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Development of A 0.75 kva Modified Sine Wave Inverter for a Viewing Centre in Nigeria

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ABSTRACT

This paper is focused on the development of a modified sine wave 0.75 kVA inverter for the viewing center in Iloro community, Ondo State. The community was chosen due to the fact that it is not connected to the national grid. The stages of power inverter were thoroughly discussed through design calculations. The load calculation method was used to determine the rating of the inverter. The design calculations of each stage of the inverter were properly presented and the no load test as well as the on load test of the device was performed. The Bill of Engineering Measurements and Evaluation for the developed inverter was estimated as N17, 000 ($44.74). Recommendation was made that such a paper should be pragmatically used by the government to better the lot of the masses with the view of providing alternative power supply.

Keywords: *Inverter; Power Supply; Modified Sine Wave; Load; Development.*

1.0 Introduction

In Nigeria, only 56 million have access to electricity out of a 140 million population. The majority of the people with access to electricity (82 per cent) live in the urban areas while a high percentage of the rural dwellers have little or no access to electricity (Power Digest, 2007). Rural population in Nigeria is high (about 87.5 million) despite the high level of rural-urban migration. Rural communities lack electricity supply, good access road, potable water, health care delivery system, social infrastructure e.g. good education, knowledge due to inaccessibility to information resources, and physical and financial capital needed to sustain livelihood (Ibukun, 2005).

Quite fundamental to rural development is the issue of critical infrastructure, particularly power supply. In Nigeria, all the renewable energy resources are in abundance for the various technologies (Badejo, 2007). Solar energy is the most promising of the renewable energy sources in view of its apparent limitless potential (Sambo, 2005). One of the major components of solar power system required to realize the above objectives is an inverter. An inverter is used to convert direct current into single or poly-phase alternating current (Owen, 1996). It can be used to provide good quality and affordable electricity as well as raise the living standard of the rural population.

There are three main types of inverter when the classification is based on the type of output waveform produced. The three types are square wave inverter, modified sine wave inverter (sometimes called a quasi sine wave inverter) and pure or true sine wave inverter. The three different wave signals represent three different qualities of power output and, consequently, three different price categories. Pure sine wave inverters are the most expensive, but they also deliver the most consistent wave output (Kayne, 2008). Similarly, there are three major types of inverters when the classification is based on their applications. These are stand-alone inverters, grid-tie inverters and battery backup inverters. The stand-alone inverter is the most common type of power inverter. It functions solely as an inverter. (Jon, 2006). They are used in isolated systems where the inverter draws its direct current (DC) energy from batteries charged by photovoltaic arrays or other sources. The grid-tie (intertie) or synchronous inverters change direct current (DC) power into an alternating (AC) power that is fed into the utility grid.

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Battery backup inverters, which are also known as multifunction inverters, are special inverters designed to draw energy from a battery, manage or maintain the battery bank that is charged via an onboard charger, and export excess energy to the utility grid (Wikipedia, 2009b).

The third way of classifying inverters is based on the technology used as switching element. There are two main types of inverters based on this arrangement. The two types are line-commutated inverters and self-commutated inverters. The line-commutated inverters use thyristor as switching elements. A line-commutated inverter is an inverter that is tied to a power grid or line. Line commutated inverters are cheaper but inhibit poor power quality. To suppress the harmonics generated by these inverters, tuned filters are employed and reactive power compensation is required to improve the lagging power factor (Rashid, 2006). The self-commutated inverters operate without AC grid voltage. They are self commutating. In these inverters, semiconductor elements with gate turn-on and turn-off capability such as Insulated Gate Bipolar Transistor (IGBT), Metal Oxide Semiconductor Field-Effect Transistor (MOSFET) and Gate Turn Off thyristors (GTO) are used as switching device (Manfred, 2008). The inverter developed is a modified sine wave inverter which acts as a stand alone and self commutating.

