DESIGN AND CONSTRUCTION OF A 3KVA PURE SINE WAVE INVERTER CIRCUIT AND CHARGER SYSTEM WITH A DSPIC30F2010 MICRCONTROLLER

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DEPARTMENT OF ELECTRICAL/ELECTRONICS ENGINEERING

FACULTY OF ENGINEERING

UNIVERSITY OF BENIN

BENIN-CITY

SEPTEMBER, 2023

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A PROJECT SUBMITTED TO THE DEPARTMENT OF ELECRICAL/ELECTRONICS ENGINEERING, UNIVERSITY OF BENIN, IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR IN ENGINEERING (B.ENG) IN ELECTRICAL/ELECTRONIC ENGINEERING

SEPTEMBER, 2023

CERTIFICATION

This is to certify that this project report was duly carried out by

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under my/our supervision and found it to be adequate and satisfactory both in scope and context for the award of Bachelor in Engineering (B.Eng) degree from the University of Benin.

Engr. E. Osa
Project Supervisor

Date

Engr. Prof. K. O. Ogbeide
Head of Department

Date

DEDICATION

This work is dedicated to the Almighty God, the one from whom all blessings flow, for giving the strength, knowledge and provision to implement this project.

ACKNOWLEDGEMENT

We are grateful to God almighty for giving us the grace to attain this level of accomplishment, we also acknowledge our project supervisor Engr. E. Osa for his tremendous contribution patience, teachings and continuous motivation throughout the course of this project.

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ABSTRACT

Electricity could be regarded as one of humanity's most remarkable inventions since numerous other innovations and operations rely on it for their effective operation. The primary source of this vital energy typically originates from utility lines linked to various power stations, including hydroelectric ones. Nevertheless, the alternating current (AC) supply from utility lines is susceptible to fluctuations such as power surges, voltage deficits, complete outages, and substantial deviations in the electrical supply frequency. The inconsistent and undependable electricity provision from the Nigerian authorities, particularly in recent years, is a significant cause for concern among conscientious Nigerians.

The energy stored in the battery undergoes a conversion process, transforming it from a direct current form into a sinusoidal alternating current (AC) output at a voltage of 220V using the inversion technique. An electronic oscillator is a type of electronic circuit responsible for generating a periodic, oscillating electronic signal, and this approach is employed. The DSPIC30F2010 microcontroller is utilized to attain a sinusoidal oscillating output. It generates pulse width modulated (PWM) output with a duty cycle that fluctuates in a sinusoidal pattern. While the inversion process is underway, the controller monitors various parameters, including battery level, overloads, the presence of AC mains, high temperatures, and numerous other features. A 16 by 2 liquid crystal display screen is employed to exhibit information regarding the inverter's status, the charge level of the battery, inverter voltage, mains voltage values, and frequency.

A system has been developed, put into operation, and set up for converting 24V DC into 220V AC using rechargeable batteries. It operates more effectively when two 12V deep cycle batteries are connected in series, each with a capacity rating of 220 AH. This setup can maintain a consistent output of 220-240 volts for over 4 hours of continuous usage.

CHAPTER ONE

INTRODUCTION

1.0 The Concept of an Inverter

Electricity is considered one of the greatest inventions of man, as it is crucial for the proper functioning of many other inventions and processes, with utility lines from hydroelectric power stations being the most common source of this energy. These utility lines transmit electricity to homes, businesses, and industries, enabling the operation of various appliances, machinery, and technologies. Additionally, electricity plays a crucial role in powering transportation systems such as electric cars and trains, revolutionizing the way we commute and reducing our reliance on fossil fuels.

However, the alternating current supply from the utility lines is susceptible to power surges, voltage shortages, total power failure, and wide variations in the electric supply frequency. The epileptic and unreliable power supply by the authority in Nigeria, especially in recent times, is a major issue of concern to every well-meaning Nigerian. (Ohajianaya *et al*, 2014) The need for a constant supply of electricity has always been claimed to be the priority of the power authority, yet they leave much to be desired. As a result, there is the dire need for the design and construction of alternative Uninterrupted Power Supply (UPS) systems. (Rehman *et al*, 2022)

For ordinary household appliances, such as incandescent lamps, heaters, fans and fridges, the common mains AC supply could be used casually, that is, without giving thought to its inherent short comings, because the performance of these appliances are seldom affected by power variations or interruptions. This is not the case with sophisticated and sensitive electronic equipment such as computers, medical equipment and telecommunication systems that require a stable and interruption-free power supply (Rehman *et al*, 2022).

An uninterrupted power supply (UPS) is an electrical system that supplies emergency power to a load when the input power source, often mains power, fails. It offers near-instantaneous protection against input power disruptions by delivering energy stored in batteries. The on-battery lifetime of most interrupted power sources is quite brief (just a few minutes), but adequate to activate a standby power source or appropriately stop the protected device (Gemma *et al*, 2022). UPS systems are commonly used in critical applications such as data centers, hospitals, and telecommunications facilities to ensure uninterrupted operation during power outages. They provide a reliable backup power solution that safeguards sensitive equipment and prevents data loss or damage. Additionally, UPS systems can also protect against voltage fluctuations, surges, and frequency variations, further enhancing the stability and reliability of the connected devices.

The energy crises affecting small, and medium scale industries and light household loads in Nigeria can effectively be addressed by devising methods of energy storage, which could be used during short-period power outage or using a generator, which is quite expensive to maintain. An absolute solution to energy demand can be achieved by the adoption of renewable energy development especially the invention of the inverter.

The inverter is a power electronic equipment that makes use of an energy source, such as solar cells, to be domestically and industrially useful for usage. In summary, it goes a long way to lower the quantity of greenhouse gases in the atmosphere and ameliorate global warming in the process. Photovoltaic electricity production is dependable. It has no moving components, thus the operating and maintenance expenses are relatively minimal. (Coker and Ogungi *et al*, 2013).

An inverter primarily converts direct current (DC) to alternating current (AC) in a process called Inversion, which is the opposite of Rectification – the conversion of Alternating current to direct current. In most cases, the input DC voltage is usually lower, while the output AC is typically equal to the grid supply in Nigeria which is 220(single phase). (www.lentoindia.com)

1.1 Statement of Problem

As a result of continuous power failure and fluctuation in power supply by the power distribution companies in Nigeria, sensitive appliances and systems are affected by the interrupted power supply and also considering the relationship between the standard of living and the energy usage, the situation gets worse year by year. An alternative reliable source of electrical energy is therefore required by the average Nigerian due to the importance of electrical energy to both commercial and household activities. This project will be timely as it provides a backup and reliable power supply of 3KVA to power sensitive equipment.

1.2 Aim and Objectives of the Project

1.2.1 Aim

The aim of the project is to design, test and implement a 3KVA/24V pure sine wave inverter and charger system.

1.2.2 Objectives

The objectives of this project include:

1. To design a 3KVA/24V inverter system capable of generating pure sine wave output.
2. To construct the designed inverter.
3. To implement a microcontroller unit as the main circuit control component.

4. To achieve a stable output voltage of 220V from the designed inverter while in operation.
5. To implement an efficient battery charging subsystem.
6. To implement safely measures, including overload protection, short circuit protection and low battery protection in the constructed inverter.
7. To incorporate a user-friendly interface for efficient operation of the constructed inverter system.

1.3 Relevance and Scope

The project seeks to improve on the efficiency of existing inverter systems, by introducing features and upgrades such as the monitoring of the mains input voltage, hereby offering protection from abnormal low and high voltages. Also, the integration of a system that maintains a constant output voltage (220V), which justifies the objectives of this project.

1.4 Methodology

To achieve the objectives set out for the project, the following methods shall be carried out:

1. A Sine wave look up table will be generated to create a sinusoidal wave form output for the 3KVA/24V inverter using DSPIC30F2010 microcontroller. The microcontroller Circuit is designed on Proteus software and a PCB diagram will be created for this design.
2. The circuit will be implemented on a Printed Circuit Board and the components will be soldered into it.
3. The microcontroller unit will be programmed using MikroC PRO for DSPIC and the PICKIT2 programmer will be used to burn the compiled HEX file into the DSPIC chip.

4. To achieve a stable output voltage of 220V from the designed inverter while in operation, a transformer will be wind to step up the voltage to 220V.
5. Charging the battery will be achieved using a controlled current charging circuit governed by the microcontroller and the transformer.
6. Circuit Breaker will be installed for short circuit protection.
7. LCD screen and buttons will be implemented into the design.

1.5 Project Report Outline

The entire project has five (5) chapters, each having its own importance.

Chapter 1: Introduction - Justifies the need for the project and outline its requirements and specifications.

Chapter 2: Literature review - (Reviews on existing inverter systems – under consideration), Literature review of parts (components, materials, etc.) and devices used together with matching circuit diagrams and principle behind the design implemented in this project.

Chapter 3: Methodology and system design consideration – Gives a thorough description of the design process.

Chapter 4: Construction, Tests, and Results - Discussion of the design's hardware implementation, the outcomes, and problems encountered. This chapter contains the Bill of Engineering Measurement/Evaluation.

Chapter 5: Conclusion and Recommendations — Summarizes the observations and conclusions made throughout the course of the research. Recommendations for additional study are also presented in this chapter.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of Inverter Systems

An inverter system is a device that converts direct current (DC) power into alternating current (AC) power. It is commonly used in renewable energy systems, such as solar panels or wind turbines, to convert the DC power generated by these sources into AC electricity that can be used to power household appliances or be fed back into the electrical grid. Inverter systems are essential for maximizing the efficiency and usability of renewable energy sources by ensuring that the generated power is compatible with standard AC electrical systems.

A solar inverter is similar to an ordinary electric inverter but in addition it implements the energy of the Sun (i.e., solar energy) (Olanrewaju L. K. *et al*. 2016). Solar panels generate electricity in the form of direct current (DC), which is not suitable for powering most household appliances. Hence, solar inverter plays a crucial role in converting this DC power into alternating current (AC), which is the standard form of electricity used in homes.

2.1.1 Choosing an Inverter

When selecting an inverter, the following factors must be taken into account:

- **Wattage rating**: It indicates the maximum amount of power in watt that the device can handle or generate continuously.

- **Surge power**: This refers to the maximum amount of power that the inverter system can handle for a short duration. It is typically higher than the device's rated or continuous power capacity, as it accounts for sudden spikes in power demand during start-up or when certain appliances are turned on simultaneously.

- **Efficiency:** This is the ability to convert direct current (DC) power into alternating current (AC) power with minimal energy loss. It also indicates how efficient the inverter is during low, medium, and high-power pulls, as well as how much power is utilized while the inverter is in idle mode.

- **Quality**: The sinusoidal wave shape is a factor in determining the quality and efficiency of the electrical wave, whether a pure sine wave or a modified sine wave.

- **Functionality**. From simple DC to AC conversion to highly sophisticated, multifunctional grid tie inverters that accept and convert energy from various sources and route excess into the grid in a compatible and safe manner.

2.1.2 Solar Inverter and Mode of Operation

Solar energy is turned into electrical energy using photovoltaic (PV) cells. During the day, this energy is stored in batteries for use whenever it is required. The suggested system is intended to use solar energy for household loads via the use of an inverter. A solar inverter transforms a PV solar panel's direct current (DC) output into utility-frequency alternating current (AC) that may be supplied into a commercial electrical grid or utilized by a local, off-line electrical network. Solar energy from PV cells is stored in the battery in this suggested system. PWM inverter IC controls the switching of the MOSFETs, converting the DC input into an AC waveform at 50Hz, which is then stepped up by the transformer to reach the required voltage level. This allows for efficient and reliable conversion of battery energy into usable AC power. (Olanrewaju L. K. *et al*. 2016).

2.2 Types of Inverter Systems

Solar inverters may be classified into three broad types.

- Off Grid inverter or Stand-alone
- Grid tie inverter
- Intelligent hybrid inverter

2.2.1 Stand-Alone or Off-Grid Inverter

Off-grid inverters are utilized in distant systems wherein the solar inverter is fed DC power from a battery panel. This battery panel is charged by solar panels. Several such inverters are incorporated with basic battery chargers, which may be used to augment the battery from an AC power source. (Olanrewaju L. K., *et al*. 2016).

2.2.2 Grid Tie Inverter

A grid tie solar electric system helps turn sunlight into electricity by using solar panels and a power inverter, along with many other smaller components. This all happens while your home (or solar powered building) remains dependent on the local grid, or utility. This is different from off-grid systems, which means that your power is not hooked up or dependent on any other utility power. The term "standalone solar electrical system" refers to a system that relies solely on solar energy as its primary energy source. These off-grid inverters are essential in remote areas where there is no access to the traditional power grid. In these regions, a standalone solar electrical system might be the most suitable source of electricity. The main advantage of this system is that it does not depend on the grid or any other source of electricity; hence, it is also known as an off-grid photovoltaic system. As the sun is the only source of energy in this system, it should have some means to make it active even at night. A storage battery system does the job. However, the reliance on storage batteries in off-grid photovoltaic systems can be expensive and require regular maintenance, making them less cost-effective and convenient compared to grid-connected solar systems that can feed excess energy back into the grid. This battery system can be omitted from the system if it is solely intended to power loads during the day. Solar lanterns, solar house lighting systems, solar water pumping systems, and other freestanding solar systems are popular examples.

2.2.3 Intelligent Hybrid or Smart Grid Inverter

An intelligent hybrid inverter or smart grid inverter is a trending generation of inverter for solar applications employing renewable energy for household consumption, notably for solar photovoltaic systems. various consider this as a new technology, yet in various regions of the globe the application of such items has been around since the 1990s. Electricity from solar panels is produced exclusively throughout the day, with peak output around noon. Generation varies and may not be synced with a load’s power usage. To bridge this gap between what is generated and what is used during the evening, when there is no solar power generation, it is required to store energy for later use and control energy storage and consumption using an intelligent hybrid (smart grid) inverter. With the growth of systems that combine renewable energy sources and growing power rates, commercial enterprises and research institutions have created smart inverters for synchronizing energy output and consumption (Olanrewaju L. K., *et al*. 2016).

A smart grid's function is to enable the consumption-based selection and direction of renewable energy, grid energy, and energy storage. Unlike traditional inverters, instead of systematically storing energy in batteries (with a high yield loss of >20%), (www.handwiki.org).

Smart grid inverters store energy when needed and allow for the choice of whether electricity from photovoltaic panels should be stored or consumed. This is possible through a method that adds different energy sources (phase coupling: on-grid or grid-tie techniques) and the management of stored electricity in the battery (off-grid technology). Hybrid inverters operate on the grid, off-grid, hybrid, and backup. According to the French Electric Network, smart inverters are the future of photovoltaic solar panel installations for energy self-use or auto-consumption. (www.handwiki.org). The technology has different functions which include:

- Off-grid inverters based on batteries are being developed for on-grid use (also known as multi-mode inverters).
- Use in off-grid mode with the possibility of also integrating a generator. The inverter must be connected to a battery bank and must have true off-grid capabilities – not all Hybrid inverters are created equal or can be used in off-grid applications.
- Use in hybrid mode where the inverter functions with a battery storage bank, but is also connected to the grid. The hallmark of hybrid inverters is their dual functionality that enables energy management (smart grid).
- Use in Backup mode or storage mode, hereby preventing power outage by quickly switching from on-grid mode to off-grid mode at the moment of a blackout, thereby eliminating network cuts.

2.3 Advantages of Solar Inverter

After thoroughly discussing what a solar inverter is and how well it is suited for powering appliances at the residential and industrial levels, it is necessary to discuss the solar inverter's numerous advantages:

- Solar energy has consistently aided in the reduction of the greenhouse effect and global warming by reducing the reliance on fossil fuels
- Solar based devices help in saving money and minimizing energy wastage.
- Solar inverters have a long lifespan and require minimal maintenance, making them a cost-effective solution for generating electricity from the sun.
- Solar inverters can be easily integrated into existing electrical systems.
- The synchronous solar inverter helps small homeowners and also power companies as they are huge in size. (Smart Flow Technologies, 2023)

2.4 Disadvantages of Solar Inverter

- The original cost of setting up the system is extremely high.
- The PV cells generates DC and operates efficiently only when the energy from the sun is high.
- Solar inverters function even without sunlight, but their battery's functionality relies on its full charge from sunlight. (Smart Flow Technologies, 2023)

2.5 Inverter Batteries

A battery is a device that stores and provides electrical energy for various electronic devices or systems. It typically consists of one or more electrochemical cells that convert chemical energy into electrical energy. Batteries are commonly used in portable devices such as smartphones, laptops, and remote controls, as well as in larger applications like cars and power grids. A redox reaction transforms high-energy reactants into lower-energy products when a battery is coupled to an external electric load, and the free-energy difference is sent to the external circuit as electrical energy. (Energy Storage Systems Technologies, 2014).

A battery is actually made up of multiple cells connected together. Each cell within the battery undergoes the redox chemical reaction to produce electrical energy. However, the usage has evolved to include devices composed of a single cell.

Battery cells are usually made up of three main components; x3

- The Anode (Negative Electrode)
- The Cathode (Positive Electrode)
- The Electrolytes

The anode is typically made of a metal or graphite material and is responsible for releasing electrons during the battery's discharge. The cathode, on the other hand, is usually composed of a different material that can accept those electrons during charging. Finally, the electrolyte acts as a medium for ion transport between the anode and cathode, allowing for the flow of electric current within the battery.

When batteries are linked, an electron accumulation is triggered at the anode, which generates a potential difference between the two electrodes. This movement of electrons through the circuit is what creates an electric current. The electrolyte prevents the electrons from spontaneously redistributing themselves. When an electrical circuit is linked, it creates a clear channel for electrons to pass from anode to cathode, energizing the circuit to which it is connected (Energy Storage Systems Technologies, 2014).

2.5.1 Types of Batteries

There are two types of batteries which are;

- Primary Batteries.
- Secondary / Rechargeable Batteries.

Figure 2. 1: Type of Battery

2.5.1.1 Primary Batteries

Primary batteries, also known as disposable batteries, are non-rechargeable power sources that provide a one-time use of energy. Primary batteries are built of electrochemical cells whose electrochemical reactions cannot be reversed. Primary batteries occur in numerous types, ranging from coin cells to AA batteries (Energy Storage Systems Technologies, 2014). They are typically employed in standalone situations when charging is inconvenient or impossible. A notable illustration of this is in military-grade electronics and battery-powered equipment. It will be impractical to use rechargeable batteries, as recharging a battery will be the last thing on the minds of the warriors. Primary batteries always have high specific energy, and the systems in which they are utilized are always intended to consume a modest amount of power to enable the battery to live as long as possible.

