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Design and Construction of 1.5 Kva Modified Sine Wave Mosfets Driver Inverter

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Abstract The need for power increases every day and problems encountered with the use of generating sets characterized with noise pollution, environmental pollution and the need for regular servicing call for the need for a system that eliminate all of the aforementioned problems. This research focus on design and construction of 1.5 kVA modified sine wave MOSFETs driver inverter to power critical loads in offices and homes. In order to achieve the focus of this research, load survey of the critical loads was done and other necessary components of the inverter were sized based on the designed loads using the appropriate equations. The load was classified into two categories namely: load A (694A) and B (593A) which were non inductive and inductive respectively. The inverter was designed to power the loads A and B (1287A) at the same time. The inverter powered critical loads A and B between 90.4 % and 91.7% efficiency respectively when it is individually connected. Also, the inverter powered the critical load A and B at the same time with efficiency of 84%. The inverter is in operation for over twelve months to date. The result showed that as the load increases, the voltage output decreases and so also the efficiency decreases. The designed inverter is suitable for all connected loads. The designed inverter can be used as a backup in case of main utility power failure for homes and offices. Higher power output could be further researched into.

Keywords: *inverter, MOSFETs, critical load, inductive load, battery, efficiency*

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1. Introduction

An inverter is an electrical system that converts direct current (d.c) power into an alternating current (a.c) [1,2,3]. The inverting process can be achieved with the help of components including but not limited to transistors, resistors, diodes, relay, rectifier and switches. Inverter can be found wherever there is a need to sustain a. c. power in an establishment or home. Inverters have become very important in sustaining critical load supply. The critical load is a function of end user's equipment priority. The inverter is preferred to generator due to its benefits of light weight, mode of operation, no fuel is required, little maintenance, compact size and noiseless against generators [4]. The aim of inverter to convert D.C power to A.C power for the use of appliances due to experience of unreliable and unpredictable power supply [5,6]. However, some essential loads (critical loads) are given priority in some cases. Although, between 19th century to mid-20th century, D.C to A.C power conversion was accomplished with the aid of rotary converters or motor generator set (M.G set) while vacuum tubes and filled tubes started to be used as switches in inverter circuit in early 20th century [7,8]. Due to unpredictable power supply associated with loss of power supply (PS), much electrical equipment have either developed a problem or even stopped working entirely. As a result, many businesses and comfort of end users have been crippled thereby affecting the economy as a whole especially Nigeria. Power disturbances occurrence are also on increase due to ON and OFF of the PS which often affect the performance of sensitive electronics equipment [2,5]. Some factors responsible for this outage are ugly situation such as natural disasters, vandalism, lack of maintenance and lack of vision by the government to invest adequately in power sectors. Also, absence of replacement policy resulting in the abandon of electrical equipment or project, inadequate human capacity and inadequate remuneration system to motivate human resources to perform well in their field of work. Considering necessity of light in weight energy source, it is therefore necessary to convert the DC power from storage batteries to AC power to power some devices and appliances. The need for a perfectly sinusoidal ac output over square wave has necessitated the development of a modified sine wave (MSW) inverter [6,7]. Hence, the design and construction of MSW inverter in this research. The aim of this research work is to design and construct a 1500VA modified sine wave inverter for a research office with an intension to power a research office critical loads. The objectives of this research work are to design oscillator unit, charger unit, driver circuit, 1.5 kVA transformer and determination of battery capacity. Early transistors signal voltage and current were lower than what are required for inverter applications hence, the introduction of the Silicon-Controlled Rectifier (SCR) in 1957 which initiated the transition to solid state inverter circuits. Inverters are classified according to input and output voltages, power rating and outputs waveforms. Waveform classification are square wave, modified sine wave and pure sine wave.

1.1. Direct Current (DC) and Alternate Current (AC)

In the world today, there are currently two forms of electrical transmission, namely DC and AC. DC power is simply the application of a steady constant voltage across a circuit resulting in a constant current. The best real-life example of direct current is a battery. In Nigeria market, the price of 1.5 kVA modified sine wave inverter range from Sixty thousand naira (₦ 60,000) and above while modified sine wave inverter sells for about thirty thousand naira (₦30,000) without battery [7].

