Design and Simulation of a 120V Electrical Inverter.

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ABSTRACT

In this work, an electrical inverter has been designed, simulated, constructed, and tested using electronic engineering techniques to transform direct current (DC) from a solar panel into alternating current (AC). The component values were first determined before simulating the circuit using electronic work bench (EWB). A computer aided design (CAD) software was used to monitored each design stage(s) and to trouble shoot any error present in the circuit after which the overall circuit of electrical inverter was constructed, tested, and housed in a rectangular metal cabinet, the electrical inverter produced 120V output when applied to 12V solar panel and the efficiency was found to be 85.8%, which is adequate for any technical design.

(Keywords: efficiency, electrical conversion, alternating current, direct current, electricity)

INTRODUCTION

An inverter 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 use of appropriate transformer, switching, and control circuits. An inverter converts the DC from the source such as batteries, solar panels, or fuel cells. The electricity can be at any desired voltage that can operate AC equipment (Wikipedia, 2010).

Power supplies in Nigeria are highly inconsistent and are distributed at a very low level compared with customers' demands. The government of Nigeria has devoted huge sums of money to improve the stability of the power supply but the situation prevails.

Nigeria is one of the countries of the world that is endowed with abundant natural resources, prominent among these resources is solar insolation which give provides pure and inexhaustible energy (EIA, 2004). This type of energy could be utilized to effectively reduce the problem of insufficient electrical power supply.

Solar energy is obtained by conversion of sunlight into electricity through solar cells and electrical inverters. These types of cells are a non mechanical device usually made from silicon alloys, and like batteries, generate DC electricity. For this direct current to operate most types of electrical appliances it must be converted to AC by using an electrical inverter; this prompted the emergence of this work.

Any reliable power company is expected to serve customers with little interference (Shalangwa, 2009). The inadequate supply of electricity deters most types of economic activities and cause a great set back to the most communities in Nigeria. Therefore it has become necessary to develop an operated electrical inverter that will serve as an alternative source of electricity supply to enable some business and other activities to move forward. All of the problems mentioned above can be mitigated with full implementation of solar systems and inverters.

DESIGN COMPONENT

This section deals with the design stages of the complete circuit diagram of the electrical inverter. The design took the following stages as shown in Figure 1.

Figure 2 shows the oscillator circuit design. The 555 timer was used in the design as a stable mode configured to operate as a multivibrator; the capacitors, C_1 and C_2, should be limited to the range $1nF$ to $100\mu F$; $(R_1 + 2R_2)$ should lie between $1K\Omega$ to $10m\Omega$ for peak to peak oscillation (Schultz, 2003); and the frequency should be 50Hz to achieve a 50% duty cycle. The oscillator generates pulse by charging and discharging of the capacitor C_1, the capacitor C_2 is used for decoupling and has no effect on the operation.

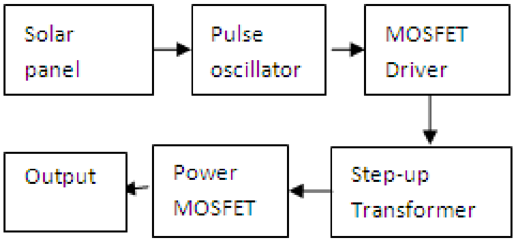

Figure 1: Block Diagram of Electrical Inverter.

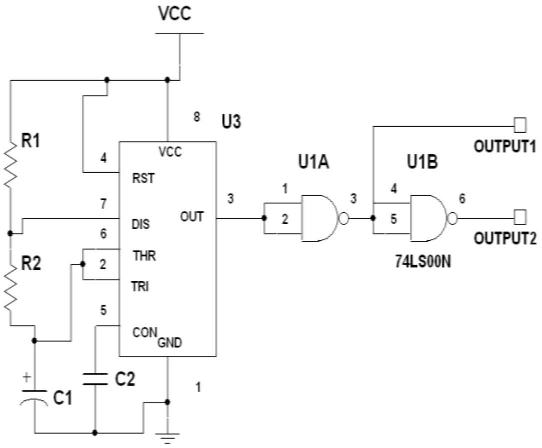

Figure 2: Pulse Oscillator Circuit.