An alkaline battery is the most common form of primary battery. They offer a high specific energy, are eco-friendly, cost-effective, and do not leak even when fully drained. They can be kept for several years, have an excellent safety record, and can be transported on an aircraft without violating any transportation or other restrictions (Energy Storage Systems Technologies, 2014). The only disadvantage of alkaline batteries is their low load current, which restricts their application to low-current devices such as remote controls, flashlights, and portable entertainment devices.

2.5.1.2 Secondary/Rechargeable Batteries

Secondary batteries, also known as rechargeable batteries, are energy storage devices that may be charged and utilized repeatedly. Secondary batteries, as opposed to primary batteries, which are disposable and cannot be recharged, are intended to be more sustainable and cost-effective in the long run. They are widely employed in a wide range of applications, including portable gadgets, electric cars, and renewable energy systems.

The electrochemical cells in rechargeable batteries undergoes a reverse chemical reaction by applying a certain voltage to the battery in the reversed direction. (Energy Storage Systems Technologies, 2014).

They can also be utilized as stand-alone power sources in conjunction with inverters to supply electricity. Although, the initial cost of purchasing rechargeable batteries is always much more than that of primary batteries, but they are the most effective over time. Secondary batteries are further divided based on their chemistry into numerous more categories. This is extremely important since the chemistry impacts some of the battery's characteristics, including as specific energy, cycle life, shelf life, and pricing, to name a few. For rechargeable batteries, there are four primary chemistries (Chem Libretexts, 2023).

- Lithium-ion (Li-ion)
- Nickel Cadmium (Ni-Cd)
- Nickel-Metal Hydride (Ni-MH)
- Lead-Acid

2.5.1.2.1 Lithium-Ion Batteries

Lithium-ion batteries are a form of rechargeable battery in which lithium ions migrate from the negative electrode to the positive electrode during discharge and back to the negative electrode during charging. In contrast to the metallic lithium used in non-rechargeable lithium batteries, lithium-ion batteries use an intercalated lithium compound as one electrode material. (Chem Libretexts, 2023)

2.5.1.2.2 Nickel-Cadmium Batteries

The nickel-cadmium battery (NiCd or NiCad) is a rechargeable battery made from nickel oxide hydroxide and metallic cadmium electrodes. It excels at maintaining voltage and holding charge when partially charged, reducing future capacity. Compared to other rechargeable cells, NiCd batteries offer a good life cycle, performance at low temperatures, and fair capacity. (Energy Storage Systems Technologies, 2014).

Their most significant advantage will be their ability to deliver their full rated capacity at high discharge rates. They come in a variety of sizes, including those used for alkaline batteries, ranging from AAA to D. Ni-Cd cells can be utilized individually or in groups of two or more cells. Smaller packs are used in portable gadgets, electronics, and toys, whereas larger packs are used in aircraft starting batteries, electric cars, and standby power supplies.

2.5.1.2.3 Nickel-Metal Hydride Batteries

Nickel metal hydride (Ni-MH) is another chemical configuration used for rechargeable batteries, similar to nickel-cadmium cells (NiCad). They both use the same nickel oxide hydroxide (NiOOH) at the positive electrode, but the negative electrodes use a hydrogen-absorbing alloy instead of cadmium. Ni-MH batteries have a longer lifespan and are suitable for high-drain devices due to their high capacity and energy density. They can have two to three times the capacity of a NiCad battery. Additionally, they are considered more environmentally friendly due to the absence of toxic cadmium. (Energy Storage Systems Technologies, 2014).

2.5.1.2.4 Lead-Acid Batteries

Lead-acid batteries are a low-cost, dependable power source that is commonly utilized in heavy-duty applications. Because of their size and weight, they are always employed in non-portable applications such as solar panel energy storage, vehicle ignition and lights, backup power, and load balancing in power generation and distribution. Lead-acid batteries are the oldest type of rechargeable batteries and are still widely used today. Lead-acid batteries have very low energy-to-volume and energy-to-weight ratios but a reasonably high power-to-weight ratio, allowing them to generate massive surge currents when needed. These characteristics, together with their low cost, make these batteries appealing for use in a variety of high-current applications, such as powering automotive starter motors and storing power in backup power supplies (Energy Storage Systems Technologies, 2014).

2.6 Review of Related Works

Maina Nbunu (2014), designed a pure sine wave inverter for house backup. In his work, he generated unipolar modulating signals from a PIC16F877A microcontroller and used them to modulate a 12V DC MOSFET-based full H-bridge. He was able to achieve an inverter that gives 240V, 600W sinewave output. Although his work was efficient, the maximum power of 600W generated by the inverter system was unable to power the majority of domestic dwellings and offices.

Idowu *et al*. (2017), worked on creating a DC-DC converter based 3KVA DC-AC power inverter using a Half-Bridge inverter topology and a boost converter. With the use of a high frequency ferrite transformer, they were able to create an inverter that was relatively smaller in size. Although a high efficiency level was reached and a maximum power of 3KVA was generated, more power could not be generated due to the design of the ferrite core transformer used. This inverter is therefore limited to a range of power applications.

Jim *et al*. (2006-2007), carried out a project titled. "DC/AC Pure Sine Wave Inverter". The design was based on a Pulse width Modulation (PWM) sine wave design architecture and a DC-DC converter. Through the use of a DC-DC converter, which enables the use of a high frequency, significantly smaller size transformer, an effort was made in their work to lower the total size of the entire inverter system. Using a DC-DC converter, low voltage DC, the high voltage DC was converted to an AC output voltage using a three level analog PWM technique, an H-bridge and a low passive filter. At the testing stage, they were able to produce an inverter with a frequency of 60Hz and an output of 120V RMS pure sine wave that functioned under light and medium loads. A limitation in the system was that high frequency oscillations had an impact on the inverters output, while carrying greater loads due to the filter design using chokes as inductors.

Adiyanju A.Y (2003), designed and constructed a 750-watts inverter that uses a renewable energy source and is based on a piece of exercise gear. The inverter used a generator-based system to harness mechanical energy and transform it into electrical energy. In his work, he generated oscillating pulses by combining a J-K flip flop with a 555-timer (IC). At that time, he was able to create an inverter with a higher efficiency at low load.

However, the inverter was unable to power equipment with higher power ratings needed in many applications today. Inefficiency of this system also resulted from the lack of a provision for the automatic switching from the mains to the inverter and vice versa.

Henry and Ige (2008), designed and constructed a 5KVA inverter, using a CD4047BCN multi-vibrator, in their work, a square wave output with a 50% duty cycle was produced by the CD4047BCN multi-vibrator and then stepped up by the transformer and filtered by the filter. They succeeded in creating an inverter with a maximum power output of 5KVA and a voltage of 220v at 50Hz. The inverter was designed to be compact, lightweight and capable of driving a range of loads.

Although their work was efficient, the project has some limitations. For example, the oscillator section of the inverter does not have a battery monitor that will update the user of the battery condition and there is no battery low shutdown circuit in the oscillator section, which can result in a reduction of battery life.

Urhide Calvin (2008), worked on a project titled," Design and Construction of 200watts Inverter." He designed a 200-watts inverter employing a half bridge topology. It included two power MOSFET transistors, two diodes and a filter capacitor. A relatively simple design was realized, which was well suited for low-powered applications. Despite the fact that this work was efficient, the output power of 200-watts is quite low in comparison to the current energy demands.

Isaac Ibrahim (2016), designed a power inverter with a 220-240V output voltage range. He used a Bubba Oscillator to generate a stable sine wave with minimal irregularities for his work. Among the components utilized in his design was a step-up transformer, full-bridge rectifier, low-pass filter and an Arduino-Uno Microcontroller which was used to control the MOSFETS switching.

He succeeded in developing an inverter that could convert a 12V DC source input voltage into a 220V AC power supply with a 50Hz frequency, and depending on the battery capacity implemented, it could be used to power 700W electrical appliances. Although the efficiency was at such a high level, the frequency after testing was not stable and fluctuated between 50Hz and 50.6Hz, and the output waveform remained sine wave despite the objective waveform was modified sine wave.

Nutra Bernard (2014), designed a microcontroller-based inverter. In his work, he generated sinusoidal pulse width modulating (SPWM) signals from a PIC16F877A microcontroller, and used them to modulate a 24V DC MOSFET based on Full H-bridge. Among the components utilized in his design were a step-up transformer, bootstrap diode, and a transformer which was used as an inductor in the LC filter design. He was able to achieve an inverter that gives 240V and at least a 600W modified sine wave output. Achieving an efficiency of 91.2% current flow was limited due to the high internal resistance of the transformer used in the LC filter design.

The inverter system proposed in this project will overcome the challenges in previous designs. It will achieve a pure sine wave with high efficiency. It will also include a higher performing microcontroller (i.e., DSPIC30F2010) than those employed in literature, making for an improved control unit.

CHAPTER THREE

DESIGN METHODOLOGY

This chapter gives an in-depth analysis of the electronic circuit design used in this work. Also, the basic principles upon which the design is based are discussed.

3.1 Block Diagram of the Inverter System

Figure 3.1 shows the block diagram which gives a simple functional view of the overall inverter system and how each unit of the system relate to each other.

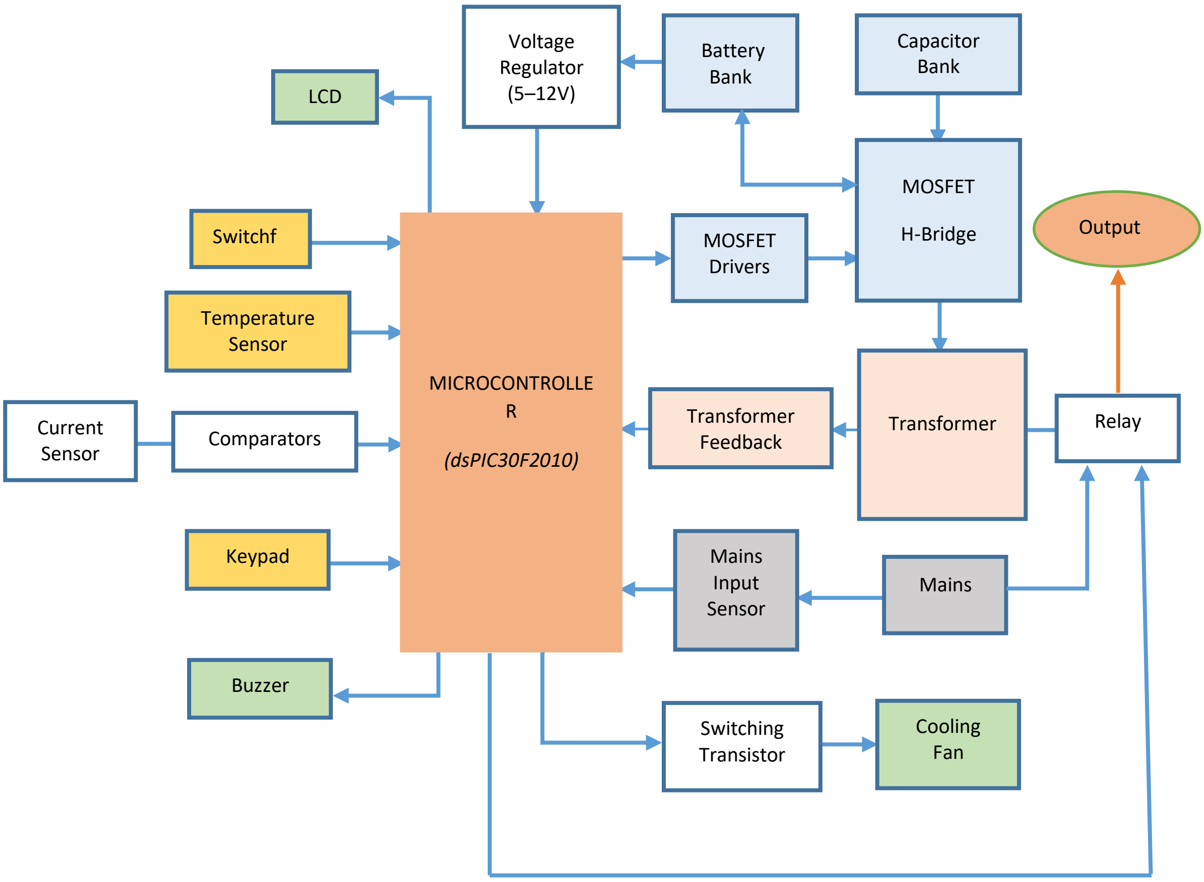

Figure 3. 1: Block Diagram of Inverter System

3.2 Design Considerations

The project design includes the following units:

The Inverter unit, AC Mains, Display Unit, Inverter feedback unit, AC mains feedback unit, Relay and the Load Outlet unit. Each of these units are discussed below according to the step-by-step procedure for the design of this project. The Microcontroller section, the MOSFET drivers' section, the Wave shaping network, the H-Bridge section, the Transformer section, the Voltage Regulation section, the Battery section, the Circuit protection section.

Design considerations comprise recognizing the proper issue and ensuring the device, equipment, machine, or facility's aims and needs are suitable to avoid failure. Hence, designing an acceptable solution assures technical quality and success.

The considerations listed below are the standards for the project design. The following parameters will be maintained throughout the design and construction process. They are as follows:

i.	System Output Power	3000VA (3KVA)
ii.	Type of waveform	Pure-Sine wave
iii.	Battery Input Voltage	24V
iv.	Frequency	50Hz
v.	Battery Capacity	400A/H
vi.	Output voltage	220V (single phase)

3.2.1 Microcontroller Unit

The Microcontroller used in this work is a DSPIC30F2010 by Microchip Technology Inc. It is an advanced 16-bit high speed processor, optimized to perform complex calculations quickly, and a DSP Engine for math intensive operations (DSPIC30f2010 Datasheet, accessed 2023). The microcontroller provides the variable frequency dependent pulse width modulation (PWM) signal that adjusts the voltage applied on the gate drive of the MOSFETs. The sine lookup table below defines the duty cycle and the frequency of the generated pulse width by the microcontroller.

SineTable64 [array] = {127, 139, 152, 164, 176, 187, 198, 208, 217, 225, 233, 239, 244, 249, 252, 253, 254, 253, 252, 249, 244, 239, 233, 225, 217, 208, 198, 187, 176, 164, 152, 139, 127, 115, 102, 90, 78, 67, 56, 46, 37, 29, 21, 15, 10, 5, 2, 1, 0, 1, 2, 5, 10, 15, 21, 29, 37, 46, 56, 67, 78, 90, 102, 115 }

These figures are used to generate a pulse width modulated signal that is directly proportional to the sine wave. The pin-out diagram of the DSPIC30F2010 microcontroller is shown in Figure3.2.

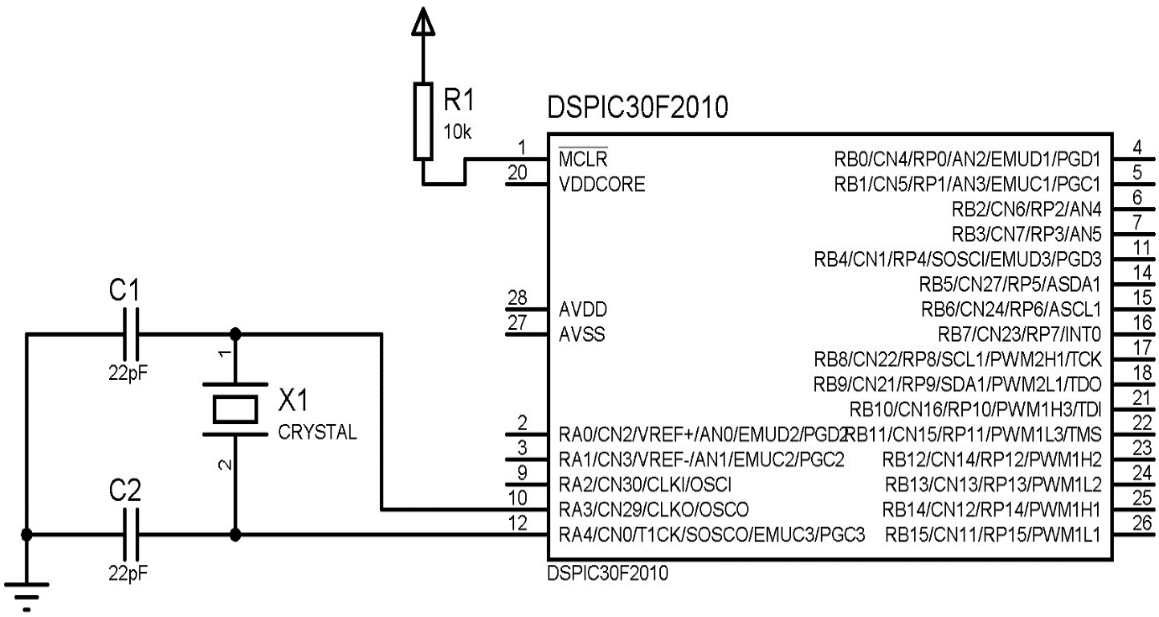

Figure 3. 2: Microcontroller Circuit Diagram

3.2.2 Battery Bank Unit

Inverter batteries are generally designed to give an output of 12V. Hence, the inverter would require at least two batteries for a 24V system. The batteries are connected in series to add up to achieve 24V. The energy stored in the batteries is converted from DC to AC at 220V through the inversion process.

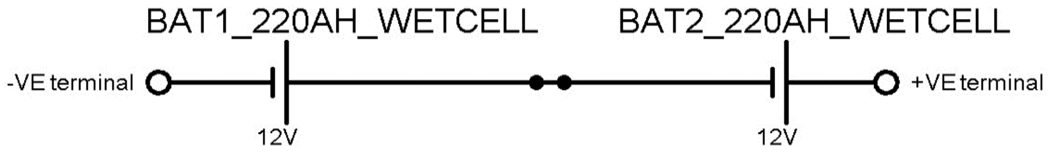

Figure 3. 3: Batteries Circuit Diagram Showing Series Connection

3.2.3 MOSFET Drivers Unit

The MOSFET driver is a pre-amplifying IC. The microcontroller lacks the circuitry to source or sink the large current required by the MOSFETs for switching. Hence, the output signal is initially sent to the MOSFET drivers which then draws more power from the battery bank, preamplifiers the signal from the microcontroller and feeds the MOSFET terminals for switching. In this design two IR250 MOSFET drivers are used and are connected to pin18 and pin 21 (PWM output pins) of the DSPIC30F2010 microcontroller as shown in Figure 3.4.