1.2. Choosing the Right Inverter

Pure sine wave inverters are more preferable over modified sine wave and square wave inverters. However, the application, cost and the energy to be consumed are considered vital in selection of an inverter. In this work, modified sine wave inverter is used due to the aforementioned considerations. Equation (1) is used for load survey calculation.

$$P = IV \cos \varnothing \tag{1}$$

The waveforms of three types of inverter are shown in Figure 1.

1.3. Mosfet

According to [5], MOSFETS is preferred to BJTS due to simpler to drive, not suffering from thermal breakdown, reduced Safe-Operating Area (SOA) since they are not affected by thermal breakdown, easy paralleling of ensuring an even distribution of current among all components,high input impedance, high switching frequency and input impedance much higher than that of JFETs. Hence, MOSFETs is used in this research as a driver.

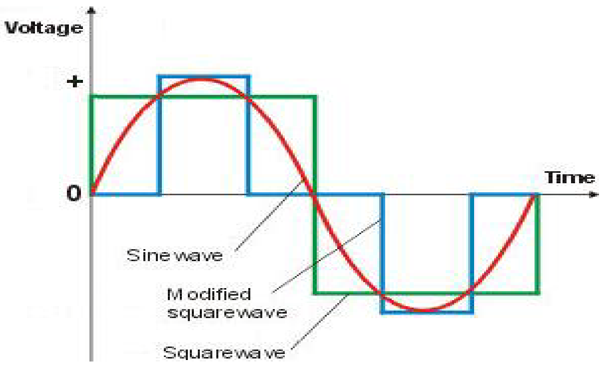

Figure 1. Sine Wave, Modify Sine Wave and Square Wave Forms [7,8]

1.4. Power Transformer

A power transformer is a device that transfers electrical energy from one circuit to another through inductively (electromagnetic induction) coupled conductors (the transformer's coils).

1.5. Change Over Switch

The change over switch in this research incorporated relay as a switch. It interchange between main power supply and inverting output section [5].

1.6. Batteries

The runtime of an inverter is directly proportional to the battery power and the amount of power being drawn from the inverter at a given time.

$$T_R \propto P_B \tag{2}$$

$$T_R \propto P_D \tag{3}$$

Where P_B is the battery power and P_D is the amount of power drawn by the load from inverter.

1.6.1. Types of Battery

There exist various type of batteries which include Gel Battery, Lead Acid battery, Deep Cycle Battery and Absorbed Glass Mat (AGM) battery. Deep cycle battery is mainly used for inverter and Starter battery may also be used on economical consideration.

Table 1. Three Types of Inverter by waveform characteristics and Applications [2,7,8]

S/N	Waveform	Characteristics	Applications
1	Square Wave	Humming (audio equipment).	Lighting and Heating
		Inductive Load not suitable	
		Low power quality (45% THD	
2	Modified Sine Wave	Reduced Humming	Lighting, heating, iron, T.V, Radio, small printer
		Cheaper than Pure sine wave	
		24-6.5% THD	
3	Sine Wave	Best inverter form of wave	Inductive load better performance: e.g. Iron, Fan medical equipment, large printer and sophisticated electronic
		Expensive	
		THD < 3%	