2.0 Design Methodology

The load of the viewing centre was estimated as a means of determining the output rating of the inverter. Other factors like future expansion of the viewing centre and the economic implication of the design were considered before finally arriving at the rating of the inverter. The design value of the components that made up the inverter circuit which comprises the oscillator unit, the driver amplifier unit, the power Metal Oxide Semiconductor Field-Effect Transistor (MOSFET) amplifier unit, the centre-tapped isolated step-up transformer and a wave modifying unit, were calculated using the existing electrical and electronics theories. These components whose values have been calculated were selected using commercial factor criteria such as the cost and availability of the component and electrical and electronics characteristic criteria such as current capacity, operating voltage and other features. The inverter was developed. The construction was done on unit basis using basic workshop knowledge after which all were coupled together and assembled in a metal case. The developed inverter was later installed at the viewing centre using standard installation procedures that puts into consideration simplicity, flexibility of operating the centre, easy access to maintenance and protection and safety of the inverter and all other components of the solar power system. The performance of the inverter was evaluated through the analyses of the results of the load and output waveform test carried out on the inverter.

2.1 Estimation of the viewing centre load

The table 1 shows the estimated load of the viewing centre. Total load for the centre as computed in table 1 is 365W.

2.2 Determination of the output rating of the inverter

The estimated total load of the viewing centre is 365 Watt. Therefore, the output rating of the inverter (W_{OR}) is estimated as follows:

$$W_{OR} = 1.30 \times \Sigma W$$

Where, 1.30 = Multiplying factor to compensate for losses.

$$W_{OR} = 1.30 \times 365 = 474.5\ \text{W};\ W_{OR} \approx 475\ \text{W}$$ (to nearest whole number)

In view of future loads and the fact that it is not all that expensive to design and develop an inverter that is a bit higher than the above design value, the output rating of the inverter is intentionally sized 600Watt which is rated 750 VA by simple calculation with a power factor of 0.8.

Table 1: Load Calculation

Item	Description	Quantity	Rating (W)
1	Television	2	170
2	Decoder	1	25
3	IndoorFluorescent Lighting	4	80
4	SecurityFluorescent Lighting	4	80
		Total=Σ(W)	365

2.3 Design of the inverter units

The inverter designed for the viewing centre contained units like an oscillator, driver amplifier, class B push pull power MOSFET amplifier circuit, centre-tapped isolated step-up transformer and a wave modifying circuit.

2.3.1 Oscillation unit

Integrated circuit (IC) CD4047 was used as the oscillator for the inverter. The IC is capable of operating in either the monostable or astable mode. However, for this design, its operation in the astable mode is utilised. The IC requires an external capacitor and an external resistor to determine the output frequency in the astable mode.

The period of the oscillator (T) when operating in the astable mode is given by:

$$T = 4.40RC \qquad (1)$$

But generally,

$$T = \frac{1}{F} \qquad (2)$$

Where, T = Period of oscillation, F = Frequency of oscillation

Assuming an operating frequency (F) of 50Hz, the period (T) of the oscillator is obtained as follows:

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

$$T = \frac{1}{50} \quad T = 0.02 \text{ Sec}$$

Substituting the values of C and T into equation 1, we obtain the value of the external resistor required as follows:

$$T = 4.40RC$$

$$0.02 = 4.40R\left(0.01\times10^{-6}\right) \qquad R = \frac{0.02\times10^{6}}{4.40\times0.01}$$

$$R = 454.55K\Omega$$

Combination of a fixed resistor with five per cent maximum tolerance and a preset resistor is used to make up the above total value of eternal resistor R. In view of the above, a 390KΩ, five per cent tolerance, fixed or decade resistor and a 100KΩ preset resistor totalling 490KΩ and which is close to the value of the external resistor R were used._To obtain the actual value of the external resistor from the combination, the preset resistor was carefully and accurately set to 64.55KΩ. The oscillator circuit also requires a low pass passive circuit of R_1C_1 for the purpose of removing the unwanted ripples in the circuit. In order to prevent the IC CD4047 from being damaged by the bulky current from the battery powering it, a limiting resistor R_1 that limits this current (I_{IC1}) to a safe value of 550mA is used. The value of the limiting resistor is obtained as follows:

