Design and Development of 2.5KVA Inverter Adopting a Microcontroller Based Frequency Meter

M. Ehikhamenle & R. O. Okeke
Department of Electronic and Computer Engineering,
University of Port Harcourt, Choba, Rivers State,
Nigeria
mattinite4u@yahoo.com, remyokeke@yahoo.co.uk

Abstract
The inconsistency of power supply in Nigeria has led to research in the quest of finding solutions in the power sector. This project deals with the design and construction of a single phase inverter which can convert DC voltage to AC voltage at high efficiency and low cost. A low voltage DC source is inverted into a high voltage AC source in two different ways. First, the DC voltage is stepped up using a boost converter to a much higher voltage. This high voltage DC source is then transformed into AC signal using pulse width modulation. Another method involves first transforming the DC source to AC at low voltage levels and then stepping up the AC signal using a transformer. The second method is the one used in this project. The converted AC can be set to any required voltage and frequency with the use of appropriate oscillator circuit, transformers, and switching and control circuits. Incorporated into these systems are devices such as MOSFETs, diodes, resistors and batteries which work hand in hand to obtain the overall desired operation of an inverter. Problems were encountered and tackled in the course of this project design. This design is especially focused upon low power electronic appliances such as personal computers, television sets, etc. the design was first mathematically modelled; then simulated in Proteus and finally, the results were practically verified.

***Keyword**; Proteus, Oscillator Circuit, Boost Converter*

1.0 INTRODUCTION

This project focuses on DC to AC power inverter. Whose aim is efficiently convert a DC power source to a high voltage AC source, similar to power that would be available at an electrical wall outlet.

An inverter is a device that takes a DC input and produces an AC output. The inverter is to be designed to handle the energy requirements of household while yet remaining efficient during periods of low demand. Inverter can be designed in a number of topologies depending on the situation and its requirement. The efficiency of the inverter is highly dependent on the switching device, topology and switching frequency of the inverter. The purpose of this project is to produce an efficient DC to single phase 220 volt AC inverter which can switch on AC household appliances and the battery will be charged by DC source from rectified PHCN.

The method, in which the low voltage DC power is inverted, is completed in two steps. The first being the conversion of the low voltage DC power to a high voltage DC source, and the second step being the conversion of the high DC source to an AC waveform using pulse width modulation. Another method to complete the desired outcome would be to first convert the low voltage DC power to AC, and then use a transformer to boost the voltage to 220 volts. This project focused on the second method described and specifically the transformation of a high voltage DC source into an AC output.

2. LITERATURE REVIEW

The quest to convert dc Power to ac Power has been since the late 19th century and from then to the mid-20th century, dc-to-ac power conversion was accomplished using rotary converters or motor generator sets (M-G sets). In the early 20th century, Vacuum tubes and gas filled tubes began to be used as switches in inverter circuits. (Owen, 1996) The origin of electromagnetic converters explains the source the term inverters. Early ac-to-dc converters use an induction or synchronous ac motor directly connected to a generator (dynamo) so that the generators commutators reversed its connection at exactly the right moment to produce dc. A later development is the synchronous converters in which the motor and generator windings are combined into one armature with slip rings at one end and a commutator at the other, with only one field frame.

The result is a dc in and ac out. With an M-G set, the dc can considered to be separately generated from the ac with synchronous converter. In a certain sense, it can consider to be "mechanically rectified ac". Given the right auxiliary equipment, an M-G set or rotary converter can be run backward; converting DC to AC. Hence an inverter can be called an INVERTED CONVERTER. In modern inverter circuits, the dc power is connected to a transformer primary through the center tap of the primary winding. A switch is rapidly switched back and forth to allow current to flow following two alternate paths through one end of the primary winding and then the other.

The alternation of the direction of flow of current in the primary winding of the transformer produces an alternating current in the secondary winding. The electromechanical version of switching devices includes; two stationary contacts and spring supported moving contact. The spring holds the movable contact against one of the stationary contacts and an electromagnet pull the movable contact to the opposite stationary contact. The current in the electromagnet is interrupted by the action of the switch so that the switch continually switches rapidly back and forth. This electromagnetic inverter switch called vibrator or buzzer was used in vacuum automobile radios. The latest inverter circuits have transistors, FETs, SCRs and other electronic switches incorporated in them because of their advantages over electromagnetic switches.

2.1 PREVIOUS STUDIES RELEVANT TO THE PROJECT

A lot of research work has been carried out over the years in the quest to achieve a noiseless, cheap, and portable converting dc power to ac power.

A circuit was designed by Lane-Fox in 1970, which consisted of two power transistors which were connected in switching mode and controlled by an oscillator from a 9v dc source (battery) to a 120v ac output through a transformer secondary. (Andrew, 1998) The problems with this circuit are:

- Very low load current (in the order of milliamps).
- Poor power efficiency

  In 1986, Jacob designed and constructed a dc-to-ac converter that yielded an output power of 6KVA, 220V AC and 50Hz with efficiency of 93.5%. This solved the problem of low output power and poor efficiency encountered by Lane-Fox's circuit. Everon, a manufacturing company which produces Uninterrupted Power Supplies (UPS) designed an inverter circuit that gave a 4KVA output, 270V AC 50Hz and an efficiency of 95% in the year 2000. This was a huge achievement in the design of inverters and uninterrupted power supplies. (Andrew, 1998)

