A REPORT ON

DESIGN AND CONSTRUCTION OF A HYBRID 2 KVA PURE SINE WAVE INVERTER

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DECEMBER, 2022

DESIGN AND CONSTRUCTION OF A HYBRID 2 KVA PURE SINE WAVE INVERTER

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A PROJECT PRESENTED TO THE DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING, UNIVERSITY OF BENIN, IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELORS DEGREE OF ENGINEERING (M.ENG) IN ELECTRICAL AND ELECTRONICS ENGINEERING, UNIVERSITY OF BENIN.

DECEMBER, 2022

DECLARATION

I, **OBASI CHINEYE, DIRISU PAUL OSIGBEMME, THEOBALD EJODAMEN IGBERAESE, OMOREBOKHAE OHIMENWINNER, IHONRE KELVIN IREGBEYEOSE, BIOSE-ONYEMANU SYDNEY CHINYE** declare that this dissertation has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree elsewhere.

The thesis is a result of my investigations, except where otherwise stated. All sources used in production of this thesis were acknowledged by appropriate citation and explicit references and were included in the bibliography that is appended.

We hereby declare that the preparation and presentation of this study were supervised in accordance with the guidelines and supervision laid down by the University of Benin.

CERTIFICATION

This is to certify that **OBASI CHINEME** with matriculation number **ENG1607902** carried out this project in partial fulfilment of his Bachelor of Engineering Programme in Department of Electrical Electronics Engineering in the **University of Benin**. This technical report was done by him and was brought to me to be graded.

This is to certify that **DIRISU PAUL OSIGBEMME** with matriculation number **ENG1604133** carried out this project in partial fulfilment of his Bachelor of Engineering Programme in Department of Electrical Electronics Engineering in the **University Of Benin**. This technical report was done by him and was brought to me to be graded.

This is to certify that **THEOBALD EJODAMEN IGBERAESE** with matriculation number **ENG1503824** carried out this project in partial fulfilment of his Bachelor of Engineering Programme in Department of Electrical Electronics Engineering in the **University Of Benin**. This technical report was done by him and was brought to me to be graded.

This is to certify that **OMOREBOKHAE OHIMEN WINNER** with matriculation number **ENG1604188** carried out this project in partial fulfilment of his Bachelor of Engineering Programme in Department of Electrical Electronics Engineering in the **University Of Benin**. This technical report was done by him and was brought to me to be graded.

This is to certify that **IHONRE KELVIN IREGBEYEOSE** with matriculation number **ENG1708904** carried out this project in partial fulfilment of his Bachelor of Engineering Programme in Department of Electrical Electronics Engineering in the **University Of Benin**. This technical report was done by him and was brought to me to be graded.

This is to certify that **BIOSE-ONYEMANU SYDNEY CHINYE** with matriculation number **ENG1604131** carried out this project in partial fulfilment of his Bachelor of Engineering Programme in Department of Electrical Electronics Engineering in the **University Of Benin**. This technical report was done by him and was brought to me to be graded.

PROF. F.O. EDEKO. (PROJECT SUPERVISOR)	**DATE**
PROF. P.O. ORUKPE (HEAD OF DEPARTMENT)	**DATE**

DEDICATION

I dedicate this project to Almighty God for His guidance, grace and protection that saw us through out our Bachelors Degree in Engineering (B.Eng).

ACKNOWLEDGEMENT

First and foremost, our sincere gratitude goes to God Almighty for His great protection upon my life from the beginning to the end of my study at the University of Benin.

We would like to express my deep gratitude and appreciation to our parents, our siblings and well-wishers for their continuous and immense support and encouragement during my stay in the University of Benin.

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ABSTRACT

In this project, a 2KVA hybrid pure sine wave inverter with battery charging and monitoring system was designed and constructed.

The inverter circuit was designed using a power transformer rated at 2.5KVA. The DC voltage source is a battery bank rated at 24V. A high performance microcontroller (DSPic30f2010) with advanced switching and control ability was used. The inverter system doubles as an inverter and a battery charger. Pulse width modulation technique was used in the inverter design.

The inverter circuit was designed, constructed and tested. It performed satisfactorily with different house appliances such as electric fans, bulbs, refrigerator, etc.

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CHAPTER ONE

INTRODUCTION

1.0 CONCEPT OF AN INVERTER

An **inverter/inverter circuit** is a **power electronic** device or circuitry that changes **direct current** to **alternating current** that is required to power electrical appliances in homes/offices/industries. It is primarily a direct current (D.C) to alternating current (A.C) type of converter. “Inversion”, which is what it does, is the opposite of “Rectification” which is the process of converting A.C to D.C. The input voltage, output voltage and frequency and its overall power handling capacity depends on the design of the specific device and circuitry.

Commercially there are three types of inverters available. They are classified here according to the quality of their output waveform. They are square wave, modified sine and the sine wave inverters.

1.1 HISTORY OF INVERTERS (https://manuinverter.blogspot,2010) (https://academickids,2008),(https://www.ijert.org,2007) (https://www.ipl.org,2012)

The conversion of direct current to alternating current (DC to AC) power was accompanied by the use of rotary converters or motor generator sets from the late nineteenth century to the middle of the twentieth century (M-G sets) (https://academickids./encyclopedia/index.php/Relay). It wasn’t until the early part of the 20th century that switches in inverter circuits were first implemented using vacuum tubes and gas-filled tubes. The “thyratron” was the sort of tube that saw the greatest amount of use. The origin of the word “inverter” may be traced back to the electromechanical inverters of the early 20th century. The first DC to AC converters consisted of an induction or synchronous AC motor that was directly linked to a generator (dynamo). This arrangement ensured that the generator’s commutator would reverse its connections at the appropriate time. The synchronous converter is a subsequent invention that combines the windings of the motor and the generator into a single armature. It has slip rings at one end and a commutator at the other, and only has one field frame. In either case, the outcome is a DC-output and an AC-input. When using an M-G set, the Dc may be thought of as being created in a manner that is distinct from the AC. When using asynchronous converter, on the other hand, the DC can be thought of as being "**mechanically corrected AC**." It is a possible to "run backwards" an M-G set rotary converter in order to convert DC to AC if the appropriate auxiliary and control equipment is present. As a result, an inverter is the same thing as an inverted converter. However, transistors and many other kinds of semiconductor switches have recently been commercially accessible and are being included into the designs of the inverter circuits. Static inverters do not have any moving components and find usage in a broad variety of applications. These applications vary from the switching power supply found in computers to the high voltage direct current applications used by utilities to transmit vast amounts of power.

1.2 AIM OF THE PROJECT

The aim of this project is to design and construct a single phase 2KVA sine wave inverter and charger system.

1.3 OBJECTIVES

The objectives of this project include:

- The inverter should produce a sine wave.
- It should be designed using a microcontroller.
- The inverter should output a stable voltage of 220V continually while in operation.
- The inverter should be able to recharge the batteries once mains utility is available.
- It should have safety measures like overload protect, short circuit protect, low battery protect e.t.c.
- It should incorporate a user-friendly interface for operation.

1.4 PROJECT REPORT OUTLINE

The entire project is divided into five (5) chapters. Chapter one deals with the introduction of the inverter, chapter two treats the literature review of parts (components, materials, etc) and devices used together with matching circuits diagrams. Chapter three is about the design method implored in design and its procedures. Chapter four details the construction, respective tests carried out and results gotten. Finally, chapter five covered the conclusion and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.0 INTRODUCTION

This chapter is to give a review of the theory of the working principle of components, devices and materials used in the design and construction of the inverter. Also, a detailed explanation is given on the components used in this design.

2.1 TYPES OF INVERTER WAVEFORMS (https://enerpowaintl.weebly.com/dc-ac-inverters.html,2000) (https://circuitdigest.com/tutorial/different-types-of-inverters,2011) (https://mybroadband.co.za/forum/threads/modified-vs-true-sine-wave-inverter-for-tv.625237/,2015) (https://en.wikipedia.org/wiki/Power_inverter, 2006) (https://www.epanorama.net/newepa/2020/12/14/sine-wave-inverter-technology/)

1. Square Wave

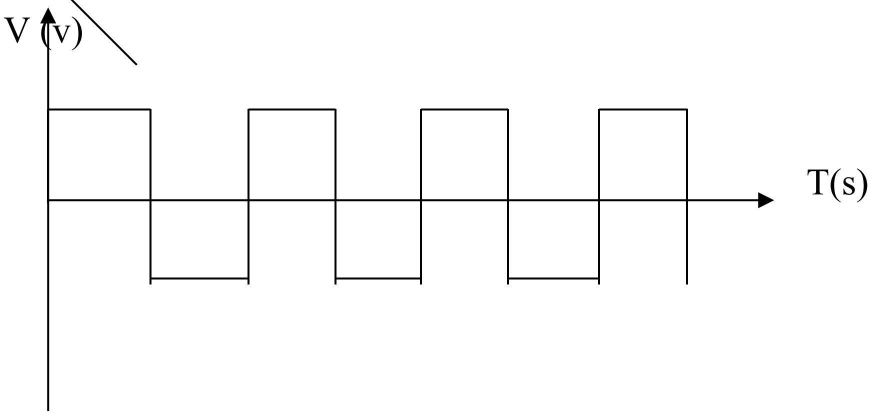


Fig 2.1 Square Wave Inverter Output Waveform

This one of the most basic waveforms that an inverter design may generate and it works well for low-sensitivity applications like lightning and heating. When linked to audio equipment, square wave output can create a sound known as “humming,” and it is not recommended for use with sensitive electronics in general.

2. Modified Sine Wave

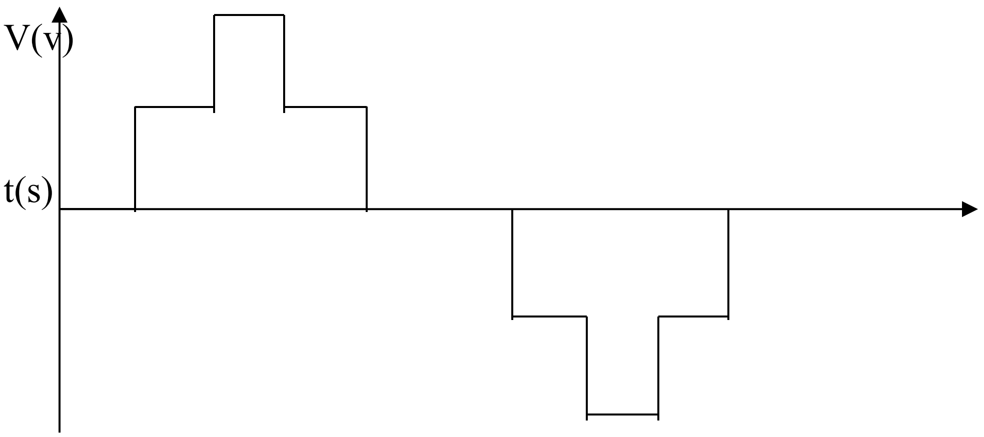


Fig 2.2 Modified Sine Wave Inverter Output Waveform

The sum of two square waves, one of which rotated by ninety degrees with respect to the other, constitutes the modified sine wave that is produced by an inverter of this type. The end product is a three-level waveform at has equal intervals of zero volts, peak positive volts, zero volts, peak negative volts and then zero volts again. This process will continue to recur. The form of a sine wave may be discerned in the ensuing wave, but only very crudely. Instead of producing a pure sine wave, the vast majority of affordable consumer power inverters generate a modified sine wave. (http://enerpowaintl.weebly.com/dc-ac-inverters.html).

The waveform of modified sinewave inverters that are available on the market is similar to that of a square wave, but there is delay in the middle of the polarity change. Positive, negative and zero voltages each have their own switching state that is produced. The ratio of the peak voltage to the RMS voltage for the waveform is the same as it is for sine wave if the waveform is set so that its peak value is represented for half the cycle. To adjust for fluctuations in DC bus voltage, the DC bus voltage may be actively controlled, or the "on" and "off" timings can be tweaked to keep the same RMS value output up to the DC bus voltage. Both of these options are available to the user. Altering the pulse width will cause a corresponding shift in the harmonics spectrum. When the pulses are spaced out through each electrical cycle by 130 degrees, a three-step modified sine wave has a THD of 30%, which is the lowest possible value. This is a little bit less than what you would expect from a square wave, the load may work in an inefficient manner and generate a buzzing or humming sound while it is in use. Since the manufacturer's nominal conversion efficiency does not take harmonics into account, this has an effect not only on the efficiency of the system as a whole but also on individual components.

3. Sine Wave

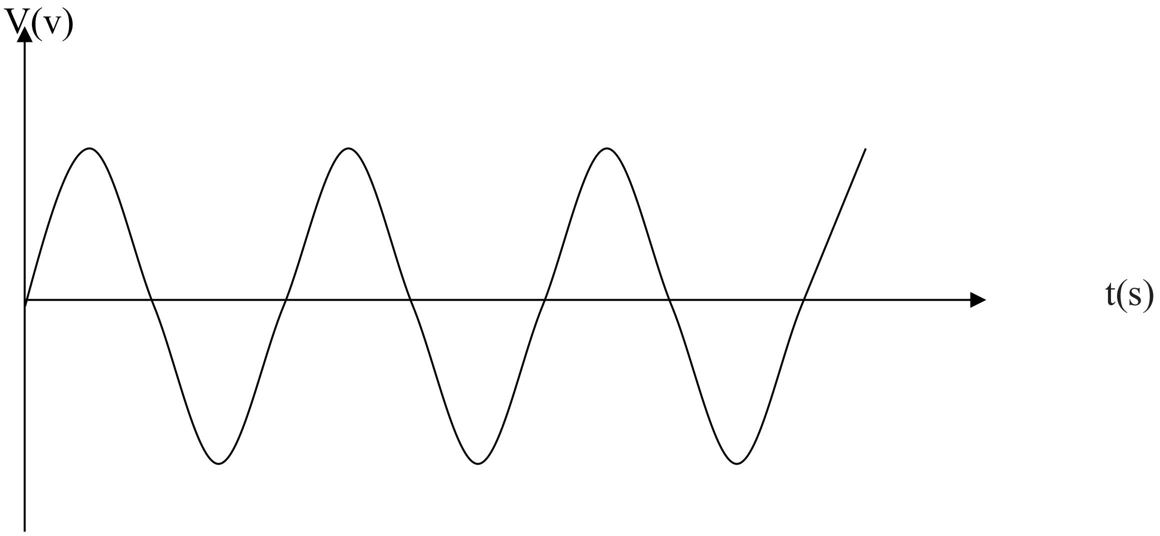


Fig 2.3 Sine Wave Inverter Output Waveform

The term "sine wave inverter" refers to a type of power inverter equipment that generates an alternating current waveform that is sinusoidal and has several steps. The phrase "pure sine wave inverter" is frequently used by manufacturers in order to more clearly differentiate the inverters with outputs that have substantially less distortion in comparison to the designs of inverters that employ a modified sine wave with three stages. The vast majority of consumer-grade inverters that are marketed as "pure sine wave inverters" do not, in fact, produce a smooth sine wave output; rather, their output is merely less choppy than that of square wave (two-step) and modified sine wave (three step) inverters. These inverters are described as having "two or three steps". However, this is not very important for the majority of electrical devices because they are able to cope with the output rather competently.

A sine wave output is ideal in situations when power inverter devices are used in place of normal line power. This is due to the fact that many electrical goods are designed to function most effectively when they are supplied with a sine wave AC power supply. The sine wave that is provided by the ordinary electric utility will generally have a few small faults, but it will occasionally have considerable distortion.

Sine wave inverters with more than three stages in the wave output are more complicated and have a much greater cost than modified sine wave inverters, which only have three steps, or square wave inverters, which only have one step, even if they are able to handle the same amount of power. Electronics that use modified sine wave electricity, such as personal computers and DVD players, are referred to as switch-mode power supply, or SMPS devices. AC motors that are directly drive non-sinusoidal power may create additional heat, may have different speed-torque characteristics, or may make more audible noise than when operating on sinusoidal power.

Inverter topologies used in the design of conventional inverters/UPS systems includes the following:

1) The PUSH-PULL topology

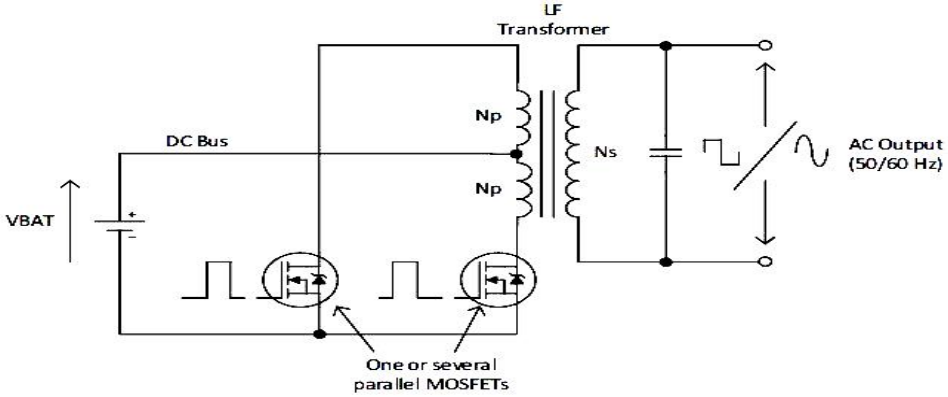


Fig 2.4 the schematic diagram of a typical push-pull topology

The push-pull topology requires only two switches, since the transformer primary center-tap is connected to the DC bus. However this has the disadvantage that during their respective off periods, twice the battery voltage appears at the drain of each MOSFET. It is necessary therefore to select devices with BVDSS ratings of at least twice the maximum battery voltage plus enough headroom to allow for transients and surges.
Additionally, in a bi-directional charger-inverter a high AC-line condition must also be taken into account in determining the required BVDSS. In some countries the AC mains voltage is known to vary over a wide range; in certain cases a nominal voltage of 220 V AC can rise to as high as 350 V AC. As the transformer is acting as a step down during charger mode, the MOSFETs will be exposed to the highest drain voltage during a high-line condition.

For a square-wave UPS the primary current is an approximate square wave with a small magnetizing current ramp added. This is shown in the blue waveform in Figure 5, which shows the current measured with a probe clamped around both end leads of the transformer primary connected to the drains of each MOSFET. The transformer is designed to keep its size and volume as small as possible and it is therefore driven farther up the B-H curve toward saturation, accounting for the rise in magnetizing current at the end of each switching cycle.

2) The FULL BRIDGE (H-BRIDGE) topology

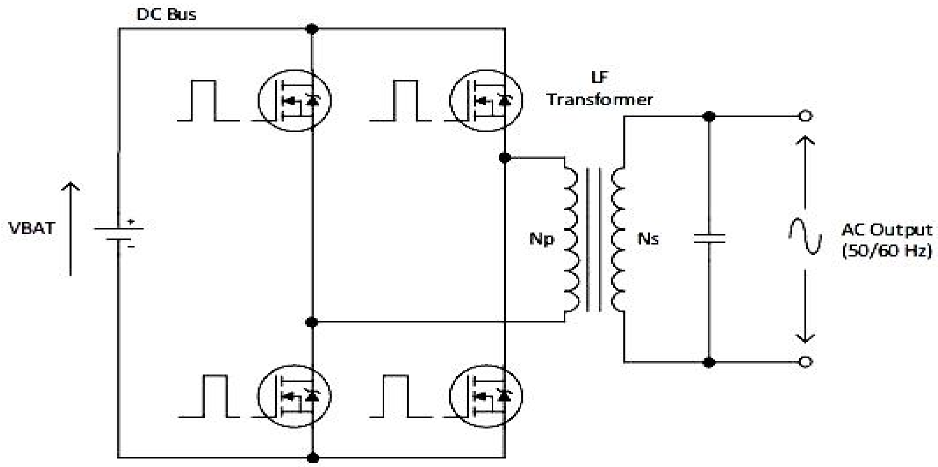


Fig 2.5 the h-bridge (full bridge) drive topology

The full-bridge inverter consists of four switches, which typically consist of a bank of parallel MOSFETs to carry the high current. The maximum drain voltage remains at one body diode drop above the battery voltage apart from a small switch-off transient, therefore the **BVDSS** (battery drain to source volt) rating may be selected based on the highest battery voltage with some appropriate headroom allowed in case of abnormal conditions. One advantage over the push-pull topology is that the transformer primary winding is driven in both polarities without the need for a center tap, which allows volume reduction. However, the drawback is that the full-bridge requires two floating high-side gate drivers.

2.2 PWM AND SPWM TECHNIQUE

PWM which stands for Pulse Width Modulation is a technique used in switching topologies simply for ease of adjustment of the output level of voltages and currents. PWM signals are actually square wave pulses with varying duty cycles. Duty cycle is the percentage of time the pulses are on relative to the period. This means as the duty cycle increases, the more power is being transmitted.

PWM requires rapid on and off signals, which can be achieved using high power MOSFETs. PWM switching are usually very fast switching techniques usually in the range of Kilo-hertz to Mega-hertz.

For switching in ac waveform generation, switching will need to be according to the waveform pattern of the desired signals. Switching in this technique is called **SPWM** which stands for Sinusoidal Pulse Width Modulation. As shown the figure below, maximum duty cycle is at the peak point of the waveform while minimum duty cycle is at the zero level of the ac signal. This SPWM signals are filtered with a low pass filter to get a clean AC output which is very similar to that of the national grid.

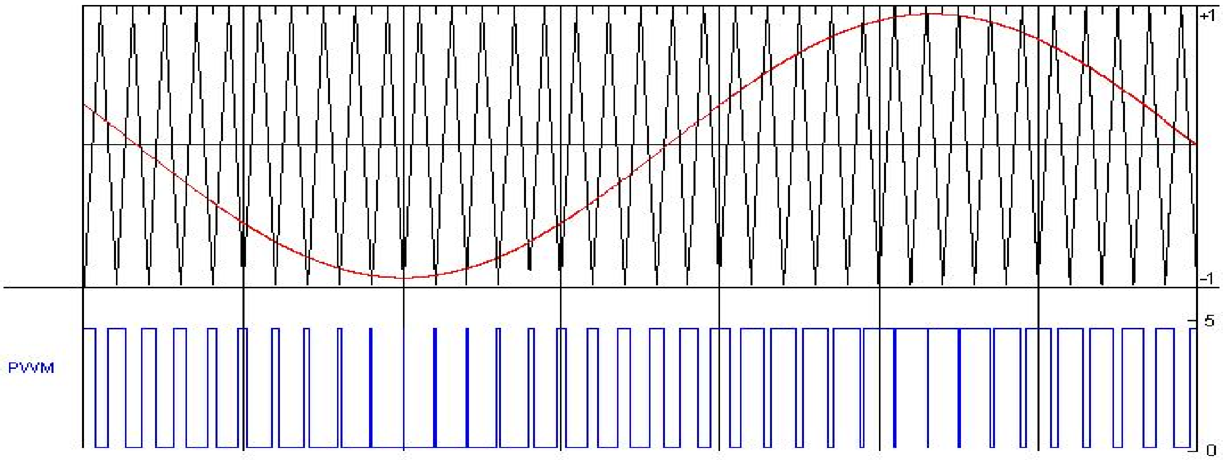


Fig. 2.6 the SPMW generation

2.3 APPLICATION OF INVERTERS

(https://www.ukessays.com/essays/engineering/dc-power-source-utilization-engineering-essay.php,2010)

In a country where the electrical power grid is not extensive and power supply unstable, the need for alternative means of generating power is of major concern. Homes, offices and industries rely heavily on electricity for their day to day operation in a developing country such as ours. Generators can equally be implored in this regards but has so many disadvantage. Noise, constant fueling, cost of regular maintenance, pollution amongst others are the reasons why the inverter is far better choice to the generator. The inverter which does not require liquid fuel, has high reliability, low maintenance and requires excellent constructional features becomes an attractive alternative, both as first line choice or use as backup for systems requiring uninterrupted power supply. Inverters could be used to power household appliances and office equipments.

