CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND INFORMATION

In recent times there has been an increasing demand for alternative energy sources as global oil reserves dwindle and concerns for the environment continue to grow. Today, we increasingly depend on devices that require electricity, but in Nigeria, one of the most populated nations in Africa, only 40% of the people are connected to the energy grid; those connected experience brownouts and total blackouts around 60% of the time. Meanwhile, it is sunny 43% of daylight hours in Nigeria, which is an average of 1885 hours of sunlight per year, this means solar as an alternative energy solution is very much feasible in this part of the world. [1]

There is therefore a growing need for inverters to convert low voltage DC to high voltage AC which are of lower cost and more efficient.

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

Inverters are used for many applications as in a situation where low voltage DC sources such as batteries, solar panels or fuel cells must be converted so that devices can run on AC power. One example of such a situation would be converting electrical power from a car battery to run a laptop, television, lighting or cell phone etc [2]

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

Beginning from the late 19th century to the middle of the 20th century DC to AC power conversion was accomplished using rotary converters, or Motor Generator (MG) sets. In the early 20th century, vacuum tube and gas filled tube began to be used as switches in inverter circuits. The most widely used type of tube was the thyraton.

The origination of electromechanical inverters explains the source of the term inverter. Early AC to DC converters used on conduction or synchronous AC motor direct connected to a generator (dynamo), so that the generators commutation reversed its connection exactly the right moments to produce DC. A later improvement is the synchronous converter, in which the motor and generator windings are combined into one armature, with slip-rings at one end and a commutation at the other end and only one field frame.

The result is either with AC-on, DC-out. With an M.G sets, the DC can be considered to be separately generated from the AC with a synchronous converter, in a certain sense, it can be considered to be mechanically rectified AC. Using the right auxiliary and control equipment, an M.G set or rotary converter can “run backward”, converting DC to AC. Hence, an inverter is inverter converter.

It should also be noted that early inverter did not use transistors for switching purposes, because its voltage and current ratings were not high enough for most inverter applications. However, in 1975, the Silicon Control Rectifier (SCR) was introduced as switches, hence initiating a transition to solid state inverter circuits. Today, however due to an increased knowledge in technology, modern inverters are less bulky, and more efficient with the use of various components such as ICs (Integrated Circuits).

1.2 PROBLEM STATEMENT

Lack of incentives to invest in the aged and inefficient national grid, transmission and distribution infrastructures, as well as the fact that energy from decentralized, renewable sources is not well fashioned to work on the electricity grids in the country has led to incessant power outage all over the country. Some of the solutions to this problem is an auxiliary AC power generator, nuclear power plants, wind turbines, solar power etc., but the cost of fossil fuels continues to increase rapidly and hence will not be cost effective in the future; while solar power has some aesthetic, economic and technical drawbacks. A more effective and reliable alternative is battery power back-up system which can be converted to AC power using power inverters.

1.3 OBJECTIVES

The main aim of this project is to design and implement a 5kVA pure sine wave inverter with 48volts for the department of Electrical and Electronics Engineering, Federal University of Technology, Owerri so as to convert the DC output from the battery bank into an AC output useable at the home, offices, etc.

The specific objectives were achieved as follows:

- Design a working circuit diagram for the proposed pure sine wave inverter.
- Acquiring the required components for the realization of the project.
- Programming the micro-controller to produce the sine pulse width modulated signal (SPWM), with automatic change over and feedback loop.
- Design and construction of the transformer with the required ratings.
- Soldering of the components into the 5KVA rated printed circuit board.

- Monitoring the display panel of the inverter to ensure concurrence with output.

1.4 JUSTIFICATION

Designing a pure sine wave inverter with the above listed features is of great significance for it serves to unveil the challenges and possible flaws that are associated with modern inverters in the market and hence give insight and practical design experience to students which will in turn encourage more researches in the area of solar inverter power system as an alternative power supply for homes and industries.

This project also serves to widen the horizon of students especially in the area of modern day solar technology and hence can serve as an area for further research and development in schools and industries.

Solar power inverter systems find application in the following areas of life:

- In homes and offices as stand-alone power supply or supplement to the mains power supply
- In industries and factories as grid-tie or stand-alone system
- In camping grounds and off grid locations as a portable power supply
- In hospitals as back-up power supply in the case mains outage
- In other power critical places as emergency power supply, etc.

In our case, it serves to provide an alternative power source for the department during the times of mains power outage.

1.5 SCOPE OF WORK

This project work covers the design and installation of a 5kVA solar inverter that can power the loads that are within its capacity. It is designed to serve majorly as a supplement to the mains power supply and is therefore not meant to serve as a permanent independent stand-alone power supply. The battery bank has the capacity of 19,200 Watt-Hour (i.e. 48V x 400Ah) and can be charged by either the mains power or the power from the array of solar modules. The design is capable of automatically switching to mains or inverter mode when appropriate and features all forms of protection techniques/schemes to guard the system and the connected appliances against any form of danger that may arise during operation.

The design does not accommodate a high power surge beyond its stated capacity and hence cannot be used to power high inductive loads like industrial electric motors and high power air conditioners. It can be used to power very sensitive and life dependent devices/equipment like medical equipment and servers because of the near absence of harmonic content in the final power output of the design.

1.6 LIMITATION OF THE PROJECT

- Cost of the components especially the transformer and the micro-controller.
- Time duration of the project.
- Unreliability of power supply.
- The scarcity of some of the components.

1.7 PROJECT REPORT ORGANISATION

This report comprises of five chapters that are well arranged sequentially in the order stated below:

- The first chapter gives a brief introduction of the entire project carried out and also reveals the objectives, significance and scope of work.
- The second chapter talks about the literature review and highlights some previous works in the area of study.
- The third chapter talks about the materials and methodology used in the design and fabrication.

- The fourth chapter forms the results obtained from testing of the completed work, results and discussion.
- The fifth chapter which is the concluding chapter presents the summary of the work, recommendations, and conclusion.

CHAPTER TWO

LITERATURE REVIEW

2.1. BACKGROUND OF STUDY

The concept of renewable energy use grew over time with the advent of the inverter which helps in the conversion of the energy from the dc form to a useable ac form. The consistent effort of researchers in developing and increasing the efficiency of photovoltaic arrays up to the level we have today also added a lot to the progress of solar powered inverters. Although the inverter generally gives out alternating current, the wave shape of the AC it produces also matters a lot. Inductive loads generally require a pure sine wave ac supply for its functionality, though there are different types of waves that can be produced by an inverter which are: square wave, modified sine wave, and then the pure sine wave inverter. We also added 40A Maximum Power Point Tracking (MPPT) charge controller to the output of our solar panels for optimization purposes and for charging our battery cells.

All these components (solar panels, batteries, MPPT charge controllers, inverter, and MPPT algorithms) together made up the core of the solar powered 5kVA inverter we designed for the departmental use. It took a gradual but consistent progression for these components to emerge to the level at which they are today in the world of technology.

2.2 CLASSIFICATION OF PV SOLAR SYSTEM

PV Solar systems can be classified based on the end-use application of the technology. There are two main types of solar PV systems:

- Grid – connected (or grid-tied).
- Off-grid (or stand-alone or autonomous).

- Hybrid

2.2.1 GRID – CONNECTED (GRID – TIED) SYSTEM

Grid-connected or utility-interactive PV systems are designed to operate in parallel with and interconnected with the electric utility grid. The primary component in grid-connected PV systems is the inverter, or power conditioning unit (PCU). The PCU converts the DC power produced by the PV array into AC power consistent with the voltage and power quality requirements of the utility grid, and automatically stops supplying power to the grid when the utility grid is not energized. A bi-directional interface is made between the PV system AC output circuits and the electric utility network, typically at an on-site distribution panel or service entrance. This allows the AC power produced by the PV system to either supply on-site electrical loads or to back-feed the grid when the PV system output is greater than the on-site load demand. At night and during other periods when the electrical loads are greater than the PV system output, the balance of power required by the loads is received from the electric utility. This safety feature is required in all grid-connected PV systems, and ensures that the PV system will not continue to operate and feed back into the utility grid when the grid is down for service or repair.

Figure 2.1: Block Diagram of Grid-connected PV system.

2.2.2 STAND ALONE SYSTEM

Stand-alone PV systems are designed to operate independent of the electric utility grid, and are generally designed and sized to supply certain DC and/or AC electrical loads. These types of systems may be powered by a PV array only, or may use wind, an engine-generator or utility power as an auxiliary power source in what is called a PV-hybrid system. The simplest type of stand-alone PV system is a direct-coupled system, where the DC output of a PV module or array is directly connected to a DC load (Figure 2.2). Since there is no electrical energy storage (batteries) in direct-coupled systems, the load only operates during sunlight hours, making these designs suitable for common applications such as ventilation fans, water pumps, and small circulation pumps for solar thermal water heating systems. Matching the impedance of the electrical load to the maximum power output of the PV array is a critical part of designing well-performing direct-coupled system. For certain loads such as positive-displacement water pumps, a type of electronic DC-DC converter, called a maximum power point tracker (MPPT), and is used between the array and load to help better utilize the available array maximum power output.

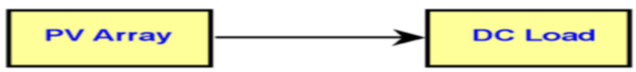

Figure 2.2: Direct coupled PV system

In many stand-alone PV systems, batteries are used for energy storage. Figure 2.3 shows a diagram of a typical stand-alone PV system powering DC and AC loads.

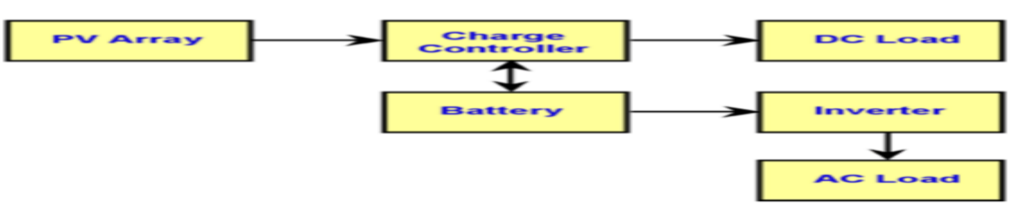

Figure 2.3: Diagram of stand-alone PV system with battery storage powering DC and AC loads

2.2.3 HYBRID SYSTEM

Hybrid photovoltaic system combines elements of both grid-connected and stand-alone systems. They are grid-connected and enable excess energy to be sold. Hybrid system architectures include energy storage as well as the ability to disconnect from the grid, but still supply energy to the home during outages.

Figure 2.4 below shows a hybrid photovoltaic system.

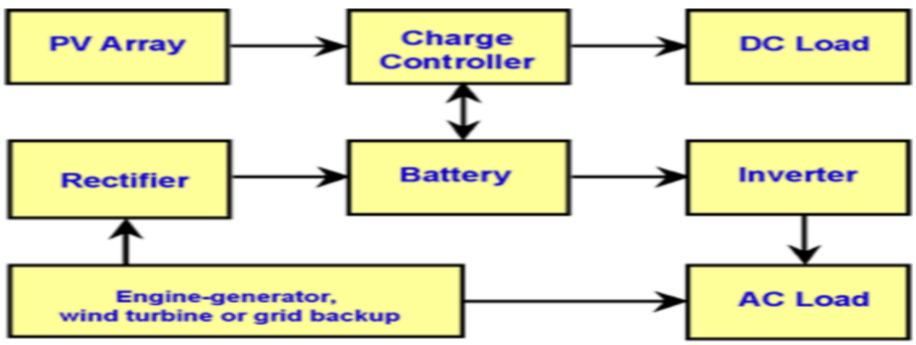

Figure 2.4: Block Diagram of hybrid PV system

2.3 REVIEW OF THE EXISTING THEORY IN HYBRID PV POWER SYSTEM

A hybrid photovoltaic system is a power system designed to source power from both PV cells (solar energy) and the grid (PHCN). It consists of an arrangement of several components, including solar panels to absorb and convert sunlight into electricity, the charge controller to control the amount of charge going into the battery bank, a solar inverter to change the electric current from DC to AC, the battery bank that stores the energy from the solar panels, as well as mounting, cabling and other electrical accessories to set up a working system. It may also use a solar tracking system to improve the system's overall performance and include an integrated battery solution. The DC back-up power source of any inverter can be replenished from diverse power sources like the mains power supply, wind turbines, stand-by generators, fuel cells etc. When the back-up battery bank is charged with solar power from an array of photo-voltaic modules, a power regulator called charge controller is normally needed to regulate the amount of power that goes to the battery bank to avoid battery overcharge which can destroy the battery bank during the charging process.

2.4 REVIEW OF THE THEORY OF THE SUBSYSTEMS OF A PV SYSTEM

Basic components of grid-connected PV systems with and without batteries are:

- Solar photovoltaic modules
- Array mounting racks
- Grounding equipment
- Combiner box
- Surge protection (often part of the combiner box)
- Inverter
- Meters – system meter and kilowatt-hour meter
- Disconnects:
    - Array DC disconnect
    - Inverter DC disconnect
    - Inverter AC disconnect
    - Exterior AC disconnect

If the system includes batteries, it will also require:

- Battery bank with cabling and housing structure

• Charge controller

• Battery disconnect

2.4.1 Solar Modules

The heart of a photovoltaic system is the solar module. Many photovoltaic cells are wired together by the manufacturer to produce a solar module. When installed at a site, solar modules are wired together in series to form strings. Strings of modules are connected in parallel to form an array.

Figure 2.5: Several types of solar modules

2.4.2 Array mounting racks

Arrays are most commonly mounted on roofs or on steel poles set in concrete. In certain applications, they may be mounted at ground level or on building walls. Solar modules can also be mounted to serve as part or all of a shade structure such as a patio cover. On roof-mounted systems, the PV array is typically mounted on fixed racks, parallel to the roof for aesthetic reasons and stood off several inches above the roof surface to allow airflow that will keep them as cool as practical.

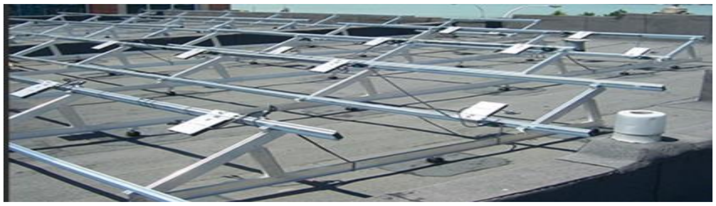

Figure 2.6: Array mounting racks

2.4.3 Grounding equipment

Grounding equipment provides a well-defined, low-resistance path from your system to the ground to protect your system from current surges from lightning strikes or equipment malfunctions. Grounding also stabilizes voltages and provides a common reference point. The grounding harness is usually located on the roof.

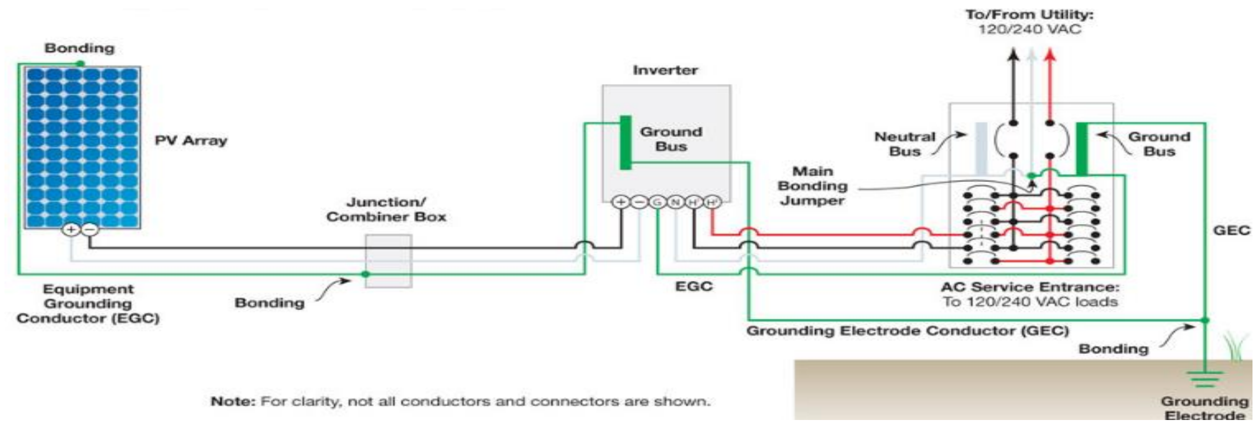

Figure 2.7: PV Grounding System

2.4.4 Combiner box

Wires from individual PV modules or strings are run to the combiner box, typically located on the roof. These wires may be single conductor pigtails with connectors that are pre-wired onto the PV modules. The output of the combiner box is one larger two wire conductor in conduit. A combiner box typically includes a safety fuse or breaker for each string and may include a surge protector.

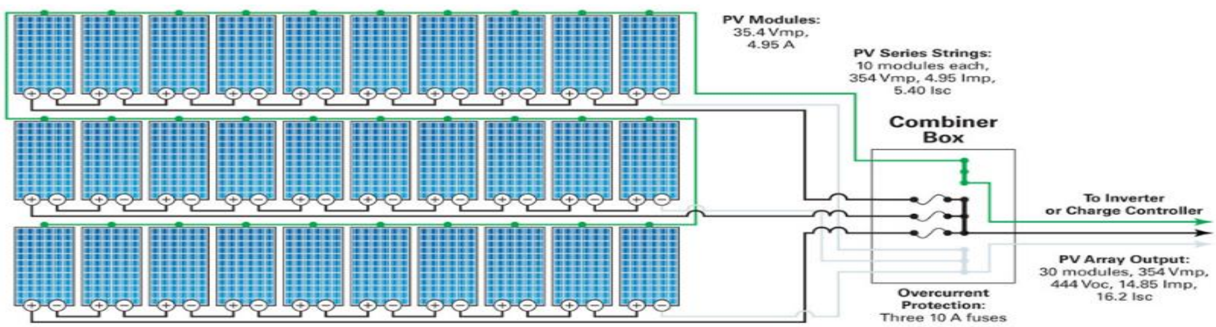

Figure 2.8: PV Combiner box wiring

2.4.5 Surge protection

Surge protectors help to protect your system from power surges that may occur if the PV system or nearby power lines are struck by lightning. A power surge is an increase in voltage significantly above the design voltage.