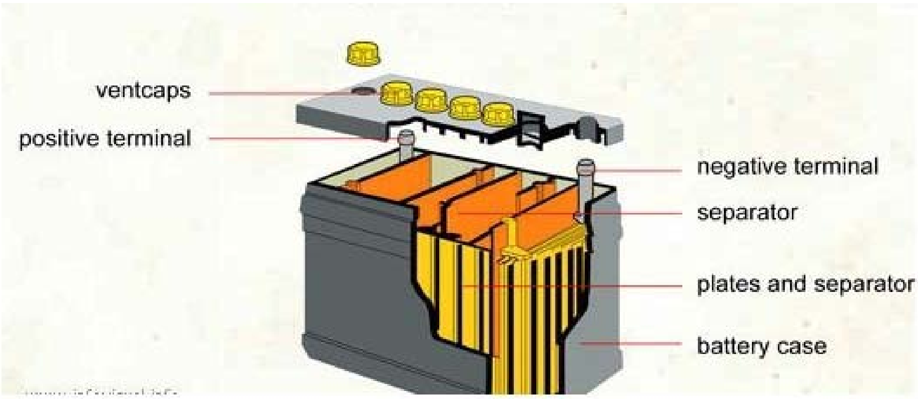

Figure 2. Automobile Battery

Best life span versus cost scene, an Inverter battery (deep cycle) can cycled down 20% drainage and can be recharge back to its original life. Also, the car battery may not charge below 20% drainage since alternator resumes recharging back to its original state after cranking and last for a number of years. It therefore follows that a car battery can be used for an inverter battery except for acid odour during charging and fear of bursting of battery if battery charger fails since it has a wet cell [8]. Due to these problems and cost consideration, inverter battery is used in this research coupled with the fact that it can cycle down to 20% and cut off at 80% retain capacity [9]. Conclusively, using automobile battery in inverter application may not be recommended expect on close monitoring of the battery charging.

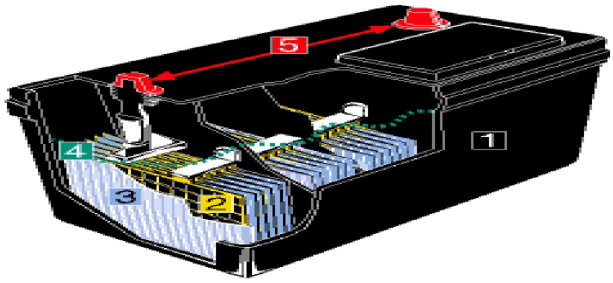

Figure 3. Deep Cycle Battery

1.7. Inverter Cooling System

This is achieved using a 12VDC fan for cooling the likely producing heat emitting devices in the inverting circuit.

1.8. Load Survey

Load survey is the estimation of the total load that the inverter will carry at a particular time. This is necessary to determine the power rating of the inverter. This is done by carry out the summation of the total loads for the inverter.

2. Methodology

The step by step approach for the design and construction of 1500VA, 240Volt 50Hz modified sine wave inverter is discussed underneath.

2.1. Inverter Design

In order to design a function-able inverter that will meet inverter aim an objectives, section 2.1.1 to 2.1.4 are essential.

2.1.1. Load Surveys

In this research, the inverter is expected to supply total load for 1.5 hours duration. The load embraces 1.5A laptop, 2X 18W LED lamps, 400mA telephone, 100W Standing Fan, 200mA radio and 2.47A printer. For economic reason 2A printer is consider as critical load 2 while others loads are considered critical load 1.

2.1.2. Elements of Inverter

There are 6 sections in the inverter under consideration which are referred to as inverter elements, Figure 1.

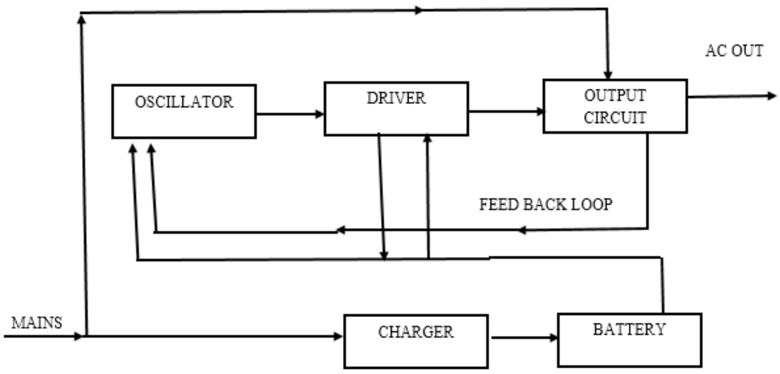

Figure 4. Inverter Block Diagram

Changeover Section:

This is a section that makes use of a relay to perform switching from inverter mode to MAINS supply mode when there is availability of mains and verse visa. The changeover relay has a COMMON pin, normally open pin, and normally close pin. The common pin stands as AC output.

Charging Section:

The circuitry here comprised of a voltage regulator of 7812, 555timer and LM358 OPAMPs, a signal diode of IN4148, 10k ohms resistor, 3 pieces of 1k resistors, 10k variable resistor preset, 47uf electrolytic capacitor and single NPN transistor driver. The battery output is 14.7 V maximum (threshold).