The uses of inverters include the following:

i. DC Power Source Utilization

Here an inverter converts the DC electricity from sources such as batteries, solar panels or fuel cells to AC electricity. The electricity can then be used to operate AC equipment's such as those that are plugged into most household electrical outlets.

ii. Uninterruptible Power Supplies

An uninterruptible power supply is a device which supplies the stored electrical power to the load in case of raw power cut-off or blackout. Some types of UPS use batteries to store power and an inverter to supply AC power from the batteries when mains power is not available. When mains power is restored, a rectifier is used to supply DC power to recharge the batteries.

iii. Induction Heating

Inverters can convert low frequency main AC power to a higher frequency to be used in induction heating. To do this, AC power is first rectified to provide DC power. The inverter then changes the DC power to high frequency AC power.

iv. High-Voltage DC transmission

With HVDT power transmission, AC power is rectified and high voltage DC power is transmitted to another location. At the receiving location, an inverter in a static inverter plant converts the power back to AC.

v. Variable Frequency Drives

A variable frequency drive controls the operating speed of an Ac motor by controlling the frequency and voltage of the power supplied to the motor. An inverter provides the controlled power. In most cases, the variable frequency drive includes a rectifier so that DC power for the inverter can be provided from the main AC power. Since an inverter is the key component, variable-frequency drives are sometimes called inverter drives or just inverters.

vi. Electric Vehicle Drives

Adjustable speed motor control inverters are currently used to power the traction motor in some electric locomotive diesel-electric locomotives as well as some battery electric and hybrid electric highway vehicles. Various improvements in inverter technology are being developed specifically for electric vehicle applications.

BLOCK DIAGRAM OF AN INVERTER

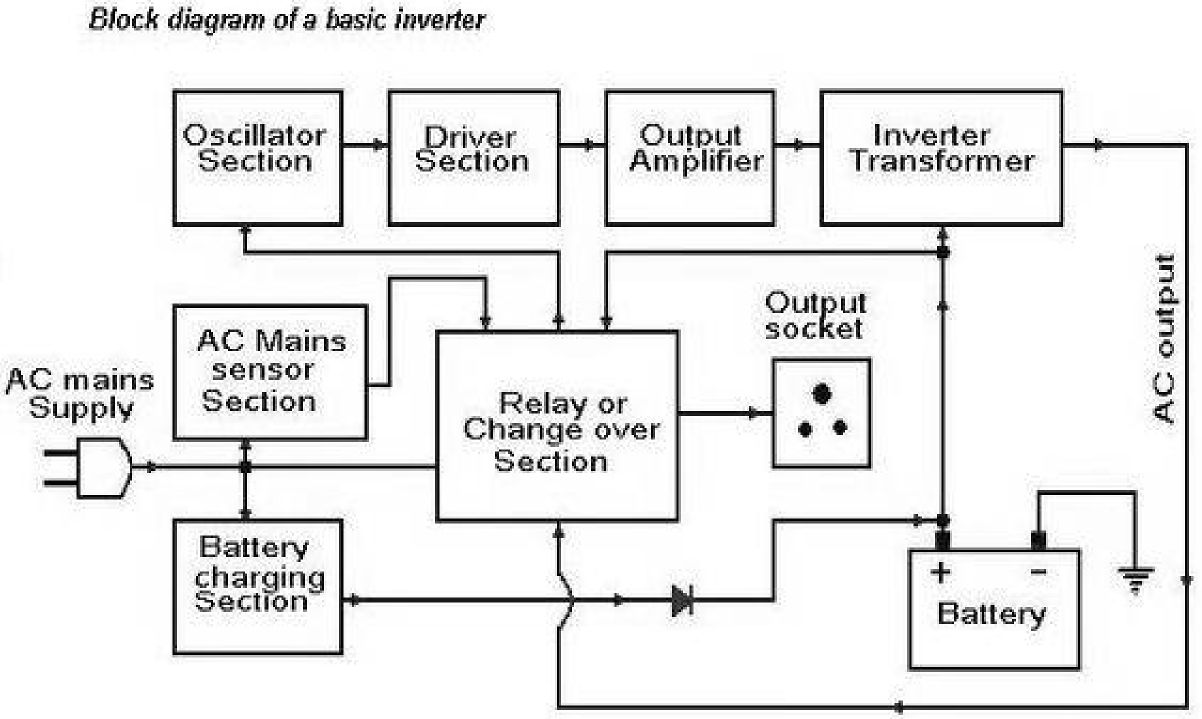


Fig 2.7 Block Diagram of an inverter system

2.4 FUNCTIONAL UNITS OF THE INVERTER

This section gives a brief explanation on the improved operation of the inverter modules. These include; power supply, controller (microcontroller) section, driver section, changeover section, cooling, alarm, display interface, mains and output sensing, battery monitoring and charging, load monitoring. It comes with protective measures like low battery trip, overload, short circuit, etc.

2.4. 1 POWER SUPPLY UNIT (Paul, D, 2022)

The input DC power to the inverter is 24V. The microcontroller, buzzer, LCD display require 5V for their operation, while the relay, OP-Amp and fan require 12V for their own operation. So the power supply section was designed to convert the 24V supply from the batteries to 12Volts and 5Volts needed. The type of converter used is the "fly-black" which is equally used in switch mode power supplies. It has efficiency close to 95%, which is better than conventional buck converters with efficiencies of 70-85%. The operating frequency is about 47.7 KHz set with the RC network at the pin4 terminal of the UC3843.

Below is the schematic diagram of a fly-back converter.

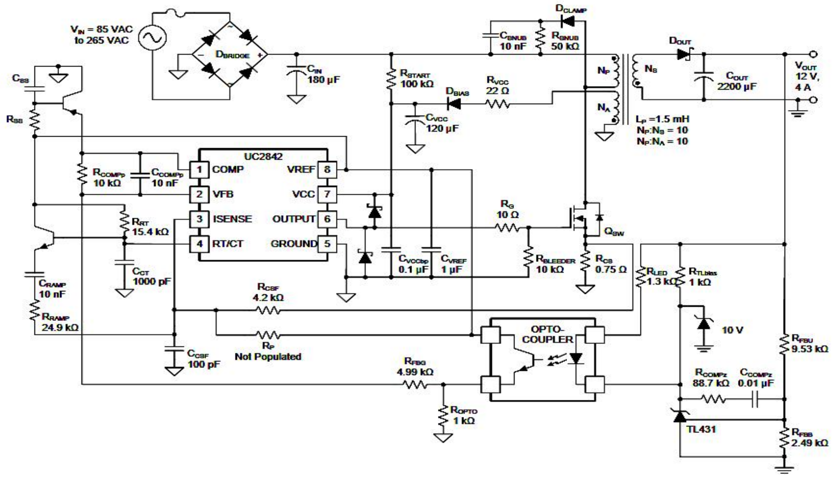


Fig 2.8 Schematic Diagram of a Fly-Back Converter with UC3842

The output of the converter is 12v and this is further stepped down to 5volts using LM7805 linear regulator for the microcontroller, buzzer, LCD, etc.

2.4.2 CONTROL UNIT

(https://ww1.microchip.com/downloads/en/devicedoc/70118e.pdf, 2016)

The control unit consists of the microcontroller, some resistors, crystal oscillator, etc. The microcontroller used for this project **is DSPIC30f2010** by **MICROCHIP** technology. It is a 16bit microcontroller with ***digital signal processing*** ability (**DSP**). It is clocked externally by a 6.144 MHz crystal oscillator for high performance. It basically does all controls like driving of the h-bridge MOSFETs, relay triggering (change-over), displays battery status, faults, warnings, input and output voltage status, etc. It is the very heart of the design.

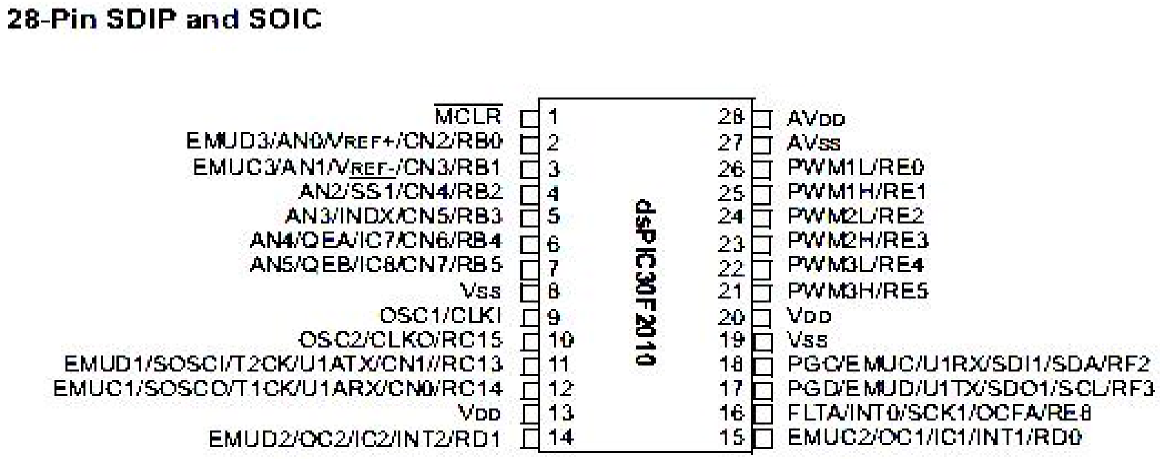


Fig 2.9 the pin out of the dsPIC30F2010

High-Performance Modified RISC CPU of the DSPIC30f2010:

- Modified Harvard architecture
- C compiler optimized instruction set architecture
- 84 base instructions with flexible addressing modes
- 24-bit wide instructions, 16-bit wide data path
- 12 Kbytes on-chip Flash program space
- 512 bytes on-chip data RAM
- 1 Kbyte non-volatile data EEPROM
- 16 x 16-bit working register array
- Up to 30 MIPs operation:

- DC to 40 MHz external clock input

- 4 MHz-10 MHz oscillators input with PLL active (4x, 8x, 16x)
- 27 interrupt sources
- Three external interrupt sources
- 8 user selectable priority levels for each interrupt
- 4 processor exceptions and software traps.

Motor Control PWM Module Features:
- 6 PWM output channels
  - Complementary or Independent Output modes
  - Edge and Center Aligned modes
- 4 duty cycle generators
- Dedicated time base with 4 modes
- Programmable output polarity
- Dead time control for Complementary mode
- Manual output control
- Trigger for synchronized A/D conversions

It has inbuilt Analog to Digital converters (ADC) used for reading input signals, Electronically Erasable Programmable Read Only Memory (EEPROM) used for storing data and adjustments made to the default settings, Motor control module for driving the h-bridge MOSFETs, DSP engine for fast processing ability, processor, etc.

Functions of the **Analog to Digital** converter module as used in this project are:

1. Reads the status of the battery bank, determine their state of charge, etc.,

2. Reads the status of the output voltage and determine the error or deviation from the set-point. This enables a fast correction to be made and stabilize the output,

3. Reads the temperature of the system and decide if to enable/disable the cooling fan,

4. Checks for the presence of the mains voltage and

5. Buttons interface to the controller.

In total, this microcontroller has 7 ADC channels but we only used five and the others where configured as digital I/O pins for other functions.

The microcontroller was also used in controlling the h-bridge which contained the MOSFETs banks.

It is fast in operation, requires low power, and very good for motor drive applications.

2.4.3 MAINS AND OUTPUT SENSE UNIT (Theobald, I, 2022)

This unit was used to check the status of the output of the inverter and give feedback to the microcontroller to make necessary adjustments to the error. It was also used to check the status of the mains voltage if it was in the safe region (150v to 260v). If this was so, it can carry out other operations like changing over to mains and start charging of the batteries.

The operational amplifier was best suited for this purpose considering costs and proper isolation of the microcontroller from the high voltage of the mains supply and the output of the inverter.

2.4.3.1 LM324N OPERATIONAL AMPLIFIER (Google web, 2022)

The lm324n is quad op-amp containing four independent operational amplifiers.

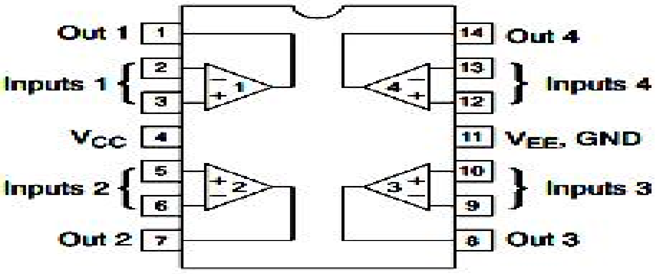


Fig. 2.10 (a) internal configuration of the lm324 op-amp

They are designed to operate from a single or dual power supply and draw a drain current of about 60uA over a wide range of supply voltage.

They can also serve as comparators. In this project, we used two of the channels in the inverting amplifier configurations for sensing the mains voltage level and the inverter output level. A third channel was used as a voltage follower to add a DC off-set voltage of 2.5volts to both signals.

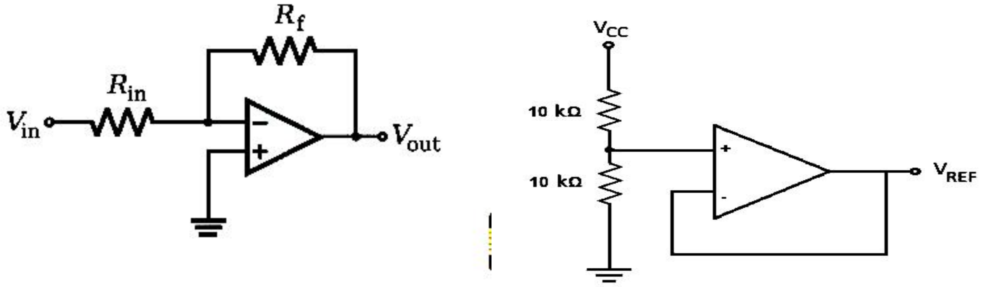


Fig.2.11 the Op-amp as: (b) an inverting amplifier (c) voltage follower

In Fig. 2.14c above, the input to the non-inverting terminal is same as the output, Vref. Vref is used as the DC offset voltage. If Vcc is 5v, from the voltage divider network, the input to the non-inverting terminal of the op-amp is 2.5v. This 2.5v will also appear at the output of the op-amp.

Microcontrollers can’t sense negative voltages, so the 2.5v offset will help to raise the DC level of the signals.

2.4.4 INVERSION UNIT (DC TO AC) (Obasi, C, 2022)

The inversion stage is where the DC energy from the battery is converted into AC. This is achieved through a forward and reversion conduction of current through switches controlled by the microcontroller through special drivers (TLP250). This stage can be achieved using configurations like the push-pull, full-bridge which is also called h-bridge, etc. For the sake of this project, we used the h-bridge due to its advantages over the others.

The **H-BRIDGE** is a two channel four-switch arrangement for the purpose of forward and reverse driving of devices which may require such operations. It is used for driving motors in conveyor belts, robots, drones, etc. The dspic30f2010 microcontroller has up to three channels and can control six switches in applications requiring three phase output. But in this project, we used only two channels since it’s a single phase system.

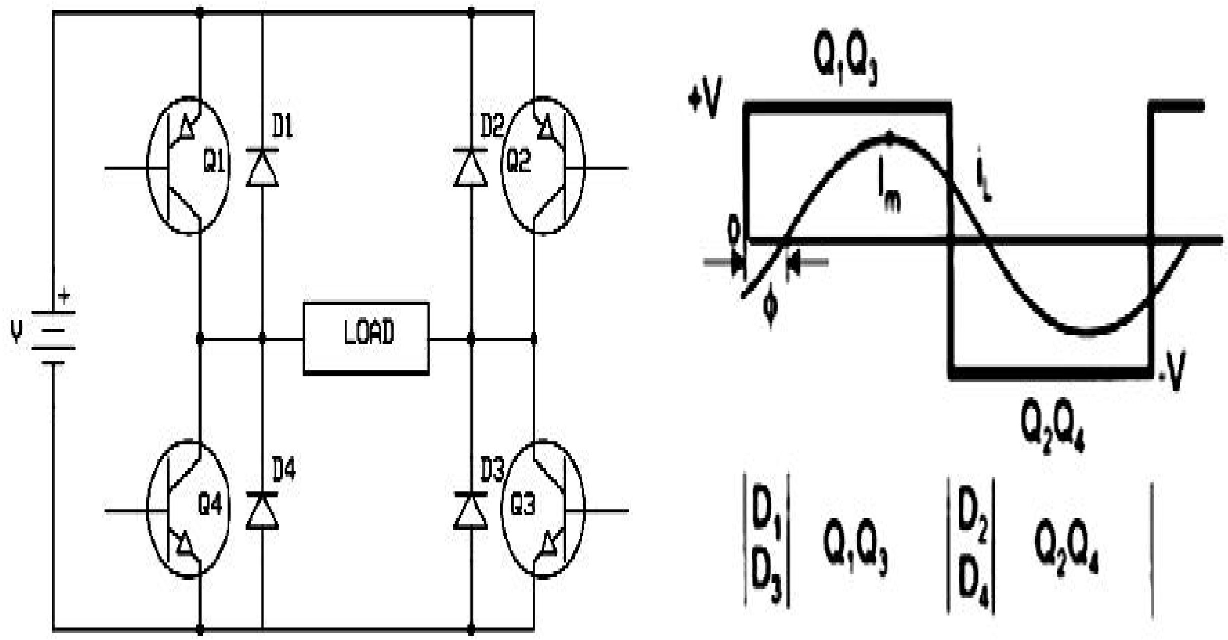


Figure 2.12 the Single Phase Full-Bridge Inverter (a) Circuit (b) Waveform

The H-BRIDGE circuit was connected to the microcontroller through special MOSFETs drivers called **TLP250** which is an opto-coupler.

An opto-coupler is a device which has its input separated from its output either partially or completely. The input is usually an LED whose light source intensity is used to control the behavior of the output. Below is the internally structure of the TLP250 driver.

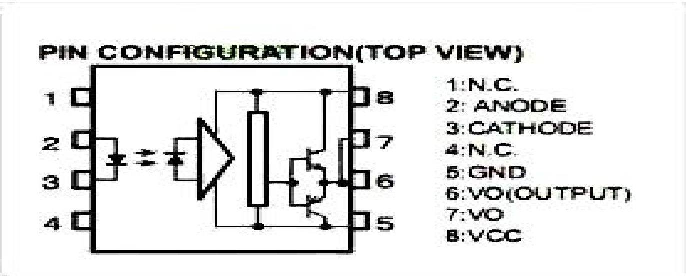


Fig. 2.12 internal circuitry of the TLP250 MOSFET driver

The h-bridge has the high and the low sides. The source terminals of the low sides are connected to the ground (negative terminal in this case) low. While the high sides require “special ground” which were created by using float voltages since in our designs we used n-channel MOSFETs in all the sides. N-channel MOSFETs were preferred to P-channel due to their lower losses during switching operations and also their high dv/dt rating.

2.4.5 CHARGING UNIT (AC TO DC) (Urvashihandelwal, 2009)

This unit is used to charge the battery bank on availability of mains supply to the inverter system. An added advantage of the topology is that it enables a fully bi-directional inverter/charger to be realized. In battery charging mode it is able to operate as a form of bridgeless PFC boost converter to provide regulated battery charge current, while drawing a roughly sinusoidal phase current from the AC supply. The transformer primary leakage inductance acts as the Boost inductor supplied with voltage stepped down from the AC-line.

Should the battery voltage be lower than the secondary peak voltage minus two body diode drops, then uncontrolled current would flow into the battery. To avoid this, a resettable fuse is often added in the UPS AC output. This offers protection against overload, abnormally low battery voltage or short circuit of the battery connections.

This charging scheme may be used in sine-wave or square-wave output full-bridge UPS systems. However, in the square-wave system a secondary winding tap change via a relay is necessary to compensate for different peak-to-RMS voltage ratios between the sine-wave charging voltage supplied by the AC-line and the square-wave output voltage produced by the inverter. This is necessary to maintain the rectified AC-line voltage low enough to allow bridgeless boost charging.

In bridgeless boost charging mode the two upper switches MH1 and MH2 are typically always off, and the lower switches ML1 and ML2 are both driven on and off together by PWM pulses at the switching frequency. Depending on the AC-line polarity boost operation will occur in one or other of the branches of the bridge.

Operation can be understood by considering the transformer primary as a voltage source with a series inductor to represent the lumped primary and secondary leakage inductances.

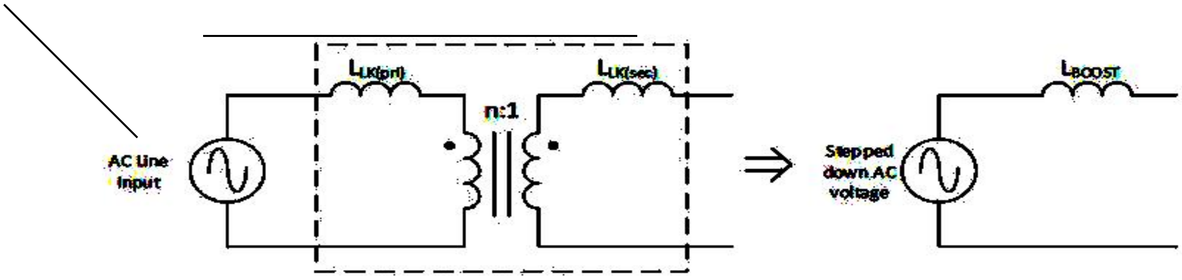


Fig 2.14 Transformer equivalent circuit in charging operation

When both lower switches are on current rises in the inductor and energy builds up in the magnetic flux. When both are switched off, the inductor current passes through the body diodes in one diagonal pair of MOSFETs depending on its direction according to the AC-line half-cycle polarity. The MOSFET body diodes thus form a bridge providing a DC charge current to the battery.

The feedback loop regulating the battery charge current is necessarily slow so that changes in duty cycle happen gradually over several AC-line cycles in the same way that they do in PFC converters. This allows line current to form a more sinusoidal shape to more closely follow the AC line voltage and thus improve the power factor, typically to above 0.8.

Power Factor Correction (PFC) can therefore be implemented during charging without the need for any additional components, simply by driving the MOSFETs differently.

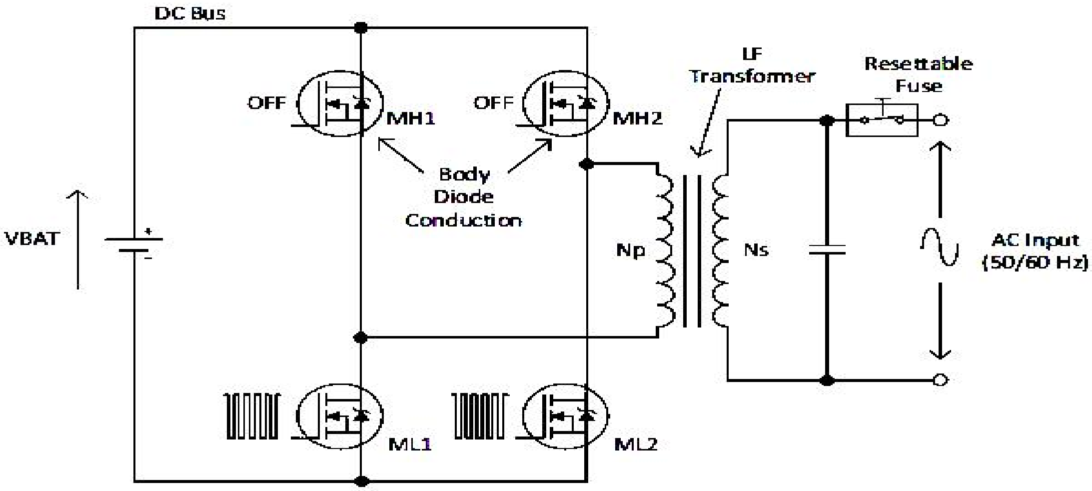


Fig 2.15 the charging sequence of the h-bridge circuit using boost pfc

2.4.6 FILTERING UNIT (Wikipedia, 2022)

The output from the transformer is not sinusoidal and contains different levels of **harmonics.** To ensure the design outputs the desired sine wave, filtering was done and this was implemented using a separate circuit. Filters find great relevance in reducing and blocking unwanted signals which can affect the quality of the output waveform. There are different types of filters which include;

(a) low-pass filter: the low-pass filter is used to block signals with frequencies above a predetermined value. Say we design a low-pass filter for 50 Hz, any frequency above this value will be blocked. Only frequencies less than or equal to 50 Hz will be allowed through.

(b) high-pass filter: the high-pass filter works in the reverse as the low-pass. It will block frequencies less than the predetermined value and only signals with frequencies greater than or equal to 50Hz will be allowed to pass.

(c) band-pass filter: this filter is designed to allow signals with frequencies lying within a specific band to pass through. Any signal with frequencies less than or greater than this value will not be allowed through.

A Low Pass Filter can be a combination of capacitance; inductance or resistance intended to produce high attenuation above a specified frequency and little or no attenuation below that frequency. The frequency at which the transition occurs is called the **"cut-off"** or "corner" frequency.