2.2 MICROCONTROLLER BASED FREQUENCY METER POWER INVERTER

In recent years, with the microcontroller incorporated into an appliance, it becomes possible to use it to measure the output frequency of the inverter. A model is developed to study the propagation of these frequencies through the input and output leads of the inverter. It had been explained that the voltage source PWM inverters generate high frequency common-mode voltage, which induces high shaft voltage, leads to bearing current, and results in premature failure of the bearing. (Hongfei, 2004) The generating mechanism of common-mode voltage of voltage source PWM inverter is discussed, which illustrates that common-mode voltage is ladder-type high dv/dt and high frequency step voltage and its amplitude varies with the states of switching devices. According to theoretical analysis and based on conventional sinusoidal output filter, common-mode connection is introduced i.e., the neutral point of filter Y-connected RC network is connected to the midpoint of DC bus of the inverter. Thus, an improved common-mode sinusoidal output filter is achieved, which can eliminate over-voltage and suppress common-mode voltage. Thus the differential-mode and common-mode problems can be solved synchronously. Results of simulations and experiments indicate the effectiveness of the proposed common-mode filter

3. DESIGN METHODOLOGY

The approach used for this project is realized through the design and implementation of its input subsystem, control unit and output subsystem. The inverter is an electronic device that converts dc voltage form a low dc source to ac voltage of a high output voltage.

In the design we started with the overall system and begin to partition it into systems. The handy tool used at this stage is the block diagram shown below in fig 1 the block diagram depicts the hierarchy of how the inverter sub-circuits will interact and interface with each other. A computer aided design software known as proteus 7.8 version was used for the design simulation of the paper design before the first hardware prototype was actualized or realized on an experimental breadboard. This was achieved through the implementation of the inverter input subsystem to the output subsystem. These were carefully done according to the

Project block diagram and the final schematic circuit diagram.

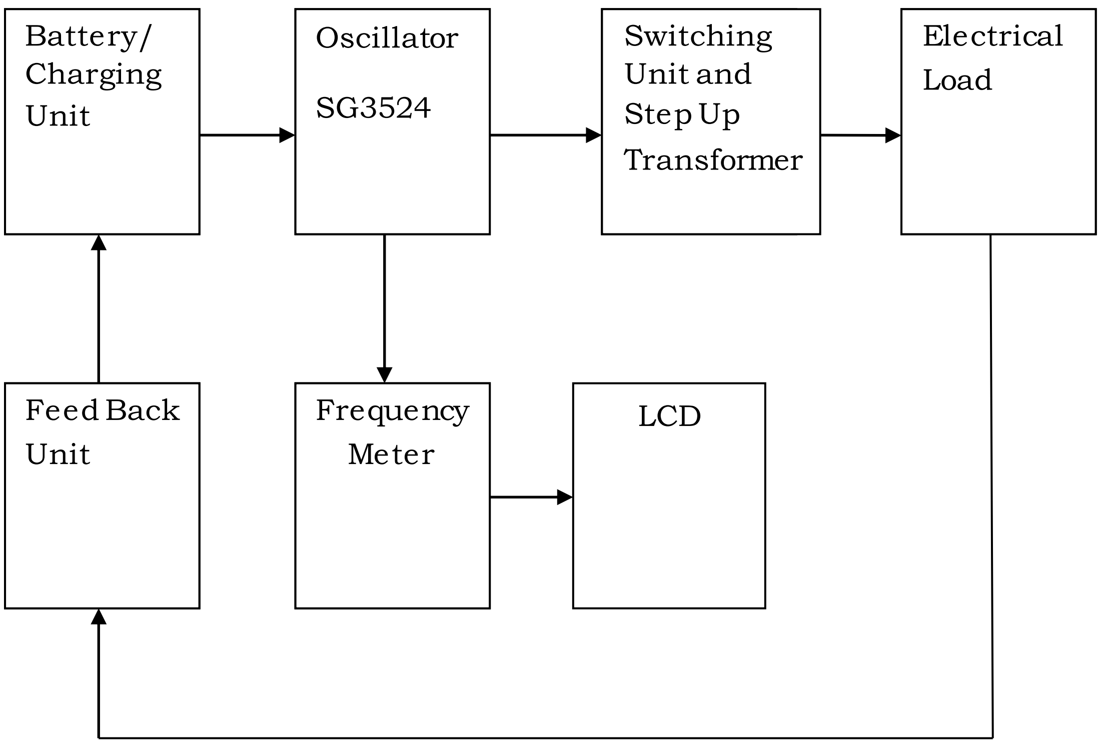

Figure 1: Block Diagram of the Inverter System

3.2 DESIGN ANALYSIS

- **Power stage**: In this stage, battery supplies the oscillator, buffer, power amplifier, and transformer stage with the necessary voltage. A 12V battery is use in our design to power the circuit.
- **Oscillator Stage**: An IC SG3524 is use to generate the necessary pulse needed to drive the MOSFET (IRF260) to alternate the DC supply. The output from the oscillator stage is amplified using power transistor MOSFET. The frequency at which circuit operate is determined with the oscillator stage.
- **Power amplifier stage**: In this stage power transistor MOSFET is use to increase the power signal of the oscillator to match the power of the transformer.
- **Transformer:** The voltage of the amplifier is fed to the transformer to increase (step up) the amplifier output voltage from 12Vac to 220Vac.
- **The electrical load:** The appliances will be connected to the transformer secondary side.
- **The frequency meter:** is used to accurately measure the frequency of the inverter
- **The LCD:** This will display:
  - the frequency output of the inverter,
  - its voltage, and
  - the battery when charging and when fully charged

3.3.1 The Battery and Charging Unit

The figure 2 shows the connection and schematic of the battery and the charging unit. A switch is used to control the flow current and voltage to the charging unit.