The time that the output is HIGH (t_H) depends on how long it take C_1 to charge from $\frac{1}{3}V_{CC}$ to $\frac{2}{3}V_{CC}$ it is given by (Floyd, 2002).

$t_H = \ln(R_1 + R_2)C_1$ **(1)**

Also, the time that the output is LOW (t_L) is how long it takes C_1 to discharge from $\frac{2}{3}V_{CC}$ to $\frac{1}{3}V_{CC}$ given by:

$t_L = in2R_2C_1$ **(2)**

Where t_H and t_L stands for charge and discharge time, respectively.

The total time taken to charge and discharge the capacitor C_1 is the sum of t_H and t_L given as,

$T = t_H + t_L$ **(3)**

Combining Equations (1) and (2) and substituting in (3) yields Equation (4):

$T = \ln 2(R_2 + 2R_2)C_1$ **(4)**

The frequency of the oscillation was computed using (5):

$F = \frac{1}{T}$ **(5)**

where, F is the frequency of the (Shalangwa 2010).

Substituting Equation (4) into (5) we have:

$F = \frac{1.44}{(R_1 + 2R_2)C}$ **(6)**

Choosing $F = 50HZ$ and C to be $0.3\mu F$ For easy selection of R_1, R_2 was also chosen as $47K\Omega$, therefore:

$(R_1 + 2R_2) = 95K\Omega$ **(7)**

Taking C_1= 0.3µF so that from Equation (6) we have $F = 50.52HZ$ (which is satisfactory).

The Duty Cycle of the oscillator circuit was determined using Equation (8):

Duty cycle $= \left(\frac{t_h}{T}\right)\%$ **(8)**

Where t_H is the time that the output is high (Floyd, 2002).

Combining Equations (1) and (4) and substituting in Equation (8) we have:

Duty cycle $= \left(\frac{R_1 + R_2}{R_1 + 2R_2}\right)\%$ **(9)**

Duty cycle $= 50.52HZ$

The output of the oscillator is connected to the logic inverter from 72L500 NAND gate to create antiphase signal of the alternating current so as to drive the MOSFET for better performance of the center tapped transformer.

MOSFET Driver circuit Design

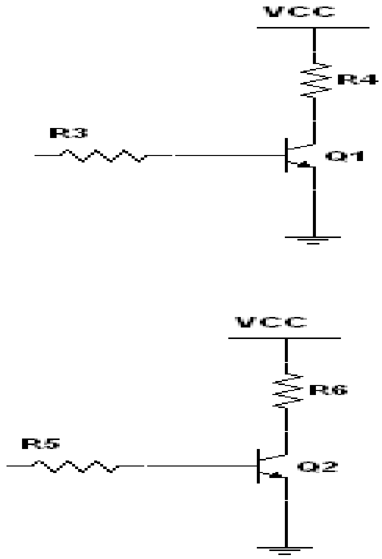

Figure 3: MOSFET Driver Circuit.

The output voltage of the oscillator ranges between 0-5V, the driver converts it to 12V (Floyd, 2002).

$$R_3 = 0.5\beta_{\min}R_4 \qquad \textbf{(10)}$$

$\beta_{\min}$ is the amplification factor.

Choosing $R_4 = 39K\Omega$ and $\beta_{\min}$ for $C1815$ is 20 (Datasheet, 2009), then R_3 becomes $R_3 = 390K\Omega$

The two transistors circuit shown in Figure 3 driven between two states OFF and ON.