Cut-Off Frequency – is the frequency above which the output voltage falls below 70.7% of the input voltage. In a capacitive/resistive low-pass filter, it is the frequency at which capacitive reactance in ohms equals resistance in ohms. For a capacitive low-pass filter containing one resistor and one capacitor, the cutoff frequency is given as:

$$f_{\mathrm{c}} = \frac{1}{2\pi RC}$$

The simplest low pass filters consist of a resistor and capacitor but more sophisticated low pass filters have a combination of series inductors and parallel capacitors.

There are two basic kinds of circuits capable of accomplishing this objective:

- Inductive Low-Pass Filter

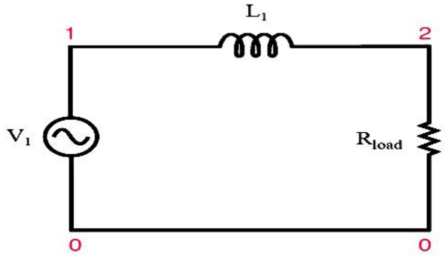


Fig. 2.16(a)

The inductor's impedance increases with increasing frequency. This high impedance in series tends to block high-frequency signals from getting to the load.

- Capacitive Low-Pass Filter

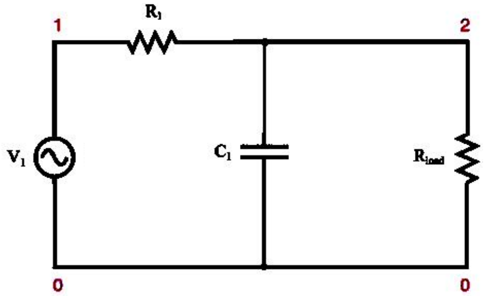


Fig. 2.16(b)

The capacitor's impedance decreases with increasing frequency. This low impedance in parallel with the load resistance tends to short out high-frequency signals, dropping most of the voltage across series resistor R_1.

For this project, we made use of Inductive Low-Pass Filter as the value of resistor needed for the capacitive low-pass filter will result in huge loss. However, we won't be making use of an external inductor in our filter design. This is because from the complete circuit of a transformer, the secondary (which is the output) of the transformer has an inductor and a resistor. We are going to be making use of the inductive property of the secondary of the transformer to carry out this task. The value of resistance is quite minimal and doesn't account for much drop.

2.5 ELECTRONIC COMPONENTS

2.5.1 MOSFETs

(http://electrathonoftampabay.org/www/Documents/Electronics/AN-9010.pdf,2008) (http://www.onsemi.com/download/application-notes/pdf/an-9010.pdf,2010) (https://u.dianyuan.com/bbs/u/41/1147396605.pdf,2018) (https://www.electro-tech-online.com/attachments/an-fairchild-on-mosfets-pdf.31706/,2009) (https://www.researchgate.net/publication/332142280_Design_And_Implementation_Of_Three_Phase_Inverter_B,2011) (https://components101.com/articles/mosfet-symbol-working-operation-types-and-applications,2012**).**

MOSFET is an acronym for Metal Oxide Semi-conductor Field Effect Transistor. The MOSFET is used in this design to provide the second stage amplification before current is now conducted to the step-up transformer unit.

Field Effect, as used in the above definition is due to the fact that the MOSFET device is controlled by a voltage “field” or “potential” applied to the input. This action of control is anonymous to the BJT device which is current controlled.

2.5.1.1 Theory

The MOSFET also called Silicon Transistor or Insulated Gate Field Effect Transistor (IGFET), operates in two modes which are the Depletion and Enhancement. Both the n-channel and the p-channel are obtainable in both modes.

2.5.1.2 Structure

The basic structure of a MOSFET consists of a lightly doped high resistant semi-conductor substrate into which is diffused two heavily doped low resistance regions to form source and drain respectively. A thin layer of Silicon (iv) Oxide, SiO2, insulates a metal electrode (an aluminum film) called the gate from the top of the substrate. The SiO2 (glass) is etched to allow the attachment of metal terminals to the source and drain.

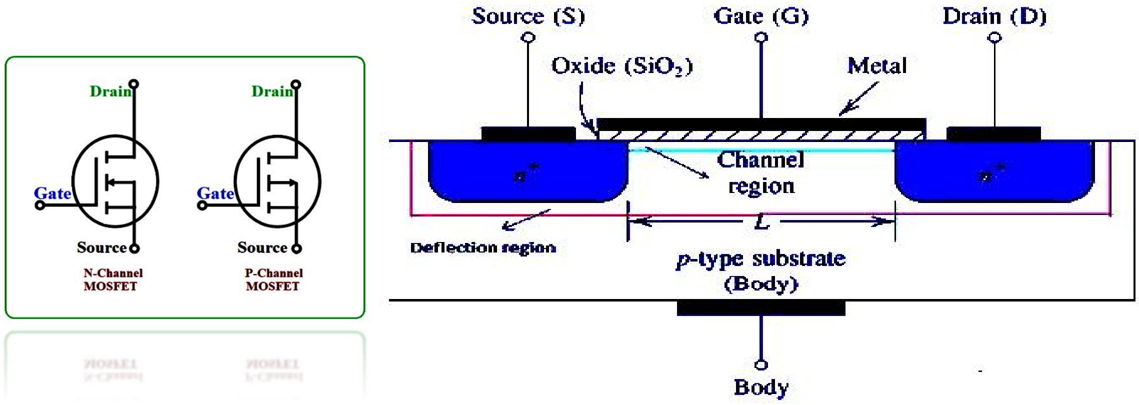


Fig. 2.17 the typical MOSFET (a) schematic (b) internal structure

MOSFETs come in different packages grouped base on current handling capacity, switching losses, etc. The MOSFETs are available with a different name in each kind of packages as follows:

Surface Mount: TO-263, TO-252, MO-187, SO-8, SOT-223, SOT-23, TSOP-6, etc.

Thru-Hole: TO-262, TO-251, TO-274, TO-220, TO-247, etc.

PQFN: PQFN 2x2, PQFN 3x3, PQFN 3.3x3.3, PQFN 5x4, PQFN 5x6, etc.

DirectFET: DirectFET M4, DirectFET MA, DirectFET MD, DirectFET ME, DirectFET S1, DirectFET SH, etc.

The significant features of the MOSFET device are:

1. Absence of secondary breakdown
2. No thermal runaway
3. Very high speed switching ability up to the gigahertz range.
4. Negligible drive power. For example, logic gates can be used to drive them.

Compared to BJT, MOSFETs can be used advantageously in order to avoid the need for commutation and to perform at switching rates up to several hundred kilohertz. MOSFETs in this design are used in parallel for greater power capability.

These power MOSFETs have some additional quality which was used during design to obtain rectification. One main quality is that it has effective diode anti-parallel to the drain-source direction. This diode was used to achieve rectification and reverse conduction (avalanche-protection) to discharge any residual charge on the device during turn-off.

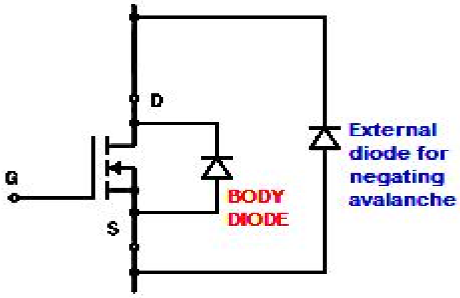


Fig 2.18 the internal circuit of the N-channel MOSFET showing the body diode

2.5.1.3 Advantages of the MOSFETs

a) **High Input Impedance-**Voltage regulating gadgets, simple to drive. A switching device known as voltage controlled MOSFET is one that is easy to drive by a channel on the surface of the semi-conductor. This channel is driven as a result of the filed effect that is created when a voltage is applied to the gate of the electrode, which is separate from the semiconductor surface. In accordance with the specifications, the gate current is low both during the switching transient and when it is in the on or off state. Additionally, the driving circuit is uncomplicated and relatively affordable.

b) **Unipolar device, Majority Carrier device, Fast switching speed-** The switching speed is in order of magnitude quicker than that of the BJT. As a result, it is beneficial to use in a circuit that operates at high frequency and suffers from significant power loss.

c) **Wide SOA (Safe Operation Area) -** it is possible to apply a high voltage and current for a brief period of time, which contributes to the device's larger SOA compared to the BJT. The risk of a destructive device failing owing to a second breakdown is therefore eliminated.

d) **Forward Voltage Drop with Temperature Coefficient –** the drop in temperature causes the forward voltage drop to rise. When many devices are connected in parallel, this ensures that the current flow the same amount through each one. Because of this, it is much simpler to use in parallel as opposed to a BJT, which has a forward voltage loss and negative temperature coefficient.

2.5.1.4 Working Principle Of MOSFET

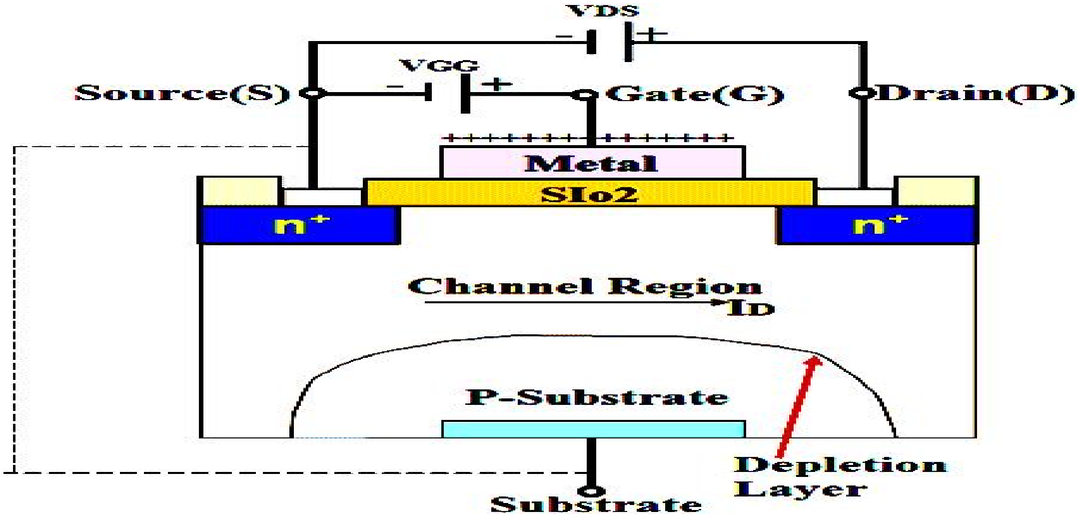


Fig 2.19 the internal layers of the MOSFET showing principle of operation

A positive voltage is applied to the Drain whenever a drain-source voltage (VDS) is linked between the drain and the source. On the other hand, a negative voltage is applied to the source whenever this type of connection is made. In this configuration, the PN junction at the drain is subjected to a reverse bias, while the PN junction at the source is subject to a forward bias. At this point, there is not going to be any flow of current between the drain and the source. If we apply a positive voltage, denoted by the symbol VGG to the terminal, the minority charge carriers, also known as electrons in the P-substrate will begin to accumulate on the gate contact as a result of electrostatic attraction. This results in the formation of a conductive bridge between the two regions. The magnitude of the positive voltage that is delivered has an effect on the total amount of free electrons that are collected at the gate contact. The higher the applied voltage, the wider the n-channel that is generated as a result of the electron accumulation. This eventually leads to an increase in conductivity, which is when the drain current (Id) begins to flow between the source and the drain of the device. There will be no current flow when there is no voltage supplied to the gate terminal, with the exception of a very little amount of current that is caused by minority charge carriers. The threshold voltage is the level of voltage that must be reached before the MOSFET will begin conducting current.

2.5.1.4.1 Operation of MOSFET in Depletion Mode:

A mode known as depletion MOSFETs are typically referred to as the “Switched ON” devices since they are typically in the closed state when there is no bias voltage applied to the gate terminal. This is why they are given this name. When we boost voltage applied to the gate terminal in the positive direction, the channel width in the depletion mode will expand as a result. Because of this, the drain current that flows through the channel will grow. The channel width in the depletion mode will expand as a result. Because of this, the drain current ID that travels through the channel will grow. If the gate voltage that is supplied is extremely negative, then the channel width will be reduced, and the MOSFET will have a greater chance of entering the cut-off area.

VI characteristics:

The V-I characteristics of the depletion-mode MOSFET transistor are depicted as a line between the drain-source voltage (VDS) and the drain current (ID). The relatively low voltage that is present at the gate terminal will exert influence over the quantity of current that is carried by the channel. When there is no bias voltage applied to the gate terminal, the channel that is created between the drain and the source will function as an effective conductor. When a positive voltage is given to the gate, the channel width and drain current will both grow. On the other hand, when a negative voltage is applied to the gate, both of these parameters will experience a drop.

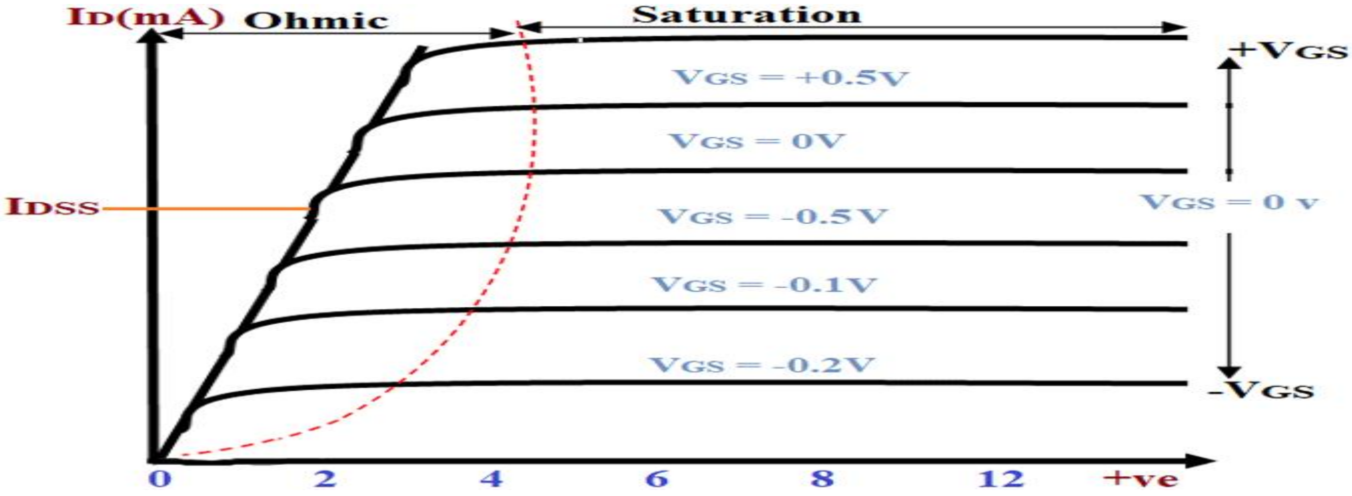


Fig 2.20 the I-V characteristics of the depletion Mosfet

2.5.1.4.2 Operation of MOSFET in Enhancement Mode:

When operating in Enhancement mode, a MOSFET behaves in a manner that is analogous to that of an open switch. It will begin to conduct only when a positive voltage (+VGS) is provided to the gate terminal of the device and when drain current begins to flow through it. When the bias voltage is raised, both the channel width and the drain current will rise accordingly. On the other hand, if the applied bias voltage is either zero or negative, the transistor will maintain its OFF state on its own.

VI Characteristics:

VI descriptors of the enhancement-mode qualities In a MOSFET circuit, the drain current (ID) and the drain-source voltage are pulled between each other (VDS). The VI properties may be broken down into three distinct zones, which are referred to as the ohmic, saturation, and cut-off regions respectively. The region where the applied bias voltage is zero is known as the cut-off zone. This is the region in which the MOSFET will be in the OFF state. When the bias voltage is provided, the MOSFET gradually transitions into the conduction mode, and the gradual rise in conductivity takes place in the ohmic region during this time. Last but not least, the MOSFET will remain in the conduction state during the saturation area, which is characterized by the continuous application of a positive voltage.

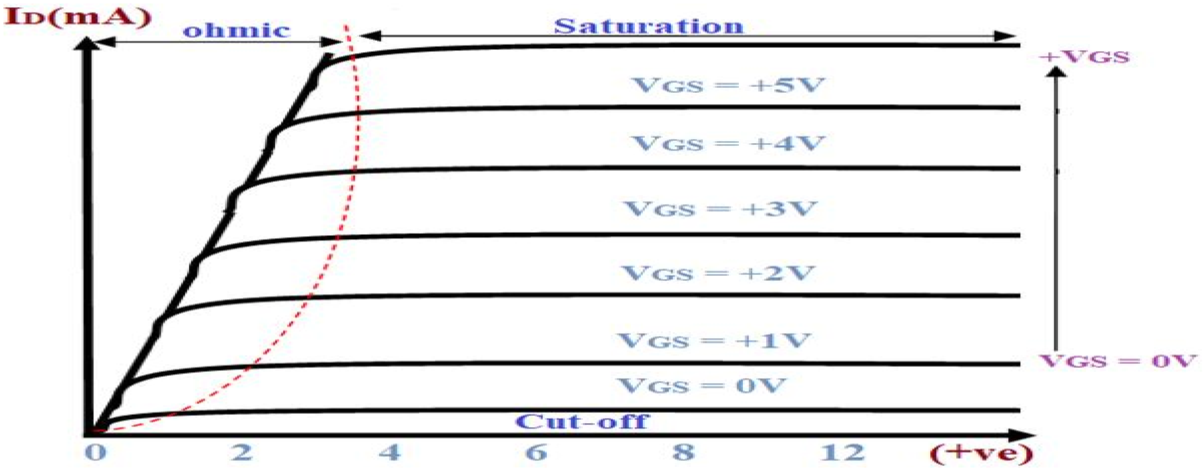


Fig 2.21 the I-V characteristics of the enhancement type Mosfet

The voltages that are present at the MOSFET's terminals can cause the device to operate in one of three distinct modes, which can be distinguished from one another. For an enhancement mode N-channel MOSFET modes are:

2.5.1.4.3 Cut-off or sub-threshold mode:

Here Vgs<Vth, where Vth is the threshold voltage of the device.

When a transistor is off, the basic threshold model predicts that there is no conduction between the drain and the source. In practice, this prediction is borne out by observation. The Boltzmann distribution of electron energies makes it possible for some of the higher energetic electrons at the source to enter the channel and flow to the drain. This result in a sub-threshold current that is turned off, the current is that is flowing between the drain and the source should ideally be zero. However, there is a faint inversion current that is termed the sub-threshold leakage.

Linear Region:

When Vgs > Vth and Vds < (Vgs – Vth), the transistor is turned on and a channel has been created which allows current to flow between the drain and the source. The MOSFET operates like a resistor controlled by the gate voltage relative to both the source and drain voltages. The current from drain to source is modelled as:

$I_D = U_n C_{ox}(W/L)[(V_{GS} - V_{TH}) V_{DS} - V_{DS}^2 /2]$

Where U_n is the charge carrier effective mobility, W is the gate width, L is the length and C_{ox} is the gate oxide capacitance per unit area.
Saturation: When $V_{GS} > V_{TH}$ and $V_{DS} > (V_{GS} – V_{TH})$

The switch is turned on and a channel is created which allows the flow of current between the drain-source. Since the drain voltage is higher than the gate voltage, a portion of the channel is turned off. The onset of the region is also known as pinch-off. The drain current is now relatively independent of the drain voltage and the current is controlled by only the gate-source voltage, given as

$$I_D = U_n C_{ox}(W/2L)[(V_{GS} – V_{TH})^2$$

The equation can be multiplied by (1+ ג V_{DS}) to take into account the channel length modulation.

2.5.1.5 IRF3205 MOSFET

This is an n-channel enhancement mode silicon gate power field effect transistor in an advanced TO-220 power package designed, tested and guaranteed to withstand a specific level of energy in the breakdown avalanche to withstand a specified level of energy in the breakdown avalanche mode of operation. All of these power MOSFETs are designed for applications such as switching regulators, switching converters, motor drivers, relay drivers and driver for high power bipolar switching transistors requiring high speed and low gate drive power. These types can be operated directly from integrated circuits.

2.5.1.5.1 Features of the IRF3205 MOSFET

- Maximum drain to source current (Ids_{max}) ……….. 98Amps
- Maximum drain to source voltage…………………… 55Volts
- Single Pulse Avalanche Energy ………………………..EAS 150mJ
- Nanosecond switching speed
- High input impedance
- Low output Impedance (Rds_{on})…………………………… 8mohm
- Linear derating factor…………………………………………1.44W/°C
- Operating and storage temperature…………TJ, TSTG -55 to 150°C
- Lead at 0.063in (1,6mm) from case for 10s…………..TL 300°C

2.5.1.6 MOSFET selection criteria

(1) Selecting BVDSS

The combination of MOSFETs to be used in a LF transformer-based UPS depends on the battery voltage, the inverter topology and, in the case of systems based on LF transformers, the maximum high-line voltage to which the system may be connected as well as the total power. The first parameter to be considered is the maximum voltage rating BVDSS, which is determined initially according to the maximum battery voltage and the topology. For a lead-acid battery the terminal voltage may be up to 15 V. In a push pull topology BVDSS must allow for 2 × $V_{BAT(MAX})$) and for full-bridge $V_{BAT(MAX),}$ which will appear at the drain. Since these are usually hard-switching topologies transient voltages will be present resulting from body diode recovery, therefore to avoid placing unnecessary stress on the devices, it is advisable to allow 100 percent extra voltage margin to avoid avalanching due to these spikes. For example, a full-bridge system operating with a 24 V battery should use 55 or 60 V rated MOSFETs. This would also apply for a 12 V push-pull system, but 30 V MOSFETs should be sufficient for a 12 V full-bridge system. It should be noted that the full-bridge clamps the leakage inductance energy to the battery voltage through the body diodes, and therefore transients are less than in the push-pull case. In HF transformer-based UPS topologies these criteria also apply for the DC-DC stage. In the back end inverter stage HV Cool MOSTM devices suitable for hard-switching operation are recommended. Here again a good safety margin is needed to avoid the avalanche condition, particularly under short-circuit where abnormally high voltage spikes are produced.

Table 2.1 Recommended BVDSS for battery voltage and UPS architecture

Battery voltage (nominal)	UPS architecture	BVDSS of Mosfet
12	Push-pull (low frequency transformer)	55 to 60
Full-bridge (low frequency transformer)		30 to 40
24	Push-pull (low frequency transformer)	75 to 100
Full-bridge (low frequency transformer)		40 to 60
48	Push-pull (low frequency transformer)	150
Full-bridge (low frequency transformer)		100
72	Push-pull (low frequency transformer)	200
Full-bridge (low frequency transformer)		100 to 150

(2) Selecting $I_{d(max)}$

Having selected the required BV_{DSS}, the next parameter to consider is the maximum continuous current rating Id_{MAX}. Where the MOSFET datasheet includes maximum silicon limited ratings as well as package or wire bond limited ratings, the lowest value should be used. For temperature de-rating a graph of $I_{D(MAX)}$ against case temperature should be provided, which may be used to determine the maximum current rating at 100 degrees C.

In both push-pull and full-bridge converters during inverter operation the average current in each power switch consisting of one or more parallel MOSFETs will be half the current being supplied from the battery. Therefore the highest current would be at the maximum load rated for the UPS and the lowest battery voltage also factoring in the converter efficiency, which may be estimated at 85 percent. Lead acid batteries should not be operated below a certain minimum voltage level since this causes damage due to sulfation. For a nominally 12 V battery severe damage will occur if it is discharged below 10.5 V. For this reason UPS systems are designed to cut out when the battery voltage drops below a minimum threshold, which may be considered the worst case for calculating the maximum current. For example, a suitable cut-off voltage

VBAT(MIN) may be set at 11.6 V, therefore a 1000 W UPS would theoretically draw a maximum current of 1000/(0.85 × 11.6) = 101.4 A. The average current passing through each switch would then be 50.7 A.

Having determined the worst-case average current the peak current should then be considered, which will typically be twice the average current assuming that the system is operating close to 50 percent duty cycle at full load and minimum battery voltage. In systems based on high frequency transformers the magnetizing current should also be taken into consideration. It is reasonable to allow an extra 50 percent of safety margin for the peak current.