Low Battery Section:

The components here consists of a 1000uf by 35 V and 100uf by 50 V capacitor, 2.2K resistor of 3 pieces, 1k resistor of 1 piece, 1N4007,1 piece of 9V zener diode, 1piece and BC337 of 3 pieces of NPN transistors, with 1 small 12V/10A relay. The zener diode activates the saturation point for the NPN (BC337) transistor which Bias the 1N4007 diode that enable the 100 uf/ 50V capacitor to charge up which determine the low battery shunt down.

Battery Capacity Sizing:

Equation 4 to equation 6 is used to size the battery. The the operation time of the inverter is 1.5 hours and the load is as computed in Table 2.

$$P_{VA} = \frac{P_r}{P.F} \tag{4}$$

Where P_{VA} is the reactive power in VA, P_r is the real power and P.f is the power factor

$$B_J = P_{VA}\ x\ hr \tag{5}$$

Where B_J is Battery energy in Joule and hr is the hour of operation

$$B_C = \frac{B_J}{V} \tag{6}$$

Where B_j is battery energy in Joule and hr is the hour ofoperation.

Modified Sine Wave Oscillation Section:

The component here comprises of the SG3524 component which is the principal component, with a 104pico-farad mylar capacitor, 2.2uf electrolytic capacitor of 2pieces, 4.7uf all rated 50v of 2 pieces which is used for band gap timing (PWM). Variable resistor of 5K and 20kpreset. And then 4.7K resistor of 4 pieces, C945 NPN transistor with 47k ohms fixed resistor and single IN4007 diode. The oscillator stage is where the frequency is been generated. The oscillator frequency is $50H_{Z.}$

Driver Stage Design/MOSFET Calculation:

This comprises of 10k and 47Ω resistor of 6 piece, MOSFET transistors of N-type (IRFP260N), heat zinc, and a mica paper being used as an insulating paper. The MOSFET used is the IRF 260 in the power switching circuit due to high switching speed. The number of MOSFETs appropriate for 1500VA is calculated using equation 7 to 9. The MOSFETs is arranged in two channels which at each channels comprises of 3 MOSFET in total with a 10k resistor is been twined between the gate and source of the each MOSFET while one channels will handle 750 watts.

$$P = IV \tag{7}$$

From equation 7, equation 8 is computed

$$I = \frac{P}{V} \tag{8}$$

MOSFET design parameters are:
Input voltage = 12V,
output power = 1500W,
MOSFET maximum current = 46A

$$Number\ of\ MOSFET = \frac{I_{Max}}{ID} \tag{9}$$

Where I_{MAX} is the current rating from equation (7), I_D is 46A

The continuous drain current of the popular MOSFET IRF 260 N is 46 A at 25°C [7]

Transformer Design:

Equation (10) was used in calculating the voltage per turns

$$K = Core\ Area * 4.44 * f * 10^{-6}\ V/Turn \tag{10}$$

Core Area is the area of core in mm^2
B_m is the magnetic flux density taken as 1.2T
F is the frequency in Hertz, f =50 Hz

Number of Turns for the Primary and Secondary Windings is given by equation (11) and (12) respectively.

$$N_P = \frac{V_P}{k} \tag{11}$$

$$N_S = \frac{V_S}{K} \tag{12}$$

N_p is the number of turns at the primary side, N_s is the number of turns at the secondary side, V_p is the primary voltage and V_s is the secondary voltage

Feedback Section:

It comprises of a 4 unit or pieces of 1N4007 diode, 200k ohms resistor by 2watts (power rating of the resistor) with an optical isolator 4N35. The bridge rectification is archived by the helps of the diode. The feedback is to control the PWM (4N35).

Inverter Cooling System:

This is achieved using a12VDC fan. The positive terminal of this fan is connected to pin 1 of the Anly timer relay via a 22Ω resistor. The negative terminal is connected to general ground. Immediately the inverter comes on, the fan starts blowing. This is possible via the Anly timing relay (the relay takes care of timing and normal switching operations). In order not to run the MOSFETS above 25°C, a large heat since is also incorporated into the design to prevent the MOSFETs from burning out as a result of excessive heat.