Figure 2.9: PV Surge protector

2.4.6 Inverter

Inverters take care of four basic tasks of power conditioning:

• Converting the DC power coming from the PV modules or battery bank to AC power

• Ensuring that the frequency of the AC cycles is 50 cycles per second

• Reducing voltage fluctuations

• Ensuring that the shape of the AC wave is appropriate for the application, i.e. a pure sine wave for grid-connected systems.

Figure 2.10: PV inverter

2.4.7 Meters

Essentially two types of meters are used in PV systems:

- Utility Kilowatt-hour Meter
- System Meter

Utility Kilowatt-Hour Meter – The utility kilowatt-hour meter measures energy delivered to or from the grid. On homes with solar electric systems, utilities typically install bidirectional meters with a digital display that keeps separate track of energy in both directions. Some utilities will allow you to use a conventional meter that can spin in reverse. In this case, the utility meter spins forward when you are drawing electricity from the grid and backwards when your system is feeding or "pushing" electricity onto the grid.

System Meter – The system meter measures and displays system performance and status. Monitored points may include power production by modules, electricity used, and battery charge. It is possible to operate a system without a system meter, though meters are strongly recommended. Modern charge controllers incorporate system monitoring functions and so a separate system meter may not be necessary.

Figure 2.11: PV Smart meter

2.4.8 Disconnect

Automatic and manual safety disconnects protect the wiring and components from power surges and other equipment malfunctions. They also ensure the system can be safely shut down and system components can be removed for maintenance and repair. For grid-connected systems, safety disconnects ensure that the generating equipment is isolated from the grid, which is important for the safety of utility personnel. In general, disconnect is needed for each source of power or energy storage device in the system.

2.4.9 Battery bank

Batteries store direct current electrical energy for later use. This energy storage comes at a cost, however, since batteries reduce the efficiency and output of the PV system, typically by about 10 percent for lead-acid batteries. Batteries also increase the complexity and cost of the system.

Types of batteries commonly used in PV systems are:

- Lead-acid batteries

  - Flooded (a.k.a. Liquid vented)

  - Sealed (a.k.a. Valve-Regulated Lead Acid)

  - Absorbent glass mat

  - Gel cell

- Alkaline batteries

  - Nickel-cadmium

  - Nickel-iron

2.4.10 Charge controller

A charge controller, sometimes referred to as a photovoltaic controller or battery charger, is only necessary in systems with battery back-up. The primary function of a charge controller is to prevent overcharging of the batteries. Most also include a low voltage disconnect that prevents over-discharging batteries. In addition, charge controllers prevent charge from draining back to solar modules at night. Some modern charge controllers incorporate maximum power point tracking, which optimizes the PV array's output, increasing the energy it produces.

2.5 INVERTER

A power inverter, or inverter, is an electronic device or circuitry that changes direct current (DC) power to alternating current (AC) power. It is simply a DC-AC power converter that takes power from a DC power source and converts it to an AC power source. The input voltage, output voltage and frequency, and overall power handling capability of an inverter depend on the design of the specific device or circuitry. The inverter does not produce any power; the power is provided to it by a DC source. A power inverter can be entirely electronic or may be a combination of mechanical effects (such as a rotary apparatus) and electronic circuitry. Power inverters can therefore be categorized into Rotary and Static inverters. Static inverters do not use moving parts in the conversion process.

A typical power inverter device or circuit requires a relatively stable DC power source capable of supplying enough current for the intended power demands of the system. The input voltage depends on the design and purpose of the inverter. Examples include: 12 VDC, for smaller consumer and commercial inverters that typically run from a rechargeable 12 V lead acid battery; 24 and 48 VDC which are common standards for home energy systems. 200 to 400 VDC, when power is from photovoltaic solar panels. 300 to 450 VDC, when power is from electric vehicle battery packs in vehicle-to-grid systems. Hundreds of thousands of volts, where the inverter is part of a high voltage direct current power transmission system.

An inverter can produce a square wave, modified sine wave, pulsed sine wave, pulse width modulated wave (PWM) or sine wave depending on circuit design. The two dominant commercialized waveform types of inverters as of 2007 are modified sine wave and sine wave. There are two basic designs for producing household plug-in voltage from a lower-voltage DC source, the first of which uses a switching boost converter to produce a higher-voltage DC and then converts to AC. The second method converts DC to AC at battery level and uses a line-frequency transformer to create the output voltage.

2.6.1 Square wave

This is one of the simplest waveforms an inverter design can produce and is useful for some applications. They can run simple appliances without problems but not much else. Square wave voltage can be easily generated using a simple oscillator. With the help of a transformer, the generated square wave voltage can be transformed into a value of 230 volt AC or higher. The Graph in Fig. 2.4 below shows a typical square waveform.

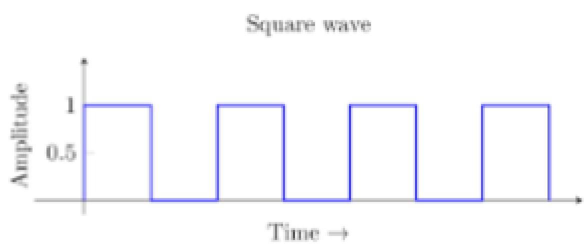

Figure 2.12: Square Waveform

The oscillator of square wave inverters is very basic, and they are fairly easy to build. Unfortunately, the ratio of peak to RMS voltage is very different from a sine wave, and this will cause stress to some appliances. Motors and transformers in particular will usually draw much higher current than they are designed for, so they may run hot enough to cause premature failure. Most switch mode power supplies don't care, and will operate quite happily from a square wave input. Interference suppression capacitors will be stressed by the fast rise time of the square wave.

Below is the circuit diagram of a typical square wave inverter as shown Fig. 2.5 below.

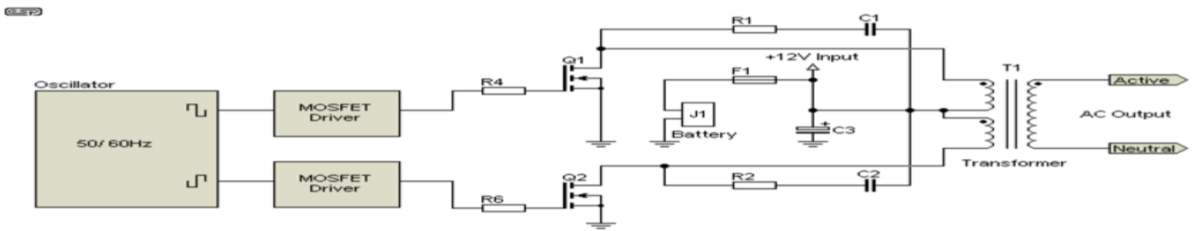

Figure 2.13: Square Wave Inverter Circuit Diagram

A sine wave has a peak to RMS ratio of 1.414 (√2), so a 230V sine wave has a peak value of 325V and a 120V sine wave has a peak of 170V (close enough in each case). A square wave with a peak value of 325V has an RMS voltage of 325V. Peak and RMS are the same. If the voltage is reduced so that the RMS voltage is correct, then many electronic power supplies will see a greatly reduced input voltage because many filter capacitors charge to the peak of the voltage. So where the load expects to see peaks of 325V (or 170V), it will only get 230V or 120V peaks. Some loads will not power up properly if the voltage is too low.

2.6.2 Sine wave

A power inverter device which produces a multiple step or smooth sinusoidal AC waveform is referred to as a sine wave inverter. To more clearly distinguish the inverters with outputs of much less distortion than the "modified sine wave" (three step) inverter designs, the manufacturers often use the phrase pure sine wave inverter. Almost all consumer grade inverters that are sold as a "pure sine wave inverter" do not produce a smooth sine wave output at all, just a less choppy output than the square wave (one step) and modified sine wave (three step) inverters. In this sense, the phrases "Pure sine wave" or "sine wave inverter" are misleading to the consumer. However, this is not critical for most electronics as they deal with the output quite well. Pure sine wave inverters are able to simulate precisely the AC power that is delivered by a wall outlet. Usually sine wave inverters are more expensive then modified sine wave generators due to the added circuitry. This cost, however, is made up for in its ability to provide power to all AC electronic devices, allow inductive loads to run faster and quieter, and reduce the audible and electric noise in audio equipment, TV's and fluorescent lights.

The graph in Fig. 2.6 below shows a sine a (sinusoidal) signal wave form.

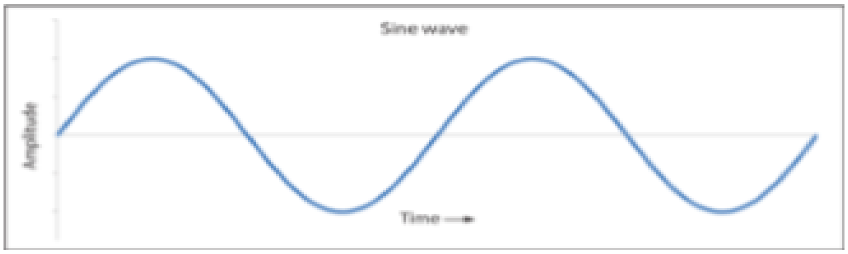

Figure 2.14: Pure Sine waveform

In cases where power inverter devices substitute for standard line power, a sine wave output is desirable because many electrical products are engineered to work best with a sine wave AC power source. The standard electric utility power attempts to provide a power source that is a good approximation of a sine wave To design a pure sine wave inverter with high efficiency and low total harmonic distortion, the conventional old method of using a sine wave oscillator and a step-up transformer will not suffice due to its inherent low efficiency and losses, hence to produce the desired high efficient and low total harmonic distortion pure sine wave inverter, a modern technique of digital signal processing called pulse width modulation (PWM) technique is employed. Pulse width modulation (PWM) is a powerful technique for controlling analogue with a processor's digital outputs. It is also known as pulse duration modulation (PDM). The leading edge of the carrier pulse remains fixed and the occurrence of the trailing of the pulses varies. The pattern at which the duty cycle of a PWM signal varies can be created through simple analogue components, a digital microcontroller, or specific PWM integrated circuits.

Analogue PWM control requires the generation of both reference and carrier signals that feed into a comparator which creates output signals based on the difference between the signals. The reference signal is sinusoidal and at the frequency of the desired output signal, while the carrier signal is often either a saw tooth or triangular wave at a frequency significantly greater than the reference. When the carrier signal exceeds the reference, the comparator output signal is at one state, and when the reference is at a higher voltage, the output is at its second state. This process is shown in Fig. 2.7 below with the triangular carrier wave in green, sinusoidal reference wave in red, and the pulse width modulated signal in blue.

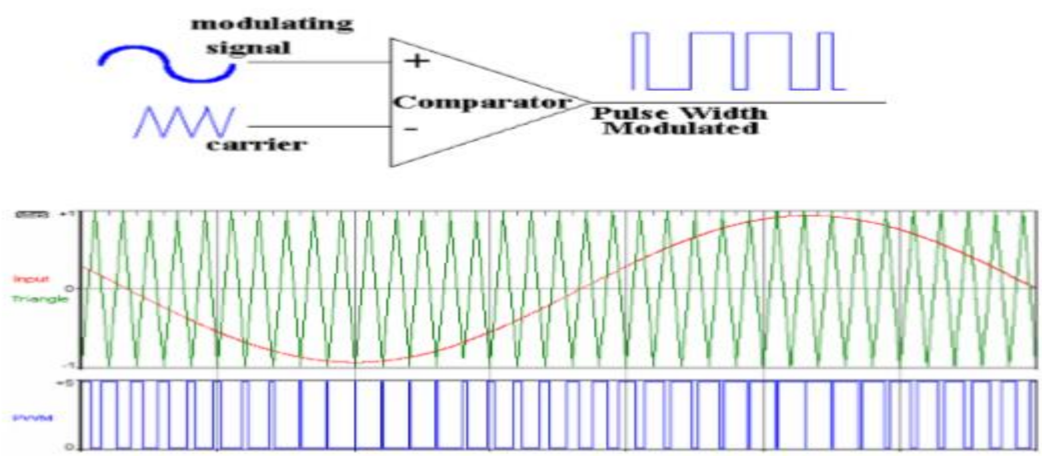

Figure 2.15: PWM Sine wave Modulation

There are many types of PWM techniques used in sine wave inverters. The commonly used techniques are:

Single or 2-level PWM: it’s the simplest way of producing the PWM signal. It’s through comparison of a low-power reference sine wave with a triangle wave as shown in figure 2.7 below. Using these two signals as input to a comparator the output will be a 2-level PWM signal as shown in the second image of figure 2.7

below. It’s the most common and popular technique of pulse-width-modulation (PWM).

a. Multilevel PWM: The harmonic content can be reducing significantly by using several pulses in each half- cycle of the output voltage. There exist different levels of multiphase PWM producing an improved output with increase of the level of the PWM used. The most common ones are: 3 levels PWM, 5 levels PWM, 7 levels PWM and 9 levels PWM. The choice of which PWM level to use is determined by the cost of the inverter and the quality of the output. To balance between cost and quality of the inverter, a 3-level PWM is commonly used. Fig. 2.8below shows a 3-level PWM.

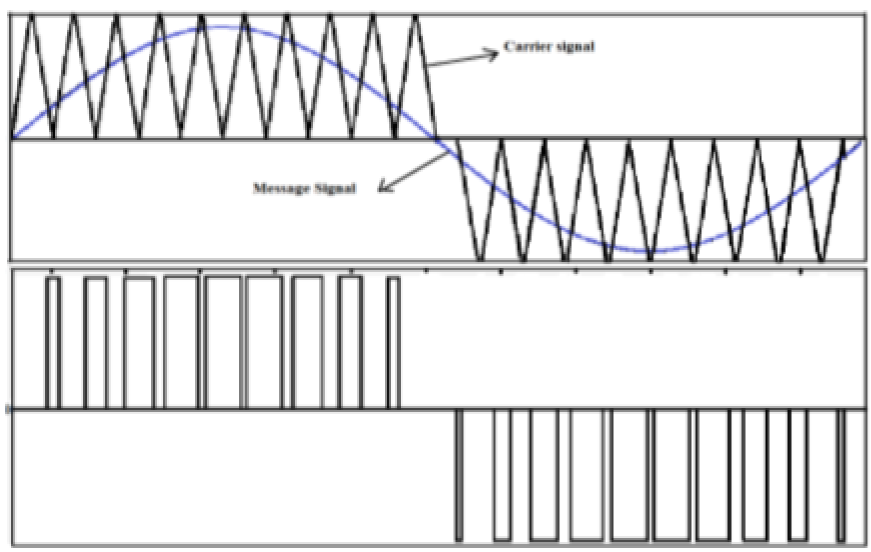

Figure 2.16: 3-Level PWM Technique

Comparing the 3-level PWM to the 2-level PWM, the harmonics plot shows no higher level harmonics of significant magnitude. This represents the 3Level signal following much more closely the desired sine wave. However, the primary frequency has a much lower voltage magnitude than that of the 2Level design. The reason for this is the presence of other frequencies which are not harmonics of the 50Hz signal, which are caused by the switching of the signal from one polarity to the other, and back. In PWM inverter, harmonics will be much higher frequencies than for a square wave, making filtering easier. Shown below in Fig. 2.9 is the block diagram of a typical PWM pure sine wave inverter.

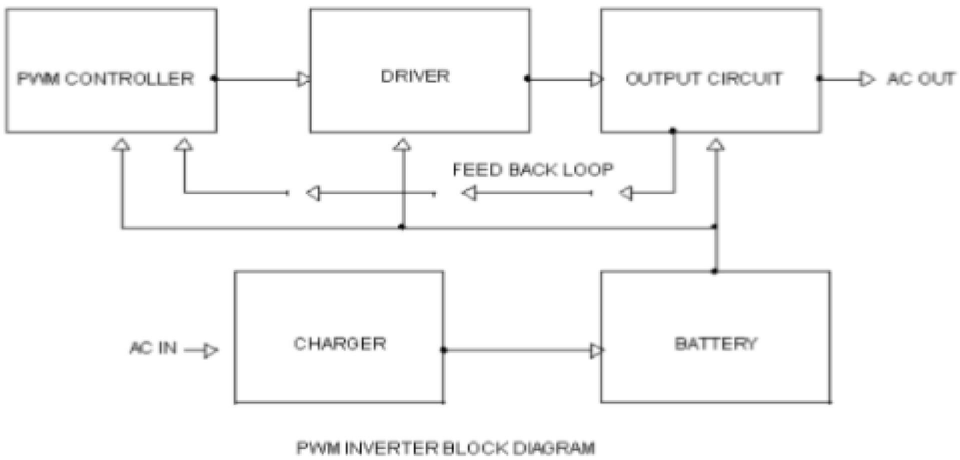

Figure 2.17: PWM Inverter Block Diagram

In PWM, the amplitude of the output voltage can be controlled with the modulating waveforms. Reduced filter requirements to decrease harmonics and the control of the output voltage amplitude are two distinct advantages of PWM. Disadvantages include more complex control circuits for the switches and increased losses due to more frequent switching. In designing pure sine wave inverters using PWM techniques two different approaches or methods can be used to achieve the same result:

1. Low Voltage PWM: here a pulse width modulated signal is generates at a low voltage level using PWM chip or discrete components and the PWM signal used to drive power MOSFETs which switch the primary winding of a low frequency (50Hz/60Hz) linear transformer. The issue with this method is that the size of the transformer is usually very large due to the low frequency of operation

2. High Voltage PWM: in this method, a DC-DC converter is used to convert the low voltage DC power supply to a level that is equivalent to the desired AC voltage output. The high voltage DC voltage is then converted to a pure sine wave AC output voltage using the PWM technique as used in method 1 above only that the voltage ratings of the solid state switches used in this case will be higher than the peak voltage of the sinusoidal output unlike those used in method 1 above. The major advantage of this method is that it enable smaller transformer to be used in the design due to the high frequency used in design.