Having determined the worst-case current for inverter operation it is now necessary for bi-directional charger/inverter topologies to establish what the maximum current during charging will be. Both the average and peak currents vary considerably in different topologies. Obviously this does not apply where separate converters are used for charging. When the worst case average and peak operating currents have been established, the power dissipation of the device and die temperature rise needs to be looked at. The power dissipation includes conduction losses in the channel and body diode during different modes of operation as well as switching losses, which have yet to be discussed.

From the table above, our MOSFET BV_{ds} should not be less than 40V for h-bridge design.

2.5.2 THE TRANSFORMER (Patrick, 2018)

After the DC is converted to AC by the inversion unit, it remains around the battery voltage level. That is, for our system which rated 24v DC, we got about 20V AC. But our inverter should output 220V AC. So the best option was to amplify this low voltage to a high voltage needed at the output of the inverter. This was achieved using a transformer.

The use of transformer in this design is essential. It is used in the power unit just after the MOSFETs bank as a step up when the inverter is used to supply a load or step-down when supply from the mains is used for charging the batteries.

2.4.2.1 THEORY

The transformer is a static electrical machine that enables electrical power to be transferred from one voltage level to another. It operates as an electromagnetic device. When it is used to either raise or lower voltage of an A.C supply, there is a related decrease or increase in current.

2.5.2.2 Construction Features

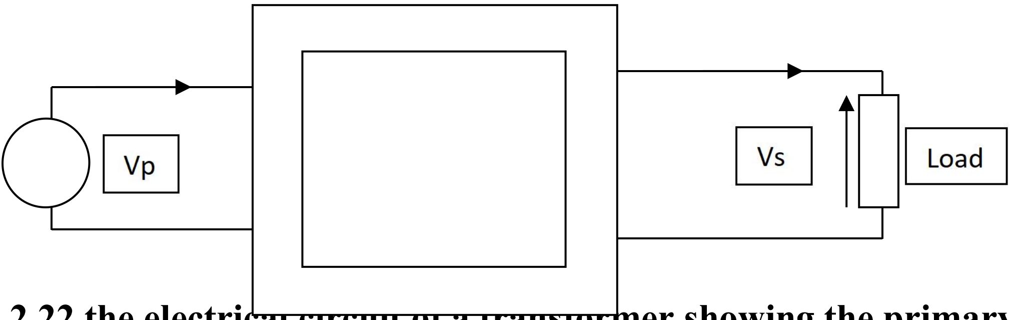


Fig 2.22 the electrical circuit of a transformer showing the primary winding and secondary winding

The arrangement of a transformer is as shown in the figure above. It consists of two coils wound on a closed magnetic circuit built on a laminated iron and the two coils will have mutual inductance. When one coil is connected to a supply, a current will flow and an alternating flux will be set up in the core, most of which will link up with the set coil. An e.m.f of mutual inductance will be set up in this coil and if the circuit is complete, a current will flow. The coil connected to the supply is called the primary (p) while the other which is connected to the load is called the secondary (s).

Let Np and Ns be the number of turns on the primary and secondary. Then,

Total e.m.f induced in secondary (s)/Total e.m.f induced in primary (p) = Ns x e.m.f per turn/ Np x e.m.f per turn…………………………………2.1

This terminal voltage is the same as the induced e.m.f. When the secondary is an open circuit, the primary current is then very small, so that the applied voltage is practically equal and opposite to the e.m.f induced in (p).

Vs/Vp = Ns/Np……………………………………2.2

Thus if Np > Ns, then Vp > Vs and the transformer is a step-up.

Else, if Ns > Np, then Vs > Vp and the transformer is a step-down.

Also;

IpVp x Qp = IsVsQs (efficient at 100%)

But Qp = Qs at full load

Then IpVp = IsVs**…………………………………2.3**

Ip/Is = Vs/Vp = Ns/Np**……………………………2.4**

The transformer is neither a source/sink of electrical power but a means of transfer from one voltage level to another.

2.5.2.3 E.M.F EQUATION OF A TRANSFORMER

The flux Φ is setup by the application of an alternating voltage to the primary winding of the transformer.

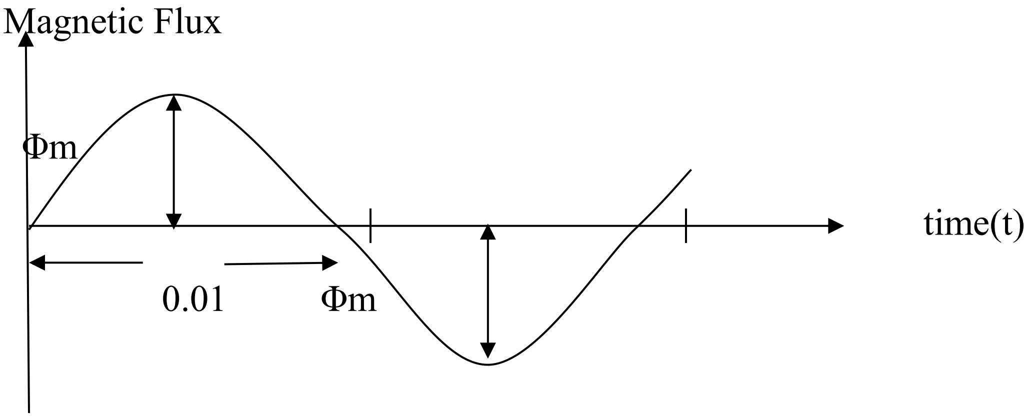


Fig.2.23 Waveform of flux variation in a transformer

Let

Np = No of primary winding turns

Ns = No of secondary winding turns

Φm = Maximum value of flux

F = Frequency

From Fig.2.162, it can be seen that the flux Φm increase from zero to ¼ F seconds.

Thus the average rate of change of flux:

$\Phi m/ (1/4F) = \Phi m \times 4F$

$\Phi m \times 4 \times F = 4\Phi F$

4 ΦmF (W/sec)**……………………………..2.5**

Assuming the flux varies sinusoidal, then the sinusoid e.m.f will be induced in each turn of both winding. For a sine wave, the formula is

r.m.s = 0.707 = 1.11

mean = 0.638

r.m.s e.m.f induced in each time = 0.11 x 4ΦmF = 4.44 ΦmFVoHz**…….2.6**

r.m.s e.m.f induced in the primary Ep = 4.44ΦmFNp Volt **……………..2.7**

r.m.s e.m.f induced in the secondary Es = 4.44ΦmFNs Volt**………………2.8**

The transformation ratio is

Es/Ep = Vs/Vp = Ns/Np = k**.. 2.9**

Where k is called the ratio of transformation

Is/Ip = Ep/Es**..……………………2.10**

In the transformers, the fluxes produced can lie wholly within the iron core (linking both winding) while others link one winding only.

Leakage fluxes are those that link only one winding on which they are produced and it is responsible for inducing an e.m.f of self-inductance. In the windings with which it is linked, half the leakage flux links the primary while the other half links the secondary and they are proportional to the load.

2.5.2.2 TYPES OF TRANSFORMERS

1) Power transformer – for transmission and distribution
2) Auto transformer – for starting A.C motor

3) Test transformer – for producing high test voltage.

2.4.2.3 COMPONENT OF A TRANSFORMER

a) **CORE:** this is the steel system which forms the magnetic circuit. The windings are wrapped around the core. A transformer is described as a core type.
b) **WINDINGS:** the low voltage windings are thicker because it carries more currents. It is wound to test and round the core, the high voltage windings are thinner.
c) **WINDINGS INSULATION:** the major insulation technique comprises of the insulation between the low voltage windings. The minor insulation consists of the insulation on individual turns between layers.
d) **LEAD FROM WINDINGS:** when the coils are assembled the lead from the top and bottom of the windings are brought out and assembled to the configuration of the transformer.

2.5.2.4 ADVANTAGES OF THE TRANSFORMER

A transformer has the following advantages;

a) The transformer is a static device. It does not contain any moving parts, so there is no wear and tear. One need not follow any specific precaution in its storage,
b) The transfer of energy from primary to secondary coil is noiseless as no moving parts takes part in this,
c) The transformer can be use to increase or reduce the current using minimum power. Transformer can be used to transfer A.C power supply from one place to another.
d) As the primary circuit is separate from the secondary circuit, use of the transformer provides isolation. When a device is connected to the transformer secondary, touching the device chassis will not provide current.

2.5.2.5 TRANSFORMER LOSS

Generally, the transformer has the following losses:

a) Eddy current loss
b) Hysteresis loss
c) Copper loss

A. EDDY CURRENT LOSS

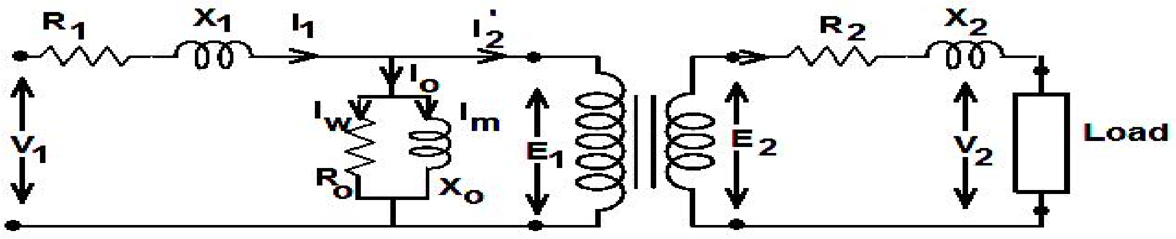
When a soft iron core is used in the transformer, during operation a small current starts to flow. This current is called "**Eddy current**." The loss of magnetic flux of transformer due to this Eddy current is known as Eddy current loss. To protect the transformer from Eddy current loss, laminate the soft iron core and insulate each core by putting vanish in between them.

B. HYSRTERESIS LOSS

When current is passed through a coil wound on an iron coil, some energy is dissipated as heat to the core. This is known as hysteresis loss. To reduce the hysteresis loss, steel is used for core. A transformer made using cheap quality core will get hot after a small use, whereas a good and quality core will make the transformer provide long service with minimal heat generation.

C. COPPER LOSS

For transformer winding, copper wire is used. The resistance of the copper wire will waste some electrical energy, which is known as copper loss.



Equivalent circuit of transformer

Fig 2.24 shows the equivalent circuit of a transformer showing the reactance of both primary and secondary windings (x_1 and x_2) as a result of their respective inductances.

2.5.3 RELAY

(http://en.wikipedia.org/wiki/relay,https://academickids.com/encyclopedia/index.php/Relay, 2009) (https://1library.net/article/basic-design-operation-project-final-report-home-automation.qo7j83mz,2011)

A relay is an electrical switch that opens and closes under the control of another electrical circuit. It operates by means of an electromagnet to open or close one or more sets of contact.

Since a relay is able to control an output circuit, it can be considered to be a form of electrical amplifier.

The operation of a relay can be described as follows. When a current flows through the coil, the resulting magnetic field attracts an armature that is mechanically linked to a moving contact. The movement either makes or breaks a connection with a fixed contact. When current to the coil is switched off, a force approximately half as strong as the magnetic force returns the armature to its relaxed position. This is usually a spring, but gravity is also used in industrial motor starter. Most relays are manufactured to operate quickly. In a low voltage application, this is to reduce noise. While in high voltage or current application, it is to reduce **arcing**.

Relays can be either of the AC or DC powered type. For the AC, the coil is designed to be energized with AC. A small copper ring can be crimped to the end of the solenoid. This shading ring creates a small out of phase current which increases the minimum pull on the armature during the AC cycle.

However, if the coil is designed to be energized with DC, a diode is connected anti-parallel to the polarity of the supply across the coil terminals. This helps to dissipate the energy from the collapsing magnetic field at deactivation which would otherwise generate a spike voltage that might cause damage to circuit components. Some automotive relays already have the diodes included inside the relay case.

Relays may have some or all of the following pin terminals viz:

1. Common: this pin is used to transfer between the other switching pins. It is common to the normally open and normally closed.

2. Normally Closed (NO): this terminal is connected to the Common directly before the relay is energized. Energizing the relay will disconnect this pin from the common terminal.

3. Normally Open (NC): this terminal is not in contact with the common terminal. It will only connect when the relay is energized.

4. The Coils: these are two pins internally connected to the coils in the relay that receives the electrical energy to activate the switching in the relay.

A diagram of a relay internal connection is shown below. The moveable level called the armature is held to one side by the spring when there is no current flowing through the electromagnet. Under these conditions, terminal X is connected to Y but not to Z. When a sufficient current is applied, the armature is pulled over to the other side. This disconnects terminal X from terminal Y and connects X to Z.

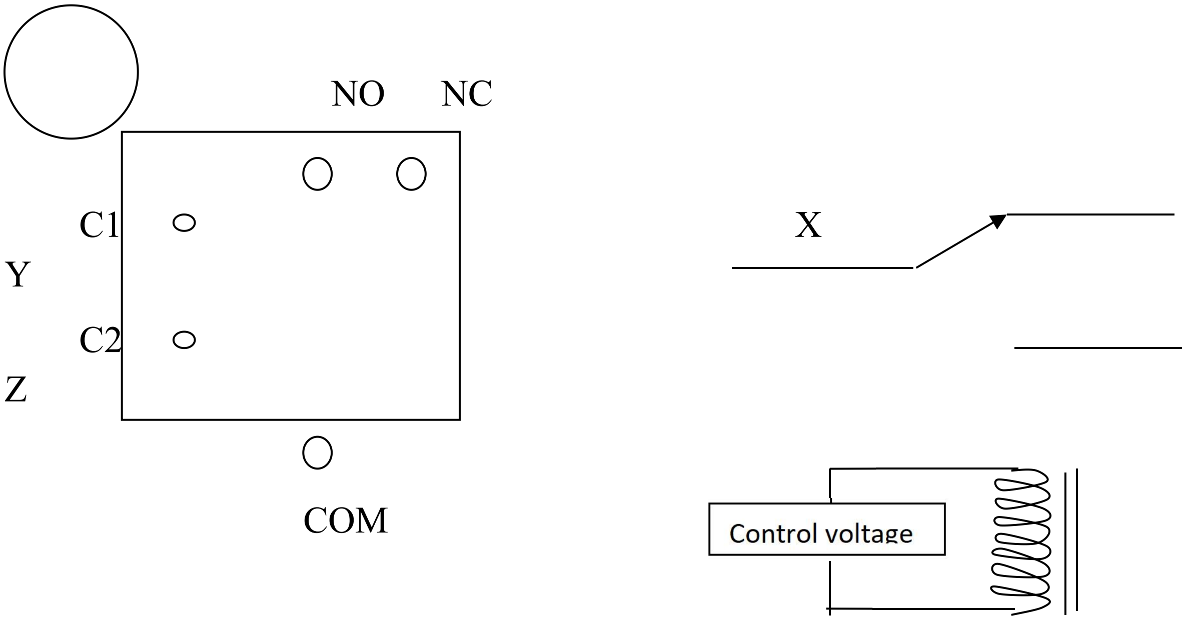


Fig. 2.25 Pin out and schematic symbol of a relay

NO is the normally open terminal. This terminal is not connected when the relay has not been energized. NC is the normally closed terminal. This terminal is in contact with the common when not energized. The COM is the common terminal that connects to either the normally closed or the normally open terminals.

Coils terminals C1 and C2 is the electromagnetic coil terminals where it is energized.

2.5.3 CAPACITOR (http://en.wikipedia.org/wiki/ capacitor,2020)

This is another basic electrical component. It is made up of conducting plates operated by a layer of dielectric (an insulating medium). The capacitor has the ability to store electric charges when a potential difference source is connected across. The circuit symbol for a capacitor is shown below.

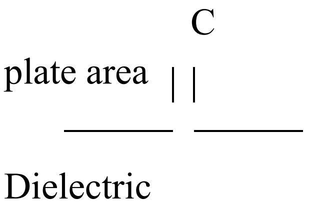


Fig. 2.26 (a) Capacitor symbol

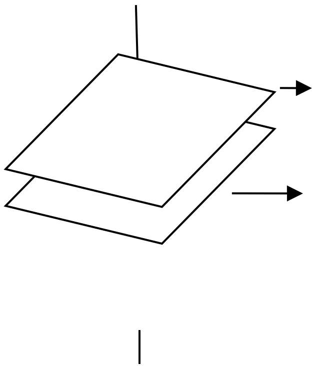


Fig. 2.25 (b) capacitor schematic

When a constant current (i) flows into the top plate, steady flow of positive charges is directed on the top plate. However, since dielectric can’t pass these charges, they pile up or accumulate at the top of plate. For current conduction to be completed across the capacitor, similar charges are built up at the bottom plate, so positive charges leave the bottom plate to establish the proper exiting current. As these charges exit at a constant rate, they leave behind a net negative charge on the lower plate. The charge unbalance between the plates is causes a difference in electric potential energy which means a voltage between the plates is established that increases in proportion to the charge increase. In other words, the voltage rate is proportional to the charge rate (current0. Mathematically, we have:

$i = \frac{dq}{dt} = c\frac{dv}{dt}$…. …. …. …. …. …. …. …. …. ….2.1

where C is the constant of proportionality called “capacitance.” The unit of C is the farad (F). Also,

$q = cv$ 2.2

Practical capacitors come in a wide range of values, shapes, sizes, voltage ratings and construction. Both fixed and adjustable devices are available. Most capacitors have the capacitance value marked on them but a few uses a code of colored dots with the colors defined as they were previously for resistors. Voltage ratings are based on the electrical breakdown of the dielectric used in manufacture and range from only a few volts to thousands of volts for capacitors used in high power applications.

2.5.3.1 Types of Capacitors

a) **Ceramic capacitor:** These find heavy applications in the low to middle range of capacitors (1pf to 0.1nf). Typically, one or more layers of thin ceramic dielectric of high permittivity are interfaced with layers of metal.

b) **Mica Capacitor:** Its construction is somewhat similar to the ceramic capacitor except that layers of metallic foil are separated by the dielectric mica. The silver-mica capacitor is a variation of this type of capacitor where the conducting metal is a thin layer of silver deposited on the mica.

c) **Paper and the Plastic Film Capacitors:** These are mostly in the middle range capacitance values (0.001 to 1nF).

d) **Electrolytic Capacitor:** In this variety, the two metal plates are separated by an electrolytic that oxidizes the inside of one of the plates. The oxide acts as the dielectric and the electrolyte in contact with the other plate acts as one of the capacitor terminals. When the oxide is been formed, a voltage of specific polarity is applied across the capacitor and any voltage applied in any application must be such as to not reverse the specific polarity.

e) **Non-polarized Electrolytic Capacitors:** These types of capacitors though electrolytic, do not have to maintain constant polarity. When time varying voltages are encountered that may have sign reversals, the non-polarized electrolytic capacitor should be used.

2.5.3.2 Losses in Capacitors

Real capacitors are not perfectly lossless, resistive losses can occur in both the metal plates, because of non-zero resistance and in the dielectrics. A model to account for losses often uses a leakage resistance in parallel with ideal capacitor as shown in the figure below:

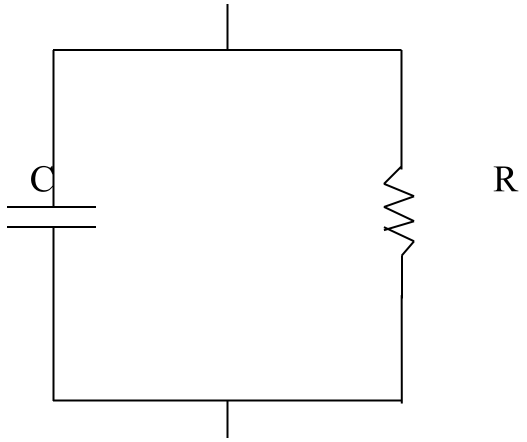


Fig 2.27 A practical capacitor

2.5.4DIODES(http://en.wikipedia.org/wiki/diodes,2016) (https://www.tutorialspoint.com/semiconductor_devices/semiconductor_devices_diode_characteristics.html,2018)

The term diode means two elements. In the early years of electronics and radio, most diodes were vacuum tubes. The cathode element emitted electrons and the anode picked up electrons. Thus current would flow as electrons though the tube from cathode to the anode but not the other way.

Basically, a diode is an electronic device having two electrode anode (+) and cathode (-). The main characteristic of a diode is its ability to pass current easily when the anode-cathode voltage is positive and to prevent current flow when anode-cathode voltage is negative. The circuit symbol of a diode is shown below.

Diodes are tiny devices made from silicon or other semi conducting materials. Some diodes handle voltage nearly as great as their tube counterparts. A major function of diodes is in electronic circuits in the rectification of alternating current.

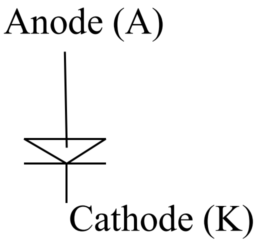


Fig 2.28 Symbol of a diode

The hallmark of a rectifier diode is it passes current only in the forward direction only. This makes it useful for changing AC to DC. Generally speaking, if the cathode is negative with respect to the anode, current flows. And when the cathode is made positive with respect to the anode, no current flows. The constraints of this behavior are the forward break over and the avalanche voltages.

CHAPTER THREE

DESIGN METHODOLOGY

3.0 INTRODUCTION

The method of sine wave inverter design used in this project is by S**inusoidal Pulse Width Modulation (SPWM)**. It is a pulse width modulation technique that follows the sine wave rise and fall in amplitude.

kiCAD design software was used to design the Printed Circuit Boards (PCBs).

3.1 BLOCK DIAGRAM OF INVERTER (Obasi, c, 2022)

A proper understanding of how the system is supposed to operate is needed aforehand to serve as a guide for the inverter design.

A suitable block diagram is designed as shown below to give an overall system operation of the inverter circuit. This also will help in troubleshooting and fault detection if the need arise during the construction.

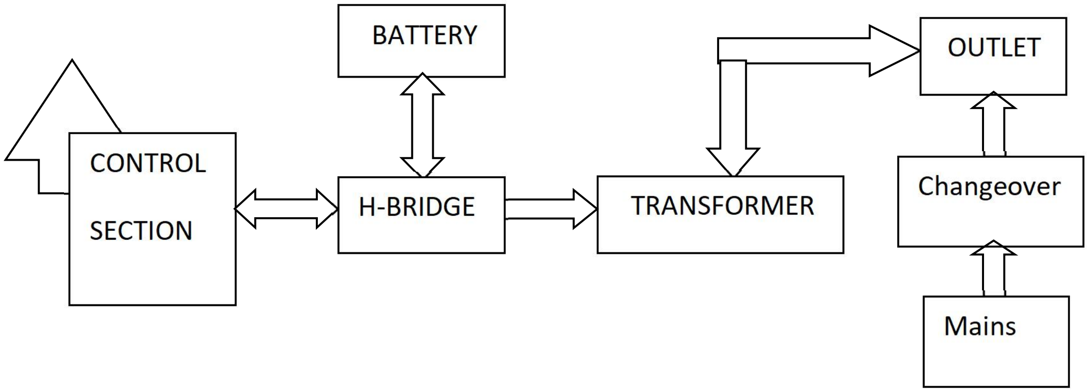


Fig. 3.1 the block diagram of an inverter circuit

The above block diagram shows the connections between the diferent sections of the inverter system.