2.1.3. Construction of Inverter

Printed Circuit Board (PCB): The board layout was designed on a stimulated software Proteus after which it was printed on a glossy paper. The board was measured and cut to the dimension of the printed layout (0.1cm tolerance). Paper tape was used to hold the printed layout covered with the PCB. An automated laminating machine was used to compress and heat the glossy paper where the model of the circuit diagram is obtained to the PCB. Its then immersed in cool water to cool down and proper softening of the paper, the paper was removed by hand from the PCB and then sun dried for some minutes. The PCB was then passed through a process called Etching by using a chemical called etchant which is called (ferricoxochlorate1acid), in order to remove the unwanted part, then bleached to remove the black printed path from the copper surface using a Nitro-cellulose solvent, thus cleaned and dried for drilling and the ready components of the circuit are mounted appropriately then soldered.

Transformer: The step by step approach taking in the construction of this project started with the building of the transformer from the laminating core, followed by the rectification stage, sensing and monitoring stage, comparator and transistor switching. The construction of the inverter was done using soldering and coupling active circuit. The soldering was done on the Printed Circuit Board with 50W soldering; the components were properly arranged by following the designed circuit diagram of the project.

Thinning: Smooth scrapping of components terminal was done with knife and sand paper before soldering.

2.1.4. Test Instruments

This equipment includes digital multi-meters (voltage and currents at different points of the circuit measurement) and 4 X 200 watts and 4 X100 watts bulbs.

3. Results and Discussion

3.1. Results

3.1 Results

The results of the design were presented in Table 2 to Table 4 and Figure 5- 8

3.1.1. Load Survey

From equations (1) the load survey is computed and result presented in Table 2.

3.1.2. Battery Capacity

From equations 4 to 6 the battery capacity computed and the result presented in Table 3

3.1.3. MOSFET Calculation

From equation 7 to 9, the MOSFET number is calculated and the result presented in Table 4

The 3 MOSFETs were connected in parallel to bring out a large amount of current needed by the transformer.

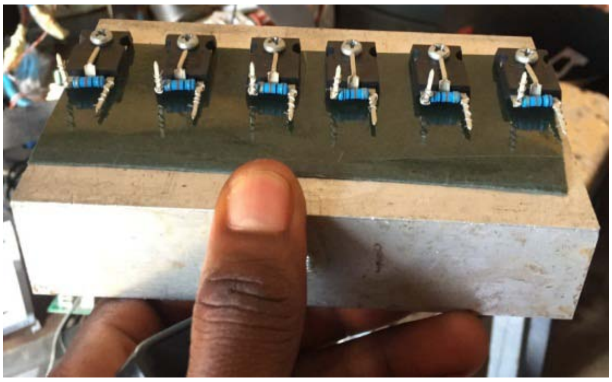

Figure 5. Driver Stage

Figure 6. Components Soldered on the Board

3.1.4. Transformer Designs

From equations 10 to 12, the transformer design is calculated and result presented in Table 5

Table 2. Load Survey Results

Load A						
Load	**Load Rated Value**	**Unit**	**Load (VA)**	**(VA)**	**Load(W)**	**1.25 FE**
Laptop	1.5A	1	380			
Led Lamps	18W	2	45			
Telephone charger	400mA	1	96			
Standing Fan	100A	1	125			
Telephone charger	200mA	1	48			
Total			694	694	555.2	867.5
Load B Profile						
Load		**Unit**				
Printer	2.47A	1	592.8	593	474.4	1482 (at 2.5 Inductive load)
Total				1287	1030	

