

**DESIGN AND CONSTRUCTION OF A 3.5KVA TRANSFORMERLESS INVERTER**

**BY**

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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  
ELECTRICAL/ELECTRONICS ENGINEERING, FACULTY OF ENGINEERING,  
UNIVERSITY OF BENIN, BENIN CITY IN PARTIAL FULFILMENT OF THE  
REQUIREMENT FOR THE AWARD OF BACHELOR OF ENGINEERING (B.ENG)  
DEGREE IN ELECTRICAL/ELECTRONICS ENGINEERING.**

**SEPTEMBER, 2023**

## **CERTIFICATION**

This is to certify that this project work was carried out by **OMOYIBO INNOCENT, ASEMOTA JOSHUA OVBOKHAN, AKINYEMI RASHEED KEHINDE, ADESINA OLAOLUWA MICHAEL, OSANEKWU CHINEDU ROMEO and AIYEDE COLLINS** of the Department of Electrical/Electronics Engineering, University of Benin, in partial fulfilment of the requirements for the award of the bachelor of engineering (B.Eng.) Degree.

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**ENGR. E.C. EKOKO**

**PROJECT SUPERVISOR**

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**DATE**

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**PROF. K.O. OGBEIDE**

**HEAD OF DEPARTMENT**

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**DATE**

## **DEDICATION**

This research work is dedicated to Almighty God, who is the repository of all knowledge and the Department of Electrical/Electronics Engineering, Faculty of Engineering, University of Benin, Benin City, Edo State.

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## **ABSTRACT**

This project involved designing and building a 3.5KVA hybrid pure sine wave inverter with a battery charging and monitoring system.

A high frequency transformer with a 3.5KVA rating was used to design the inverter circuit. The 24V battery bank serving as the DC voltage supply. It was controlled by a high-performance microprocessor (DSPic30f4012) with sophisticated switching and control capabilities. The inverter design made advantage of the pulse width modulation technology.

Design, construction, and testing were done on the inverter circuit. It worked well with a variety of home appliances, including a refrigerator, electric fans, and lightbulbs.

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# CHAPTER ONE

## INTRODUCTION

### 1.0 BACKGROUND TO THE STUDY

Electricity is a form of energy resulting from the movement of charged particles, such as electrons or ions. Electric power can be generated by converting other forms of energy, such as chemical, nuclear, or mechanical energy, into electrical energy through various processes such as electromagnetic induction, thermoelectric effect, or photoelectric effect.

In many parts of the world, sadly, there are still large populations without access to electricity. In such locations, alternative sources of electricity are used or in most cases most residents live without power supply. Alternative sources such as Renewable energy could be used. But what then is renewable energy?

Renewable energy refers to energy that is generated from naturally replenishing resources that can be used repeatedly without being depleted. These resources include sunlight, wind, water, and geothermal heat. Renewable energy is a clean and sustainable alternative to traditional fossil fuels, which are finite resources and contribute to climate change and other environmental problems. There are different types of renewable energy sources which includes:

Solar energy: Generated by capturing the energy of the sun using photovoltaic (PV) cells or concentrating solar power (CSP) systems.

Wind energy: Generated by capturing the kinetic energy of the wind using wind turbines.

Hydro energy: Generated by harnessing the power of moving water, such as in hydroelectric power plants or tidal power.

Geothermal energy: Generated by tapping into the natural heat of the Earth's crust to produce electricity or heat buildings.

Biomass energy: Generated by using organic matter, such as wood chips, agricultural waste, and landfill gas, to produce heat and electricity through combustion, gasification, or anaerobic digestion.

Even though hydro energy is the most used among the listed renewable energy, Solar and wind power are also growing rapidly and have seen significant increases in usage in recent years. In 2020, solar photovoltaics (PV) and wind power were the fastest-growing sources of new

electricity generation worldwide, accounting for almost 80% of new capacity additions, according to the International Renewable Energy Agency.

In this research work, we'd be considering Solar Energy as a Renewable source of energy and how it can be harnessed in these locations without power or poor power supply. The cost of renewable energy technologies, such as solar and wind power, has been decreasing in recent years, making them more competitive with traditional sources of electricity and one way this is possible is the use of Photovoltaic (PV) systems to convert the solar energy. What is PV's?

Photovoltaic (PV) is a method of generating electrical power from sunlight using solar cells. Solar cells are made of semiconducting materials such as silicon, which absorb photons of sunlight and release electrons, creating a flow of electric current. PV cells are usually combined in solar panels, which can be used to generate electricity for a variety of applications.

PV technology has many advantages over traditional fossil fuel-based sources of electricity. It is a renewable and sustainable energy source that produces no greenhouse gas emissions or other pollutants. It can be used to generate electricity in remote areas where grid access is limited or non-existent. PV systems are also modular and scalable, meaning they can be customized to meet the specific energy needs of homes, businesses, and communities.

Photovoltaic (PV) systems are typically used in conjunction with other equipment and components to generate, store, and manage the electricity they produce. Here are some examples of equipment commonly used in or together with a PV systems:

Solar panels: PV systems use solar panels, also called modules, to capture sunlight and convert it into electricity.

Inverters: PV systems typically use inverters to convert the DC (direct current) electricity produced by the solar panels into AC (alternating current) electricity that can be used in homes and businesses.

Batteries: Some PV systems use batteries to store excess electricity generated during the day for use at night or during periods of low sunlight.

Charge controllers: PV systems that use batteries typically use charge controllers to regulate the flow of electricity between the solar panels, batteries, and other components.

Monitoring systems: PV systems may also include monitoring equipment to track the performance of the system and detect any issues or problems.

Inverters are one major combination in which PV systems are used with. An inverter is an electrical device that converts DC (direct current) power into AC (alternating current) power. This is useful for a variety of applications, including powering household appliances, solar power systems, and electric vehicles. Inverters are essential for enabling the integration of renewable energy sources into the power grid.

In the context of solar PV systems, traditional inverters are used to convert the DC electricity produced by the solar panels into AC electricity that can be used in homes and businesses. There are several types of traditional inverters used in solar PV systems, including:

**String inverters:** These are the most common type of inverter used in solar PV systems. They are designed to handle the output from multiple solar panels wired together in a series (or "string") and convert the DC electricity to AC electricity.

**Microinverters:** These are small inverters that are installed on each individual solar panel, allowing each panel to operate independently and maximize energy production.

**Central inverters:** These are large inverters used in utility-scale PV systems. They are designed to handle the output from multiple strings of solar panels and convert the DC electricity to AC electricity at high voltage levels.

While traditional inverters are effective at converting DC electricity to AC electricity, they have several disadvantages, including:

**Efficiency losses:** Traditional inverters can experience energy losses of up to 5-10% during the DC to AC conversion process, reducing the overall efficiency of the PV system.

**Partial shading:** Traditional inverters are vulnerable to power losses when even a small part of a solar panel is shaded. This can significantly impact the overall energy production of the system.

**Reliability:** Traditional inverters contain many electronic components that can fail over time, leading to reduced performance or complete failure of the inverter.

**Safety:** Traditional inverters can pose a safety risk if they are not installed or maintained properly. In particular, high voltage DC electricity from the solar panels can be dangerous if it is not handled properly.

To address these issues, newer inverter technologies such as microinverters and DC optimizers have been developed that offer improved efficiency, reliability, and safety, as well as better performance under partial shading conditions. This brings us to the idea of TRANSFORMER-LESS inverters.

A transformer-less inverter is a type of inverter used in solar PV systems that does not use a transformer to convert DC electricity to AC electricity. Instead, transformer-less inverters use advanced electronics to convert the DC electricity generated by the solar panels directly to AC electricity that can be used in homes and businesses. There are several advantages to using transformer-less inverters in solar PV systems, including:

**Higher efficiency:** Transformer-less inverters are more efficient than traditional inverters, with energy losses of less than 2% compared to up to 5-10% for traditional inverters. This means that transformer-less inverters can generate more electricity for a given amount of sunlight, leading to higher overall energy production.

**Lower cost:** Transformer-less inverters are generally less expensive than traditional inverters, since they require fewer components and are easier to manufacture.

**Smaller size:** Transformer-less inverters are typically smaller and lighter than traditional inverters, making them easier to install and transport.

Better performance in low-light conditions: Transformer-less inverters can maintain high energy production levels even in low-light conditions, since they do not rely on a transformer to convert DC to AC electricity.

Greater reliability: Transformer-less inverters have fewer components and are less prone to failure than traditional inverters, leading to greater reliability and longer lifetimes.

Transformer-less inverters have been gaining popularity in recent years due to their compact size, high efficiency, and low cost. It is a type of inverter that operates without the use of a transformer. It converts DC power from a DC source, such as a battery, into AC power that can be used to power various types of loads.

Transformer-less inverters are becoming increasingly popular in various applications, including photovoltaic (PV) systems, motor control, and uninterruptible power supplies. Compared to transformer-based inverters, transformer-less inverters have advantages such as higher efficiency, smaller size, and lighter weight. Additionally, transformer-less inverters with timing capabilities are gaining attention because they allow for the control of both frequency and voltage of the AC output. This feature is important for applications such as grid-tied PV systems, where it is necessary to synchronize with the grid frequency and maintain the voltage within the acceptable range. In order to achieve precise control of the output frequency and voltage, a high-quality inverter control system is required. A study on the design and implementation of a transformer-less inverter with timing capabilities would contribute to the ongoing research in the field of power electronics and renewable energy systems.

Several research papers have focused on the design and control of transformer-less inverters for various applications. For example, Meir and Saggini (2016) reviewed and compared transformer-less and isolated inverters for PV systems. They discussed various topologies of transformer-less inverters, including those with and without a neutral point, and compared their performance in terms of efficiency, reliability, and safety. Rivas, Cárdenas, and García (2013) presented a control strategy for a transformer-less inverter used in a PV power generation system. They proposed a

proportional-integral (PI) controller to regulate the DC-link voltage and maintain the output voltage within the acceptable range. Lee, Kang, and Baek (2010) designed a transformer-less inverter with reactive power control for grid-tied PV systems. They proposed a control strategy that includes reactive power control, output voltage regulation, and maximum power point tracking (MPPT) to achieve high performance and stability.

In addition to PV systems, transformer-less inverters are also used in motor control applications. Liu, Tolbert, and Ozpineci (2014) reviewed three-phase grid-tied inverters with active power decoupling for motor control applications. They discussed various control strategies, including direct torque control, field-oriented control, and model predictive control, and compared their performance in terms of efficiency, speed response, and torque ripple.

Overall, the design and implementation of a transformer-less inverter with timing capabilities requires a good understanding of power electronics, control systems, and renewable energy systems. Researchers have proposed various topologies and control strategies for transformer-less inverters in different applications. Further research is needed to improve their performance, reliability, and safety, and to explore their potential in new application

In addition to their primary function of power conversion, some inverters also have timing capabilities. This means that they can control the frequency and voltage of the AC power output, which is important for certain applications, such as motor control and grid-tied solar systems.

In the design of an inverter, an important section of the inverter is protection. Protection in a transformer-less inverter refers to the various safety mechanisms built into the inverter to protect it from damage and ensure safe operation. Transformer-less inverters are designed to operate at high voltages and currents, and they can pose a safety risk if they are not installed or maintained properly. To address these risks, the following protection features will be discussed in the course of this design:

Overvoltage protection: This feature monitors the DC voltage output from the solar panels and shuts down the inverter if the voltage exceeds a safe level. This protects the inverter and other components in the PV system from damage.

Overcurrent protection: This feature monitors the DC current output from the solar panels and shuts down the inverter if the current exceeds a safe level. This protects the inverter and other components in the PV system from damage and can also prevent electrical fires.

Ground fault protection: This feature detects ground faults (when electricity flows to ground through an unintended path) and shuts down the inverter to prevent damage or electrical shocks.

Arc fault protection: This feature detects arc faults (when electricity jumps between two conductors) and shuts down the inverter to prevent damage or electrical fires.

Temperature protection: This feature monitors the temperature of the inverter and shuts it down if it exceeds a safe level. This protects the inverter and other components in the PV system from damage and can also prevent electrical fires.

This project design seeks to handle the protection section of a transformer-less inverter.

### **1.1 STATEMENT OF THE PROBLEM**

Despite the technological advantage of a conventional inverter, there's still need for improvement as some salient challenges have been raised, some of which are the weight of the inverter, due to the presence of a transformer in the conventional or traditional inverter, this makes it difficult to take it out for maintenance in the case of a fault.

Traditional inverters work through only one power point, which means panels that are performing at lower frequencies will lower the dc output of the entire system. The traditional inverters are built with an internal transformer that synchronizes the dc voltage with the ac output which could also be possible with a more sophisticated electronic method. The presence of a transformer also introduces some amount of loss to the inverter.

These problems contribute to the inefficiency of the inverter and on a long run challenge the reliability of the inverter, using one power point also affects the estimated time it takes to charge the battery because of the low dc output, which reduces the operation time of the system.

However, with the help of a transformerless inverter, we will be able to prove that this issues can be resolved in large percentage. We use a computerized multi-step process and electronic

components to convert dc to high frequency ac, back to dc, and ultimately to standard-frequency ac in place of a transformer. Simulate the system to show its feasibility and efficiency.

Nonetheless, inadequate and proper design of the conversion section in the transformerless inverter could drastically affect the performance and efficiency of the inverter as against the traditional inverter, so therefore there is need for us to have a properly designed conversion section, having the durability, reliability, performance and efficiency at heart.

## **1.2 AIM**

To design, simulate and implement the converter / conversion in a transformerless inverter.

## **1.3 OBJECTIVE(S)**

The objective of this project is to design and develop a conversion process for a transformer-less inverter for efficient and reliable conversion of dc power from renewable energy sources to ac power.

1. Research requirements for design to optimize the topology and control strategy of the transformer-less inverter to achieve high efficiency and accuracy in voltage and frequency regulation.
2. Develop, implement and validate the inverter, such as reactive power compensation, grid synchronization, and power factor correction to enhance the stability and reliability of the renewable energy system.
3. Evaluate and compare the performance, reliability and cost-effectiveness of the transformer-less inverter with traditional inverters and other state-of-the-art solutions, using simulation and experimental tests under different operating conditions and loads

## **1.4 SCOPE OF THE STUDY**

This project will focus on the conversion of a commercially available transformerless inverter to be powered by either solar panels or on grid electricity. The project will involve investigating the necessary components and technologies needed for the conversion process, as well as developing a testing methodology to evaluate the performance of the conversion process in the inverter and then simulate.

## **1.5 METHODOLOGY**

The methodology for this project will involve the following steps:

1. Researching the necessary components and technologies needed for the conversion process.
2. Design a circuit diagrams for transformerless inverter.
3. Developing a conversion process for the transformerless inverter
4. Testing and analyzing performance results of the transformerless inverter.

## **1.6 RELEVANCE OF THE STUDY**

To enhance swift conversion of power from direct current to alternating current and boost the efficiency of the transformerless inverter.

## CHAPTER TWO

### LITERATURE REVIEW

An inverter is an electronic device that converts direct current (DC) power into alternating current (AC) power. It plays a vital role in various applications, which includes residential and commercial electrical systems, renewable energy systems such as solar and wind power, and electronic devices that require AC power for operation. Inverters are used to convert the DC power generated by sources like solar panels or batteries into AC power that can be used to run household or commercial appliances. They enable the integration of renewable energy sources into the existing electrical grid and facilitate the efficient utilization of generated power (Mohan, 1995).

In renewable energy systems, inverters are essential components that convert the DC power produced by solar panels or wind turbines into AC power suitable for feeding into the electrical grid or for local consumption. They ensure compatibility between the intermittent nature of renewable energy sources and the continuous AC power requirements of the grid or connected devices.

Furthermore, inverters are utilized in various electronic devices that require AC power for operation. These devices include laptops, televisions, refrigerators, air conditioners, and many others. Inverters in these applications enable the efficient conversion and delivery of DC power from batteries or power sources into AC power, allowing electronic devices to operate without relying solely on grid power.

#### 2.1 TYPES OF INVERTERS

Inverter can be classified into many types based on output, source, type of load etc.

##### 2.1.1 CLASSIFICATION ACCORDING TO OUTPUT CHARACTERISTICS

According to the **output characteristic of an inverter**, there can be three **different types of inverters** (Kansagara, 2018).

- Square Wave Inverter
- Sine Wave Inverter

- Modified Sine Wave Inverter

1) Square wave inverter

The voltage output waveform of this inverter is a square wave. This type of inverter is the least common because all appliances are designed for a sine wave supply. If we send square wave to appliances that use sine wave technology, they may be harmed or suffer considerable losses. This inverter has a very small range of applications despite being relatively cheap. It can be used by basic tools with a universal motor.

2) Sine wave Inverter

The sine wave output waveform of the voltage allows us to obtain an output that is pretty comparable to the utility supply. The fact that all of our equipment is designed for the sine wave is the key advantage of this inverter. Its output is perfect as a result, giving reassurance that machinery will operate as planned. Although it is more expensive, this form of inverter is often used in both domestic and commercial applications.

3) Modified sine wave Inverter

The construction of this type of inverter is complex than simple square wave inverter but easier compared to the pure sine wave inverter. The output of this inverter is neither pure sine wave nor the square wave. The output of such inverter is the sum of two square waves. The output waveform is not exactly sine wave but it resembles the shape of a sine wave (Kansagara, 2018).

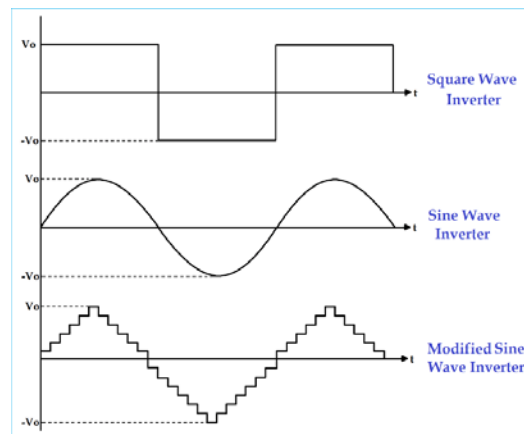


Figure 2.1 Classification based on output characteristics

## 2.1.2 CLASSIFICATION ACCORDING TO CONTROL TECHNIQUES

The output of the inverter is square wave signal and this signal is not used for the load. Pulse width modulation (PWM) technique is used to control AC output voltage. This control is obtained by the controlling of ON and OFF period of switches. In PWM technique two signals are used; one is reference signal and second is triangular carrier signal. The gate pulse for switches is generated by comparing these two signals. There are different types of PWM techniques (Kansagara, 2018).