Shown below in Fig. 2.10 and Fig. 2.11 are two diagrams of a typical low and high voltage PWM inverter respectively.

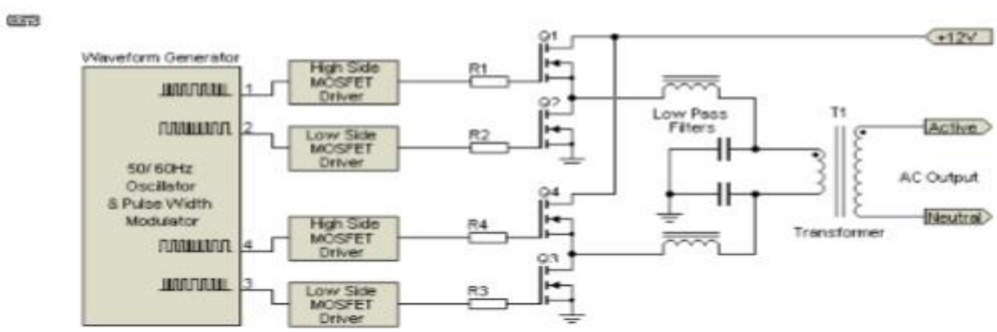

Fig 2.18: Low Voltage PWM Inverter Circuit Diagram

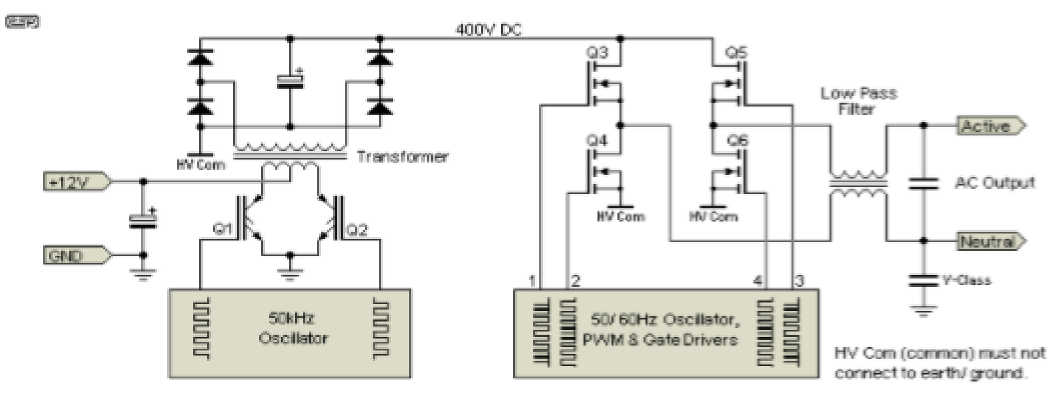

Figure 2.19: High Voltage PWM Inverter Circuit Diagram

2.6.3 modified sine wave:

A "modified sine wave" inverter has a non-square waveform that is a useful rough approximation of a sine wave for power translation purposes as shown in Fig. 2.12 below.

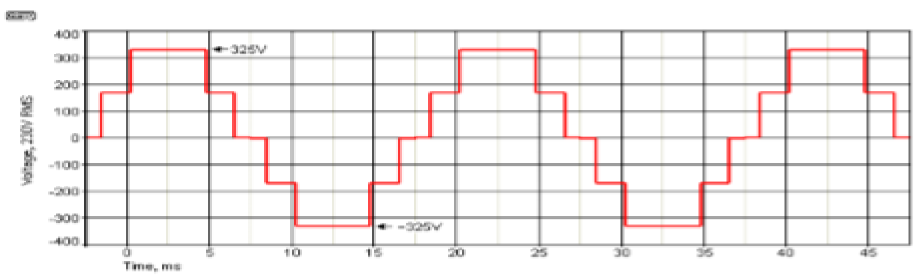

Figure 2.20: Modified Sine waveform

The waveform in commercially available modified-sine-wave inverters is a square wave with a pause before the polarity reversal, which only needs to cycle back and forth through a three-position switch that outputs forward, off, and reverse output at the pre-determined frequency. Switching states are developed for positive, negative and zero volts. The peak voltage to RMS voltage does not maintain the same relationship as for a sine wave. The DC bus voltage may be actively regulated or the "on" and "off" times can be modified to maintain the same RMS value output up to the DC bus voltage to compensate for DC bus voltage variation.

The ratio of on to off time can be adjusted to vary the RMS voltage while maintaining a constant frequency with a technique called PWM. Many electrical equipment will operate quite well on modified sine wave power inverter devices, especially any load that is resistive in nature such as a traditional incandescent light bulb. Most AC motors will run on MSW (Modified Sine Waveform) inverters with an efficiency reduction of about 20% due to the harmonic content. However, they may be quite noisy. A series LC filter tuned to the fundamental frequency may help in such case.

Shown below in Fig. 2.13 is a circuit diagram of a typical modified sine wave inverter.

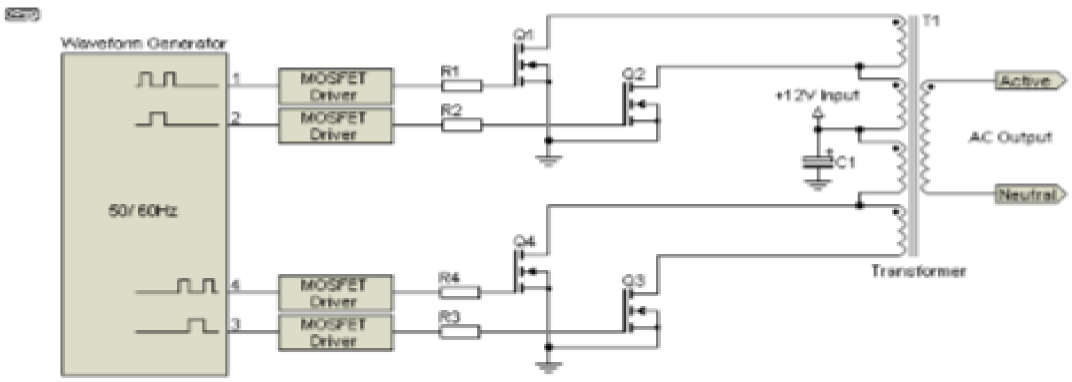

Figure 2.21: Modified Sine wave Inverter Circuit Diagram

By definition there is no restriction on the type of AC waveform an inverter might produce that would find use in a specific or special application.

The AC output frequency of a power inverter device is usually the same as standard power line frequency, 50 or 60 hertz. If the output of the device or circuit is to be further conditioned (for example stepped up) then the frequency may be much higher for good transformer efficiency.

The AC output voltage of a power inverter device is often the same as the standard power line voltage, such as household 120 VAC or 240 VAC. This allows the inverter to power numerous types of equipment designed to operate off the standard line power. The designed-for output voltage is often provided as a regulated output. That is, changes in the load the inverter is driving will not result in an output voltage change from the inverter. In a sophisticated inverter, the output voltage may be selectable or even continuously variable.

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2.5 REVIEW OF INVERTER SYSTEMS

PV systems have evolved over the years mostly due to modern discoveries in the field of semiconductors and power electronics. Today, electronics hobbyists can even design their own power electronic devices like power inverters/UPSs, charge controllers etc, thanks to modern PV modules, efficient solid state components and Integrated circuit chips that are made readily available in today’s market. In the course of this development, many people have done some good job in developing their own PV systems by designing their own power inverters/UPSs and charge controllers at cheaper rate and yet fairly efficient. Hobbyists in their designs generally make use of the components that they can lay their hands on and using the knowledge they have acquired from school and research works. An example of such work is a 600Watts pure sine wave inverter designed by MainaBenardMburu from University of Nairobi, Kenya (Figure 2.1). This inverter was designed and implemented to serve as a portable 600Watts that can convert a 12Volts Dc power from a battery bank to a 240Volts AC output that can be used to power electrical and electronic devices. Its sole purpose was to provide back-up power in places where power outage is mostly encountered. MainaBenardMburu in his design used a three level analogue PWM technique in conjunction with a microcontroller to generate a pulse width Modulated sinusoidal

Fig. 2.22: 600Watts Pure Sine wave Inverter

Another reputable work which was titled "DC/AC Pure Sine Wave Inverter" shown in Figure 2.2 below was carried out by three students from Worcester Polytechnic Institute: Jim Doucet, Dan Eggleston and Jeremy Shaw. The work was a prototype of a DC/AC Pure Sine wave Inverter which was meant to deliver a pure sine wave AC power at a given power rating. It was basically designed to serve as an affordable and efficient household backup power supply for power outage prone areas in the country.

The design was based on DC-DC converter and PWM sine wave design topology. In their design, they tried to reduce the overall size of the entire inverter system by making use of a DC-DC converter which allows the use of high frequency much reduced size transformer. The design was such that the low voltage power from a battery is first stepped up to a high voltage DC using a DC-DC converter after which the high voltage DC is converted to AC output voltage using the three level analog PWM technique, a H-bridge and a low pass passive filter. One thing that is very remarkable about their design is its reasonable simplicity, reduced cost and much reduced size when compared to many similar designs in today's market. The finished work under test is shown in the picture below [2].

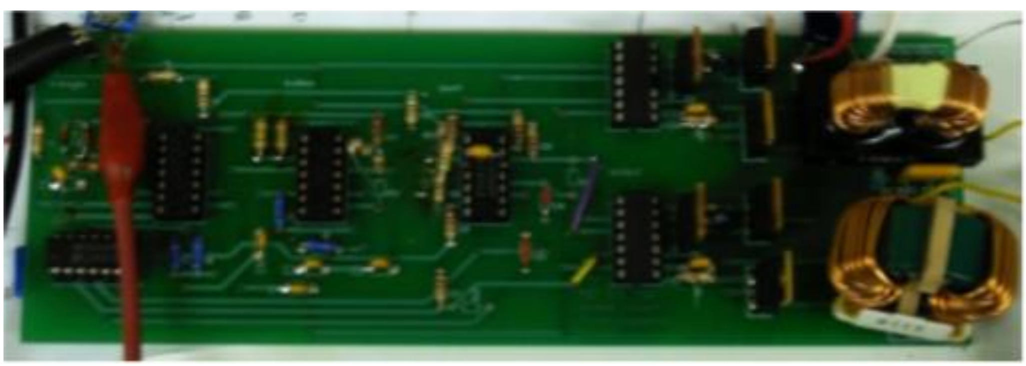

Figure 2.23: DC/AC Pure Sine Wave Inverter

In another work titled "DC-AC/DC Inverter shown in Fig. 2.3 below was carried out by a team of five personnel; Matthew Brown, Henry Brown, John Martinez, Dylan Paiton and Matthew Paiz. Their design, "An intelligent DCDC/AC converter system" was designed and implemented in the spring of 2010 for New Mexico Tech's Junior Design Class. The intelligent converter draws power from two energy harvesters; a 400W-12V Sunforce Wind Generator and a 60W-12V Sunforce Solar PV kit. The power is stored in an Optima 12V sealed lead acid battery. The inverter comprised of five major subsystems: smart battery charger, inverter, measurement system, data logger and internet interface. Components were selected through decision matrices and purchased. Circuits were designed in Protel 99SE and created from etching and milling processes. Data was sent via HTTP to the EE server on the NMT campus and displayed real time information on a web page. Operation of each subsystem was demonstrated independently and in whole.

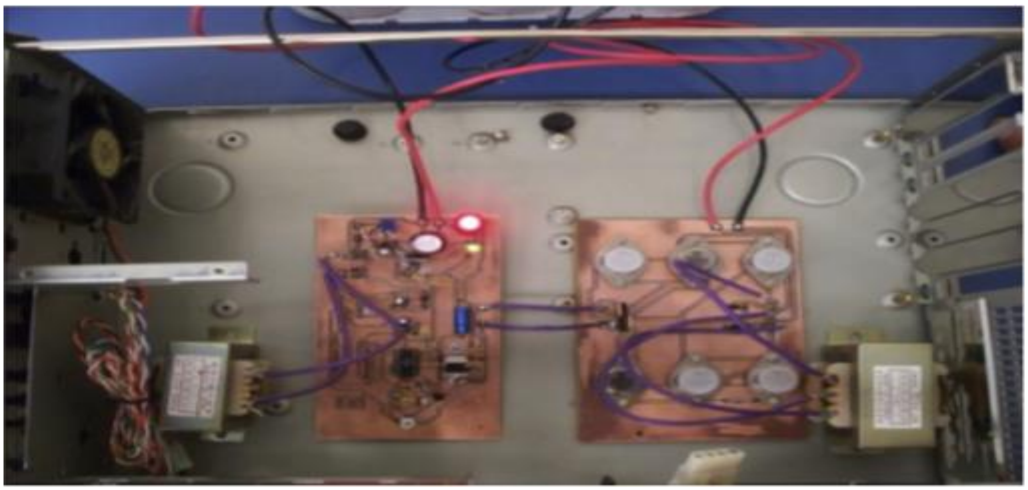

Figure 2.24: Intelligent DC/AC Converter system

Unlike the other designs, this work included an intelligent subsystem; the data logger which is used to transmit real-time information on the voltage and current status/values of the various parts of the entire system as well as the voltage and current characteristics being delivered to the loads and that of the batteries and energy harvesters over the internet to the monitoring unit.

2.6.4 Applications of inverters

• DC power source utilization

• Photovoltaic power systems

- Uninterruptible power supplies
- Induction heating
- High-voltage direct current (HVDC) power transmission
- Variable-frequency drives
- Electric vehicle drives
- Electroshock weapons
- Electric motor speed control
- Etc.

2.7 BATTERY

A battery is a combination of several electrochemical cells either in parallel, series or a combination of both that is capable of providing a direct current electricity using a chemical process between two electrodes and a chemical compound. A battery is an electrical storage device. Batteries generally do not produce electricity; they only store and release electricity and are rated according to their voltage (V) and capacity to store electric charge (Q = It in Amp-hours (Ah)). The voltage rating of a battery indicates the maximum electromotive force (E.M.F in Volts) the battery can supply whereas the capacity indicates the quantity of electricity (in Coulombs (C)) that the battery can give out under standard conditions. Batteries are generally classified into two types: Primary cell (non-rechargeable) and Secondary cell (rechargeable) batteries. The chemical energy in primary batteries cannot be replenished ones they are used up but that of secondary batteries can be replenished after they used up by passing a direct current to the battery (i.e. Recharging the rechargeable battery). Rechargeable batteries are mostly used in long term applications and for flexibility: allowing the reuse of the battery for a repeated number of times during its useful life.

2.7.1 Classification of Batteries

Batteries can be classified in a number of ways based on:

1. Rechargeability – Primary or Secondary

2. Chemistry – Lead acid, Lithium-ion-polymer (LiPO), Nickel-Cadmium (NiCd), Nickel-iron (NiFe), Nickel-metal-hydride (NiMH), Lithium-ion (Li-ion), Alkaline, Galvanic cell, Daniel cell, Leclanché cell, Dry cell batteries, etc.

3. Application – Cranking (Starting), Marine, and Deep cycle batteries.

4. Construction – Flooded (wet), Absorbed Glass Mat (AGM), and Gel batteries.

5. Maintainability – Maintenance and Maintenance-free (Valve Regulated (VR)) batteries.

6. Etc.

Primary cell/batteries are mostly classified according to their chemistry and packaging features. Shown in Fig. 2.14 below are different types of primary cell/batteries based on their different packaging styles.

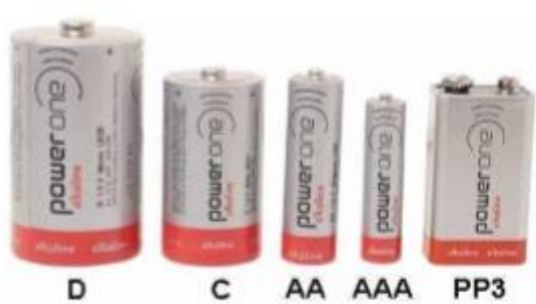

Figure 2.25: Primary Cell Types.

Nearly all large rechargeable batteries in common use are Lead-Acid type. In lead acid batteries, the acid is typically 30% Sulphuric acid and 70% water at full charge. Lead acid batteries are generally classified based on maintainability, application and construction. In stand-alone PV systems, maintenance-free (valve regulated) AGM deep cycle batteries are used.