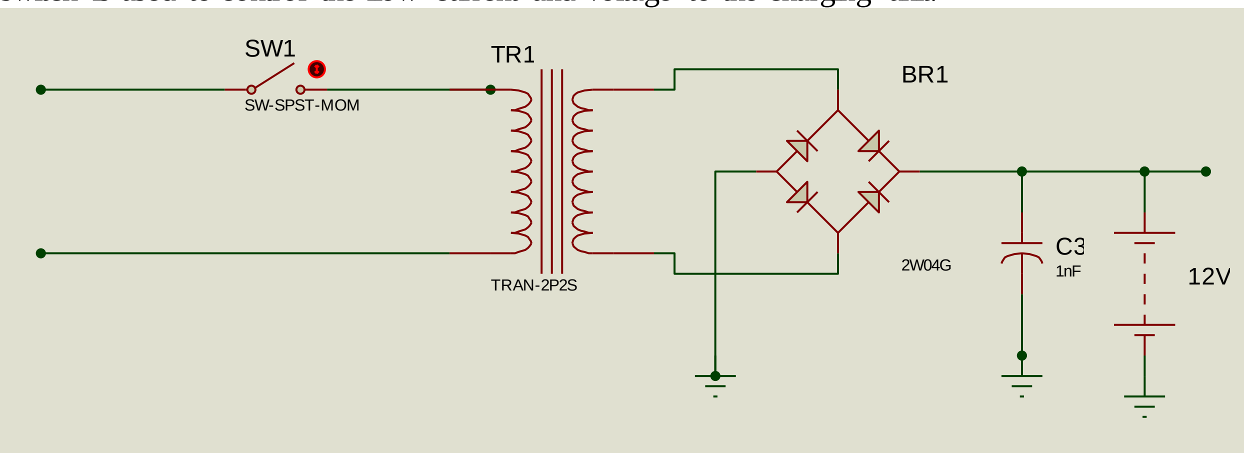

Figure 2: Circuit Diagrams of Battery and Charging Unit

A 12V rechargeable battery is used to store dc voltage. It is connected to the low voltage cutoff circuit. When a load is placed between a cell's terminals, a conductive bridge is formed that initiates chemical reactions within the cell. These reactions produce electrons in the anode material and remove electrons from the cathode material step down transformer is used to step down the main 220V to 12V. It converted the high voltage from PHCN to a voltage that can be used by the electronics component. The following calculation was considered for the choice of the transformer use for the circuit

The transformer has two terminals both in its input and output of 0Vac – 12Vac of the secondary part. The primary side of the transformer has a rating of $220V_{Ac}$ the transformer has a calculation formula for the primary and secondary which is shown below.

$$\frac{E_p}{E_s} = \frac{V_p}{V_s} = \frac{I_s}{I_p} = \frac{N_p}{N_s} = k$$

Where K = transformer constant ratio

The transformer of the circuit was chosen in respect to the load of the circuit. So the transformer of $12_V - 0 - 12_V$ will be able to supply voltage to the circuit.

The main power supply in Nigeria is not always 240_V. So this was taken into account.

$V_p = 220, \quad V_s = 12$

$$\therefore K = \frac{V_p}{V_s} = \frac{220}{12} = 18.33$$

$K = 18.33$

When the main voltage becomes 180v, the secondary voltage will be

$$V_1 = \frac{V_p}{18.33} = \frac{180}{18.33} = 9.82_V$$

Since this is the Vrms voltage, it will be able to supply power to the circuit efficiently due to the peak voltage.

$$V_p = \sqrt{2} \times V_1 = 1.414 \times 9.82 = 13.9v$$

A bridge rectifier is an electronic components used in converting ac voltage into dc voltage. The full-wave bridge rectifier 2W04G was used, having 50V and can pass a peak current of 2A.

A bridge rectifier will be connected to the transformer as shown in fig 3.2 above. There will be a forward voltage drop across the two diodes. Since silicon diodes were used for the bridge rectifier. The forward voltage drop is 1.4 volt.

Therefore, the rectifier voltage gotten after the bridge rectifier will be

$V_{dc} = V_p - V_d = 13.9 - 1.4 = 12.5\ V_{dc}$

Note: $V_d = forward\ voltage\ drop\ across\ diode.$

The PIV rating of the diode to be used should be at least

$PIV = V_p - V_D$

$= 12.5V$

Therefore PIV is far greater than this value 12 thus, making it suitable for this design. A capacitor is used to filter off the ripples before it is then connected to the battery, for the circuit to charge the battery.

3.2.2 Oscillator Unit

The oscillator unit is achieved with the use of SG3524 integrated circuit chip. The oscillator circuit is shown in figure 3