### 1) Single Pulse Width modulation (single PWM)

For every half cycle, the only pulse is available in this control technique. The reference signal is square wave signal and the carrier signal is triangular wave signal. The gate pulse for the switches is generated by comparing the reference signal and carrier signal. The frequency of output voltage is controlled by the frequency of the reference signal. The amplitude of the reference signal is  $A_r$  and the amplitude of the carrier signal is  $A_c$ , then the modulation index can be defined as  $A_r/A_c$ . The main drawback of this technique is high harmonic content (Kansagara, 2018).

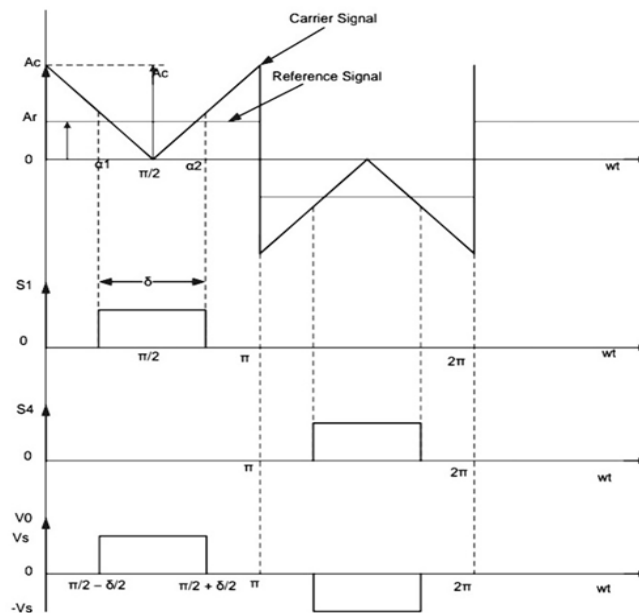


Figure 2.2: Single pulse width modulation

## 2 Sinusoidal Pulse Width Modulation (SPWM)

This control technique is widely used in industrial applications. In above both methods, the reference signal is a square wave signal. But in this method, the reference signal is a sine wave signal. The gate pulse for the switches is generated by comparing the sine wave reference signal with the triangular carrier wave. The width of each pulse varies with variation of amplitude of the sine wave. The frequency of output waveform is the same as the frequency of the reference signal. The output voltage is a sine wave and the RMS voltage can be controlled by modulation index. Waveforms are as shown in below figure.

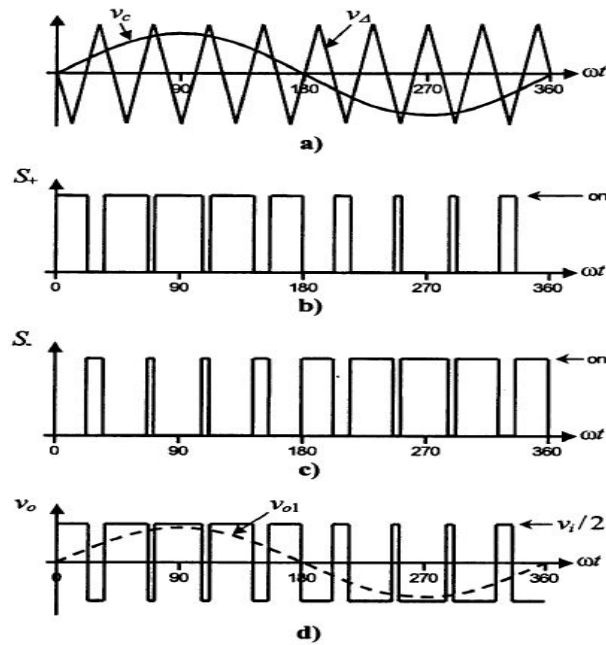


Figure 2.3 Sinusoidal pulse width modulation.

## **2.2 RELEVANT WORKS ON CONVENTIONAL INVERTERS**

**AUTHOR:** Doucet et al

**TITLE:** CONSTRUCTION OF A DC/AC PURE SINE WAVE INVERTER

**AIM:** The goal for this project were to produce a pure sine wave DC/AC inverter that would output at 60Hz, 120 volts RMS with 250Watt output.

**METHOD:**

The control circuit consists of three basic blocks: the six-volt reference, sine wave generator, and triangle wave generator. These three blocks control the PWM signals that the two MOSFET drives will send. These two MOSFET drives perform level translation to drive four N-channel MOSFETs in an H-Bridge configuration. The signal is then sent through a low pass LC filter to produce a pure sine wave at the output.

**DRAWBACK**

Does not have power management, larger in size with efficiency less than that of the transformer less inverter.

**AUTHOR:** Kashappa et al (2013)

**TITLE:** IMPLEMENTATION OF A LOW COST 5 LEVEL PWM INVERTER

**AIM:** Design of A Five-Level Inverter Which Converts The 9V DC To 9V AC

**METHOD:**

A H-bridge five level inverter prototype is created in a lab. The 5-level inverter system's experimental findings are contrasted with those of the 3-level inverter system. It has been found that a 5-level inverter system produces less total harmonic distortion than a 3-level voltage source inverter system. There is a 51% decrease in THD. The provided experimental waveforms and FFT spectra. Embedded controller is used to implement the hardware module.

**DRAWBACK:**

It does not have power management, larger in size with efficiency less than that of the transformer-less inverter.

**2.3 RELEVANT WORKS ON TRANSFORMER-LESS INVERTERS**

**AUTHORS:** Durgalaksmi k, Nivetha G, Sanjay G, Vignesh

**TITLE:** Design of single-phase transformer-less inverter

**AIM:** The aim of this work is to design a single-phase grid connected transformer-less inverter with reduced leakage current by using different topologies such as H5, H6 and HERIC and compare with justification, suitable adoptable methods of current leakage reduction.

**METHOD**

This study examines how, in the case of a transformer-based PV inverter, the common mode voltage is directly related to the current generated path. Using H5 topologies, the single-phase transformer-free grid inverter was developed and put into use. It was discovered that the common mode voltage (CMV) was primarily responsible for the leakage current. All types of operation can get rid of this. The common mode voltage must remain consistent during all modes of operation in order to eliminate leakage current. According to the findings, the H5 topology has less leakage current than the H6 and HERIC topologies. The synchronization of inverter output voltage with grid voltage demonstrates unequivocally that the design's goal was met.

## THE COMPLETE BLOCK DIAGRAM OF THE INVERTER

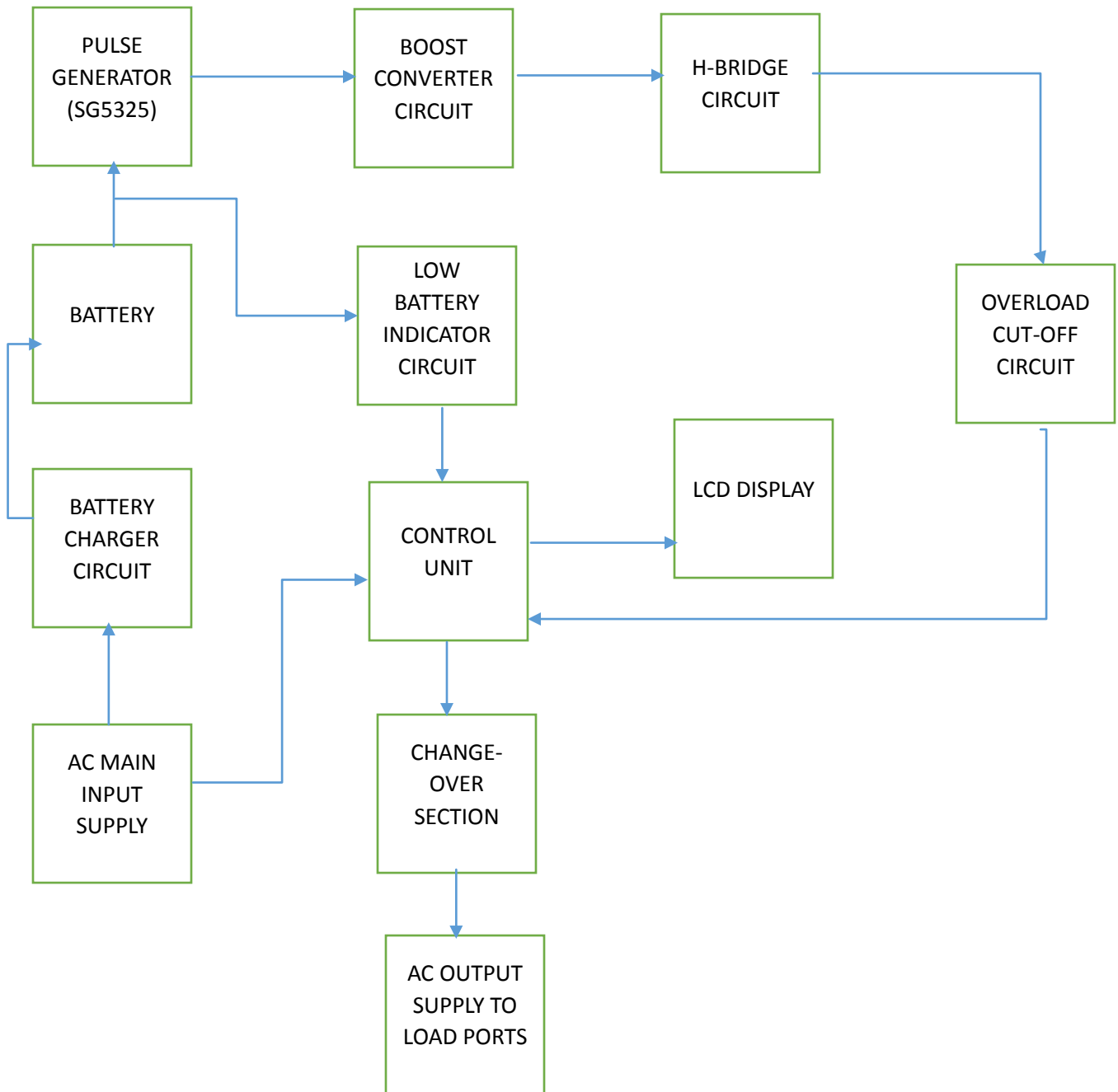


Figure 2.4 Full Block Diagram of the Inverter

## CHAPTER THREE

### METHODOLOGY AND DESIGN ANALYSIS

#### 3.1 THE BATTERY SYSTEM

An electric battery is a device consisting of one or more electrochemical cells that convert stored chemical energy into electrical energy. Each battery consists of a negative electrode (anode) that holds charged ions, a positive electrode (cathode) that holds discharged ions, an electrolyte that allows ions to move from anode to cathode during discharge (and return during recharge) and terminals that allow current to flow out of the battery to perform work. Batteries are either primary (single-use or "disposable") that are used once and discarded or secondary (rechargeable batteries) that are discharged and recharged multiple times.

A battery, which is actually an electric cell, is a device that produces electricity from a chemical reaction. Strictly speaking, a battery consists of two or more cells connected in series or parallel, but the term is generally used for a single cell. A cell consists of a negative electrode; an electrolyte, which conducts ions; a separator, also an ion conductor; and a positive electrode. The electrolyte may be aqueous (composed of water) or non-aqueous (not composed of water), in liquid, paste, or solid form. When the cell is connected to an external load, or device to be powered, the negative electrode supplies a current of electrons that flow through the load and are accepted by the positive electrode. When the external load is removed the reaction ceases. A primary battery is one that can convert its chemicals into electricity only once and then must be discarded. A secondary battery has electrodes that can be reconstituted by passing electricity back through it; also called a storage or rechargeable battery, it can be reused many times (Bedford et.al., 2014).

Batteries are made from many materials including various metals, carbon, polymers and even air. The most common are lead-acid batteries used in vehicles and lithium-ion batteries used for portable electronics. Batteries come in many shapes and sizes, from miniature cells used to power hearing aids and wristwatches to battery banks the size of rooms that provide standby power for telephone exchanges and computer centers. The picture of such battery is as below:



Figure 3.0: Battery

The circuit diagram of the system is as below:

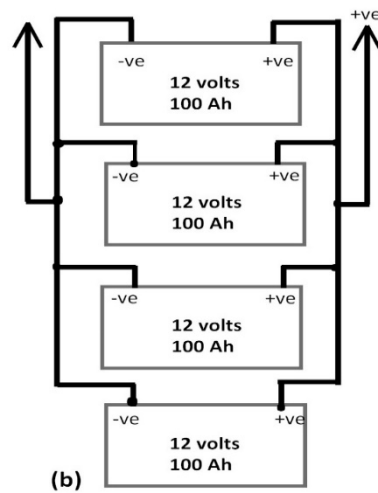


Figure 3.1 Battery Arrangement Diagram

Paralleled batteries (or paralleled strings of series connected batteries) must all be the same voltage. They may, however, be of varying capacity. Paralleled batteries have socialist tendencies. Each takes according to its needs. Each gives according to its means. If two unequally charged batteries are paralleled, that more highly charged slowly discharges into the less highly charged. That continues until voltage is equal.

## 3.2 CHARGING SYSTEM

The block diagram of the system is as below:

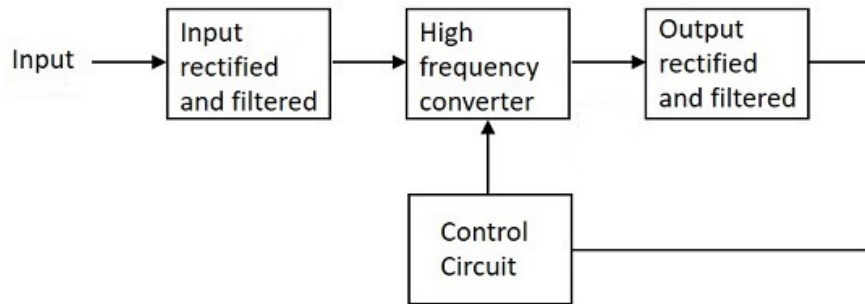


Figure 3.2: Charging System Block Diagram

In the block diagram above, the mains are fed directly into the first block without using a transformer. Of course, diodes and capacitors used made up the job. The incoming AC mains current is now a high voltage rectified DC current.

### 3.2.1 Input Stage

The AC input supply of frequency (**50-60**) Hz is fed directly to the **rectifier** and filter **circuit**. Its output contains many variations and the **capacitance value** of the capacitor should be higher enough to handle the input fluctuations. Finally, the **unregulated dc** is given to the central switching section of SMPS in order to regulate it. This section does not contain any transformer for the step down in **input voltage supply**.

### 3.2.2 Switching Section

It consists of **fast switching devices** like a **Power transistor** or a **MOSFET**, which switches ON and OFF according to the variations in the voltage.

### 3.2.3 Output Stage

The output that is derived from the switching section is again rectified and filtered. It uses a rectification and filter circuit to get the desired DC voltage. The obtained **regulated output voltage** is then given to the **control circuit**.

### 3.2.4 Control Unit

This unit is all about **feedback**, which has many sections contain in it. The inner control unit consists of an **oscillator**, **amplifier**, **sensor**, etc. The sensor senses the **output signal** and **feedback** to the control unit. All the signals are isolated from each other so that, any sudden spikes should not affect the circuitry. The **reference voltage** is given as one input along with the signal to the **error amplifier**. The amplifier is a **comparator** that compares the signal with the required signal level.

## 3.3 CHARGING SYSTEM CIRCUIT DIAGRAM

The circuit diagram of the system consists of the charging section which of the SMPS and the display is as below:

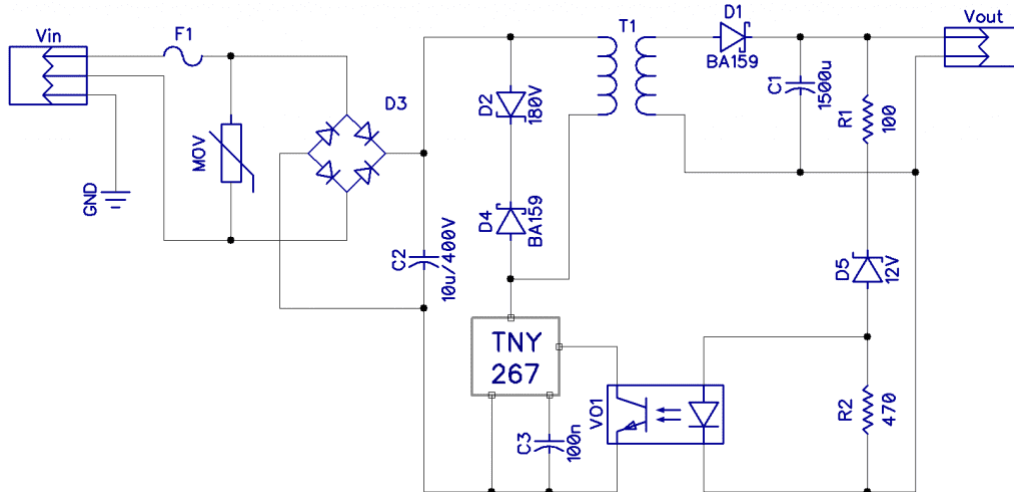


Figure 3.3: Charging system circuit diagram

### 3.4 CIRCUIT DESCRIPTION

The heart of this circuit is the TNY267 switching regulator. This one IC performs the functions of the PWM generator, MOSFET chopper switch, error amp, and control circuit.

The final output of this circuit is 12V, and it can deliver 5A

- $V_{in}$  is a 100-300V AC mains connector.
- MOV is a metal oxide varistor, used to protect the circuit from high voltage spikes.
- D3 is a full-wave bridge rectifier, and the DC output appears across capacitor C2. With a 220V AC input, this would be about  $220V * 1.4 = 308V$  DC, so be careful!
- D2 is a 180V transient suppression diode to handle back EMF spikes.
- The TNY267 runs at about 132kHz.
- Diode D1 (Schottky) on the secondary rectifies the 132kHz AC, and capacitor C1 smooths out the ripple.
- Capacitor C3 is a required bypass capacitor.
- Resistors R1, R2, and diode D5 provide a feedback circuit to the TNY267 via an opto-isolator to ensure there is electrical isolation from the mains at all points.

The primary of transistor T1 is 157t, and the secondary is 14t. The core is an E19 type ferrite transformer with a central core of about 4.5×4.5mm.

#### 3.4.1 DESIGN CALCULATION

This study is based on the battery supply and charging system of a transformer-less inverter. Batteries have energy storage ratings mentioned in Amp-hour (Ah) or milli-Amp-hour (mAh). They also have a nominal voltage that they generate (typically deep discharge batteries are 12 V batteries, cell phone batteries are 5V batteries, etc). To calculate the total energy a battery can store you can use following formula:

$$\text{Units} = (\text{Volt} \times \text{Ah}) \div 1000 \text{ or } (\text{Volt} \times \text{mAh}) \div 1000000$$

We have already talked about how to calculate the total units required in a day and also the sizing of the PV system. Batteries should be sized in such a way that the units of energy generated by the PV system should be equal to the number we have calculated above.