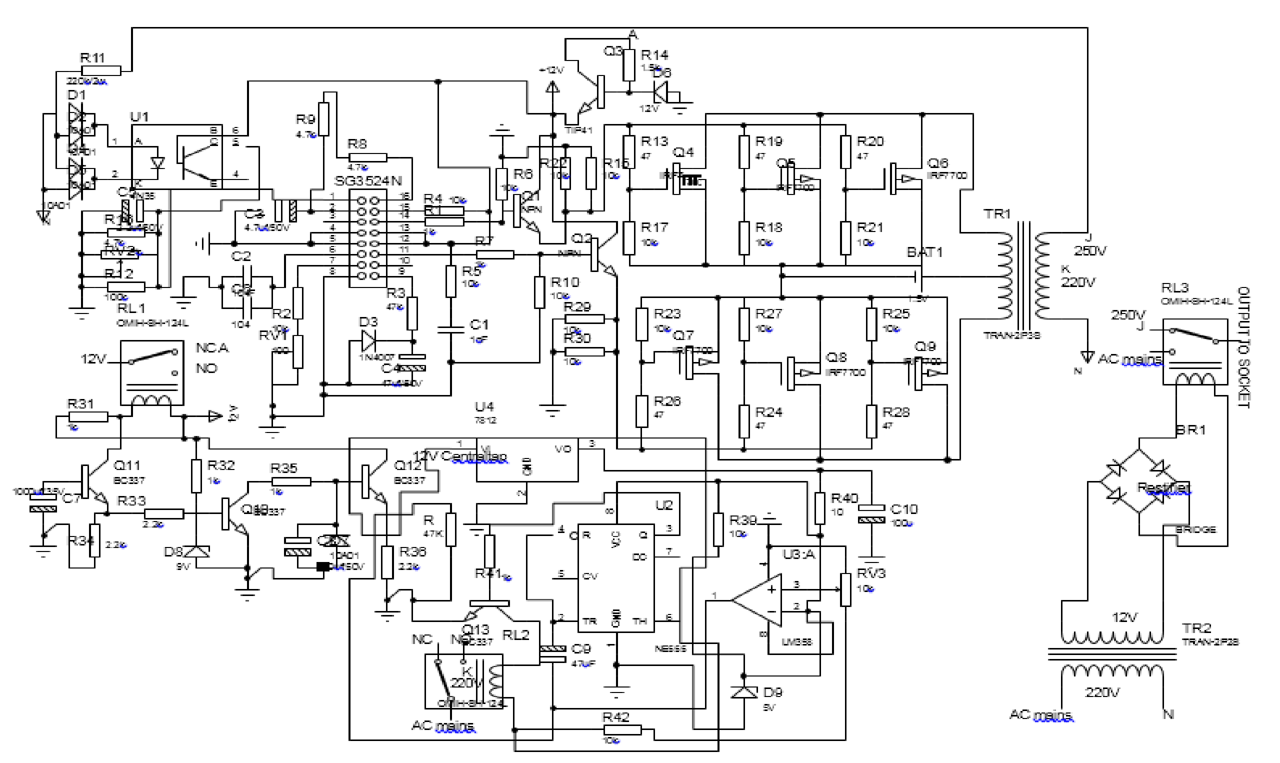

Figure 7. 1.5 kVA 240V, 50Hz, modified sine wave circuit diagram

Table 3. Battery Capacity Result

Device	Rating
Battery Capacity	200AH

Table 4. MOSFET Design Result

Device	Number
Number of MOSFET (1st half cycle)	3
Number of MOSFET (2nd half cycle)	3
Battery Capacity	200AH

Table 5. Transformer Design Results

S/N	Design Parameter	Values
1	Primary Current	6.82A
2	Secondary Current	125A
3	Core Area	1710mm^2
4	Number of Turn in Primary	30 Turn
5	Number of Turn in Secondary	568 Turn

3.1.5. Complete Inverter Circuit

The result of 1.5 kVA 240V, 50Hz, modified sine wave is presented in Figure 7. And internal structure is presented in Figure 8.

3.2. Discussions

After the entire components were fixed on the board, Figure 8, the entire circuit was housed in a case, Figure 9. The case is to protect the circuit against water, object falling on component and mechanical damage. The inverter under test with the loads is presented in Figure 10. The loads test result is presented in Figure 11.