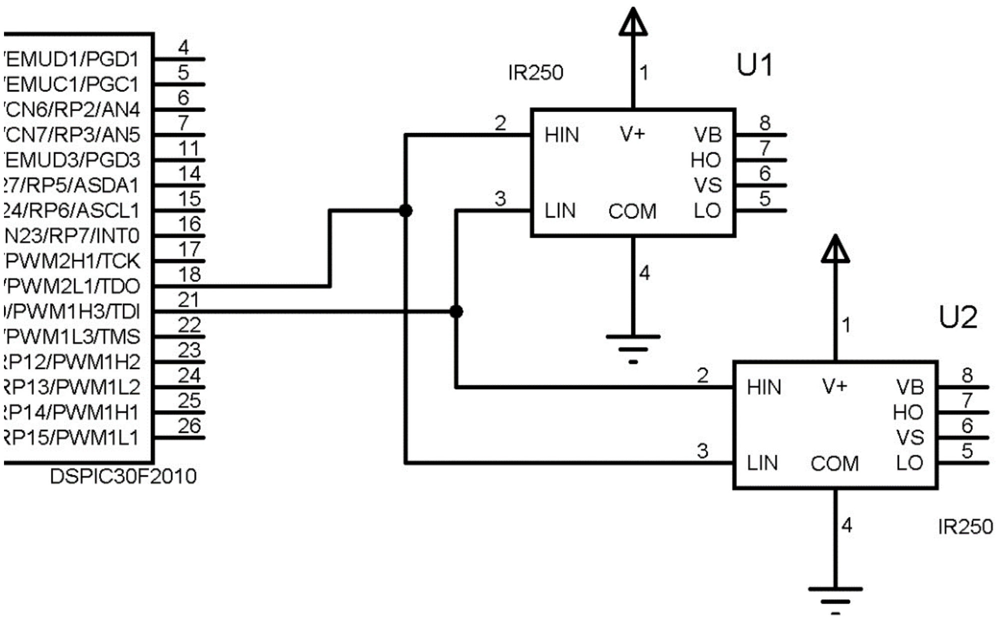

Figure 3. 4: MOSFET Driver Circuit

3.2.4 MOSFET H-Bridge Unit

An H-Bridge is an electronic circuit that switches the polarity of the voltage applied by a load (Wikipedia, accessed 2023). The name stems from its schematic diagram with four switching sections, configured as the branches of the letter ‘H’ and the load connected as the cross bar in the circuit diagram as shown in Figure 3.5.

To calculate the ratings of MOSFETs required for the design, the power rating of the inverter is considered. For an inverter power rating of 3000VA, and a battery voltage of 24V, the load current I, is given by

$$I = \frac{P}{V} \quad (3.1)$$

Where,

P = Power rating

V = Voltage Rating

$$I = \frac{3000\,VA}{24\,V} = 125\,A \quad (3.2)$$

Therefore, the MOSFETs are selected with voltage ratings anywhere not more than the battery voltage root mean square value as its drain source voltage (V_{DSS})

$$V_{DSS} = V_{Battery} \times \sqrt{2} \quad (3.4)$$

$$V_{DSS} = 24 \times \sqrt{2} \quad (3.5)$$

$$V_{DSS} = 33.94\,V \quad (3.6)$$

The continuous drain current I_D equals the Load current which is 125Amps

To ensure proper management of current, each side of the H-bridge must be able to have at least 1.5 times the current, i.e.

$$125A \times 1.5 = 187.5A \qquad (3.7)$$

The IRF3205 MOSFET is rated to have a drain-source current of 110A, and a drain- source voltage of 50V. However, more IRF3205 MOSFETs are paralleled together to form each section of the H-bridge to meet the required voltage and current requirement. Heat sink are attached directly to the MOSFETs to conducts the heat to its fins. The heat sink is then kept cool by the cooling fan. Heat sinks hereby ensures that the internal heat generated in the MOSFETs is properly dissipated. The MOSFET circuit diagram is shown in Figure 3.5.

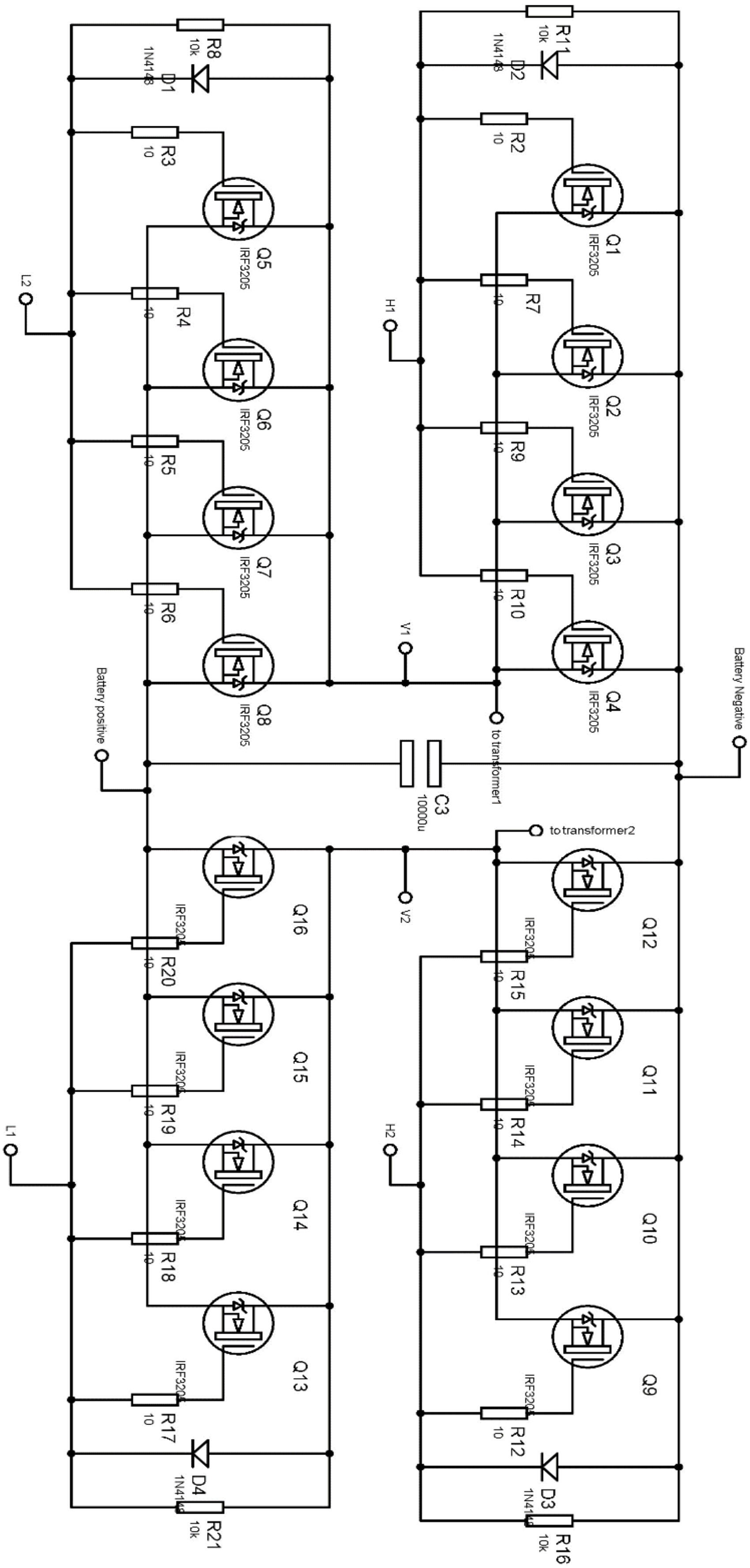

Figure 3. 5: H-Bridge MOSFET Circuit

3.2.5 Voltage Regulation

A voltage regulator is a device that keeps the output voltage constant regardless of any fluctuation in the input voltage from its power source. This is necessary to keep the voltage within the compatible range for other electronic component using that voltage level (Britannica, accessed 2023).

The voltage regulators used in this design were 7805 voltage regulator and LM317 voltage regulator. The 7805 regulator IC generates an output of 5V, while the LM317 regulator gives an output of 12V. The 5V output is used to power certain devices or ICs on the control board which requires 5V input voltage, such as the microcontroller.

The 12V is required by the switching relays.

$$\%VR = \frac{V_{OL} - V_L}{V_L} \times 100 \quad (3.8)$$

Where,

%VR = Percentage voltage regulation

V_{OL} = No load voltage

V_L = Full load voltage

For the 7805-voltage regulator (5V),

V_{OL} = 5V

V_L = 4.5V

$$\%VR = \frac{5 - 4.5}{4.5} \times 100 = 11.11\% \quad (3.9)$$

For the LM317 regulator (12V),

V_{OL} = 12V

$V_L = 11.5V$

$$\%VR = \frac{12 - 11.5}{11.5} \times 100 = 4.34\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.10)$$

This implies that the 7805 and the LM317 voltage regulators are 88.89% and 95.66% efficient respectively. The circuit diagram is shown in Figure 3.6.

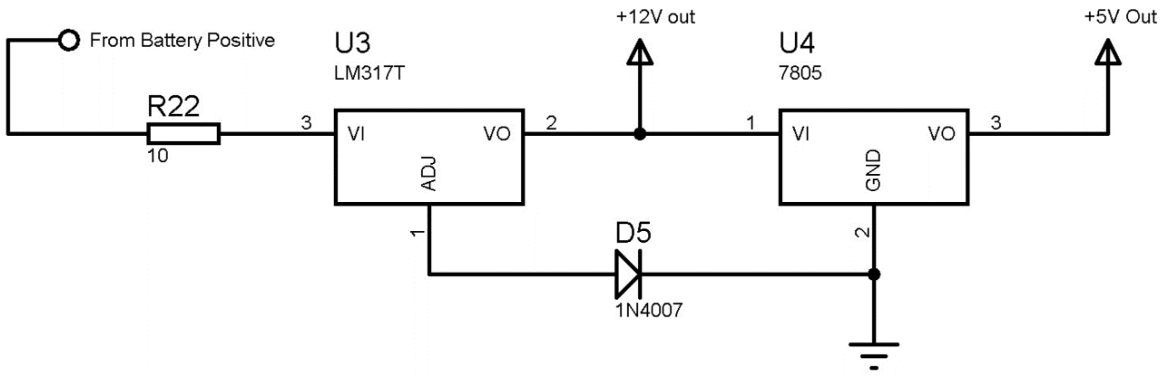

Figure 3. 6: Voltage Regulator Circuit

3.2.6 Transformers

A transformer is a static electrical device which can be used to step-up voltage level or step-down voltage level, while the frequency remains constant. It works based on the principle of electromagnetic induction. It is made up of primary and secondary windings (Britannica, accessed 2023).

The transformer used in this work is a shell type transformer. It has a power rating of 3 KVA, and is wound with enamel copper coils. The primary side of the transformer is connected to the H-Bridge MOSFET unit, while the secondary side is connected to the load.

The design calculations for the transformer are shown below:

i. **Calculation for the Core**

The area of the core can be calculated using the formula

$$A_i = \frac{P}{4.44\, f B_m T_e} \qquad (3.11)$$

Where,

P = Output Power

A_i = Area of the core

f = Operating frequency

B_m = Magnetic flux density

T_e = Turns per volts

The following assumptions were made:

- During the design process of a small transformer, the flux density is taken as 1 or 1.2 T
- The current density of copper wire is assumed to be between 2.2 to 2.4A/mm^2

Given that the frequency, f is 50Hz and the magnetic density is assumed to be 1.2Wb/m^2 with Te = 4 turns per volt,

Substituting these values in the equation 3.11 above,

$$A_i = \frac{3 \times 10^3\, VA}{4.44 \times 50 \times 1.2 \times 4} \qquad (3.12)$$

A_i = 1.45 inch^2

Due to the fact that the standard bobbins available are 1 inch x 1 inch, 1.2 inch x 1.2 inch, 1.5 inch x 1.5 inch, etc.

Considering the nearest core available in the calculation, a bobbin of 2.25 $inch^2$ (1.5 x 1.5) or $0.00145161m^2$ was chosen. The number of turns per volt using the core area as $0.00145161m^2$, flux density as 1.2 units and frequency as 50Hz was given as:

$$T_e = \frac{3 \times 10^3\ VA}{4.44 \times 50 \times 1.2 \times 0.00145161} = 2.6\ turns\ per\ volts \ldots\ldots\ldots\ldots\ldots\ldots \text{(3.13)}$$

ii. <u>Calculation for the current in the secondary winding</u>

Secondary voltage V_s = 220V

Output Power, P = 3000VA

Secondary current, $I_s = P/V_s$

$$I_s = \frac{3000}{220} = 13.636A \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.14)}$$

Assuming that the machine is operating at 95% efficiency η,

$$I_s = \frac{P}{\eta V_s}$$

$$I_s = \frac{3000}{220 \times \frac{95}{100}} = 14.354A \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.15)}$$

iii. <u>Calculation for the number of turns in the secondary winding</u>

The number of turns in the secondary was calculated using:

Total number of turns (N_s) = Number of turns per volt × Secondary Voltage

N_s = 2.6 × 220 = 572 turns …………………………………………………..… (3.16)

iv. Calculation for the Secondary winding conductor size

Given that the current density is current per unit area,

Area of copper conductor for primary (a_i)

$a_i = \frac{14.354}{2.3} = 6.239mm^2$………………………………………………….… (3.17)

Using the Standard American wire gauge table (Calmont wire and cable, accessed 2023), we can choose a wire of this thickness. It is shown that the required primary side wire is of 27 gauge and will be suitable for the current required.

v. Calculation for the current in the primary winding

Primary voltage V_p = 24V………………………………………………………….… (3.18)

Primary current, $I_p = {P}/{V_p}$ ……………………………………………………..… (3.19)

$I_P = \frac{3000}{24} = 125\ A$…………………………………………………………….… (3.20)

From the standard wire gauge table, it is shown that the required wire thickness is of gauge 14.

vi. Calculation for the number of turns in the primary winding

The number of turns in the primary winding is calculated using:

Total number of turns (N_p) = Number of turns per volt × Primary Voltage

N_p = 4× 24 = 92 turns ……………………………………………….………………. (3.21)

The Transformer circuit diagram is shown in Figure 3.7.

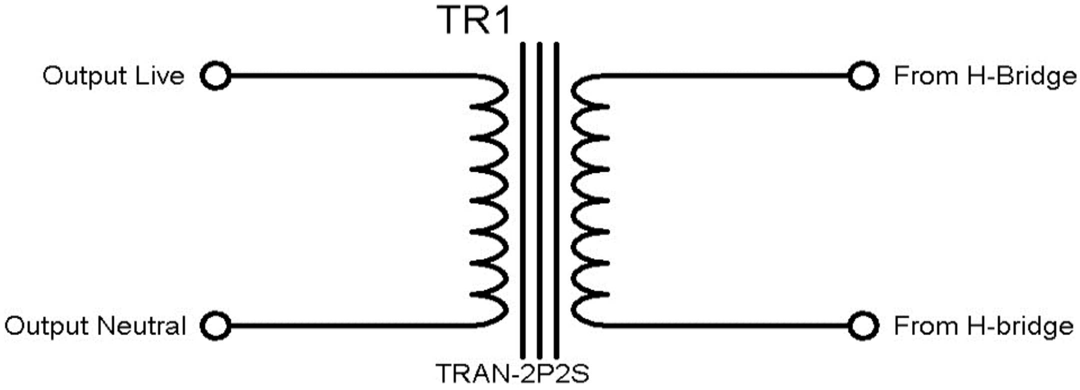

Figure 3. 7: Transformer Circuit Diagram

3.2.7 Transformer Feedback Unit

The transformer feedback is basically another loop winding attached to the transformer. Considering the fact that when the inverter is used, the input battery voltage reduces, which in turn results in a reduction of the inverter supply output voltage, a voltage level which varies with the output of the inverter is feedback into the microcontroller on a 12V scale. The microcontroller then compensates for the continuous drop in the battery voltage during operation by adjusting the duty cycle of the pulse width send to the MOSFET drivers which in turn increases the current drawn from the battery during operation. This ultimately ensures that the inverter system provides a steady output throughout its period of use.

The feedback voltage turns value is calculated as follows:

From transformer equation,

$$\frac{N_1}{N_2} = \frac{V_1}{V_2} \quad (3.22)$$

$$\frac{N_p}{N_{fb}} = \frac{V_1}{V_b} \quad (3.23)$$

Where,

N_p = Number of turns in the primary side

N_{fb} = Number of turns in the feedback section

V_1 = Primary voltage

V_{fb} = feedback voltage

The feedback voltage level is 12V,

$$N_{fb} = \frac{N_b V_{fb}}{V_1} = \frac{572 \times 12}{220} = 31.2\ turns \quad (3.24)$$

The transformer feedback circuit is shown in Figure 3.8.

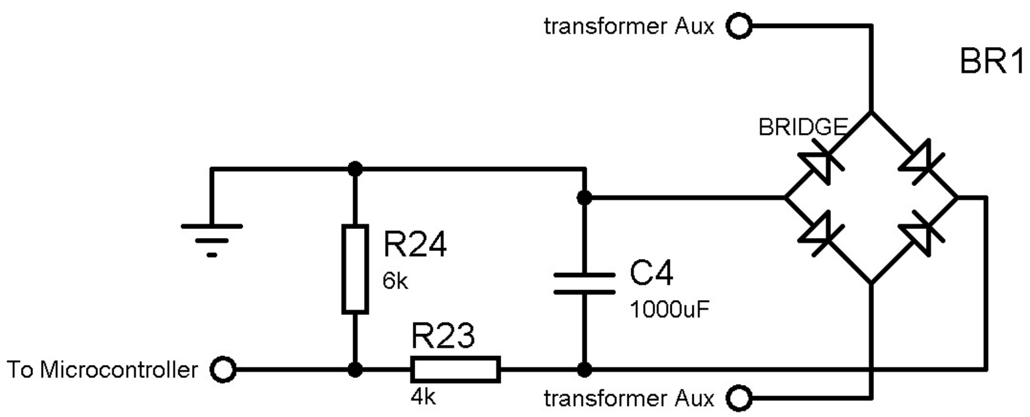

Figure 3. 8: Transformer Feedback Circuit

3.2.8 MAINS

This unit highlights the AC supply from the power distribution company. The rated voltage is 220V (per phase) at a frequency of 50Hz and it is assumed that the power rating is infinite.