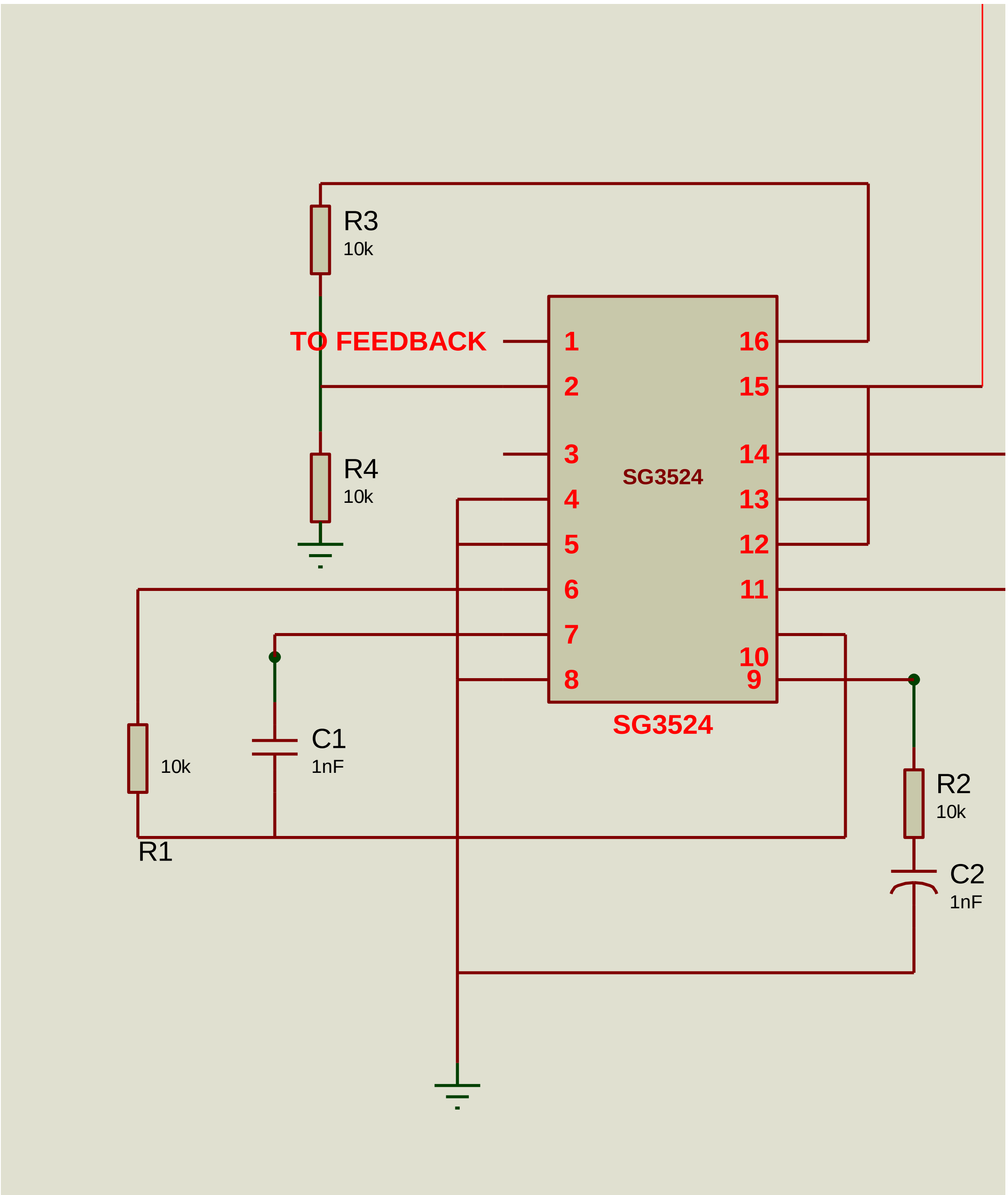

Figure 3 Circuit Diagram of the Oscillator Unit

The oscillator produces the pulse necessary inverter system, the frequency generated is 100 hertz this gotten from the calculation gotten from a formula in the datasheet of the IC.

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

Where F = Frequency of signal, R= the resistor for the oscillator, C= capacitor for the oscillator. The frequency is 100 hertz, the capacitor value is 1nF. (gotten from the data sheet) So the resistance value will be calculated.

$$100 = \frac{1}{1 \times 10^{-6} \times R}$$

$$R = \frac{1}{100 \times 1 \times 10^{-6}}$$

R = 100,000 ohms.

Therefore the resistor that will be used is 100,000ohms. This frequency that is generated is from the two output terminals of the oscillator which are pin 11 and pin 14.
This will give the frequency of 50 hertz each at pin 11 and pin 14 of the pulse width IC. Pin 8 of the IC is the ground terminal. pin 15 is the voltage input of the IC 12V from the battery is connected to it. Pin 11 and pin 14 is connected to the MOSFET gate via a 1kilo ohms resistor.

3.2.3 Frequency Meter and the Charging Monitoring Unit

The frequency meter unit is used to measure the output frequency of the inverter unit.

