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NUST COLLEGE OF

ELECTRICAL AND MECHANICAL ENGINEERING

Stand Alone Power Generation using PV Array System

PROJECT REPORT

DE-40 (DEE)

Submitted by

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PROJECT SUPERVISOR

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COLLEGE OF

ELECTRICAL AND MECHANICAL ENGINEERING

PESHAWAR ROAD, RAWALPINDI

YEAR 2022

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It is to certify that the project "**Stand Alone Power Generation using PV Array**" was done by **NC Shahid Hussain, NC Muhammad Roshaan Arif** under the supervision of **Dr. Taosif Iqbal**. This project is submitted to **Department of Electrical Engineering**, College of Electrical and Mechanical Engineering (Peshawar Road Rawalpindi), National University of Sciences and Technology, Pakistan in partial fulfilment of requirements for the degree of Bachelor of Engineering in Electrical engineering.

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Thank you to everyone who assisted; without everyone's support and admiration, things could have turned out differently. We hope that this initiative will add value to people's lives and that it will be developed so that this technology can be used more widely.

ABSTRACT

This thesis covers the research and design of Single Active Bridge (SAB) converters for use in inverters, rectifiers, and high frequency transformers. The motive of this project is to harness the power of the sun and convert it into an AC source that can be used in your home or business. This can be done with an array of solar panels and a device called a photovoltaic cell (PV module), which converts the light energy into electricity. The PV cells are ideal for use in remote locations where no connection to electricity is available, such as solar powered airports, offices, or campgrounds. This study is expected to create instruments for more efficient energy delivery and consumption, particularly in rural areas. This study considers the power efficiency of a 100W load system. The ambition is to support the power needs of an apartment by using photovoltaic panels to generate solar energy. To do so efficiently, we will have to consider the load requirements and size of the system required to meet those demands.

Using the full-wave rectifier for the secondary side, the gate pulses supplied by square wave PWM and an H-bridge inverter as the primary side, you can create a unique single phase high-frequency transformer with a suggested architecture of the inverter. The electricity is conducted from the primary to the secondary side of a high frequency transformer. The SAB converter serves as a boost stage for DC voltage, converting LV to HV based on the gain/turns ratio. After sending the output of the inverter through an LC filter, to remove distortion and achieve up to sinusoidal 220V rms.

The single active bridge (SAB) is an innovative DC/DC converter that exhibits more complex behavior than its standard counterparts. The SAB's static behavior differs significantly from that of similar DC/DC converters and can provide interesting advantages in certain applications. People living in off-grid communities will be able to improve their standard of living because of our proposed solar hybrid solution.

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Chapter 1: Introduction and Literature Review

1.1 Motivation & Literature Review

In this day and age of depleting energy, solar energy serves as a significant replacement for other renewable energy sources. A significant proportion of the global population lives in remote rural areas that are geographically isolated and sparsely populated. Because such areas have very low power demand, they are not connected to the grid. However, electricity is one of the cleanest energy transfer options and is thus the foundation for an area's development regardless of the source of power. And, in a developing country like Pakistan, where the majority of the population lives in remote rural areas without access to utilities, this is the main impediment to overall development.

SAB and PSFB (Phase Shifted Full Bridge) are ideal for applications requiring unidirectional power transfer. At the output, the PSFB converter functions as a reactor, as previously stated. Because the reactor is substantial, this converter can achieve a unity voltage conversion ratio and operate in a continuous current mode.

Bridge 1 works as an inverter, producing high-frequency AC voltage v1 at its output. The Ti switches on the active bridge diode. The SAB converter also has a second bridge, which is known as Bridge 2. DC powers this bridge voltage Vb and comprises low-side switches and diodes. It acts as a rectifier, converting from AC to DC power by turning on its lower-side switches during forward operation and off during reverse operation.

1.2 The Proposed System

Our proposed system consists of a Panel containing photodiodes, Single Active Bridge, and a three-phase H-Bridge inverter and LC Filter.

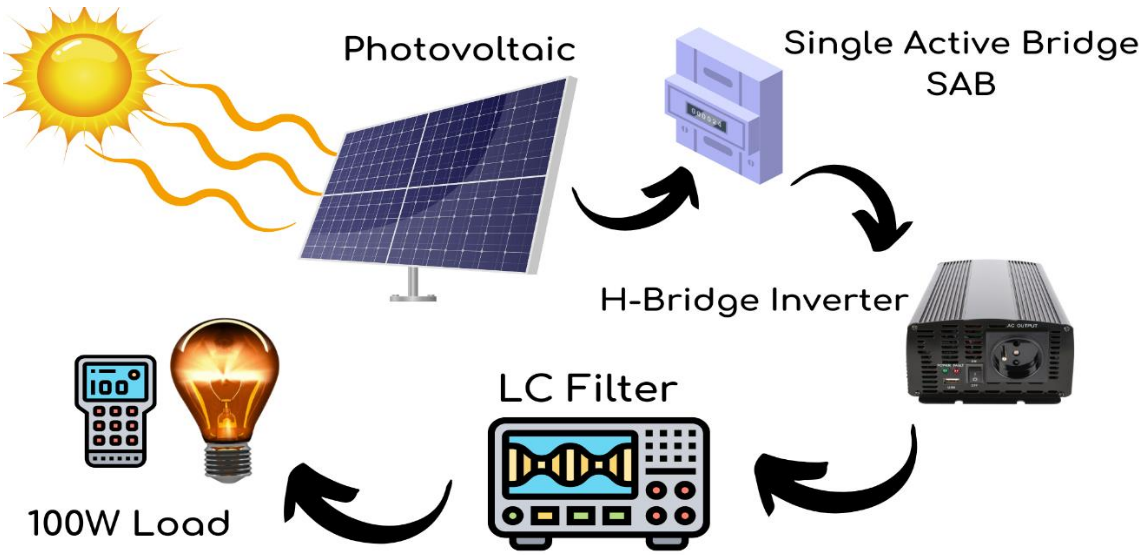

Figure 1: Pictorial Representation

1.3 Objectives

A device that converts the energy of sun to electrical energy. To form the PV array, cells are connected in series and parallel. Temperature and insolation affect the effective power of a PV array.

It is a light sensor that converts light into electrical energy (voltage or current). A photodiode is a semi-conducting device with a PN junction. Between the p (positive) and n (negative) layers is an intrinsic layer. The photo diode accepts light energy as an input to generate electric current.

The terms photodetector, photosensor, and light detector all refer to the same thing. The negative terminal of the battery (or power supply) is connected to the p – side of the photodiode, while the positive terminal is connected to the positive terminal of the battery.

Common photodiode materials include silicon, germanium, indium gallium arsenide phosphide, and indium gallium arsenide.

Figure 2: Photo Sensor

Photodiodes are light-sensitive devices that convert light energy into electrical energy. Their symbol is similar to that of an LED, but the arrows point inwards as opposed to outwards in the LED. Photodiodes are used in many different areas of electronics; they are used in solar panels and photovoltaic cells, camera sensors, bioimaging (light microscopy) among others.

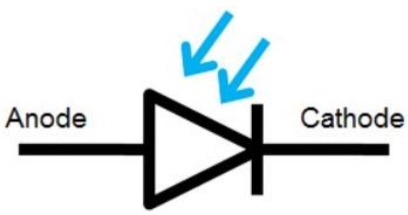

Figure 3: Photo Diode

1.3.1 Working of a Photodiode

It has a P and N junction and is wired in reverse bias, which creates a large depletion zone at the PN junction. In P-type, holes predominate, whereas electrons predominate in n-type. When the photodiode is connected in reverse bias and there is no illumination or light on the photodiode, we receive a very small current in microamperes, which we call dark current.