So, assuming we have a 1kW system and we assume that on an average it generates 6 units a day and if we have to buy 12 V battery for it, the Ah (or storage) of battery required would be:

$$(6 \times 1000) \div 12 = 500 \text{ AH}$$

In the absence of solar you need energy from the battery

Total required energy from battery per day = 4KW (16h) = 64KWh

If we use lead acid batteries of 24V and capacity 200AH

If the depth of discharge is considered to be 75%

Then no of batteries need =  $64\text{KWh} / (24\text{V} \times 200\text{Ah} \times 0.75) = 17.77$

### **3.5. DESIGN OF THE DC-DC BOOST CONVERTER**

This section provides a thorough analysis and calculations of the DC-DC boost converter's design parameters for the designed inverter.

The converter can deliver up to 2.88KW of output power to a single-phase AC load and is powered by a low DC input voltage from the battery. A crucial element of the inverter design is the DC-DC section. This kind of boost converter was developed since it would be impractical to use a flyback DC-DC converter to deliver a DC voltage of up to 325Vdc. Moreover, single switch topologies like the flyback are not usable due to the output power of rating.

### 3.5.1 DESIGN OF PULSE WIDTH MODULATOR

A variety of isolated and non-isolated switching power supplies, including inverters, boost or buck converters, etc., can employ this adaptable PWM controller. A specific PWM IC, the SG3525, is used in the pulse width modulator stage to create a frequency of 15 kHz for the MOSFET in the DC-DC boost converter. The chip's pin arrangement is shown in Figure 3.1.

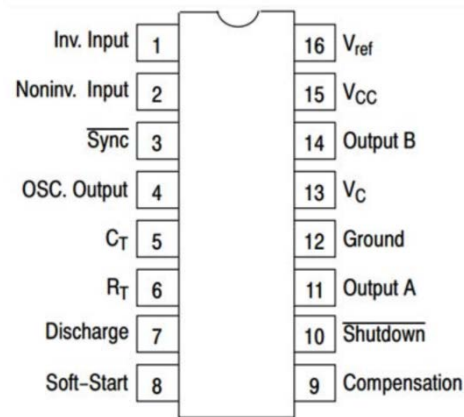


Figure 3.4 Pin configuration of SG3525 PWM IC

- Battery voltage is 24Vdc
- V<sub>IN</sub> for the PWM IC (24 volts) is taken from the battery source
- Pin 16 outputs a constant +5V and it was used to set the voltage reference of 2.5V for the pulse-width control through voltage divider resistors to pin 1
- Pin 1 and pin 2 was used as the feedback control input from the Opto-coupler stage
- Connected to the load output to automatically adjust the output voltage using pin 16 voltage reference as its reference voltage to either increasing the width or reducing the width of the PWM to keep the output load voltage stable.
- Pin 11 and pin 14 is the output of the PWM
- Pin 5 and 6 is used to set the output frequency of the PWM using the formula from the datasheet  $1.15T = RC$  for single output and  $1.15T = 2RC$  for double output.

For a frequency of 15khz

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

Where  $F = \frac{1.15}{2RTCT} = 15\text{KHz}$

Choosing  $C_T = 0.01\mu\text{F}$

$$R_T = \frac{1.15}{2FC} = \frac{1.15}{2 \times 15000 \times 0.01 \times 10^{-6}} = 3,833.3 = 3.8\text{k}\Omega$$

Value of resistor that was used in the design is  $3.8\text{k}\Omega$

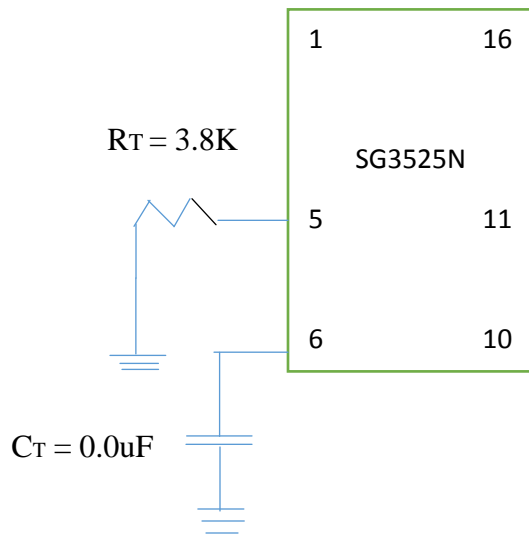


Fig 3.5 circuit of the output frequency for the PWM IC

### 3.5.2 SOFT START

The compensation pin 9 and reference pin 16 was used for the soft start circuit. This helps to prevent overshoot of the output at start. It uses a resistor and a capacitor charging circuit to introduce the delay.

The time delay can be obtained thus,

$$T = RC$$

For time delay of

$$T = \frac{1}{15000} = 0.067\text{mS}$$

A  $6.8\text{k}\Omega$  was used instead. This will give delay of  $T = 6800\Omega \times 0.01 \times 10^{-6} = 0.068\text{ms}$

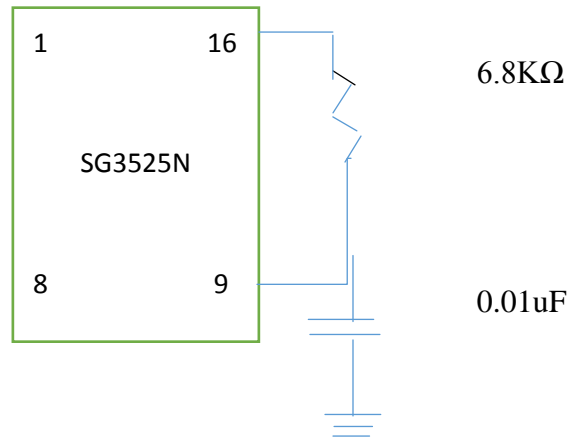


Figure 3.6: Soft start circuit for the PWM IC

### 3.6. DESIGN OF THE PUSH-PULL STAGE.

The MOSFET stage conducts or switches the necessary load current through the step-up ferrite core transformer.

- The MOSFET used in the push-pull switching step up stage is the IRFB4321 N-channel HEXFET. The reason for this type of MOSFET is that it has low gate charge which improves the switching performance.
- Fixed resistors of 10kΩ were connected between the gate and source to aid fast switching by discharging any residual static charge at the gate.
- A total of 4 MOSFET were used for the design of the push pull boost converter. 2 MOSFET function for each half of the full period.
- Max. watts output of MOSFET in the design is given as: Max. Output power of MOSFET = Watts x efficiency x total number of parallel MOSFET.

Number of parallel MOSFET = 2

Maximum power rating of MOSFET (from Datasheet) = 350 W

Assuming worse case efficiency of each MOSFET= 90%

Therefore, Max. Output-power of MOSFET= 350 x 0.90x 4 =1,260watts.

The ferrite core was used in the booster stage to step up the 28.8 volt to 325v with a frequency of 15kHz

### 3.6.1 DESIGN CALCULATIONS

The transformation ratio was determined by taking the duty cycle into account. The input to output voltage transfer function is given by the equation below.

$$N = \frac{N_2}{N_1} = \frac{V_{out}}{2V_{in}D} \quad (3.5)$$

Where  $V_{out}$  = Output Voltage of the converter

$V_{in}$  = Nominal input voltage from battery to the primary windings of the transformer

$N_2$  = Number of turns in the Secondary of the High frequency ferrite core transformer

$N_1$  = Number of turns in the primary of the High frequency ferrite core transformer

$D$  = Duty cycle of the square wave pulse sent by a voltage mode PWM regulator (SG3525).

Note that;

Ferrite core selected for transformer: **E80/38/20**

Area of ferrite core  $A_e = 390\text{mm}^2$  (from data sheet)

Max flux density  $B_m = 0.1 \text{ wb/m}^2$  ( for push pull configuration)

Air gap = 0

Frequency of oscillation = 15KHz

Recall that

$$E = 4.44FB_m A_c N$$

$$\frac{N}{E} = \frac{1}{4.44 FB_m A_c} \quad (\text{turn per volt})$$

Where  $F$  = oscillation frequency

$B_m$  = magnetic flux density

$A_c$  = area of the core

$$\frac{N}{E} = \frac{1}{4.44 \times 15 \times 10^{-3} \times 0.1 \times 390 \times 10^{-6}} = 0.38 \text{ turns per volts}$$

Primary turns will be

$$2(24\text{v} \times 0.38) = 18 \text{ turn}$$

$$N_1 = 18 \text{ turns}$$

Recall that the primary side is center tapped

Secondary turns will be

$$N_2 = 230\text{v} \times 0.38 = 88 \text{ turns}$$

A high frequency transformer with primary turns of 18 turns and secondary of 88 turns was used for the design of the boost converter circuit.

### **3.7 DESIGN OF THE RECTIFICATION STAGE**

Four Hyper fast recovery diode (RHRP1560) were used for the design of the rectifier circuit. Since the switching time is small thus making the switching frequency very high, a high frequency diode with high switching time is required. The output from the bridge rectifier circuit is fed into a pi filtering into a pure DC.

Recall that

$$V_o = V_{\text{rms}} \times \sqrt{2}$$

Where  $V_o$  = DC Peak voltage

$$V_{\text{rms}} = \text{stepped up AC voltage} = 230\text{AC volts}$$

$$V_o = 230 \times \sqrt{2}$$

$$V_o = 325 \text{ volts}$$

Since it is a full – wave bridge rectifier, the peak inverse voltage (PIV) of each diode that was used in the design has a PIV value of 600V.

### 3.8 DESIGN OF THE PI (CLC) FILTER CIRCUIT

One inductor and two capacitors are connected across either end of the CLC filter, also referred to as the pi filter. It was chosen for the input capacitor to have a very low reactance to the ripple frequency. Therefore, the input capacitor performs the bulk of the filtering. The output capacitor and inductor L work together to remove the majority of the residual ripple.

#### 3.8.1 DESIGN CALCULATIONS

The ripple factor of the filter is given by  $\gamma = \frac{\sqrt{2}}{8W^3 L R_L C_1 C_2}$

Where  $w = 2\pi f$

L = filtering inductor

C<sub>1</sub> = input capacitor

C<sub>2</sub> = output capacitor

R<sub>L</sub> = load resistance

F = frequency of the ripple voltage

Taking a ripple factor value of  $\gamma = 0.01$ , a capacitor value of  $C_1 = C_2 = 130\mu\text{F}$ ,  $f = 15\text{KHz}$  (frequency of the ripple voltage). Taking the maximum load power the inverter can handle without cut-off, we have  $p = IV$  and taking the maximum output current into account.

$I = P/V = 3500/230 = 15.217\text{A}$  (maximum current the boost converter can supply)

$R_L = V/I = 230/15.217\text{A} = 15.115\ \Omega$

Using the formula of ripple factor above we can calculate the value of our inductor.

$$L = \frac{\sqrt{2}}{8(2\pi \times 15000)^3 (130 \times 130) \times 10^{-12} \times 15.115 \times 0.01}$$

$L = 0.058\mu\text{H}$  (minimum value of inductance to give a ripple value of  $\gamma \leq 0.01$ )

The value of the inductor used in the design was  $0.5\mu\text{H}$ .

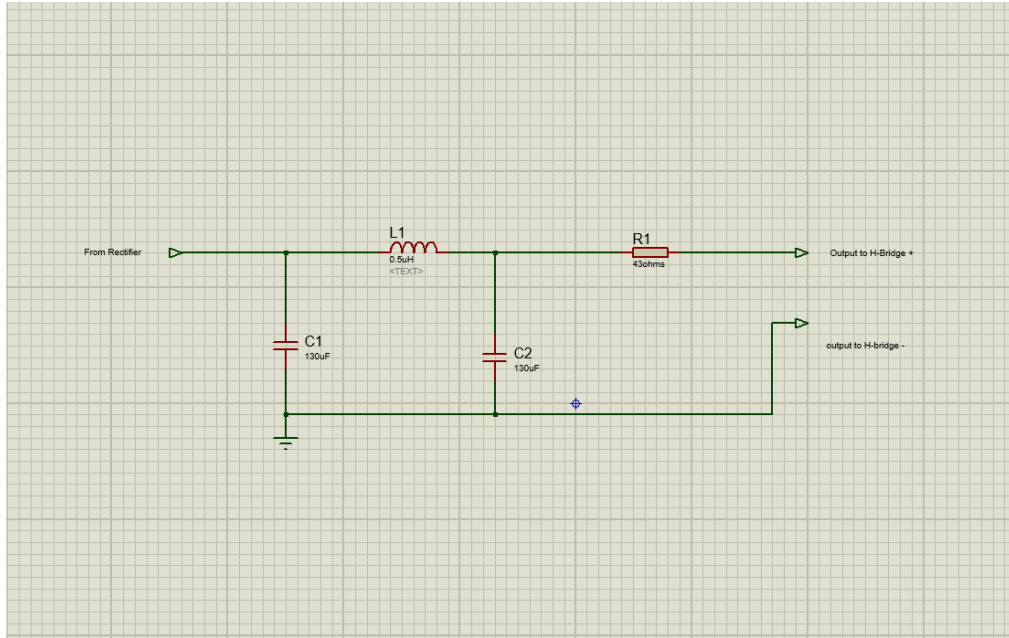


Figure 3.7 PI Filter Circuit

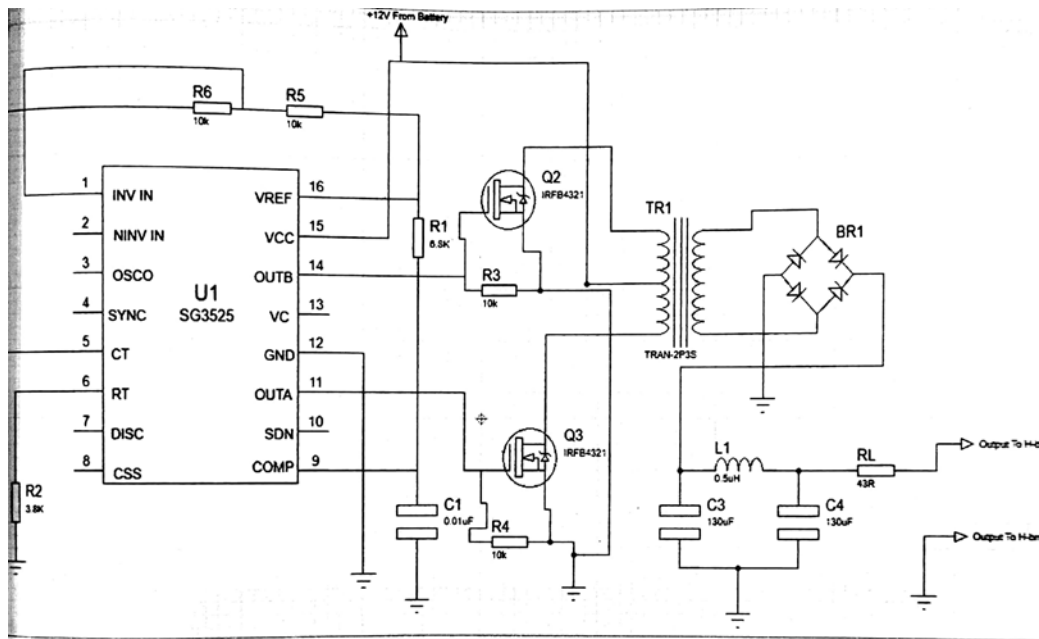


Figure 3.8 DC-DC Boost Converter

### 3.9 H-BRIDGE DESIGN AND CONFIGURATION

A switching configuration known as an H-bridge converter is made up of four switches arranged in the shape of an H. Both a positive and negative voltage across the load are necessary to produce a sine wave that is centered on zero volts. Through the use of four MOSFET switches organized in an H-Bridge configuration, this can be accomplished from a single source. to increase switching speed while reducing power loss. In the bridge, N-Channel MOSFET (IRFP460) were selected as the switches.

Because N-channel MOSFET have a lower "ON" resistance and hence less power loss, it is advantageous to utilize them as both the high side and low side switches. The drain of the high-side device is, however, connected to the 325 Vdc source in order to convert it to 230 VAC power. This is a problem since the system's highest voltage, 325 V, requires a voltage at the gate terminal that is 10 V greater than the system's highest voltage (325 V) in order for the MOSFET to turn on. A MOSFET driver and bootstrap capacitor were utilized to generate the additional voltage required to turn on the MOSFETS.

The MOSFET controller uses the battery voltage source (12V) that the inverter requires to power its operation and receives a 50Hz signal input from the microcontroller. The H-bridge's high and low sides can both be operated by the driver. The circuit diagram for the H-Bridge circuit with MOSFET drivers is shown in Fig. 3.9.

