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# DESIGN, CONSTRUCTION AND PERFORMANCE EVALUATION OF 1kVA PURE SINE WAVE POWER INVERTER

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## *Abstract*

*An inverter is a device that takes a direct current input and produces a sinusoidal alternating current output. It maintains a continuous supply of electric power to connected equipments or load by supplying power from a separate source, like battery, when utility power is not available. It is inserted between the source of power and the load is protecting. In this research, the design, construction and performance evaluation of 1kVA pure sine wave power inverter is presented. The methods implemented for the design were DC-DC converter and DC-AC inverter topologies. The DC-DC converter in the design made use of a high switching frequency transformer, enabling the reduction of size of the parts and to meet the efficiency constraint, while the DC-AC inverter circuit made use of a microprocessor to digitally pulse the transistors on the inverter side of the circuit. The project was broken down into smaller components and tested individually at every different stage of the design by the oscilloscope and digital multi-meter for their unique specifications. After component tests, they were incorporated for final assembly and integration. The results of the oscilloscope and digital multi-meter tests showed that half-bridge converter produced square wave output waveforms, sinusoidal pulse width modulated controller circuit yielded modified sine wave. After filtering, the full bridge inverter gave clean sinusoidal sine wave. The inverter was successfully converted 12VDC into 120VAC at 50Hz frequency and 1000W output power for a special laboratory equipment.*

***Key Words:*** *Inverter, Transformer, Microprocessor, Converter, Direct Current, Alternating Current.*

## 1. Introduction

Power electronic systems are used widely to convert electric energy from one form to other using electronic devices. Four basic power electronics functions are AC to DC conversion, DC to AC conversion, DC to DC conversion and AC to AC conversion. These basic functions are used to build power supplies, DC transmission systems, electric drives and others [11].

Mobility and versatility have become a must for the fast-paced society today. People can no longer afford to be tied down to a fixed power source location when using their equipments. Overcoming the obstacle of fixed power has led to the invention of a DC/AC power inverter [5].

Companies, Industries, Organizations, Homes among the others are posed with a major problem of power shortage especially here in Nigeria. Although in developing countries, shortage of power is a problem commercially and domestically. New offices have tremendous load on already existing power generation sources. When added to rapidly increasing private and domestic demand, the situation, especially in certain urban areas becomes devastating. Simply stated, our ability to consume power is growing faster than our ability to supply power. Under such conditions, failure will occur unpredictably and without any warning due to stresses on the inadequate sources of power. Hence, there is need for the alternative source

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of power which could fill in the gap and cover the lapses of shortage in power supply. Overcoming this obstacle led to the invention of DC/AC power inverters.

At the early stage, sun was the source of energy for generating power. Due to the inadequacy of the power generated through this source, there was a need to find other ways to improve the power supply when the generating station could not meet the demand of the people.
As the technology advances, the hydroelectric generation was developed, gas firing generating station, and wired tubing methods of generating power supply were developed. In spite of all these developments, there was still failure in electrical power generation as a result of obsolete equipment at the generating stations. There was still need to find alternative for solving the problem. As a result of this, some options like alternators, inverters and others were developed [4].

Power inverter is an electronic device that has the ability to convert the direct current (DC) from the battery or solar cells (panels) into an alternating current (AC) which is the conventional form that powers many electrical appliances. It maintains a continuous supply of electric power to the connected loads or equipments when the utility power is not available.

Inverters are generally used in a host of applications that include variable speed drive, uninterruptible power supplies, flexible AC transmission systems, (FACTA), high voltage DC transmission systems (HVDC), active filters among the others [6].

An inverter is a device which maintains a continuous supply of electric power to connected equipments or load by supplying power from a separate source, like battery, when utility power is not available. It is inserted between the source of power (typically commercially utility power) and the load is protecting. For alternative energy systems, inverters are the essential step between a battery's DC power and the AC power needed by standard household electrical systems. In a grid connected home, an inverter/charger connected to a battery bank can provide an uninterruptible source of backup power in the event of power failures, or can be used to sell extra alternative energy power back to the utility company. Batteries produce power in direct current (DC) form, which can run at very low voltages but cannot be used to run most modern household appliances. Utility companies and generators produce sine wave alternating current (AC) power, which is used by most commonly available appliances today. Inverters take the DC power supplied by a storage battery bank and electronically convert it to AC power.

An inverter used for backup power in a grid connected home will use grid power to keep the batteries charged, and when grid power fails, it will switch to drawing power from the batteries and supplying it to the building electrical system. For a business home or office, a reliable power source is invaluable for preventing lost data on computer systems. Most modern inverters also include overvoltage and under voltage protection, protecting sensitive equipment from dangerous power surges as well [3].

An inverter is a device that takes a direct current input and produces a sinusoidal alternating current output. An inverter needs to be designed to handle the requirements of an energy hungry household yet remain efficient during periods of low demand. The efficiency of inverter is highly is dependent on the switching device, topology and switching frequency of the inverter [11].