OFF state

$$I_3 = I_4 = 0 \qquad \textbf{(11)}$$

Applying KCL to the circuit of Figure 3, this now enable us to determined the collector emitter voltage with respect to the ground given by (Horowitz, 1998).

$$V_{out} = V_{CE} = V_{CC} - I_4R_4 \qquad \textbf{(12)}$$

Consider V_{CC} = 12V, if $I_3 = I_4 = 0$, V_{CC} become equal to $V_{CC} = V_{out} = V_{CE} = 12V$.

ON state

Using Ohm's law from the circuit of Figure 3, we have:

$$I_{R_4} = \frac{V_{CC}}{R_4} \qquad \textbf{(13)}$$

Therefore I_4 is then computed as:

$$I_{R_4} = 307.7\mu A$$

The collector emitter voltage with respect to the ground can also be computed using Equation (12) as $V_{CE} = V_{out} = 0V$.

Therefore, when Q_1 is OFF Q_2 is ON and $V_{out} = 0V$, and when Q_1 is ON Q_2 is OFF and $V_{out} = V_{CC}$.

Power MOSFET Switching Circuit and Transformer Design

This circuit employed two power MOSFET transistors $(IRFP250N)$. The arrangement provided is for shearing of load current and allowed a better power handling. The transistors are connected directly to the power transformer to make up the power at all stages. Each transistor was connected to each side of the transformer primary to share the heavy current. The power dissipated in the transistor increases the internal temperature above the ambient temperature, and the heat sink is used to conduct the heat from the transistor. Since the transformer is a step-up, the output voltage can be computed as:

$$\frac{V_S}{V_P} = \frac{N_S}{N_P} \qquad \textbf{(15)}$$

Where VS,VP,NS and NP is the secondary voltage of the secondary turns, voltage of the primary turns, number of secondary turns and number of primary turns of the transformer, respectively (Tharaja, 2005).

$$V_S = \frac{V_P N_S}{N_P} \qquad \textbf{(16)}$$

V_S, then computed as;

$$V_S = 122.6V$$

The power can be computed using Equation (17) as:

P = IV **(17)**

Where I is the current and V is the voltages.

CONSTRUCTION DETAILS

The construction of the inverter circuit comprises of pulse oscillator circuit, MOSFET driver circuit, power MOSFET switching circuit, and the output transformer. The electronic components of the inverter were first assemble on the breadboad to ascertain their function, before being transferred on the vero board where constructions were done step by step (Shalangwa, 2010).

Pulse Oscillator Circuit and MOSFET Driver Circuit Construction

The pulse oscillator circuit was first constructed on a breadboard with the 555 timer and passive components built around it. It was powered by a 12V D.C tapped from the 12V D.C source. The IC regulator was introduced to regulate the 12V to 5V, since the output of the oscillator takes on 0V to 5V. The MOSFET driver was connected to the 5V output of the oscillator and the driver convert the 5V to 12V before it was finally transferred on to a vero board as shown in the Figure 4.

Transformer Construction (Windings)

The transformer consists of primary and secondary windings. The primary winding of the transformer has 70 turns with a wire of thickness 0.55mm diameter. The secondary winding of the transformer has 715 turns with a wire of thickness 0.60mm diameter. The wire gauge of the two conductors was tested by a micrometer screw gauge. The continuity of both conductors was also tested using a multi-meter. The primary winding has two tapping points each point has equal number of turns, the secondary winding also has two tapping points with an equal number of turns which gave 120V AC output voltage.

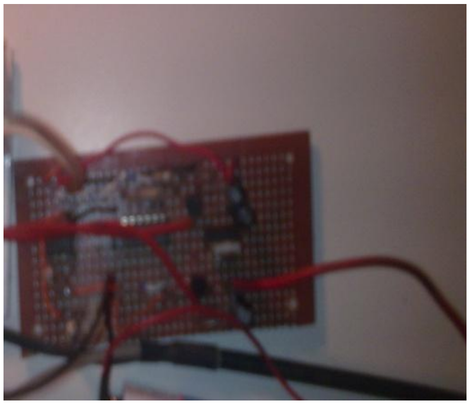

Figure 4: Circuit Layout of the Oscillator.