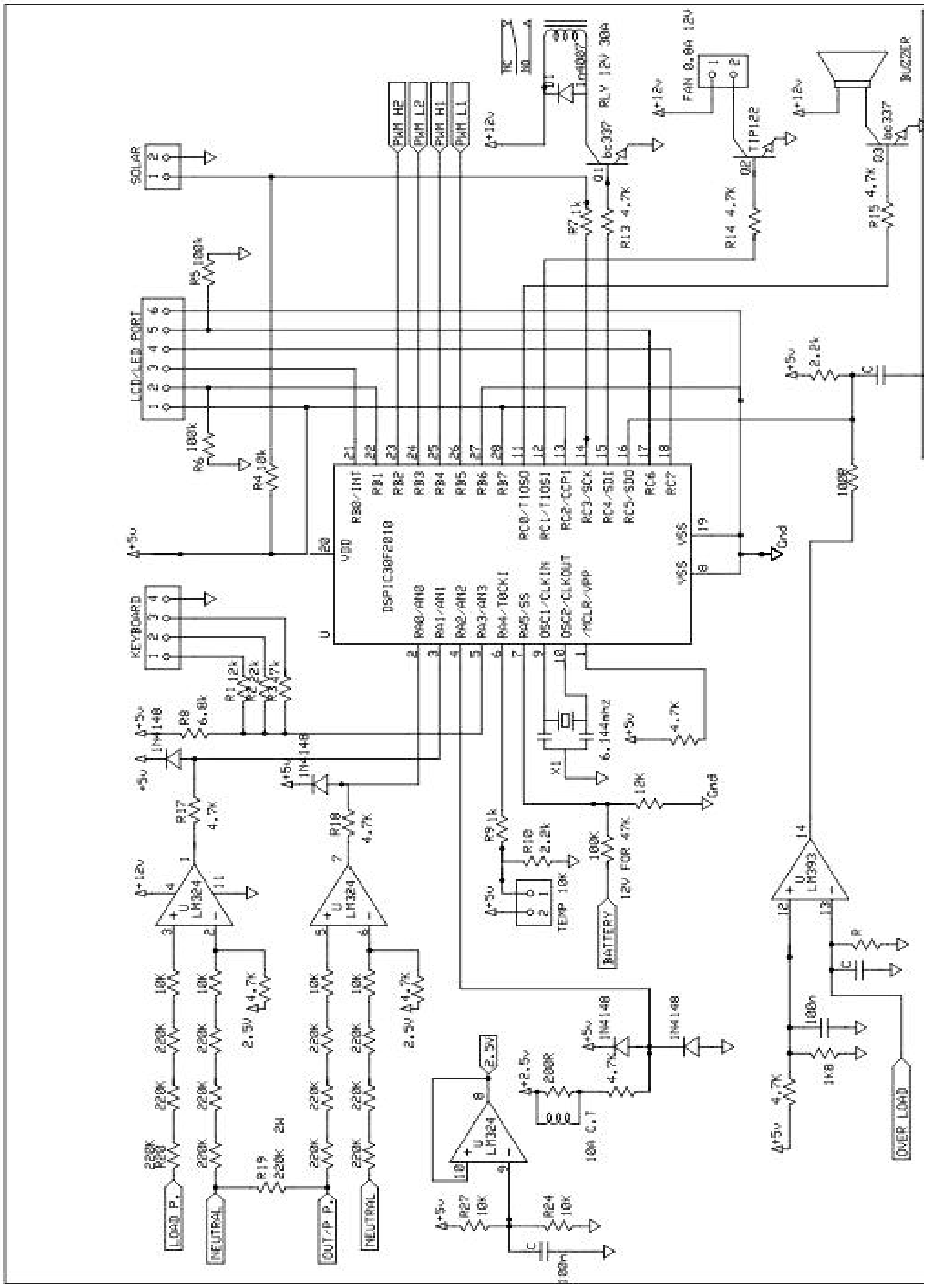
The control section is contains the microcontroller, the relay, buzzer, MOSFET drivers, the SMPS, the high voltage sense (op-amp), resistors, capacitors networks. This is where all regulations, modulations and interfacing are done.

The next stage is the H-bridge stage which contains the MOSFETs, capacitors and resistors networks. The H-bridge section is where the conversion of the incoming DC power to AC power is achieved. It also does the charging of the batteries. This stage receives commands from the control stage.

The battery stage is not part of the inverter as this is the external source of DC energy to the inverter machine.

The transformer does the stepping up of the incoming low voltage AC from the h-bridge stage to a high voltage (220V in this case) during inverting. Also, it does the stepping down of the incoming high voltage from mains utility to a lower voltage during charging processes.

The changeover is contained in the control section. Changeover is done when there is mains utility available and the system will need to stop inverting and start charging if need be. It is achieved with the relay. This section is used to disengage mains input when not available to avoid feed the inverter supply to the grid (utility). If this were to happen, it would result in either a short or an overloading of the inverter system.



DSPIC30F2010
SOLAR
LCD/LED PORT
KEYBOARD
PWM H2
PWM L2
PWM H1
PWM L1
RLY 12V 30A
1n4007
FAN 0.0A 12V
TIP122
BUZZER
bc337
LM324
LM393
LOAD P.
NEUTRAL
OUT/P P.
NEUTRAL
BATTERY
TEMP 10K
OVER LOAD
6.144mhz
12V FOR 47K
10A C.T
2.5V
Gnd

Fig 3.2 the schematic diagram of the control stage

3.2 KiCAD DESIGN TOOL

The KiCAD EDA Suite is a set of open source applications for the creation of electronic schematic and printed circuit board. Also included are image converter, symbol editor, calculator, drawing sheet, etc.

3.3 DESIGN OF PRINTED CIRCUIT BOARDS

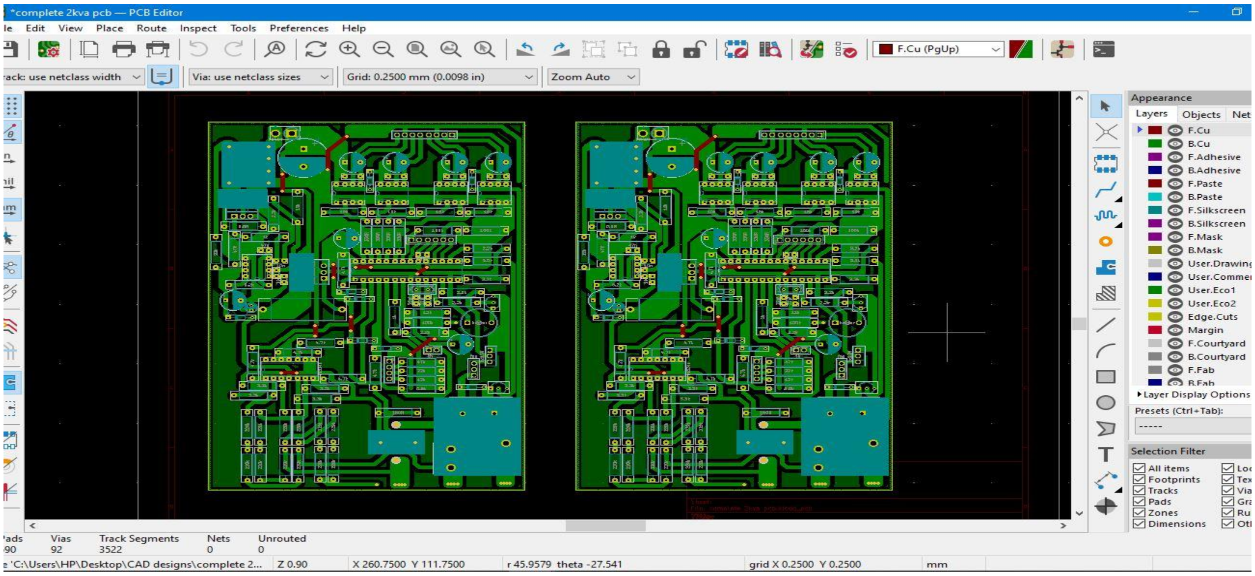
The Printed Circuit Boards (PCBs) were designed using the KiCAD design tool. The image below shows the control boards used in this design which contains various electronic components that were part of the schematic proposed for this design.

When the PCB design was completed on the KiCAD software, the design files were generated and printed out with Direct Image (DI) printer for best clarity and output quality. Then the pcb files were transferred to the copper clad boards through heat transfer technique.

3.4 DESIGN OF THE CONTROL BOARD

The contol board pcb was designed using the PCB editor. It was indeed resourceful as over 99% of the components were available in the editor. Others that weren’t here had their dimensions taken and necessary voids made to represent them in the design.

The board dimension is 158mm by 105mm and sits on the MOSFET bank.



Via: use netclass sizes

Grid: 0.2500 mm (0.0098 in)

Zoom Auto

Vias 92, Track Segments 3522, Nets 0, Unrouted 0

Z 0.90 X 260.7500 Y 111.7500 r 45.9579 theta -27.541 grid X 0.2500 Y 0.2500 mm

Fig 3.3 the CONTROL BOARD PCB design

The Microcontroller absolute maximum currrent (MICROCHIP TECH, 2012)

The microcontroller can supply 20mA per pin.

Total current drawn sourced or sunked by all ports = total number of gpio pins x maximum current per pin

I_{max} = 20x20mA = 400mA

Total power dissipation = maximum current x voltage input

P_{max} = 400mA x 5

= 2W

The Operational Amplifier gain

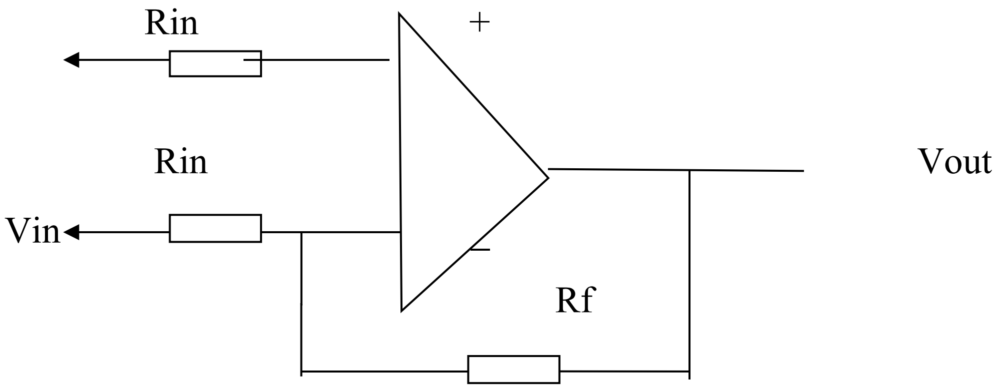


Fig 3.4 the operational amplifier as an inverting amplifier

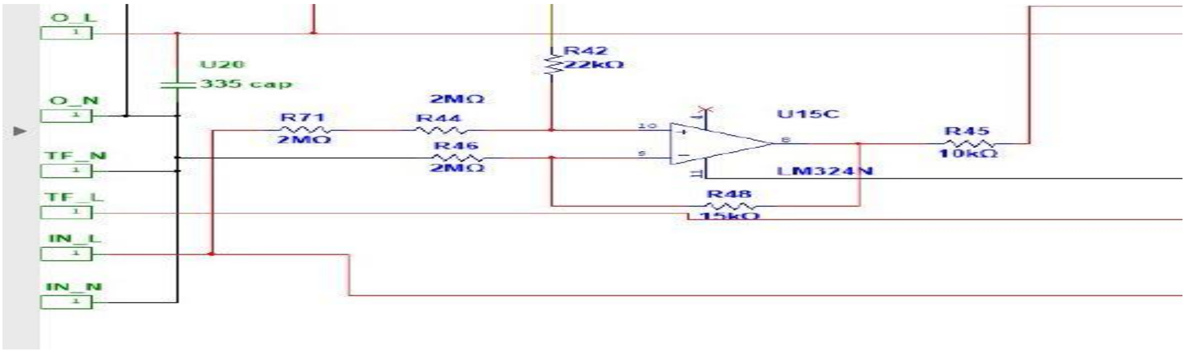


Fig 3.5 the high voltage sense of the inverter output and mains input using the operational amplifier

Two designs were extracted for construction so that if there is any error in one, the other can be substituted for it.

the above configuration is an inverting amplifier circuit. This circuit is applied thus:

mathematically,

current, $In = Vin/Rin$……………………………3.1

it is assumed that no current flows into the input terminal of the operational amplifier.

So current flow through Rin will continue through Rf

We have;

$Iin = Vin/Rin = (0-Vout)/Rf$……………………………….3.2

Ie, $Vin/Rin = -Vout/Rf$…………………………………………….3.3

$Vout/Vin = -Rf/Rin$……………………………………………..3.4

Now, gain is simply the output voltage divided by the input voltage

$Av = Vout/Vin = -Rf/Rin$………………………..3.5

$Av = -Rf/Vin$……………………………………………………3.6

As used,

Rin = 660kohms

Rf = 3.3kohms

The gain factor, Av is now calculated from (5) as:

$$Av = -(3.3/660)$$

$$= -0.005$$

The SMPS operating frequency

The Switched Mode Power Supply was used in the steping down of the input battery voltage (21-30v) to 12v which was used to power the relay, drivers and operational amplifier. The 12v output was further stepped down to 5v for the microcontroller. The analog ic uc3843 was used in this design to drive the chopper and mosfet in the "flyback converter" configuration.

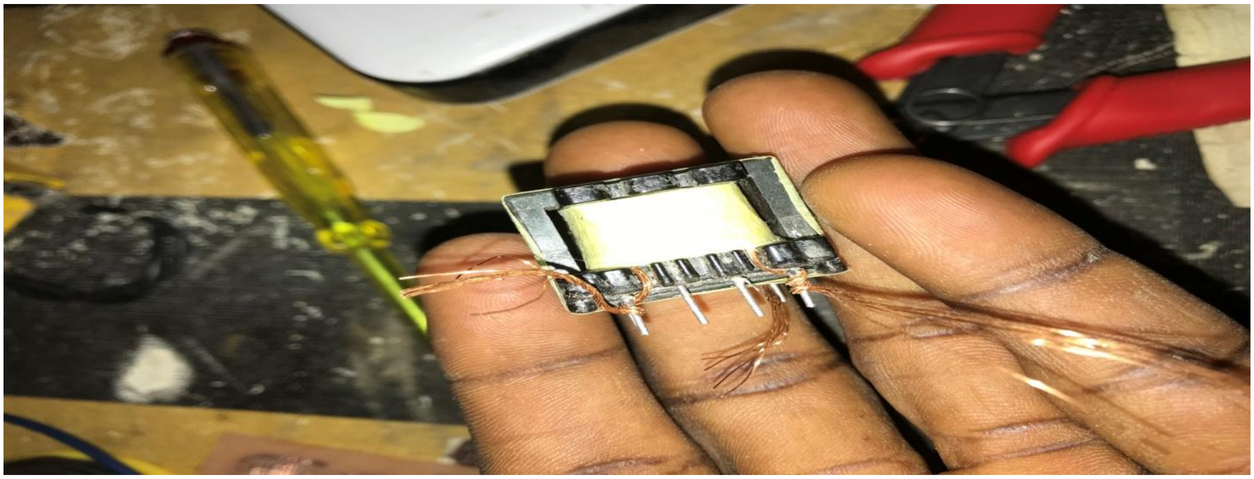


Fig 3.6 the chopper used for the flyback converter

UC3843 from datasheet gave an RC oscillator relationship to operating frequency as,

$$F = 1.8/(RC) \quad \text{for } R >= 5\text{kohms}$$

Where,

F is the frequency of operation

R is the resistance

C is the capacitance

For an operating frequency of 47khz which will yield high output power from the chopper:

R = 8.2kohms

C = 4.7nf

F = 1.8/(8.2×10^3 x4.7×10^{-9}) hz

= 47.7khz

It is worth mentionong that this frequency is not the output frequency of the inverter which is constantly at 50hz. It was used in the fly-back converter design as explained earlier.

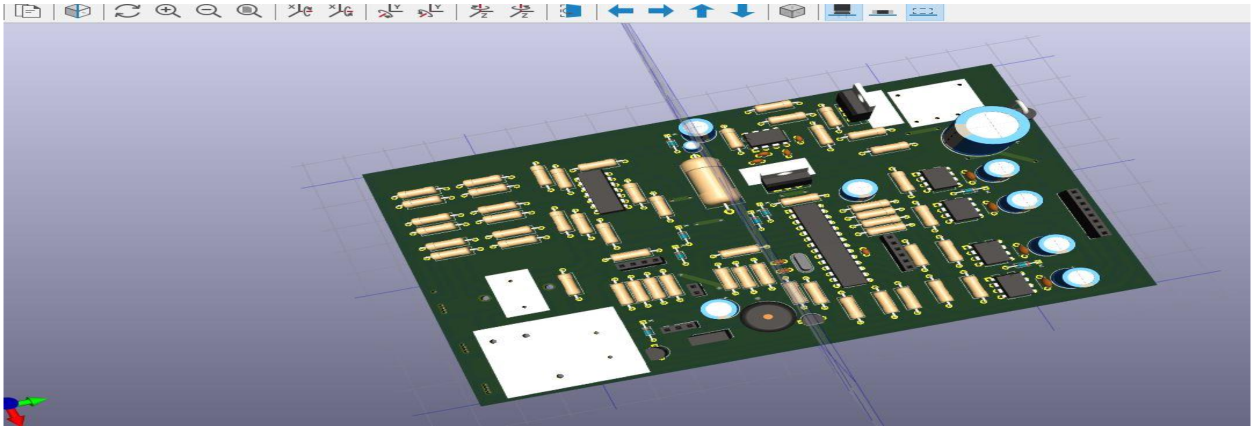


Fig 3.7 the 3D view of the control board

3.5 DESIGN OF THE MOSFET BOARD (Paul, D, 2022)

The MOSFET circuit or bank is a full-bridge circuit comprising of 4 MOSFETs per switching side. This gives a total of 16 MOSFETs in the overall circuit. It also contained the capacitors used to suppress ripples currents during charging and the MOSFETs heat sink. The MOSFETs were screwed to the heat sinks and together bonded to the board.

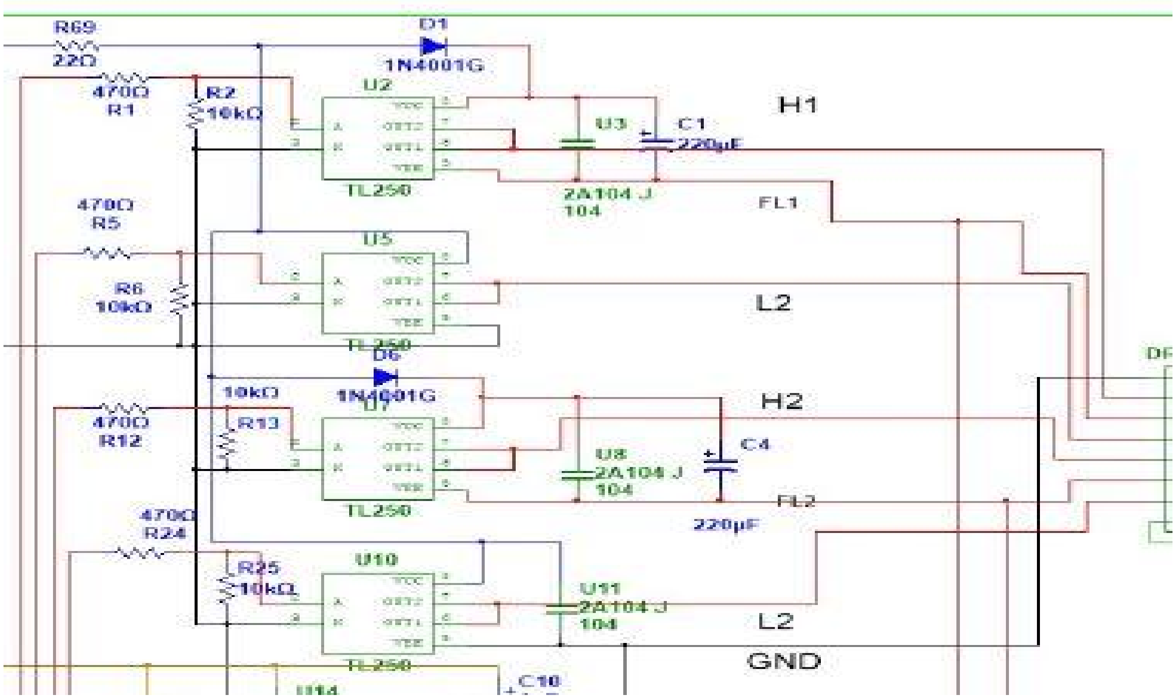
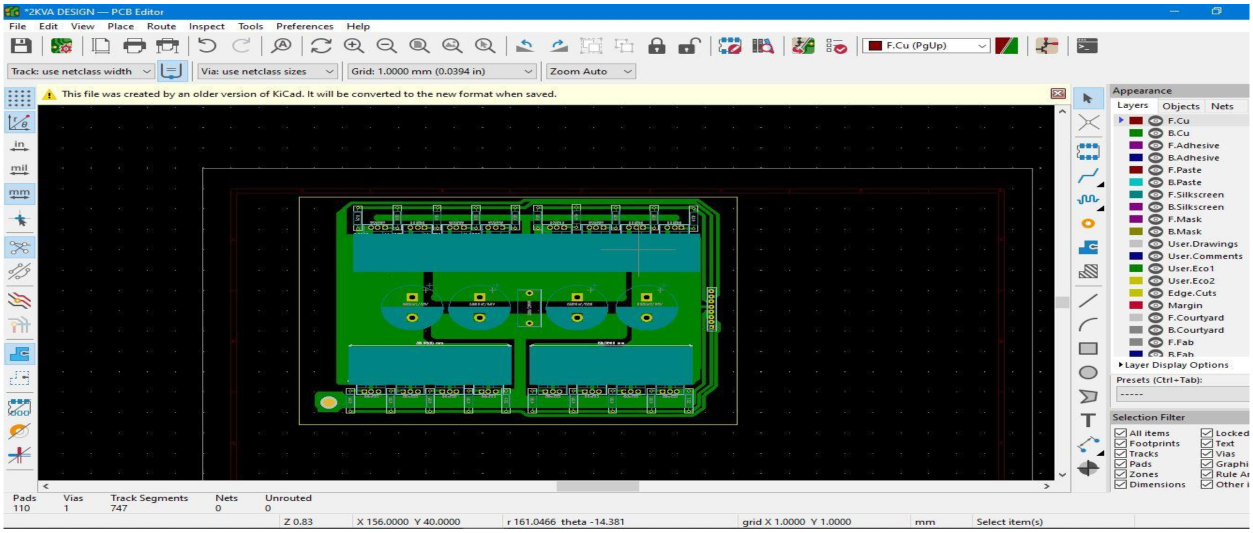


Fig 3.8 the MOSFET driver stage schematic diagram



Track: use netclass width
Via: use netclass sizes
Grid: 1.0000 mm (0.0394 in)
Zoom Auto

This file was created by an older version of KiCad. It will be converted to the new format when saved.

Pads	Vias	Track Segments	Nets	Unrouted
110	1	747	0	0

Z 0.83 X 156.0000 Y 40.0000 r 161.0466 theta -14.381 grid X 1.0000 Y 1.0000 mm Select item(s)

Fig 3.9 (a) shows the MOSFETs bank PCB design

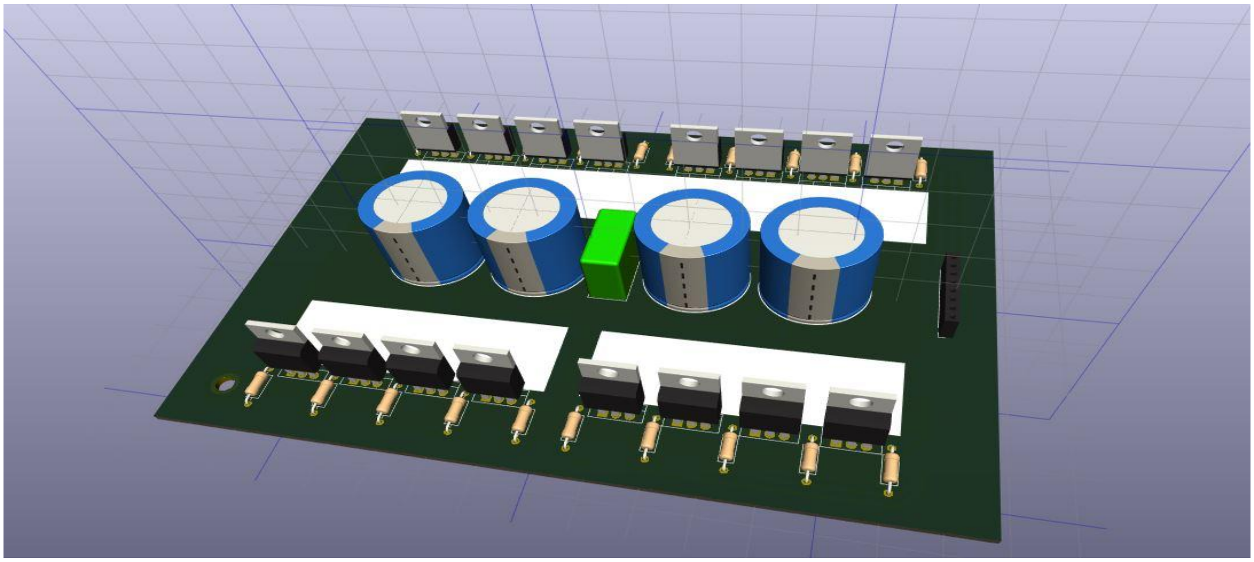


Fig 3.9(b) a 3-dimensional view of the designed MOSFETs bank PCB

The mosfet bank consist of four mosfets IRF3205 in parallel on each switch side. Total number of mosfets used is sixteen (16) to handle the primary winding current of the transformer.