Alternating current (AC) power is used as a power source as well for transmission purpose because it can be generated and also converted from one voltage to another. Transmission of AC power over long distance is still used until now, however it results in relatively high transmission loses. The types of loses are transient stability problem and operational requirements such as dynamic damping of electrical system may also arise along the transmission line. Direct Current (DC) transmission is an alternative which overcomes most of this problem. Besides that, it is more economically feasible only when the transmission distance exceed 500 to 600 km, underwater cables for the case in a small distance transmission. At the receiving end HVDC is converted back to HVAC or LVAC. The design of an inverter is referring to the requirement of point distribution and economical aspect [10].

Power inverters come in all shapes and sizes, from low power functions such as powering a car radio to that of backing up a building in case of power outage. Inverters may come in different varieties, differing in price, power, efficiency and purpose. Power inverters are used today for many tasks like powering appliances in a car such as cell phones, radios and televisions. They also come in handy for consumers who own camping vehicles, boats and at the construction sites where an electric grid may not be as accessible to hook into [7].

Inverters, besides coming in a wide variety of power capacities, are distinguished primarily by the shape of the alternating current wave they produce. The three major waveforms are square-wave, modified sine-wave and true sine-wave. Square wave inverters are largely obsolete, as the waveform shape is not well suited for running most modern appliances, and prices have come down considerably for the superior modified sine wave and true sine wave types [3].

An inverter with the use of many batteries is capable of generating power for hour's even days depending on the capacity of the battery and the load connected to it, and this power could be very crucial since in some office set-up, a failure of about one minute could cause losses that could run into millions. The ability of the inverter to change over automatically gives it an advantage over some UPS and they find applications in the following areas;

─ The computer field: An unpredictable power failure can wipe out the information stored in the memory bank of the complete data base system.

─ Air traffic system: Radar and essential aircraft information are on constant display in air traffic control system, and mains failure could cause a break out of radar and lead to unprecedented disaster.

─ Other processes like boilers, flame detectors, etc.

─ Domestic uses include items like TVS, CD players, Fans, Light points, boilers, etc.

## 2. Design and Methodology

### 2.1 Design Requirements

Power electronic systems are used widely to convert electric energy from one form to other using electronic devices. Four basic power electronics functions are AC to DC conversion, DC to AC conversion, DC to DC conversion and AC to AC conversion. These basic functions are used to build power supplies, DC transmission systems, electric drives and others [10].

The design that will be implementing will solve the problem associated with modified sine wave inverters by using a microprocessor to obtain a more efficient and smooth means of switching the inverter's transistors. This will reflect in the overall design a greater efficiency, less power loss to heat, the ability to power even the most sensitive digital devices, minimize the size of the final product, and make it a more versatile product in the global economy.

There are several factors involving power that can be easily overlooked by the average person. These issues deal primarily with efficiency but are not limited to it. First, the amount of power consumed by the load must be looked at. Different devices call for different power wattages. Because of this fact, our inverter would not be able to power larger devices that require a lot of power. This does not affect the efficiency of our device; it is just one of its limitations. Next, the sensitivity of the load being driven should be considered. This means the output signal of the inverter must provide a cleaner signal without distortion for more sensitive devices. The amount of undesired harmonics present in our output signal would need to be limited.

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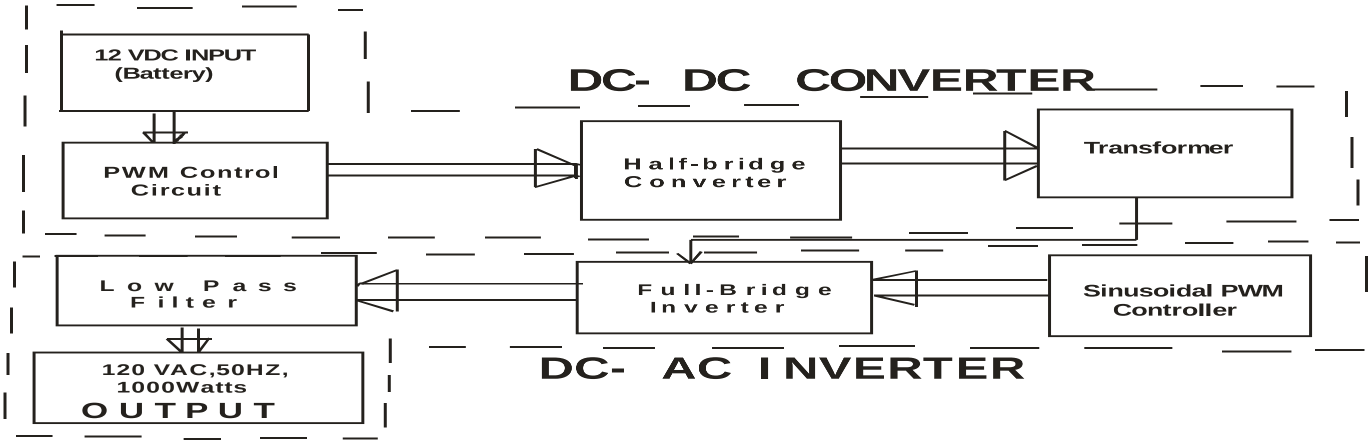


**Figure 1: Power inverter block diagram**

The DC-DC converter consists of a battery which supplies the 12 VDC input voltage to the circuit. Then the PWM control circuit which is used to pulse the half bridge converter. The half bridge converter will chop up the 12 VDC supplied by a vehicle battery so that an AC is seen by the transformer. The transformer is responsible for boosting the voltage by stepping up the voltage from the half bridge converter.