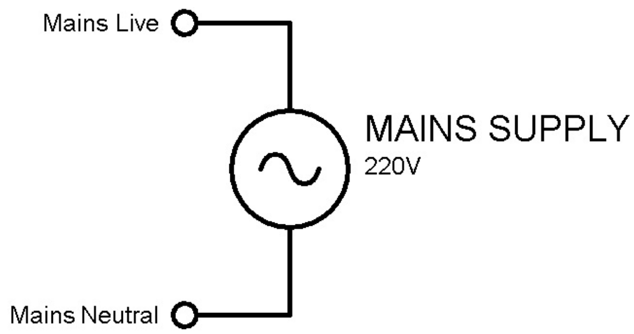

Figure 3. 9: Mains Circuit Diagram

3.2.9 Mains Input Sensor

The mains input sensor is used to detect the presence/ availability of external AC power supply, in order to switch the inverter's load to the AC supply and simultaneously charge the battery bank. The circuit that charges the inverter battery consists of a full wave diode bridge. The diode bridge is made from the arrangement of four (4) 1N4007 diodes. This is a 1000V, 1A diode which is most suitable for this application. The diode bride rectifies the AC supply and is passed to a 1M Ω potentiometer which reduces the voltage level to a very small value of about 5V. This voltage is then sent to the base of the transistor. The transistor functions as to send input voltage signal to microcontroller. The Mains input sensor circuit is shown in Figure 3.10.

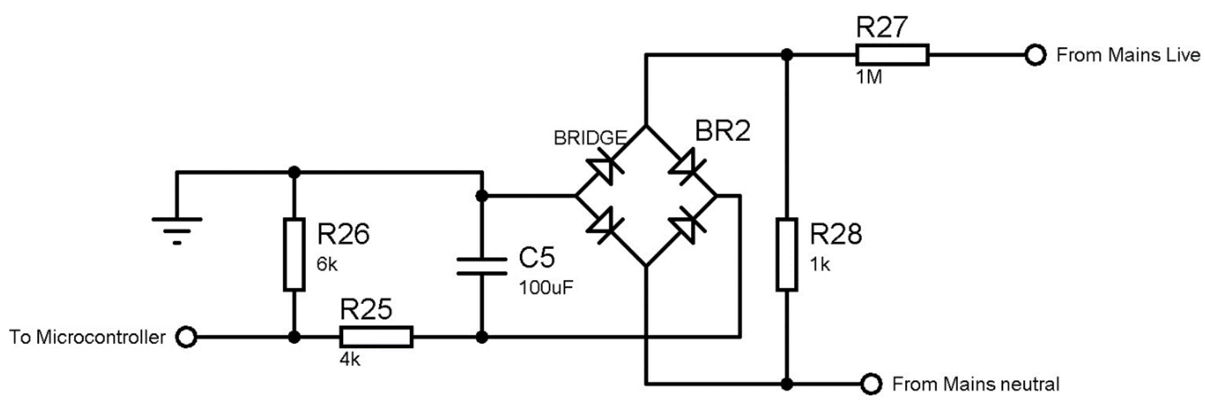

Figure 3. 10: Mains Input Sensing Circuit

When AC mains signal is sensed, the microcontroller stops inverting and the charger section starts its operation. In this mode, the system transformer works as a step-down transformer and output 24V at its secondary winding. During the charging, MOSFET transistors at the output section works as rectifier with the drain working as the cathode while the source works as the anode. The center-tapping of the transformer receives positive supply and the MOSFET source receives negative supply from the battery. The center-tapping is connected to the positive terminal of the battery and the MOSFET source 'S' is connected to the negative terminal with a shunt resistance. Thus, when the inverter receives AC mains supply, the transformer and MOSFETs together work as a charger and charge the battery. The following are design considerations in this regard:

i. Calculation for the Diode Bridge

The average DC output voltage across the load resistor is double that of the half wave rectifier circuit, assuming no losses.

$$V_{dc} = \frac{2\,V_{max}}{\pi} \qquad (3.25)$$

$$V_{max} = 24V \qquad (3.26)$$

$$V_{dc} = \frac{2 \times 24}{\pi} = 15.2V \qquad (3.27)$$

ii. Ripple Factor

The ripple factor is a measure of the purity of the DC output of a rectifier and is given as:

$$\mathrm{R} = \frac{V_{ac}\,(output)}{V_{dc}\,(output)} \qquad (3.28)$$

$$V_{dc} = 15.2V \qquad (3.29)$$

$$V_{ac} = 24V \qquad (3.30)$$

$$R = \frac{24\,V}{15.2\,V} = 1.96 \quad (3.31)$$

iii. <u>Rectification Efficiency</u>

The rectification efficiency, η is given by:

$$\eta = \frac{d.c\ power\ delivered\ to\ load}{a.c\ power\ delivered\ at\ input} \quad (3.32)$$

$$\eta = \frac{V_{dc}I_{ac}}{V_{ac}I_{ac}} \quad (3.33)$$

$$I_{ac} = \frac{3\ kva}{24} = 0.13A \quad (3.34)$$

$$I_{dc} = \sqrt{2}\, I_{ac} = 0.18A \quad (3.35)$$

$$\eta = \frac{15.2 \times 0.18}{24 \times 0.13} = 0.88 \quad (3.36)$$

$\eta = 88\%$,

The rectification efficiency is 88%

3.2.10 Capacitor Banks

When the inverter is instantly loaded, the MOSFETs requires a large amount of readily available power. However, the battery banks are not fast enough to deliver that amount of power, due to the conversion of chemical energy to electrical energy. A capacitor however, stores its charges directly onto its plates and discharges faster than a battery when needed to correct power factor lags or phase shifts in an AC (alternative current) power supply. Capacitor banks hereby serve as a kind of shock absorber. The capacitors are discharged when the inverter sporadically demands heavy current and is slowly charged back by the battery. This helps maintain optimum efficiency and prevents undesirable dips or surges in voltage which can damage electrical equipment. The capacitors also serve as a DC-link to provide a more stable DC voltage, limits fluctuations and filter out ripples on the voltage used to charge the battery.

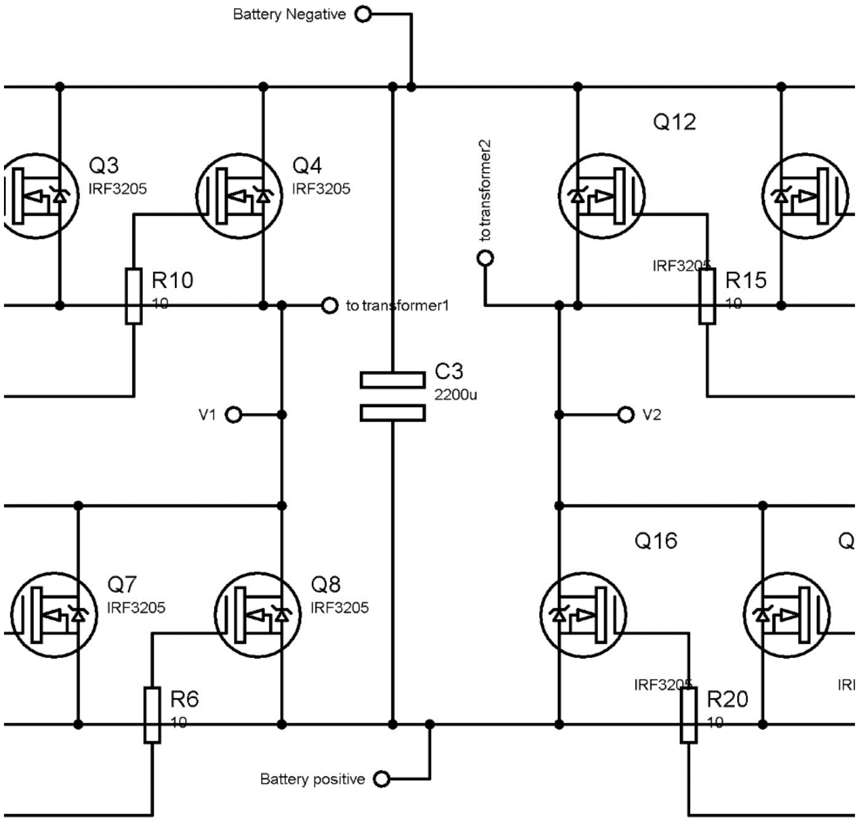

Figure 3. 11: Capacitor Bank at the Centre of the H-bridge

i. Capacitance Reactance Calculation

The measure of the opposition to the flow of alternating current by the capacitor is given by

$$Xc = \frac{1}{2\pi f c} \quad (3.37)$$

Where, Xc = Capacitive reactance

f = Frequency

c = Capacitance

Since the capacitor to be used is a 2200 microfarad (2200μF) capacitor.

$$Xc = \frac{1}{2\times\pi\times50\times2200\times10^{-6}} \quad (3.38)$$

$$Xc = 1.447\Omega$$

3.2.11 Switching Transistor and Relays

A 12V relay is connected to a BC547 transistor as shown in Figure 3.12, to switch the output of the inverter during charging and discharging operations. During charging, the relay switches to ensure that the AC mains voltage is connected directly to the transformer.

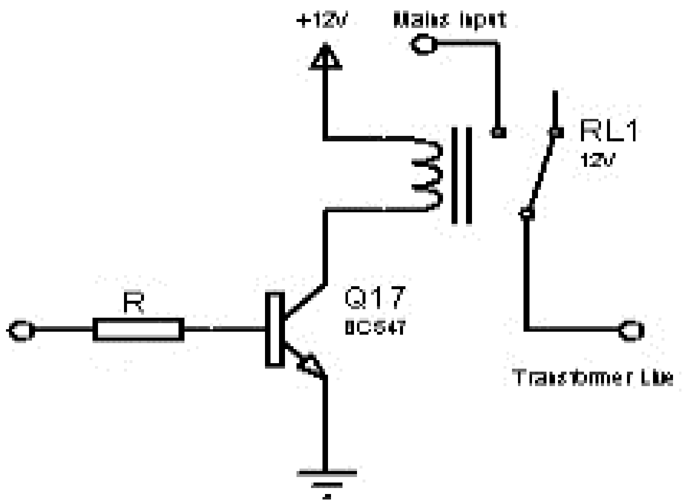

Figure 3. 12: Mains Switching Transistor and Relay

As seen in figure 3.12 above, a BC547 bipolar junction transistor (BJT) is used in this circuit, this transistor has the following key features (BC547 Datasheet, 2023).

i. It is an NPN transistor

ii. The gain of DC current (h_{fe}) is 8

iii. The continuous collector current I_C is 100mA

iv. Emitter Base voltage (VBE) is 6V

v. The maximum switching frequency is 300Hz

vi. Power dissipation is 625mW

i. **Transistor Base Resistor Calculations**

The expression in 3.39 shows the formula for determining the transistor's base resistor.

The formula for calculating the base resistor of the transistor is given by the expression:

$$R = \frac{(Us - 0.6)h_{fe}}{Relay\ Coil\ Current} \quad (3.39)$$

Where,

R = base resistance of the transistor

Us = Trigger voltage or source voltage to the base resistor,

h_{fe} = Forward current gain of the transistor,

The last expression which is the "relay coil current" may be found out by solving the following Ohm's law:

$$I = \frac{Vs}{R} \quad (3.40)$$

Where,

I = the required relay current

V_S = Supply voltage to the relay.

Given that the relay used is a 5V relay with a relay coil resistance of 500ohms, h_{fe} of the BC547 transistor is 8 the relay current I can be calculated as follows:

$$I = \frac{5}{400} = 0.0125A$$

Applying the above values to equation 3.39 we get,

$$R = \frac{(5-0.6)8}{0.0125} \quad (3.41)$$

R = 2816ohms, R ≈ 3Kohms

3.2.12 Current Sensor Unit

The current sensor is made up of a current transformer connected to a voltage divider arrangement. It senses the amount of current flowing through the output cable on the secondary side of the transformer. This is an effective method in monitoring overload and regulating the charging current. The current sensor works based on the principle of Hall Effect.

The Hall Effect principle states that when a semiconductor or a conductor which carried electrical current is introduced into a perpendicular magnetic field, a voltage can be measured at the right angle to the current path (Wateletronics, accessed 2023).

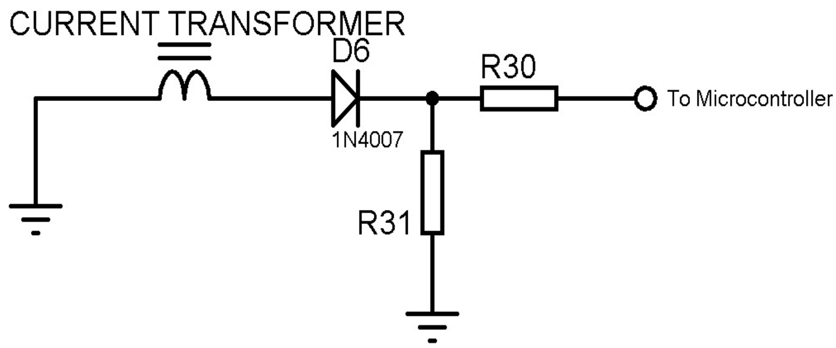

Figure 3. 13: Current Sensor

3.2.13 Temperature Sensor

The temperature sensor is made using a device called the thermistor. The thermistor is a device whose internal resistance is directly proportional to the temperature (ºK) (Wateletronics, accessed 2023).

The thermistor is attached to the MOSFET heat sink. Hence, it monitors the temperature of the MOSFET. The output signal voltage of the thermistor is monitored by the microcontroller, which sends a control signal to turn on the system cooling fan when the temperature goes above a certain pre-set value.

The thermistor used in this project is a NTC D-13 thermistor.

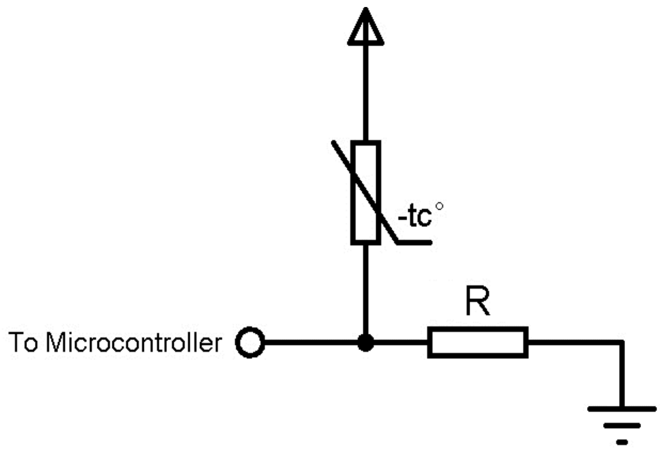

Figure 3. 14: Temperature Sensor

3.2.14 Comparator

An LM3581C is used in this work for low battery detection and overvoltage protection. It is a quad core comparator IC. It has four comparator units.

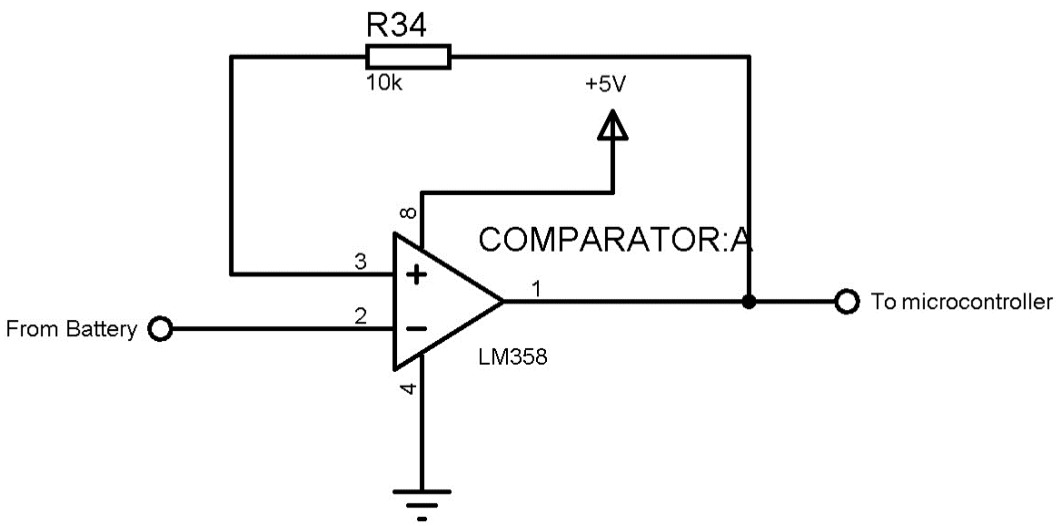

Figure 3. 15: Battery Comparator Circuit

3.2.15 LCD

The LCD (Liquid Crystal Display) used is a 16 x 2 LCD. It has two display lines and can display a maximum of 16 characters per line. Each character displayed is a 5 by 7pixel matrix. The LCD is interfaced with the microcontroller using the GPIO pins of the microcontroller and is used to display relevant information concerning the state of the inverter. This includes the battery charge level, the battery voltage level, the mains input voltage, output frequency and the status of the microcontroller. To optimize the number of pins connected to the controller the LCD is connected via the use of the 4015 4-bit serial in parallel out shift register IC.

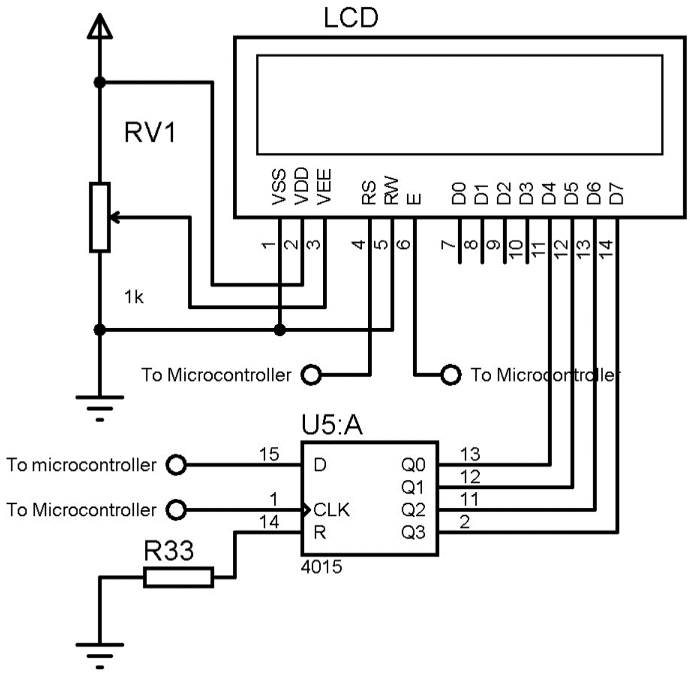

Figure 3. 16: LCD Circuit

3.2.16 Keypad and Power Switch

The keypad consists of three buttons (center, left, and right), designated to navigate and configure the inverter settings. The switch is used to turn off or turn on the inversion process in the microcontroller.