Batteries do not make electricity; they store it, just as a water tank stores water for future use. As chemicals in the battery change, electrical energy is stored or released. In rechargeable batteries this process can be repeated many times. Batteries are not 100% efficient though- some energy is lost as heat (due to the internal resistance of the battery) and chemical reactions when charging and discharging. If one uses 1000 watts from a battery, it might take 1050 or 1250 watts or more to fully recharge it. Part or most of the losses in charging and discharging batteries is due to internal resistance. This is converted to heat which is why batteries get warm when being charged up. The lower the internal resistance of a battery is, the better. Slower charging and discharging rates are more efficient. A battery rated at 180 amp-hours over 6 hours might be rated at 220 Ah at the 20-hour rate, and 260 Ah at the 48-hour rate. Much of this loss of efficiency is due to higher internal resistance at higher amperage rates - internal resistance is not a constant - kind of like "the more you push, the more it pushes back". Typical efficiency in a lead-acid battery is 85-95%, in alkaline and NiCad battery it is about 65%. True deep cycle AGM (such as Concorde and Genus) can approach 98% under optimum conditions, but those conditions are seldom found so you should figure as a general rule about a 10% to 20% total power loss when sizing batteries and battery banks. Practically all batteries used in PV and all but the smallest backup systems are Lead-Acid type batteries. Even after over a century of use, they still offer the best price to power ratio.

2.7.2 Battery lifespan

The lifespan of a deep cycle battery will vary considerably with how it is used, how it is maintained and charged, temperature, and other factors. In extreme cases, it can vary to extremes.

Below are some typical (minimum - maximum) typical expectations for batteries if used in deep cycle service. There are so many variables, such as depth of discharge, maintenance, temperature, how often and how deep cycled, etc. that it is almost impossible to give a fixed number.

Starting: 3-12 months

Marine: 1-6 years

Golf cart: 2-7 years

AGM deep cycle: 4-8 years

Gelled deep cycle: 2-5 years

Deep cycle (L-16 type etc.): 4-8 years

Rolls-Surrette premium deep cycle: 7-15 years

Industrial deep cycle (Crown and Rolls 4KS series): 10-20+ years.

NiFe (alkaline): 5-35 years

NiCad: 1-20 years

2.8.3 Starting, marine, or deep-cycle batteries

- Starting (sometimes called SLI, for starting, lighting, ignition) batteries are commonly used to start and run engines. Engine starters need a very large starting current for a very short time. Starting batteries have a large number of thin plates for maximum surface area. The plates are composed of a Lead "sponge", similar in appearance to a very fine foam sponge. This gives a very large surface area, but if deep cycled, this sponge will quickly be consumed and fall to the bottom of the cells. Automotive batteries will generally fail after 30-150 deep cycles if deep cycled, while they may last for thousands of cycles in normal starting use (2-5% discharge).

- Deep cycle batteries are designed to be discharged down as much as 80% time after time, and have much thicker plates. The Deep Cycle battery's construction allows it to deliver energy for extended periods of time (deep cycle) without sustaining the life-shortening damage such use would cause to a standard automotive battery. It is designed to go through this cycle repeatedly.
- Marine batteries are usually a "hybrid", and fall between the starting and deep-cycle batteries, though a few (Rolls-Surrette and Concorde, for example) are true deep cycle. In the hybrid, the plates may be composed of Lead sponge, but it is coarser and heavier than that used in starting batteries.

2.7.4 Amp-hours rating

All deep cycle batteries are rated in amp-hours. An amp-hour is one amp for one hour, or 10 amps for 1/10 of an hour and so forth. It is amps x hours. If you have something that pulls 20 amps, and you use it for 20 minutes, then the amp-hours used would be 20 (amps) x .333 (hours), or 6.67 Ah. The generally accepted Ah rating time period for batteries used in solar electric and backup power systems (and for nearly all deep cycle batteries) is the "20 hour rate". (Some, such as the Concorde AGM, use the 24 hour rate, which is probably a better real-world rating). This means that it is discharged down to 10.5 volts over a 20 hour period while the total actual amp-hours it supplies is measured. Sometimes ratings at the 6 hour rate and 100 hour rate are also given for comparison and for different applications. The 6-hour rate is often used for industrial batteries, as that is a typical daily duty cycle. Sometimes the 100 hour rate is given just to make the battery look better than it really is, but it is also useful for figuring battery capacity for long-term backup amp-hour requirements.

2.7.5 Why amp-hours are specified at a particular rate

Because of something called the Peukert Effect. The Peukert value is directly related to the internal resistance of the battery. The higher the internal resistance, the higher the losses while charging and discharging, especially at higher currents. This means that the faster a battery is used (discharged), the LOWER the Ah capacity. Conversely, if it is drained slower, the Ah capacity is higher. This is important because some manufacturers and vendors have chosen to rate their batteries at the 100 hour rate - which make them look a lot better than they really are.

2.7.6 Peukert's law

Battery manufacturers often use specifications known as Amp Hours and Reserve Capacity to provide an indication of what a battery's storage capacity is. However, the problem with quantifying the storage capacity of a lead acid battery is that the amount of energy stored (and hence the amount of energy it can deliver) is dependent on the battery's discharge rate. The greater the discharge rate, the lower the delivered capacity. This phenomenon is well documented and is often known as Peukert's Law. Peukert, a German scientist, first presented this law in 1897 and provided an equation that helps to tell us what a battery capacity is based on the rate that it is being discharged.

` $t = H(\frac{C}{HI})^{K}$

The equation for peukert's law

- t – Time in hours. It is the time that the battery will last given a particular rate of discharge (the current).
- H – The discharge time in hours that the Amp Hour specification is based on. For example, if you had a 100 Amp Hour battery at a 20 hour discharge rate, H would equal 20.
- C – The battery capacity in Amp Hours based on the specified discharge time. For a 100 Amp Hour battery, this would be 100.
- I – This is the current that is been solved for. For example, if one wanted to know how long a battery would last while drawing 7.5 amps, one would enter it here.
- k – The Peukert Exponent. Every battery has its own Peukert exponent. Sometimes the manufacturer will provide it and other times one may need to figure it out.

2.7.8 Peukert exponent for a particular battery

It is different from battery to battery. Worse, many manufacturers do not readily publish a Peukert's exponent. Nevertheless, there are some general ranges for the different kinds of lead acid batteries that can be used for estimation purposes.

- AGM batteries range between 1.05 and 1.15
- Gel batteries range between 1.1 and 1.25
- Flooded batteries range between 1.2 and 1.6

  If more accurate estimates are required, it is possible to calculate the Peukert exponent from most battery manufacturer specifications.

2.7.9 Peukert's law limitations

Peukert's law is a valuable tool for estimation. However, it has limitations. Among them are:

- The effect that temperature has on batteries is not included in the equation.
- Battery age is not considered. The Peukert exponent increases with battery age.
- If one is calculating for a low discharge rate, the equation does not account for the fact that each battery has a self-discharge rate.

All that said, in terms of estimation, Peukert's law gets us much closer to estimating real world performance of a battery than simple extrapolations of the amp hour rating.

An important fact is that ALL of the batteries commonly used in deep cycle applications are Lead-Acid. This includes the standard flooded (wet) batteries, gelled, and AGM. They all use the same chemistry, although the actual construction of the plates etc. varies. Below in Fig. 2.26 is the internal make up of a typical lead acid battery.

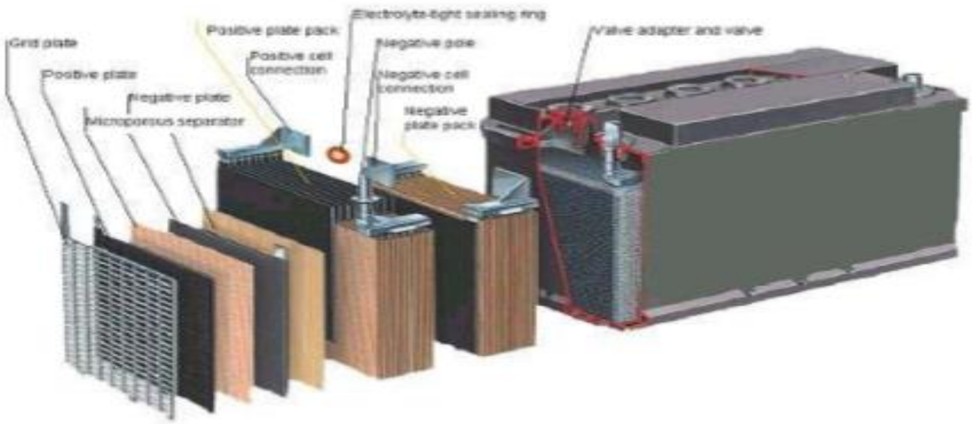

Figure 2.26: Internal Make-up of Lead Acid Battery

2.7.10 Battery chemistry

Every lead acid battery no matter the type is made up of three basic components; the sulphuric electrolyte, the anode and the cathode. The electrolyte is made of sulphuric acid and water solution usually in the ratio of 30% to 70% respectively. The anode is made of lead oxide or lead antimony while the cathode is made of pure lead plates. Both the anode and cathode are moulded into a thin flat grid to increase the surface area as well as to reduce the overall physical size of the whole battery. The anode and the cathode are completely immersed in the electrolyte and are separated with a non-conductive material that does not deteriorate in the acidic electrolyte (Fig. 2.15).

2.7.11 Battery discharging

In the discharged state both the positive and negative plates become lead (II) sulphate (PbSO4) and the electrolyte loses much of its dissolved sulphuric acid and becomes primarily water. The discharge process is driven by the conduction of electrons from the negative plate back into the cell at the positive plate in the external circuit. The equations below shows the chemical reactions that take place at cathode and the anode of a lead acid battery during discharge respectively.

Negative plate reaction: $Pb(s) + HSO_4^-(aq) \rightarrow PbSO_4(s) + H^+(aq) + 2e^-$

Positive plate reaction: $PbO_2(s) + HSO_4^-(aq) + 3H^+(aq) + 2e^- \rightarrow PbSO_4(s) + 2H_2O(l)$

The total reaction can be written as: $Pb(s) + PbO_2(s) + 2H_2SO_4(aq) \rightarrow 2PbSO_4(s) + 2H_2O(l)$

2.7.12 Battery charging

The charging process in rechargeable batteries simply involves the passing of current in the opposite direction as done when discharging. Hence, during the charging process, the reverse of the discharge reactions take place at both plates

$$\underset{\text{positive plate}}{PbO_2} + \underset{\text{negative plate}}{Pb} + 2H_2SO_4 \underset{\text{charge}}{\overset{\text{discharge}}{\rightleftarrows}} 2PbSO_4 + H_2O$$

(anode and cathode). The general charge and discharge equation is thus represented as shown in the equation below:

Overcharging with high charging voltages generates oxygen and hydrogen gas by electrolysis of water, which is lost to the cell. Periodic maintenance of lead–acid batteries requires inspection of the electrolyte level and replacement of any water that has been lost. Due to the freezing-point depression of the electrolyte, as the battery discharges and the concentration of sulphuric acid decreases, the electrolyte is more likely to freeze during winter weather when discharged.

Battery charging takes place in 3 basic stages: Bulk, Absorption, and Float.

- Bulk Charge: The first stage of 3-stage battery charging. Current is sent to batteries at the maximum safe rate they will accept until voltage rises to near

(80-90%) full charge level. Voltages at this stage typically range from 10.5 volts to 15 volts. There is no "correct" voltage for bulk charging, but there may be limits on the maximum current that the battery and/or wiring can take.

- Absorption Charge: The 2nd stage of 3-stage battery charging. Voltage remains constant and current gradually tapers off as internal resistance increases during charging. It is during this stage that the charger puts out maximum voltage. Voltages at this stage are typically around 14.2 to 15.5 volts. (The internal resistance gradually goes up because there is less and less to be converted back to normal full charge).
- Float Charge: The 3rd stage of 3-stage battery charging. After batteries reach full charge, charging voltage is reduced to a lower level (typically 12.8 to 13.2) to reduce gassing and prolong battery life. This is often referred to as a maintenance or trickle charge, since its main purpose is to keep an already charged battery from discharging. PWM, or "pulse width modulation" accomplishes the same thing.

2.7.13 Battery aging

As batteries age their maintenance requirements change. This means longer charging time and/or higher finish rate (higher amperage at the end of the charge). Usually older batteries need to be watered more often (for vented maintenance batteries). And, their capacity decreases while the self-discharge rate increases [19], [20].

In this project, the battery bank was designed with deep cycle rechargeable AGM lead acid batteries so that the batteries' energy can be replenished during the day through the PV modules and the stored energy utilized at night and due to its durability and maintainability.

CHAPTER 3

DESIGN AND METHODOLOGY

3.1 METHODOLOGY

In this chapter, the various components that make up this project will be carefully examined. This project consists of a microcontroller based circuit board enclosed in a sheath metal casing. The heart of this project is a microcontroller from the microchip family (PIC16F8763A). It is a flash based 8-bit microcontroller with 28 pin package. It has 128 byte of EEPROM data memory, 5 channels of 10 bit analog to digital converters, synchronous serial port serial peripheral interfaces, universal asynchronous receiver transmitter (UART), Inter-integrated circuits (I^2C). It is ideal for automotive, industrial appliances, consumer applications.

Outline of methodology

- Design Objectives
- Design Considerations
- Design Specifications
- Hardware design
- Integration of all the subsystems that make up the whole PV power system.

3.2 DESIGN OBJECTIVES

i. To design an inverter that can output a pure sine waveform.

ii. To design an inverter that is affordable and reliable.

iii. To design an inverter that is efficient.

iv. To design an inverter that is safe for both the loads and the consumer.

v. To add smart functionalities to the inverter such as automatic changeover, etc.

3.3 DESIGN CONSIDERATION

In the design of the PV system, so many factors were duly considered but the most crucial factors that were stringently taken into consideration include but not limited to the following:

i. Cost:

In every design, cost is one of the major factors to be considered especially when the design is meant for consumers in a known market. In our design, the cost of the materials used were closely considered and well optimized without trading off their quality and reliability. Every component used in the design was selectively chosen to suit the above enlisted objectives without tampering with any of the desired feature of the system.

ii. Availability of the Required Components:

While making the choice of components to be used in the design, it is also non-trivial to consider their availability in the market so as to ensure that the project design meets up with the expected time frame of its delivery, because when the needed components required for a design is readily available in the nearest market, it reduces the lead time (i.e. the time it takes to deliver the components to the user) and hence reduces the overall time taken to fully actualize the project design.

iii. Reliability and Performance Efficiency of Components:

The use of simple but durable components was solely to avoid the complexity that is associated with too many complex components that often lead to system losses and inefficiency; all of which affects the system's performance, reliability, ease of design and implementation as well as the system's efficiency. Having reliability and efficiency at heart, superfluity and unnecessary redundancy was duly avoided to keep the system design simple and affordable. The choice of 59 components used in the design was made having the objectives and the other design consideration in mind.

3.4 DESIGN SPECIFICATION

The under listed specifications were the basis of the project design. They were used as a guide during the entire design process.

i. System Capacity (Output Power): 5000VA (5KVA)

ii. Type of output Waveform: Pure Sine wave AC power

iii. Output Voltage: 220Volts

iv. Output Frequency: 50Hz

v. Battery Bank Capacity: 48Volts/400Ampere-hour

vi. PV Modules Specification: 300Watts/24Volts/6Amperes

vii. Charge Controller Specifications: PWM charge controller rated at 48Voltage/40Amperes.

3.5 THE DESIGN OF 5KVA PURE SINE WAVE INVERTER SYSTEM

This design of a homemade inverter system was made to provide affordable and reliable alternative power to the common man. It was necessary in other to make power readily available where needed for any intended purpose. In the design of the power inverter, some factors and specifications were taken into consideration to ensure that it meets the desired goal. The power inverter was designed to supply a maximum power of 5000watts at 220Volts AC of electricity with minimal losses. Some of the factors that were taken into consideration in the design included but not limited to the following:

i. The kind of loads to be powered; inductive, capacitive, resistive or a combination of any of the three.

ii. The maximum possible surge power that can be encountered especially from inductive loads: This helped to make provision in the design for the maximum possible power surge that can come from any connected inductive load/loads.

iii. The sensitivity of the loads to be powered: this is one the reasons why the power inverter was designed to supply pure sine wave AC power which can swiftly power any type of electrical loads; even some medical and laboratory equipment.

The power inverter comprises of several sub circuits: the oscillator circuit (the PWM controller), MOSFET driver, output Amplifier, AC battery charger, automatic changeover, and the transformer; these are depicted in Fig. 3.11 below.

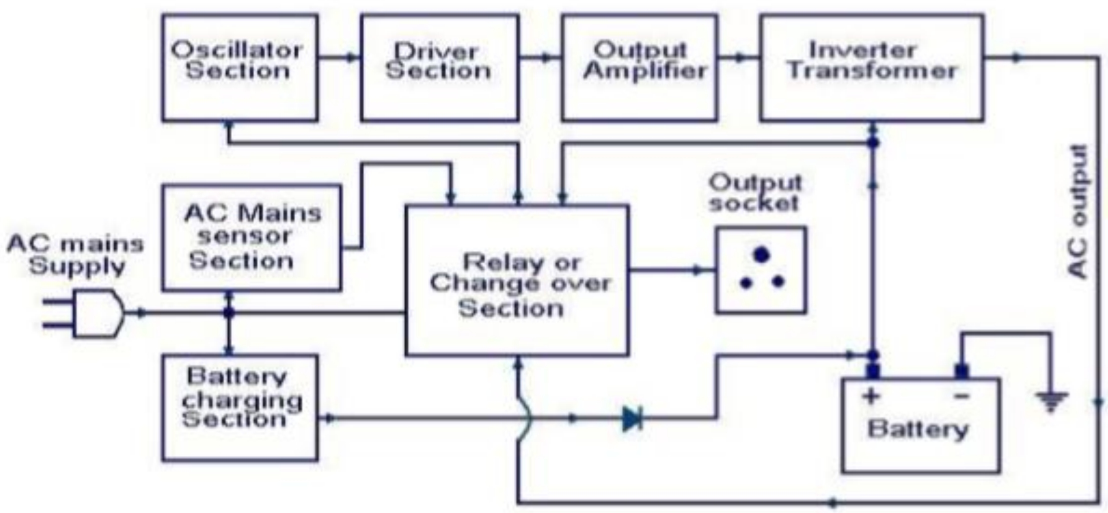

Figure 3.1: Block Diagram of a Basic Inverter

The block diagram shown above depicts the several components/subsystems that make up a functional PWM power inverter. Each of the subsystems is explained below [2].