In the DC-AC inverter stage, the sinusoidal PWM controller circuit produces two output pulses with varying duty circles in order to drive the full bridge inverter circuit. The full bridge inverter converts the DC voltage supplied by the DC-DC converter into a desired AC voltage. The low-pass filter eliminates the switching frequency and multiples of the switching frequency. At the final output the 120 VAC is being generated.

The following equations were used to calculate the modulation amplitude and modulation frequency for the PWM signal:

$$\text{Amplitude Modulation Ratio} = \frac{V_{control}}{V_{tri}} \qquad (1)$$

$$\text{Frequency Modulation Ratio} = \frac{f_s}{f_1} \qquad (2)$$

Where, $V_{control}$ is the peak amplitude of the reference sine wave with frequency of $f_1$ and $V_{tri}$ is the peak amplitude of the saw-tooth wave with frequency of $f_S$.

The following equation gives the minimum charge which needs to be supplied by the capacitor:

$$Q_{bs} = 2Q_g + \frac{I_{gbs(\max)}}{f} + Q_{Is} + \frac{I_{cbs(leak)}}{f} \qquad (3)$$

IR2181 data sheet [13]

where: $Q_g$ = Gate charge of high side FET.

Icbs(leak) = bootstrap capacitor leakage current.

$Q_{Is}$ = level shift charge required per cycle = 5nC (for the 600 IC that was used in this design).

$I_{gbs}$ = quiescent current for the high side driver circuitry.

$$C \geq \frac{2\left[2Q_g + \frac{I_{gbs(\max)}}{f} + Q_{Is} + \frac{I_{cbs(leak)}}{f}\right]}{\left(V_{cc} - V_f - V_{Is}\right)} \quad (4)$$

where: $V_f$ = forward voltage drop across the bootstrap diode side FET
$V_{Is}$ = voltage drop across the low side FET

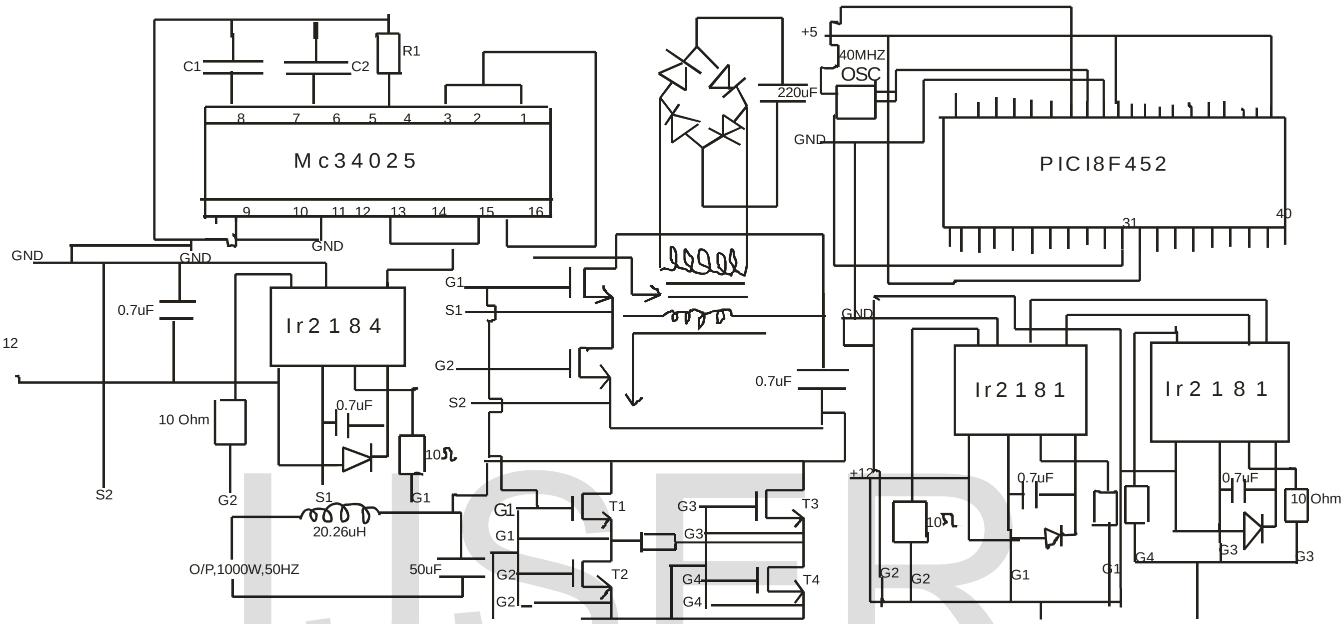


**Figure 2: 1000W Pure Sine Wave Power Inverter Model**



## 2.2 The Power Supply Stage

The power supply stage is specially designed for the charging section of the battery in other to power the voltage controller of the charging stage. The most readily available power source, the 120V/50Hz A.C wall outlet is used in the project. For a charging voltage of 120 VDC, this unregulated supply needs a transformer of $12\sqrt{2}$ = 16.97Vrms.

To achieve a fast charging rate, an 18V transformer is required for charging. A bridge rectifier was selected to rectify the transformer output and a capacitor of 1000μF was used to filter the rectified voltage. The regulator type used is a positive voltage regulator of 12V with three terminals was used.