The Power MOSFET Switching Circuit Construction and Assembling

The two power MOSFET transistors (IRFP250) used in the switching circuit were mounted on a heat sink and connected together as designed. A nylon bust was placed in each of the holes on the heat sink where the power transistor was mounted. A mica washer was placed between the power transistors and the heat sink, this process was done to prevent the bodies of the power transistor from making contact with the heat sink. The power MOSFET transistors mounted on the heat sink was soldered on a separate vero board, and it was connected to the AC transformer. The transformer and the inverter circuit were mounted inside the casing which has provision for outlet switch, display meter, fuse, and cord for the battery. The transformer was screwed on the bottom of the case as shown in Figure 5.

TESTING AND SIMULATION

The instrument used to test the value of the resistors was multimeter. This test was carried out to find out whether the values of each resistor is in accordance with what is stated by the manufactures in respect to each resistor. Other components such as transistors, capacitors and diodes were also tested to determine their working condition before inserting them on to the circuit board.

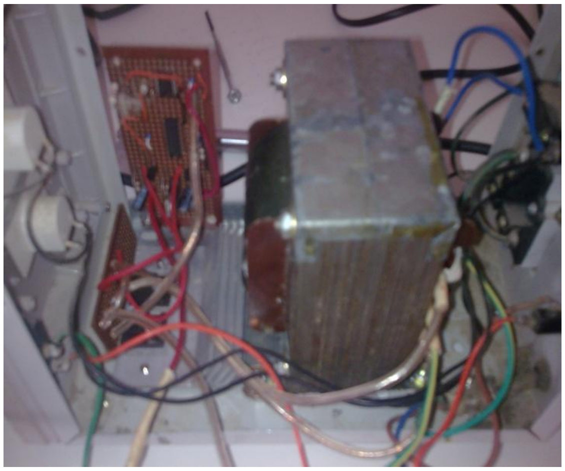

Figure 5: Complete Assembly of the Power Inverter.

Oscillator Pulse Circuit Testing

This stage was tested to ensure the workability of the oscillator circuit which was designed to operate at 50Hz. In the test, simulation was applied and live oscilloscope test, a square wave was generated with 50% duty circle as shown in Figure 6 and Figure 7, respectively.

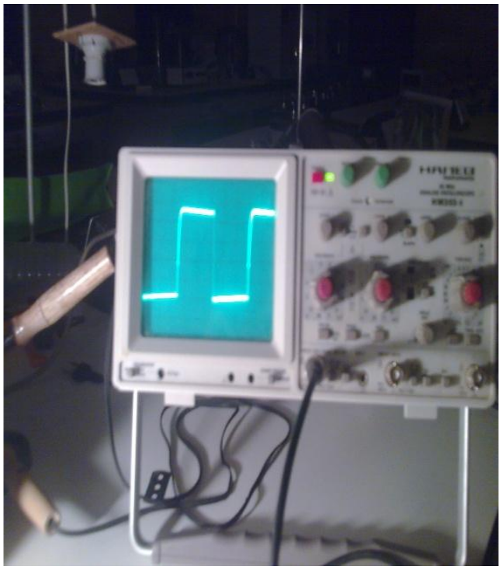

Figure 6: Live Oscilloscope Test of Oscillator Pulse Circuit.