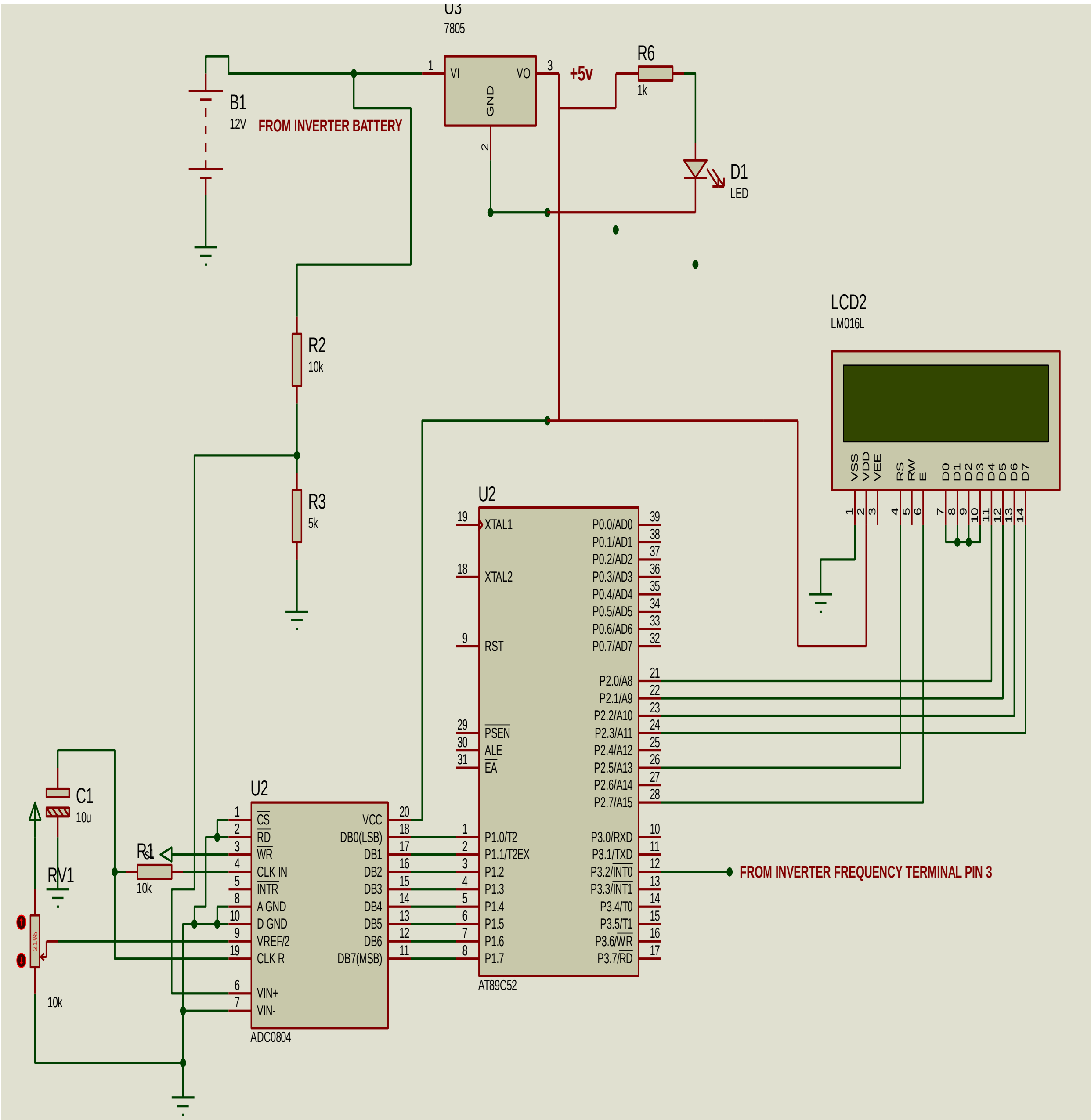

Figure 4: Circuit Diagram of the Frequency Meter and charging monitoring Section

This is done by using the timers of the Atmel microcontroller. The timer is use to count the rising time of the pulse generated by the oscillator circuit. The value of the timer is displayed on a liquid crystal display. The diagram of the timer and charging monitoring system is shown in figure 3.5. The charging monitoring unit circuit is made up of the voltage divider circuit and an analogue voltage converter circuit. The voltage divider circuit is made up of the two resistor connected together in series to drop the voltage. The ADC circuit is use to convert the voltage from the voltage divider to a digital voltage.

3.2.4 Switching Unit and Step - Up Transformer

This is the stage where voltage polarity and power generation takes place. A center tapped transformer is required for switching of the push pull arrangement.

