J., Davidson, A., & Monahov, B. (2018). Lead batteries for utility energy storage: A review. *Journal of energy storage*, *15*, 145-157.

[23] Babarinde, O. O., Adeleke, B. S., Adeyeye, A. H., Ogundeji, O. A., & Ganiyu, A. L. (2014). Design and construction of 1kVA inverter. *International Journal of Emerging Engineering Research and Technology*, *2*(3), 201-212.

[24] Gupta, J., & Singh, B. (2021). Bridgeless isolated positive output Luo converter based high power factor single stage charging solution for Light Electric Vehicles. *IEEE Transactions on Industry Applications*, *58*(1), 732-741.

[25] Yilmaz, M., & Krein, P. T. (2012). Review of battery charger topologies, charging power levels, and infrastructure for plug-in electric and hybrid vehicles. *IEEE transactions on Power Electronics*, *28*(5), 2151-2169.

[26] Rodriguez, C., & Amaratunga, G. A. (2008). Long-lifetime power inverter for photovoltaic AC modules. *IEEE Transactions on Industrial Electronics*, *55*(7), 2593-2601.

[27] Whitaker, J. C. (2018). *AC power systems handbook*. CRC press.

[28] Barzegarkhoo, R., Siwakoti, Y. P., & Blaabjerg, F. (2020). A new switched-capacitor five-level inverter suitable for transformerless grid-connected applications. *IEEE Transactions on Power Electronics*, *35*(8), 8140-8153.

[29] Doucet, J., Eggleston, D., & Shaw, J. (2007). DC/AC pure sine wave inverter. *PFC Worcester Polytechnic Institute*.