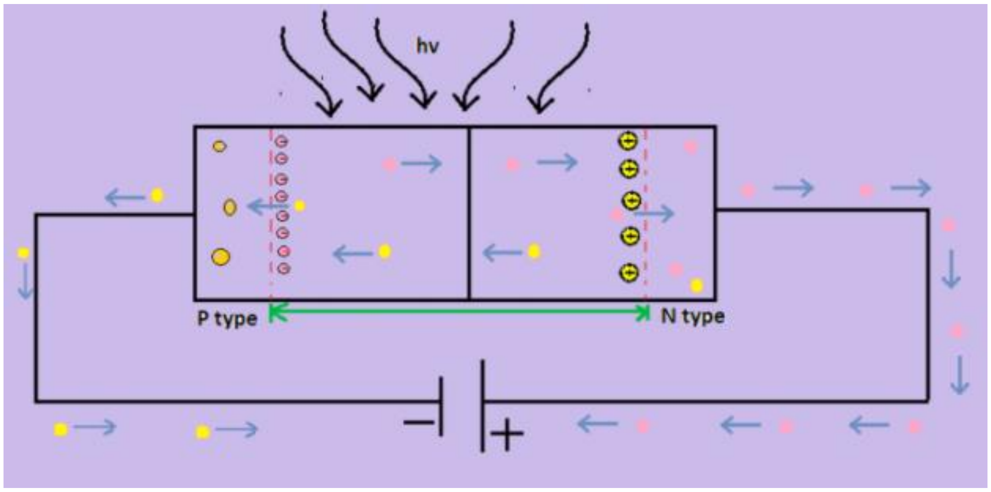

Figure 4: Working of Photodiode

When a photon with a higher energy than the bandgap energy hits a diode, the covalent bond breaks, resulting in the formation of new electron and hole pairs. When electrons and holes move towards the anode and electrons move toward the cathode, photocurrent is produced. The total current that flows through the diode is the sum of the dark current and the photocurrent. To improve photodiode sensitivity, the dark current must be kept to a minimum.

Chapter 2: SAB Converter

2.1 DC-DC Converter:

The recent trend of photovoltaic (solar) power generation has created a need for high-voltage, medium-power dc/dc converters used in solar power inverters. SAB dc/dc converters offer galvanic isolation and a diode-based output side in this context, making them appealing for unidirectional dc/dc conversion in future medium power generation applications. In contrast to dual active bridge converters, which use phase-shift angle control, SAB dc/dc converters must be controlled by adjusting the active bridge switching duty cycle. This article provides an in-depth examination of the operational principles of three-phase SAB dc/dc converters with varying duty cycle operation ranges. Furthermore, the converter performances, such as transformer harmonic currents, are analyzed and compared between different input and output dc voltage conditions.

This paper presents an overview of half-bridge (HB) and full-bridge (FB) SAB converters, which are mostly concerned with both their operating principles and the transistors' soft-switching capabilities, as well as other specialized elements. The first section of the paper describes the dynamics and basic operation of an HB SAB converter. The switching losses of the FB SAB converter were reduced in the second part by using a dual-current pulse control. To reduce conduction losses, a partial-resonant FB SAB converter was used.

The Boost converter's output voltage is greater than the input voltage. As a result, the name" BOOSTS" was chosen. A DC/DC converter is required to solve a load impedance matching problem when recording maximum power. Its primary application is to convert an uncontrolled DC input voltage to a constant output voltage at a predetermined level. The source impedance must match the load impedance in order to extract maximum power. By adjusting the duty cycle, the source impedance becomes equivalent to the load impedance. DC to DC converters come in a variety of shapes and sizes, and they're used to step up or down the DC voltage.

2.2 Operation of Boost Converter:

A direct current to direct current converter is an electrical circuit that changes the voltage level of a direct current source. It’s a specific type of power converter. Switch-mode electronic DC to DC converters work by temporarily holding input energy and then releasing it at a different voltage and current to the output. They essentially alters the input energy into a different impedance level, much like a transformer. So, regardless of the output voltage, the output power is entirely derived from the input; no energy is generated within the converter.

In fact, the converter circuitry and components consume some energy while performing their duties. A DC-DC Converter is necessary because of this principle. The converter creates an electrical burden on the solar panel that fluctuates with the converter’s output voltage. As a result of the load variation, the panel’s operating point (current and voltage characteristics) changes. Thus, the power output of the panel may be intelligently managed and made to output the utmost possible by intelligently directing the operation of the DC-DC converter.

Buck Converter was used in our actual implementation. A buck converter is a voltage and current step-down converter. Two switches control the current in an inductor in the basic operation of a buck converter (usually a transistor and a diode). In the ideal case, we assume all components are perfect: no voltage drops across switches or diodes, no current flow through them (they’ve “shorted” themselves), and no series resistance in the inductor. Ideal components are represented by straight lines on a schematic showing their relationship to each other, whereas real components show up as curved lines—resistance and capacitance curves, respectively. Straight lines don’t curve because all imaginary forces are zero.

2.3 Boost Converter Topology Diagram:

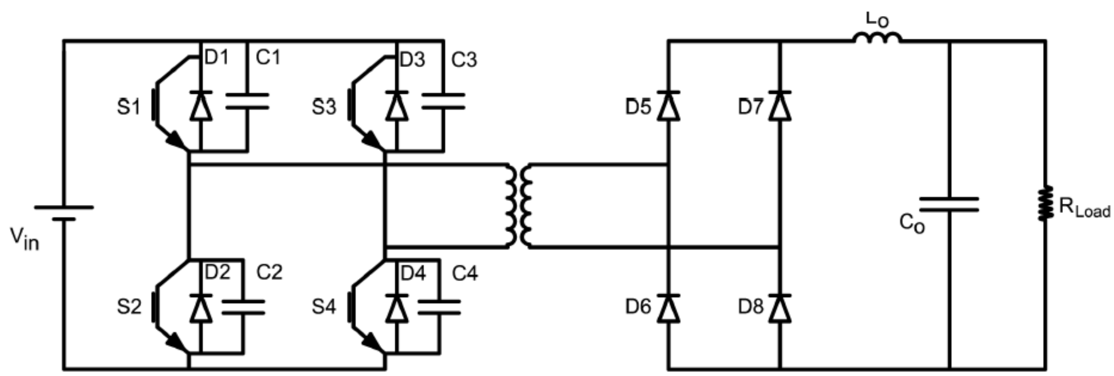

Figure 5: Circuit Diagram of SAB Converter

2.3.1 Duty Cycle:

When the switches in the two legs are turned on, the voltage across the transformer is identical to the input voltage in a complete bridge converter with duty cycle control. When all the switches are turned off in the off state, the load current in the output diodes freewheels, resulting in zero voltage across the transformer. The output voltage divided by the transformer ratio equals the mean voltage across the transformer in duty cycle control, according to this explanation.

For t=t1, all the switches are turned off, and the load current flows through the output diodes, which is the full bridge converter's operation concept with duty cycle control. This is known as the inactive state. The active state begins at t=t1 with the activation of S2 and S3. It takes some time for the current to reach the load current, but once it does, the output bridge is no longer short-circuited, and the current remains constant.

Switches S2 and S3 are turned off at t=t3, and the current begins to decrease. However, because the current takes some time to reach zero due to the leakage inductance of the transformer, it is forced to pass through D1 and D4 until it does. When the current reaches zero at t=t4, all of the switches are turned off, and the load current flows through the output bridge. Similarly, the next half period begins at t=t5. The idealized current and voltage waveforms for the switches and transformer in duty cycle control mode.

2.3.2 Controlling Phase Shift:

The phase-shift control method is another way to control the switches in the full bridge converter. Each leg of the converter is operated at 50% of the time in this approach, which means the top switch is on for half of the period and the bottom switch is on for the other half. In half of the time, the output of each leg equals the input voltage, while in the other half, it equals zero. The voltage to the transformer can be changed by changing the phase between these two voltages.

2.4 Operation Modes of Boost Converter:

The SAB converters are one of the most popular switching topologies for power conversion applications. In contrast to the simple on/off operation of its half-bridge counterpart, SAB converters allow for continuously adjustable output voltage and can be used in applications with high input voltage or large output current range (depending on the number of outputs).

The active bridge switches Ti are composed of two elements (transistor Qi and freewheeling diode Di) and a snubber circuit Cs. For medium- and high-power applications, Qi, the transistor, could be a MOSFET or an IGBT. The snubber circuit soft-switches Qi, allowing negative current to flow through Ti via the diode Di.

A power converter includes a rectifier bridge, an isolation transformer and at least one SAB converter. A primary winding of the isolation transformer is connected to an input voltage source. The bridge is connected in parallel with a secondary winding of the isolation transformer to produce an output voltage Vo for powering an electronic device.

2.4.1 Boost Converter Mode 1 Operation:

At t=0 is the point in time where nothing happens. The current goes between inductor L and MOSFET when the MOSFET switch is closed. In this mode, the inductor's current rises, storing energy in the inductor. When the switch is turned off, the inductor charges and stores energy via the voltage source.