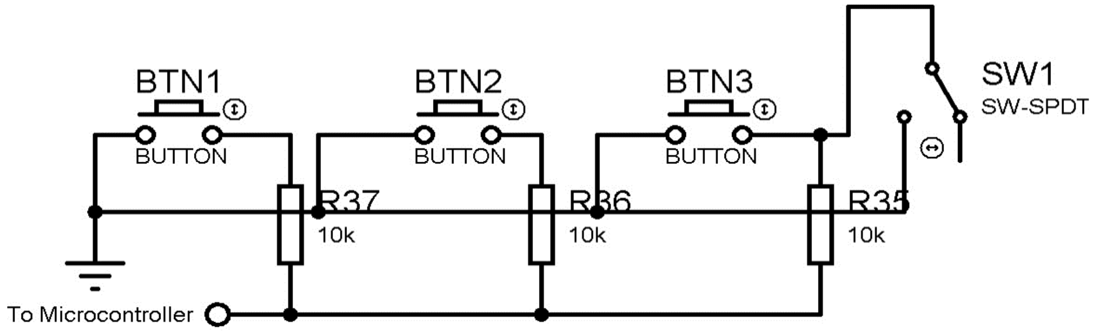

Figure 3. 17: Keypad and Power Switch Circuit

3.2.17 Buzzer

The buzzer is used to produce a buzzing/beeping sound to call to attention, regards different states of the system. These include a low battery state, charging state, inverter overload, a keypad press, etc.

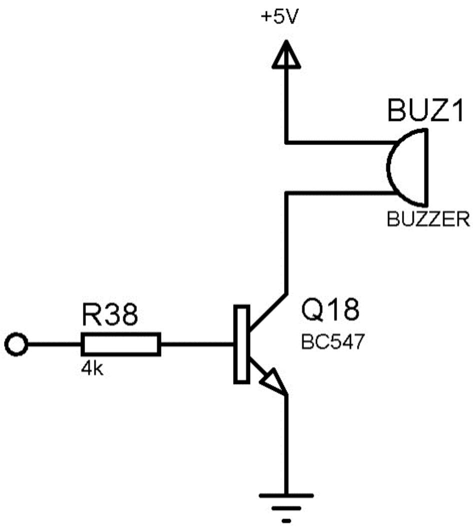

Figure 3. 18: Buzzer Circuit

3.3 Overall Circuit Diagram

The overall circuit diagram is shown in Figure 3.19.

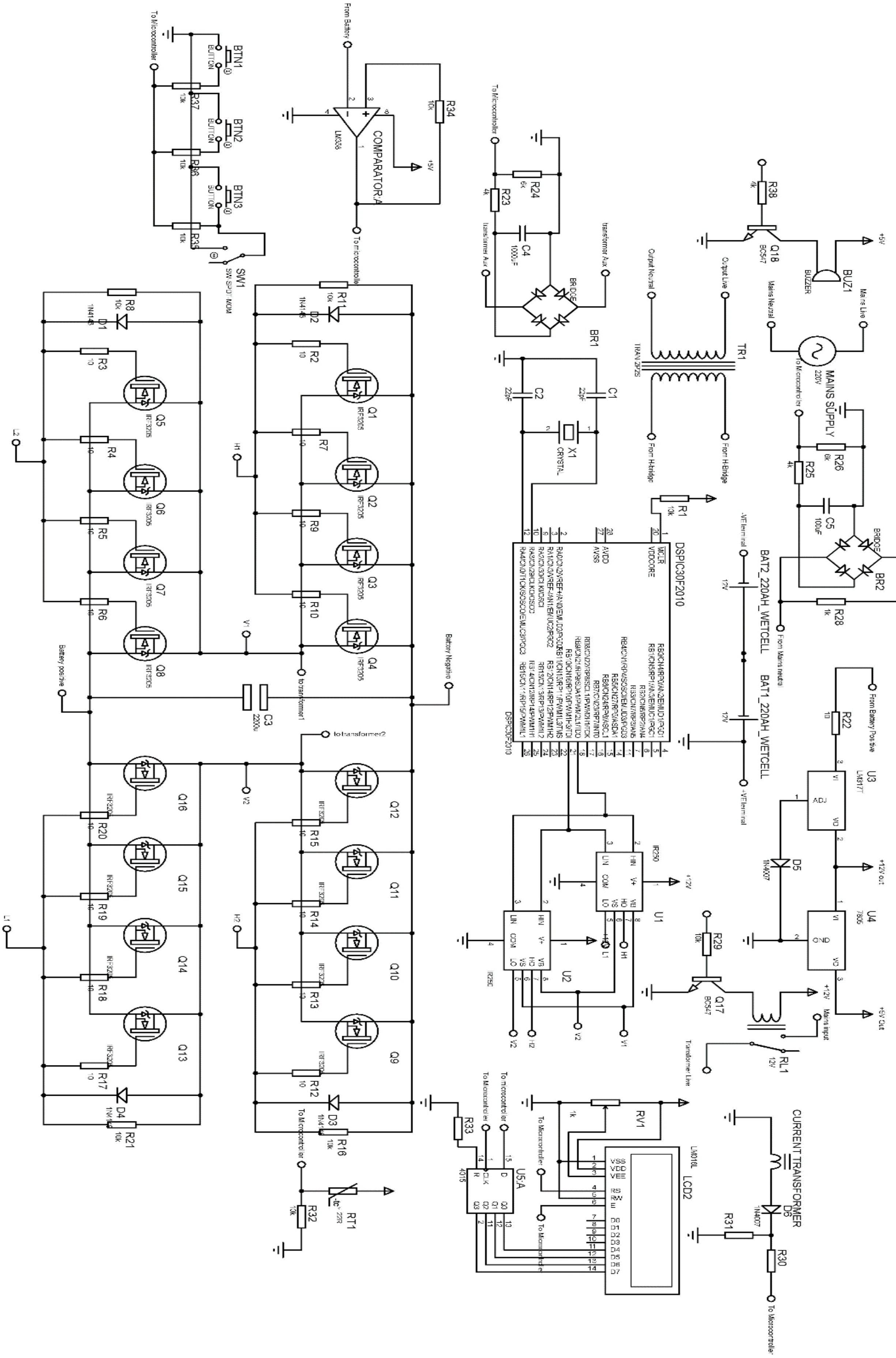

Figure 3. 19: Overall Circuit Diagram

3.4 Principle of Operation

The inverter requires a 24V battery for its operation, the energy stored in the battery is converted from its Direct current form to a sinusoidal AC output at 220V through the process of inversion. An electronic oscillator is an electronic device whose circuitry produces a periodic, oscillating electronic signal and this technique is applied. A sinusoidal oscillated output is achieved using a DSPIC30F2010 microcontroller. The microcontroller produces pulse width modulated (PWM) output whose duty cycle varies in a sinusoidal manner. The duty cycle values are programmed following a sine wave Look-up Table to ensure the smoothness of the wave form. The controller checks for battery level, overload, AC mains presence, high temperature, and many other features while the inversion process is going on.

A 16 by 2 liquid crystal display screen is used to display the status of the inverter, the battery’s state of charge, the inverter voltage and mains voltage values and frequency. Push Buttons are used to configure the inverter.

CHAPTER FOUR

DESIGN IMPLEMENTATION, TESTING AND RESULTS

The implementation of this design gives an insight to the outward appearance of the device, the physical design stages and the type of materials used both internally and externally in the design implementation.

4.1 Outward Casing of Inverter System with Dimensions

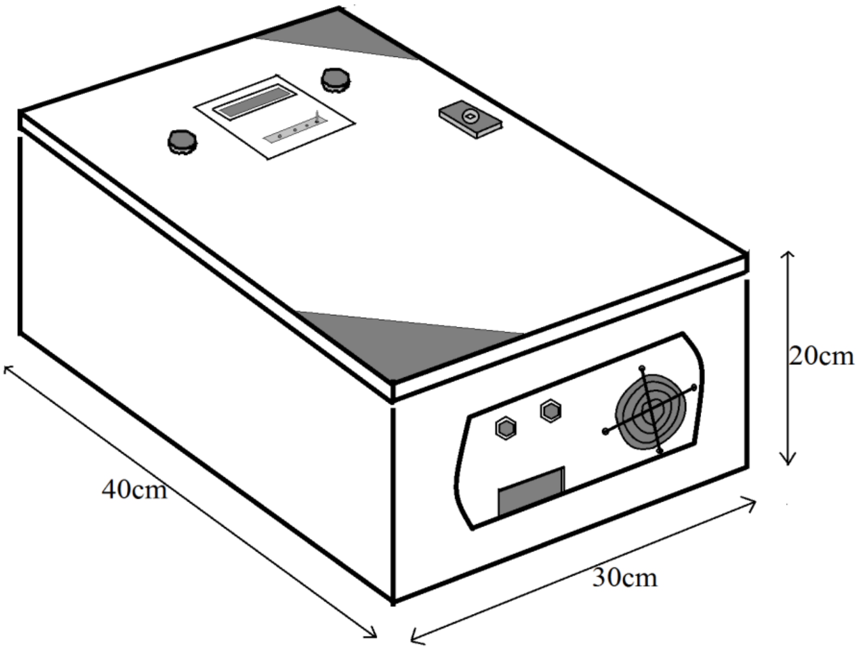

Figure 4. 1: Outward Casing of Inverter System

The proposed outward Casing and package dimensions of the pure sine wave inverter system is shown in figure 4.1 above.

4.2 Materials Used

A metal box made from iron was used to case the entire system. Medium density fibre (MDF) plywood was used as a base to isolate the internal circuits from the metal box casing. Other materials like polyvinyl chloride (PVC) plastics and aluminium were also used in the implementation of this package.

4.3 Construction

The steps in the development of this pure sine wave inverter system are as follows:

- Acquisition of required materials and electronic components.
- Sorting of tools
- PCB etching and masking
- Soldering and connection of electronic component and modules to make up the designed system.
- Packaging

4.3.1 Acquisition of Components

Some of the components were purchased from Ali-express (an online international market), and the others from Hub360 electronics shop via their website at www.hub360.com.ng.

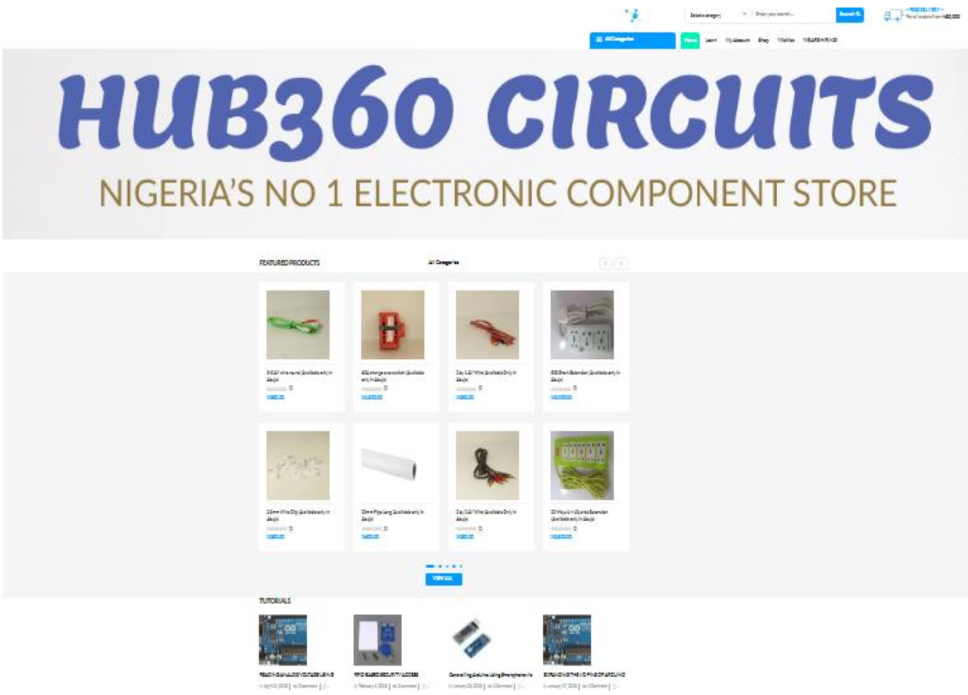

Figure 4. 2: Components acquisition via Hub360

4.3.2 Sorting of Tools

Tools make work easier and faster, when the right tools are not available, some certain work cannot be executed. The tools used in the implementation and testing of the DSPIC30F2010 pure sine wave inverter are as follows;

- Soldering iron
- Screw driver
- Cutter
- Pliers
- Hammers
- Cutting knife
- Digital multi-meter
- Digital Oscilloscope
- Adjustable Spanner
- Electric Tapes
- Measuring Tapes

Figure 4. 3: Some Tools used during implementation

4.3.3 Printed Circuit Board Etching and Masking

The PCB design was done in Proteus Design Suite with ARES (Advanced Routing and Editing Software). ARES is a design tool/module in Proteus Design Suite software. It offers net-list based PCB design which perfectly complements the ISIS schematic capture software. The suite offers high-performance design automation tools, which include design rule checking, 3D visualization, shape-based router, automatic component placer, manual route placement and editing (User Guide for Proteus 8.8, accessed 2023).

Some of the major features of ARES Professional include:

- 32 bit high-precision database offering a linear resolution of 10nanometer, an angular resolution of 0.1° and a maximum board size of +/- 10m.
- Board level mitring to avoid solder traps and minimise track length
- Hardware accelerated display (Direct 2D or OpenGL) using the power of your graphics to improve speed and provide true layer transparency.
- State of the art ergonomic user interfaces with modeless selection, selection and activity indicators and localized functionality via context menus.
- Live net list and shared database binding with the ISIS schematic capture module, including the ability to specify routing information on the schematic (User guide for Proteus 8.8, accessed 2023).