3.5.1 THE OSCILLATOR/PWM CONTROLLER (THE SIGNAL GENERATOR)

The oscillator/PWM controller comprises of electronic circuitries that are responsible for generating the sinusoidal control signal that is used to drive the output amplifier stage in the inverter. The control circuit in this pure sine wave inverter is designed using a Microcontroller. One advantage of this inverter is the use of a low cost microcontroller that has built in PWM modules. In this project, PIC16F876A was used that was able to store required commands to generate the necessary PWM and square waveforms. In PIC16F876A there are 28 pins each with different functions. PORT C has two outputs that produce PWM while PORT B is driven high and low to give a square wave.

The microcontroller (Fig. 3.12) is tasked with generating the four control signals to drive two MOSFET drivers. They are two 50Hz square waves, each at 180^0 phase angle of each other, and two 2-level, 2 kHz pulse width modulation signals operating at a switching frequency of 50Hz also at 180^0 phase angle of each other.

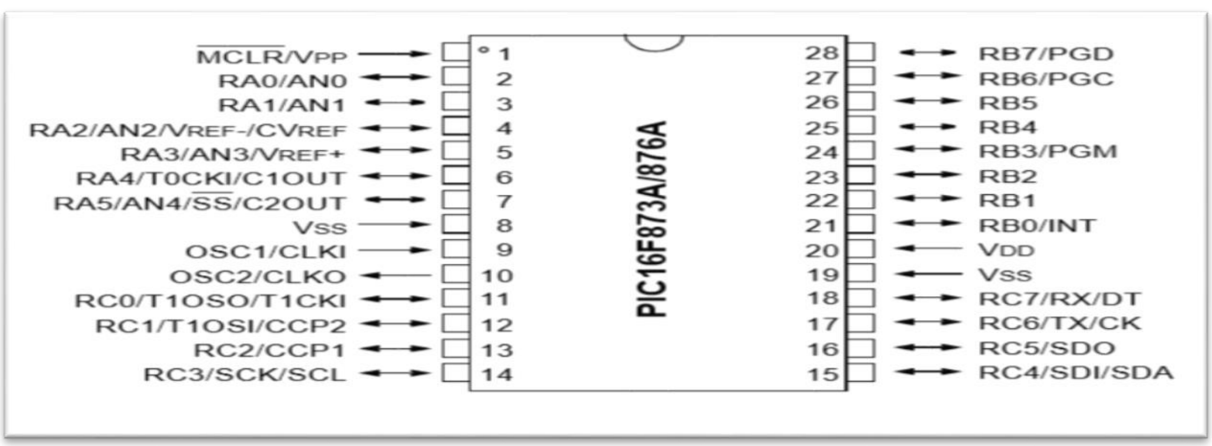

Figure 3.2: PIC16f876A pin-out

The characteristics of the make-up signals of the PWM signal are listed as follows: Carrier frequency (C) = 2 kHz, message frequency (M) = 50Hz

A delay of 305us was introduced to prevent one side of the H-Bridge switches being on at the same time.

The following steps were taken when configuring the CCP module for PWM operation:

- Set the PWM period by writing to the PR2 register.
- Set the PWM duty cycle by writing to the CCPR1L register and CCP1CON
- Make the CCP1 and CCP2 pins an output by clearing the TRISC
- Configure the CCP1 and CCP2 modules for PWM operation.

These steps were summarized in a flow chart as shown in Fig. 3.13 below.

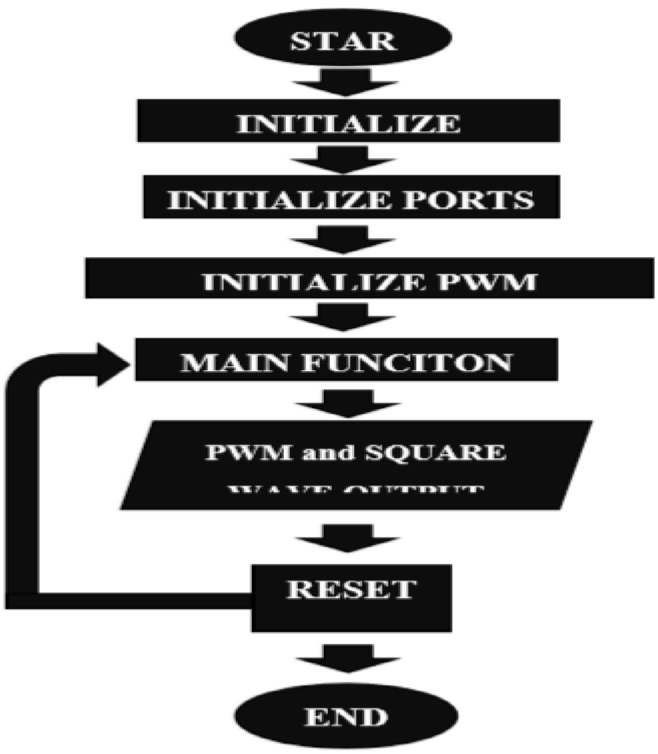

Figure 3.3: Flowchart of the PWM Program

A program (MIKROC PRO for PIC) was used to write the PIC code for the flowchart in Fig. 3.13. The written PIC code is attached in appendix (B). A 12V dc from the battery was fed to the microcontroller through a 5V constant regulator with ac filter capacitors at both input and output side. The capacitor values were obtained from 7805 regulator datasheet.

The microcontroller was clocked with an external clock of 8MHz which was grounded using capacitors whose values were obtained from PIC16F876A datasheet. The High PWM and Square wave output were obtained from pins CCP1 and RB1 while Low PWM and Square wave were obtained from pin CCP2 and RB2 respectively.

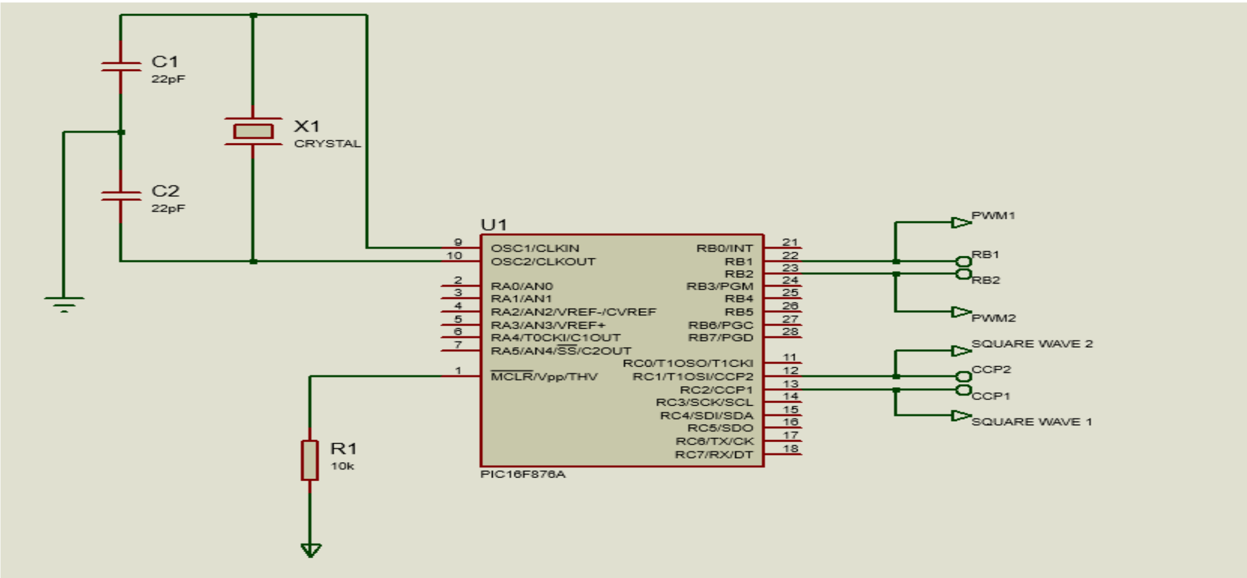

Figure 3.4: Microcontroller Signal Generator

3.5.2 MOSFET drivers

The IR2112 High and Low Side MOSFET Driver exceed all requirements for driving the MOSFETs in the bridge. Each of the MOSFETs used in the design is capable of handling up to 75V at a current rating of 140A at fast switching speeds. The MOSFET driver is required to drive the high side MOSFETS in the circuit designated HO, due to the fact that the gate to source voltage must be higher than the drain to source voltage, which is the highest voltage in the system. With a full bridge configuration, two of these devices are utilized, as shown in figure 3.15

below. A typical connection of a single IRF3808 device is shown in the Fig. 3.15 below.

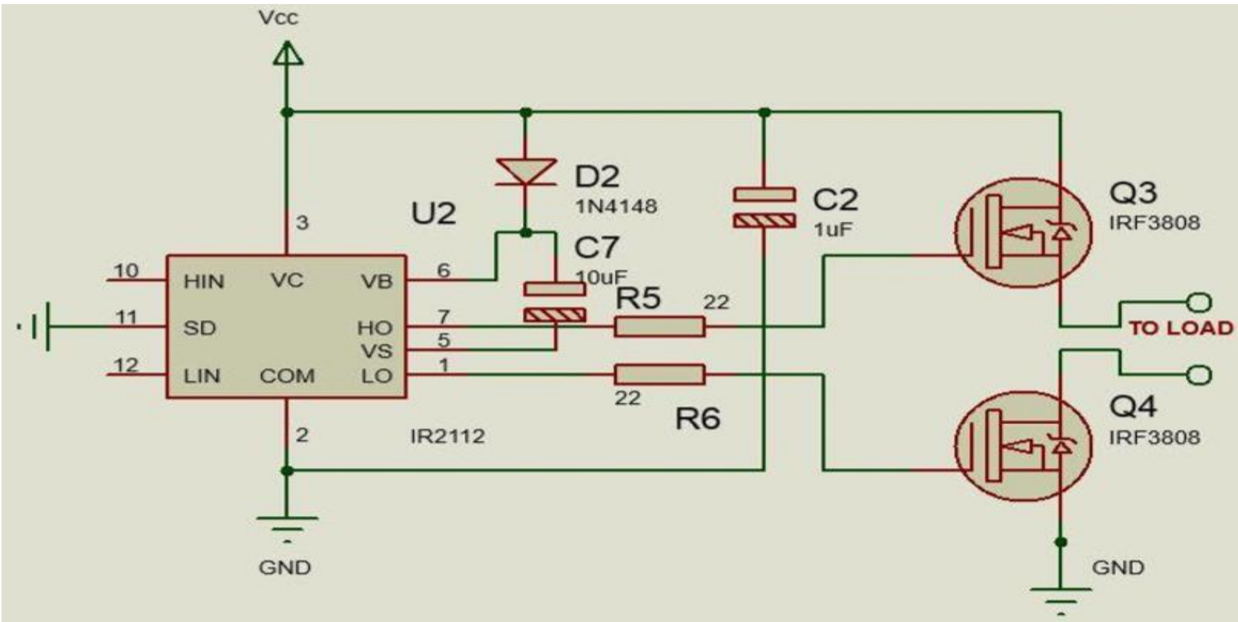

Figure 3.5: MOSFET driver connection

Operation of the IR2112 device is controlled through generated PWM and square signals. The PWM and square signals will be fed to the HIN and LIN pins simultaneously. If the internal logic detects a logic high, the HO pin will be driven; if a logic low is detected, the LO pin will be driven. The SD pin controls shut down of the device and will be unused and tied to ground. Additional pins that require external connections are the Vss pin which will be tied to ground, the Vcc pin which will be tied to 48V, pins requiring connections to bootstrapping components and outputs to the MOSFETS. Bootstrapping capacitors and diodes will be connected as designated. The values for these components are calculated from International Rectifier’s AN978 application note.

3.5.3 The H-Bridge

Generating a sine wave centred on zero volts requires both a positive and negative voltage across the load, for the positive and negative parts of the wave, respectively. This can be achieved from a single source through the use of four MOSFET switches arranged in an H- Bridge configuration as shown in Fig. 3.16 below.

The IR2112 MOSFET driver integrated circuit was used for level translation between PWM and square signals and voltages required to forward bias high side

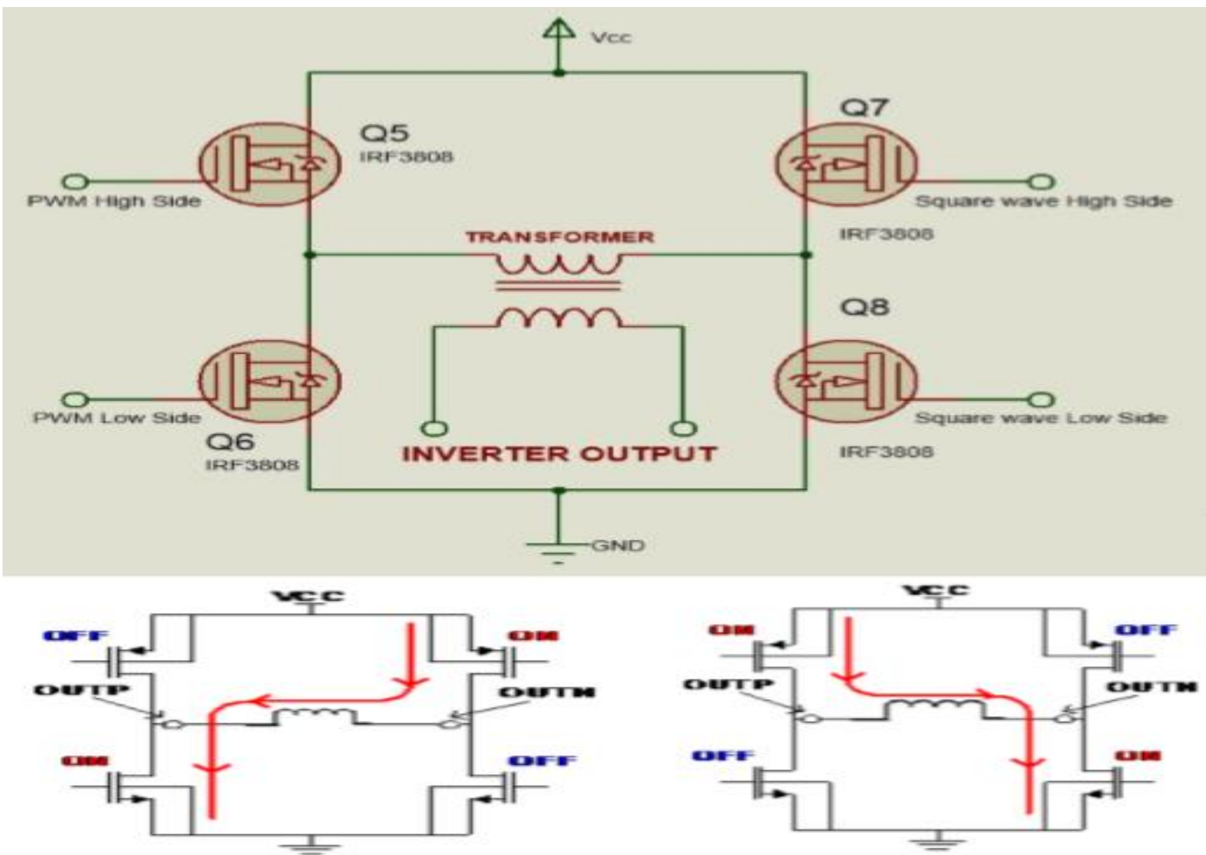

Figure 3.6: H-Bridge Configuration and Current Flow Pattern

N-Channel MOSFETS. To minimize power loss and utilize higher switching speeds, N-Channel MOSFETs were chosen as switches in the bridge.

Driving the four MOSFETs in an H-Bridge configuration allows +48, -48, or 0 volts across the load at any time. To achieve this, the left side of the bridge is driven by the PWM signals to determine whether the output voltage is non-zero or zero while the right side of the bridge is driven by the square wave signals to determine the polarity, either positive or negative. The MOSFETs used in the design are IRF3808 Power MOSFETs rated for 75V at 140A with power handling capability of 330W. A diagram of the H-Bridge circuit with MOSFETS and drivers is shown in Figure 3 below.

3.5.4 Output filter

The final component necessary to output a pure sine wave signal is an output filter. For our circuit, a basic LC low pass filter with the following setup below in Fig. 3.17 is needed.