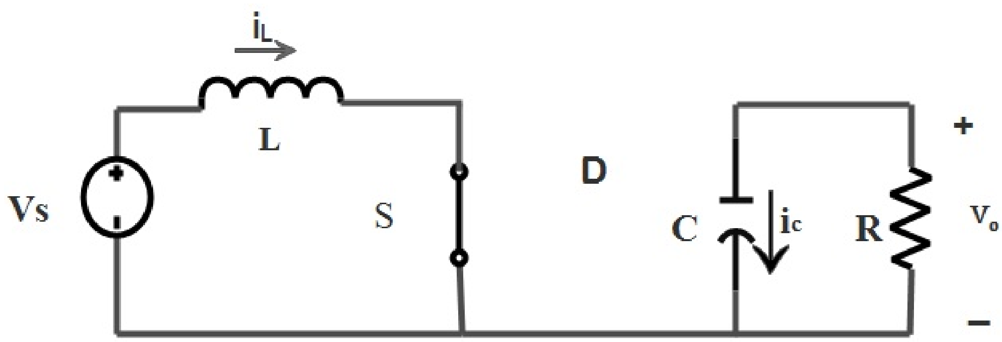

Figure 6: Equivalent Circuit when MOSFET closed

2.4.2 Boost Converter Mode 2 Operation:

In this mode, the MOSFET switch is open, causing the inductor to gradually drop in value, the capacitor to charge, and the diode to behave as a short circuit. During this mode, the load current remains constant.

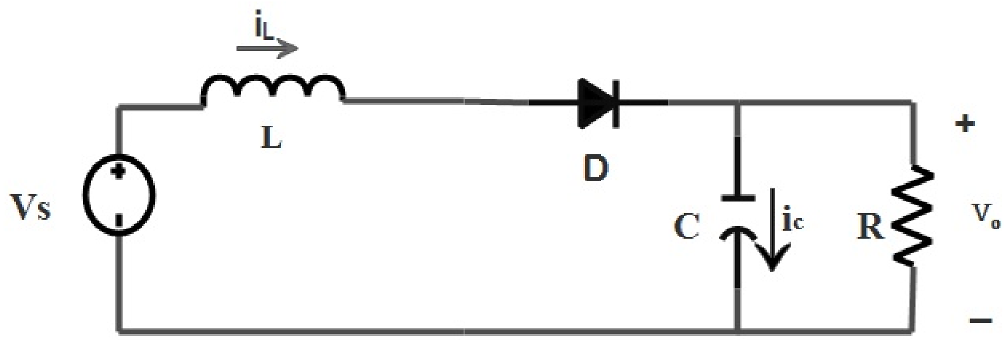

Figure 7: Equivalent Circuit when MOSFET open

2.5 SAB Converter Evaluation:

The SAB converter is described by three operation modes depending on the current in the inductor L. Metered quantities such as output voltage, frequency and power are found to be related to the input quantities via equations depending on the mode of operation. They are obtained by restricting oneself to primary inputs only, without including any kind of feedforward control. As a result, each mode is examined separately. The equations are written with the following hypotheses in mind:

• The isolation transformer's turns ratio n is equal to one.

• It has a large enough magnetization inductance to make the magnetizing current negligible.

• Co is large enough to make the output voltage Vo's ripple negligible.

The reason behind different SAB converter operation modes is discussed in detail. Also, three operation modes are studied as a function of the angle θ, which is proportional to time according to θ = ωsT. The working frequency of the SAB converter is given by 2π/Ts, where Ts is the period of the SAB converter. The phase-shift angle between the driving of two transistors on the same side is designated with β and ranges from 0 to π.

The voltage v1 at the active bridge's output and the voltage v2 at the passive bridge's input are shown in the two sets of waveforms. The two sets at the bottom show the current iL in the inductor L and the current iout at the output of the passive bridge. When the waveforms are examined, it is clear that they have an unusual symmetrical property with respect to.

2.6 Mode of Continuous Conduction:

The circuit analysis is simplified by replacing the transformer with a leakage inductance L. In the Continuous Conduction Mode, a pair of output bridge diodes is always conducting (CCM). Depending on the sign of the current iL, the voltage v2 can be either Vo or Vo. Voltage and current waveforms in CCM, demonstrating that the voltage v1 has a quasi-square waveform and the voltage v2 has a pure square waveform with the same zero crossings as the current iL; the delay angle of v2 to v1 is denoted by. In turn, the voltage vL applied to the inductor terminals forces the current iL to have a linear piecewise waveform.

2.6.1 1st Interval:

The span of Interval 1 is [0 ÷ ϕ]. The voltage vL equals (Vi + Vo), and the current iL grows linearly from iL(0) to =; the expression of the current at is

$$i_L(\varphi) = i_L(0) + \frac{V_i + V_o}{\omega_s L}\varphi \equiv 0$$

Equation 1: Ist interval of CCM mode

2.6.2 2nd Interval:

The duration of Interval 2 is [ϕ ÷ β]. The voltage vL equals (Vi – Vo), and the current iL grows linearly from 0 to its maximum value, which is reached at θ = β; the peak current expression is

$$i_L(\beta) = i_L(\varphi) + \frac{V_i - V_o}{\omega_s L}(\beta - \varphi)$$

Equation 2: 2nd interval of CCM mode

2.6.3 3rd Interval:

The duration of Interval 3 is [β ÷ π]. The inductor L is not fed by the dc voltage source Vi, and the voltage vL is equal to -Vo; thus, the current iL drops linearly, and its expression at θ= π is

$$i_L(\pi) = i_L(\beta) - \frac{V_o}{\omega_s L}(\pi - \beta)$$

Equation 3: 3rd interval of CCM mode

The current iL(π) is equal to -iL(0) because of the odd symmetrical property (0). Because the current iL takes the same value, equal to zero, at the two extremes of the interval, the average value of vL in the interval [ϕ÷ π + ϕ] is zero. As a result of this,

$$\frac{V_o}{V_i} = \frac{\beta - 2\varphi}{\pi}$$

Equation 4

As Vo is a positive value, some basic properties of the SAB converter operation in CCM. Firstly, 2ϕ is lower than β. Secondly, Vo is lower than vi and this indicates that the SAB converter works as a step-down converter. Thirdly, it is

$$\frac{V_o}{V_i} < \frac{\beta}{\pi}$$

Equation 5

The distinctive condition for the SAB converter to operate in CCM is Equation (5). The expressions of the current iL at 0 and can be written as a function of the input and output voltages, Vi and Vo, and the phase-shift angle by obtaining from Equation (4) and substituting it in Equations (1) and (3). It is

$$i_L(0) = -\frac{V_i}{2\omega_s L}\left(1 + \frac{V_o}{V_i}\right)\left(\beta - \frac{V_o}{V_i}\pi\right)$$

$$i_L(\beta) = \frac{V_i}{2\omega_s L}\left(1 - \frac{V_o}{V_i}\right)\left(\beta + \frac{V_o}{V_i}\pi\right)$$

Equation 6

2.7 Mode of Boundary Conduction:

The Mode of Continuous Conduction (CCM) is separated from the Mode of Discontinuous Conduction (DCM) by the Boundary Conduction Mode. It stands out because the current iL is exactly zero when = 0, and then when θ = π. Figure 4b depicts the waveforms of voltages and currents in DCM, which show that during the half-period [0 ÷ π], the voltage vL is equal to Vi – Vo from 0 t βo and to -Vo from β to π. If the average value of vL in this half-period is zero, we get

$$\frac{V_o}{V_i} = \frac{\beta}{\pi}$$

Equation 7

The distinguishing condition that allows the SAB converter to operate in BCM. It reveals that for the same input voltage Vi and phase-shift angle, the voltage Vo in BCM is greater than in CCM. The current iL's peak value is given by

$$i_L(\beta) = \frac{V_i}{\omega_s L}\left(1 - \frac{\beta}{\pi}\right)\beta$$

Equation 8

2.8 Mode of Discontinuous Conduction:

The current iL in the DCM is not in the half-period [0 ÷ π]. From [π – α] to π, the current iL doesn't flow, due to all diodes of passive bridge being reversed biased now, the voltage v2 is also zero during this interval. Furthermore, the voltage vL is equal to Vi-Vo from 0 to β and to −Vo from β to [π – α]. If the average value of vL for the half-period is 0

$$V_o = V_i \frac{\beta}{\pi - \alpha}$$

Equation 9

Because [π – α] is greater than, as in CCM, Vo is less than vi, the converter operates in step-down mode. It follows that

$$\frac{V_o}{V_i} > \frac{\beta}{\pi}$$

Equation 10

2.9 SAB Converter Characteristics:

In general, the SAB converter can be described by describing the input-to-output characteristics of a three-phase converter without compensation. In particular, sinusoidal currents and voltages can be generated in this case. The frequency of sinusoidal voltage is determined by the resonance frequency of the circuit while the current is determined by its impedance and power factor. The effective value of resistance and reactance components depends on whether there are controls such as thyristors or diodes in series or parallel with each other, which determine operating conditions.