$$R_1 = \frac{V_{IC1}}{I_{IC1}} \qquad (3)$$

Where, V_{IC1} = 12V (Voltage across the IC_1)

$$R_1 = \frac{12}{550\times10^{-3}} \qquad R_1 \approx 22\Omega$$

Similarly, the value of the capacitor C_1 was carefully chosen so as not to unnecessary delay the starting or powering of the IC CD4047 when the power switch is ON. In view of the above, 240μSecs was preferred as the R-C charging time constant (t). The value of capacitor C_1 is obtained as:

$$C_1 = \frac{t}{1.1R_1} \qquad (4)$$

$$C_1 = \frac{240\times10^{-6}}{1.1\times22} \qquad C_1 \approx 10\mu F$$

2.3.2 Driver amplifier unit

The driver amplifier in this design is used to amplify and strengthen the weak output signal from the oscillator. The amplifier also prevents frequency drift. The driver consists of two complementary transistors connected in a common collector configuration at each output of the oscillator. Transistors BF422 and BF423 are used as the driver because they are complementary of each other. They are also high voltage components that have collector to base volts (BV_{CBO}) and collector to emitter volts (BV_{CEO}) of 300V each. The current at the terminals of the oscillator must be limited to a safe value for the common base of transistors BF422 and BF423. The value of the limiting resistor (R_4 or R_5 as the case may be) required for this purpose is obtained as follows:

$$I_B = \frac{V_B}{R_4} \qquad (5)$$

Where, I_B = Base current of the transistor and V_B = Base voltage of the transistor

Also,

$$I_C = I_B h_{FE} \qquad (6)$$

Substituting equation 5 into equation 6 and making R_4 the subject of the formular, we obtain,

$$R_4 = \frac{V_B \times h_{FE}}{I_C} \qquad (7)$$

Where, h_{FE} = Current gain of the transistor and I_C = Maximum collector current.

The value of R_4 or R_5 can be obtained using the above equation 7.

V_B = 6V (Voltage at the base of the transistor during the half cycle oscillation). From the data sheets of the transistor BF422 and BF423, h_{FE} = 40 and I_C = 500mA (0.5A)

$$R_4 = \frac{\mathrm{V_B} \times h_{FE}}{\mathrm{I_C}}$$

$$R_4 = \frac{6 \times 40}{0.5} \quad R_4 = 480\Omega$$

The nearest value of resistor which is 470Ω was used as R_4 or R_5. The limiting resistor was connected between the oscillator and the driver amplifier.

3.0 Power MOSFET Amplifier Unit

The power MOSFET amplifier unit provides the requisite amount of power for the inverter. In this design, a class B push pull amplifier that uses MOSFET was used as the power amplifier. In order to prevent the gate region of the MOSFET from being damaged by excessive gate current, small current of 5.29mA was used. In view of the above, a series resistor was required between the emitter output of the driver amplifier and the gate of each of the MOSFET for the purpose of limiting the gate current to the above chosen value. The value of the series limiting resistor (R_S) is obtained as follows:

$$R_S = \frac{\mathrm{V_E}}{\mathrm{I_G}} \tag{8}$$

Where, V_E = Voltage at the emitter of the transistor and I_G = Gate current

But $V_E = V_B - 0.6$ (9)

Where, V_B = Voltage at the base of the transistor (BF422/BF423) at the half cycle of the oscillation

0.6 = Voltage drop at base of the transistor since it is in common collector configuration

$$R_S = \frac{\mathrm{V_B} - 0.6}{\mathrm{I_G}} \tag{10}$$

$$R_S = \frac{6 - 0.6}{5.29 \times 10^{-3}} \quad R_S = 1020.79\Omega$$

Two series resistors of 1KΩ and 22Ω being the nearest to the value of R_S are used. R_6 and R_7 are 1KΩ each while R_7, R_8, R_9, R_{10}, R_{11}, R_{12} and R_{13} are 22Ω each.