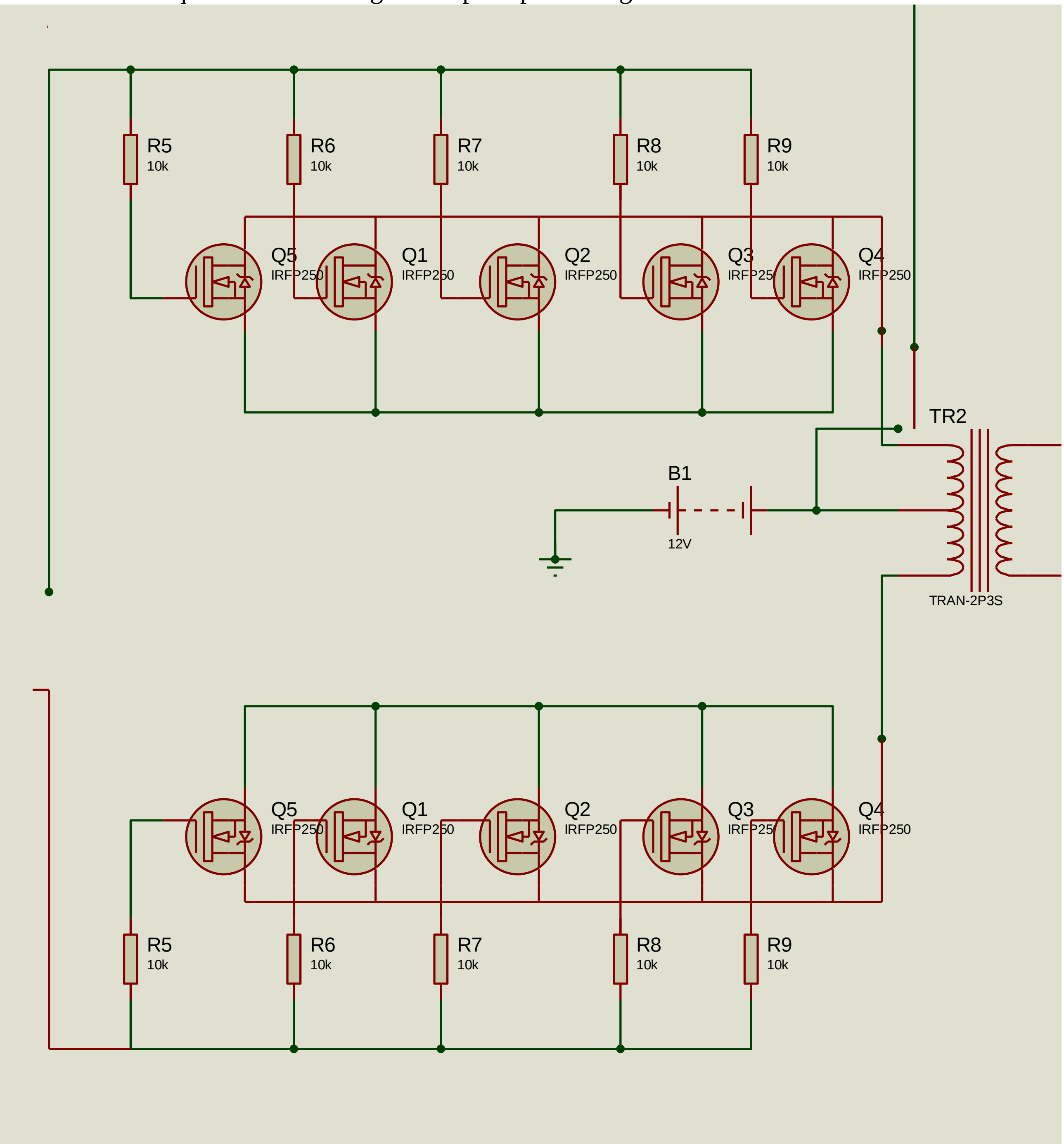

Figure 5 Switching Unit and Step - Up Transformer

When large amount of power is needed, the MOSFETS is cascaded to get the amount of power required. The power to be generated depends on the capacity of the MOSFET and the rating of the transformer. The circuit diagram is shown as in figure 5.

The power output for the design is 2500VA by using a power factor of
0.8×P (.VA) = 0.8×2500VA= 2000Watts.

I = P (w)/V (v) = 2000/12(using 12v battery)
= 166.67A
This implies that the power element must have a current handling capacity in excess of 166.67A. Since the maximum AC power for a class B amplifier (switching circuit) is given as:
$P_{ac} = V_{cc} \times I_{max}/2 = 12\times166.67/2 = 1000W$
The power dissipation of the circuit is given by
$P_{dis} = 2\times P_{ac}/2\pi$
$= 2 \times 1000/2*3.142$
$= 278.485W$
$\approx 278.5W$
This means that energy dissipated as heat on the MOSFET on full load will be appropriately 278.5W.
This choice of MOSFET selection depends on max current and power dissipation of the project; IRFP260N MOSFETs were used. The IRFP260N has the required specifications of power dissipating of 280watt. Continuous source current of 50amp.
Since the power dissipation of the MOSFET is greater than the expected power dissipation of the circuit, the MOSFET will work perfectly. Each channel of the the switching unit consist of five MOSFET, the maximum heat that will be dissipated by the MOSFET is shown in the calculation below,

$$\max power\,for\,mosfet = \frac{278.485}{5} = 55.7\,watt$$

From the calculation shown the power that will be dissipated by each MOSFET is 55.7 watt.

3.2.5 The Feedback

The feedback unit is made of a high resistance part; it sends the signal at the output terminal of the transformer to the pin 1 of the oscillator IC. The oscillator has a differential amplifier; pin 1 and pin 2 are the inverting and non-inverting terminal of the oscillator circuit. This is used to set the voltage to give a constant voltage at the output of the inverter that the electrical load is connected to. The diagram is shown in figure 6. The transformer is used to reduce the voltage from 220 Vac to 12 Vac voltage. The bridge rectifier converts the voltage from 12 Vac to 12 Vdc. A voltage divider circuit is used to reduce the voltage coming from the bridge rectifier. This voltage is sent to the differential amplifier in the oscillator IC, inverting terminal.