The output voltage and current characteristics are referred to as external characteristics. External characteristics reflect the SAB converter's electrical behavior as seen from its output terminals. The control characteristic is a relationship between the input voltage and output voltage that defines the SAB converter's electrical behavior as seen from its input terminals.

2.10 Simulation on Simulink

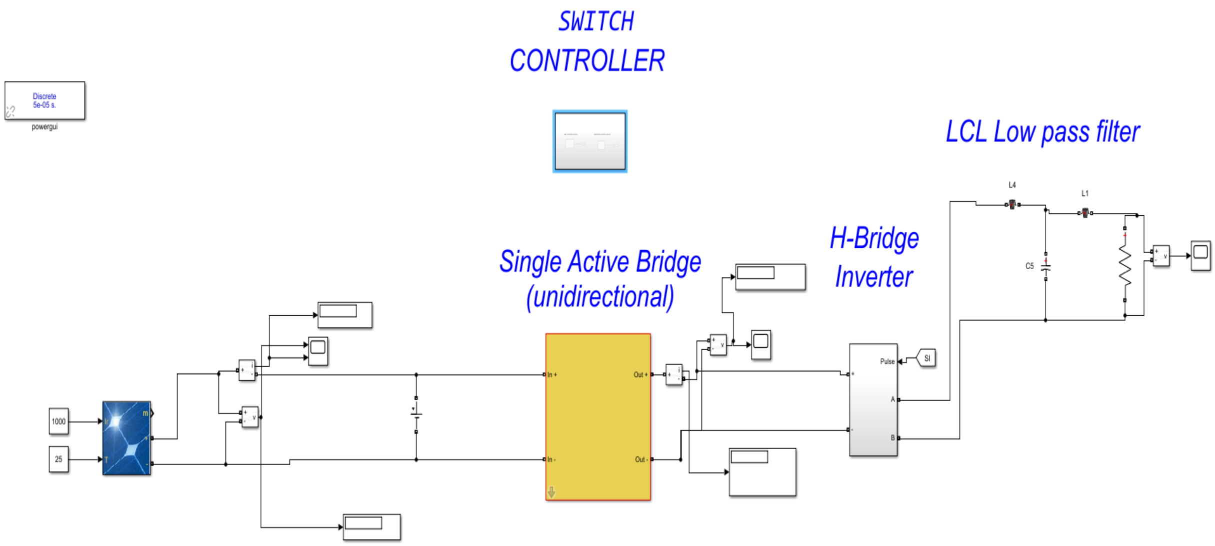

Figure 8: Simulink Model of Project

2.10.1 Circuit of simulation on Proteus

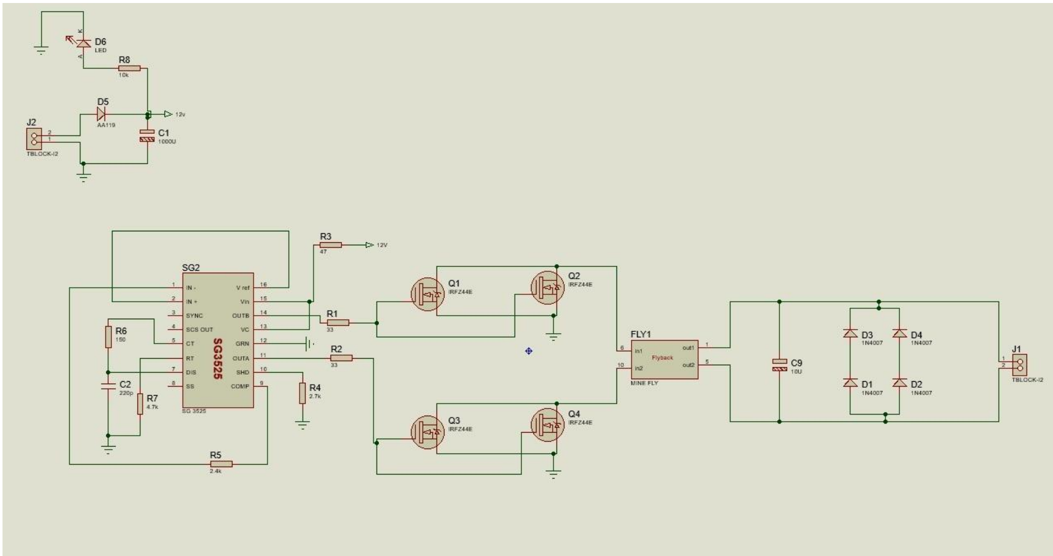

Figure 9: Proteus Simulation

2.10.2 Circuit of simulation of SAB on Simulink

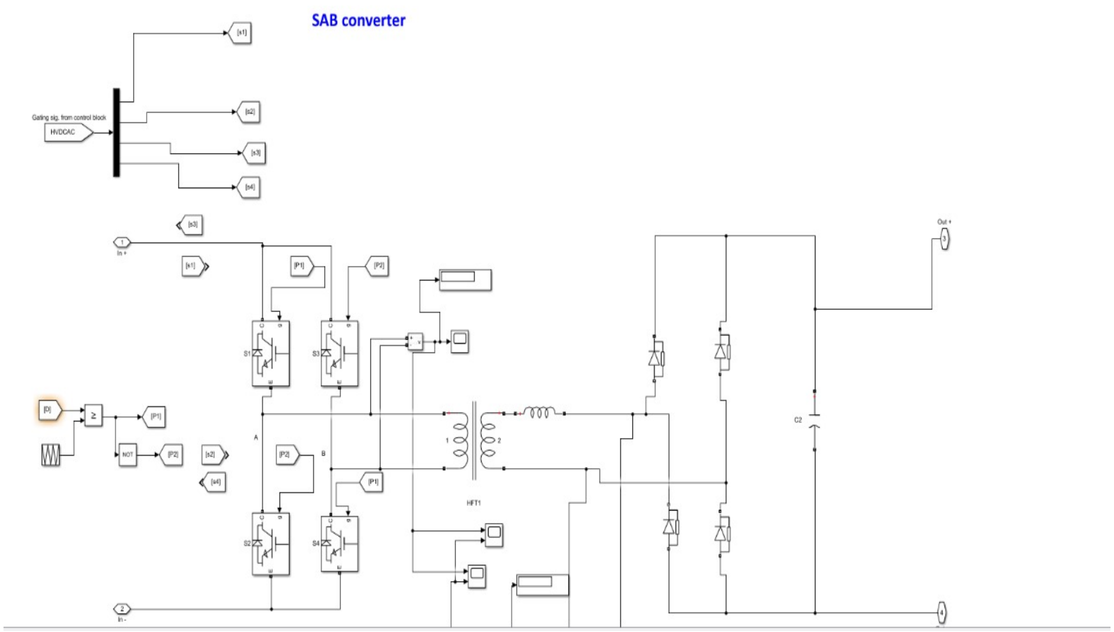

Figure 10: Simulink Model SAB

2.10.2 Results

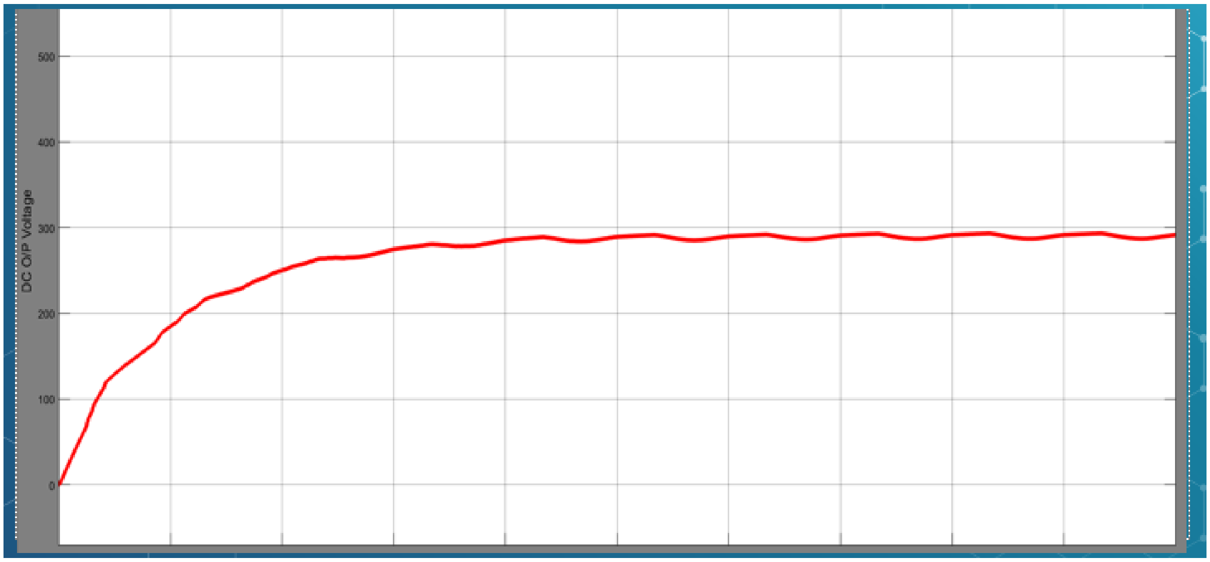

Figure 11: Output SAB Converter on Load

2.11 Hardware and 3D Model

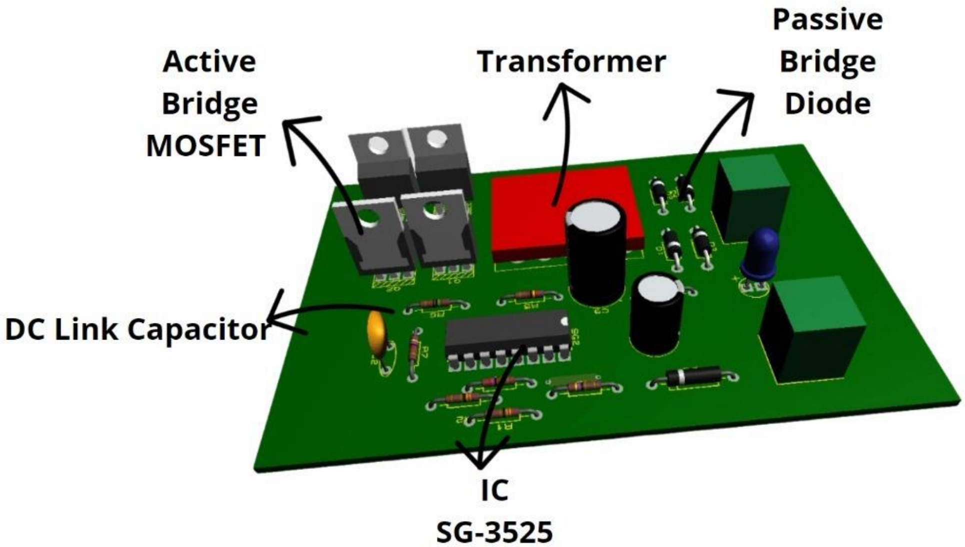

Figure 12: 3D Model SAB

2.11.1 Hardware Model

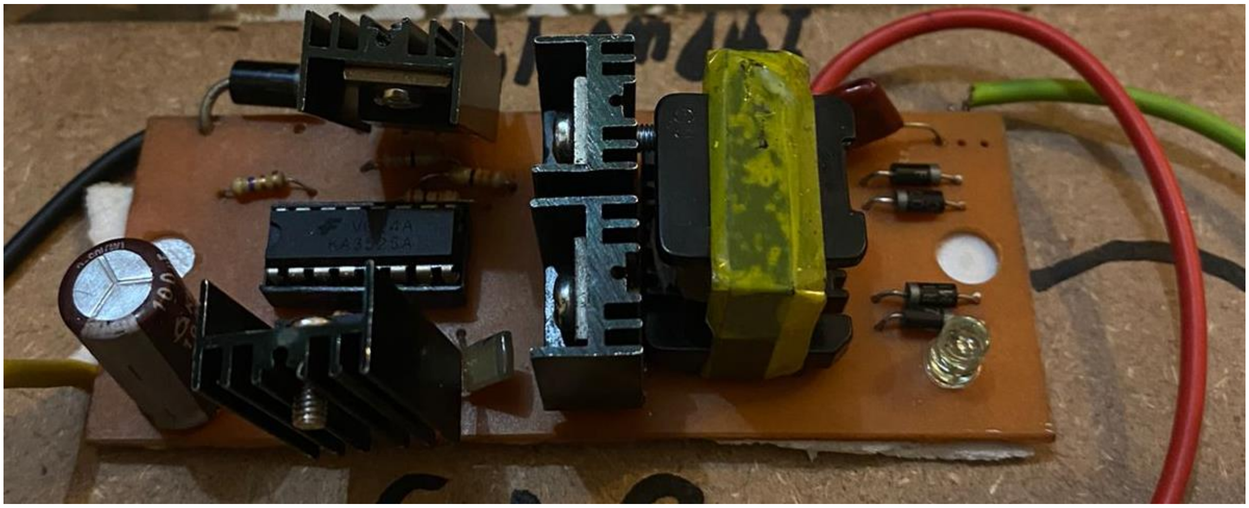

Figure 13: Hardware Model SAB Converter

2.11.2 PCB Design

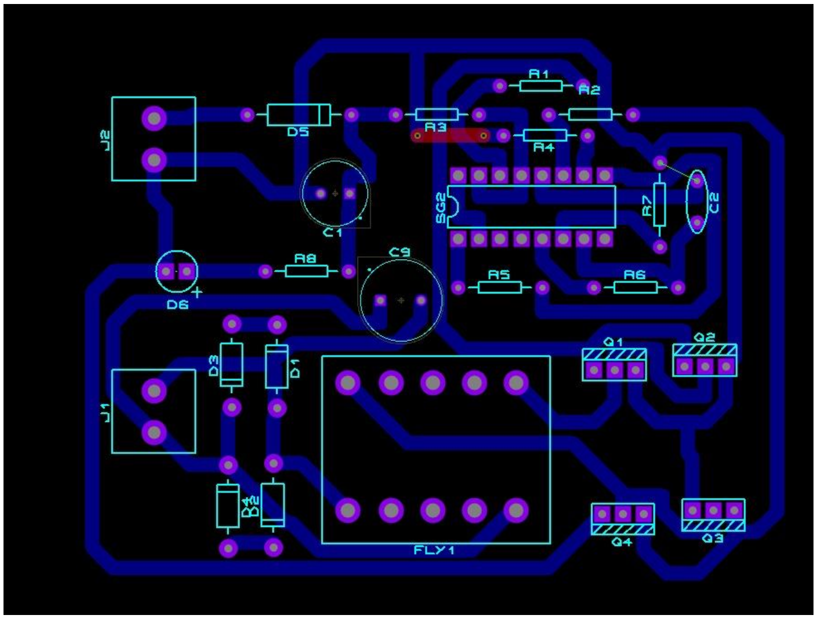

Figure 14: SAB PCB Layout

Chapter 3: High Frequency Transformer

3.1 Introduction

DC/DC converters in single phase photovoltaic (PV) power systems employ the planar and coaxial high frequency power transformers. In order to reduce eddy current losses, skin and proximity effects, leakage inductance, and inter-winding coupling capacitance, the winding construction includes a Faraday shield between the main and secondary windings. The magnetic flux and eddy current distributions are examined using the finite element method. In comparison to the traditional high frequency transformer, the shielded transformers produce results with a comparatively low coupling capacitance.