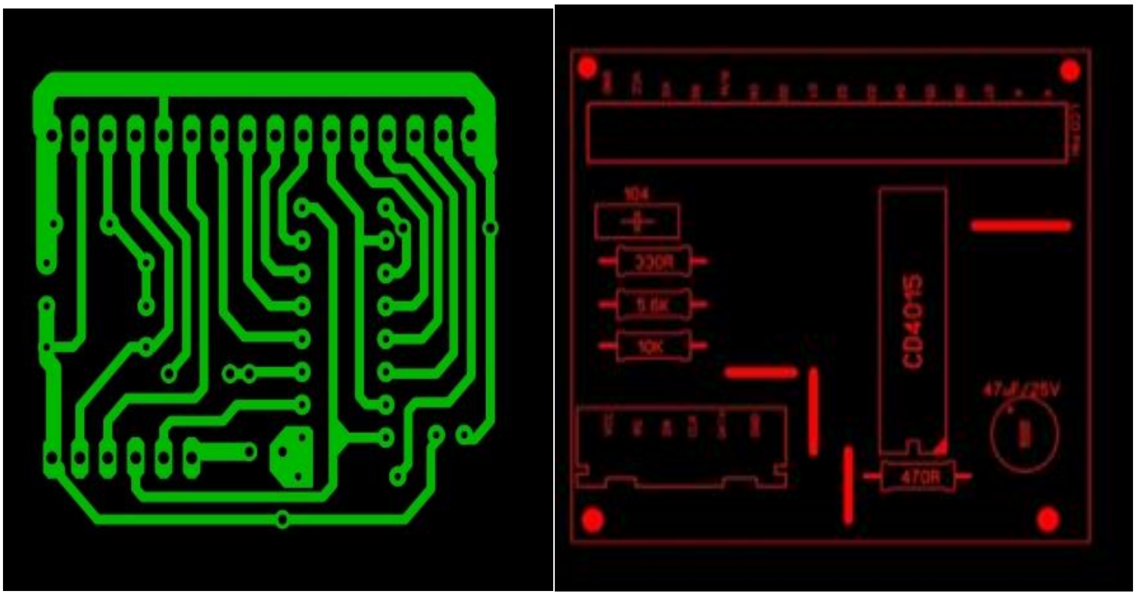

Figure 4. 4: LCD PCB Layout

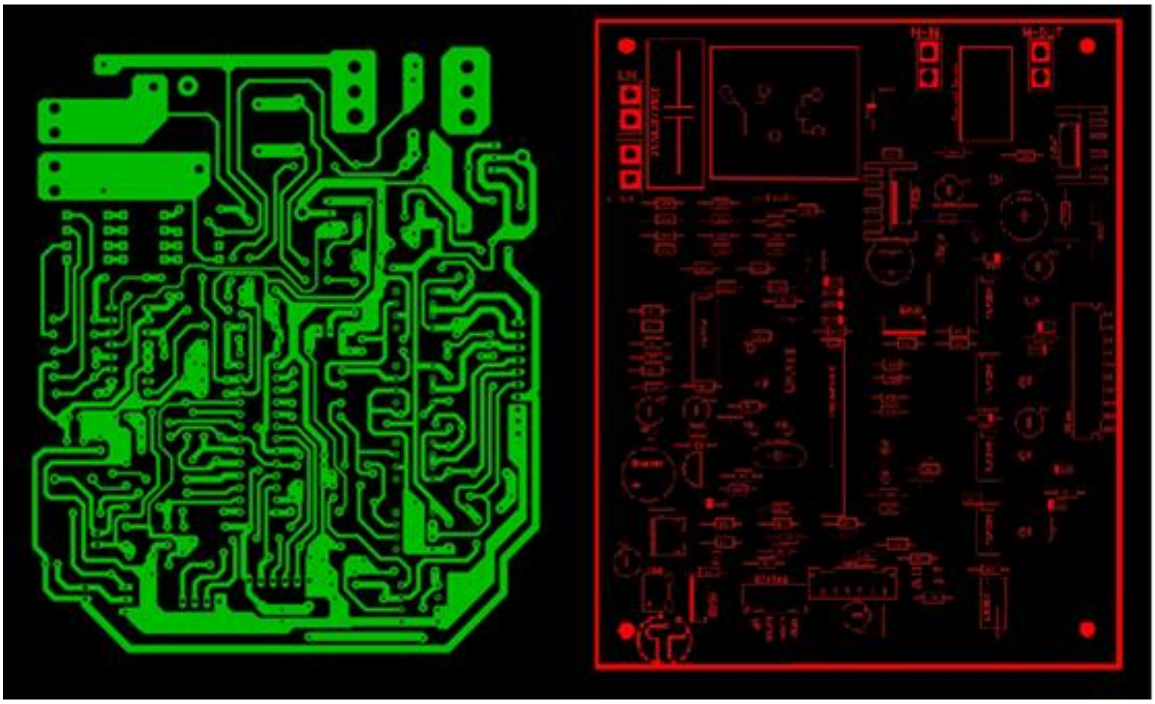

Figure 4. 5: Microcontroller Board PCB Layout

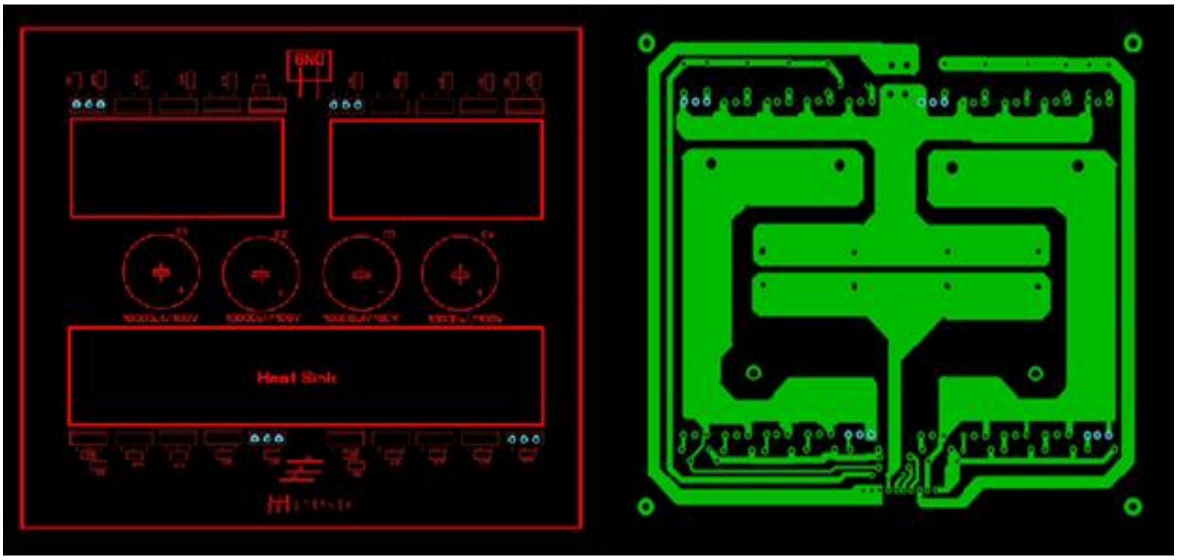

Figure 4. 6: MOSFET Board PCB Layout

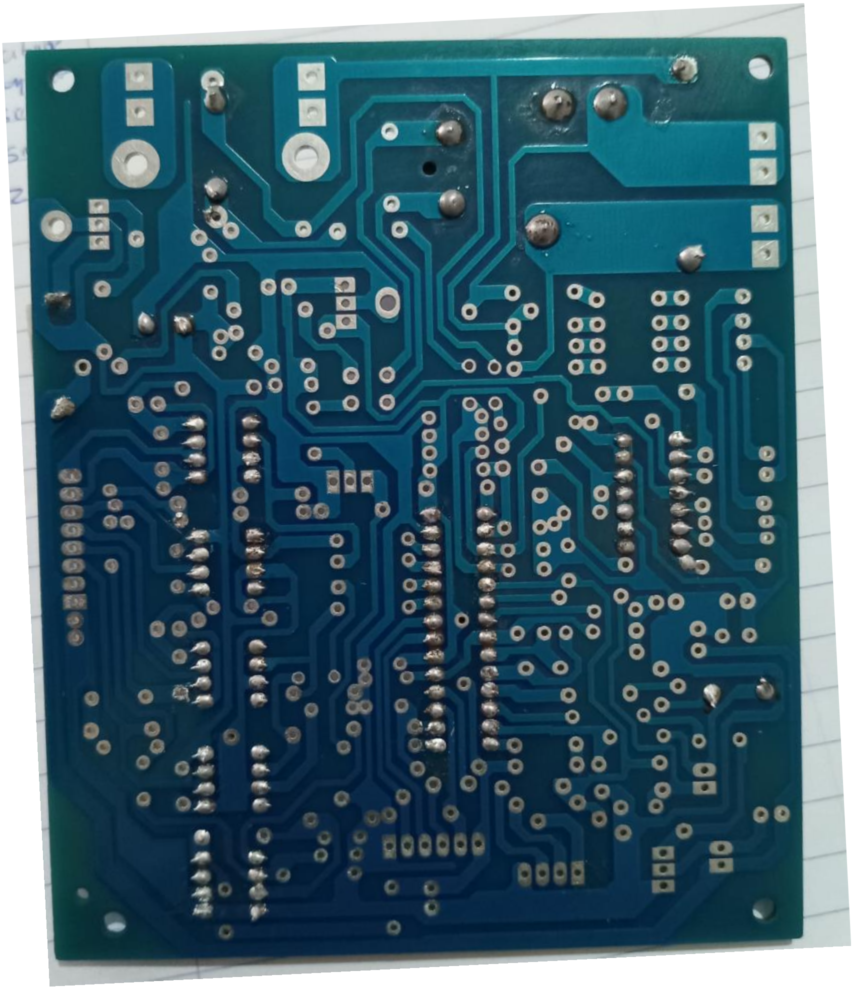

Figure 4. 7: Microcontroller Printed Circuit Board

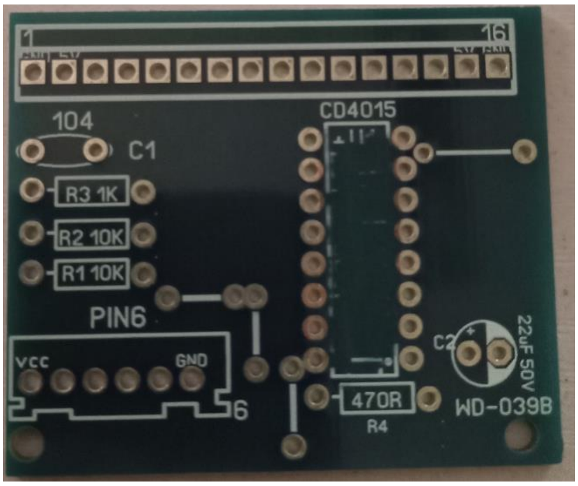

Figure 4. 8: LCD Printed Circuit Board

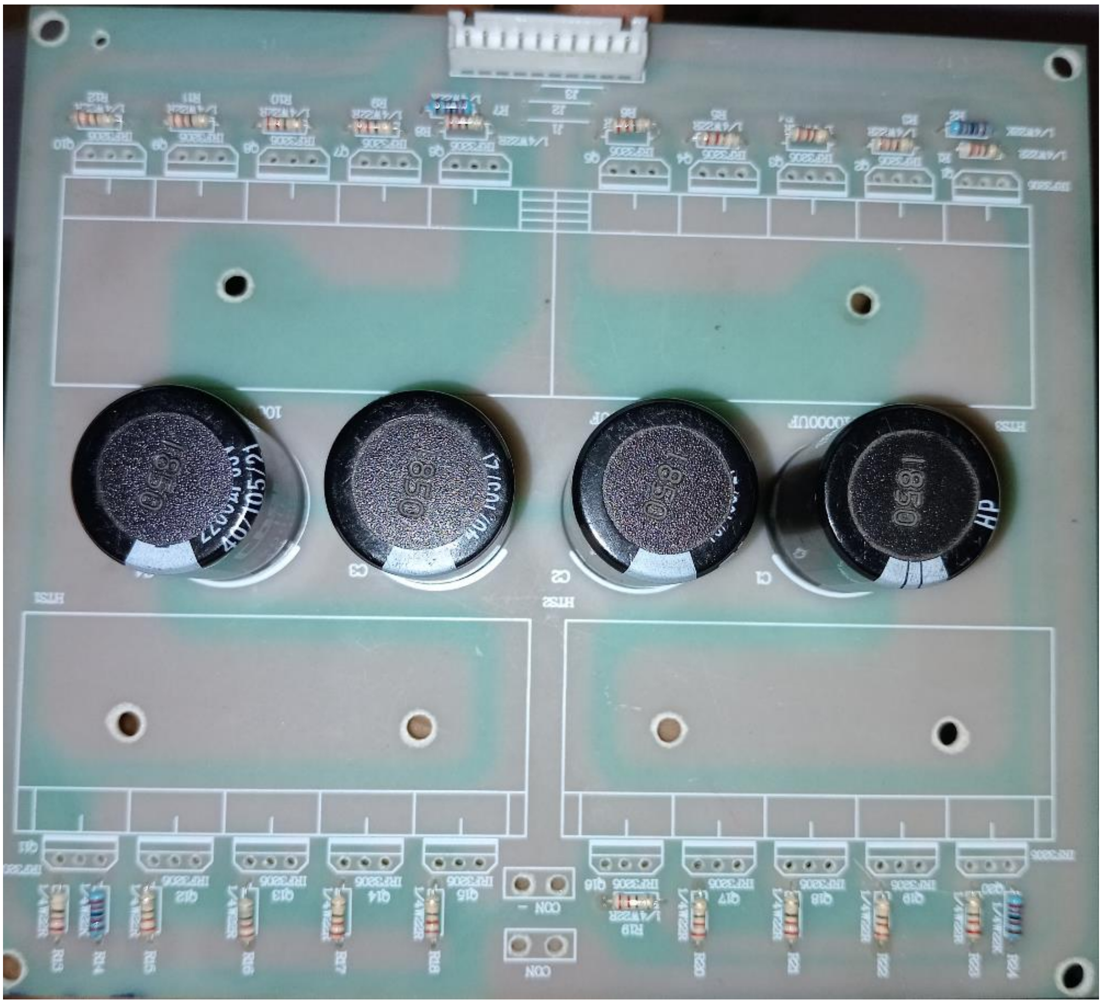

Figure 4. 9: MOSFET Printed Circuit Board with Capacitors Installed

4.3.4 Soldering and Components Build Up

Soldering is used to form a permanent connection between electronic components (Wikipedia, accessed 2023). With the use of a Vero circuit board the electronic components were soldered according to the circuit schematics.

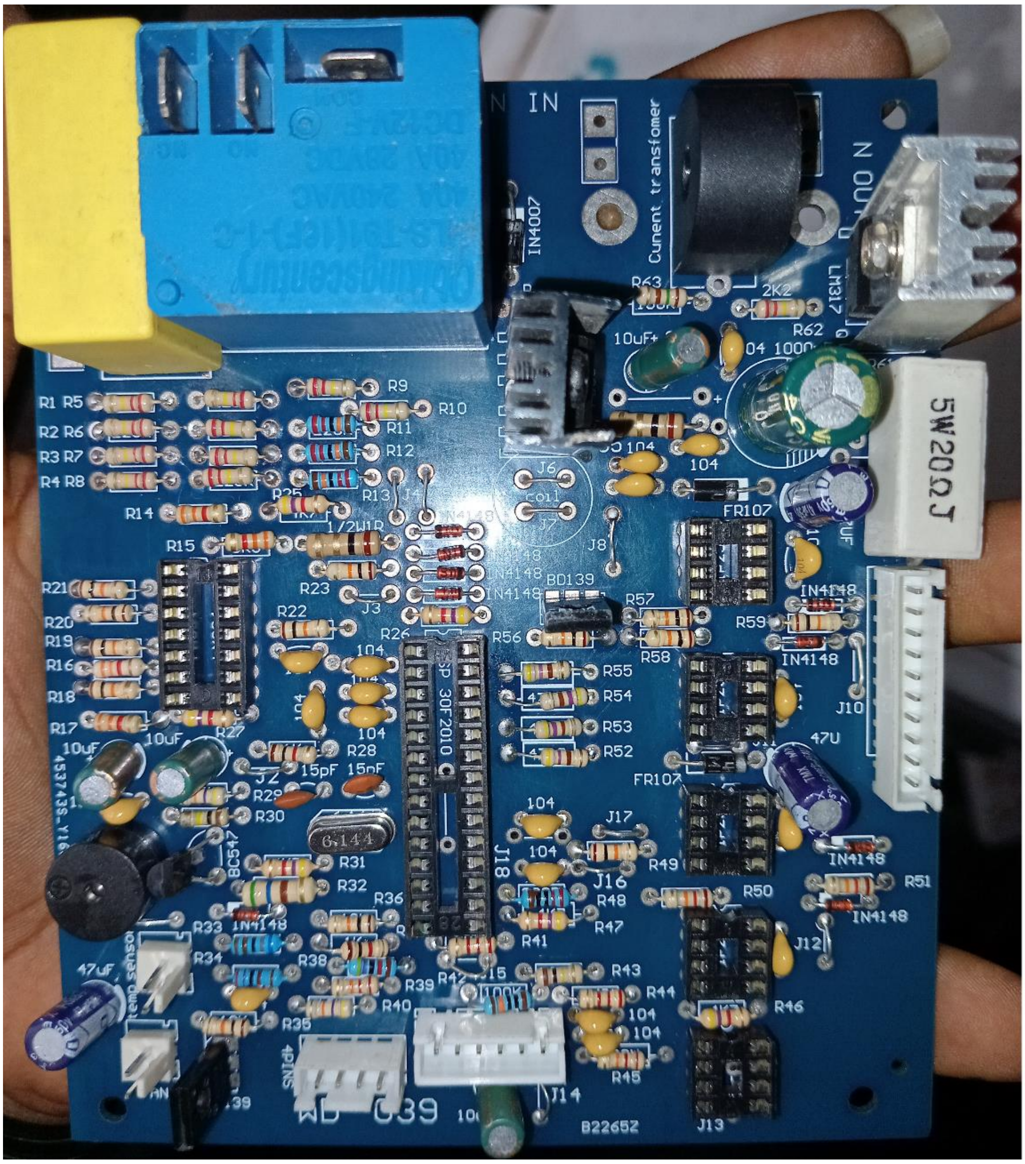

Figure 4. 10: Microcontroller Board

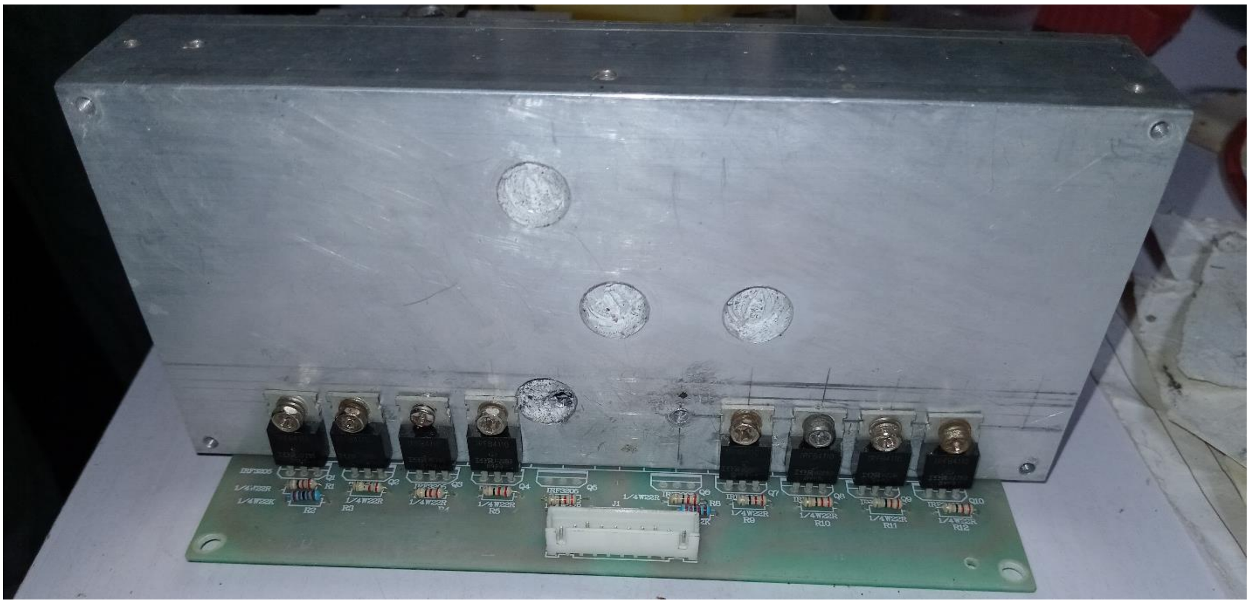

Figure 4. 11: MOSFET Board with Heat Sink

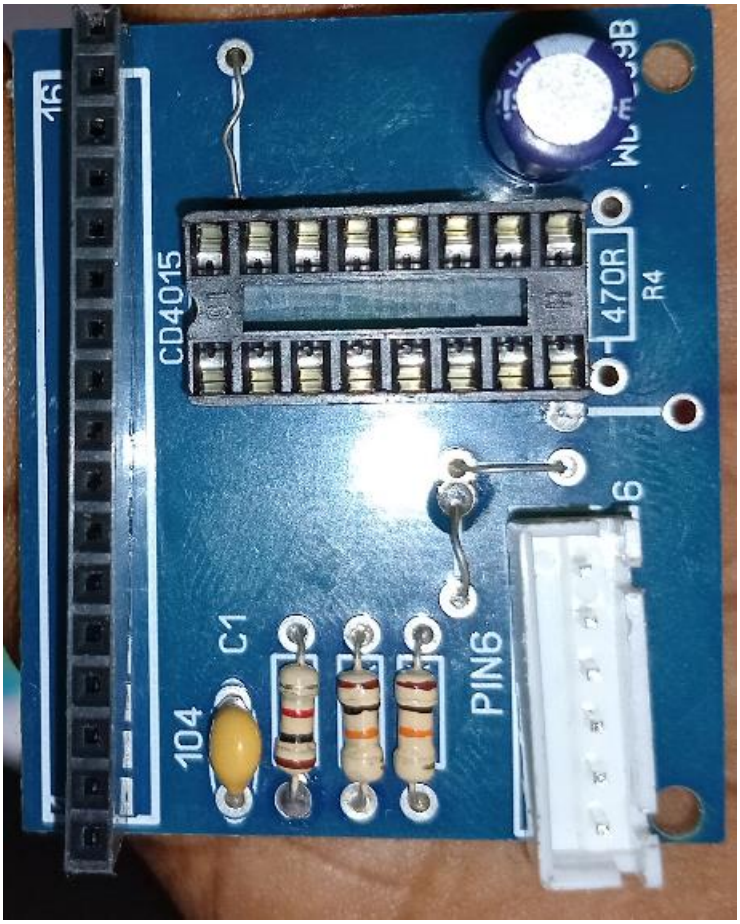

Figure 4. 12: LCD Board

4.3.5 Packaging

The full packaging of the inverter system is shown in Figure 4.13.