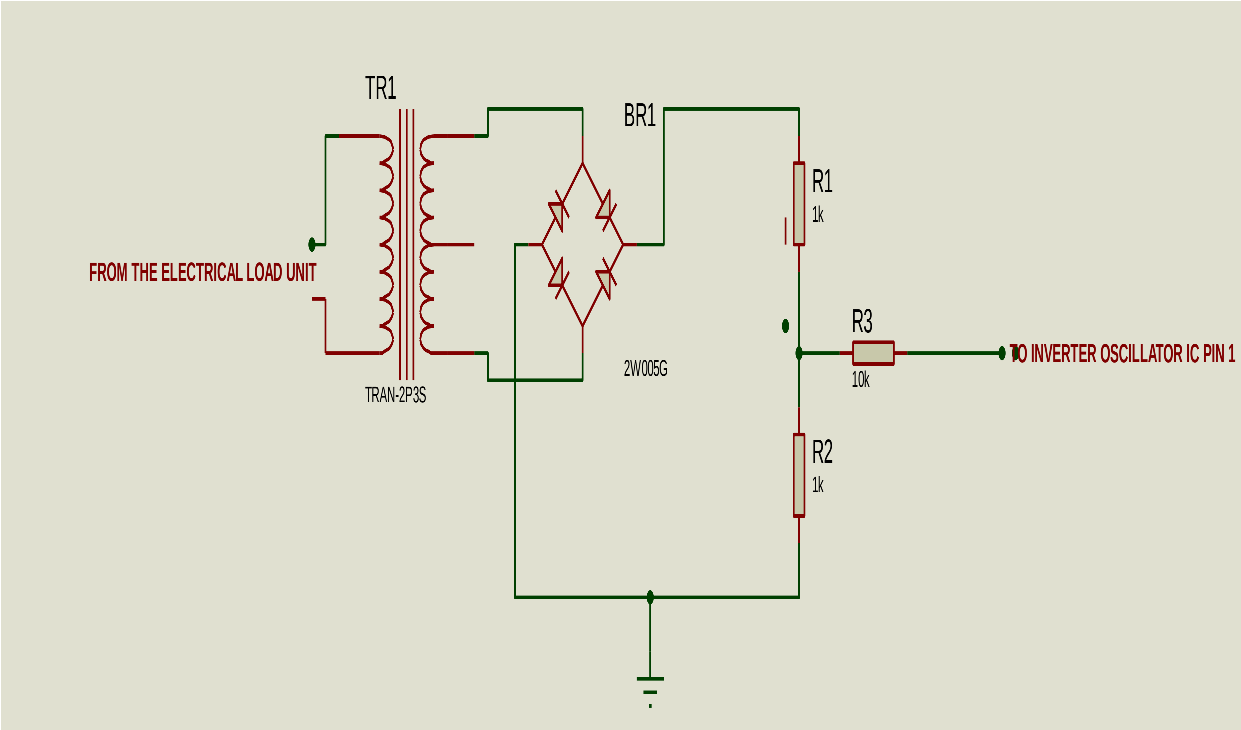

Figure 6: Feedback unit circuit diagram

3.2.6 The electrical load unit

This made up of the electrical load socket. This socket is connected to the high voltage side of the inverter transformer.