Transformers are commonly used in power electronic converters to provide galvanic insulation as well as to achieve a desired voltage level. Switch mode converter transformers operate at high frequencies and with non-sinusoidal waveforms. Furthermore, the size of the transformer influences the size of the converter. Because of these characteristics, we created a high-density power transformer for our full bridge converter.

3.2 Basic principle:

The fundamental operating principles of ordinary transformers apply to high-frequency transformers as well. The main distinction is that high-frequency transformers run at frequencies significantly higher than those of line voltage transformers, which typically operate at 50 or 60 Hz. In contrast, high-frequency transformers employ frequencies ranging from 20 KHz to over 1MHz. The first advantage of operating at a higher frequency is size. The smaller the transformer can be for a given power rating, the higher the frequency. Second, the transformer is more efficient since less copper wire is required due to its reduced size, which lowers losses. Additionally, because ferrite is frequently used for the core, a broad range of shapes are available, allowing the transformer to be specifically designed for the purpose.

There's a strong probability that a ferrite core may be found to fulfil the need, whether more shielding or a certain form factor is needed. However, the advantages of light weight, small size, and better power density come with several drawbacks. When building high-frequency transformers, minimizing problems like skin and proximity effects is a major priority.

3.3 SMPS Topology

- Buck
- Boost
- Buck-boost
- Flyback
- Forward
- Push-pull

3.4 Designing High-Frequency Transformers

The quantity of power that has to be transmitted and the operating frequency are two criteria that are utilized in several formulae to precisely determine the mechanical size of high-frequency transformers. High-frequency transformers may now be made smaller and more affordably because to recent innovations like the usage of GaN diodes, which enabled frequency improvements.