The inverter has a useful AC output power ($P_{OUT(AC)}$) of 600watt. This corresponds to 78.5 per cent (maximum efficiency of class B push pull amplifier) of the input DC power.

The input DC power ($P_{IN(DC)}$) is computed as follows:

$$P_{IN(DC)} = \frac{P_{OUT(AC)}}{78.5\%} \tag{11}$$

$$P_{IN(DC)} = \frac{600}{78.5\%} \quad P_{IN(DC)} = 764.33 Watt$$

Total heat dissipated (P_D) is obtained as follows:

$$P_D = P_{IN(DC)} - P_{OUT(AC)} \tag{12}$$

$$P_D = 764.33 - 600 \quad P_D = 164.33 Watt$$

The total input current (I_{IN}) required to deliver the desired output AC power is computed as follows:

$$I_{IN} = \frac{P_{IN(DC)}}{V} \tag{13}$$

Where, V = Operating direct current voltage

$$I_{IN} = \frac{764.33}{12} \quad I_{IN} = 63.69 Amps$$

Six numbers of power MOSFET transistors are used in the circuit, the current delivered by each power MOSFET transistor (I_T) is obtained as shown below:

$$I_T = \frac{\mathrm{I_{IN}}}{6} \tag{14}$$

$$I_T = \frac{63.69}{6} \quad I_T = 10.62 Amps$$

Since it is better and safer to use component that has value that is higher than the design value, IRFP 260N power MOSFET transistor that is n – channel type operating in the enhancement mode and which can deliver 50 Amps is used.

3.1 Centre-tapped isolated step-up transformer unit

The transformer designed for this inverter is a centre-tapped isolated step- up transformer. The transformer is a small power transformer of 600W capacity.

3.2 Complete inverter circuit

Figure 1 is the complete 750 VA inverter circuit. In addition to this, the table 1 below also shows the various components used in the inverter circuit and their respective functions.

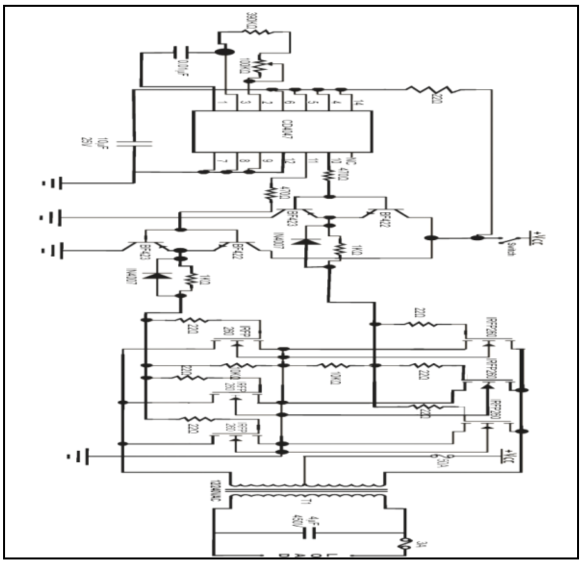
4.0 Development of the Designed Inverter Units

Circuit diagram shown in figure 1 was used for the development of the various units of the inverter.

4.1 Oscillation and driver amplifier units:

Oscillator and the driver amplifier units were constructed on the same vero board. A 14 Pin integrated circuit (IC) holder for the CD4047 used as the oscillator was positioned on the board and soldered. The purpose of this was to prevent excessive heat at the legs of the IC when soldered directly. Other components like the resistors (fixed and variable); capacitors were connected to the appropriate pin number of the IC on the board and soldered. Pin numbers 4, 5, 6 and 14 and 7, 8, 9 and 12 of the IC on the board were looped together using strands of copper wire. After the soldering, the excess leads of the capacitor, resistors were cut off. Driver amplifier unit was also constructed. Transistors BF422 and BF423 were arranged in common collector configuration on the board and soldered. The bases of the two transistors were connected to pin 10 of the IC through a 470Ω resistor. The above procedures were also repeated at pin 11. A 1KΩ resistor and a diode connected in parallel (i.e. the two ends of both the resistor and the diode soldered together) was connected and soldered to the common emitter of the two transistors at pin 10 and 11 respectively. The excess leads of all these components were cut away to make the board look neat. At the tail end of the board, two short lengths of solid wire were soldered at the upper tail end and lower tail end of the board as positive and ground terminals respectively. The loop of IC pin number 4, 5, 6 and 14 was connected through a 22Ω resistor to the positive terminal. The collectors of BF422 transistors at both pin 10 and 11 were also connected to the positive terminal. Moreover the loop of IC pin number 7, 8, 9 and 12 was connected to the ground terminal. The collector of BF423 transistors were also connected to the ground terminal.