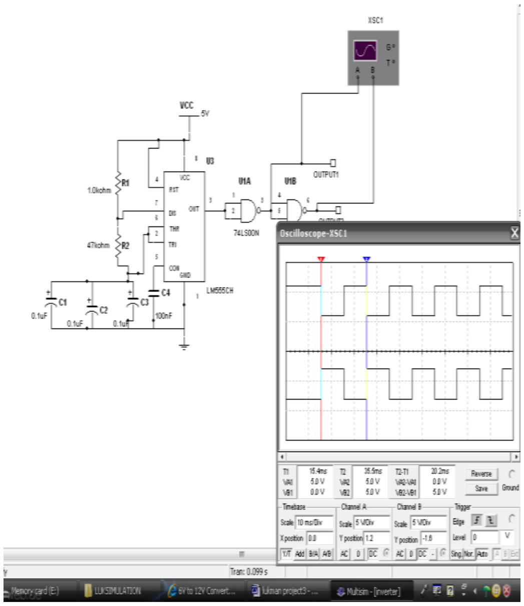

Figure 7: Oscillator Pulse Circuit Test Using Simulation.

MOSFET Driver Testing

This test is to confirm the function of the MOSFET Driver. The circuit which is made up of transistors is expected to operate in two states (ON and OFF) as determine by the both simulation and live oscilloscope. The ON-time of one transistor was found to be equal to the OFF-time of the other transistor and vice versa as shown in Figure 8 and Figure 9, respectively.

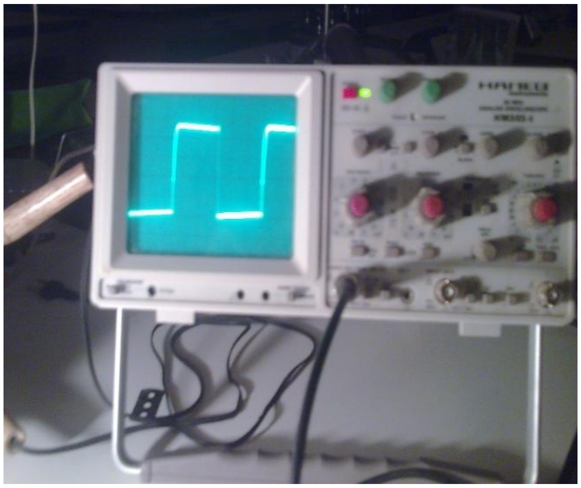

Figure 8: Live Oscilloscope Test of MOSFET Drivers.

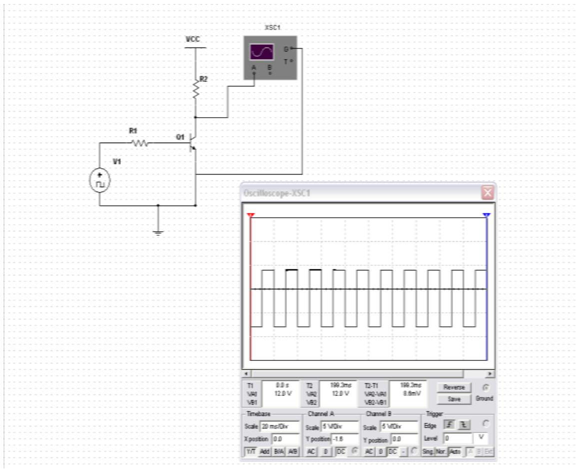

Figure 9: Simulated Circuit of MOSFET Driver.

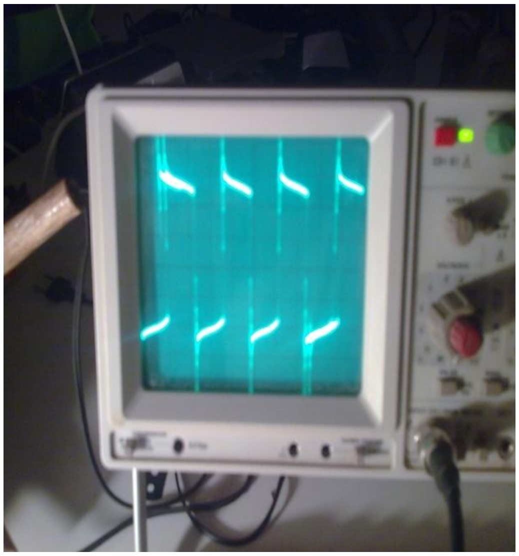

Figure 10: Live Oscilloscope Test of the Complete Power Inverter.