For instance, the 50-100 KHz frequency range was typical until a few years ago. Today, however, it is conceivable to use frequencies as high as 400–500 KHz and even 1 MHz These higher frequencies have made it possible for transformers to get smaller, as shown by the equation below, using a reduced Ae (core cross section) for any given number of turns. Design engineers must strike a compromise between this equation and the fact that as frequency rises, a smaller core and fewer turns are needed to function at the necessary flux density.

3.5 Calculate a High Frequency Transformer

- Select the proper core.
- Based on the flux density the engineer decides to operate at, determine the number of primary rotations required.
- Determine the ratio of primary to secondary voltage, which is used to indicate the number of secondary turns.

Given is the necessary number of turns:

N = V x108 /(4.44)(F)(B) (Ae)

N = Primary turns here

V is the input voltage

F = Frequency (in Hertz).

B = Gaussian flux density

Ae= the core's cross-sectional area (cm2)

In addition, the designer of high-frequency transformers must ensure that the wire thickness does not exceed two times the frequency's skin depth. The skin effect is caused by the current flowing further outward as frequency rises.

The formula S = 2837/F provides this.

Where F = Frequency in Hz and S = Skin depth (mils)

3.6 Numerous Advanced Applications

From powering personal computers to supplying energy to homes and commercial buildings, high-frequency transformers are utilized in a broad range of sophisticated applications, both big and small. The item may also be used for:

- Electronic switching devices.
- LED lighting.
- Plasma generation.
- Military power supplies.
- Alternative energy inverters.
- Personal electronics.

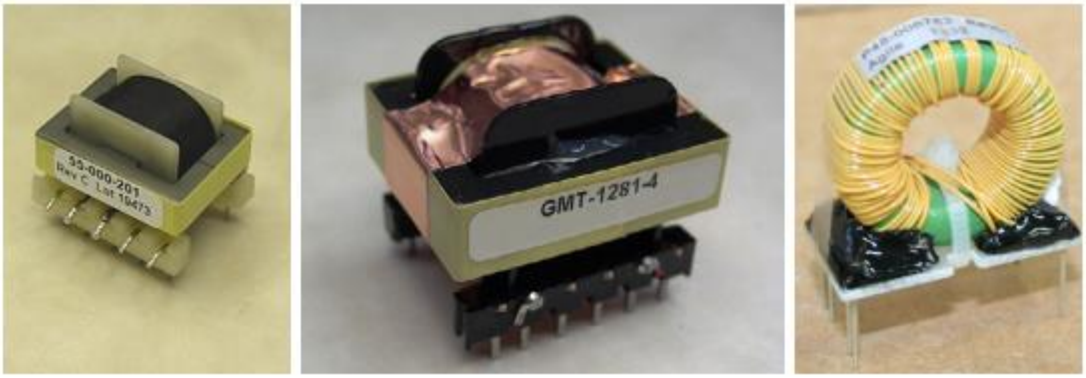

Figure 15: Transformer Types

3.7 Conclusion:

A high frequency coaxial and planar isolation transformer used in a solar PV DC/DC converter are discussed in depth. The winding arrangements and Faraday shield arrangements are examined using a FEM eddy current simulation under various load circumstances. For an HFCT with or without a Faraday shield, a parasitic capacitance network model is suggested to compute these capacitances via FEM. The computed inter-capacitance value for an HFCT without a shield is well-aligned with the findings of the experiment. The method for determining the intra- and inter capacitances of HFCTs that has been provided may also be used to determine the intra- and inter capacitance for other high frequency transformers.

Chapter 4: Single Phase Inverter

4.1 INTRODUCTION

The inverter transforms DC power to AC supply at specified frequency and output voltage. A rectifier is used to provide DC power to the inverter from different sources such as solar array, magneto hydrodynamic generator or battery fuel. A filter capacitor provides a consistent DC link voltage across its input terminals. Hence, the inverter that may be adjusted in frequency as voltage source. It possesses combination of ac to dc and vice-versa combination due to which it is called as DC link converter.

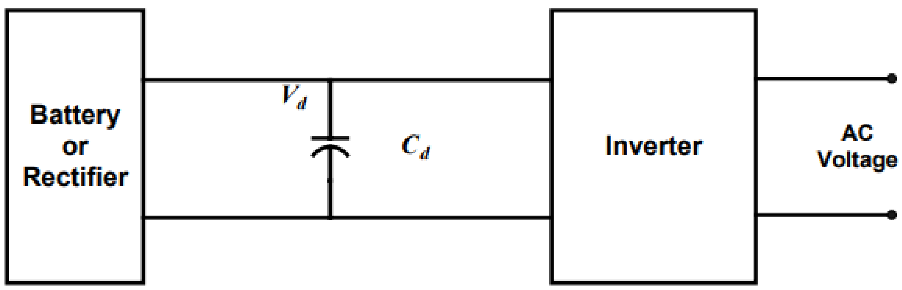

Figure 16: Schematic Inverter

4.2 TYPES OF INVERTERS

There are two types of inverters on the bases of there working

- **Voltage _fed inverter (VSI):**

An inverter having a low or negligible impedance dc source is said to be voltage source inverter .it keep its voltage constant at input terminals . thyristors are utilized as switches for some sort of necessary combination of this type of inverter, but these inverter needs self-communication using base and gate of the transistors as switch such as MOSFET, power transistors and IGBTs.

- **Current Source Inverter (CSI):**

An adjustable current from a high-impedance dc source received by an inverter that is said to be current source inverter. The half-bridge or full-bridge arrangement of a conventional CSI or single-phase voltage is available. Three-phase or multiphase topologies can be created by joining single-phase components. There are many examples of CSI that include likes of induction heating, UPS, HVDC transmission lines and adjustable AC drives.

4.3 Single – Phase Inverters:

These are several ways for controlling the output voltage of inverters.

- **External control AC output voltage**
- **External control DC input voltage**
- **Internal control of the inverter.**

The first two ways requires peripheral components; however, the later approach does not necessitate the use of any external components. The internal control of inverter is addressed in considerable length in the next part, as it is mostly concerned with the internal control of the inverters.

4.3.1 Pulse Width Modulation Control (PWM)

Inverter exercise control in itself to adjust the basic magnitude of its output voltage constant, which eliminates the need for external control circuit. The most effective way to do this is to control PWM within the inverter. A set input voltage is fed to inverter in this design, and by altering the inverter components' on and off durations the AC voltage is regulated in the circuit.

4.3.2 Benefits of the PWM

a) The output voltage can be controlled without the need of any external components.

b) Lower order harmonics are reduced by PWM, whereas a filter can eliminate the higher order harmonics.

PWM is used in industrial equipment widely due to its low switching time. The other switching devices used inverter has high switching time and they are costly as well. Inverter output voltage is managed, and its harmonic current is reduced by PWM through providing constant amplitude pulses with variable frequency for each period while pulse bandwidth varies there. Techniques differ primarily in the harmonic current of their respective output voltages; hence, PWM method is used for permitted harmonic current in the inverter output voltage.

4.3.3 Sinusoidal Pulse Width Modulation (SPWM)

In industrial applications, SPWM approach, also known as the sub harmonic, or sub oscillation method, triangulation is particularly common.

SPWM is simple to implement in both hardware and software. SPWM is accomplished by comparing a sinusoidal waveform to a high frequency triangular waveform. The frequency of a sinusoidal wave is assigned to the frequency of an output voltage or current waveform. SPWM is commonly used in motor drive and grid-tied inverter applications. For three-phase inverters, SPWM outperforms the traditional sinusoidal PWM algorithm. SPWM produces pulses with constant amplitude but varying pulse width for each period.

The modulation depth ma is defined as the sine wave amplitude divided by the triangular wave amplitude. The amplitude of the modulating signal sine wave is Vm, and the amplitude of the carrier triangular wave signal is Vc.

$$m_a = \frac{Vm}{Vc}$$

$$n = \frac{fc}{fm}$$

Equation 11

While fc is the carrier frequency, fm is the sinusoidal signal frequency. To remove the even harmonic in the output voltage or current waveform, the ration "n" should be odd and multiple of "3." As we increase fc, the switching loss increases, and the output harmonics decrease. There is no triple harmonic in a three-phase system's line voltage or current.

The gate of a three-phase inverter receives a switching sequence. When the upper is turned on, the lower should be turned off. SPWM is the best PWM technique for the following reasons

SPWM is achieved by comparison of sinusoidal reference wave and a high frequency triangular carrier wave. The modulated pulse's commutation and switching times are determined by the intersection of Vc and Vr waves.