Fig 1: The Complete 750 VA Inverter Circuit



4.2 Power MOSFET amplifier unit

A solid ferro board (i.e. board with no holes and which can withstand high current) was used for this unit. Two sets of heat sinks were used with each having a capacity for three transistors. Three power MOSFET transistors were connected to each of the two short lengths of the heat sinks. The heat sinks were arranged on the board with the gate and source leads of the power MOSFET transistors fixed on them. The gate and source lead of each of the transistors was soldered to the board. Moreover, the 22Ω resistors to limit the respective gate currents were arranged and soldered appropriately. It was also ensured that all the sources of the power MOSFET transistors were connected to the ground.

4.3 Centre-tapped isolated step-up transformer unit

The transformer constructed for this inverter was a centre-tap isolated step-up transformer. A plastic former and laminated iron core were used for the transformer. The primary and the secondary winding of the transformer were wounded with insulated copper wire of standard wire gauge 14 and 20 respectively.

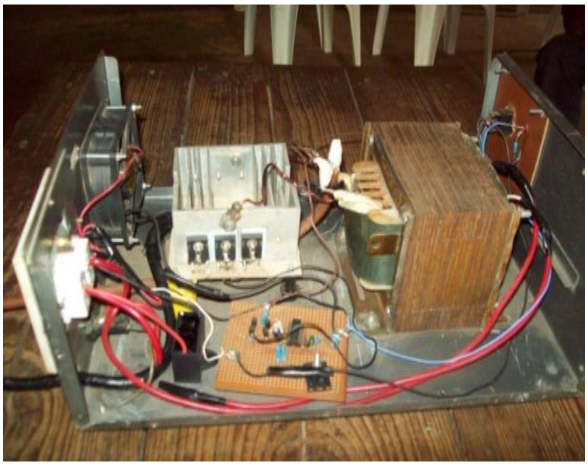
4.4 Assembling of the inverter units

All the above constructed components of the inverter were assembled together inside a metal case (35cm × 25cm × 14cm) fitted with a 12VDC heat extractor fan. The board containing the oscillator and the complementary class B push-pull amplifier was seated on a locally made stand. Similarly the board containing the power MOSFET amplifier was seated next to the oscillator board on a special locally- made stand. Wires were used to connect the limiting resistors on the oscillator and complementary class B push-pull amplifier board to the gates of the MOSFET transistors. The transformer was bolted to the base of the metal case immediately after the power MOSFET amplifier board. Each of the two leads of the primary winding were fitted with cable lug and connected with bolts and nuts to each of the heat sinks respectively. The two leads of the secondary windings were connected to the output socket fitted to the metal case. A 4μF 450V capacitor was connected across the output of the transformer. The supply cable to the positive of the 12VDC battery was connected through a rewire-able fuse to the centre-tap of the transformer. Also, the supply cable to the negative of the 12V battery was connected to the ground on the power MOSFET amplifier board. Figure 2 shows the picture of the completed designed and developed 0.75kVA inverter circuit.