IRF3205 MOSFET datasheet states a BV_{ds} of 55V and current handling capacity of 98Amp. So using four on each side gave a max current of:

$$I_{max} = 2000 / (21 \text{ x } 0.850) = 112\text{Amps}$$

The current through each MOSFET at the worst case scenario will be:

$$I_{dmax} = I_{max} / 4 \quad \text{(Texas Instruments Inc, 2006)}$$

$$= 28 \text{ Amps}$$

Operating the MOSFET at a lower current yields a better conductivity and extends its life span.

3.6 DESIGN OF THE TRANSFORMER

3.6.1 DESIGN SPECIFICATION

(1) INPUT VOLTAGE RANGE_____21V TO 28.8V

(2) OUTPUT VOLTAGE____220VAC (TOLERANCE OF 2%)

(3) FREQUENCY___50HZ

(4) OUTPUT POWER CAPACITY____2KVA (1.5KW)

(5) DESIGN TYPE___________SHELL TYPE

(6) COOLING MEDIUM______FORCED NATURAL AIR (FAN)

Power at the secondary, Ps = Secondary Current, Is x Secondary Voltage, Vs…………………………………………………………………….3.1

Power at the primary, Pp = Primary Current, Ip x Primary Voltage, Vp…………3.2

Now, in an ideal case,

Ip x Vp = Is x Vs……………………….33

$\frac{Ns}{Np} = \frac{Vs}{Vp}$ ……….……………………..3.4

3.6.2 MAXIMUM CURRENT, I_{MAX}

Let's calculate the maximum values of current to be conducted during operation:
For the primary windings:
Maximum current will flow when the battery is at their lowest value for this design
Our minimum battery voltage is 20v.
Maximum current in the primary, Ip_{max}= Power/ minimum battery voltage
That is, Ip_{max} = 2000/20 = 100Amps
Secondary current, Is = 2000/220 = 9.09Amps
But for the inverter to start, it must draw 20% of its starting current
Istart = 15% of Ip ………………………………………….3.5
= 1.3635Amps
And starting power = Istart x Vp…………………………………………………3.6
= 32W
Total power Pc = Pstart + P…………………………………….3.7
= 32 + 2000
Pc = 2032Watts

But Pc power of the core must be greater than the calculated value
Assuming an allowance of 20% percent, we have that;
Pc = 120% of Pc (calculated)……………………………….3.8
Pc = 2438.4Watts
So a 2.5kva transformer was used in this construction since it was the closest to the size needed.

The total real power (watts) obtainable from this transformer was gotten using the **Alfred Babani** formula of coil design
Alfred Babani formula of coil design is mathematically stated as:

$$A = \frac{\sqrt{w}}{5.58}$$

Where A = area of the core
W = power in watts
5.58 is a constant

Note: Area dimension in this formula are in inches (1inch = 2.54cm = 25.4mm)

Area of the core = length of the window x breadth of the window
$= L_W X$
B_W………………………………………………………….3.9
$= 8.176x6 = 49.056cm^2$

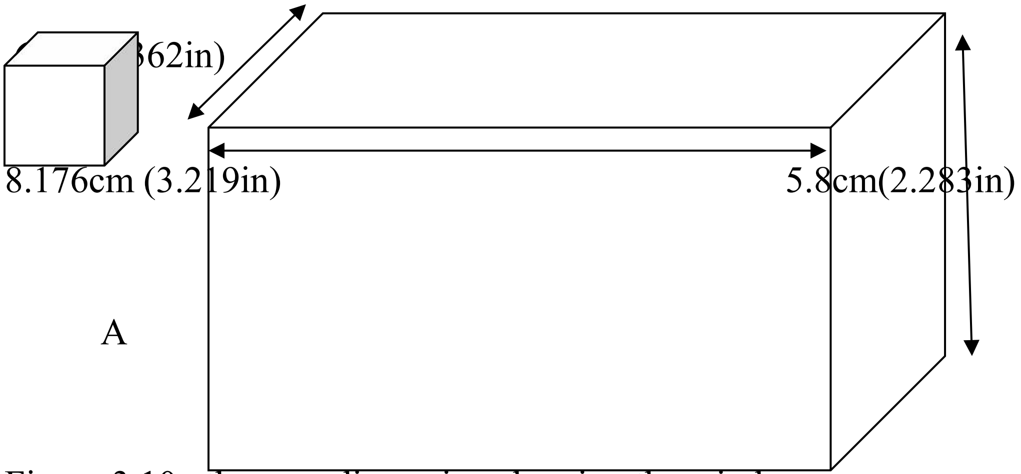


Figure 3.10 the core dimension showing the window area

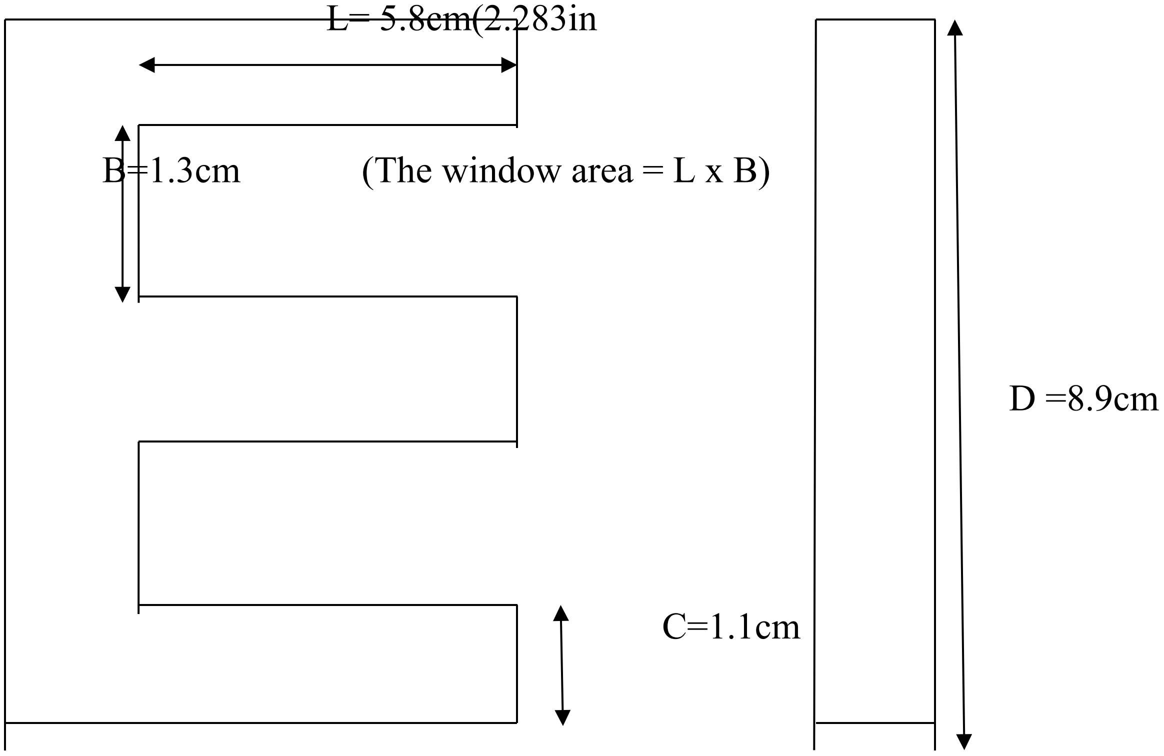


Fig 3.11 the dimensions of the transformer laminations (a) E-shaped (b) I-shaped

Lamination pieces, n = stack height/lamination thickness

For a thickness of 0.5mm, n = 91/0.5

= 182 laminations

3.6.3 MAXIMUM WATTAGE OBTAINABLE FROM THE TRANSFORMER

The core area was calculated as 7.60329in

From the Alfred Babani equation, (Alfred, B, 2002)

Power = $(5.58 \times 7.60329)^2 = 1800W$

So setting our maximum load at 1500 W gave a transformer load factor of 83%.

3.6.4 NUMBER OF TURNS

From transformer **induced voltage** equation,

Induced voltage, $E = 4.44 \times F \times N \times \Phi$ ……………3.10

Where E is the induced voltage
F is the frequency
N is the number of turns
Φ is the total flux

But $\Phi = Bm \times A$ ……………………………………………3.11
where Bm is the flux density and A is the area of the core
Equation (5) becomes $E = 4.44 \times F \times N \times Bm \times A$

The required ration of the turn per volt can be gotten thus:

Turns Per Volt, TPV $= \frac{N}{E}$.... $= \frac{1}{(4.44 \times F \times Bm \times A)}$……………………….3.12

Turns per Volt (TPV) as used here is the number of turns to be wound to induce one volt in the transformer.

Now the turns per volt can be easily gotten from the area calculated

$TPV = 1 / (4.44 \times f \times Bm \times A)$

Bm for our transformer core was assumed to be between 1.2T to 1.3T for iron type

So we chose Bm to be 1.2T

$TPV = 1 / (4.44 \times 50 \times 1.25 \times 6 \times 8.176 \times 10^{-4})$

$= 1.389$ approximated to 1.4

Primary voltage is gotten from:

$Vp = Vbat_{min.} / \sqrt{2}$ for our transformer design

$Vp = 14$Volts

Number of primary turns, Np = TPV x Vp……………………..3.13

1.4 X 14V

= 19.6 approximated to **20 turns**

Number of secondary turns, Ns = TPV x Vs……………………………3.14

= 1.4 x 220V

= **308 turns**

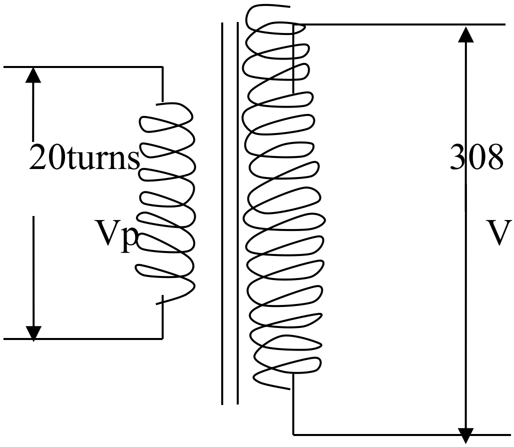


Fig 3.12 the schematic of the 2kva transformer showing turns wounded

3.6.5 MEAN LENGTH PER TURN

M.L.T = 2(width of central limb + stack height + window width)…………….3.15

= 2(180+110+30)

= 640mm

3.6.6 TOTAL LENGTH OF WINDING (T_L)

T_L = m.l.t X Total Number of turns………………………………………..3.16

For primary, L1 = 640x20 = 12800mm

For secondary, L2 = 640X308 = 197120mm

3.6.7 TOTAL MASS OF COPPER

Volume of Copper = Total length x Area…………………………………..3.17

Primary Volume = 12 x 1280 x $2.27x10^{-2}$ = $348.672cm^3$

Secondary Volume = 19712 x 7.32 x 10^{-2} = $357.948cm^3$

Total Volume = 348.672+357.948 = 706.62 cm^3

Mass = Density X Volume……………………………………………………..3.18

For copper, density = $9x10^{-3}kg/ cm^3$

So, total Mass of Copper used = $9x10^{-3}$ X 706.62 = 6.35958Kg

Going by current density of $5A/mm^2$,

Primary gauge = 8 strands of 14 ‘’

Secondary gauge = 16’’

The transformer was wound both manually and with the aid of a winding machine.

3.7 OPERATIONAL PRINCIPLES OF THE DESIGNED HYBRID INVERTER CIRCUIT

The battery DC energy is fed to the h-bridge through the DC breaker where it is converted to AC form. The entire circuitry in the control stage operates on either 12v or 5v. Since the battery is rated 24v, it must be stepped down.

Stepping down of the 24V to 12V is achieved with a flyback converter circuit on the control board. The heart of the flyback circuit is the IC UC3843. It has pwm abilities which it uses in pulsing the chopper through the MOSFET from its pin 6. Feedback from the ouput of the chopper is through a resistor network of voltage divider and is fed to pin 2. It is switched by an RC oscillator between pin 8 and pin 4. The values of R and C determines the frequency of switching. The output of the flyback converter is 12V which can be used to power the MOSFET drivers (TLP250), relay, operational amplifier and cooling fan directly.

This 12V supply from the flyback is further reduced to 5V through a linear regulator (LM7805). This 5V supply is now used to power the microcontroller, buzzer, LCD screen and several others operating on this level.

The inverter has setup functionality which can be used to adjust the output voltage, maximum load and charging current. For safety reasons, this functionality was not added for user interface. The push button is used to switch on the inverter when mains is not available or to enable inverting function when mains is available and the user will want automatic switch mode to inverter mode when the is grid failure.

The microcontroller has ADCs functionality for sensing mains availabilty, inverter output stability, battery voltage level, temperature of the system, load wattage and charging current.

It is a digital system. No need for calibration with varaible resistors or trimpots as everything is to be done by the button interface if need. It is worth mentioning at this point that every necessary calibration and parameters setting has been done before presentation of the project.

The microcontroller cycle frequency is set by the crystal oscillator between pin 9 and 10. This value is 6.144Mhz and it is then amplified using the phase lock looping to increase the clock frequency which improves the overall performance of the system.

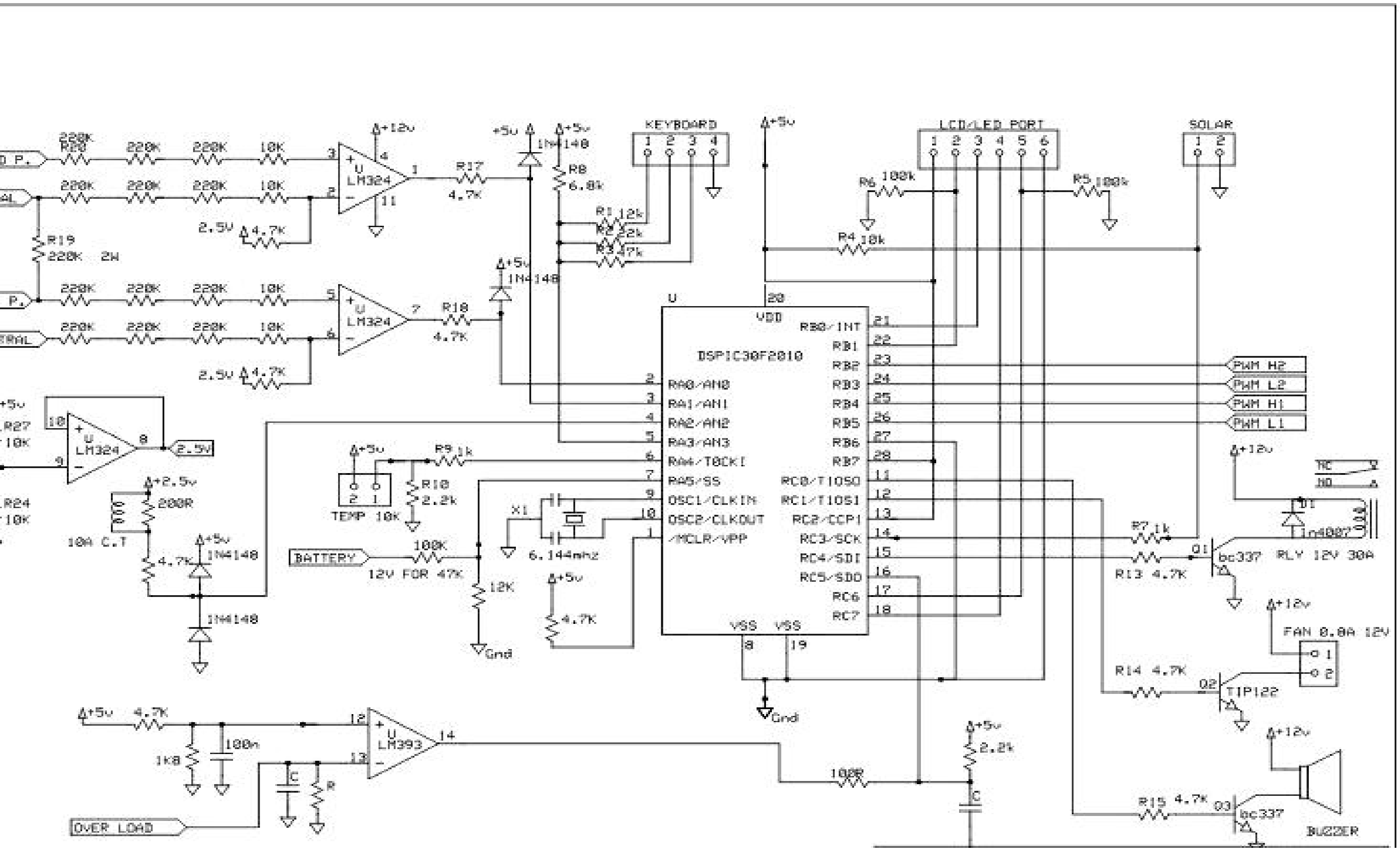
The MOSFET drivers are used to provide an isolation between the microcontroller (which has a limited voltage of 5V maximum and can only deliver about 25mA of current per pin) and the MOSFETs which require 12V for effective switching and using many in parallel, may increase the input capacitance between their gates and source thereby requiring more current to drive them.

The microcontroller provides four PWM output for switching the four arms of the h-bridge in a forward and reverse direction. This to and fro switching is in similitude of an alternating waveform. So the output of this MOSFETs stage is a noisy form of AC voltage.

This output is then fed to the transformer which increases the voltage to the desired value. Then a properly designed LC filter is used to eliminate the noise from the outputs and then a pure sine wave output is obtained at this stage.

The inverter stops inverting and start charging when there is mains available.

More light is thrown on the principle of operating the system on part 4.6 in chapter four.


KEYBOARD
LCD/LED PORT
SOLAR
DSPIC30F2010
U
VDD
VSS
RB0/INT
RB1
RB2
RB3
RB4
RB5
RB6
RB7
RC0/T1OSO
RC1/T1OSI
RC2/CCP1
RC3/SCK
RC4/SDI
RC5/SDO
RC6
RC7
RA0/AN0
RA1/AN1
RA2/AN2
RA3/AN3
RA4/T0CKI
RA5/SS
OSC1/CLKIN
OSC2/CLKOUT
/MCLR/VPP
PWM H2
PWM L2
PWM H1
PWM L1
R1 12k
R2 22k
R3 47k
R4 10k
R5 100k
R6 100k
R7 1k
R8 6.8k
R9 1k
R10 2.2k
R13 4.7K
R14 4.7K
R15 4.7K
R17 4.7K
R18 4.7K
R19 220K 2W
R20 220K
R24 10K
R27 10K
220K
10K
2.5V
4.7K
LM324
LM393
1N4148
+5v
+12v
+2.5v
Gnd
2.5V
TEMP 10K
BATTERY
100K
12V FOR 47K
12K
X1
6.144mhz
10A C.T
200R
1K8
100n
C
R
100R
2.2k
OVER LOAD
Q1
bc337
RLY 12V 30A
1n4007
D1
NC
NO
Q2
TIP122
FAN 0.8A 12V
Q3
BUZZER
D P.
AL
P.
TRAL

CHAPTER FOUR

CONSTRUCTION, TESTING AND RESULTS

4.1 CONSTRUCTION

The construction of this inverter involved the connecting together of various electrical and electronic components in the correct manner to ensure that it worked perfectly and according to specification. Some of these components were sourced from the local electrical/electronics stores and some were in discrete form while others in integrated components. The transformer used was locally fabricated using available raw materials.

As seen in the inverter block diagram of chapter two and three, the construction of the inverter project was done in segments.

The first unit installed was the 2.5KVA transformer which was screwed to the base of the casing. A 2.5KVA transformer was used as a safety measure to ensure that after losses, we will still have a 2KVA output capacity. The next unit installed was the MOSFETs bank which were screwed to heat sinks to ensure adequate and effective cooling is carried out. The temperature sensor was screwed to the heat sinks to get the temperature of the transistors which was used to control the cooling fan. The control unit was installed untop the MOSFETs bank tightly with adequate separation to also help in channeling the cooling air through the whole bank. Then all the connections between the individual sub circuitries were done. The cooling fan, the output filter capacitors, and the connecting terminals were alos installed in place.

Different stages of the designed work were tested and various interconnections made. Spacing was taken into consideration and also appropriate positioning of the components was given adequate priority.

The project was constructed such that will allow for load variations without any adverse effect on the inverter circuit hence the use of a 2.5KVA transformer which gives a safety factor of 20%, meaning the capacity of the inverter can be upgraded to give more power output to the tune of 2.5KVA. The number of MOSFETs used as well as the rating of the transformer point to this fact.

Some tools and materials used during the construction of this project includes a digital multimeter, cutters, soldering iron and lead, long nose and short nose pliers, copper clad boards, a set of screw drivers, lead suckers, glue gun and wax, angle grinder, electric drilling machine, mini drilling machine for pcb, etc…

COMPONENTS AND MATERIALS USED

Some of the components and materials used in the construction are listed below:

1. DSPIC30F2010
2. LM324 Op-Amp
3. MOSFET: IRF3205
4. 7805 VOLTAGE REGULATOR
5. DIODES: RECTIFIER, SCHOTSKY
6. BIPOLAR JUNCTION TRANSISTOR: BD139, BC547
7. 40A RELAY 5-PIN
8. HEAT SINKS
9. EE25 TRANSFORMER
10. UC3843
11. CAPACITORS: ELECTROLYTIC, POLYESTER
12. 12V DC FAN
13. MALE AND FEMALE HEADERS
14. RIBBON CONNECTORS
15. IC SOCKETS
16. FIBRE-GLASS COPPER CLAD BOARD
17. BUZZER
18. CD4017 SHIFT REGISTER
19. TLP250 MOSFET DRIVERS
20. RESISTORS: VARIETIES
21. 5A AC CURRENT SENSOR
22. CRYSTAL OSCILLATOR (6.144MHZ)
23. LIQUID CRYSTAL DISPLAY (LCD-1602)

Table 4.1: **BILL OF ENGINEERING MEASUREMENT AND EVALUATION**

S/N	**DESCRIPTION OF ITEMS**	**QUANTITY**	**UNIT RATE (₦)**	**TOTAL AMOUNT (₦)**
1	2.5KVA transformer	1	5000	5000
2	DSPic30f2010	1	6500	6500
3	TLP250 MOSFET drivers	4	500	2000
4	Heat Sink	5	500	2500
5	Copper clad board	1	3000	3000
6	LM324N Op-Amp	1	200	200
7	Irf3205 MOSFETs	17	350	5950
8	Relay	1	400	400
9	Buzzer	1	200	200
10	Ribbon Cables	2	200	400
11	EE25 ferrite transformer	1	500	500
12	Copper Wires	6.5 (Kg)	8000	52000
13	Casing	1	8000	8000
14	12V DC Fan	1	400	400
15	100A DC Breaker	1	3500	3500
16	16A AC Breaker	1	1800	1800
17	Switch	1	150	150
18	10A Current transformer	1	1500	1500
19	Resistors (all varieties used)	30	10	800
20	Capacitors (all varieties used)	20	20	850
21	6.144Mhz Crystal	1	150	
22	DIP IC Sockets	7	70	490
23	Diodes	8	40	320
24	UC3843	1	150	150
25	Connecting AC wires	2 (yards)	100	200
26	16MM DC Cables	3 (yards)	800	2400
27	Connectors	1 (Row)	400	400
28	CD4045	1	300	300
29	Buttons	4	50	200
30	BJT Transistors	3	50	150
31	Etchant	1		2000
32	Cable Lock	5	150	750
TOTAL				**106910**

4.1.1 CONSTRUCTION OF THE CONTROL STAGE

The control pcb design as shown in fig 3.5 in chapter 3, was done and extracted in pdf form. Then it was transferred to the copper clad board of same dimension and its prints were transferred by the use of pressing iron. Although, this heat transfer could have been done easier and safer by use of laminating machine, but we went for the former to save cost that would have been incured using the latter.

Then pcb etching was achieved using ferric chloride in a displacement reation. Since copper is more electro-positive than iron, it displaced it from the salt to form copper(ii)chloride with residues of displaced iron left in the solution.