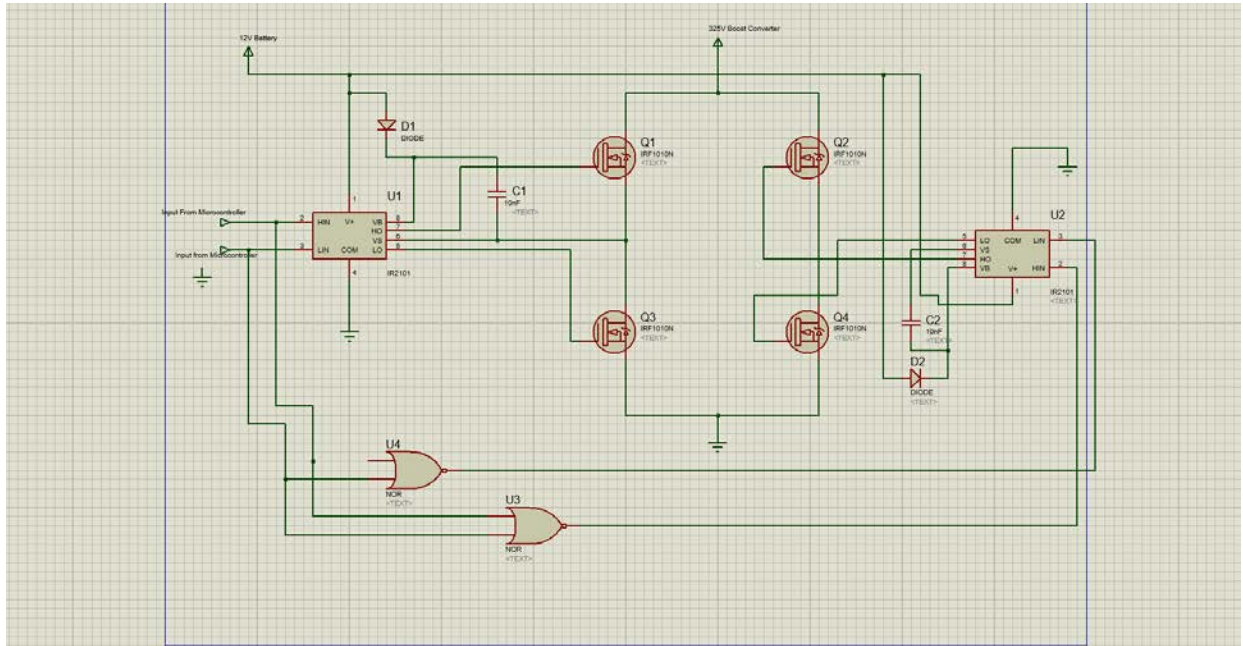


Figure 3.9: H-bridge with MOSFET Drivers

The IR2110 device's operation is managed by produced signal input from a microcontroller. The produced signal is simultaneously delivered to the LIN and HIN pins. The HO pin will be activated if the internal circuit detects logic high on the HIN pin. The LO pin will be driven if a logic low is found. Q1 and Q4 switch on and conduct if the microcontroller's two signals are both high. A positive load voltage polarity is produced as a result. When both of the microcontroller's signals are low, Q2 and Q3 switch on, turning the conductor on. A negative load voltage polarity results from this. The Vcc pin needed connections to bootstrapping components and outputs to the MOSFET because it was linked to 12V from the battery. The H-bridge's potential switching positions are listed in the table below.

Table 3.1 H-bridge Switching positions

HIGH SIDE LEFT	HIGH SIDE RIGHT	LOW SIDE LEFT	LOW SIDE RIGHT	LOAD VOLTAGE POLARITY
ON	OFF	OFF	ON	POSITIVE
OFF	ON	ON	OFF	NEGATIVE

ON	ON	OFF	OFF	ZERO
OFF	OFF	ON	ON	ZERO

### 3.10 PROTECTIONS IN THE INVERTER

Every design without adequate protection is likely to fail over the course of usage, endanger the life of the user or operating personnel, incur unplanned cost and definitely increase the rate of failure or the MDT (Mean Down Time) of the system. Protection is a critical aspect of power system design and operation, and a well-designed protection system can help prevent damage to equipment, minimize downtime, and ensure the safety of people working with or near the power system. For the above reasons, it is important to protect our designs, in this case, an Inverter.

Protection mechanisms are implemented in inverters to safeguard the equipment, users, and electrical infrastructure from potential hazards and malfunctions.

There are basically four (4) protection methods for an inverter which can be classified into just two (2) (Wei, 2019):

1. Hardware Protection
2. Combination of Hardware & Algorithm Based Protection

1. Hardware Protection

- a. Primary Hardware Protection

Fuses: Overcurrent fuses usually find their use here as they are the most common form of overcurrent protection. They are basically used as a backup protection method to isolate the converter when there's an overload or overcurrent occurrence. The use this method is almost not so effective because fuses have a delayed response-time and for that reason can't be utilized alone as they require other protection circuits in addition (Koutroulis, 2003).

- b. Relays: Relays also finds its use here. The use of relays will lead to chattering of contacts at high currents leading to damaged terminals of the relay and ultimately leading to higher inoperative time or downtime.

## 2. Combination of Hardware & Algorithm Based Protection

### a. Driver Circuit Based Hardware Protection:

This method utilizes real time characteristics of the switching devices (IGBTs or Power MOSFET) when working under different connected loads. It makes use of a microcontroller which houses the logic for detection and protection control for turning off the switching devices (Transformer-less inverters uses switching devices to generate their sinusoidal AC wave forms instead of a transformer). It basically monitors the VCE (Collector-Emitter Voltage) or VDS (Drain-Source Voltage) or Collector current of the switching devices and switch them off if they go beyond a certain threshold.

### b. Main power circuit-based hardware protection or combined with modified algorithm control method:

The protection methods used here are based on modifying the main power circuit by adding auxiliary protection circuit or using different control method in the software under fault condition. The concept of the protection in is using an auxiliary switch, connected along with driving circuit, between the positive rail of the DC bus capacitors and the collector/drain terminal of the upper switching transistor. This circuit also incorporate a micro-controller to monitor the changes.

### c. Algorithm based overload or short circuit protection method:

The overcurrent control strategy is based on generating new current reference according to a current limit function. A current limiting method was proposed based on a hysteresis comparator circuit and switched to current controlled mode after overcurrent happens.

However, there are various protection techniques or types of protection used in most inverters, shortly we'd delve into details how each of this circuit works:

1. Overvoltage Protection
2. Overcurrent/Overload Protection
3. Overtemperature Protection
4. Ground Fault Protection
5. Short Circuit Protection

**Overvoltage Protection:** Inverters monitor the AC output voltage to prevent it from exceeding safe limits. Overvoltage protection mechanisms may include voltage sensors, surge protectors, or voltage limiters. If the voltage exceeds the predetermined threshold, these protection features can trigger

**Overcurrent/Overload Protection:** Overcurrent protection is crucial for preventing excessive currents from flowing through the inverter especially when it is connected to high level of load. Inverters typically employ current sensors or current limiters to monitor the current levels. If an abnormal or dangerous current is detected, protective measures such as shutting down the inverter or activating circuit breakers are initiated to safeguard the system.

**Overtemperature Protection:** Inverters generate heat during operation which usually occur during switching in the case of transformer-less inverters, and excessive heat can damage internal components or reduce efficiency. Overtemperature protection mechanisms use temperature sensors to monitor the operating temperature of critical components such as power semiconductors or transformers. If the temperature exceeds a safe threshold, the protection system can reduce the power output, activate cooling mechanisms, or shut down the inverter to prevent damage.

**Ground Fault Protection:** Ground fault protection detects and mitigates ground faults, which occur when a connection is established between a live conductor and a ground path. Ground fault protection mechanisms use ground fault detectors or ground fault interrupters (GFI) to detect imbalances in current flow. When a fault is detected, the inverter can automatically shut down or isolate the faulty circuit to prevent electric shocks or damage.

**Short Circuit Protection:** Short circuits can cause excessive currents and potentially damage the inverter or connected devices. Inverters employ short circuit protection mechanisms such as current limiters or fuses that detect and isolate short circuits. These protection features can disconnect the faulty circuit and prevent further damage.

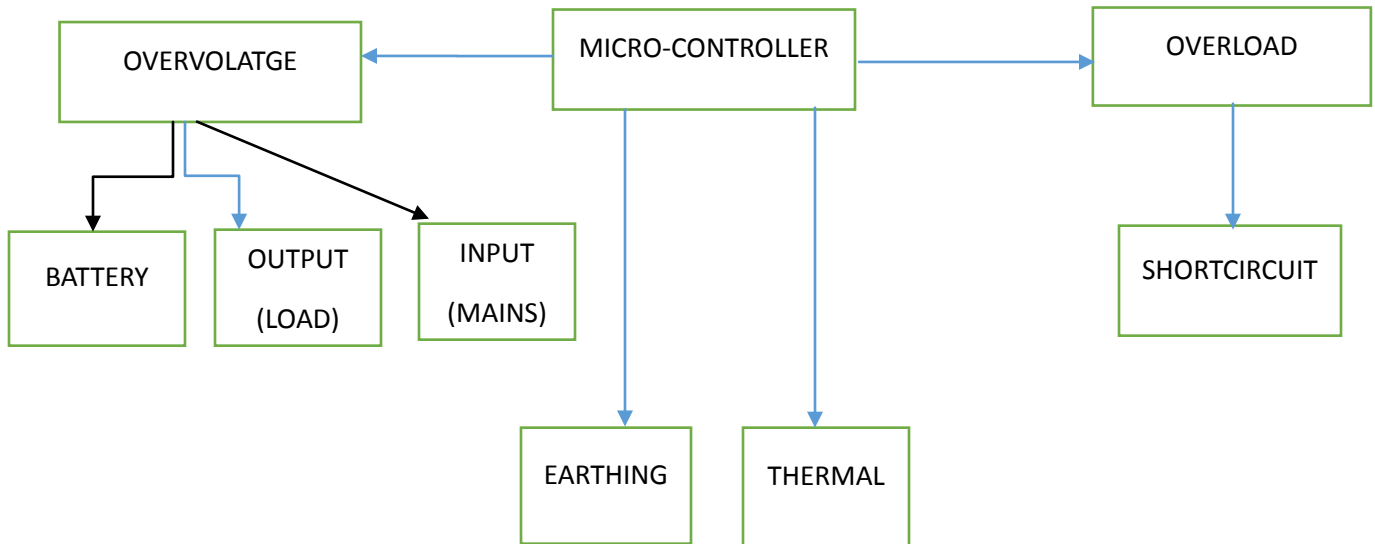


Figure 3.10: Block diagram of protection

### 3.10.1 OVER-VOLTAGE/UNDER VOLATGE PROTECTION

In electrical power systems, overvoltage is the rising of voltage beyond the design limit of a circuit or circuit element. In Inverters in this case, this condition may be hazardous and may result in either the destruction of the inverter or the appliance connected to it. Depending on its duration, the overvoltage event can be transient, a voltage spike or permanent, leading to a power surge.

The maximum supply voltage that electronic and electrical equipment may function at is specified in the design ratings, and exceeding this voltage can result in significant damage to the devices. For example, an electric light bulb has a wire in it that at the given rated voltage will carry a current just large enough for the wire to get very hot (giving off light and heat), but not hot enough for it to melt. The voltage delivered determines how much current flows through a

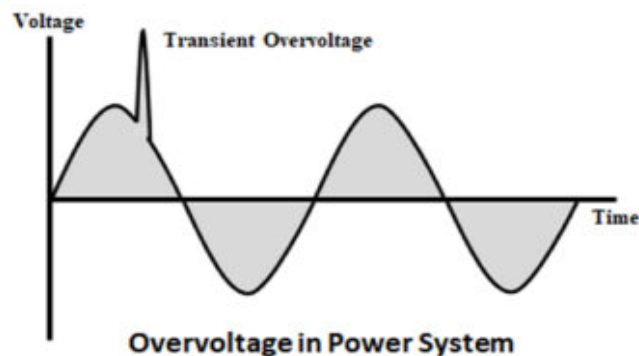
circuit; if the voltage is too high, the wire may melt and the light bulb may burn out. Similar to other electrical devices, if an overvoltage is applied to the circuit, it may cause it to stop working or possibly catch fire.

## CAUSES

1. **Faulty Components or Circuitry:** Malfunctions in critical components or circuitry within the inverter can lead to improper voltage regulation and cause overvoltage.
2. **Ambient Temperature:** Extreme temperatures can affect the performance of electronic components and, in some cases, lead to an increase in the output voltage of the inverter.
3. **Input Voltage Fluctuations:** The DC input voltage to the inverter, which comes from the battery bank or solar panels, can vary due to factors like fluctuations in solar power output or battery conditions. If the inverter does not handle these variations adequately, it may result in overvoltage.
4. **Inverter Output Regulation:** The inverter's output voltage needs to be regulated to maintain it at the desired level. If the inverter's voltage regulation circuit malfunctions or is improperly calibrated, it may produce output voltages higher than the intended value.

### 3.10.2 DESIGN ANALYSIS

The circuit below shows an analog overvoltage design protection of a load using analog components like Zener diodes and PNP transistors. The circuit disconnects the output when the voltage exceeds the preset level. The preset value is the rated value of the Zener diode connected to the circuit which can be changed according to your suitable voltage value.



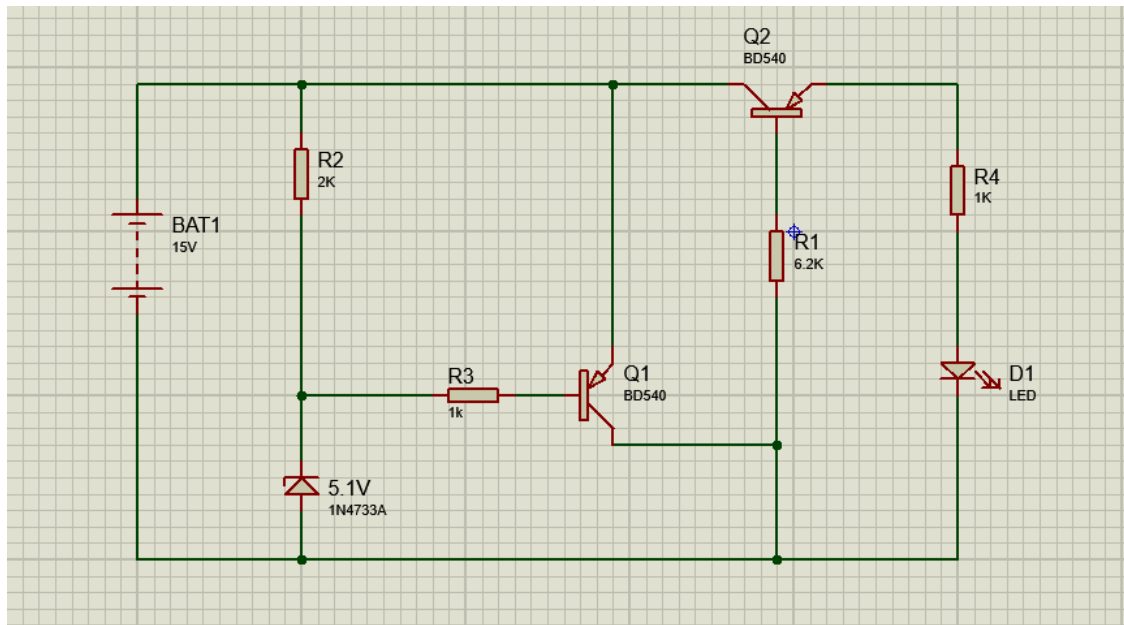


Figure 3.11: Analog design of an overvoltage protection

This Circuit works to protect the output voltage to the load from going beyond normal values. It uses two PNP transistors in switching mode alongside a Zener diode. A Zener diode is a special kind of diode that works in a breakdown region in reverse biased. This means it only works when connected in reverse polarity. The main components in this circuit are the Zener diode and the transistors. The Zener diodes sets the margin for the voltage level of the circuit; this implies that base on how this circuit is configured, if the Zener diode gets active, it implies an Over-Voltage has occurred and the transistor immediately cuts off the output to the load.

Ideally, Zener diodes have a breakdown voltage ranging from 2.4 to as high as 180V or 200V. In the circuit above, our aim is to protect the output Voltage from going beyond 260V. To achieve this, two Zener diodes of the same specifications are connected in series. This is important because if the current characteristics are different the diodes may not operate as expected. For anything below 260V, the transistors T2 in the Circuit will keep conducting.

T2 is a PNP transistor and as such, it requires a low potential to open up its base for current to flow from the emitter to the collector so it works as a switch. Since its input is connected to ground which is at zero potential, the base is open and it conducts. If for any reason a fault occurs or there's a load change causing transient and the voltage goes beyond 260V, the Zener

diode immediately pulls the base potential of the transistor T1 to a zero potential causing it's base to open immediately and immediately conducting the current from the positive potential through its emitter to the collector straight to ground thereby causing the base of T2 to go high and closing it gates which then cuts off supply to the load in an instant until the fault is cleared.

### 3.10.3 UNDER-VOLATGE

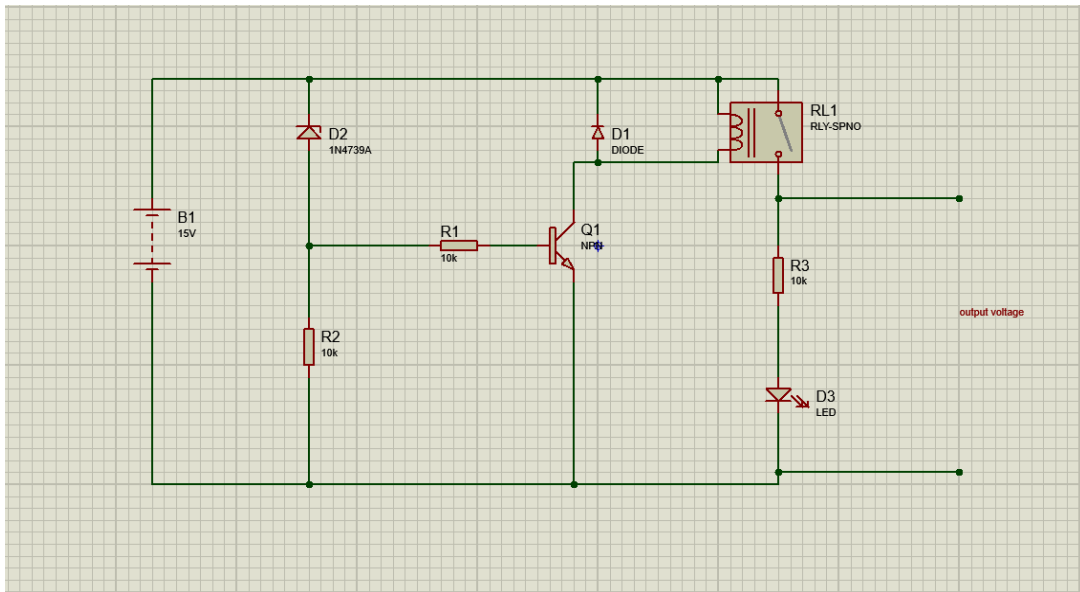


Figure 3.12: Analog design of an overvoltage protection

In the case of an under voltage like the one above the Zener diode will pull down the voltage from the positive terminal to ground if any voltage above 150V is passed across it and immediately pulls up or stop conducting of for any reason the supply voltage goes below 150V. When the voltage is above 150V, the breakdown region is activated, and the diodes behind to conduct thereby causing the base of the transistor to open. When it opens, the current can now flow through the relay to the collector and then to ground thereby completing the circuit. On completing the circuit, it gets magnetize and the NC flips to NO and the load circuit it completed and currents begin to flow.

While all of these circuits works fine, it makes the design of our INVERTER bulky and more expensive, difficult to repair and diagnosed. Compared to a digitized control, this circuit is also slow to respond and also can't respond to precise values.