Table 2: Result of Load Test

Load(W)	Input DC Power (W)	Output AC Power (W)
60	116.38	52.60
100	170.10	106.68
160	202.86	134.46
200	218.37	159.25
300	295.78	224.64
400	332.95	257.60
500	419.46	321.63
600	443.92	339.48
700	521.98	405.90

Fig 2: The Picture of the Assembled 0.75kVA Inverter



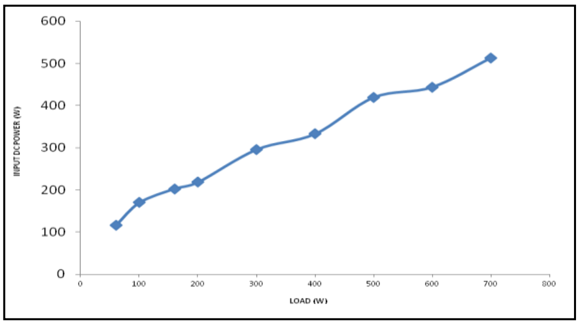
5.0 Results and Discussions

The developed and installed inverter was tested under load by using it to supply load ranging from 60W to 700W. The corresponding input direct current power $P_{IN(DC)}$ and output alternating current power $P_{OUT(AC)}$ for each of the loads was obtained and this is shown in table 2.

5.1 Discussion of the load test result

The results obtained from the load test show that the higher the load, the higher the input direct current power drawn from the battery. This is seen more clearly from the figure 3.

Fig 3: Input DC Power Versus Load



Similarly, the results also show that an increase in the load will lead to increase in the output alternating current power supplied by the inverter. Figure 4 illustrates this.

Fig 4: Output AC Power versus Load

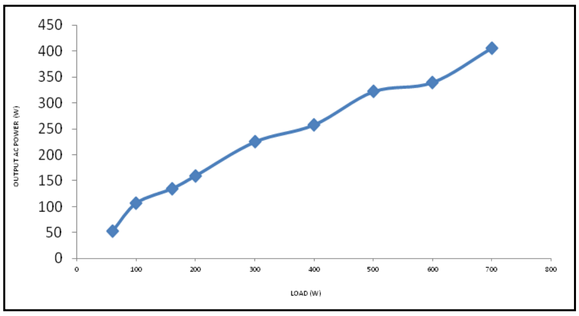


Table 3: Bill of Engineering Measrement and Evaluation for 750 VA Inverter

Items	Quantity (Pieces)	Unit Price (#)	Total (#)
Semiconductors			
CD 4047	1	400	400
IRFP 260N	6	750	4500
BF 422	2	50	100
BF 423	2	50	100
IN 4007	2	10	20
Resistors			
22Ω	7	10	70
100Ω	1	20	20
390KΩ	1	10	10
470KΩ	2	10	20
1KΩ	2	10	20
10KΩ	2	20	40
Capacitors			
0.01μF	1	10	10
10μF	1	20	20
4μF	1	10	100
Others			
Switch	1	40	40
Fan	1	100	100
Soft Iron Core	–	4000	4000
Ferro Board	–	200	200
Metal Casing	–	2500	2500
Cable	1M	300	300
Coil	2.5 K	1800	4500
Total= # 17,070			

5.0 Conclusions

An inverter that is suitable for use in a solar powered viewing centre at a selected rural community of Iloro II was developed. Electrical and electronics materials used for its construction are readily available in the Nigerian market. This inverter was later installed. The performance of the inverter in a stand-alone system was also evaluated. Average efficiency of the inverter was about 70 %. Load test and output waveform test were used to analyse the performance of the inverter which was found to be satisfactory.

This study has fulfilled one of the objectives for the establishment of the university, which is to solve problems through the use of science and technology. The problem of lack of access to information has been solved at the selected rural community of Iloro II. The villagers now gather themselves at the viewing centre in the evenings after the day's work to watch programmes on NTA, OSRC and the satellite channels and hence keep themselves abreast of happenings in their environment, the nation and the world at large. They also benefit maximally from the various advantages of electronic information, education and entertainment. These are some of the ways by which government can educate, inform, govern and entertain people at the grass roots. The inverter has serviced the solar powered viewing centre at Iloro II effectively and efficiently. It can be safely concluded that this inverter is suitable for this type of application. There is room for improvement on the developed inverter. The output waveform of the inverter may be improved upon. Also, an additional circuitry to shut down the inverter when the voltage of the battery is low may be included in the design.

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