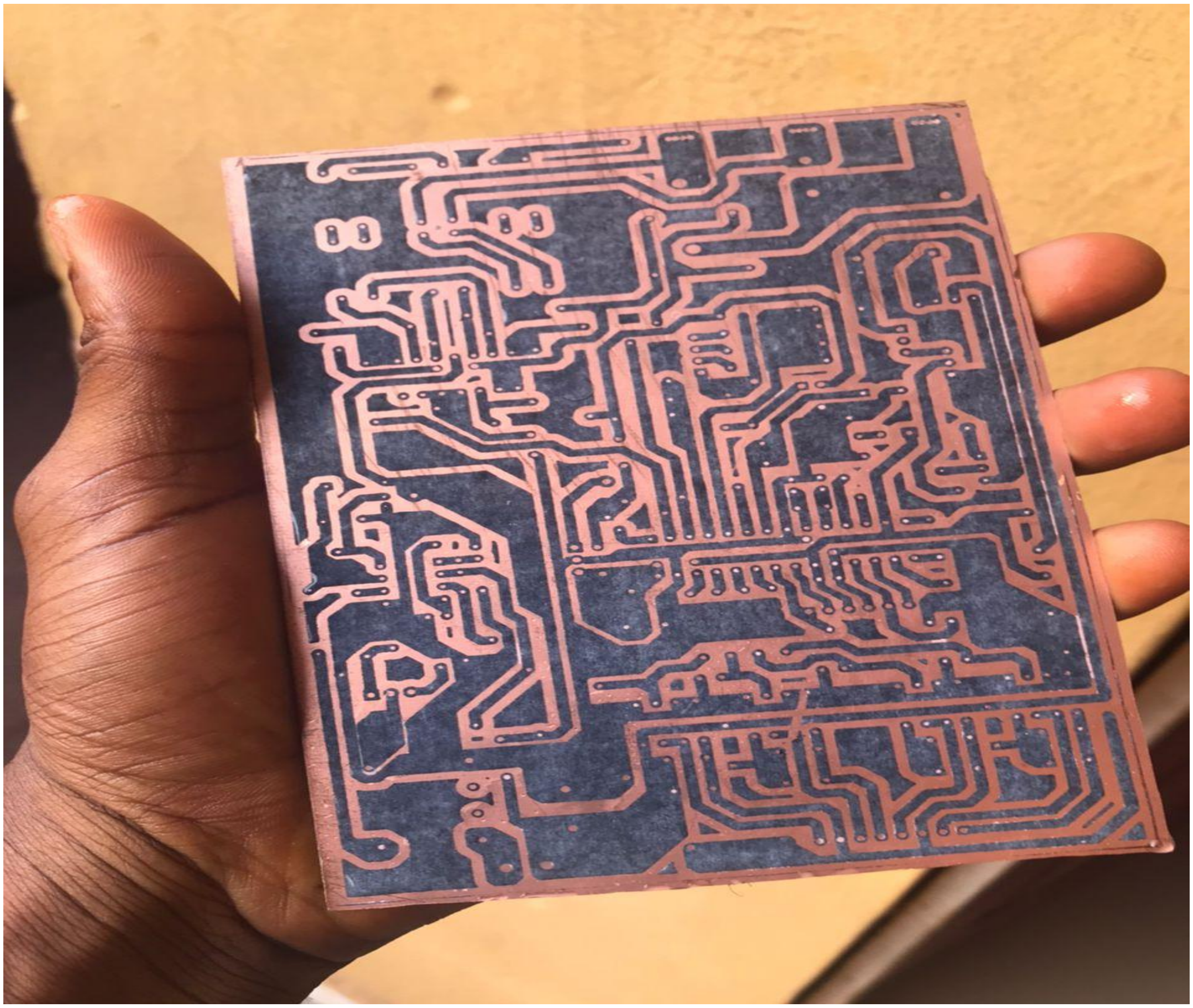


Fig 4.1 (a) the control stage pcb after ink transfer

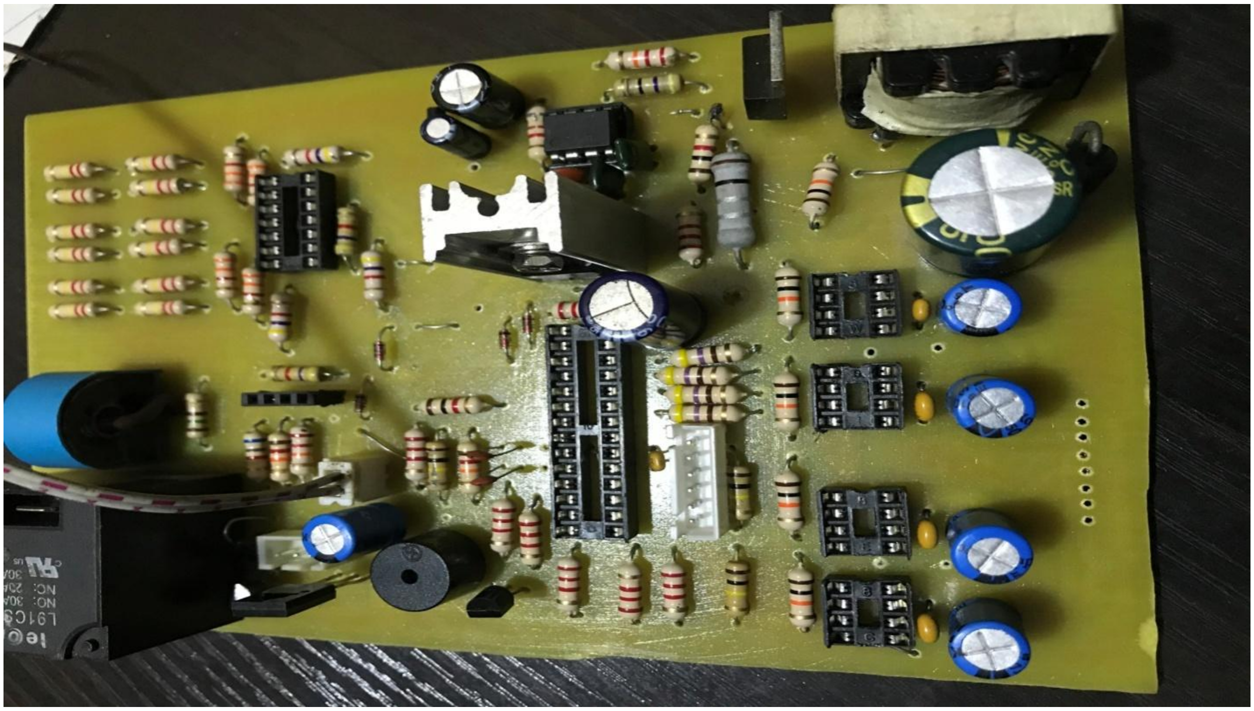


Fig. 4.1 (b) the control stage pcb after construction with components layout

The control stage pcb sits on a copper board of dimensions 140mm by 80mm. it contains the microcontroller, mosfet drivers, operational amplifier, buzzer, relay, current sensor, resistors, capacitors, diodes etc as shown in the figure above all interconnected to achieve their various objectives.

4.1.2 CONSTRUCTION OF THE MOSFET STAGE

The MOSFETs bank was constructed in a similar way like the control pcb. It contains 16 MOSFETs grouped in fours fornthe four-switching arms that makes up the h-bridge. There is also the capacitors that are used for energy storage during the charging and to suppress riple current. The MOSFETs are screwed to heat sinks since they are power devices and heating is inevitable. In chapter two, we showed why we used four on each sides by calculations. This was so to reduce conduction losses and therefore improve overall efficiency.

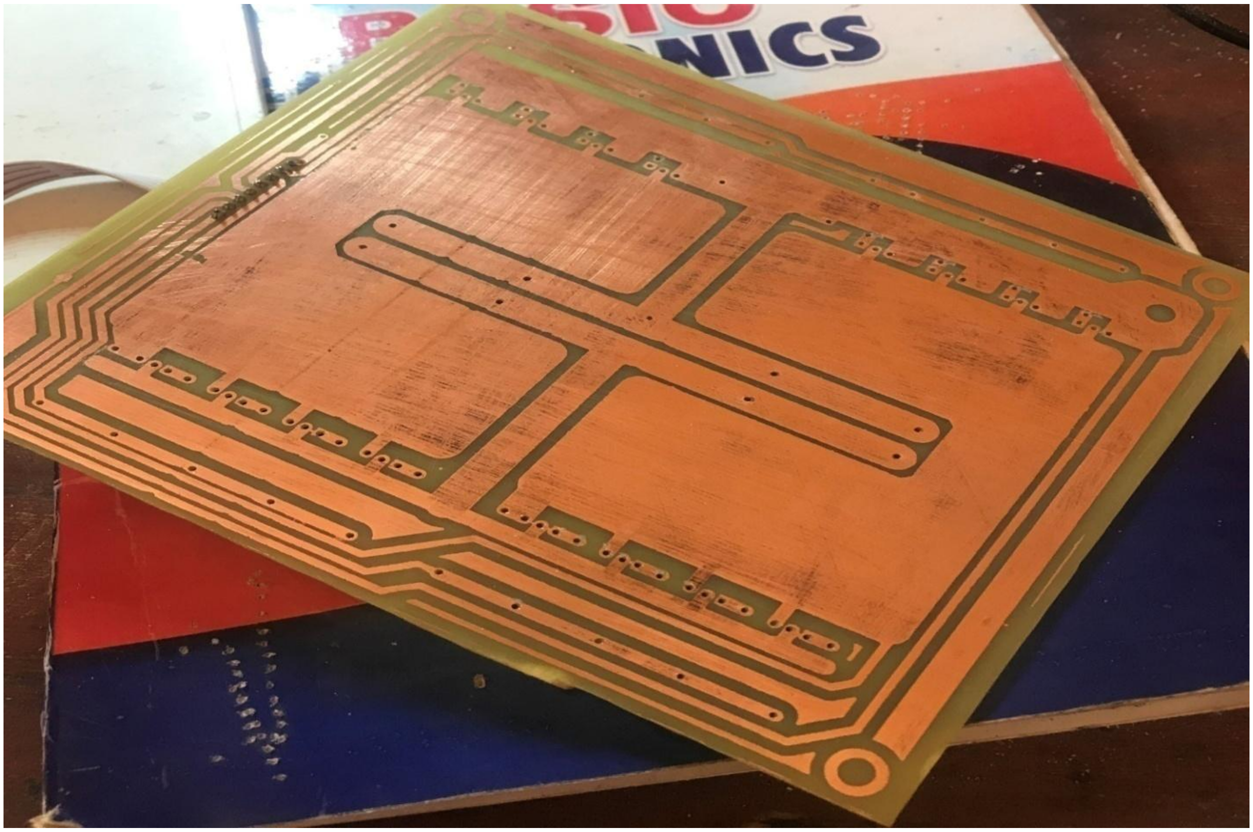


Fig 4.2: the bottom view of the MOSFETs bank and its copper tracks

The MOSFETs bank PCB was mounted at the based of the casing using bolts and nuts to ensure a firm and rigid grip. The input DC power from the batteries goes directly to this stage as it is where conversion (inversion) from DC to AC is achieved. Also, power is sent from this section to the control section and modulatating signals from the control section is sent here to drive the MOSFETs.

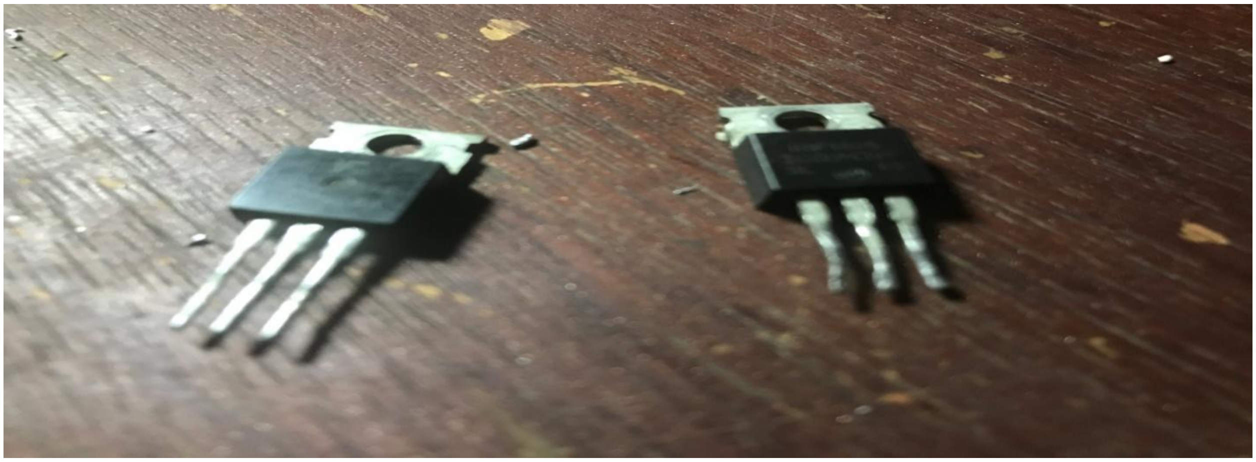


Fig. 4.3: the MOSFET IRF3205 used in the construction of the MOSFETs bank

4.1.3 CONSTRUCTION OF THE TRANSFORMER

Several factors were needed to be considered before the transformer target design could be met. For a transformer using a sine or square wave, one needs to know the incoming line voltage, the operating frequency, the secondary voltage, the secondary current, the permissible temperature rise, the target efficiency, the physical size one can use, and the cost limitations.

From the previous chapters, the design parameters were already achieved and they serve as a rule to foster our construction of the 2.5KVA transformer.

A 5kVA stabilizer transformer was purchased for the following reasons:

- the power capacity of an automaticvoltage stabilizer transformer is about double as when it is used as a single phase transformer with its primary side completely isolated from the secondary. Reason is because a automatic voltage stabilizer transformer is actually an auto-transformer which is more powerful than the former of the same size.
- From the Alfred Babani equation, a conventional 2KVA transformer found in the stabilizer gave only 700W while its 5KVA version gave about 1800W maximum.

Fig. 4.4: the transformer after full assembly

4.1.4 CASING

After the construction of the inverter and other components, a casing which was adequate to house the different units was gotten based on the space requirements of the different parts. Also taken into consideration was the future upgrading (if found to be necessary).

A casing with dimension measuring (560 x 310 x 190) mm was obtained. Mounted inside at one end of the case is the cooling fan for ventilation. Also, holes were drilled on the sides to ensure cross-ventilation. The 3-dimensional view of the casing is shown below:

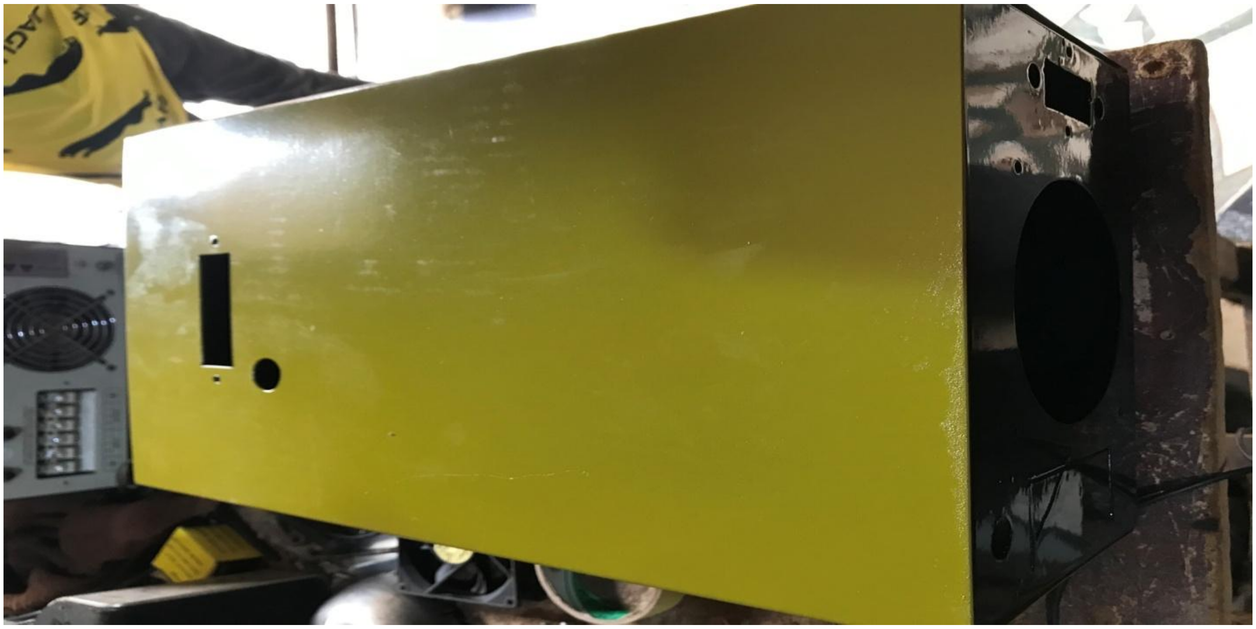


Fig. 4.5(a) the three-dimensional view of the inverter casing before assembling

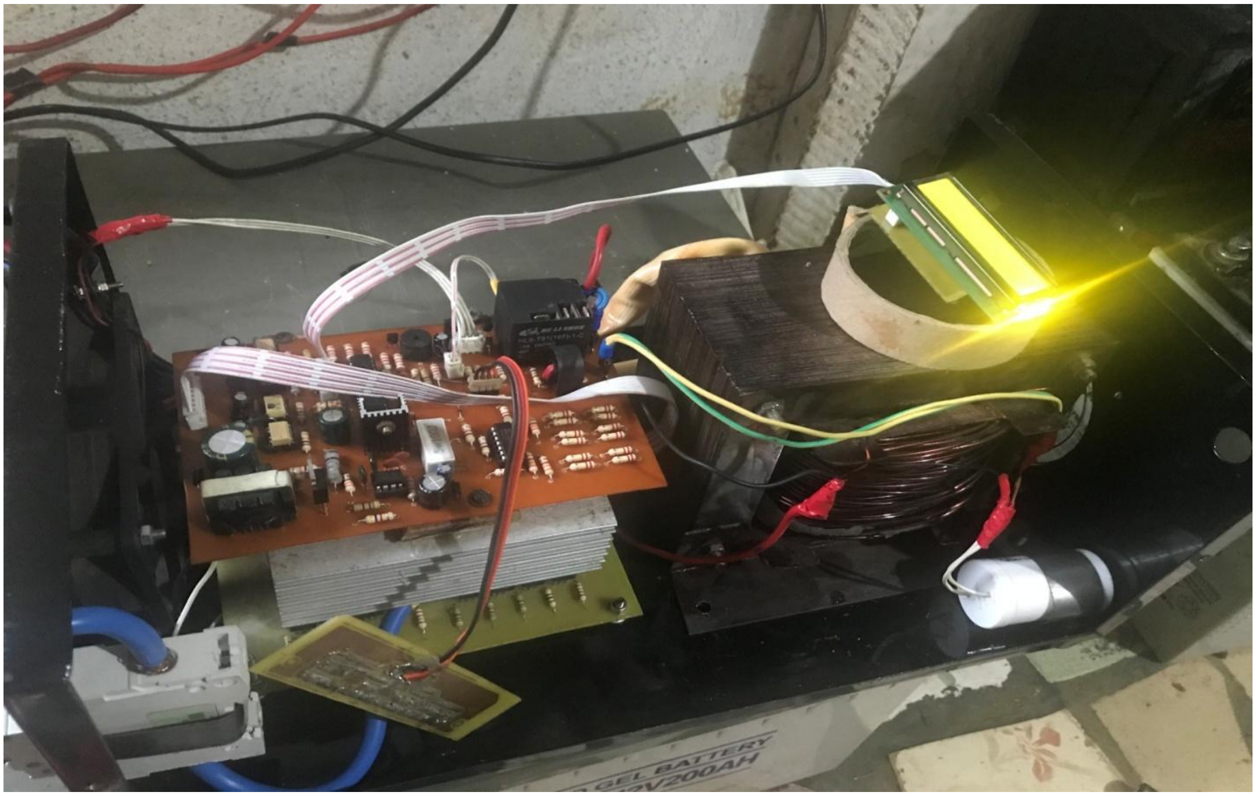


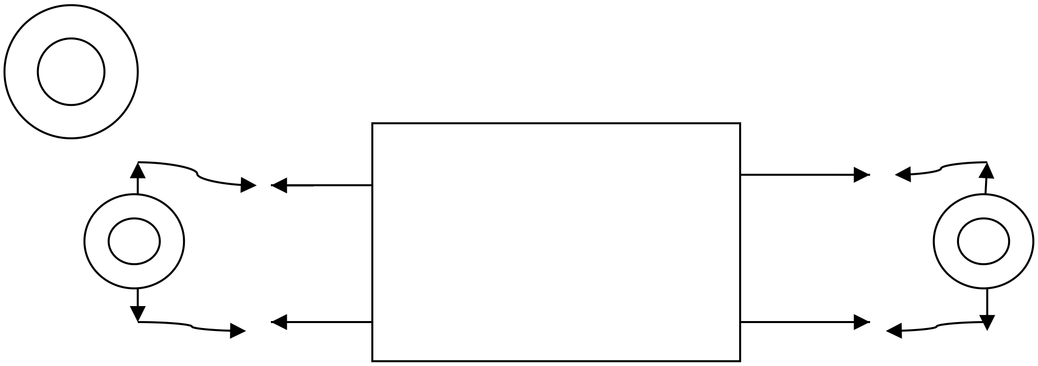
Fig. 4.5 (b) The internal view of the assembled circuitry inside the casing

4.2 TESTING

At each stage of the design/construction and after assembly of the various parts and components, tests were carried out immediately. This was to ensure that the design is in accordance with the design parameter. Tests carried out include continuity test, no load test and load test on the transformer/inverter system. Also, battery no load test was also carried out.

4.2.1 Continuity Test

On completing the winding of the transformer, the continuity test is carried out to ascertain if there are leakages or breakages in the conducting path. The circuit connection for this is shown below:



Ohmmeter
Ohmmeter

Fig. 4.6: the continuity test diagram

4.4.2 Open Circuit Test

This is carried out to ascertain the output voltages for various input voltages. A variac was used for this purpose. The test was carried on the 2.5KVA transformer. The circuit for this test is shown below:

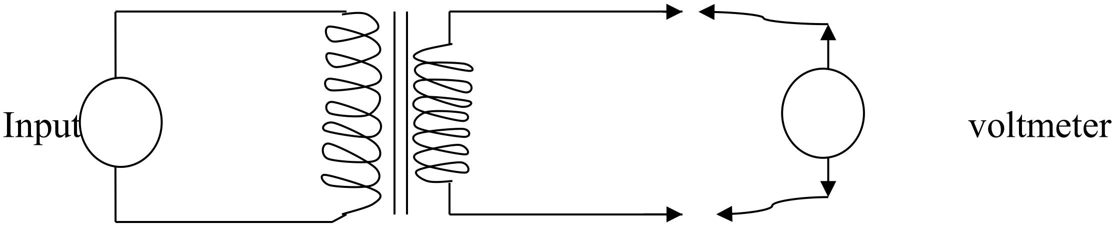


Fig. 4.7: the Open Circuit test diagram

4.2.3 Short Circuit Test

In the short circuit test, the secondary windings is “shorted” or “bridged” together while about 5-10% of the primary voltage is fed to the primary winding and the current drawn is measured with an ammeter. In our own case, short circuit voltage fed to the primary is 15volts which is about 6.82% of the rated input voltage and the current drawn was about 3.5Amps. This gave us a copper loss of 52.5Watts.

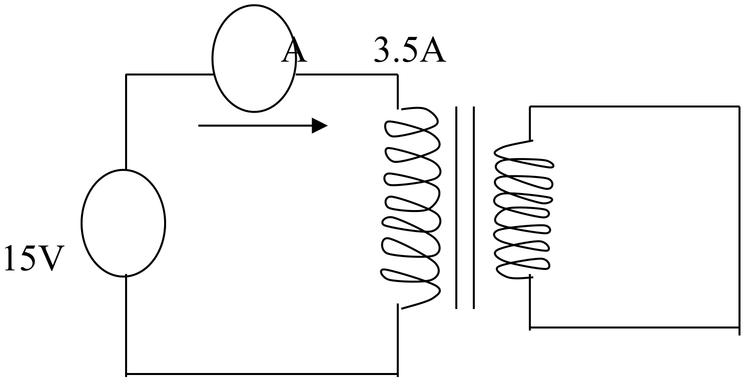


Fig. 4.8: the Short Circuit test diagram

4.2.4 Output Waveforms

The output waveforms obtained and recorded from the oscilloscope during tests are shown in the Figures 4.9 below.