In an inverter over-voltage and under-voltage protection, the battery, the output and the supply to the inverter are the possible areas where an over Voltage and under Voltage is likely to occur and hence these areas need to be protected. In the design, analog circuit alongside a micro controller was used to ensure super-fast response and protection in order to save the load and the inverter it's from self-destructing

### 3.10.4 MICROCONTROLLER

The control unit consists of the microcontroller, some resistors, crystal oscillator, etc. The microcontroller used for this project is DSPIC30f4012 by MICROCHIP technology. It is a 16bit microcontroller with digital signal processing ability (DSP). It is clocked externally by a 6.144 MHz crystal oscillator for high performance. It basically does all controls like driving of the h-bridge MOSFETs, relay triggering (change-over), displays battery status, faults, warnings, input and output voltage status, etc. It is the very heart of the design.

28-Pin SDIP and SOIC

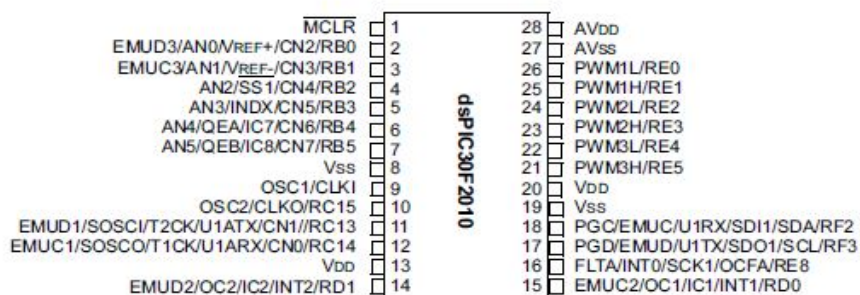


Figure 3.13: Architecture of DSPIC30f4012

High-Performance Modified RISC CPU of the DSPIC30f4012:

- Modified Harvard architecture
- C compiler optimized instruction set architecture
- 84 base instructions with flexible addressing modes
- 24-bit wide instructions, 16-bit wide data path
- 12 Kbytes on-chip Flash program space

- 512 bytes on-chip data RAM
- 1 Kbyte non-volatile data EEPROM
- 16 x 16-bit working register array
- Up to 30 MIPs operation:
  - DC to 40 MHz external clock input
  - 4 MHz-10 MHz oscillators input with PLL active (4x, 8x, 16x)
- 27 interrupt sources
- Three external interrupt sources
- 8 user selectable priority levels for each interrupt
- 4 processor exceptions and software traps.

#### Motor Control PWM Module Features:

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

It has inbuilt Analog to Digital converters (ADC) used for reading input signals, Electronically Erasable Programmable Read Only Memory (EEPROM) used for storing data and adjustments

made to the default settings, Motor control module for driving the h-bridge MOSFETs, DSP engine for fast processing ability, processor, etc.

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

1. Reads the status of the battery bank, determine their state of charge, etc.,
2. Reads the status of the output voltage and determine the error or deviation from the set-point. This enables a fast correction to be made and stabilize the output,
3. Reads the temperature of the system and decide if to enable/disable the cooling fan,
4. Checks for the presence of the mains voltage and
5. Buttons interface to the controller.

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

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

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

### **3.10.5 INVERTER OVERVOLTAGE PROTECION**

In the inverter, there are basically three (3) areas to prevent from overvoltage. They include:

1. Battery Protection
2. Inverter output Protection/Overload (AC Output)
3. Supply Protection (Mains supply)

### **3.10.6 BATTERY PROTECTION**

To prevent the battery from overcharging and over-discharging, it is necessary to protect the battery at points where the voltage is low and too high. The Micro-controller sends a signal to

turn on the charge circuit and when the battery is low, it sends another trip signal to stop the charging.

A battery is rated 12V. This means that 12V is a about middle of the range of the battery. A fully discharge 12V lead acid is around 11V, fully charged it's about 14 to 15V (Puffafish, 2020). This means two fully charged 12V battery would give a volage of roughly 28.8V. This voltage is fed through a voltage divider to give a maximum output of 5V. This way we can measure the voltage level of the battery.

### 3.10.6.1 DESIGN CALCULATIONS

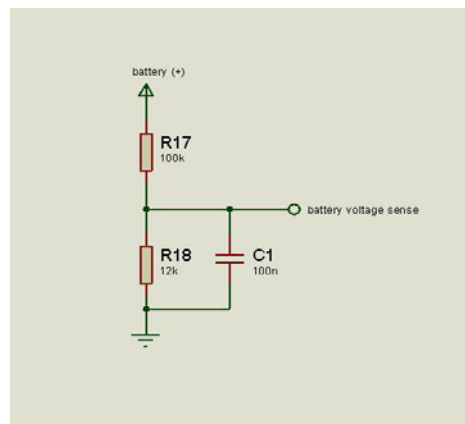


Figure 3.14: Voltage Divider Network for Battery Charging

From the image above, 28.8V is coming from a fully charged battery,  $R17 = 100K\Omega$ , and  $R18 = 12k$

But from voltage divider rule,

$$V_{out} = V_{battery} \left( \frac{R18}{R17+R18} \right)$$

Where,

$V_{out}$  = Expected voltage output.

$V_{battery}$  = Voltage from the battery

$$V_{out} = 28.8 \left( \frac{12k}{100k + 12k} \right)$$

$$V_{out} = 3.08V$$

This is the voltage the Micro-controller would see at full voltage charge of the battery (Fully charged) base on the chosen resistance.

For the low voltage,

$$V_{out} = 21 \left( \frac{12k}{100k + 12k} \right)$$

$$V_{out} = 2.25V$$

This is the voltage the Micro-controller would see at low voltage charge of the battery (Low Battery) base on the chosen resistance.

Using Mapping,

$$V_{\text{micro-controller}} = \frac{(V_{\text{battery-max}}) - (V_{\text{battery-min}})}{V_{out}}$$

$$V_{\text{micro-controller}} = \frac{28.8 - 21}{3.08}$$

$$V_{\text{micro-controller}} = \frac{7.8}{3.08}$$

$$V_{\text{micro-controller}} = 2.53V$$

This simply means, for every 1V drop from the 3.08V output from the voltage divider, the Micro-controller subtracts 2.53V from the battery to keep track of its voltage level until its 21V and vice-versa for charging. This way we are able to protect the battery from overcharging and over-discharging.

### 3.10.7 OVERCURRENT/OVERLOAD PROTECTION

Overload, Overcurrent and Short-circuit all have one thing in common and that is the fact that they produce maximum current at the specific time of occurrence. Overcurrent refers to the situation when the current flowing through an electrical circuit exceeds its designed or normal rating especially due to too much load on the system, in this case an Inverter. It is a common

occurrence in electrical systems and can lead to a range of issues, from equipment damage to potential fire hazards.

Short-circuit on the other hand is a critical electrical fault condition that occurs when two conductors with differing potentials come into direct contact, creating a low-resistance pathway for current to flow. This abnormal flow of current possesses very severe consequences for electrical systems and poses significant safety risks.

For this reason, it is very important to ensure that the system is well protected against such cases. Because of how important and how fast these events occur, a protection system that must be implemented must be able to see the fault just immediately after it occurs so that it can be cleared. Such protection system must be very sensitive, very fast and must possess high accuracy.

In the design of the Inverter, a dsPIC30f4012 was used because it possesses a very high processing speed of 40MHz. A 40 MHz clock frequency for a microcontroller like the dsPIC30f4012 is relatively fast for embedded systems and microcontroller applications because of how suitable it is for tasks that require real-time signal processing, control systems, motor control, and other applications where rapid data manipulation is essential.

### 3.10.8 HOW OVERCURRENT/OVERLOAD IS DETECTED

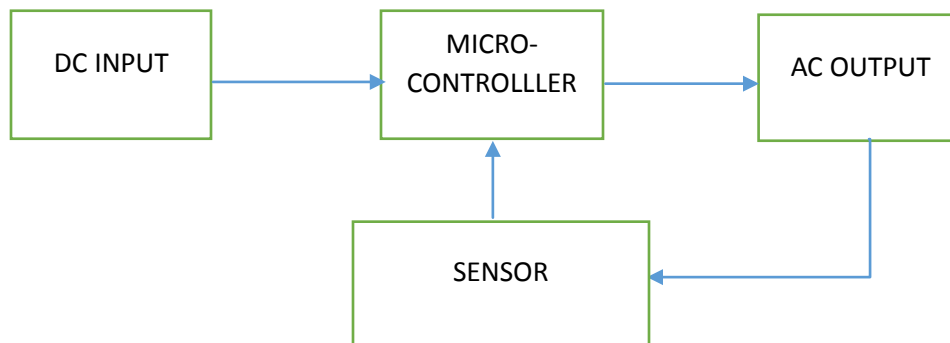


Figure 3.15: Inverter Over-Current Protection Block Diagram

The block diagram above gives a visual representation of how the Microcontroller detects an over current or short circuit fault in the system using a current transformer as a sensor and then tripping off the inverter.

### 3.10.9 OVERLOAD/OVERCURRENT

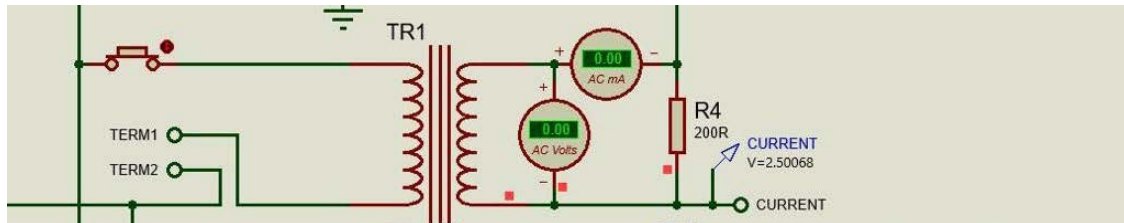
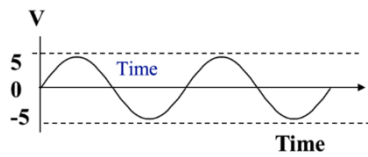


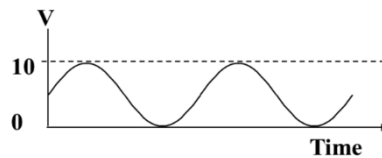
Figure 3.16: Overcurrent circuit for detecting overload/overcurrent

From the image above, TR1 is current transformer. A Current Transformer (CT) is an electrical device used to measure or monitor alternating current (AC) in electrical systems. It's a type of instrument transformer that's designed to transform a high current on the primary side into a lower, proportional current on the secondary side, making it easier to measure and monitor without directly connecting to the high-current circuit. Its input is connected to the AC output of the inverter where current can be accurately measured. It has a turns ratio of 1000:1, which simply means for a 1000A current on the primary side of the transformer there's an equivalent 10A being produced on the secondary side which is then passed through a 200Ω resistor to cause a voltage drop that can be measured by the micro controller because the micro controller cannot measure current directly. Since our microcontroller cannot work with current directly, the current produced by the current transformer have to be converted to voltage by connecting a resistor on the output of the transformer causing a voltage drop on the output.

The output from the current transformer is an alternating current and hence contains a negative part in its sine waveform. The microcontroller cannot work with negative input form hence the voltage needs to have to undergo an offset using a DC voltage to raise it above the negative cycle. It is a mean amplitude displacement from zero, like the image below.



Without DC offset



With DC offset

Figure 3.17: DC offset waveform

### 3.10.10 HOW THE DC OFFSET VOLTAGE WAS ACHIEVED

The DC offset voltage was produced using an LM358 Op Amp using the voltage follower technique from Op Amp. An electronic circuit in which the output voltage follows the input voltage is known as a voltage follower. In simple words, a voltage follower is an electronic circuit whose output voltage remains the same as the input voltage.

### 3.10.11 DESIGN OF THE VOLTAGE FOLLOWER SECTION

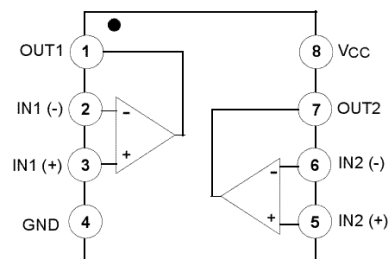


Figure 3.18: LM358 Pin Configuration

LM358 IC is a dual operational amplifier integrated circuit with two Op-Amp powered by a common power supply. It consists of two independent compensated operational amplifiers with low power and high gain frequency.

LM358 is specially designed to operate from a single supply over a wide range of voltage. It is more flexible for low voltage AC and moderate voltage DC applications. LM358 IC can handle 3V- 32V DC supply and source up to 20 mA per channel.

- Pin1 and pin8 are the output of the comparator
- Pin2 and pin6 are inverting input.
- Pin3 and pin5 are non-inverting inputs
- Pin4 is the GND terminal
- Pin8 is VCC+/positive supply.

The internal circuitry of the IC is configured to our design as follows

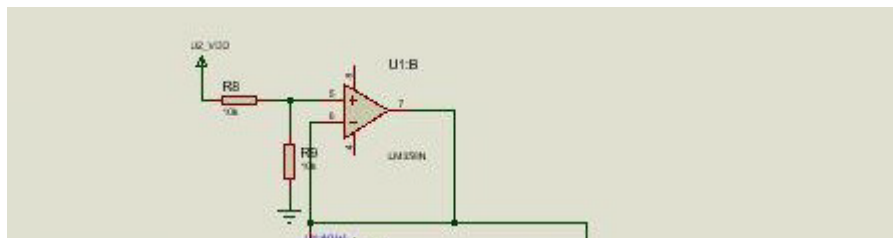


Figure 3.19: Voltage Follower

The LM358 consist of two operational amplifiers,  $U_{1-A}$  &  $U_{1-B}$ .  $U_{1-B}$  is configured as a voltage follower with its input coming from a voltage divider consisting of resistor  $R8 = 10K$  and  $R9 = 10K$  from a VDD of 5V. Each resistor has a voltage drop of 2.5V which makes the input to the pin 5 of  $U_{1-B}$  2.5V. The output is fed back into pin 6 as an offset voltage to offset the negative voltage from the sinusoidal input voltage on the second operational amplifier.

### 3.10.11.1 DESIGN CALCULATION OF THE VOLTAGE FOLLOWER.

$$V_{DD} = 5V$$

$$R8 = 10K$$

$$R9 = 10K$$

Using Voltage Divider rule

$$V5 = V_{DD} \left( \frac{R8}{R8+R9} \right)$$

$$V5 = 5 \left( \frac{10K}{10K+10K} \right)$$

$$V5 = 2.5V$$

$$V_{out} = 2.5V$$

This value is now fed into the output of the current transformer to give an output of 2.50068V.

This 2.50068V would be actually the offset voltage, to get the real voltage output from the transformer:

### 3.10.11.2 OUTPUT VOLTAGE CALCULATION

Output voltage from transformer,

$$V_{out} = V_{Total} - V_{offset}$$

$$V_{out} = 2.50068 - 2.5$$

$$V_{out} = 0.00068V$$

Current on the secondary side of the CT

Recall,  $V = I_s R$

Where  $I_s$  = Secondary current of the CT

R = Output Resistance

$$I_s = \frac{V}{R}$$

$$I_s = \frac{0.00068}{200}$$

$$I_s = 0.0000034A$$

Recall,

For every 1000A on the primary there's an equivalent 1A on the secondary

Therefore,

$$1000 \longrightarrow 1$$

$$I_p \longrightarrow 0.0000034$$

$$I_p = 1000 \times 0.0000034$$

$$I_p = 3.4mA$$

Where  $I_p$  = primary current of the CT

The Micro-controller gets the total voltage and subtract the offset voltage from the total voltage to get the actual reading from the current transformer. The Micro-controller samples this data in real time and know when to shut down the system when it's drawing beyond the maximum load demand. The current flowing through the 200Ω resistor is determined by the load connected to the inverter. The whole essence of the CT is just to ensure the current measuring is simplified enough for the Micro-controller to be able to read it. A 3.4μA on the secondary side of the CT tells the Micro-controller that there's an output of 3.4mA on the Primary side.

### **3.10.12 HOW THE MICRO-CONTROLLER MEASURES DIGITAL SIGNALS FROM ANALOG SIGNALS.**

The output from the current transformer is an alternating current but the Micro-controller works with DC, hence, there have to be a way for the Micro-controller to read the data. That's where Analog to Digital Converter (ADC) comes in.

## ANALOG TO DIGITAL CONVERTER

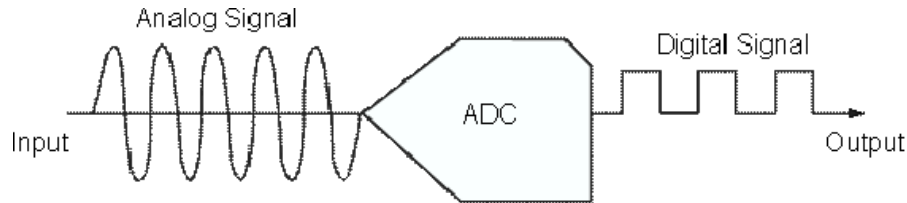


Figure 3.20 Analog-Digital Converter

An analog to digital converter, often known as an ADC converter, transforms an analog signal into a digital one. One type of integrated circuit, or IC, that directly changes a signal from continuous form to discrete form is this converter. They are usually embedded in a micro-controller.

The analog signal sent into the ADC is sampled into different values and then converted to binary numbers of 1's and 0's or bits. The ADC have different bits values, like 3-Bits, 4-Bits, 5-Bits, 8-Bits e.t.c

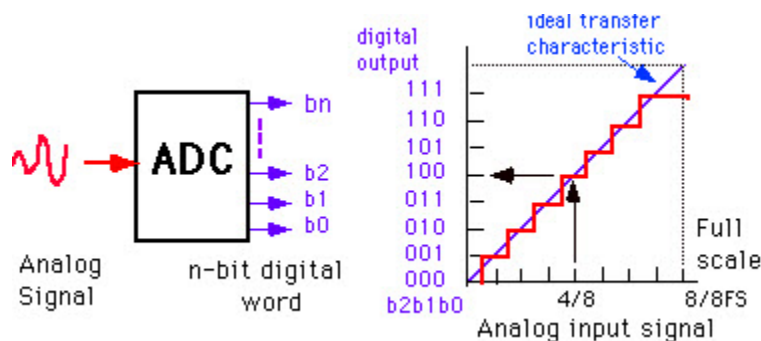


Figure 3.21: Analog-Digital Conversion Representation

If a 1V signal is to be converted to a digital form by using 3-bit ADC as shown above, a total of  $2^3 = 8$  divisions will produce 1V output. This results in  $1/8 = 0.125V$  which is called the quantization level represented for each division as 000 for 0V, 001 for 0.125, and likewise up to 111 for 1V. If we increase the bit rates like 6, 8, 12, 14, 16, etc. we will get a better precision of

the signal. Thus, bit rate or quantization gives the smallest output change in the analog signal value that results from a change in the digital representation.