## 2.3 The Battery Charger Stage

The charging circuit is a constant voltage type. The charging voltage is derived from a constant regulated D.C voltage while the control for the charge is composed of transistors connected as switch. This circuit is made of a voltage controller to automatically shut down the charger when the battery is fully charged by a D.C voltage source, which is the charging voltage. A 12V relay was also used in this design.

## 2.4 DC-DC Converter Stage

The inverter stage is made up of the pulse width modulator, push- pull amplifier, driver circuit and the MOSFET driver circuit.

### 2.4.1 The Pulse width Modulator

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The pulse width modulator produces the timing signals that trigger the gates of the MOSFET. The IR2181 transistor was used in this project.

From the IR2181 data sheet [8], $F = \frac{1.3}{R_T C_4}$ (6)

IR2181 data sheet [8],

$$R_T = \frac{1.3}{FC_4}$$

Where F = Frequency = 50Hz, Capacitor value, $C_4$ as a matter of choice is chosen to be 2.6µF. $R_T$ and $C_4$ are the frequency determining components.

$$R_T = \frac{1.3}{50 \times 2.6 \times 0.003} = 10\Omega$$

### 2.4.2 The MOSFET Driver Circuit

MOSFETs were chosen for use in this project due to its fast switching rate and ruggedness. The signal from the push-pull amplifier driver circuit was used to trigger the gate of MOSFET to enable it to start conducting at the rate at which the pulses switches. 10Ω resistors were connected between the output from the driver circuit and then gate of the MOSFET to prevent static electricity from getting into the gate. This was necessary because the gates are prone to static electricity which can damage them. Since a large amount of power is needed, the MOSFETs have to be cascaded to get the desired amount of power at the output.



The power output needed is 1000VA. By applying a power factor of 0.7 (due to loses). The output power = 0.7 x 1000VA = 700watts.
For power to be equal to 700watts. According to Akande et al, (2007) [1];

$$I = \frac{P}{V} \tag{7}$$

$I = \frac{700}{12} = 58.33$ (Using 12V battery).

This implies that the power element must have a current handling capability in excess of 58.33A.
IR2181 MOSFETs with the following specifications were thus selected for use.

**TABLE 1: TABLE SHOWING IR2181 SPECIFICATIONS**

| $I_D$ (MAX) | $V_{DS}$ (MAX) | $P_D$ (MAX) |
|---|---|---|
| 39A | 60V | 200Watts |

Where $I_D$ = Drain current, $V_{DS}$ = Drain source voltage, $P_D$ = Power dissipated.

## 2.5 DC-AC Inverter Circuit

In this circuit, the only necessary adjustment will be in the choice of transformer rating and the MOSFETs to be used.

### 2.5.1 The Transformer Choice

Primary winding; $I_P = \frac{P}{V} = \frac{1000}{12} = 83.33A$

Secondary winding; $I_S = \frac{P}{V} = \frac{1000}{120} = 8.33A$

Each half of the centre tapped transformer will therefore carry 8.33A. Hence, a transformer with the following parameters will be required:

Primary winding: 12V, 83.33A
Secondary winding: 12-0-12, 8.33A

### 2.5.2 The MOSFET Choice

The same MOSFET type can be employed. The only change will be in the number of MOSFETs employed. The power output is 1000VA. By applying a power factor of 0.7 (due to loses).

The output power = 0.7 x 1000VA = 700watts.

For power to be equal to 700watts;

$$I = \frac{700}{12} = 58.33A$$ (Using 12V battery).

This implies that the power element must have a current handling capability in excess of 58.33A. Using the IRFF740A power MOSFET {$P_D$ (MAX=200W)}.

Using the design parameters and formulas below according to Akande et al (2007) [1], Alade and Akande (2010) [2], with G = Power gain, $P_{out}$ = the AC output power, $P_{dc}$ = DC input power, η = the efficiency, $V_{out}$ = output voltage, Vcc = supply voltage, $I_{dc}$= direct current, $R_L$= load and V = input voltage.



$$V = IR \quad (8)$$

$$I = \frac{5}{10} = 0.5A$$

$$P_{in} = I^2 R \quad (9)$$

$$P_{in} = 0.25 \times 10 = 2.5W$$

$$P_{out} = \frac{V_{out}}{8R_L} \quad (10)$$

$$P_{out} = \frac{340}{8.0 \times 10} = 4.25W$$

$$G = \frac{P_{out}}{P_{in}} \quad (11)$$

$$G = \frac{4.25}{2.5} = 1.7$$

$$P_{dc} = V_{cc} I_{dc} \quad (12)$$

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$$P_{dc} = 12.0 \times 0.5 = 6.0W$$

$$\eta = \frac{P_{out}}{P_{dc}} \times 100\% \tag{13}$$

$$\eta = \frac{4.25}{6.0} \times 100\% = 71\%$$

The following equation gives the minimum charge which needs to be supplied by the capacitor:

$$Q_{bs} = 2Q_g + \frac{I_{gbs(\max)}}{f} + Q_{Is} + \frac{I_{cbs(leak)}}{f} \tag{14}$$

IR2181 data sheet, http://www.irf.com/product-info/datasheets/data/ir2181.pdf [8].