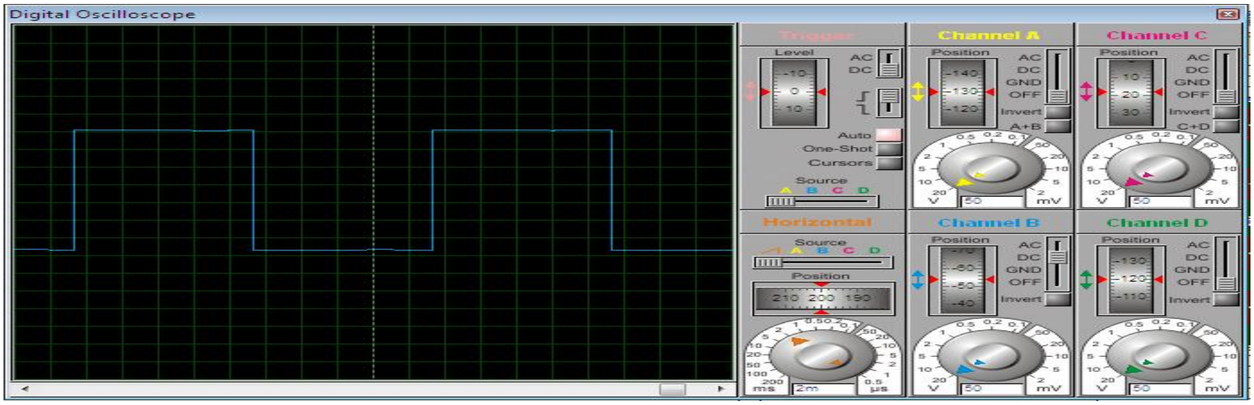


Fig 4.9 (a): Square wave signals sent to the high side MOSFETs

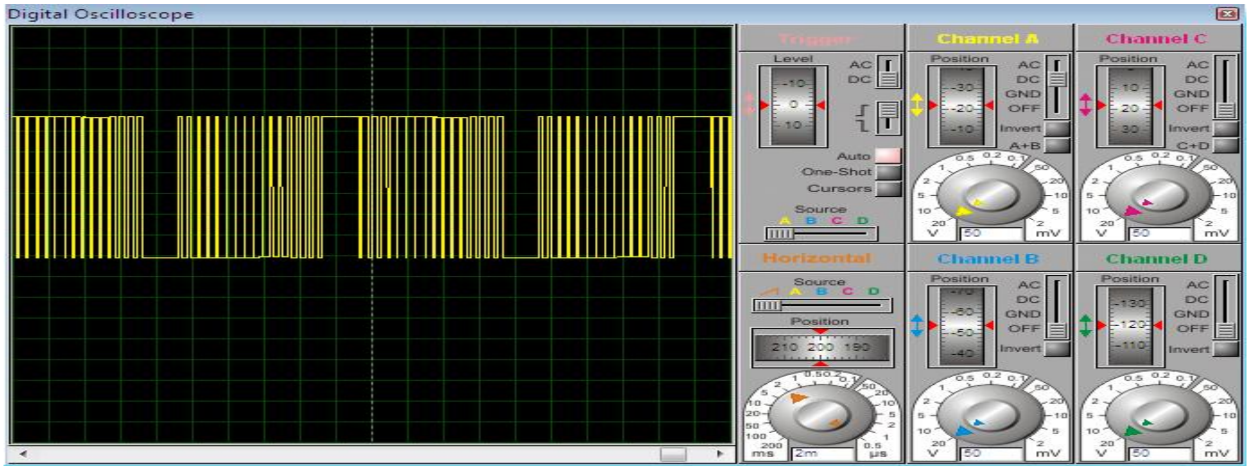


Fig4.9 (b): PWM signals fed to the low sides MOSFETs for modulation

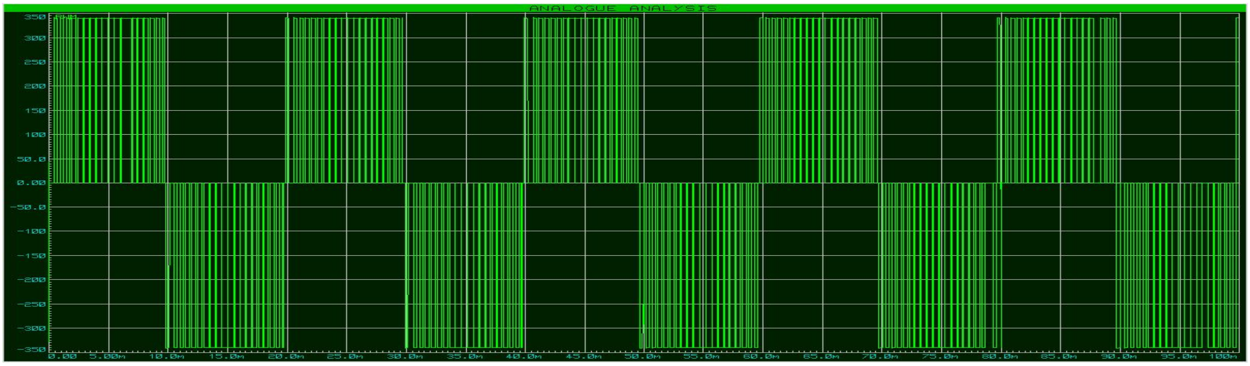


Fig4.9 (c): Full H-bridge Output before filtering

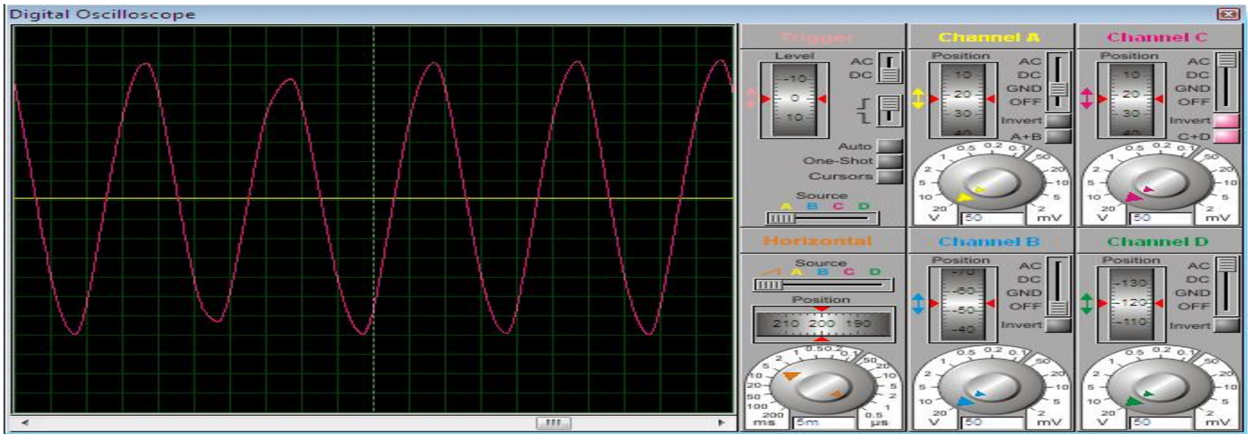


Fig 4.9 (d): Waveform of the inverter after filtering

Fig. 4.10: the inverter when connected to the batteries

Fig 4.11: the 2KVA inverter on load test

Fig 4.12: the 2KVA inverter connected to mains to charge the batteries

4.3 RESULTS

The results obtained in the implemented tests procedures are shown in Fig 4.11 and 4.12. The measured data are shown in Tables 4.2 and 4.3

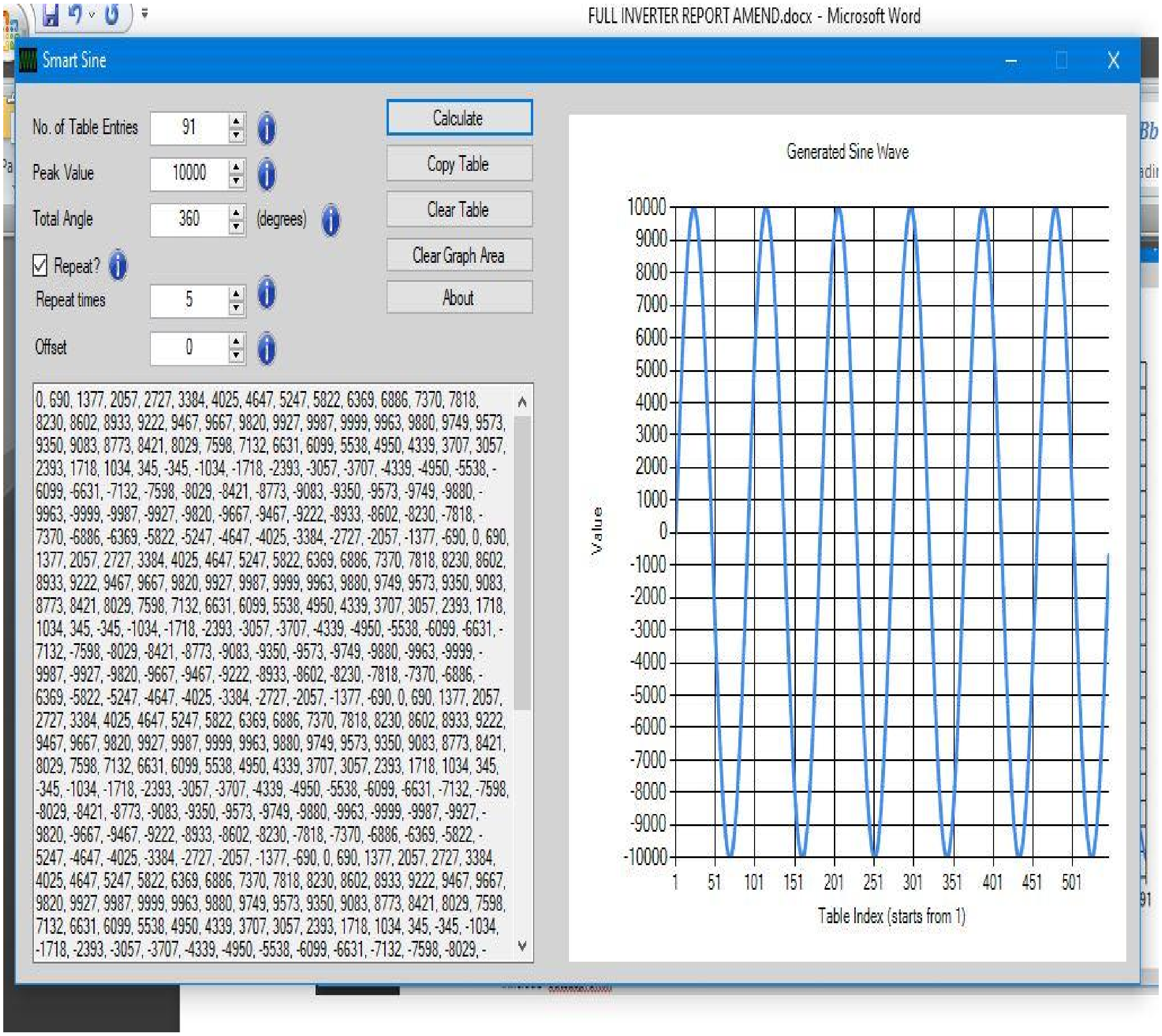
TABLE 4.2 THE INVERTER OUTPUT VOLTAGE WITH LOAD VARIATION

S/N	**LOAD(WATTS)**	**VOLATGE READINGS**	**%DROP IN OUTPUT VOLTAGE**
1	NO LOAD	220.0	0.00
2	200	220.0	0.00
3	400	220.0	0.00
4	700	219.0	0.45
5	900	218.0	0.91
6	1300	213.4	3.00

Significant voltage drop is experienced at 900W which is due to copper loss of the transformer. But the output voltage at this load was still okay.

TABLE 4.3: THE INVERTER VOLTAGE, BATTERY VOLTAGE AND POWER COMPARISON

S/N	BATTERY VOLTAGE (V_{IN})	OUTPUT VOLTAGE (V_{OUT})	POWER (LOAD)
1	26.8V	220V	100W
2	26.4V	220V	200W
3	25.9V	220V	400W
4	25.6V	220V	500W
5	23.9V	219V	700W
6	23.5V	218V	800W
7	22.2V	217V	1100W



No. of Table Entries 91

Peak Value 10000

Total Angle 360 (degrees)

☑ Repeat?

Repeat times 5

Offset 0

```
0, 690, 1377, 2057, 2727, 3384, 4025, 4647, 5247, 5822, 6369, 6886, 7370, 7818,
8230, 8602, 8933, 9222, 9467, 9667, 9820, 9927, 9987, 9999, 9963, 9880, 9749, 9573,
9350, 9083, 8773, 8421, 8029, 7598, 7132, 6631, 6099, 5538, 4950, 4339, 3707, 3057,
2393, 1718, 1034, 345, -345, -1034, -1718, -2393, -3057, -3707, -4339, -4950, -5538, -
6099, -6631, -7132, -7598, -8029, -8421, -8773, -9083, -9350, -9573, -9749, -9880, -
9963, -9999, -9987, -9927, -9820, -9667, -9467, -9222, -8933, -8602, -8230, -7818, -
7370, -6886, -6369, -5822, -5247, -4647, -4025, -3384, -2727, -2057, -1377, -690, 0, 690,
1377, 2057, 2727, 3384, 4025, 4647, 5247, 5822, 6369, 6886, 7370, 7818, 8230, 8602,
8933, 9222, 9467, 9667, 9820, 9927, 9987, 9999, 9963, 9880, 9749, 9573, 9350, 9083,
8773, 8421, 8029, 7598, 7132, 6631, 6099, 5538, 4950, 4339, 3707, 3057, 2393, 1718,
1034, 345, -345, -1034, -1718, -2393, -3057, -3707, -4339, -4950, -5538, -6099, -6631, -
7132, -7598, -8029, -8421, -8773, -9083, -9350, -9573, -9749, -9880, -9963, -9999, -
9987, -9927, -9820, -9667, -9467, -9222, -8933, -8602, -8230, -7818, -7370, -6886, -
6369, -5822, -5247, -4647, -4025, -3384, -2727, -2057, -1377, -690, 0, 690, 1377, 2057,
2727, 3384, 4025, 4647, 5247, 5822, 6369, 6886, 7370, 7818, 8230, 8602, 8933, 9222,
9467, 9667, 9820, 9927, 9987, 9999, 9963, 9880, 9749, 9573, 9350, 9083, 8773, 8421,
8029, 7598, 7132, 6631, 6099, 5538, 4950, 4339, 3707, 3057, 2393, 1718, 1034, 345,
-345, -1034, -1718, -2393, -3057, -3707, -4339, -4950, -5538, -6099, -6631, -7132, -7598,
-8029, -8421, -8773, -9083, -9350, -9573, -9749, -9880, -9963, -9999, -9987, -9927, -
9820, -9667, -9467, -9222, -8933, -8602, -8230, -7818, -7370, -6886, -6369, -5822, -
5247, -4647, -4025, -3384, -2727, -2057, -1377, -690, 0, 690, 1377, 2057, 2727, 3384,
4025, 4647, 5247, 5822, 6369, 6886, 7370, 7818, 8230, 8602, 8933, 9222, 9467, 9667,
9820, 9927, 9987, 9999, 9963, 9880, 9749, 9573, 9350, 9083, 8773, 8421, 8029, 7598,
7132, 6631, 6099, 5538, 4950, 4339, 3707, 3057, 2393, 1718, 1034, 345, -345, -1034,
-1718, -2393, -3057, -3707, -4339, -4950, -5538, -6099, -6631, -7132, -7598, -8029, -
```

Fig. 4.13: the sine graph of the duty ratio against the table values. The signals used for switching are called Sinusoidal Pulse Width Modulation (SPWM) signals.

Smart Sine software was used to design the sine waveform. Values like maximum duty cycle, number of sine entries and angles were inputted into the software which gave a very good sine waveform. These values were loaded into the microcontroller which gave sinusoidal pulse width modulation according to the preloaded duty cycles.

TABLE 4.4: SINUSOIDAL PWM (SPWM) DUTY RATIO AND THEIR CORRESPONDING SINE TABLE VALUE

Sin_table[x]	duty cycle
0	0
1	345
2	690
3	1034
4	1377
5	1718
6	2057
7	2393
8	2727
9	3057
10	3384
11	3707
12	4025
13	4339
14	4647
15	4950
16	5247
17	5538
18	5822
19	6099
20	6369

21	6631
22	6886
23	7132
24	7370
25	7598
26	7818
27	8029
28	8230
29	8421
30	8602
31	8773
32	8933
33	9083
34	9222
35	9350
36	9467
37	9573
38	9667
39	9749
40	9820
41	9880
42	9927
43	9963
44	9987
45	9999

46	9999
47	9987
48	9963
49	9927
50	9880
51	9820
52	9749
53	9667
54	9573
55	9467
56	9350
57	9222
58	9083
59	8933
60	8773
61	8602
62	8421
63	8230
64	8029
65	7818
66	7598
67	7370
68	7132
69	6886
70	6631

71	6369
72	6099
73	5822
74	5538
75	5247
76	4950
77	4647
78	4339
79	4025
80	3707
81	3384
82	3057
83	2727
84	2393
85	2057
86	1718
87	1377
88	1034
89	690
90	345

4.4 PERFORMANCE ANALYSIS & DISCUSSION OF RESULTS

The test result shows that the circuit of the inverter worked satisfactorily and the stability under load was very good. The output waveform was tested with inductive loads. The standing fan is known to emit a humming sound when powered from a source that is not sine wave. In our own case, when the fan was connected to the inverter, it emitted no hum which goes to prove that it was a sine wave output. Also, there was good stability on the incandescent bulb when connected to it and the output voltage was very stable with true RMS test using voltmeter.

4.5 OBSERVATIONS

It was observed in the results of the test earlier discussed that maximum performance and efficiency of this inverter will be guaranteed if the appliance is not over loaded.

It was observed that overloading of the inverter would occur at above 1400W. At 1300W the voltage drop at the output was significant at about 7V, so a load limit (overload) was set at 1400W which gave a yield of 70%.

There was no noise for inductive loads like standing fan and freezer.

Another observation worth mentioning here is that the frequency remained the same at 50Hz even with inductive loads.

4.6 OPERATION OF THE INVERTER

Installation of the inverter should be done by a **professional**. The input and output connections should be done properly. And also a good earthing system should be made available for the system as microcontrollers are very sensitive to noise and may get damaged in the event of a lightning strike. Loads that are rated above the system's capacity should not be installed on it. Also the system must be installed with a good battery health capacity. Having done this, the following steps must be followed to put on the inverter:

Step 1: put on the DC breaker to connect the inverter system to the batteries. The batteries must be a 24V rated bank. Several banks of this may be connected together to prolong the backup period.

This should put on the system. The buzzer and display comes on to show it is well connected. If this does not happen, then the breaker should be put off and the connections should be checked again.

Note: step 1 is done only once. The breaker is put on when installed and should not be used to disable the inverting function while installed.

Only put off the breaker when the system will not be used for inverting and charging purposes.

Step 2: press the switch on the front of the inverter. The switch is a momentary switch (this means it contacts when pressed and returns when released). Once pressed, the inverter sounds the buzzer and the display shows “inverting on” to acknowledge the switch was pressed. The inverter should output to the loads now and will remain so while the battery level is okay.

The inverter will switch to mains and start charging when it is available. It will work as a UPS when the system is enabled by inverting function (step 2). When mains is not available, it returns to inverter function and continues outputting to the loads it is connected to.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSION

A 2KVA inverter powered by a 24V DC battery supply has been designed and constructed as laid out in the aim and objectives of this project.

As earlier stated, this DC to AC inverter delivers a pure sine wave output voltage, because they convert the incoming DC into AC by using MOSFET transistors as electronic switches. This gives very high conversion efficiency and very stable amplitude.

Most appliances work best with a sine wave output and this was our target as we designed our inverter project. Generally speaking, this type of design implores more complex circuitry than their modified sine wave counterparts.

As a result, sine wave inverters are more expensive than those with a modified sine wave of the same output power rating.

5.2 RECOMMENDATIONS

A better, more efficient and less costly design can be achieved by using the high frequency method. This method involves first boosting the low voltage DC to high voltage DC using high frequency DC to DC converters. Then this high voltage will then be supplied to the H-bridge (MOSFETs bank) and with good quality pulse width modulation convert the high voltage DC to “chopped” AC which is passed through an L-C low pass filter to produce the final clean 50Hz sine wave output.

This method will greatly improve the efficiency of the system since losses have been reduced.

Also the high cost of copper wires used will also be reduced.

Some of the important conclusions that can be drawn from this work are;

- Output waveform frequency was found to be satisfactory at 50Hz equivalent of standard Nigeria Power System.
- Sine pulse with modulation circuit is much simplified by the use DSPIC30f2010 microcontroller

- In addition with the high programming flexibility, the design of the switching pulses can be altered without further changes on the hardware. Just a few changes in the codes are needed.

REFERENCES

Edeko F.O "Lecture notes on Electronics" 2005, Unpublished

Peyton Z.P & Tayeb A.G "Principles of Electrical Engineering" McGraw-Hill Inc, 1st edition, 1991

Peter B. Green ( ) MOSFET selection for low voltage UPS

M. Abdelati, and G. Frey "A Method of Building A Simple and Applicable Power Inverter." In 2nd International Congress on Energy Efficiency and Energy Related Materials. Springer International Publishing, 2015 pp. 357-356.

https://abledesigns.blogspot.com/2017/01/

https://components101.com/articles/mosfet-sysmbol-working-operation-types-and-applocations

https://manuinverters.blogspot.com/

https://ww1.microchip.com/downloads/en/devicedoc/70118e.pdf

https://eepower.com/technical-articles/leakage-indcutance-considerations-for-custom-transformers/

https://www.electronics-tutorials.ws/filter/filter_2.html\

https://en.wikipedia.org/wiki/Low_pass_filter

https://www.theengineeringprojects.com/2018/01/introduction-to-transformer.html
https://abledesigns.blogspot.com/2017/01/ INTERNET 6% 2

https://components101.com/articles/mosfet-symbol-working-operation-types-and-applications INTERNET 5% 3

https://www.ukessays.com/essays/engineering/dc-power-source-utilization-engineering-essay.php INTERNET 3% 4

https://enerpowaintl.weebly.com/dc-ac-inverters.html INTERNET 2% 5

https://circuitdigest.com/tutorial/different-types-of-inverters INTERNET 1% 7

https://www.epanorama.net/newepa/2020/12/14/sine-wave-inverter-technology/ INTERNET 1% 8

https://www.primidi.com/mosfet/mosfet_operation/modes_of_operation INTERNET 1% 9
https://www.iproject.com.ng/electrical-engineering/the-design-and-construction-of-2kva-inverter/index.html INTERNET 1% 10

https://1library.net/article/basic-design-operation-project-final-report-home-automation.qo7j83mz INTERNET 1% 11

https://www.researchgate.net/publication/337656497_Review_of_methods_for_Voltage_Control_in_AC_Inverters #:~:text=DC-AC inverters are electronic devices used to produce,the usual AC mains power is not available. INTERNET 1% 12
https://ww1.microchip.com/downloads/en/devicedoc/70118e.pdf INTERNET 1% 13
https://eepower.com/technical-articles/leakage-inductance-considerations-for-custom-transformers/ INTERNET
https://www.homemade-circuits.com/using-mosfet-body-diodes-to-charge-battery-in-inverters/ INTERNET

https://engineerexperiences.com/design-calculations.html INTERNET

https://en.wikipedia.org/wiki/Electrolytic_capacitor

http://electrathonoftampabay.org/www/Documents/Electronics/AN-9010.pdf

https://www.eng.auburn.edu/~dbeale/ESMDCourse/Chapter2.htm

https://en.wikipedia.org/wiki/Leakage_inductance https://www.theengineeringprojects.com/2018/01/introduction-to-transformer.html

https://en.wikipedia.org/wiki/Low-pass_filter

https://o3schools.com/the-transformer-and-its-importance-in-electric-systems/

https://www.allaboutcircuits.com/textbook/alternating-current/chpt-8/low-pass-filters/

https://mybroadband.co.za/forum/threads/modified-vs-true-sine-wave-inverter-for-tv.6252

https://academickids.com/encyclopedia/index.php/Relay

https://www.alldatasheet.com/datasheet-pdf/pdf/52809/FAIRCHILD/HRF3205.html

https://en.wikipedia.org/wiki/Power_inverter

https://www.ipl.org/essay/Advantages-And-Disadvantages-Of-Inverter-PKBTYPHESCF6#:~:text=Static inverters have no moving parts and are,DC sources such as solar panels or batteries.