Figure 4. 13: Internal View of Inverter Package

Figure 4. 14: Front View of Inverter Package

4.4 Test and Result Analysis

The following tests were carried out on the developed inverter system.

- Output Voltage and Frequency Test
- Load and Over Load test
- Sinusoidal Output test
- Power Efficiency test

Figure 4. 15: Testing the Inverter

4.4.1 Output Voltage

This a simple test that was done with aid of a digital multi-meter. For the voltage test, the multi-meter was set to the AC voltmeter mode, then the probes of the meter were used to read the inverter output terminals, the AC voltage value was displayed on the multi-meter screen. After testing this reading was observed to be stable with an approximate AC voltage value of 220V.

A similar process was carried out for the frequency test, the multi-meter was set to the frequency mode, then the probes of the meter were used to read the inverter output terminals, the frequency of the AC voltage value was displayed on the multi-meter screen. After testing this reading was observed to be stable at an approximate frequency value of 50Hz. The images in Figure 4.16 and 4.17, shows the output voltage and frequency tests respectively.

Figure 4. 16: Output Voltage Test

Figure 4. 17: Frequency of output Voltage

4.4.2 Load and Overload Test

This test was aimed at checking the ability of the installed inverter system to meet the load requirement of the home without switching into its overload protection mode. This test was done by gradually loading the inverter system from no load to full load while observing for overload indication from the device. The results from this test are shown in table 4.1 while figure 4.17 displays the process.

Table 4. 2: Load and Overload Test

S/N	Description of Load	Overload Indication
1.	No Load	No
2.	Lights Only	No
3.	Lights, TV, Laptop, Fans and Phones	No
4.	Lights, TV, Laptop, Fans, Phones and Refrigerator	No

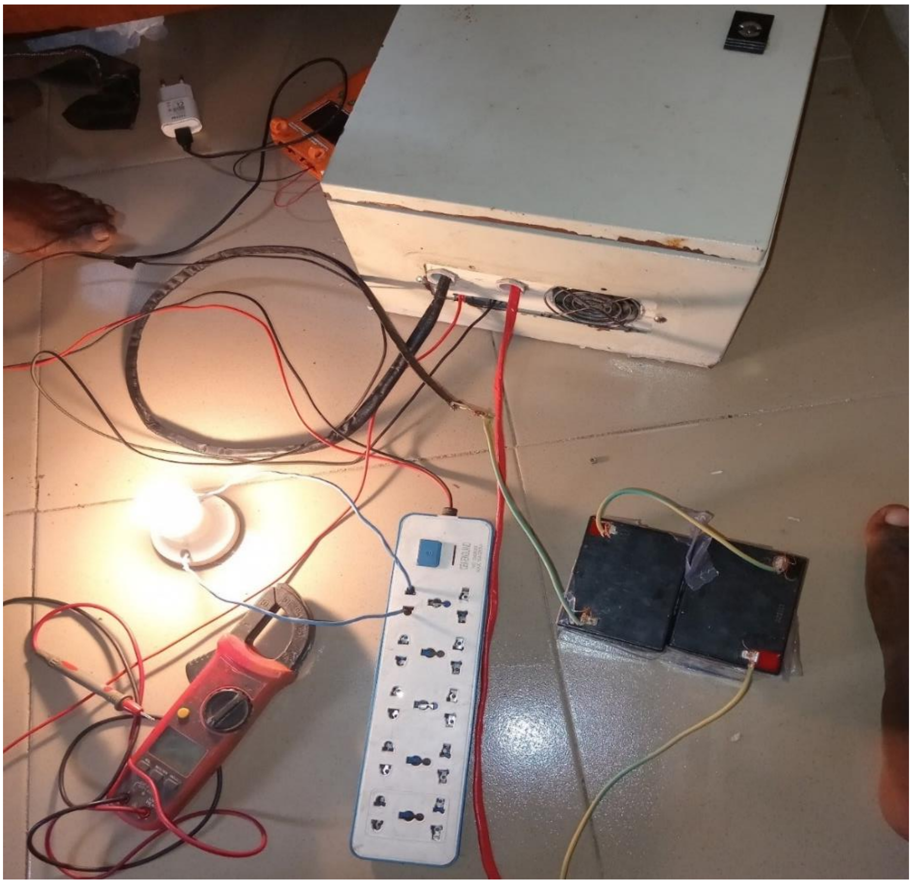

Figure 4. 18: Load Test

4.4.3 Sinusoidal Output test

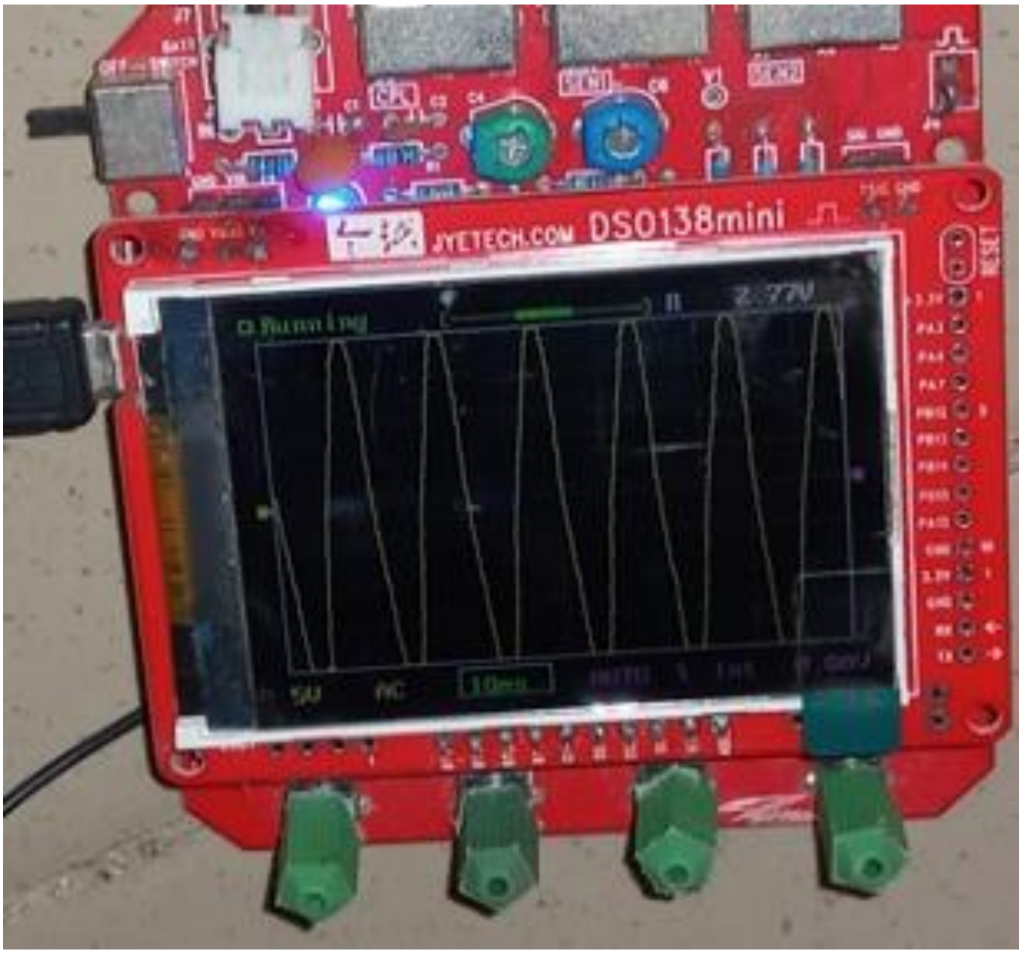

Figure 4. 19: Sinusoidal Output Test

As seen in the digital Oscilloscope output in figure 4.18 above. the inverter supplies a sound sinusoidal output voltage and current.

4.4.3 Power Efficiency Test

The aim of this test was to test the power efficiency of the inverter system, a clamp meter was used to measure the input current drawn from the battery and output current fed into the house by the inverter system while it was running on full load.

The objective of this test was to test the power efficiency and performance of the inverter system. A clamp meter was used to measure the input current supplied by the battery and output current supplied to the load by the inverter system while it was operating on maximum capacity. The battery voltage and the output AC voltage were measured as well. The inverter percentage efficiency is calculated as follows;

Percentage Efficiency = $\frac{output\ power\ delivered/consumed}{input\ power\ or\ power\ drawn}\ x\ 100$………………… (4.1)

Output Power in VA = Output Voltage x Output Current

Assuming a Power factor of 0.95,

Output Power in Watts = Output Voltage x Output Current x 0.95…..………….. (4.2)

Input Power = Input Voltage x Input Current

Table 4.2 shows the voltage and current readings entering and leaving the inverter system while it is operating on full load, a clamp meter was used to extract these readings.

Table 4. 3: Power Efficiency Test

	Voltage (V)	**Current(A)**	**Power (Watts)**
Input	24.5	81.63	1989.9
Output	220V	8.63	1803.7

Percentage Efficiency = $\frac{1803.7}{1989.9}$ x 100 = 90.64%…………………….………… (4.3)

4.5 Bill of Engineering Measurements Evaluation (BEME)

Table 4. 4: Bill of Estimate for Materials

i. Transformer Design

S/N	Items Required	Description	Unit	Price Per Unit (N)	Amount Required	Price Per Amount (N)
1.	Transformer Core	Iron Laminated Core	Sheets	-	-	12500
2.	Primary Copper Coil	Average Wire Gauge 12, Enameled Copper Cable	Kilogram	12000	1	12000
3.	Secondary Copper Coil	Average Wire Gauge 17, Enameled Copper Cable	Kilogram	12000	1	12000
4.	Transformer Bobbin	Etched PCB 1ft x 1ft	Piece	2500	1	2500
5.	**TOTAL**	**-**	**-**	**-**	**-**	**39000**

ii. Sine Wave Generator Circuit Design

S/N	Items Required	Description	Unit	Price Per Unit (N)	Amount Required	Price Per Amoun t (N)
1.	DSPIC30f2010	32bit Microcontroller	Piece	7000	1	7000
2.	Printed Circuit Board	Copper Cladded board for MOSFET, microcontroller and sine oscillator circuits	Pieces	3000	1	3000
3.	Capacitors	10mF, 100uF, 105, 1000uf, 10uf, 220uf, 33pF 0.01uF, 47uF,	Pieces	200	30	6000
4.	Resistor	10kOhm, 10Ohm, 4.7Ohm, 5.6kOhm, 1kOhm, 2.2KOhm, 2KOhm.	Piece	100	30	3000
5.	Crystal Oscillator	6.144 MHz	Piece	1	500	500
6.	1n4001 Diodes	PN diode	Pieces	50	10	500

7.	Relays	10A, 60A, 12V relay	Pieces	500	5	2500
8.	Current Transformer	10A	Pieces	1000	1	1000
9.	337 Transistor	NPN Amplification Transistor	Pieces	100	20	2000
10	2N2222A	NPN Amplification Transistor	Pieces	100	4	400
11	IC Socket	28 pin IC socket, 8pin socket, 16pin socket	Piece	50	1	50
12	Jumpers and inter connecting wires	Twisted pair jumper cable	Yard	1	200	200
13	LEDs	Red and Green Led	Pieces	20	2	40
14	LCD Screen	16x2 LCD	Piece	3000	1	3000
15	Keypad	4 x 1 Keypad	Piece	1000	1	1000
16	Toggle Switch	Push toggle	Piece	200	1	200
17	Buzzer	12V Buzzer	Piece	500	1	500
18	Switching ICs	LM393, IC4015, IC250, LM324, IRF2807	Pieces	500	10	5000
19	**TOTAL**	**-**	**-**	**-**	**-**	**35890**

iii. MOSFET Circuit Design

S/N	Items Required	Description	Unit	Price Per Unit (N)	Amount Required	Price Per Amount (N)
1.	IRFP 3205 MOSFET	High Power Transistors	Pieces	600	16	9600
2.	Heat Sink	Aluminum	Pieces	1000	4	4000
3.	10mm^2 Copper Cable	Positve and Negative Battery Connector Cables	Yards	800	2	1600

4.	Line connectors	8 in 1 line connector, 2 in one line connector	Pieces	200	5	1000
5.	Terminals and Plugs	Battery Logs, 2 pin connectors, 8 pin connectors.	Pieces	-	-	3000
6.	1n4148 Diode	Zener Diodes	Pieces	30	20	600
7.	Temp Sensor	25V	Pieces	1500	1	1500
8.	**TOTAL**	**-**	**-**	**-**	**-**	**21300**

iv. Packaging and Peripherals

S/N	**Items Required**	**Description**	**Unit**	**Price Per Unit (N)**	**Amount Required**	**Price Per Amount (N)**
1.	Cooling Fan	12V Cooling Fan	Piece	300	1	300
2.	12V AC to DC module	SMPS rectifier Module.	Pieces	1500	1	1500
3.	Casing	Plastic Box Casing with metal framework	Pieces	5000	1	5000
4.	13 Amp Plug	Load separation adapter plug	Pieces	500	2	1000
5.	13Amp Socket	Load Separation adapter socket	Pieces	500	2	1000
6.	Screws	1 inch	Packet	500	1	500
7.	**TOTAL**	**-**	**-**	**-**	**-**	**9300**

v. Logistics

1.	Logistics and Miscellaneous	-	-	-	-	10000
GROSS TOTAL		**-**	**-**	**-**	**-**	**115490**

4.5.1 Cost Summary

1. Transformer design ……………………………………………..………….N39000
2. Sine wave generator circuit design ……………………………………...N35890
3. MOSFET circuit design …………………………………………………... N21300
4. Packaging and peripherals …………………………………………….....N9300
5. Logistics ……………………………..N10000

Gross Total………...…………………….…………....………………………**N115490**

Approx. ...…………………….…………....…………………………………**N116000**

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

An inverter system that transforms a 24V DC voltage level a to 220V AC voltage level, utilizing a rechargeable battery bank has been designed, built and programmed. For this design, at least two batteries are required, each with an output of 12V and then connected in series to get a resultant output voltage of 24V. For effective solar energy conversion, a sealed deep cycle battery is recommended.

The system can maintain a continuous output of 220-240 volts to an external load for more than 5 or 6 hours of steady usage when a battery with a capacity of 220AH. The working duration however relies on the wattage demanded by the load connected to the system. Cables with big diameters are required for the input connections to the inverter in order to withstand the enormous current sourced by the inverter when a load is connected to the output. The entire system design is a small assembly that may take the place of electromechanical generators that is being utilized in most houses, by delivering an environmentally friendly back-up power to compensate for frequent power outages. Although the initial cost may become quite overwhelming for persons with a low income or budget, but the long-term cost-effectiveness and advantages considerably exceeds the disadvantage. When photovoltaic cells are integrated into the existing system, the performance of the system is projected to enhance in dry season when solar radiation is at its peak.

5.2 Limitations

The main drawbacks of the developed inverter system includes the following:

- This device functions with only single-phase AC inputs, three phase devices are excluded from the design and scope of this work.
- Inverter components and batteries can be expensive especially ones that are more efficient, lighter, and less bulky.

5.3 Recommendations

After the completion of the project work, the following recommendations are necessary so as to achieve a more efficient inverter user experience;

- More batteries can also be added to increase the storage capacity as this will extend the days of system autonomy.
- In case of future increase in load, photovoltaic cells and charge controllers can be added to the existing system to extend the working duration and charge the battery.
- More solar panels should be used to reduce the time required to charge the batteries via solar panels.
- Power consumption should be optimized by switching off connected devices that are not in use.