The elements of the equation above were determined from data sheets as;
$Q_g$ = Gate charge of high side FET=110nC
Icbs(leak) = bootstrap capacitor leakage current=250µA
$Q_{Is}$ = level shift charge required per cycle = 5nC
$I_{gbs}$ = quiescent current for the high side driver circuitry =230µA

By substitution, $Q_{bs} = 9 \times 10^{-3} C$

From $C = \frac{Q}{V}$ (15)

$$C = \frac{9 \times 10^{-3}}{12} = 0.7\mu F$$



## 2.6 RESULTS AND DISCUSSION

### 2.6.1 Test Specification

### 2.6.2 Hardware

All individual hardware design is tested using an oscilloscope and a digital multi-meter. The key components of the overall power inverter are a PWM control circuit, a half-bridge inverter, a transformer, a sinusoidal PWM controller, a full-bridge inverter, and a low-pass filter. Each component was tested for the desired voltages, currents, efficiencies, and frequencies. The following sub-sections demonstrate the results of the tests that were performed on the power inverter hardware. The test specifications explain the methods used to show that design constraints have been met. The power inverter is composed of many components that require testing separately and as a complete system. Testing each component individually helps to locate unique problems that are specific to each component. Complete system testing will ensure that each hardware and software component is fully functional at a mutual level. Table 4 illustrates each main system component, the design constraints relative to each component, and the various testing methods with results that will be utilized in designing a single phase power inverter.

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**TABLE 2: COMPONENT CONSTRAINTS AND TESTING METHODS**

| Testing Equipments | Components | Oscilloscope | Results |
|---|---|---|---|
| **DC-DC Converter** | **Half-bridge PWM Control Circuit** | | |
| | Frequency | √ | 108.0767kHz |
| | Output voltage | √ | 11.6V |
| | **Half-Bridge Converter Output Waveform** | | |
| | Frequency | √ | 109.875kHz |
| | Output voltage | √ | 12.8V |
| **DC-AC Inverter** | **Low Pass Filter** | | |
| | Output voltage | √ | 34.5V |
| | **Sinusoidal PWM Controller** | | |
| | Output Voltage | √ | 1.24V |
| | Frequency | √ | 18.937kHz |
| | **Full Bridge Inverter** | | |
| | Output voltage | √ | 34.0V |
| | Frequency | √ | |
| | **Final Inverter** | | |
| | Frequency | √ | 63.661kHz |
| | Output voltage | √ | 34.0V |