This is how the Micro-controller is able to tell what 0.5V in analog form will be.

### 3.10.13 PULSE WIDTH MODULATION & DUTY CYCLE

When the load in a system increases, the current demand in the system simultaneously increases, causing the voltage to drop. If the system doesn't compensate for the additional load by supplying more power, the connected loads may not function up to maximum capacity. If the output voltage drops due to overload, the Micro-controller quickly compensates for that drop in output voltage by opening the channels of the MOSFET to conduct for a longer time. This is why the concept of overcurrent/overload protection becomes important because the system knows at what point to supply more power and when to shut down the system completely and this is the concept of Pulse Width Modulation.

Pulse Width Modulation (PWM) is a technique used in electronics and control systems to manipulate the average voltage or current delivered to a load by rapidly switching a signal between high and low states. It is commonly used to control the speed of motors, the brightness of LEDs, and other applications where smooth and precise control is desired.

In PWM, a constant voltage or current source is switched on and off at a fixed frequency. The duty cycle, often expressed as a percentage, represents the ratio of the time the signal is in the high state (on) compared to the total period of one cycle. A higher duty cycle results in a higher average voltage or current, while a lower duty cycle results in a lower average voltage or current.

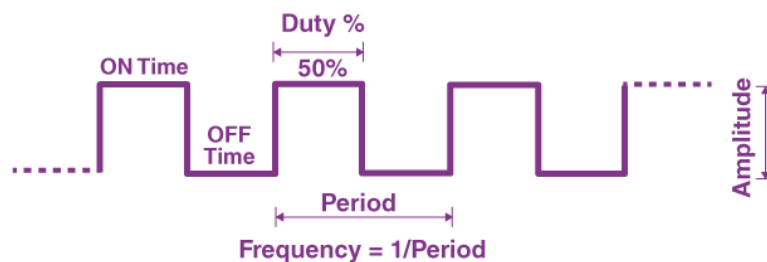


Figure 3.22: Duty Cycle of 50%

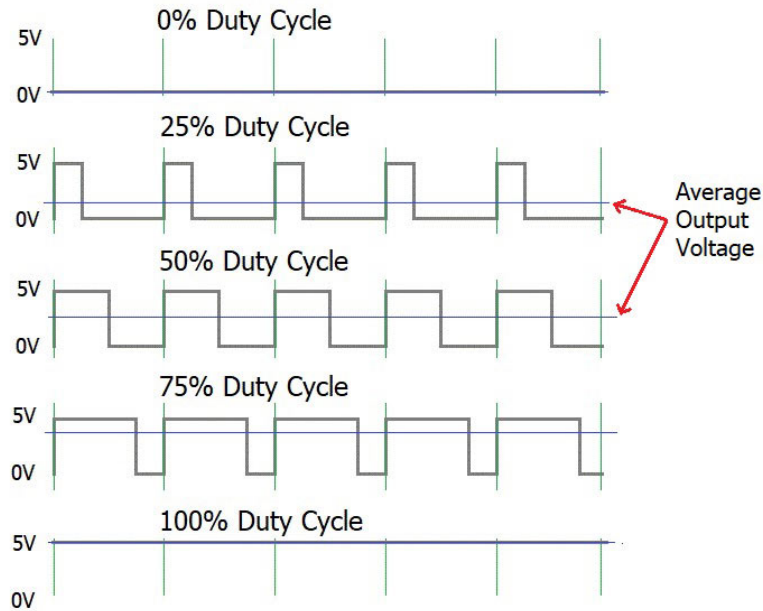


Figure 3.23: Duty Cycle of 0-100%

For example, let's consider controlling the brightness of an LED using PWM:

- If the PWM signal is on (high state) for 80% of the time (duty cycle = 80%), the LED will be relatively bright because it's receiving a higher average current.
- If the PWM signal is on for only 20% of the time (duty cycle = 20%), the LED will be dimmer because it's receiving a lower average current.

The high-frequency switching of the PWM signal is generally much faster than the response time of the device being controlled. This means that the device perceives the average voltage or current and responds accordingly, providing a smooth and controlled output.

PWM is widely used in various applications including motor control, power inverters, audio signal generation, and more. It's an efficient way to control power without dissipating excessive energy as heat, which can be particularly useful in energy-sensitive applications.

**3.10.14 FLOWCHART DIAGRAM OF OVERLOAD/OVERCURRENT CONTROL WITH PWM**

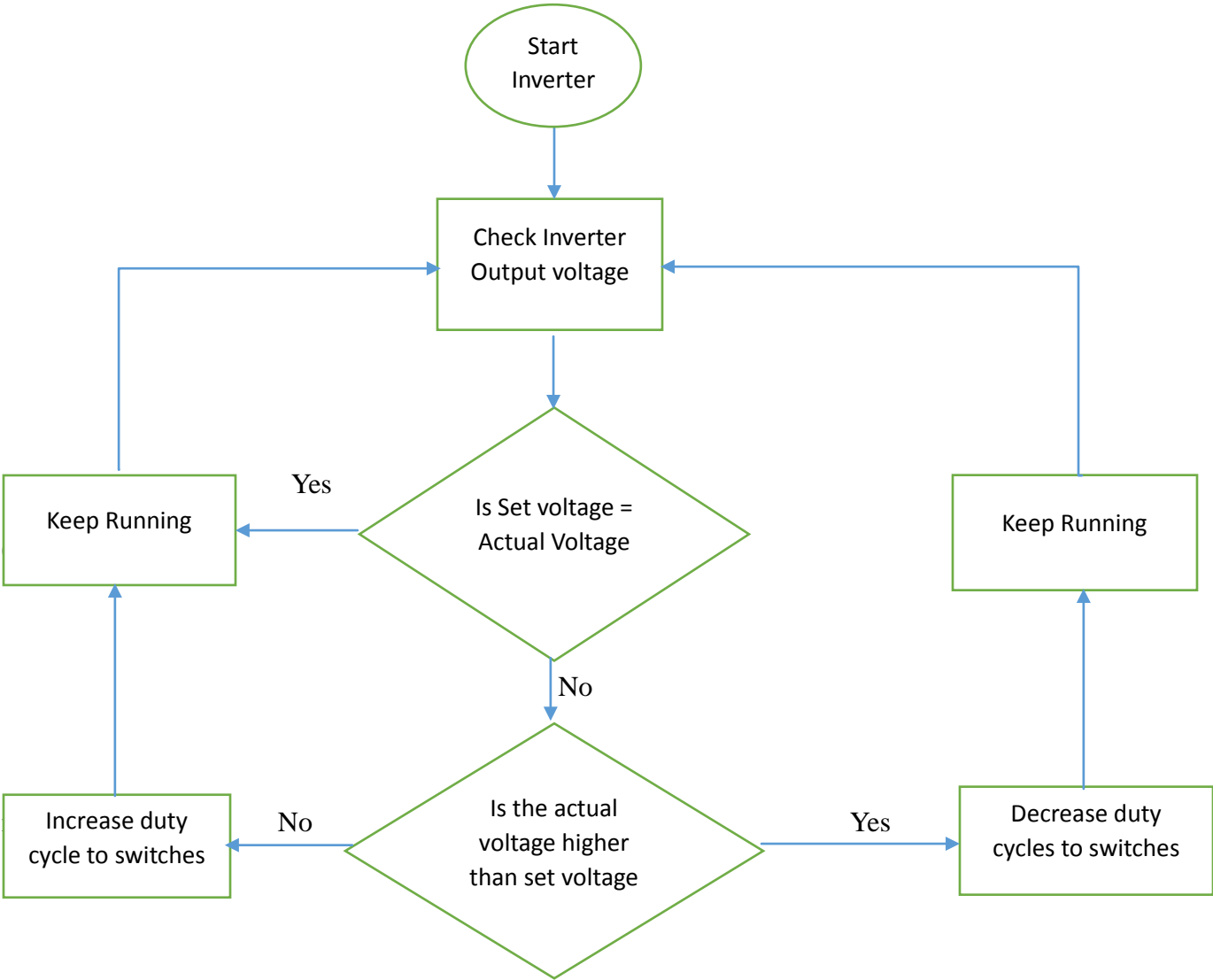


Figure 3.24: Flowchart Diagram of Overload/Overcurrent Control With PWM

### 3.10.15 MAINS SUPPLY

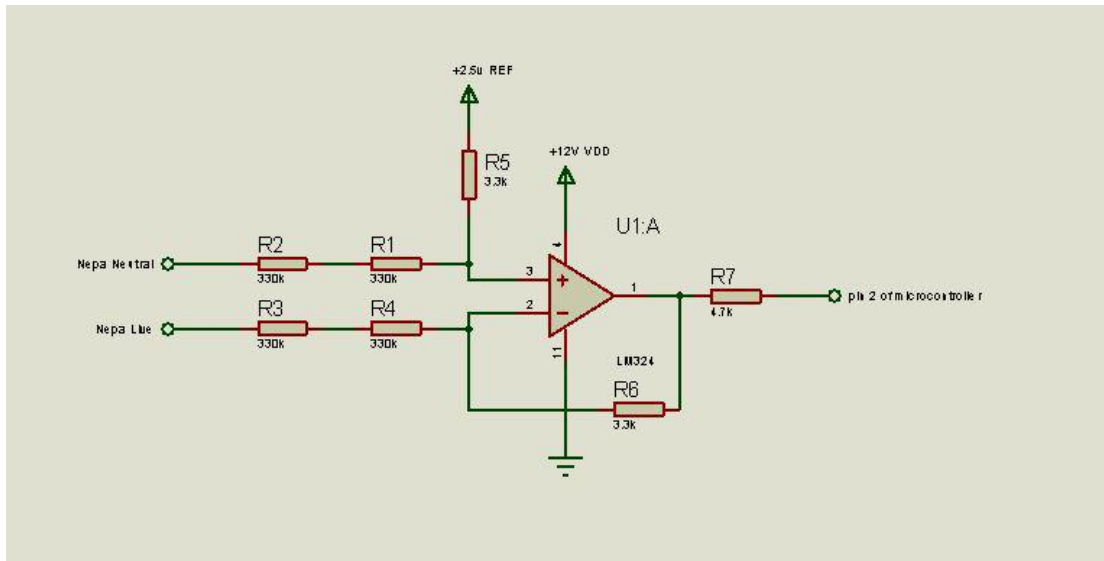


Figure 3.25: Main Supply Circuit

In the case of the mains supply, the inverter is being protected from an overvoltage from BEDC. The same circuit on our overload protection applies here alongside with an algorithm. The supply range is first checked before the inverter switches over to BEDC, otherwise it will remain on inverter mode.

3.10.16

FLOWCHART DIAGRAM

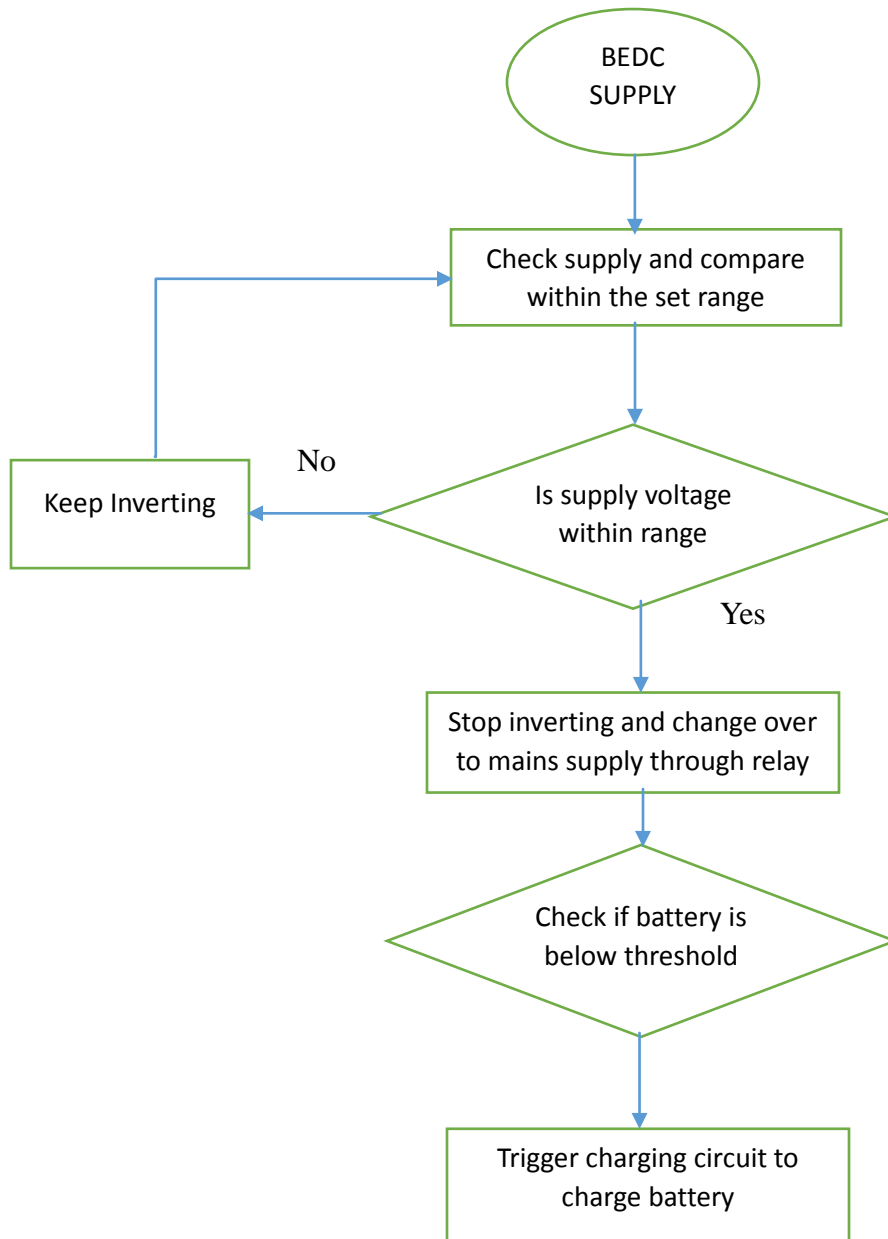


Figure 3.26: Flowchart Diagram of Overvoltage from Mains Supply

### 3.10.17 SHORTCIRCUIT

Just like we've seen prior, short-circuit can be classified as a form of overcurrent but it's not an overload. For the design, a threshold limit of the maximum current that the inverter can deliver was set and if the load demand goes beyond that threshold, the micro-controller shuts-down the inverter. While overload may just lead to the heating up of the system, a short could lead to fire within a very small instant of time, which makes it a very disastrous occurrence and hence must be protected in a special way.

A short circuit is said to have occurred when there's a direct connection between the positive potential and the negative potential creating a zero-resistance path for current to flow.

Mathematically, we know that

$$V=IR$$

Since  $R=0$  and say for a voltage of 240V, the current in the system becomes thus:

$$I = \frac{240}{0} = \infty$$

This means when a short circuit occurs, an infinite current flows through the system causing design components to immediately blow up and hence it becomes important to protect such scenario from ever occurring. A system designed to protect against short circuit must be fast to both detect and respond to the short because a delay of 1sec is disastrous when it comes to short circuit.

3.10.18 FLOWCHART DIAGRAM OF SHORTCIRCUIT CONTROL WITH PWM

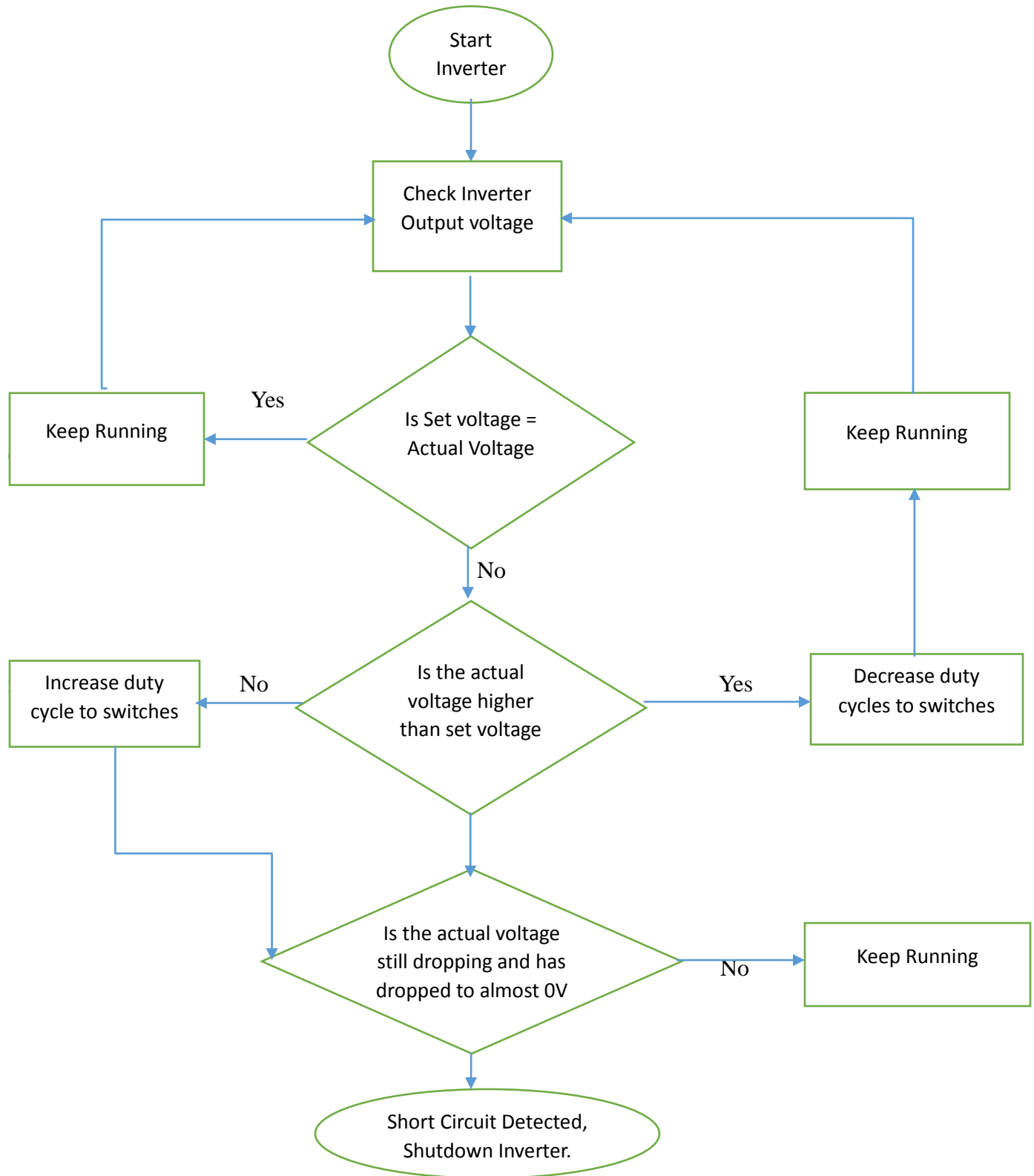
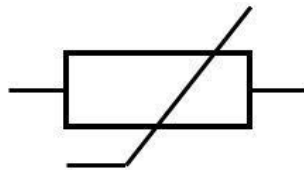


Figure 3.27: Flowchart Diagram of Short-circuit Control With PWM

The diagram above shows how the Micro-controller is able to detect the short circuit and short down the Inverter. If the output voltage from the inverter keeps dropping while the Micro-controller increases duty cycle, it indicates a short circuit and the inverter is immediately shutdown.