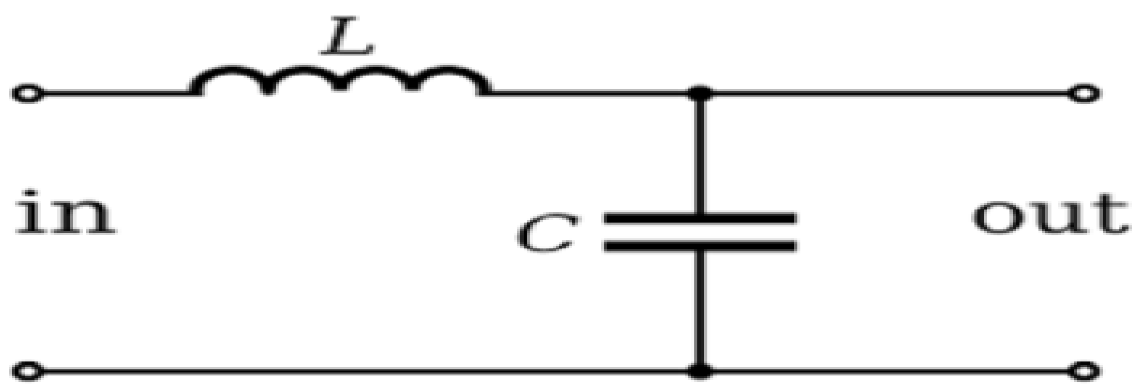

Figure 3.7: LC Low Pass Filter

This will filter out all the excess noise above the critical frequency. The goal for this was to bring the critical frequency as close as possible to the desired frequency of 50 Hz, removing other harmonics that crop up within the system. The slower the cut-off frequency, the greater the capacitance and inductance required to properly create the filter. Therefore, filter design becomes a trade-off between the effectiveness of the filter and the cost and size of the component. The output of the

H-bridge was ideally a 50Hz sine wave. Because it was encoded using a 2 kHz PWM signal it was to be filtered. Due to the high current expected to be sourced ((20*600w)/(240) = 50A by the load of our output, the only option Fig. 3.17: LC Low Pass Filter was a passive low pass filter, which is an inductor and capacitor in series, with the load connected across the capacitor designed for passing all signals under 50Hz.

$$Fc = \frac{1}{2\pi\sqrt(LC)} \quad \text{...... 3.1}$$

Using an inductor of 2.07H requires a capacitor of 4.5μFto obtain the required cut-off frequency. The closest capacitor value was 1uF was used. The selected inductor was to be able to handle at least 50A current and the capacitor at least 50V. A 48V/220V step up transformer was used to boost 48 volts to 220 volts. A capacitor of 1uF was placed at the output of the secondary coil to filter harmonic distortions.

3.5.5 MOSFET drivers and full H-bridge

The microcontroller outputs were used to control the MOSFETs Full H-Bridge through MOSFET drivers U1 and U2 whose pins connection was done as shown in Fig. 3.18 below as gotten from the IR2112 datasheet. C6 and C8 are stabilizing capacitors which filter all the ac currents. Their values were obtained from the datasheet. C1 and C7 are bootstrap capacitors whose values were calculated in the design. They are charged through diodes D1 and D2. The outputs of the MOSFET drivers were fed to the MOSFET gates through resistors R1, R2, R5 and R6 which controlled the MOSFET switching speed. Their values were obtained from the IR2112 datasheet. Resister R7, R8, R9 and R10 were used for discharging the MOSFETs' gate-source capacitance CGS to allow for proper MOSFET switching. The H-Bridge was powered by a 48V dc from the battery and the output was obtained between the outputs PWM and SQR.

Circuit Diagram Simulation:

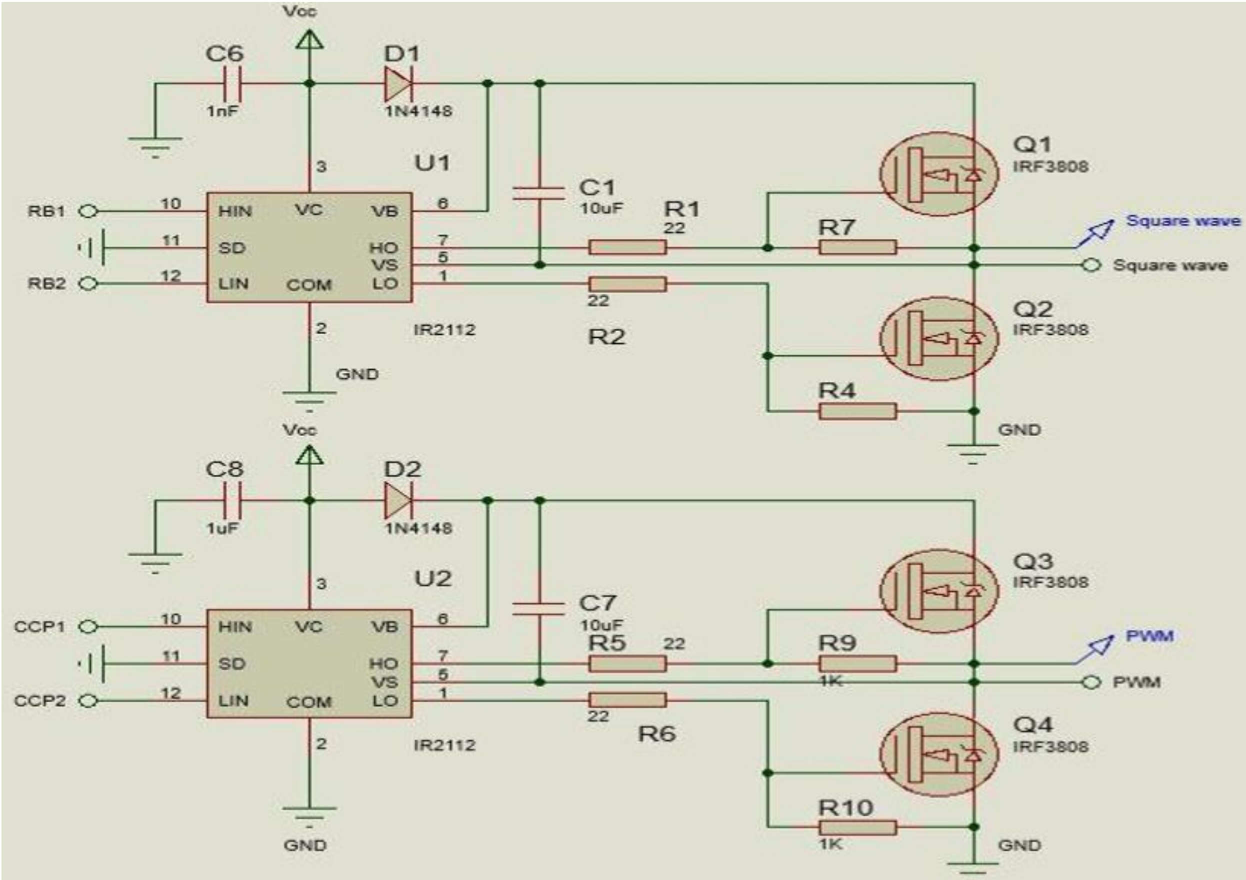

Figure 3.8: MOSFET Driver and Full H-Bridge Connection

3.5.6 Filter and boost transformer

The H-Bridge output was fed to a RL Passive Filter. The values of the inductor L1 and Capacitor C9 were as calculated in the design and was connected with the output transformer as shown in Fig. 3.19 below.

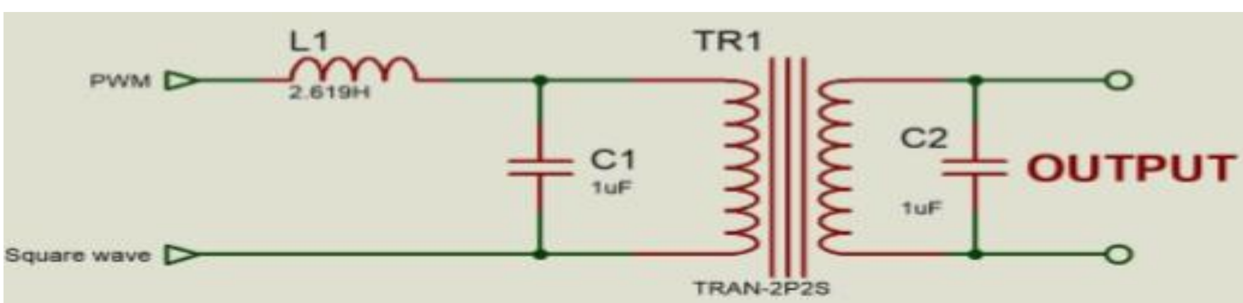

Figure 3.9: Low Pass Filter and Transformer Connection

The idea behind realizing digital-to-analog (D/A) output from a PWM signal is to analog low-pass filter the PWM output to remove most of the high frequency components, ideally leaving only the D.C. component.
This is depicted in Fig. 3.20 below. The bandwidth of the low-pass filter will essentially determine the bandwidth of the digital-to-analog converter.

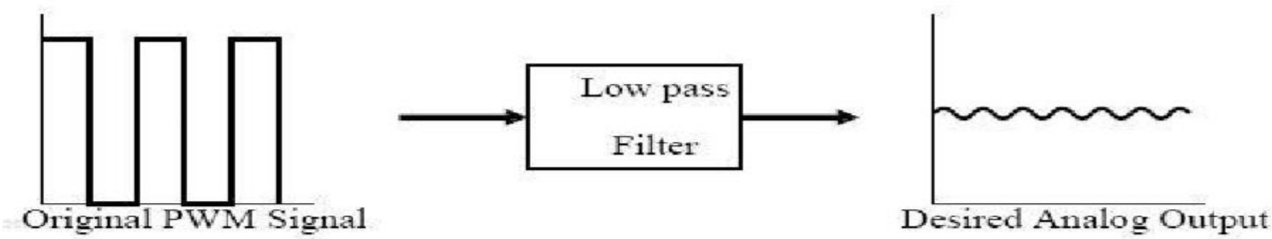

Figure 3.10: Low Pass Filter Description

The output of the Filter was boosted using a Step-up Transformer with a transformation ratio of 18.3. A capacitor C10 was placed at the output to filter the harmonics. Its value was obtained from a range given in the general transformer output stabilizers.

3.5.7 The complete sine wave inverter circuit

Shown in Fig. 3.21 below is the complete circuit diagram of the microcontroller based power inverter. As already said earlier, the microcontroller generates the PWM and square wave signals used to drive the MOSFET drivers that directly drive the H-bridge MOSFET channel. Through a 48V/220V step-up transformer, the pulse width modulated power form the 48V battery bank is transformed to 220V AC output as shown in the circuit diagram below [3].

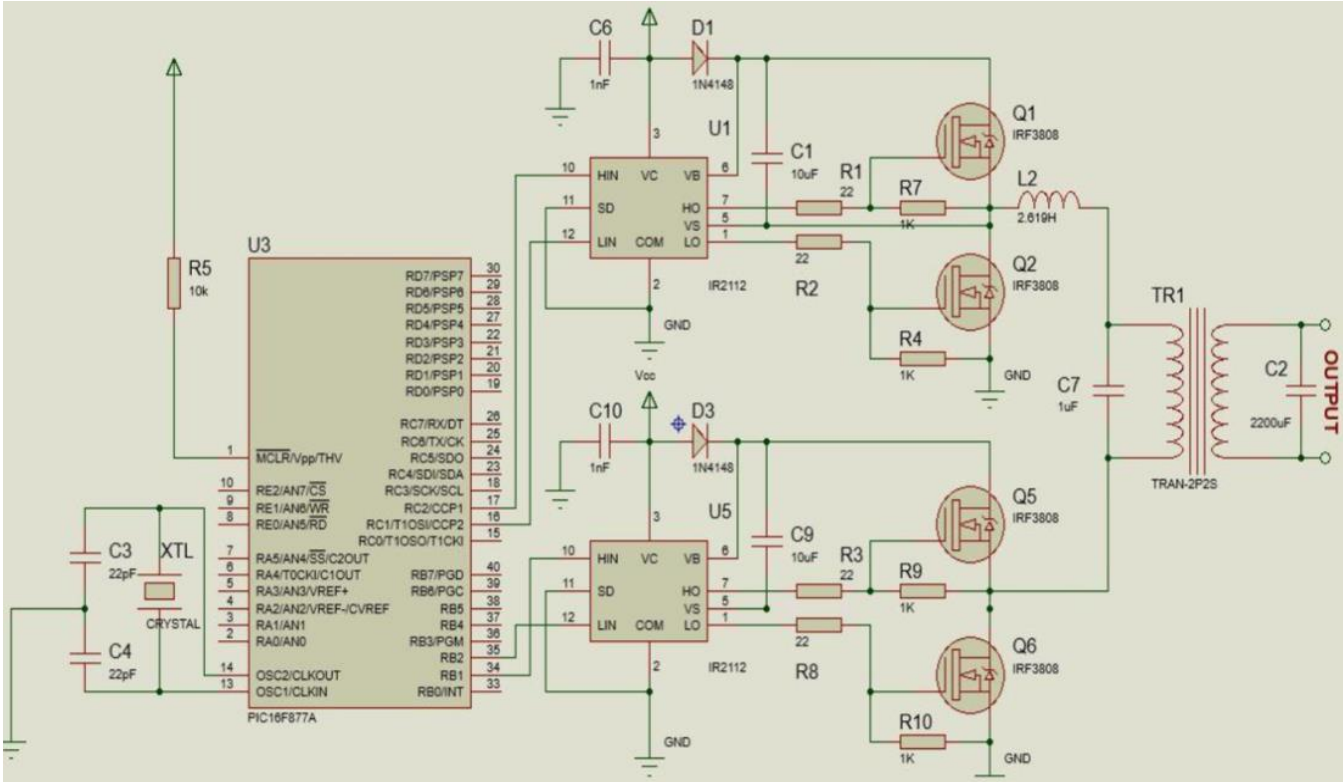

Figure 3.11: Complete Circuit Diagram for the Microcontroller-based PWM Inverter.

3.6 DESCRIPTION OF INVERTER COMPONENTS

The hardware design comprises of all the necessary design procedure, block diagram(s), theory, and design calculations of the basic components that make up the inverter system.

3.6.1 Transformer

A transformer is an electronic device which reduces or increases the voltage of an electric power supply. It consists of two inductive coils which are electrically separated but magnetically linked through a path of flow reluctance. The two coils posses high mutual inductance if one coil is connected to a source of alternating fix is set in the laminated core, most of which it produces. If the second coil circuit flows in it and so electric energy is transferred from the first coil in which electric energy is fed from AC supply mains is called primary winding and the other from which supply is drawn off is called secondary winding.

Transformer design

$A = \sqrt{P}$

Where:

A = cross-section of the core

P = power of the transformer required

P = 5000W (given)

$A = \sqrt{5000} = 70.7\ cm^2$

We use the transformer of $(8.4 \times 9)\ cm^2$

Therefore Area = $8.4 \times 9 = 75.6\ cm^2$ which is a good match for the transformer.

Turns calculations for a sine wave voltage supply, the fundamental of all the transformer equations is:

$E = 4.44NFAB_{max}x10^{-8}$

Where:

E = applied voltage at the primary side

N = number of turns

A = cross-sectional area of the magnetic core

B_{max} = maximum flux density of the core (in gauge)

From core manufacturer data sheet,

The B_{max} ranges from 1200 – 1800 gauge

For best performance, 1200 gauge has been chosen for this design.

To calculate the voltage per turns of the primary of the transformer, the above EMF equation can be modified.

$E = 4.44NFAB_{max}x10^{-8}$

Dividing both sides by N,

$E/N = 4.44FAB_{max}x10^{-8}$

Where:

E/N = voltage per turn

For this transformer, the input parameters include,

Frequency = 50Hz

Power = 5000W

Area = 70.7cm^2

Primary voltage = 48V

Secondary voltage = 220V

Maximum flux density of the iron core = 1200 gauge (from core data sheet)

$E/N = 4.44 x 50 x 70.7 x 1200 x 10^{-8} = 1.88V/T$

Therefore, voltage per turn = 1.88V/T

Primary turns calculation:

Number of turns of the primary to give 48V can be calculated from the voltage per turn.

If the voltage per turn = 1.88

That is, 1 turn = 1.88V

Number of turns to give 48V = 48/1.88 = 25.5 = 26 turns

Secondary turns calculation

The secondary turns can be calculated from the equation below:

$E_p/E_s = N_p/N_s$

$48/220 = 26/N_s$

$N_s = 26x220/48 = 5720/48 = 119$ turns

3.6.2 Capacitors

A capacitor is a device for storing electric charges; it consists of parallel plates separated by a dielectric.

The capacitors used in this circuit are numerous, but only perform two functions:

1. For stray inductance cancellation at the primary to prevent MOSFET destruction by spike.
2. For filtration of the secondary, that is recovering of the spurn of the secondary of the transformer

The capacitor used at the secondary help in the removal of carrier frequency and noise from the output voltage allowing a pure 50Hz sine voltage to be outputted.

The capacitor is rated 2.2µF, 400V.

3.6.3 Resistors

A resistor is a device which opposes the free flow of current in a circuit. A large number of resistors were used in this circuit, but the major functions are:

1. For current limiting to some fragile components (microcontroller and LM7805 regulators)
2. As potential divider for voltage referencing and sensing at the ADC inputs of the microcontroller

3.6.4 Relay

A relay is an electromagnetic switch whose contact or set of contacts open or closes when a signal (voltage) is applied.

The contacts of a relay can be either normally open (NO) or normally closed (NC).

When a signal is applied to a relay, it is said to be energized. When a relay is energized, the contacts changes state. That is, normally closed becomes normally open and vice versa.

The function of the relay in this project is to carry out the following functions:

Automatic change over from mains to inverter and from inverter to mains based on the decision taken by the microcontroller. For instance,

a. When mains is present and the value is within the specified window (>140 and <255) the microcontroller sends a change over signal to the relay to accept the mains and start charging the battery.

When the mains is higher than 255V, the inverter protect the loads and itself by changing from mains to inverter mode.

3.7 Theory, Design Procedure and Calculation on the Photovoltaic System

The design of the 5KVA photovoltaic system followed some specified projected, backed with validated theory of operation and meticulous calculations. These theories, procedure and calculation are described with respect to the system component.

3.7.1 Solar modules

We could not possibly design and manufacture the solar panel by on our own, we checked and considered so many parameter before procuring one. Based on the efficiency of various types solar available in the market, we choose mono-crystalline photovoltaic panel. After testing, its efficiency is 14.61%.

Below is a brief description of how to calculate the peak efficiency of a solar panel.