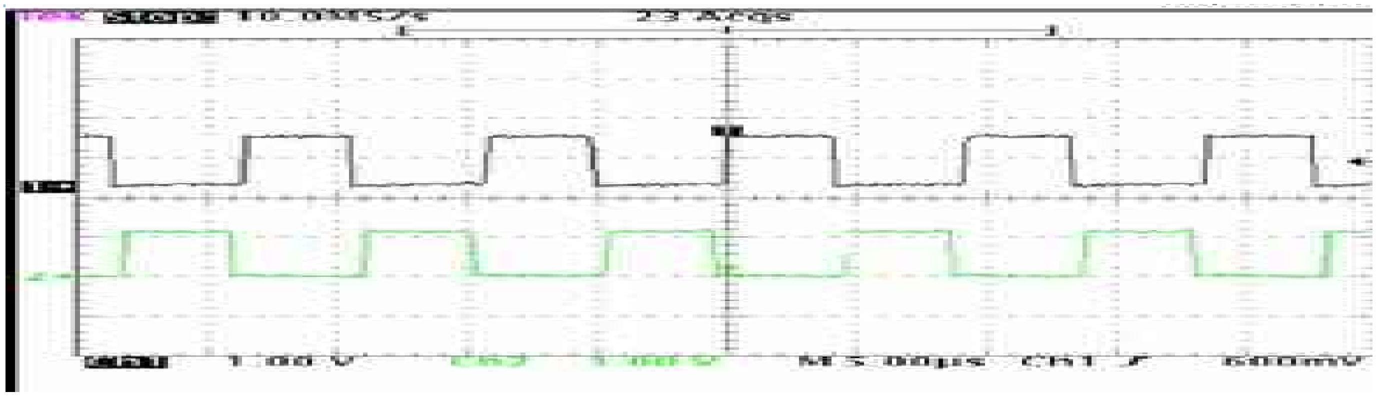

**Figure 3: Half-Bridge Control Circuit Pulses**

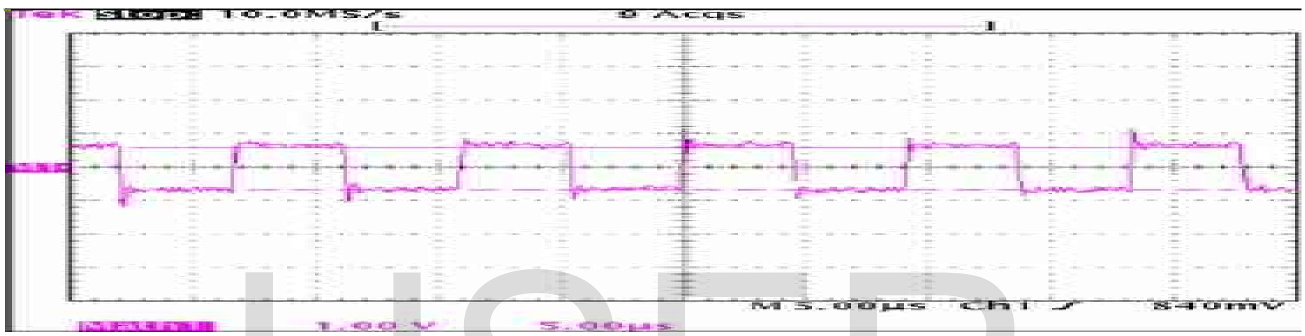

**Figure 4: Half-Bridge Converter Output Waveform**

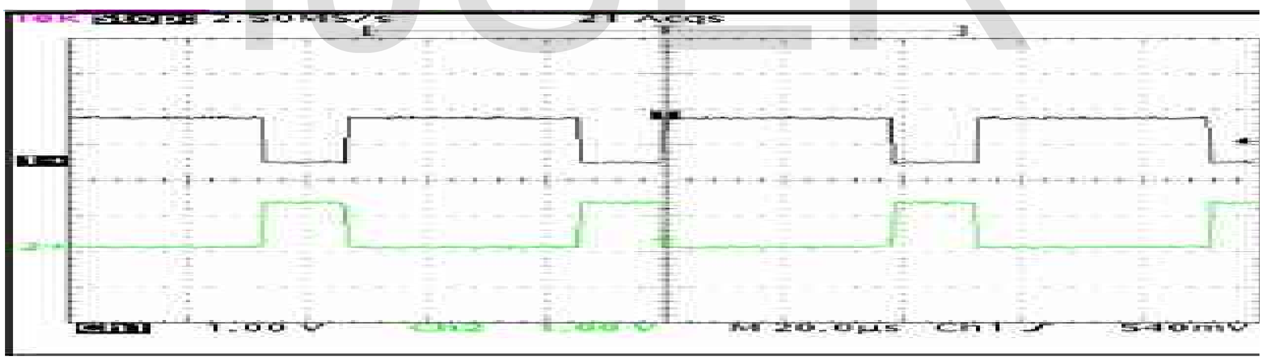

**Figure 5: Sinusoidal PWM Inverter Control Circuit Pulses**

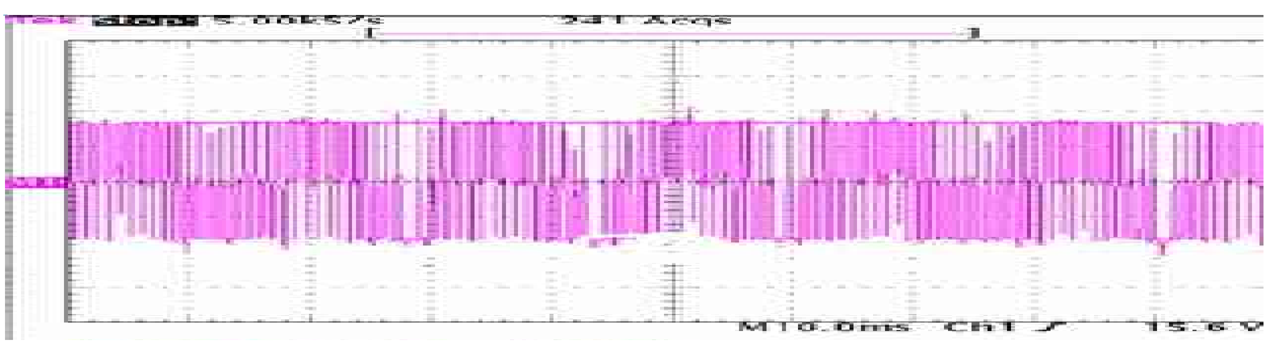

**Figure 6: Full-Bridge Inverter Unfiltered Voltage Output Waveform**

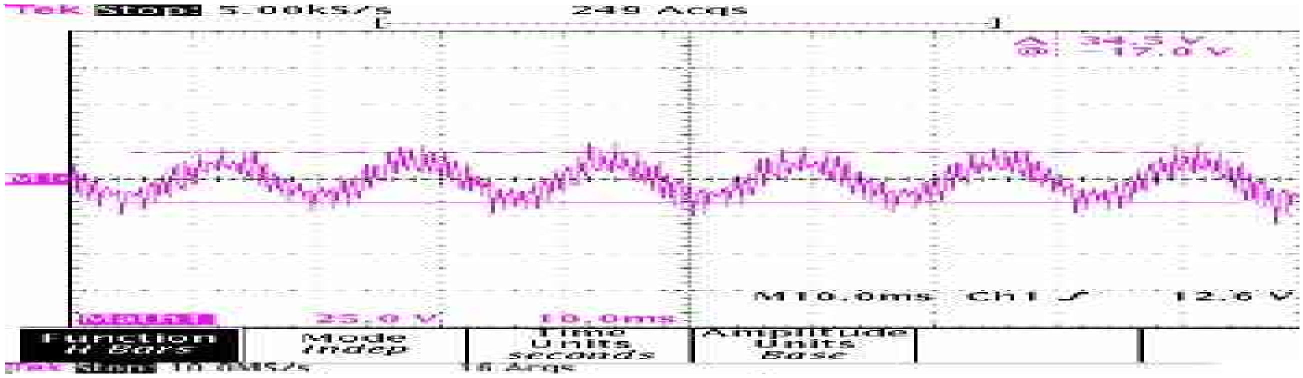

Figure 7: Low-Pass Filter Voltage Output Waveform

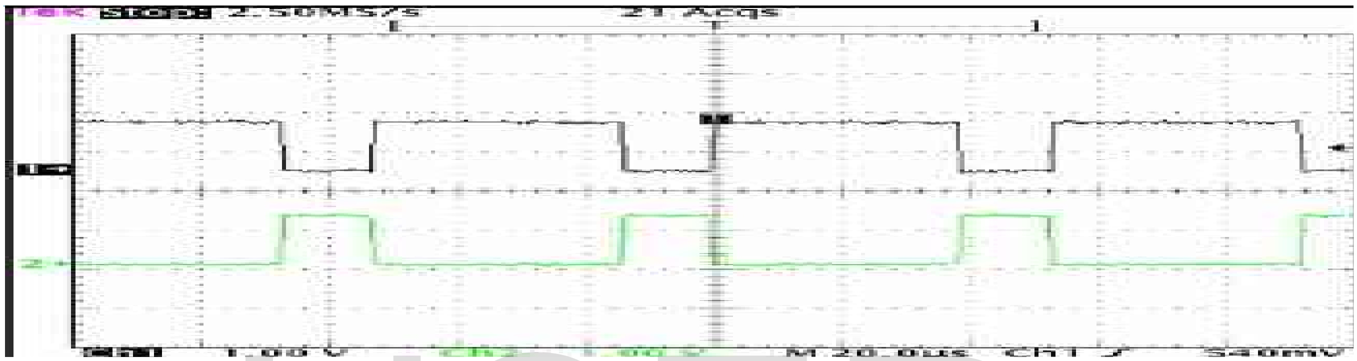

Figure 8: Control Pulses from PICI8F522 Microcontroller

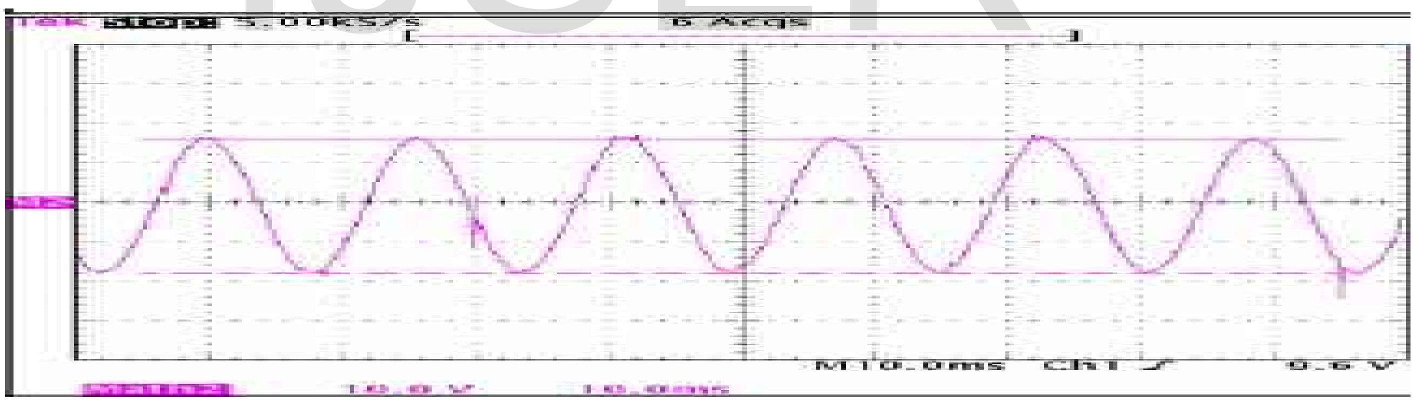

Figure 9: Voltage Waveform of Final Inverter Output

TABLE 3: PACKAGED PRODUCT RESULTS VERSUS DESIGNED CONSTRAINTS

| Name | Design Constraint | Packaged Product Results | Pass/Fail |
|---|---|---|---|
| **Voltage** | Convert 12VDC to 120VAC | 12VDC to 120VAC | Pass |

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| | | | |
|---|---|---|---|
| **Power** | Provide 1000W Continuous Power | >600W Continuous | Fail |
| **Efficiency** | >70% Efficient | >71% Efficient | Pass |
| **Waveform** | Pure 50Hz Sinusoidal | Pure 50Hz Sinusoidal | Pass |
| **Total Harmonic Distortion** | < 3% THD | < 9% THD | Fail |
| **Physical Dimension** | 8” x 4.75” x2.5” | 9” x 6.5” x 2.5” | Fail |
| **Costs** | ₦35,000 | ₦25,000 | Pass |