### 3.10.19 THERMAL /TEMPERATURE PROTECTION

Thermal Protection is a method of detecting overtemperature conditions in electrical systems, Inverters in this case, and disconnecting power to the load. It's a system that shuts-down the power supply when the internal temperature exceeds safe values. This feature ensures the system is not been overheated and it usually involves the use of sensors to measure the temperature level of the Inverter. The features also ensure longevity and reliable operation of the Inverter. To measure temperature, we need a sensor called "Thermistor". Thermistors, short for "thermal resistors," are temperature-sensitive resistors that exhibit a significant change in resistance with variations in temperature.



**Thermistor symbol**

Figure 3.28: Thermistor Symbol

They are widely used in various applications for temperature sensing, temperature compensation, and control purposes.

There are two main types of thermistors:

Positive Temperature Coefficient (PTC)

Negative Temperature Coefficient (NTC) thermistors.

1. NTC Thermistors: Negative Temperature Coefficient thermistors exhibit a decrease in resistance as the temperature increases. In other words, their resistance decreases as the

temperature rises. NTC thermistors are commonly used for temperature sensing, where their resistance change is utilized to measure temperature. They are also used in applications like temperature compensation in electronic circuits.

2. PTC Thermistors: Positive Temperature Coefficient thermistors, on the other hand, experience an increase in resistance as the temperature rises. Their resistance goes up as the temperature increases. PTC thermistors are used in applications such as overcurrent protection and self-regulating heaters. When used in circuits, their increasing resistance can be employed to limit current flow as temperature rises, providing a kind of built-in protection mechanism.

Thermistors offer some advantages over other temperature-sensing devices:

- Accuracy: Thermistors can provide accurate temperature measurements over a specific temperature range.
- Compact Size: They are small in size, making them suitable for applications where space is limited.
- Rapid Response: Thermistors can respond quickly to temperature changes due to their small size and thermal characteristics.
- Cost-Effectiveness: Thermistors are often more cost-effective compared to other temperature-sensing technologies.
- Customization: Their resistance-temperature characteristics can be tailored to specific applications by selecting appropriate thermistor materials and manufacturing methods.

### 3.10.20 HOW IT WORKS IN A CIRCUIT

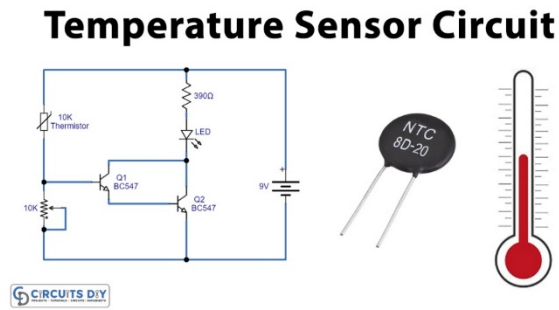


Figure 3.29: Analog Design of a temperature circuit

The working of this circuit is simple. It is operating at 9 volts. Initially, when there is no heat, the circuit will remain turned off. When the thermistor receives heat its resistance will be decreased and it will let the current flow.

This will activate both the transistors and the voltage will be passed to LED, the circuit will be completed and it will light up. A variable resistor of 20K ohms is used to adjust the circuit for activation of LED on the required temperature or heat.

### 3.10.21 DESIGN ANALYSIS

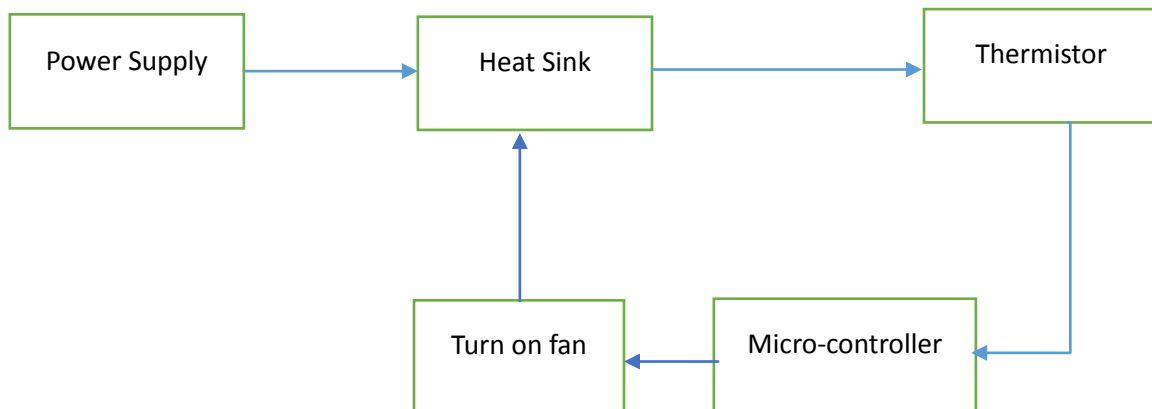


Figure 3.30: Flowchart diagram of the thermal protection

The heat sensor is connected to the heat sink where it measures the temperature of the heatsink. The heat sink is meant to absorb the excess heat from the switching MOSFETS because at such high frequency of switching, they'd dissipate so much heat and if that heat isn't conducted out, it could damage the heat sink. The sensor is the mediator between the Micro-controller and the heat sink.

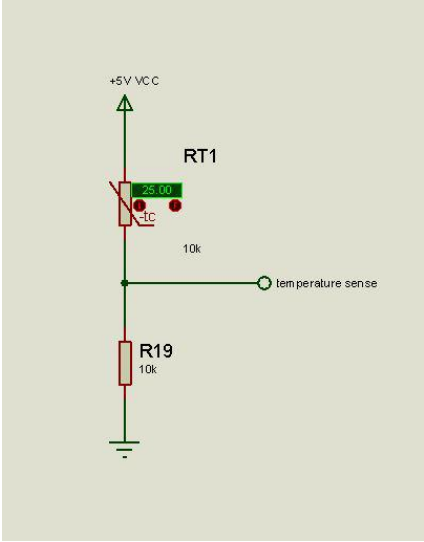


Figure 3.31: Thermal Protection Circuit

When the Micro-controller receives a signal from the heat sink, it turns on the fan to cool the system while still measuring the temperature and if the temperature still doesn't drop, it shuts down the system to prevent it from overheating.

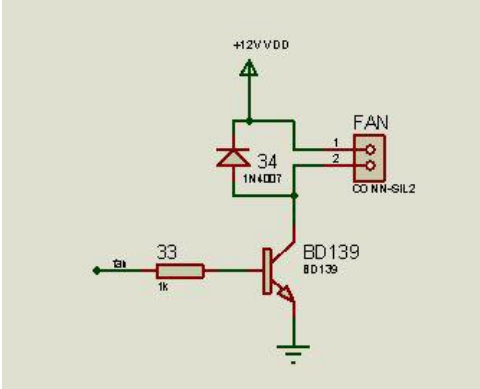


Figure 3.32 Fan cooling circuit

When the thermistor receives heat, the resistance drops causing the voltage sent to the Micro-controller to increase. As the voltage to the Micro-controller increases from 1V to 5V, the micro controller detects the severity level of the temperature and goes ahead to trigger the fan to come on, if the temperature goes up to 5V and the system doesn't cool, the Micro-controller shuts down the system to prevent the overheating as shown in the flowchart algorithm below. For our system, on normal operation mode, the fan is ideally active and running when the temperature gets to 38° C. If the temperature rises up to 60° C, the Micro-controller stops inverting while keeping the fan running to keep the system cooling.

3.10.22

FLOWCHART DIAGRAM

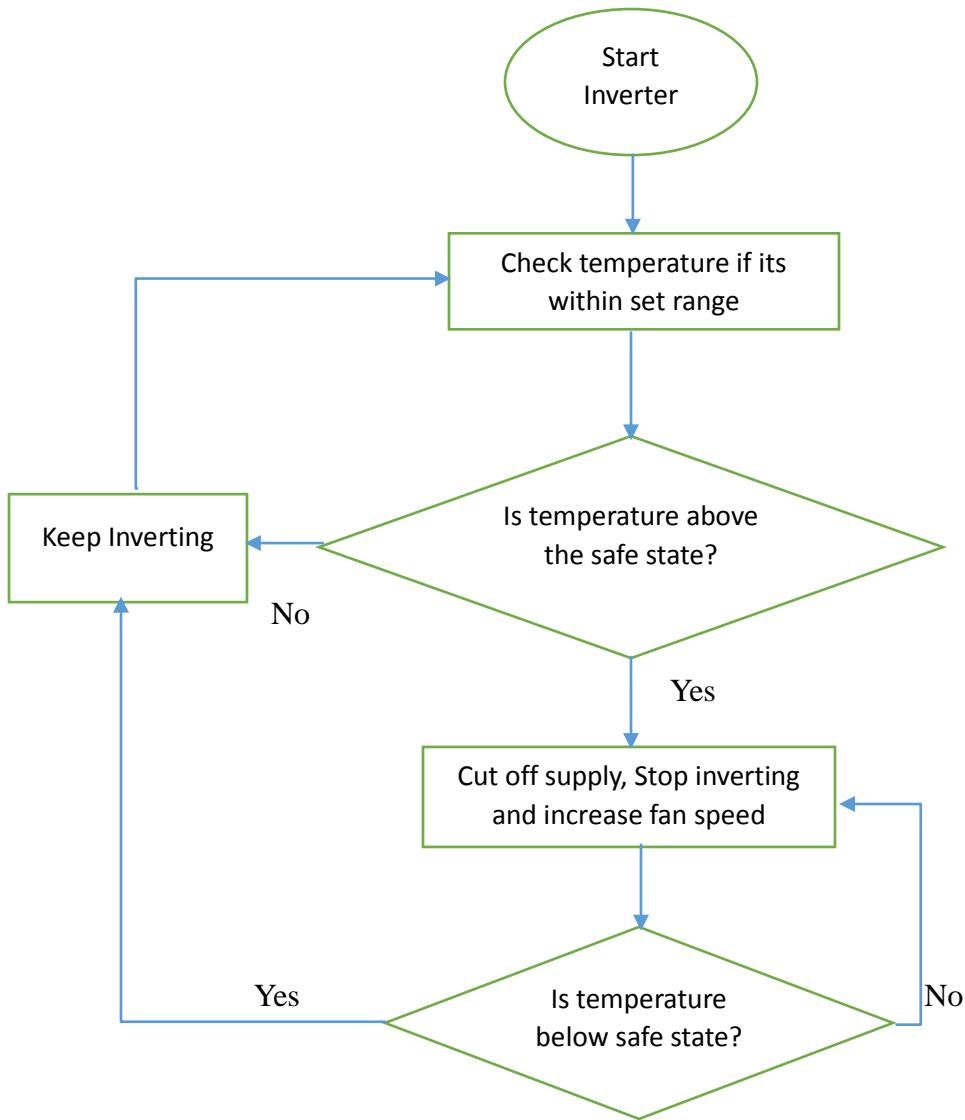


Figure 3.33 Flowchart Diagram of the thermal protection

Using the thermistor formula, we can calculate any parameter of our choice

$$R_2 = R_1 e^{\beta \left( \frac{1}{T_1} - \frac{1}{T_2} \right)}$$

Where  $R_1$  = Negative Temperature Coefficient (NTC) Resistance

$R_2$  = Resistor in series with the NTC.

$\beta = \text{Constant}$

T1 = Initial temperature of the NTC

T2 = Final temperature of the NTC

temperature (°C)	nominal resistance ( $\Omega$ ) for NTC
0	32565
5	25345
10	19875
15	15700
20	12500
25	10000
30	8060
35	6535
40	5330
45	4370
50	3605
55	2989
60	2490
65	2085
70	1755
75	1480
80	1260
85	1070
90	920
95	785
100	680

Figure 3.34 Temperature Table of an NTC

From the image above its obvious that each temperature have a resistance value for an NTC. It is evident that the lower the temperature the higher the resistance and the higher the temperature, the lower the resistance. This mechanism causes a varying voltage drop that enables the micro-controller knows when to turn on the fan circuit.

Since our normal operating temperature is 38°C, from interpolation, the resistance would be:

T(K)	R(Ω)
308k	8060Ω
311k	xΩ
313k	6535Ω

$$\frac{311-308}{313-308} = \frac{x-6535}{8060-6535}$$

$$\frac{3}{5} = \frac{x-6535}{1525}$$

$$4755 = 5x - 32675$$

$$X = 7.45K\Omega$$

At 38°C the resistance of the NTC would be 7.45kΩ. This simply means at that temperature the Micro-controller would see 2.86V from the calculation below.

Recall that from voltage divider,

$$V_{out} = V_{DD} \left( \frac{R_2}{R_1 + R_2} \right)$$

$$V_{out} = 5 \left( \frac{10000}{17450} \right)$$

$$V_{out} = 2.86V$$

From the command written on the Micro-controller, at this voltage the fan circuit would be triggered.

For the shutdown temperature of 60°C, the resistance of the NTC at that temperature is 2490Ω.

Therefore, from the voltage divider rule again,

$$V_{out} = V_{DD} \left( \frac{R_2}{R_1 + R_2} \right)$$

$$V_{out} = 5 \left( \frac{10000}{12490} \right)$$

$$V_{out} = 4.00V$$

From the command written on the Micro-controller, at this voltage the fan circuit speed would increase and the system would be shut-down for faster cooling.

### 3.10.23 EARTHING PROTECTION

Earthing refers to the practice of connecting electrical equipment, appliances, and systems to the Earth or a conductive structure that serves as an alternative pathway for electric current. This is done for a variety of safety, functional, and regulatory reasons. The Earth in this context acts as a reference point with a stable potential that helps prevent the buildup of excessive voltage and ensures the safe dissipation of electrical energy.

1. **Safety:** Earthing is a fundamental safety measure in electrical systems. It provides a pathway for fault currents to flow directly into the ground, reducing the risk of electric shock to humans and animals, and preventing damage to equipment and structures. Without proper earthing, fault currents could potentially flow through unintended paths, causing hazardous situations.
2. **Fault Current Dissipation:** In the event of a fault, such as a short circuit, earthing ensures that excess current has a low-resistance pathway to flow into the ground. This prevents the accumulation of potentially damaging energy within the system and helps avoid overheating and fires.
3. **Stability:** Earthing helps stabilize voltage levels in electrical systems. By providing a reference point (ground potential), it limits the potential difference between different parts of the system, promoting consistent and safe operation of equipment.
4. **Electromagnetic Interference (EMI) Reduction:** Earthing can help reduce electromagnetic interference generated by electrical systems. This is particularly important for sensitive electronic equipment that can be affected by unwanted electromagnetic noise.
5. **Lightning Protection:** Properly designed earthing systems can help protect structures and equipment from lightning strikes. Lightning-induced currents can be safely directed into the ground, minimizing damage.

There are different types of earthing systems, including:

- **System Earthing** (Neutral Earthing): In electrical power distribution systems, the neutral point of the power supply is often connected to the Earth, providing a reference point for voltage levels and allowing fault currents to flow safely during faults.
- **Equipment Earthing**: This involves connecting the metal parts of electrical equipment and appliances to the Earth to prevent the buildup of dangerous voltages on their surfaces.
- **Lightning Earthing**: This focuses on providing a low-resistance path for lightning-induced currents to travel safely to the ground, protecting structures and equipment.

## CHAPTER FOUR

### CONSTRUCTION AND TEST RESULTS

#### 4.0 CONSTRUCTION

A step-by-step construction approach was employed in the course of this project. The order of construction started with programming the DSPIC30f4012 Micro-controller: boost converter stage, H-bridge Drivers and H-bridge MOSFET section, overload cutoff section and battery charging section, Temperature section, Short-Circuit section.

The construction also involved the connecting together of various electrical and electronic components in the correct manner to ensure that it worked perfectly and according to specification. Some of these components were sourced from the local electrical/electronics stores and some were in discrete form while others in integrated components.

The following tools and instruments were employed in the construction work:

- a. Digital multi-meter
- b. Soldering iron and lead
- c. Lead sucker
- d. Copper stripping knife
- e. Wire cutter / stripper
- f. Long nose pliers
- g. Project board
- h. Vero-board.

Bread boarding was done first as it was essential to confirm that the design will work when tested and if not, what necessary correction and adjustments must be done before transferring the components to the Vero-board for permanent soldering.

The component layout was planned first before the components were laid out on the breadboard and Vero-board respectively. After the bread boarding and test carried with necessary adjustment done, the circuit components were transferred to the Vero board for permanent soldering.

I.C socket stand was used for all the ICs and the components were neatly soldered and the copper strips along the Vero board were neatly scrapped off at point where it is not needed to avoid short-circuits.

After complete soldering has been done, continuity test was carried out to check for any likely shorts.

Each of the sections was carefully soldered on the Vero-board with LEDs for indicators and voltmeters connected out.

The looping of the power cord to the booster section and also connecting wires from the relay was carefully and neatly done.

The MOSFETs were screwed down to heat sinks for effective head dissipation.

#### **4.1 CASING AND BILL OF ENGINEERING MEASUREMENT AND EVALUATION**

The complete unit was housed in a metallic casing with the battery terminals for positive and negative, power switches, output LCD screen, control buttons, circuit breaker and power connector were neatly connected and placed in their allotted space and slots.