Figure 4.2 a show the PWM system, it is depicting the reference or modulated signal as Vr while Vc is showing the peak value high frequency wave. This diagram shows the modulated signal and triangular signal with their frequency and magnitude.

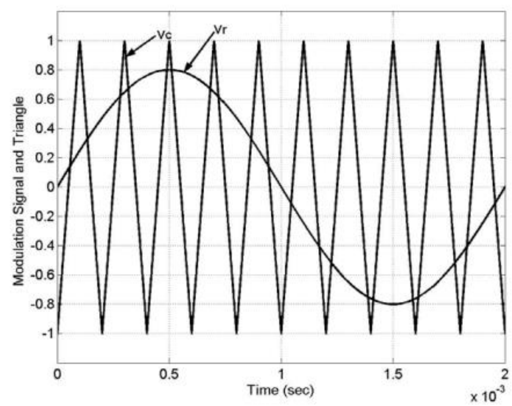

Figure 17: Comparison Triangular Wave and Sine Wave

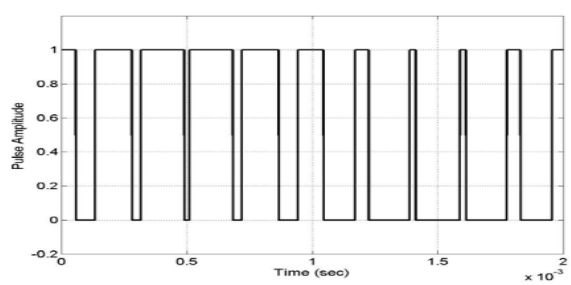

Figure 18: Switching Pulse width Modulation

Figure 18 shows four switches (two on each leg) of single-phase inverter in full bridge circuit. A full bridge inverter may provide twice the output power of a half-bridge inverter at the same input voltage. This section discusses three distinct PWM switching schemes that improve the inverter's properties. The devices should clamp to either the positive or negative dc rail so zero sequence to modulated voltage signals is added to achieve it. Consequently, the voltage gain is enhanced, resulting in a higher load voltage, lower total harmonic current, and a higher power factor.

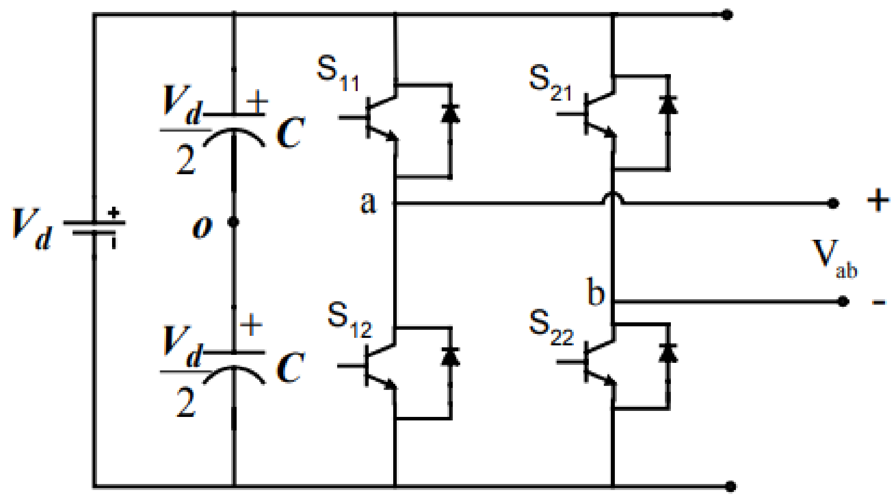

Figure 19: Single Phase full-bridge Inverter Circuit

The top devices are labelled S11 and S21 in Figure 2.5, while the bottom transistors are labelled S12 and S22. The voltage equation are as follows.

$$\frac{V_d}{2}(S_{11} - S_{12}) = V_{an} + V_{no} = V_{ao}$$

$$\frac{V_d}{2}(S_{21} - S_{22}) = V_{bn} + V_{no} = V_{bo}$$

$$V_{ab} = V_{an} - V_{bn}$$

Equation 12

The output voltages at A and B to an arbitrary point n are Van and Vbn, respectively, while the neutral voltage between point n and the DC source's mid-point is Vno. The Fourier series may approximate the switching function of the devices as 1/2 (1+ M), where M is reference signal, which produces the switching pulses after comparison with triangle waveform. As a result of Equations, the modulation signal expressions are as follows:

$$M_{11} = \frac{2(V_{an} + V_{no})}{V_d}$$

$$M_{21} = \frac{2(V_{bn} + V_{no})}{V_d}.$$

Equation 13

For single-phase dc-ac converters, the preceding equations provide a standard formulation for modulation signals. Using proper definitions for,Van, Vbn, and Vno, this equation may yields many form of modulation signals and relations reported in literature . Various modulation systems have been developed based on this approach, some of which given in the discussion below.

4.4 Bipolar Switching

The diagonally opposed transistors S11, S22, and S21 and S12 are switched on or off at the same time in this arrangement. Leg A's output and Leg B's output are equal and opposite to each other.

$$V_r > V_c \ , \quad S_{11} \text{ is on } \Rightarrow V_{ao} = \frac{Vd}{2} \text{ and } S_{22} \text{ is on } \Rightarrow V_{bo} = -\frac{Vd}{2};$$

$$V_r < V_c \ , \quad S_{12} \text{ is on } \Rightarrow V_{ao} = -\frac{Vd}{2} \text{ and } S_{21} \text{ is on } \Rightarrow V_{bo} = \frac{Vd}{2};$$

hence

$$V_{bo}(t) = -V_{ao}(t)$$

Equation 14

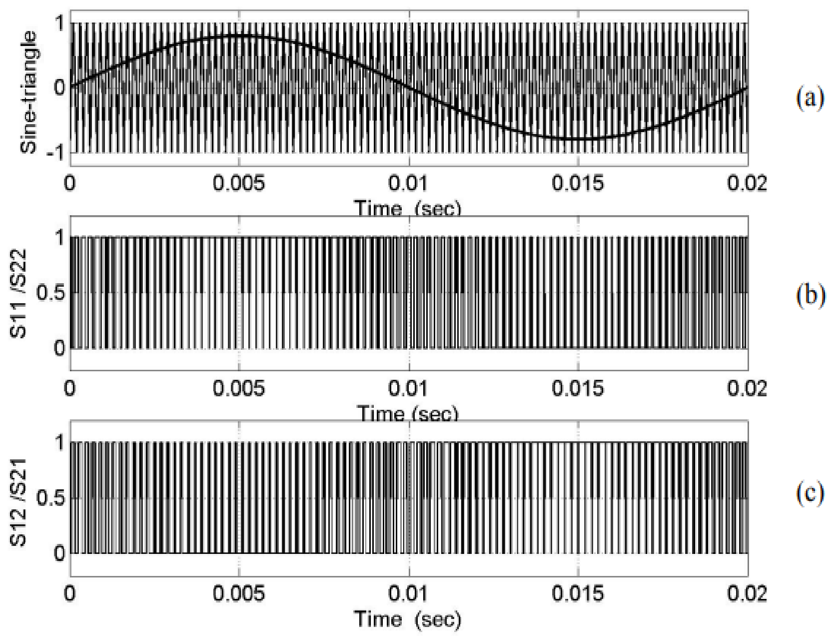

Figure 20: Bipolar PWM scheme (a) Modulation signal (b) Output voltage (c) Load current

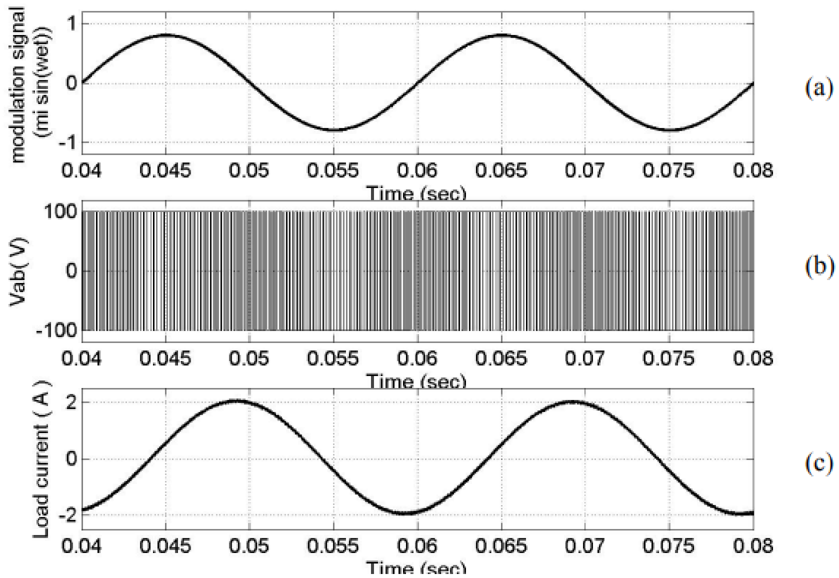

Figure 21: Bipolar PWM scheme (a) Modulation signal (b) Output voltage (c) Load current

4.4.1 SPWM With Unipolar Switching

The devices in one leg are switched. Switching in this method based on the reference signal Vr being compared to a triangle wave. By comparing both modulation signal with the same high frequency triangle wave, the devices are switched in the opposite leg as well.