**TABLE 4: BILL OF QUANTITY**

| **S/N** | **ITEM** | **QUANTITY** | **UNIT PRICE(₦)** | **TOTAL AMOUNT(₦)** |
|---|---|---|---|---|
| 1 | Inverter Transformer | 1 | 1000 | 1000 |
| 2 | Charger Transformer | 2 | 500 | 1000 |
| 3 | MOSFETs | 4 | 100 | 400 |
| 4 | Resistors | 20 | 100 | 2000 |
| 5 | Capacitors | 20 | 100 | 2000 |
| 6 | MC34025 | 1 | 1000 | 1000 |
| 7 | Microcontroller | 1 | 3000 | 3000 |
| 8 | IRF758A | 5 | 100 | 500 |
| 9 | Battery | 1 | 10000 | 10000 |
| 10 | Full-bridge Rectifier | 1 | 200 | 200 |
| 11 | IR2181 | 3 | 100 | 300 |
| 12 | Casing | 1 | 2500 | 2500 |
| 13 | Transistors | 6 | 100 | 600 |
| 14 | Inductor | 5 | 200 | 1000 |
| 15 | Diodes | 10 | 100 | 1000 |

| | | | | |
|---|---|---|---|---|
| | **TOTAL** | | | **23 600** |

## 3. SUMMARY

The design of 1kVA pure sine wave power inverter demonstrated above if well assembled and integrated will undoubtedly supply 1000W of continuous power for our electronic gadgets at the power outage. In this study, the methods implemented for the design were two circuit topologies. The circuit topologies were DC-DC converter and DC-AC inverter topologies. The DC-DC converter in the design made use of a high switching frequency transformer, enabling the reduction of size of the parts and to meet the efficiency constraint, while the DC-AC inverter circuit made use of a microprocessor to digitally pulse the transistors on the inverter side of the circuit.

In this design, the PICI8F252 and IR1281 transistors used were specially designed to produce optimum pure sine wave output. Some of the inverters in the market, unless otherwise told are either square wave or modified sine wave inverter that capable of generating great noise and high total harmonic distortion and eventually cause havoc to our sensitive devices. But with this pure sine wave power inverter, the sensitive devices are guaranteed from expected damages as a result of amount of unwanted harmonics and some other possible defects that can be caused by square wave and modified sine wave power inverter. Again, the output power of 600 – 1000W that can be accommodated with 12VDC battery by this inverter is unique when compare to the previous work.

The project was broken down into smaller components and tested individually at every different stage of the design by the oscilloscope and digital multi-meter for their unique specifications. After component tests, they were incorporated for final assembly and integration. The results of the oscilloscope and digital multi-meter tests showed that half-bridge converter produced square wave output waveforms, sinusoidal pulse width modulated controller circuit yielded modified sine wave. After filtering, the full bridge inverter gave clean sinusoidal sine wave. The inverter was successfully converted 12VDC into 120VAC at 50Hz frequency and 1000W output power for a special laboratory equipment. The inverter produced a sinusoidal output signal with 7% total harmonic distortion with more than 70% efficiency. The real life testing result shows that at the electric power outage, the inverter is able to power the electronic devices like TV set and standing fan for six hours successively with 48Ah battery.

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## PLATE 1

**The Voltage Waveform of Final Inverter Output (Signal Response)**

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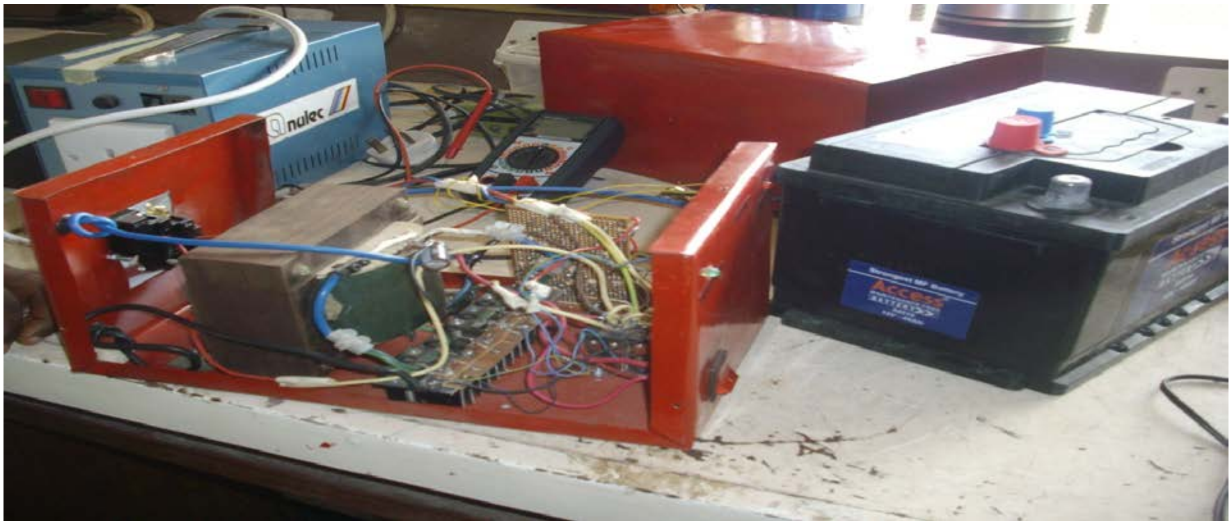
**PLATE 2**




**The Assembled Components of Inverter**

**PLATE 3**


**The Final Stage of Inverter Coupled Together by the Researcher (Sheu, A.L.)**

**PLATE 4**


**The Completed Inverter, Battery, Oscilloscope and Digital Multi-meter**