The casing was earthed and the components were also carefully laid out inside it. The diagram of the casing is shown in Figure 4.0

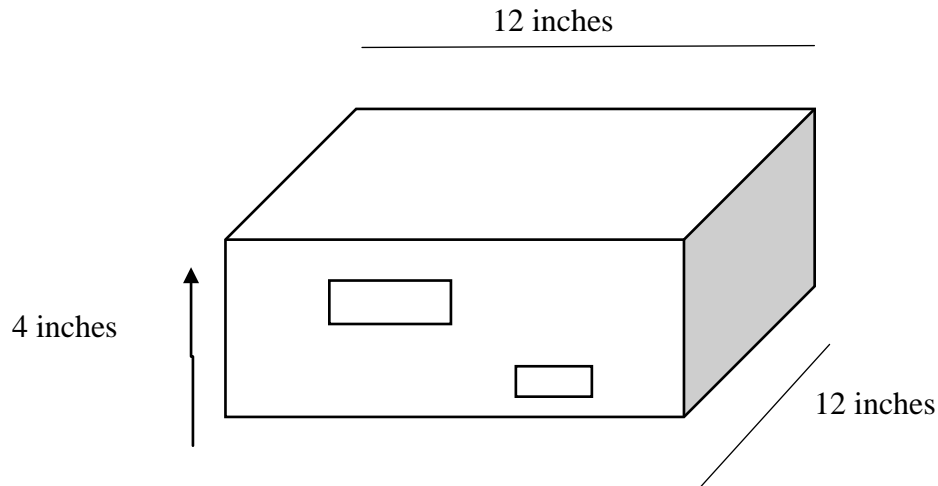


Figure 4.0: Casing

**Table 4.0: BILL OF ENGINEERING MEASUREMENT AND EVALUATION**

S/N	DESCRIPTION OF ITEMS	QUANTITY	UNIT RATE (₦)	TOTAL AMOUNT (₦)
1	24V/120 HF transformer	1	5000	5000
2	DSPIC30f4012	1	6500	6500
3	TLP250 MOSFET drivers	4	500	2000
4	Heat Sink	5	500	2500
5	Copper clad board	1	3000	3000
6	LM324N Op-Amp	1	200	200
7	Irf3205 MOSFETs	17	350	5950
8	Relay	1	400	400
9	Buzzer	1	200	200
10	Ribbon Cables	2	200	400
11	EE25 ferrite transformer	1	500	500
12	Copper Wires	6.5 (Kg)	8000	52000
13	Casing	1	8000	8000
14	12V DC Fan	1	400	400
15	100A DC Breaker	1	3500	3500

16	16A AC Breaker	1	1800	1800
17	Switch	1	150	150
18	10A Current transformer	1	1500	1500
19	Resistors (all varieties used)	30	10	800
20	Capacitors (all varieties used)	20	20	850
21	6.144Mhz Crystal	1	150	
22	DIP IC Sockets	7	70	490
23	Diodes	8	40	320
24	UC3843	1	150	150
25	Connecting AC wires	2 (yards)	100	200
26	16MM DC Cables	3 (yards)	800	2400
27	Connectors	1 (Row)	400	400
28	CD4045	1	300	300
29	Buttons	4	50	200
30	BJT Transistors	3	50	150
31	Etchant	1		2000
32	Cable Lock	5	150	750
<b>TOTAL</b>				<b>106910</b>

## 4.2 TESTING

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

#### 4.2.1 INVERTER DISPLAY TESTS

The inverter display is as presented in Figure 4.1.



Figure 4.1: Inverter display test

#### 4.2.2 INVERTER LOAD TEST

The test was done to ensure that the inverter is working as expected. The test would help to ascertain its behavior under load with respect to the output voltage stability. A variac was used to obtain the variable voltage applied to the input of the inverter until the full load current in the output of the inverter was reached. The test result is in the table below

**Table 4.2 Inverter Load Test Result**

VOLTMETER ( $V_{in}$ )	AMMETER ( $I_{out}$ )	WATTMETER (Watt)
0.00	0.00	0.00
5.00	2.57	5.90
7.00	3.85	12.40
10.00	4.00	18.40
12.00	6.50	35.86

From the test data in table 4.1 and 4.2, we have a rated voltage of 12volt from the open circuit test and it was used to obtain a value of 32watt and 0.71A when no load is applied. At a rated current of 6.50 from the short circuit a value of 12volts and 35.86 watt was obtained.

Using the given data in the data tables, the % loading obtained from equation. (4.1) and the maximum load KVA is obtained from Eqn. (4.2): (Theraja, 2008)

$$\% \text{Loading } x = \frac{KVA \times \text{power factor}}{KVA \times \text{power factor} + \text{total losses}}$$

$$\text{Efficiency, } \eta = \frac{X \times S \cos \theta}{x \times S \cos \theta + P_{\text{core}} + x^2 P_{\text{cu}}}$$

Where x = ratio of actual load to full-load KVA

The designed Full load KVA rating, S = 3.5KVA

Core loss at rated voltage & frequency, P<sub>core</sub> = 32watt

Full load copper loss, P<sub>cu</sub> = 35.86watt

For load power factor, cos θ = 36.86/12x6.5 = 0.46

$$\% \text{loading, } x = \frac{3500 \times 0.46}{3500 \times 0.46 + (32 + 35.86)} = \frac{1610}{5228} = 0.307$$

Therefore, the percentage of loading at 30.8% loading is

$$\text{Efficiency at 30.8\% of full load, } \eta = \frac{0.307 \times 3500 \times 0.46}{0.307 \times 3500 \times 0.46 + 32 + 0.307^2 \times 35.86} = 0.879$$

% efficiency at 0.31 of full load, η = 87.9%

Per unit value of loading for maximum efficiency η<sub>max</sub> is  $x = \sqrt{P_{\text{core}}/P_{\text{cu}}} = 0.94$

Thus, the load for maximum efficiency = full load × √P<sub>core</sub>/Copper loss = S × X

$$S = 0.94 \times 3.5 \text{ KVA} = 3.29\text{KVA}$$

The maximum load the inverter can carry practically is 3.29KVA. Although our inverter is theoretically assumed to be able to carry a load of 3.5KVA.

From the test data in table 4.1 and 4.2, we have a rated voltage of 12 volts from the open circuit test and it was used to obtain a value of 32 watts and 0.71 amp when no load is applied. At a rated current of 6.50 from the short circuit a value of 12volt and 35.86 watts was obtained.

Using the given data in tables, the % loading obtained from equation. (4.1) and the maximum load in KVA is obtained from Eqn. (4.2): (Theraja, 2008)

### 4.2.3 Continuity Test

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

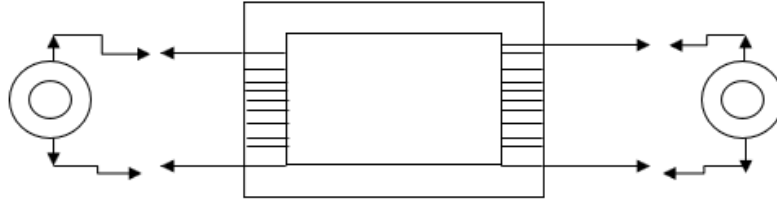


Figure. 4.2: The continuity test diagram

### 4.2.4 OPEN CIRCUIT TEST

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

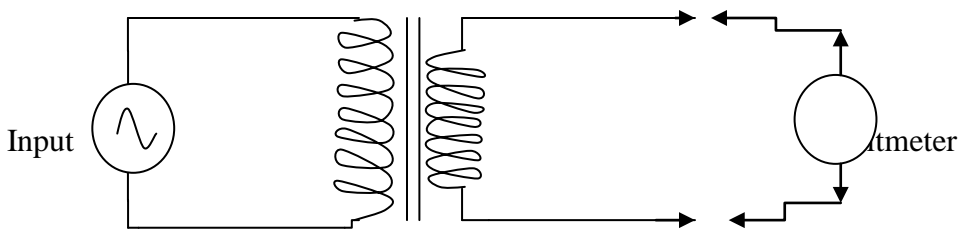


Figure 4.3: the Open Circuit test diagram

### 4.2.5 SHORT CIRCUIT TEST

In the short circuit test, the secondary windings is “shorted” or “bridged” together while about 5-10% of the primary voltage is fed to the primary winding and the current drawn is measured with an ammeter. In our own case, short circuit voltage fed to the primary is 15volts which is

about 6.82% of the rated input voltage and the current drawn was about 3.5Amps. This gave us a copper loss of 52.5Watts.

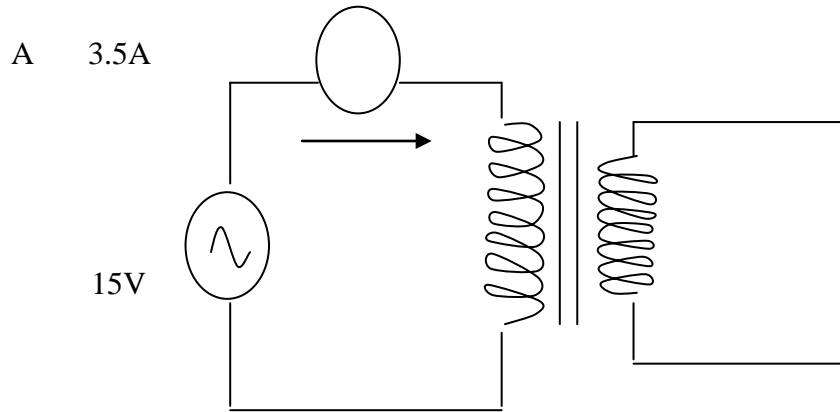


Figure 4.4: the Short Circuit test diagram

#### 4.2.7 OUTPUT WAVEFORMS

The output waveforms obtained and recorded from the oscilloscope during tests are shown in the Figures 4.5 below.

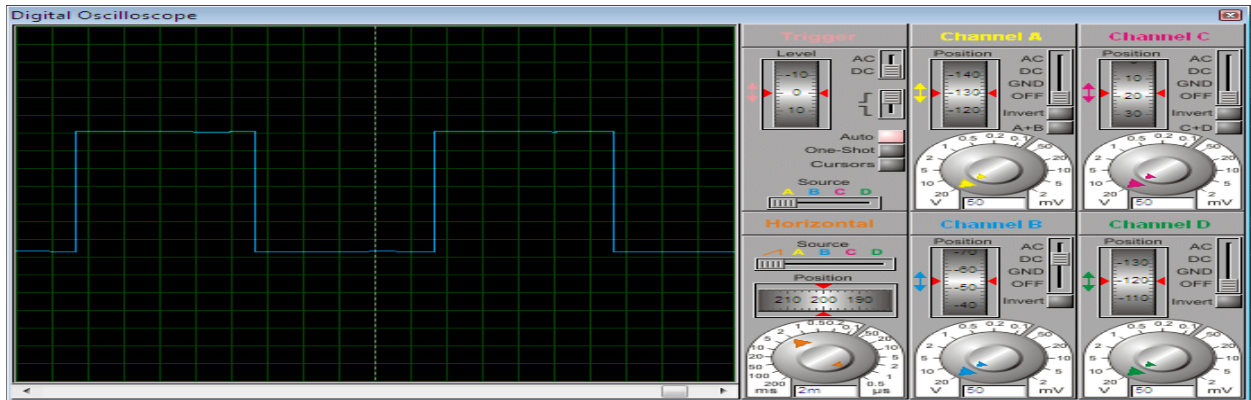


Figure 4.5 (a): Square wave signals sent to the high side MOSFETs

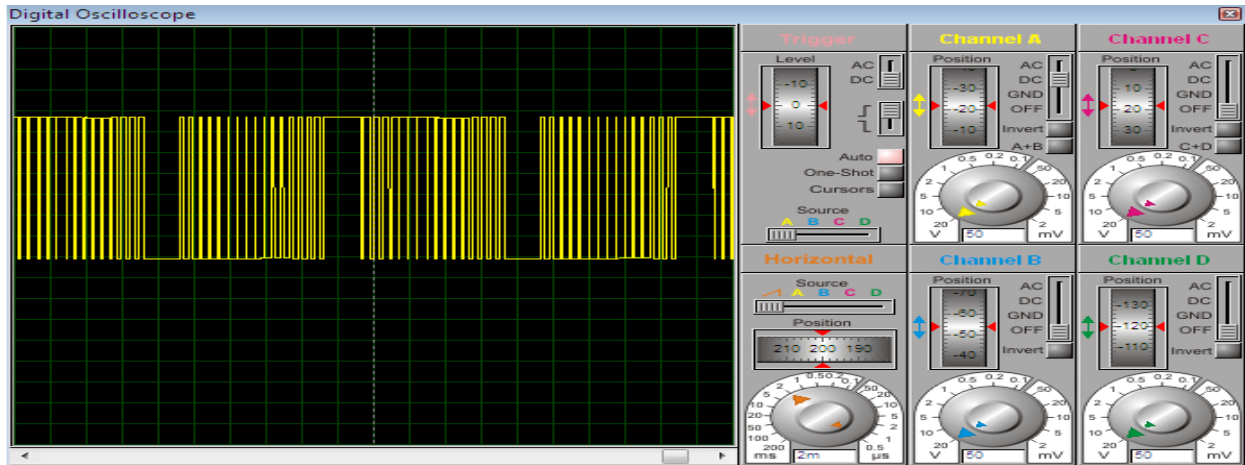


Figure 4.5 (b): PWM signals fed to the low sides MOSFETs for modulation

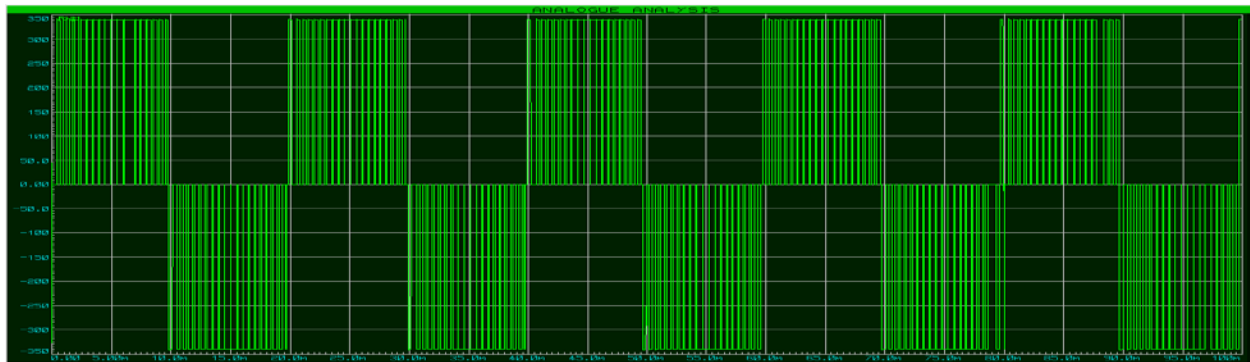


Figure 4.5 (c): Full H-bridge Output before filtering

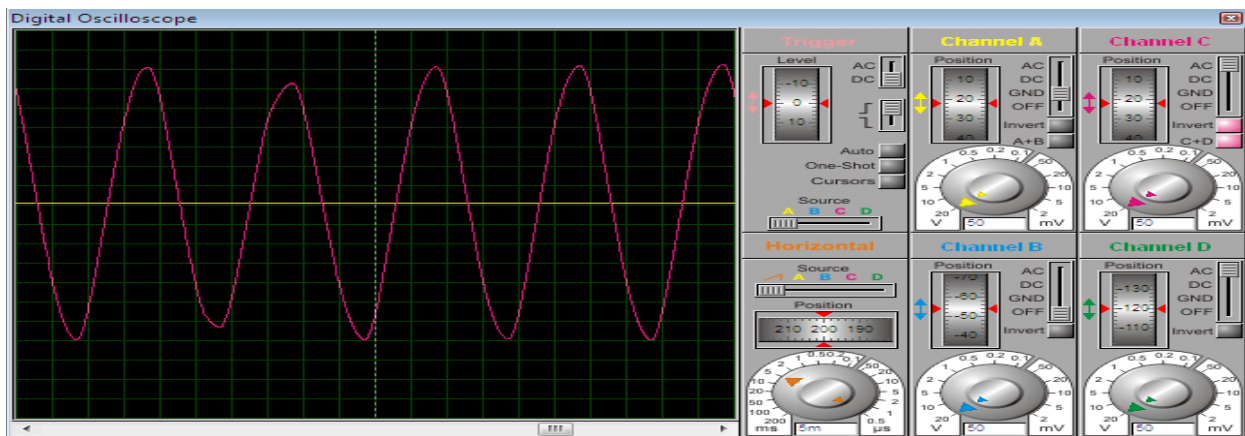


Figure 4.5 (d): Waveform of the inverter after filtering

**TABLE 4.3: THE INVERTER OUTPUT VOLTAGE WITH LOAD VARIATION**

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

Significant voltage drop is experienced at 900W which is due to copper loss of the transformer.

But the output voltage at this load was still okay.

**TABLE 4.4: THE INVERTER VOLTAGE, BATTERY VOLTAGE AND POWER COMPARISON**

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

## **CHAPTER FIVE**

### **CONCLUSION AND RECOMMENDATION**

#### **5.1 CONCLUSION**

The design and construction of a transformer-less hybrid inverter was based on the need to productively design a lighter weight inverter with high efficiency. A 3.5KVA inverter powered by a 24V DC battery supply has been designed and constructed as laid out in the aim and objectives of this project.

As earlier stated, this involves first boosting the low voltage DC to high voltage DC using high frequency DC to DC converters. Then this high voltage will then be supplied to the H-bridge (MOSFETs bank) and with good quality pulse width modulation convert the high voltage DC to “chopped” AC which is passed through an L-C low pass filter to produce the final clean 50Hz sine wave output.

Most appliances work best with a sine wave output and this was our target as we designed our inverter project. Generally speaking, this type of design implodes more complex circuitry than their modified sine waves counterparts. As a result, sine wave inverters are more expensive than those with a modified sine wave of the same output power rating

This greatly improve the efficiency of the system since losses have been reduced compared to the regular convectional inverters. Also, the high cost of copper wires was reduced with the help of the high frequency transformer. This gives very high conversion efficiency and very stable amplitude.

#### **5.2 RECOMMENDATION**

One problem with the Transformerless inverters is the galvanic connection of the solar panels to the ground. This can cause leakage current. Despite the generally acceptable efficiency of new inverters, issues such as grounding cells are still required to be addressed as they are essential in reducing leakage current. Also deployment of other topologies such as HERIC, H5, H6 etc could reduce the effect of leakage current and greatly increase the efficiency and performance of the inverter.

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

- Output waveform frequency was found to be satisfactory at 50Hz equivalent of standard Nigeria Power System.
- Sine pulse with modulation circuit is much simplified by the use DSPIC30f4012 microcontroller
- In addition, with the high programming flexibility, the design of the switching pulses can be altered without further changes on the hardware. Just a few changes in the codes are needed.

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