RESULTS AND DISCUSSION

Table 1: Incandescent Bulb Measured Results.

P_B (W)	I_{in} (A)	I_o (A)	V_{in} (V)	V_o (V)	P_{in} (W)	P_o (W)
60.0	1.56	0.81	12.0	19.5	19.1	16.4
40.0	1.20	0.12	12.0	97.0	14.4	11.6
15.0	0.57	0.03	12.0	107	6.84	3.21

The Institute of Electrical Engineers IEE (1985) Regulation stipulates that every new assembly requires testing before it can be connected to the power supply in other to be sure that it function properly and safely. In line with this regulation, all the modules were tested and satisfied as functional before the inverter was connected to the DC source battery.

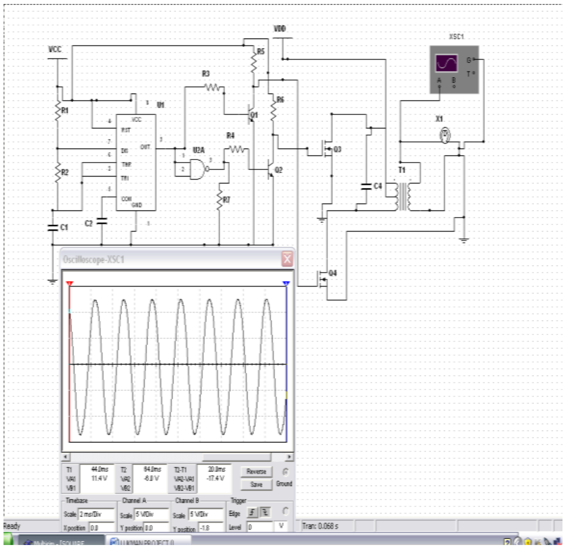

Figure 11: Simulated Circuit of the Power Inverter.

As a test bed, car battery was used first instead of the solar panel for the input power supply and the incandescent bulbs were used as the load. The input voltage, output voltage, input current and output current were all measured as shown in Table 1, while the input power and output power were also computed by using equation (17 using the parameters in Table 1).

When increasing the wattage of the bulb, the input current, output voltage fall as shown on Figure 12 to 13, whereas the output current, input power and output power increases as the wattage of the bulb increases as shown on Figure 14 to 15, but the input voltage remain constant as the wattage of the bulb increases, from the result measured and the graphs plotted it will help us to determine the variation of the current, voltage and power consumption.

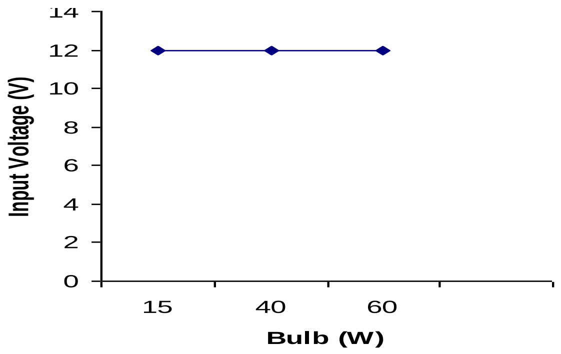

Figure 12: Variation of Input Voltage with Bulb.

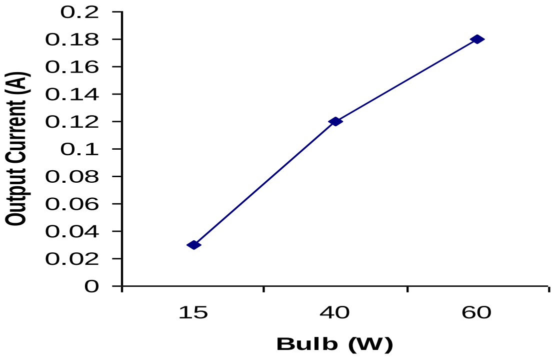

Figure 15: Variation of Output Current with Bulb.