- Determine the surface area of the panel by multiplying the length by the width. Our 245W Mono panel is 1675 mm long by 1001 mm wide or 1,676.67 square meters. The surface area is aperture area of the solar panel, therefore, this does include the frame.
- We pulled the name plate rating of the panel from the datasheet.
- At STC the watts per meter squared (W/m^2) is 1,000 W/m^2. This is the standard used to determine how many watts of power are produced in a

square meter on earth. Temperature is always a factor in the output of a panel so STC assumes less than 25 degrees C.

- Divide the name plate rating by the square meters at 1000 W/m² to get the solar panel efficiency. In our case, for the SW 245 mono (245/1.676.67)=14.61% efficiency
- We ensured to look at the power tolerance as although the name plate rating might be 245W, the power tolerance will tell you how many more or less Watts at the STC the panel produce. In this case, the SW 245 Mono have a power tolerance of -3%/+3%.

The solar cell peak efficiency might be a few percentage points higher when tested at STC. Those points of efficiency are lost in the movement of energy from the cell to the output of the module.

3.7.2 Array Mounting Racks

Arrays are most commonly mounted on roofs or on steel poles set in concrete. In certain applications, they may be mounted at ground level or on building walls. Solar modules can also be mounted to serve as part or all of a shade structure such as a patio cover. On roof-mounted systems, the PV array is typically mounted on fixed racks, parallel to the roof for aesthetic reasons and stood off several inches above the roof surface to allow airflow that will keep them as cool as practical.

In our design, we used roof-mounted procedure. The solar panel is design to be mounted on the roof of the target building to ensure maximum exposure to sunlight.

3.7.3 Grounding Equipment

Grounding equipment provides a well-defined, low-resistance path from your system to the ground to protect your system from current surges from lightning strikes or equipment malfunctions. Grounding also stabilizes voltages and provides a common reference point. The grounding harness is usually located on the roof. All system components and any exposed metal, including equipment boxes, receptacles, appliance frames and PV mounting equipment, should be grounded.

3.7.4 System Grounding

System grounding requires taking one conductor from a two-wire system and connecting it to ground. In a DC system, this means bonding the negative conductor to ground at one single point in the system. This must be accomplished inside the inverter, not at the PV array.

3.7.5 Combiner

Wires from individual PV modules or strings are run to the combiner box, typically located on the roof. These wires may be single conductor pigtails with connectors that are pre-wired onto the PV modules. The output of the combiner box is one larger two wire conductor in conduit. A combiner box typically includes a safety fuse or breaker for each string and may include a surge protector.

3.7.6 Surge Protection

Surge protectors help to protect your system from power surges that may occur if the PV system or nearby power lines are struck by lightning. A power surge is an increase in voltage significantly above the design voltage.

3.7.7 Battery Bank

To make practical use of the solar-generated energy batteries are used to store the energy that is not needed immediately. Charge input from solar arrays is insufficient to keep the batteries fully charged. During sun-less days, batteries are discharged but not charged. These conditions result in battery operating in Partial

State of Charge (PSOC), Cycling and Deep cycling. Also, solar systems are installed in open atmosphere exposing the batteries to extreme Temperatures. Lead acid batteries fail in such conditions due to sulphation, stratification, corrosion and plate shedding. This is why we choose GENUS VRLA battery.

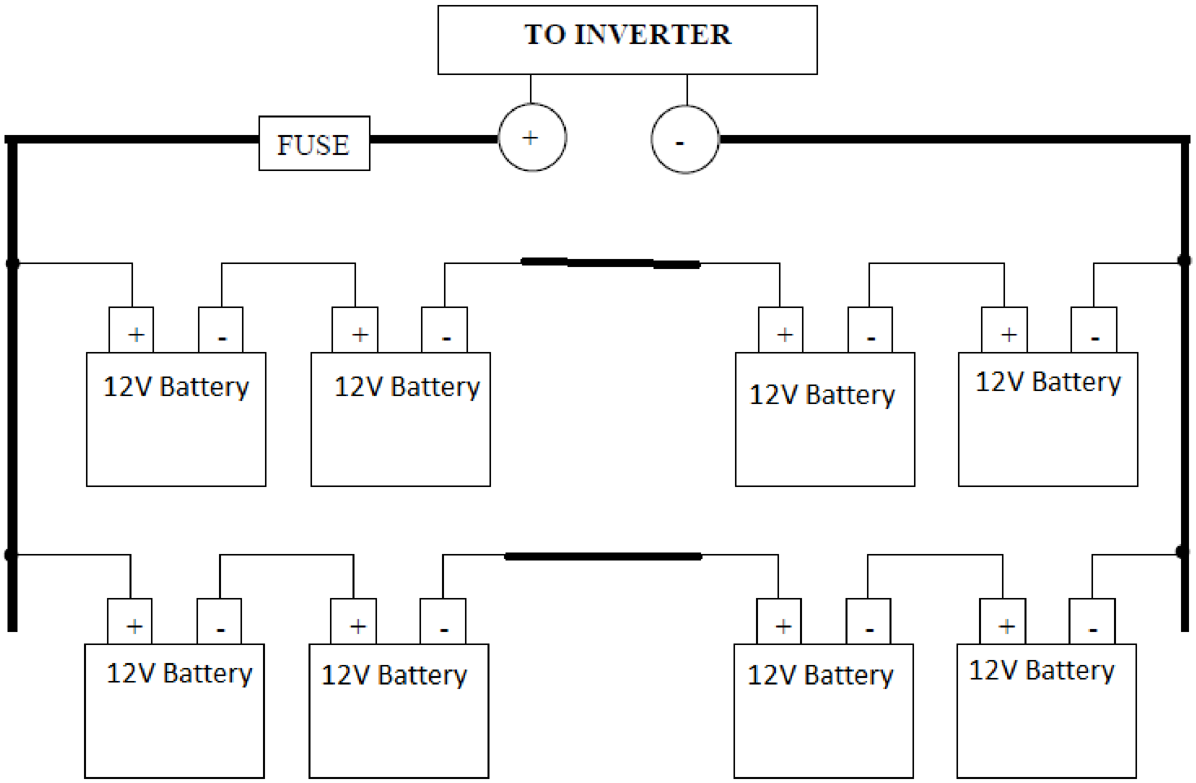

Figure 3.12: Block Diagram of Battery connection.

To meet such rigors of usage, Tubular Gel VRLA battery is a perfect fit for solar applications. VRLA stands for valve regulated lead acid and is the designation for low maintenance lead-acid batteries.

We used 8 pieces of GENUS VRLA battery of 12V and 200A each. Two (2) set of 4 batteries, connected in series to meet the 48V demand of the system, are connected in parallel to ensure supply of 48V for a longer time.

3.7.8 Charge Controller

A charge controller, sometimes referred to as a photovoltaic controller or battery charger, is only necessary in systems with battery back-up. The primary function of a charge controller is to prevent overcharging of the batteries. Most also include a low voltage disconnect that prevents over-discharging batteries. In addition, charge controllers prevent charge from draining back to solar modules at night. Some modern charge controllers incorporate maximum power point tracking, which optimizes the PV array's output, increasing the energy it produces.

Types of Charge Controllers

There are essentially two types of controllers: shunt and series.

1. A shunt controller bypasses current around fully charged batteries and through a power transistor or resistance heater where excess power is converted into heat. Shunt controllers are simple and inexpensive, but are only designed for very small systems.
2. Series controllers stop the flow of current by opening the circuit between the battery and the PV array. Series controllers may be single-stage or pulse type. Single-stage controllers are small and inexpensive and have a greater load-handling capacity than shunt-type controllers. Pulse controllers and a type of shunt controller referred to as 'a multistage controller' (e.g., three-stage controller) have routines that optimize battery charging rates to extend battery life. Most charge controllers are now three-stage controllers. These chargers have dramatically improved battery life.

Selection of Charge Controller

Charge controllers are selected based on:

- PV array voltage – The controller's DC voltage input must match the nominal voltage of the solar array.
- PV array current – The controller must be sized to handle the maximum current produced by the PV array.

Interaction with Inverter

Since the majority of charge controllers have been installed in the off-grid systems, their default settings may not be appropriate for a grid-connected system. The charge controller must be set up such that it does not interfere with the proper operation of the inverter. In particular, the controller must be set up such that charging the batteries from the PV array takes precedence over charging from the grid.

Interaction with Batteries

The charge controller must be selected to deliver the charging current appropriate for the type of batteries used in the system. For example, on a 12V system, flooded lead-acid batteries have a voltage of 14.6V to 15.0V when fully charged, while sealed lead-acid batteries are fully charged at 14.1 V.

Since the brighter the sunlight, the more voltage the solar cells produce, the excessive voltage could damage the batteries. A charge controller is used to maintain the proper charging voltage on the batteries. As the input voltage from the solar array rises, the charge controller regulates the charge to the batteries preventing any overcharging. While charging The batteries, the charge controller follows some stages. The stages are:

- **Bulk:** During the Bulk phase of the charge cycle, the voltage gradually rises to the Bulk level (usually 14.4 to 14.6 volts) while the batteries draw maximum current. When Bulk level voltage is reached the absorption stage begins.
- **Absorption:** During this phase the voltage is maintained at Bulk voltage level for a specified time (usually an hour), while the current gradually tapers off as the batteries charge up.
- **Float:** After the absorption time passes the voltage is lowered to float level (usually 13.4 to 13.7 volts) and the batteries draw a small maintenance current until the next cycle.

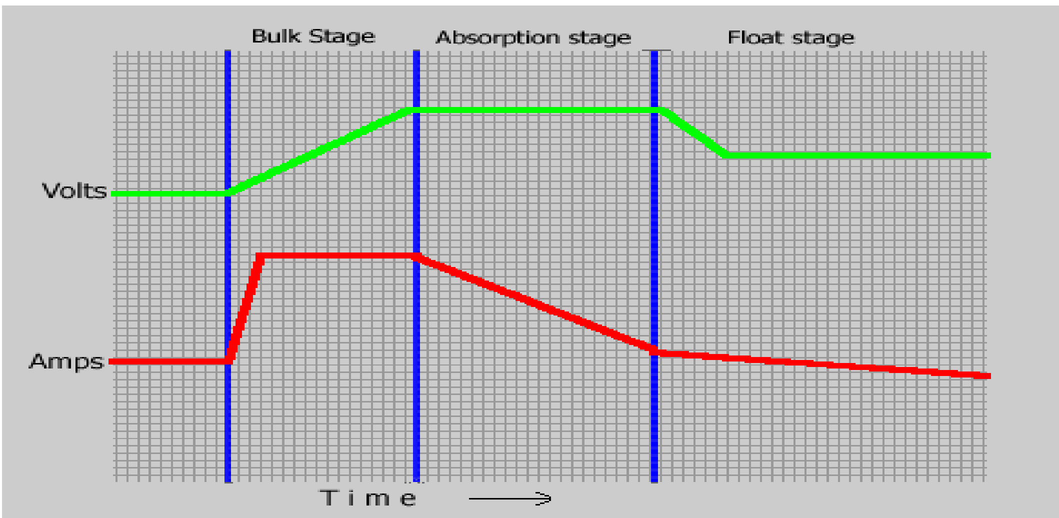

Fig. 3.13: Multi-stage charging.

Specification of charge controller

Based on this understanding, our charge controller is a multi-stage type with 48V and 45A specification.

3.7.9 Disconnects

Automatic and manual safety disconnects protect the wiring and components from power surges and other equipment malfunctions. They also ensure the system can be safely shut down and system components can be removed for maintenance and repair. For grid connected systems, safety disconnects ensure that the generating equipment is isolated from the grid, which is important for the safety of utility personnel. In general, a disconnect is needed for each source of power or energy storage device in the system.

For each of the functions listed below, it is not always necessary to provide a separate disconnect. For example, if an inverter is located outdoors, a single DC disconnect can serve the function of both the array DC disconnect and the inverter DC disconnect.

Before omitting a separate disconnect, however, consider if this will ever result in an unsafe condition when performing maintenance on any component. Also consider the convenience of the disconnect location. An inconveniently located disconnect may lead to the tendency to leave the power on during maintenance, resulting in a safety hazard.

Array DC Disconnect – The array DC disconnect, also called the PV disconnect, is used to safely interrupt the flow of electricity from the PV array for maintenance or troubleshooting. The array DC disconnect may also have integrated circuit breakers or fuses to protect against power surges.

Inverter DC Disconnect – Along with the inverter AC disconnect, the inverter DC disconnect is used to safely disconnect the inverter from the rest of the system. In many cases, the inverter DC disconnect will also serve as the array DC disconnect.

Inverter AC Disconnect – The inverter AC disconnect disconnects the PV system from both the building's electrical wiring and the grid. Frequently, the AC disconnect is installed inside the building's main electrical panel. However, if the inverter is not located near the electrical panel, an additional AC disconnect should be installed near the inverter.

Exterior AC Disconnect – Utilities commonly require an exterior AC disconnect that is lockable, has visible blades and is mounted next to the utility meter so that it is accessible to utility personnel. An AC disconnect located inside the electrical panel or integral to the inverter would not satisfy these requirements. One alternative that is as acceptable to some utilities as an accessible AC disconnect is the removal of the meter itself, but this is not the norm. Prior to purchasing equipment, consult the electric utility to determine their requirements for interconnection.

Battery DC Disconnect – In a battery-based system, the battery DC disconnect is used to safely disconnect the battery bank from the rest of the system.

3.7.10. PROJECT CALCULATION ANALYSIS

With estimated daily peak sunlight of 6hours and a daily load requirement of 5000W, the following calculation analysis was made:

- We chose a 5KVA inverter to suite the load requirement.
- Inverter input: 48V dc, output voltage: 240V ac.
- Assuming an average efficiency of 75%.

- Ratio of output voltage to input: 240/48 = 5; this means that we need to generate 5times as many direct current as we need to generate alternating current. 5000W/240V = 20.8 A (ac), therefore the direct current input = 5 x 20.8 = 104.2 (ac).
- Since we are figuring a 25% loss, we must divide this figure by 0.75 = 138.9A, this is the ampere demand that must be generated by dc.
- Considering 5days of possible sunlight, we have; total dc input = 0.714 x 138.9A = 99.2A. in A/hr we have; 99.2A x 7hrs = 694.2 Ah.
- Incorporating a 10% loss in wire and voltage regulator (I^2R), the above figure becomes 694.2/0.9 = 771.33Ah. This resultant figure represents the 'Ah' average daily charging current requirement from we are designing to satisfy the load.
- Current from array = 771.33/6 = 128.56A (required charging current from the battery)
- With a 6A output panel; no of parallel panels = 128.6/6 = 22 panels; with two panels in series, we have the total no panels as 2 x 22 = 44 panels.

We therefore would need three 45A charge controllers to cater for this.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 RESULTS

This chapter presents the test results of the design works that were carried out in this project. At the end of the design and construction, the system was tested to ensure that it meets the desired stated objectives and specifications that guided the entire project work. The results of the test carried out are as below;

4.1.1 THE OSCILLATOR CIRCUIT TEST RESULTS

The oscillator circuit was designed and simulated with Proteus ISIS circuit simulation (CAD) software; this is due to its versatility and simplicity of use, and because it is one of the best and latest electronic circuit simulation software as at the time of this project.

After the design of the microcontroller based signals generator (oscillator), the output signal was tested to ensure that it conforms to the expected Sine Pulse Width Modulation (SPWM) scheme and the equivalent square wave signals that would be used to control the MOSFET drivers for each H-bridge channel. When the test was carried out the first time, the resulting output signal was not fully replicating the expected sinusoidal waveform but after several observation and adjustments, the final test resulted to the expected Sine Pulse Width Modulated (SPWM) signal.

Below in Figure 4.1 is the resulting output signals of the oscillator circuit (signal generator).