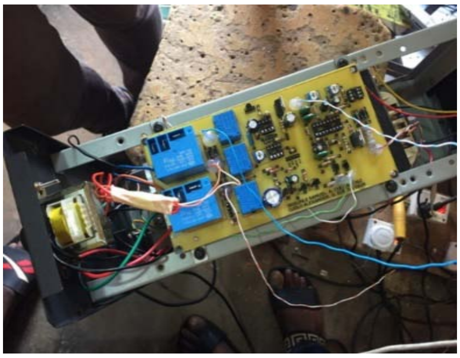

Figure 8. Inverter Internal Structure

Figure 9. Inverter Front View

Figure 10. Inverter Load

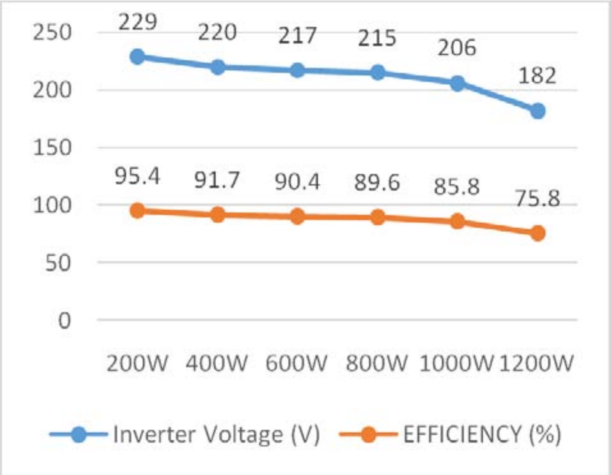

Figure 11. Loads Test Result

Table 6. Bill of engineering measurement and evaluation

S/N	PARTICULAR	QUANTITY	EXIT COST (₦)	TOTAL (₦)
1	MOSFET	6	200	1200
2	Fixed Resistor	30	10	300
3	Transformer	1	8000	8000
4	Op-amp	1	350	350
5	Diodes	6	15	90
6	Zener Diodes	2	100	200
7	Capacitors	7	50	350
8	Fuse	2	50	100
9	PCB	1	350	350
10	Cable	3	150	450
11	13A Plug	2	100	200
12	13A Socket Outlet	1	200	200
13	Switch	1	150	150
14	Battery	1	75,000	75,000
15	Variable resistor	4	100	400
16	Metallic case	1	1,500	1,500
17	Miscellaneous	-	4000	4000
18	SG3524	1	500	500
19	Optical isolator	1	100	100
20	Relay	5	120	600
21	Transistor	5	100	500
22	Heat zinc	1	2000	2000
23	Voltmeter	1	5400	5400
24	Mica paper	1	300	300
	TOTAL			**102,240**

From Table 2, the inverter carried the total load A, 694 VA and Load B 593 VA. Inductive load 593 VA was switched on first because of it inductive nature. Thereafter, load A and load B total load 1287 VA was connected and it powered the loads. From Table 3, 200Ah battery was sized. A deep cycle battery is preferably used because of its advantages. From Table 4, the number of MOSFETs were computed as 3 numbers. This 3 numbers of MOSFETs in parallel array gives first cycle in positive direction and the other cascaded 3 numbers of MOSFETs gives second cycle in negative cycle. This implies that A/C waveform is produced. From Table 5, Primary current and secondary current were used to determine primary and secondary turn winding of the transformer using approximately transformer gauge. The transformer is able to produce 240V at the output. From Figure 11, the designed inverter carried 200W, 400W, 600W, 800W, 1000W and 1200W load with 95.4%, 91.7% 90.4%, 89.6%, 85.8% and 75.8% efficiency respectively. This inverter has been supplying the designed office loads as in Table 2 for at least 12 months. It is still in operation. However, in Nigeria, if the public utility supplies 170V (70% efficiency), we shall be jubilating that will have power because load like heating, TV, radio and lighting load shall be working at 75.8% efficiency except for inductive load like air condition and refrigerator. Even with voltage stabilizer the aforementioned inductive loads will still work. Hence, the designed inverter is okay for all our critical loads.

From Table 6, the cost of the design and construction is twenty seven, thousands two hundred and forty naira only (₦ 27, 240:00) as at October, 2019 without cost of battery. With 12V battery, it is one hundred and two thousands. (₦ 102, 240.00)

4. Conclusions and Recommendations

4.1. Conclusions

The need for power increases every day and problems encountered with the use of generating sets including noise pollution, environmental pollution and the need for regular servicing call for the need for a system that eliminates all of the aforementioned problems.

i The designed 1.5 kVA, 50Hz, 240V MSW inverter provides solution to the aforementioned difficulties.
ii The inverter powered 1287 VA non inductive and inductive loads for over 12 months and it is still in operation.
iii As the load increases, the voltage output decreases and so also the efficiency decreases.
iv The inverter powered critical loads A and B between 90.4 % and 91.7% efficiency respectively when it is individually connected.
v The inverter powered load A and B at 84% efficiency at the same time when load B is firstly switch ON.
vi The inverter is suitable for all the connected loads in this research.

4.2. Recommendation

The designed inverter is recommended as a backup in case of main utility power failure. It is recommended for homes and offices critical loads.

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