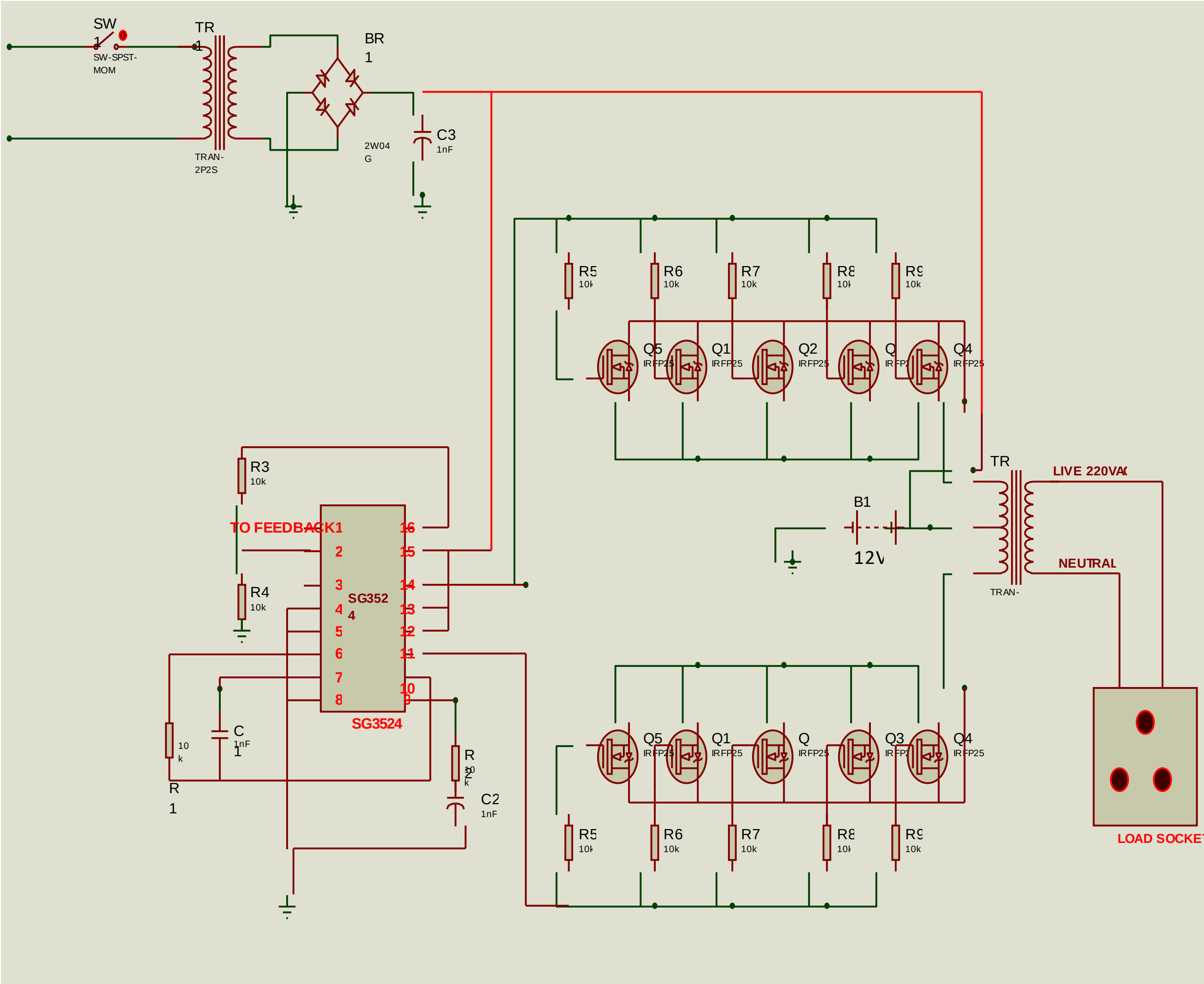

Figure 7: Circuit Diagram of 2.5KVA Inverter

4. DISCUSSION OF RESULT

4.1 Testing

After the design and implementation phase, the system built has to be tested for Durability, Efficiency, and Effectiveness and also ascertain if there is need to modify this design. The system was first assembled using a breadboard. All components were properly inserted into the breadboard according to the designed circuit and tests were carried out at various stages. To ensure proper functioning of components' expected data, the components were tested using a digital multimeter.

4.2 Testing Of Components

4.2.1 Transformer Testing

The transformer was the first component tested. The output power transformer was tested. It was connected to the AC main where the voltage was checked to be within the voltage ratings of the transformer. It gives a voltage of 12Vac at the secondary when a voltage of 220Vac was applied to its secondary.

The transformer was also tested to see if the secondary wires was shorted and primary resistance of the coil of the wire are higher than that of the secondary.

Table 1 Results Table for 2.5KVA Transformer VA Test

VA	Primary Theoretical	Primary Measured	Secondary Theoretical	Secondary Measured
Voltage	12V	12.4V	220V	217.6V
Current	208.33A	210.02A	11.36A	11.4A

The table 1 shows the 2.5KVA test carried out to determine the input voltage and output voltage as well as the input and output current respectively. The power of the transformer remains constant with the ideal power.

4.2.2 Testing of the Oscillator

The oscillator circuit was powered by the battery source. The pin 16 was tested by a voltmeter it gives a constant voltage of 5 volt.

Pin 11 and pin 14 is tested with a frequency meter it gave 50 hertz at each pins. This shows that the oscillator is working. The table below show the result obtained from oscillator test.

Table 2 Results Table for 2.5KVA oscillator unit

SG3524A Pin outs	Output Voltage (V)	Frequency (Hz)
Pin 11	4.5	50.6
Pin 14	4.5	50.6
Pin 3	5	100.20

Other components like the resistor, light emitting diode, capacitor etc. were tested. All the components were found to be good. The resistor was tested with ohms meter, the capacitor with a digital multimeter and the light emitting diode was tested using continuity test; where the light glows if the light emitting diode is good.

4.3 Implementation

This is a very important aspect of the project, because the workability and presentation depends on the actual construction work. A number of construction tools and equipment are used for effective performance. The construction works involves.

4.3.1 Developing Implementation

After designing the circuit and making the necessary calculation the circuit was simulated in a software environment Proteus version 7.6, and simulating it. The values of each component were obtained and ordered from the marketers and when they arrived construction began.

The 2.5KVA transformer was constructed with an inductive coil wound in different turns to get the primary and secondary voltage and currents respectively. The inductive coils used are of different gauge sizes for primary and secondary windings. The inductive coils used where determined by using WSG gauge table.

The construction of the charging, switching and oscillation circuit started with mounting of components on the Vero board; each component was tested before mounting and then soldered to the Vero board.

The battery charge unit was built first and the voltages from the voltage regulator were tested before going into the next stage. The oscillator unit was soldered and tested. The MOSFET was soldered on the board and was joined to a transformer. From the output a wire is connected to the feedback to achieve constant output voltage irrespective of the load connected. Various load where plugged and tested. Each stage is connected (joined) by a connecting wire or placed in the same row for continuity and tested before packaged with a metal iron frame. After packaging (casing) the prototype was tested and checked for any fault arising because of vibration and shaking owing to packaging.

4.4 PROJECT TESTING

The output voltage, current, power and frequency were measured using multimeter, watt-meter, and frequency meter. Household appliances were also connected to the inverter. The results obtained are tabulated below.

Table 3 output parameters obtained from testing the inverter

S/N	INPUT VOLTAGE	OUTPUT VOLTAGE	OUTPUT CURRENT	OUTPUT POWER	OPERATING FREQUENCY
1	12V	217.6V	11.4A	2480.6VA	50Hz

The results show that the output voltage, current and power depends on the rating of the battery.
When various household appliances and bulbs were connected to the inverter and the duration measured as shown on the next page.

Table 4 duration of operation of the inverter on different loads

S/N	LOAD DESCRIPTION	LOADED POWER	POWER DURATION
1	LCD TV (125W), LAPTOP(65W), HOME THEATRE(97W)	287W	3 HOURS,8 MINUTES
2	LCD TV (125W), LAPTOP(65W), HOME THEATRE(97W), 6 BULBS(60W EACH)	647W	1 HOUR, 23 MINUTES

5. CONCLUSION

The inadequacy of public power supply in our country calls for a temporary or an alternative source of power supply to be used in case of contingencies. This project met the objective and purpose which is to design and construct a 2.5KVA inverter with a microcontroller based frequency meter that could be used domestically. The advantages include:

- Low maintenance cost though power inverters have huge purchase/capital cost
- No moving parts (as seen in generators)
- Easy installation
- No need for petrol or diesel
- Inverters offer noise free operations
- Power inverters do not emit dangerous gases during operations

This project could be used by many other electrical/electronic appliances so long as it is used according to specifications. The construction was done in such a way that it makes maintenance and repairs an easy task and affordable for the user, should there be any system breakdown.

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