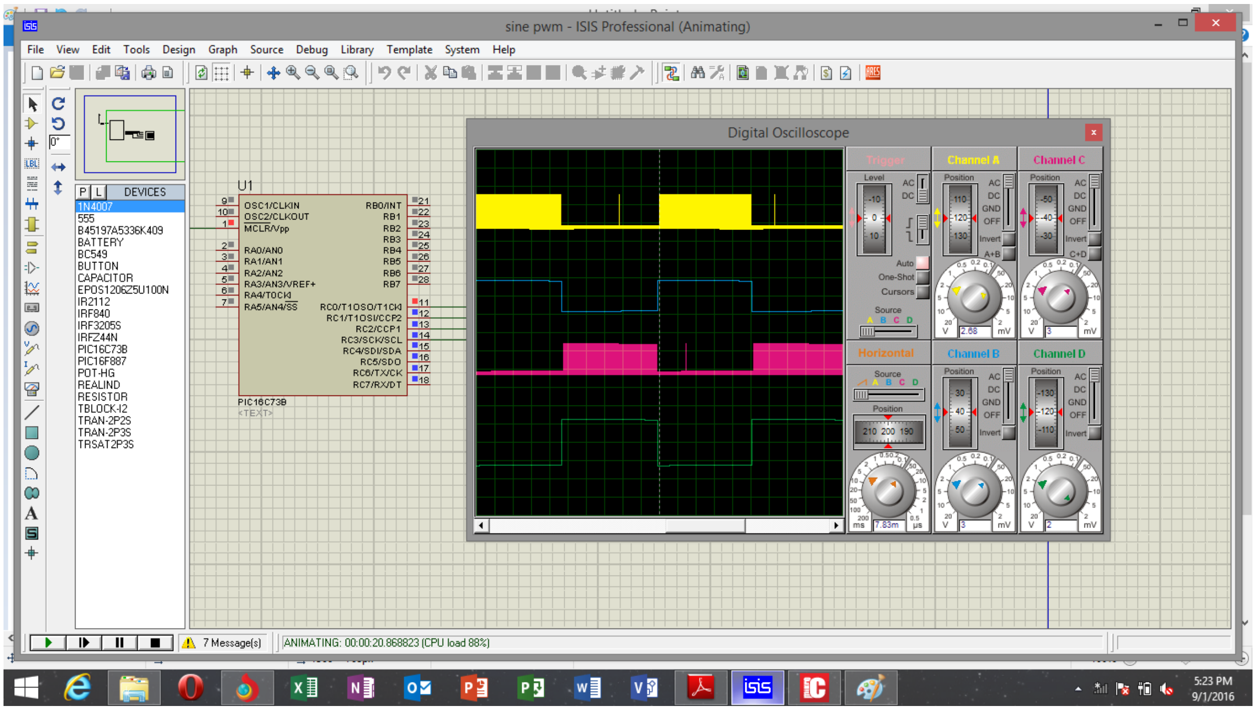

Figure 4.1: The result output signals of the oscillator circuit

4.1.2 TESTING THE COMPLETE INVERTER CIRCUIT

The H-Bridge circuit was also tested with a multimeter to ensure that each of the MOSFETs are in good working condition before connecting them to the output transformer and the MOSFET drivers for the final test. When the signal generator circuit had been tested and confirmed working, its output was fed to the MOSFET drivers and the output of the drivers fed into the four MOSFETs as shown in figure 3.13 and 3.22 above. The final output signal of the whole PWM inverter circuit is shown in Figure 4.2 below;

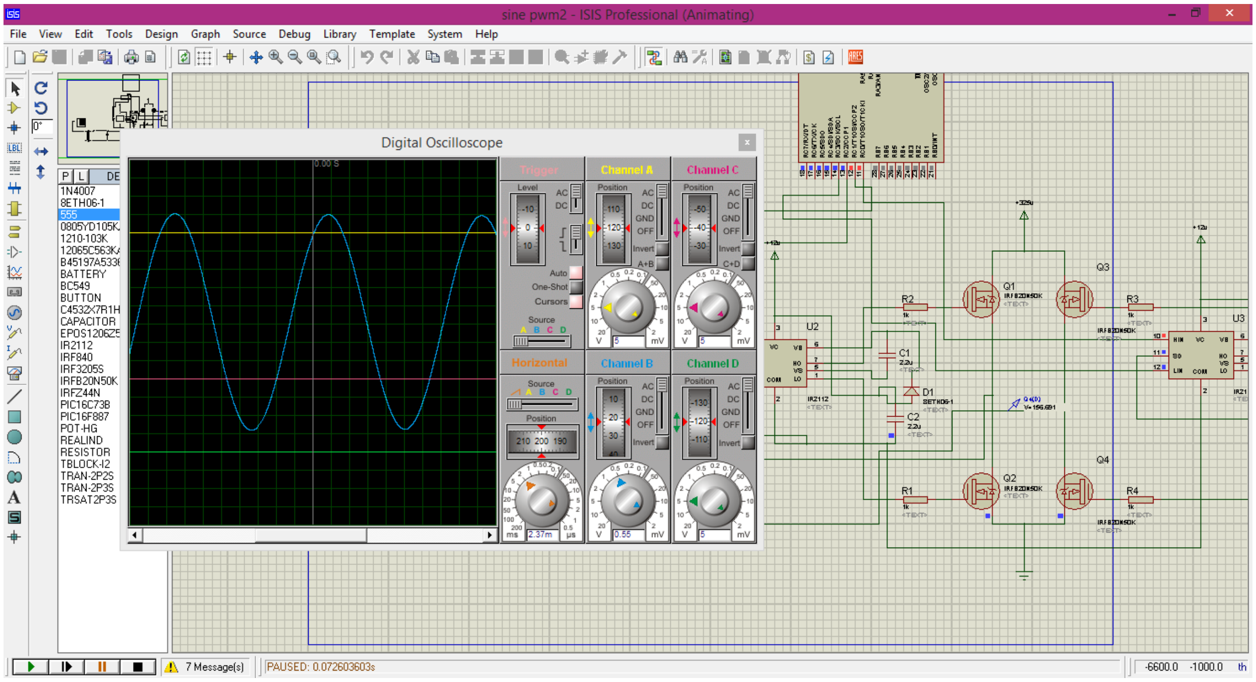

Figure 4.2: The modulated and final output signals

The tables below give the specifications of the input parameters and the corresponding output parameters;

Table 4.1: Input specification parameters

Input parameters	Specification	Realised?
Voltage	48VDC	YES
Current	400AH	YES

Table 4.2: Quality Test Report of our 5KVA Static UPS Inverter, 48VDC

S/No	Testing Parameter	Required	Observed
At Battery Mode			
1.	Max. Battery No Load Current	3.0A	2.5A

2.	No Load Output Voltage	225-230V	226.4V
3.	Output Frequency	49.5-50.5V	50.1Hz
4.	Full Load Battery Voltage at 48V	100-104A	103A
5.	Full Load Output Voltage at 48V	195-215V	191V
6.	Overload Protection	Should be OK	OK
7.	Fan at Full Load	Should be OK	OK
8.	Short Circuit Protection	Should be OK	Ok
Mains Mode			
9.	UPS to Main Synchronisation	Should be OK	Ok
10.	UPS High Cut	260-270V	268V
11.	Mains High Cut	270 - 310V	276V
12.	Max. Charging Voltage	14 - 15A	14.1A
13.	Boost Charging Voltage	56.8 – 58.4V	57V
14.	Float Charging Voltage	53.6 – 54.8V	54V
15.	Mains MCB Trip	Buzzer ON Continue	OK
16.	Max. Output Voltage	As Input Voltage	OK
17.	Low Battery Cut	40.8V –42.4V	40V
18.	Rotary Switch Function	Ok / not Ok	Ok

19.	Seal No. of Top Front Corner	55338786	Ok
20.	Seal No. of Back Corner	55338787	OK
21.	Seal No. of left Side	55338788	Ok
22.	Seal No. of Right Side	55338788	Ok

4.2 DISCUSSION

The results of the tests that were carried out throughout the whole design were all gotten through systematic checks and observations, and using the appropriate test tools and equipment where necessary. The major tests that were carried out all met the expected specifications with negligible deviation or tolerance. One thing was peculiar about the results; each of the tests that were carried out in each of the subsystems that make up the inverter system was done in relation to the next subsystem that was connected to it.

The outputs from the inverter system were all as expected as shown by the final results. When the final installation was made, the system was tested by gradually loading it to see that it responds to the load increase as expected; and after the load test we observed that batteries voltage dropped slightly due to the loading effect and that was normal.

Before final assembling, the different sections that make the whole system were tested individually. This pattern was adopted to make troubleshooting, analysis and testing easy and reliable. It is expected that all the results of the tests that were carried out continuously conform to the specified standards as long as the system is used within its capacity and under the standard test conditions. Based on the pattern of tests and observations used in this project, it is expected that the system performs its intended duty throughout its useful life as long as it is used as prescribed, and this is because of the fact that the system was designed under standard operating conditions of the immediate environment.

4.2.1 THE FINAL OUTPUT SIGNAL OF THE 5kVA PURE SINE WAVE INVERTER

The microcontroller basically performs two functions: serves as a sine pulse width modulation generator as well as providing the square wave control signal that is used to drive the MOSFET driver which in turn drives the MOSFET as shown in the Figure 4.1. The resulting signals from the H-bridge channels were fed to a low pass LC filter to filter out the high frequency modulating signal leaving only the fundamental signal of 50Hz which was then fed to the primary of the step up transformer to yield a 220Volt AC sinusoidal output voltage and current as shown in the oscilloscope result in Figure 4.2 above.

The two square waveforms in figure 4.1 above show the simulation result of the two output signals from the microcontroller. The first one with yellow trace indicates the Q output while the second one indicates its compliment. When Q is HIGH, the PWM signal from the opposite half of the MOSFET channel is allowed to flow in one direction while the compliment of Q remains OFF during that period. Likewise, when Q is LOW the reverse process happens and current flows through the transformer in the opposite direction. These process is what yields the three level PWM from the two level PWM coming from the microcontroller, and from figure 4.2, the green sinusoidal waveform shows the final simulation result from the filtered output of the transformer.

Based on the results gotten from the final design work, it was apparent that this design was able to meet most the requirements and it will also go a long way in providing a better and affordable alternative power supply for any intended use; in homes on in the industries. The design conforms to most of the recent similar works that have been done by different people in different places. In as much as this design cannot meet up to the latest state of the art technologies used in the factory/custom made pure sine wave inverters like the Genus inverter/UPS due to the sophisticated technological equipment and techniques that are not readily available to the common man, this design goes a long way in providing a clean, affordable, readily available and reliable power that can fully be used in most applications that are not very critical like in medical and sensitive laboratory equipment.

This project work provides some additional features and not only serves to provide the intended power needs, but also provided us with the new knowledge of the fact that the seemingly sophisticated technology of modern SPWM inverters can be achieved with some basic electronic components like microcontrollers and some other analogue devices like op-amps and logic gates. The most interesting part of it all is the simplicity and affordability of the whole design work when compared to the highly sophisticated factory/custom made equivalents and this homemade design of ours serves as a cheaper alternative to the off-the-shelf inverters/UPS.

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The application of our knowledge of engineering in solving our local problem is one thing desperately needed in our country today. That is the opportunity this project offered us; by the implementation of this project, we have successfully made the department less reliant on grid supplied energy which would boost productivity.

After the implementation of the 5kVA inverter installed for the department, the following were achieved:

- We successfully did a proper load sizing of the department
- We successfully learnt and practiced the load and panel analysis necessary for the installation of solar panels and inverters in buildings.
- We successfully designed and constructed 5kVA pure sine wave inverter we installed in the department.
- We as well gained great entrepreneurial skill through this project. This is of immense benefit as it would reduce our dependence on the job market for survival after school.
- The end product of the project is the availability of a reliable and consistent power supply for the department.

5.2 PROBLEMS ENCOUNTERED

Every successful project has some challenges encountered, and ours was not an exception. In the course of the project, some difficulties were encountered while trying to meet the expected results and specifications.

- One major difficulty that was encountered in this project was majorly financial constraints, due to the present economic condition of the country.
- Another challenge encountered was purchasing the various components needed for the fabrication, seeing that the required components were not readily available in our location.
- Another major challenge we encountered was time constraint, we had very limited time to implement this project, this warranted us working under pressure and overtime most of the time to actualize the project.
- The major hiccup in the design of the homemade pure sine wave inverter was the trouble of generating the appropriate microcontroller code that produces the SPWM and square wave signals used in controlling the MOSFET drivers. The problem was due to components modelling issues with Proteus ISIS. This was a very big challenge at first, but it was finally surmounted.

5.2.1 LIMITATIONS OF PROJECT

1. The PV power system can only power regular household loads and hence cannot be used to drive heavy industrial loads like electric motors and pneumatic machines.

2. The capacity of the system in limited only to 5000VA at 220VAC (Maximum safe level of loading is about 80% of the inverter capacity).

5.3 RECOMMENDATIONS

1. A maintenance check (e.g. periodic maintenance) should be carried out on the photovoltaic components (the solar panels, the power inverter, the charge

controller, the batteries, the wires and cables, the monitors and meters) probably once a month. This will ensure that any fault is discovered and looked into on time. The components should not be tampered with in case any fault is discovered, experienced technicians should be contacted to check on the problem and proffer solutions.

2. We would recommend that close attention be paid to the loading of the inverter. For the best interest of the life span of the inverter, it should not be run at the peak load. Members of staff should ensure that heavy duty loads are not connected to the inverter during the usage of the inverter.

3. We recommend that students be issued their projects early enough to enable them learn in details what the project entails and projects like this (solar energy based) should be encouraged by the government to ensure optimal solutions to major issues like power failure problems.

REFERENCES

[1] A. Musa, G.S.M. Galadanci, “5KVA power inverter design and simulation based on boost converter and H-bridge inverter topology”, Bajopas, vol. 2,June 2009.

[2] Roberto Faranda, Sonia Leva, Piazza Leonardo da Vinci, “renewable energy resources for households”, WSEAS transactions on power systems, issue 6, Vol. 3, June 2008.

[3] Steven L. Brunton, Clarence W. Rowley, Sanjorv R. Kulkarni, “Maximum power point tracking for photovoltaic optimization using ripple-based extreme seeking control”, Princeton University, NJ. 08544.

[4] Ali RessaReissi, Mohammed Hassan MaradiJamab, “Classification and comparison of maximum power point tracking techniques for photovoltaic systems; a review”, Renewable and Sustainable Energy Review, Vol. 19, Pg. 433-443.

[5] Cheng-Wei Chen, Kun-Hung Chen, Yaow-Ming Chen, “Modeling and Controller Design of an Autonomous PV Module for DMPPT PV systems”, IEEE Transaction on power electronics, Vol. 29, No. 9, September 2014, pg. 4723-4732.

[6] R.C.N Pilawa-Podguski, D.J Foreault, “Submodule integrated distributed maximum power point tracking for solar photovoltaic applications,” IEEE Trans. Power electron, Vol. 28, no. 6, June 2013, Pg. 2957-2967.

[7] N. Femia, G. Lisi, G. Petrone, G. Spagnuolo, M. Vitelli, “Distributed maximum point tracking of photovoltaic arrays: Novel approach and system analysis,” IEEE Trans. Ind. Electron, Vol. 55, No. 7, Pg. 2610-2621, Jul. 2008.

[8] Juan M. Galvez, Martin Ordinez, “Swinging Bus Operation of Inverters for Fuel Cell Applications with Small DC-Link Capacitances,” IEEE Transactions on Power Electronics, Vol. 30, No.2, February. 2015.

[9] Mazen Abdel-Salam, Adel Ahmed, MAhmoud Amery, “Design and Implementation of Stand-alone Residential PV System,” IEEE Jordan Conference on Applied Engineering and Computing Technologies (AEECT), Pg. 1050-1062, 2011.

[10] AmmarMunir. “Inverter Technology for the Solar Industry Inverter Technology and Inverters in Solar Power Systems.” Internet: www.academia.edu/6165051/Inverter Technology for the Solar Industry/ Inverter Technology and Inverters in Solar Power Systems. 2009. [21st May 2015]

[11] Lander, C.W. (1999). Power Electronics (Second Edition). S Chad & Company.

[12] Boylestad, R.L. and Nashelsky, L. (1999). Electronics Devices and Circuit Theory (Seventh Edition). Prentices Hall Inc.

[13] Rasheed, M. (1992). Power Electronics, Circuits, Device and Application (Second Edition). Prentice Hall Inc.

[14] Forrest, M. (2000) .Getting Started In Electronics (2nd Edition).

[15] Oni, J.O.(2005). Fundamentals of Power Systems Protection.

[16] Mgottlieb, I. (1985). Power switching Regulator Inverters and Converters (1st Edition). Tab Book Inc.

APPENDIX A

LIST OF COMPONENTS IN 5kVA INVERTER DESIGN

S/N	COMPONENTS	QUANTITY
1.	TRANSFORMER	1
2.	SETS OF HEAT SINK	
3.	1RF4110 (MOSFET)	20
4.	1RF2110 (MOSFET DRIVER)	2
5.	12V ZEN. (ZENER DIODE)	4
6.	5V ZEN. (ZENER DIODE)	1
7.	68R (5W) (RESISTOR)	1
8.	100R (10W) (RESISTOR)	1
9.	180K (1W) (RESISTOR)	1
10.	220K (1W) (RESISTOR)	1
11.	470R	4
12.	47R	1
13.	47K	1
14.	0.47µF, 275V	1
15.	22R	24

16.	4.7K	12
17.	2.2K	11
18.	2K	2
19.	1K	2
20.	10R	6
21.	100K	1
22.	BUZZER	1
23.	4700µF, 100V	4
24.	C547 (CAPACITOR)	4
25.	D882 OR C945	1
26.	TIP 41 (TRANSISTOR)	1
27.	LM 317 (12V REGULATOR)	1
28.	LM 7805 (5V REGULATOR)	1
29.	LM 358 (OP-AMP)	1
30.	PC 817 (OPTO-COUPLER)	1
31.	P 521 (OPTO-COUPLER)	1

32.	IN4007 (DIODE)	14
33.	IN4148	4
34.	10µF 25V	2
35.	47µF 50V	3
36.	100µF 50V	5
37.	470µF 25V	1
38.	0.1µF, 250V	2
39.	104J (MICA CAPACITOR)	6
40.	103J OR 123	2
41.	8 PIN IC SOCKET	2
42.	28 PIN IC SOCKET	1
43.	14 PIN IC SOCKET	2
44.	2 PIN WIRE CONNECTOR	5

45.	8 PIN WIRE CONNECTOR	1
46.	16 X 2 LCD	1
47.	20MHZ	1
48.	10K THERMISTOR	1
49.	12V FAN	1
50.	PCB & PREPROGRAMMED MICROCONTROLLER	
51.	CAST	1
52.	FEEDBACK SENSE TRANSFORMER	1
53.	AC FAN (220VAC)	1
54.	SMALL PRESS BUTTON	3
55.	560R	1
56.	1K	1

57.	10R	1
58.	90A RELAY	1

APPENDIX B

BILL OF ENGINEERING MEASUREMENT AND EVALUATION

S/N	COMPONENT NAME	COMPONENT DESCRIPTION	QUANTITY	UNIT PRICE (Naira)	TOTAL PRICE (Naira)
1	Batteries	12V Lead acid battery	8	110,000	880,000
2	Solar panels	300 watts, 24V panels	16	80,000	640,000
3	Charge controller	60 amps MPPT charge controller	1	60,000	60,000
4	Cables	$4mm^2$ copper cables	2	21,000	42,000
5	Battery rack		1	15,000	15,000
6	Transportation			20,000	20,000
	Total				1,657,000