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APPENDIX

C program source code

```
// Include necessary header files

#include <p30F2010.h>

#include "DataEEPROM.h"

// Configuration bits for the microcontroller

_FOSC(CSW_ON_FSCM_OFF & XT_PLL16); //Turn on RC Oscillator, turn off FSCM module, sets PLL factor to 16

_FWDT(WDT_OFF); //Watchdog timer off

_FBORPOR(BORV_42 & MCLR_EN & RST_PWMPIN & PBOR_ON & PWMxH_ACT_HI & PWMxL_ACT_HI); //Enables MCLR, Power on brown out reset, brown-out voltage level bit, PWM reset

_FGS (CODE_PROT_ON); //Enable code protection

// Define PWM frequency and other constants

#define PWM_FREQUENCY 50000 // PWM switching frequency in Hz

#define PWM_PERIOD    (FCY / PWM_FREQUENCY)

#define change LATDbits.LATD1

#define faultin LATEbits.LATE8

#define buzzer_alarm LATEbits.LATE4

#define invstnby 1

#define mode_ups 2

#define mode_inv 3

#define key_mode 4

#define keyup 5

#define keydown 6

#define ups_stby 7

#define temp_fan 640

const signed int sine_table[91] =
{0,174,348,523,697,871,1045,1218,1391,1564,1736,1908,2079,2249,2419,2588,2756,2923,3

090, 3255,3420,3583,3746,3907,4067,4226,4383,4539,4694,4848,5000,5150,5299,5446, 55991,5735,5877,
6018,6156,6293,6427,6560,6691,6819,6946,7071,7193,7313,7431,7547,7660,

7771, 7880,7986,8090,8191,8290,8386,8480,8571,8660,8746,8829,8910,8987,9063,9135,9205,9271,9335,
9396,9455,9510,9563,9612,9659,9702,9743,9781,9616,9848,9876,9902,9925,9945,9961,9975,9986, 9993,1
0000,10000};

// Function to initialize the microcontroller and peripherals

void init() {int osc = 16000000;// Configure oscillator and other settings as needed

   // Configure PWM outputs

   // Initialize timers and PWM module for generating AC output waveform}
```

```
// Function to generate PWM signal for inverter operation

void generatePWM(uint16_t dutyCycle) { Implement code to generate PWM signal with specified duty cycle}

// This function controls the output voltage and frequency of the inverter

void controlInverter() {    // Implement control algorithm to regulate output voltage and frequency

   // This might involve adjusting the duty cycle based on feedback signals}

signed int factory[16]={0,0,100,350,220,80,265,180,270,100,142,108,100,115,5000};

signed int setting[16]; char arr[4];

struct{unsigned int frstdisp:1;

unsigned   int   olcut:1;

unsigned   int   var_lbcut:1;

unsigned int var_setup:1;

unsigned int var_vcorrect:1;

unsigned int var_onflag:1;

unsigned   int   var_lbwarn:1;

unsigned int var_chrcorrect:1;

unsigned   int   var_firston:1;

unsigned   int   zincfail:1;

unsigned int var_gravity:1;

unsigned int var_nofeed:1;

unsigned   int   mainsok:1;

unsigned int chon:1;

unsigned   int   chrmsgrtn:1;

unsigned   int   var_olwarn:1;

unsigned   int   msgrtn:1;

unsigned   int   var_shorttrip:1;

unsigned int var_swon:1;

unsigned   int   var_fault:1;

unsigned   int   var_hiload:1;

}flags;

int var_achshoot;

int var_achshootdly=0;

int var_aflicker=0;

int * var_aadjust;

int * var_aptr;

int var_aadj;
```

```
int * var_vavalue;
int var_achadj;
int var_achamps1;
signed int duty_cycle_1;
signed int p=0,flag=1,rising=1;
signed int pr=0,kflag=1,rising1=1;
int var_amplitude=0;
int var_pb, var_qb, var_cth, var_ctl;
unsigned int var_peakfail;
unsigned int var_deadshortdly;
ned int var_chrdly;
unsigned int var_fltdly;
unsigned int var_mainsdisp;
unsigned int var_battdisp;
unsigned long var_heatavg;
unsigned int var_battvolts;
unsigned int var_batrecharge;
unsigned int var_keydly;
unsigned int var_fbdly;
unsigned int var_slowdly;
unsigned int var_buzzcount;
unsigned long varmainsavg;
unsigned long var_wattsavg;
unsigned long var_batavg;
unsigned long var_keyavg;
unsigned int var_lbdly;
unsigned int var_acdly;
unsigned long var_outavg;
unsigned int var_gravitydly;
unsigned int var_ctfaildly;
unsigned int var_resumedelay;
unsigned int var_round;
unsigned int var_buzzdelay;
unsigned int var_buzzoftme;
unsigned int var_buzzontme;
unsigned int var_loaddisp;
```

```
unsigned int var_acoutdisp;
unsigned int var_batrestart;
unsigned int var_loadpercent;
unsigned int var_menudelay;
unsigned int var_lcdtmr;
unsigned int var_counter;
unsigned int var_blinkdly;
unsigned int var_startdly;
unsigned long var_endtimer;
unsigned long var_controlavg;
unsigned int var_oldelay;
unsigned int var_tripdly;
unsigned int var_msgrtndly;
unsigned int var_loadclb;
signed int  var_acpeak;
signed int   var_ctpeak;
unsigned int var_controlvolt;
unsigned int var_setvout;
unsigned int var_mainsvolt;
unsigned int var_setoverload;
unsigned int var_heat;
unsigned int var_post;
unsigned int var_setinvlo;
unsigned int var_indummy;
unsigned int var_setupslo;
unsigned int var_setinvhi;
unsigned int var_setbatres;
unsigned int var_pdctemp;
unsigned int var_ntcvalue;
unsigned int var_batts;
signed int   var_batclb;
signed int var_mainsclb;
unsigned int var_cherr;
unsigned int var_prect;
unsigned int var_setupshi;
unsigned int var_champs;
```

```
unsigned int var_chdisp;
unsigned int var_outdummy;
unsigned int var_ctdummy;
unsigned int var_setdly;
unsigned int var_chrclb;
unsigned int var_keys;
unsigned int var_modeavg;
unsigned int var_acout;
unsigned int var_keyvalue;
unsigned int var_key;
signed int   var_upspeak;
unsigned int var_setchramp;
unsigned int var_setbatlo;
unsigned int var_x, var_y, var_u;
unsigned int var_deadshort;
unsigned int var_setbatful;
unsigned int var_err;
unsigned int var_defaults;
unsigned int var_setbatwrn;
unsigned long var_Ax, var_bx;
unsigned int var_aclo;
unsigned int var_achi;
unsigned int var_zinc;
void InitADC1(); // initialing ADC function
extern void Eeprom_WriteWord(unsigned short pushAddressOffset, unsigned short
value);
extern unsigned short Eeprom_ReadWord(unsigned short pushAddressOffset);
void delay_ms(unsigned int gs);
void delay_us(unsigned int gs);
const char str0[17]= "PARAMETER MENU";
const char var_str20[17]="BATT VOLT:     V";
const char var_str21[17]="INVERTER TURN ON";
const char var_str25[17]="SUPPLY VOLT:    V";
const char var_str26[17]="INVERTER V:    V";
const char var_str22[17]=" U.P.S TURN ON ";
const char var_str23[17]=" STBY SWITCH OFF ";
```

```
const char var_str35[17]="BRK:SYNC ERROR ";
const char var_str36[17]="AC CHARGER:     A";
const char var_str33[17]=" WARNING:OV-LOAD ";
const char var_str28[17]="BRK:C-T FAULT ";
const char var_str24[17]=" STBY SWITCH ON ";
const char var_str32[17]="WARNING:LOW-BAT";
const char var_str29[17]="BRK:LOW-BATTERY";
const char var_str30[17]="BRK:OV-LOAD ";
const char var_str27[17]="TOTAL LOAD:    %";
const char var_str31[17]="SHORT CKT ERROR";
const char var_str34[17]=" BRK:F-B ERROR ";
const char var_str38[17]="SINEWAVE ";

#include "lcdsoft.h" //inports LCD standard library
#include "functions.h" //imports function.h library
void clear_flag(); //calls the flag clearing function
void trip(int s);
int getvalue(int ch);
void func_chargeron();
void func_chroff();
void func_invon();
void func_invoff();
void func_stabilise();
void func_Modulate();
void func_find_key();
int var_findpeak(int ct);
void func_find_mainsvolt();
void func_find_load();
void func_find_champs();
void func_find_upsvolt();
void func_chr_stabilize();
void func_mains_stat_check();
void func_find_batvolt();
void func_lobat_check();
void func_overload_check();
void func_feed_buzz(int a,int b,int c){
```

```
    var_buzzdelay=0;
     var_buzzoftme=b;
     var_buzzontme=a;
     var_buzzcount=c;}
void __attribute__((__interrupt__,no_auto_psv)) _FLTAInterrupt(void){
_FLTAIF = 0;}
void __attribute__((__interrupt__, __auto_psv__)) _T1Interrupt(void)
  {     _T1IF = 0;     // Clear interrupt flag
      if(PORTEbits.RE8==0)
      {       var_fltdly++;
      if(var_fltdly>3000)
      {         var_flags.olcut=1;
      __asm__ volatile ("reset");}}
    counter++;
    var_acpeak= var_getvalue(0);          //4.4 us
    var_indummy= var_acpeak;
    var_acpeak= var_indummy-508;
    if(var_acpeak<0)
    { var_acpeak=508- var_indummy;
    if(!var_flags.onflag)
    {     rising=0;
    var_flag=0;}}
   var_mainsavg+= var_acpeak;
  if(var_flags.setup)
 {OVDCON=   0X0000;
change=0;
var_buzzer_alarm=0;     }
     if(!var_flags.setup)
    {if((var_indummy<600)&&( var_indummy>400)&&( var_flags.swon))
    {    if(var_peakfail<150)
    {    var_peakfail++;}
if(var_peakfail==149)
{if(var_flags.vcorrect)
{ var_invon(150);}}}
else{
var_peakfail=0;}
```

```
if(var_flags.onflag)
{ var_func_Modulate();                    //4.4 us
`var_upspeak=func_getvalue(1);              //4.4 us
var_outdummy=var_upspeak;
var_upspeak=var_outdummy-508;
if(var_upspeak<0)
var_upspeak=508-var_outdummy;
var_outavg+= var_upspeak;
if(var_upspeak<150){
  var_fbdly++;
  if(var_fbdly>30000)
  {  var_flags.fault=1;
func_trip(5);}}
else
var_fbdly=0;}
else{
var_rising=1;
var_flag=1;
var_loadpercent=0;
var_acout=0;}
var_ctpeak=func_getvalue(2);
if(var_flags.onflag)
{if((var_ctpeak>750)||( var_ctpeak<250))
{ var_deadshortdly++;
if(var_deadshortdly>1500)
{ var_deadshort=1;
   OVDCON=    0X0000;
   func_trip(1);  }}}
else      {       if(var_flags.chon==1)
      {       if((var_ctpeak<508)||( var_ctpeak>512))
      var_ctfaildly=0;
      else{
      var_ctfaildly++;
      if(var_ctfaildly>10000){
      func_chroff(); }       }}}
   if(var_ctpeak>506)
```

```
  { var_pb= var_ctpeak-506;
  if(var_cth< var_pb)
  var_cth= var_pb;}
  if(var_ctpeak<506)
  {    var_qb=506- var_ctpeak;
  if(var_ctl< var_qb)
  var_ctl= var_qb;}
  var_wattsavg+= var_cth+ var_ctl;
  var_ctl= var_cth=0;
  var_heat=func_getvalue(3);}
  var_batavg+=func_getvalue(5);
  var_lcdtmr++;
if(var_counter==359) /20 milli sec
{     mainsvolt=__builtin_divud(mainsavg,288)+mainsclb;   //2.2 microseconds
 mainsavg=0;
  if(mainsvolt<90)
   {     mainsvolt=0;
   mainsdisp=0;}
  else
   {     if((indummy>180)&&(indummy<900))
   {     if(mainsdisp==0)
   {     mainsdisp=mainsvolt-80;}
   if(mainsdisp<mainsvolt-2)
   {     mainsdisp++;     }
   if(mainsdisp>mainsvolt+2)
   {     mainsdisp--;}}}
   find_batvolt();
   keyavg+=getvalue(4);
   keydly++;
   if(keydly==10)
   find_key();
   if(!flags.setup)
   {    mains_stat_check();
   if(flags.onflag==1)
   {     acout=__builtin_divud(outavg,285);
   outavg=0;
```

```
if(acoutdisp<acout-2)
acoutdisp++;
if(acoutdisp>acout+2)
acoutdisp--;
find_load();
overload_check();
lobat_check();}}
wattsavg=0;
if(buzzcount>0)
{     buzzdelay++;
if(buzzdelay<=buzzontme)
buzzer_alarm=1;
else
{     buzzer_alarm=0;
if(buzzdelay>=buzzoftme)
{     buzzdelay=0;
buzzcount--;
fltdly=0;}}     }
else
{     FLTACON=0x0001;
IEC2bits.FLTAIE = 1;
if(round>0)
{     if((!flags.onflag)&&(flags.swon)&&(round<4))
{     if(mainsvolt<110)
{     clear_flag();
invon(0);}}     }
if(round==4)
change=0;}
if(!flags.setup)
{ if((resumedelay==200)||(flags.mainsok==1))
{ LCD_DB6=1;
if(flags.swon==1)
{ blinkdly++;
if(blinkdly<30)
LCD_DB7=1;
else
```

```
 LCD_DB7=0;
 if(blinkdly>60)
 blinkdly=0;}
 else
 LCD_DB7=0;}
 else
{   LCD_DB6=0;
   if(flags.onflag==1)
   LCD_DB7=1;
   else
   LCD_DB7=0; }}
counter=0;
if((key==modekey)&&(flags.setup==0))
{menudelay++;
if(menudelay>124)
flags.setup=1;}
else
menudelay=0;
if(flags.setup==1)
{setdly++;
if(setdly>3000)
__asm__ volatile ("reset");}}
   cherr=mainsvolt; }
void init_PWM()
    {   PTCON=    0XE003;
    PTMR =    0x0000; //resets the configuration bits
    PTPER = PDC1=PDC2= 1230;
    SEVTCMP = 0x0000; //resets the configuration bits
    PWMCON1 = 0x0033;
    PWMCON2 = 0x0000; //resets the configuration bits
    DTCON1=   0X0059;
    FLTACON = 0x0000; //resets the configuration bits
    OVDCON=   0X0000; //resets the configuration bits
    PTCONbits.PTEN = 1;
    IEC2bits.PWMIE = 0;    // disable PWM interrupts
    T1CON = 0XE000;
```

```
    TMR1 = 0;
    PR1 = 1355;
   _T1IF = 0;
   _T1IE = 1;}
void memread()
{int x;
for(x=0;x<15;x++)
{setting[x]=Eeprom_ReadWord(x);}}
void memwrite()
{int x;
for(x=0;x<15;x++)
{if(flags.setup==0)
Eeprom_WriteWord(x,factory[x]);
else
Eeprom_WriteWord(x,setting[x]);}}
void modedisp()
{if(flags.msgrtn)
return;
if((key==mode_ups)||(key==ups_stby))
{printmes(str22,100);         //"\fU.P.S MODE ON";
if(key==mode_ups)
{aclo=setupslo;
achi=setupshi;}}
if((key==mode_inv)||(key==invstnby))
printmes(str21,100);        //"\fINVERTER MODE ON";}
void swdisp()
{if(flags.msgrtn)
return;
if((key==invstnby)||(key==ups_stby))              //"\fSBY SWITCH OFF";
{printmes(str23,100);
aclo=setinvlo;
achi=setinvhi;}
if((key==mode_ups)||(key==mode_inv))
printmes(str24,100);         //"\fSBY SWITCH ON";}
int main()
{TRISF=0X0000;
```

```
TRISE=0X010F;
TRISD=0X0000;
TRISC=0X0000;
TRISB=0XFFFF;
OVDCON=0X0000;
PWMCON1 = 0x0000;
PTCONbits.PTEN = 0;
buzzer_alarm=0;
lcd_init();
InitADC1();
init_PWM();
keyvalue=getvalue(4);
   if(((keyvalue>660)&&(keyvalue<680))||((keyvalue>560)&&(keyvalue<575)))
   {flags.swon=1;
   flags.firston=1}
prect=getvalue(2);
flags.frstdisp=0;
defaults=Eeprom_ReadWord(14);
if(defaults!=50)
{memwrite();}
memread();
var_batclb=setting[0];
var_mainsclb=setting[1];
var_chrclb=setting[2];
var_loadclb=700-setting[3];
var_setvout=setting[4];
var_setchramp=setting[5];
var_chshoot=setchramp;
var_setchramp+=30;
var_setupshi=setting[6];
var_setupslo=setting[7];
var_setinvhi=setting[8];
var_setinvlo=setting[9];
var_setbatful=setting[10];
var_setbatwrn=setting[11];
var_setbatlo=setting[12];
```

```
var_setbatres=setting[13];
var_defaults=setting[14];
var_battdisp=90;
var_aclo=setinvlo;
var_achi=setinvhi;
var_batrestart=setbatful-13;
var_menudelay=0;
while(1)
{//lcd_init();
//while(1){
//lcd_init();
//printmes(str36,3);      //"AC CHARGR:";
//flags.msgrtn=0;
////printmes(str20,1);      //"\fBATTERY V:";
//printmes(str25,2);    //"\fMAINS VOLT:";
//printmes(str27,4);        //"\fTOTAL LOAD:";
////printmes(str23,0);
//printmes(str24,100);         //"\fSBY SWITCH ON";
//printmes(str26,0);        //"\fINVERTER V:";
////printmes(str27,4);        //"\fTOTAL LOAD:";}
while(PORTEbits.RE8==0)
{flags.msgrtn=0;
printmes(str31,100);      // SHORT CKT FAULT
if(flags.swon==0)
__asm__ volatile ("reset")}
while(flags.nofeed==1)
{  flags.msgrtn=0;
printmes(str34,100);    // NO FEED BACK
if(flags.swon==0)
__asm__ volatile ("reset")}
//while(flags.ctfail==1)
//{ flags.msgrtn=0;
//printmes(str28,100);    // BRK:C-T FAULT
//if(flags.swon==0)
//__asm__ volatile ("reset");}
while(flags.zincfail==1)
```

```
{   flags.msgrtn=0;
printmes(str35,100);     // TRIP:SYNC FAULT!
if(flags.swon==0)
__asm__ volatile ("reset");
  flags.fault=1;}
while(flags.lbcut==1)
{  flags.msgrtn=0;
printmes(str29,100);        //" BRK:LOW-BATTERY ";
if((flags.swon==0)||(resumedelay>175))
__asm__ volatile ("reset");}
while(flags.olcut==1)
{  flags.msgrtn=0;
printmes(str30,100);        //" BRK:OVER-LOAD ";
if((flags.swon==0)||(resumedelay>175))
__asm__ volatile ("reset");}
while(flags.olwarn)
{  flags.msgrtn=0;
printmes(str33,100);        //" WARN:OVER-LOAD ";
if(flags.swon==0)
__asm__ volatile ("reset");}
while(flags.lbwarn==1)
{  flags.msgrtn=0;
printmes(str32,100);        //"WARN:LOW-BATTERY";
if(flags.swon==0)
__asm__ volatile ("reset");}
printmes(str20,1);         // 0/0/"\fBATTERY V:";
if(flags.chon==1)
{if(champs==0)
goto outmes;
printmes(str36,3);         //"AC CHARGR:";}
outmes:
if((key==mode_ups)||(key==mode_inv))
{if(flags.onflag==1)
{printmes(str27,4);        //"\fTOTAL LOAD:";}
modedisp();
swdisp();
```

```
printmes(str25,2);        //"\fMAINS VOLT:";
if(flags.onflag==1){
printmes(str26,0);        //"\fINVERTER V:";}}
else{
func_modedisp();
func_swdisp();
printmes(str25,2);        //"\fMAINS VOLT:";}
//printmes(str38,100);       //"\fTITLE NAME
if(menudelay>=125){
func_flags.setup=1;
var_menudelay=0;
lcd_putc('\f');
printmes(str0,100);           //"\fPARAMETER MENU";
while(key==modekey);
while(1){if(key==modekey{
setchramp=setting[5]/10;
loadclb=setting[3];
func_functions();
func_memwrite();
flags.setup=0;
__asm__ volatile ("reset");}}}}
}//main
```