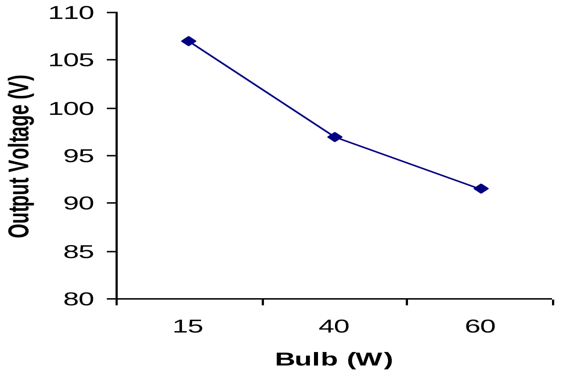

Figure 13: Variation of Output Voltage with Bulb.

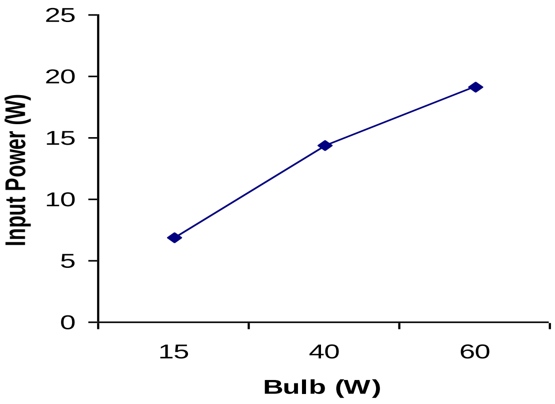

Figure 16: Variation of Input Power with Bulb.

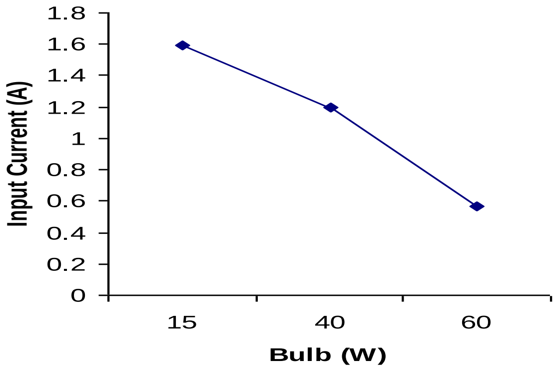

Figure 14: Variation of Input Current with Bulb.

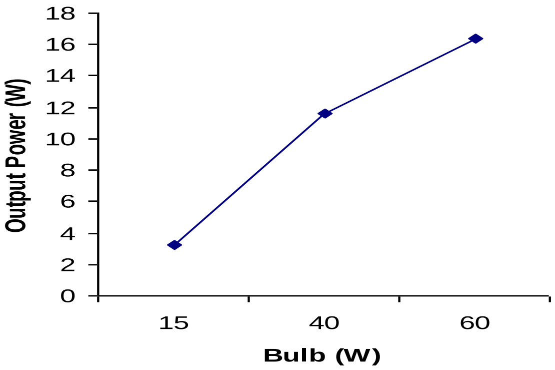

Figure 17: Variation of Output Power with Bulb.

CONCLUSION

The design of the electrical inverter was achieved successfully despite a lot of assumptions and approximation made in the design. The circuit design was able to convert the 12V DC supply from the solar panel to 120V alternating current. We believe to the best of our knowledge that this design had expose some technical content of designing an electrical inverter, if desired the same approach can be applied in designing inverter with a better output like 220V-240V.

RECOMMENDATION

The following recommendations are made based on the findings of the study:

1. The output voltage should be extended to 220V or 240V.

2. Provision for the safe and proper use, storage of solar cells and batteries should be properly made due to the high cost of these solar cells.

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