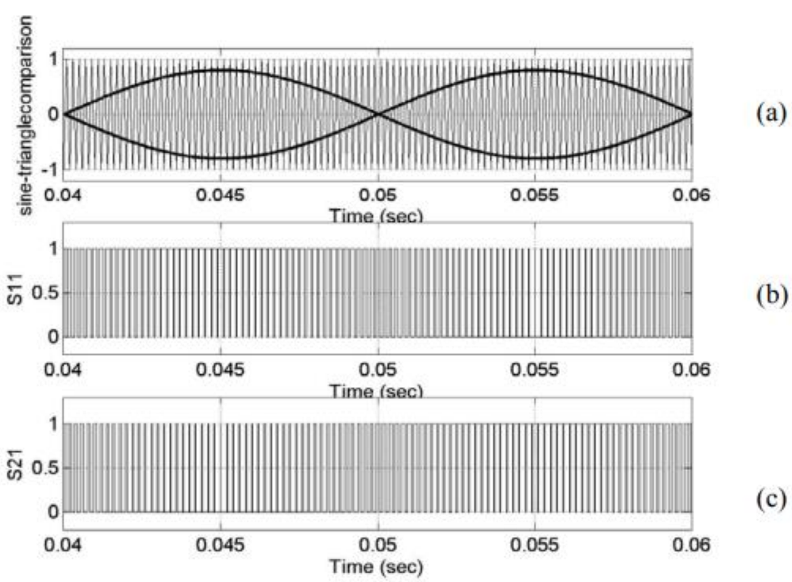

Figure 22: Unipolar PWM voltage switching scheme (a) Signal comparison (b) switching pulses for 1st switch (c) switching pulses for 2nd switch

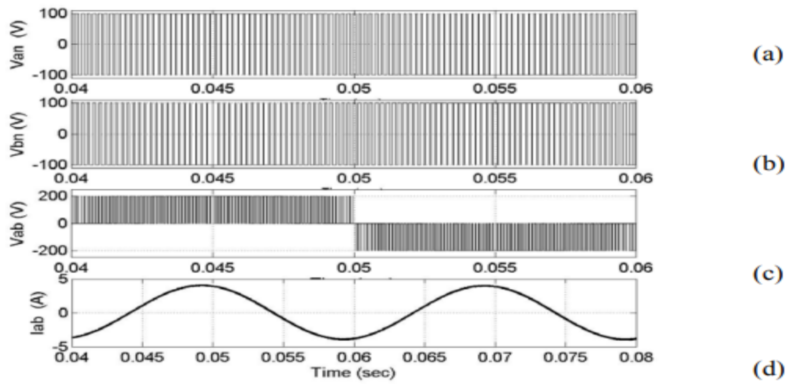

Figure 23: Uni polar PWM voltage switching (a) phase voltage 'a' (b) phase voltage 'b' (c) line to line voltage (d) load current

4.4.2 SPWM With Modified Bipolar Switching Scheme (MBPWM)

One of the top devices in one of the switching legs is kept on continuously while the other two switching devices in the other leg are PWM operated, and one of the bottoms switching devices is kept on continuously while the other two switching devices in the other leg are PWM operated during the negative half of the modulation signal in a bipolar switching inverter. The output voltage is derived by comparing the control signal Vr with the triangle wave.

Vr > Vc , S21 is ON And Vr < Vc S22 is ON

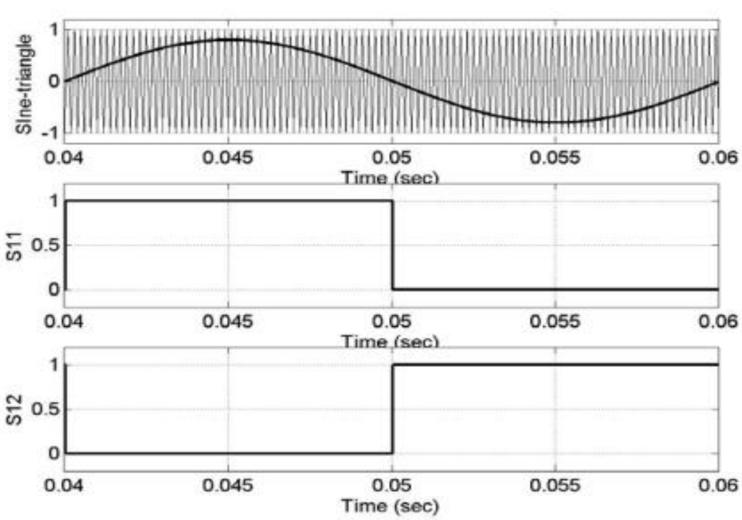

Figure 24: Modified bipolar PWM Sine-triangle comparison

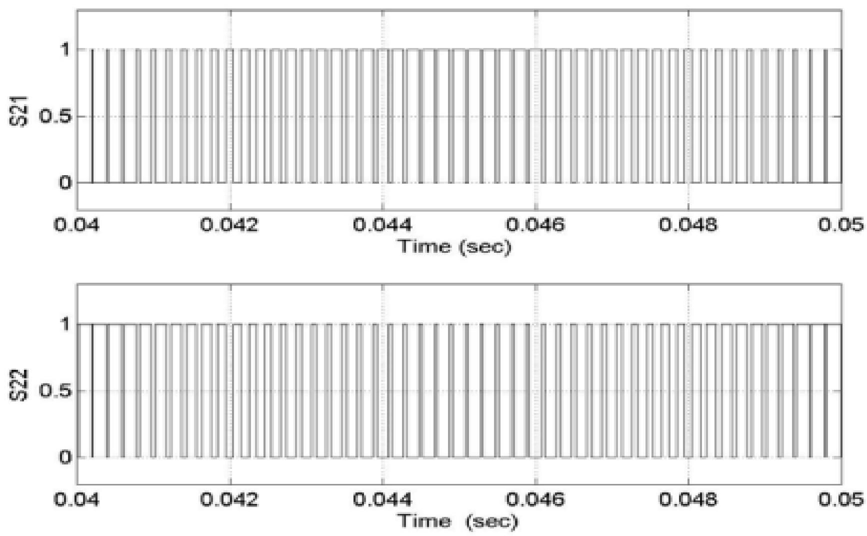

Figure 25: Switching pulses for devices S11, S12, S21 and S22

4.5 Applications

- UPS (Uninterruptible Power Supply)
- ASDs (Adjustable Speed Drives)
- Induction heating, welding, and other electronic frequency changer circuits
- At lower power levels, HVDC transmission.
- Solar and fuel cell-to-AC conversion are examples of renewable energy.
- Compact Fluorescent Lamps and Electronic Ballast
- Improved power quality with active filters.
- FACTS: STATCOM, SSSC, UPFC, etc., are examples of custom power devices.

4.6 Advantages

- Power usage is low.
- High energy efficiency of up to 90%.
- Ability to handle a lot of power.
- There was no drifting or decrease in linearity because of temperature changes or ageing.
- It’s simple to set up and manage.
- Modern digital processors are compatible.

4.7 Disadvantages

- The fundamental desired component is attenuation of waveform.
- Device switching and, as a result, device de-rating.
- High-frequency harmonic components are created.
- Significantly higher switching frequencies, resulting in increased stress on linked components.

4.8 THE SIMULATION MODEL

Matlab simulation model of a single phase PWM inverter with a voltage source (VDC=400~500 V), LCL filter (L=4.5μH and C=100μF), PWM and inverter (The PWM simulation model had i/p and o/p, with i/p (sine wave, sawtooth, and comparative) and o/p (sine wave, sawtooth, and comparative) respectively (pulses). I/p and o/p were present in the single-phase inverter simulation model, with the i/p having (VDC and pulses) and the o/p having VAC. After the filter is connected to the load, the input filter is attached to it.

4.9 Simulation of H-Bridge inverter on Proteous and Simulink

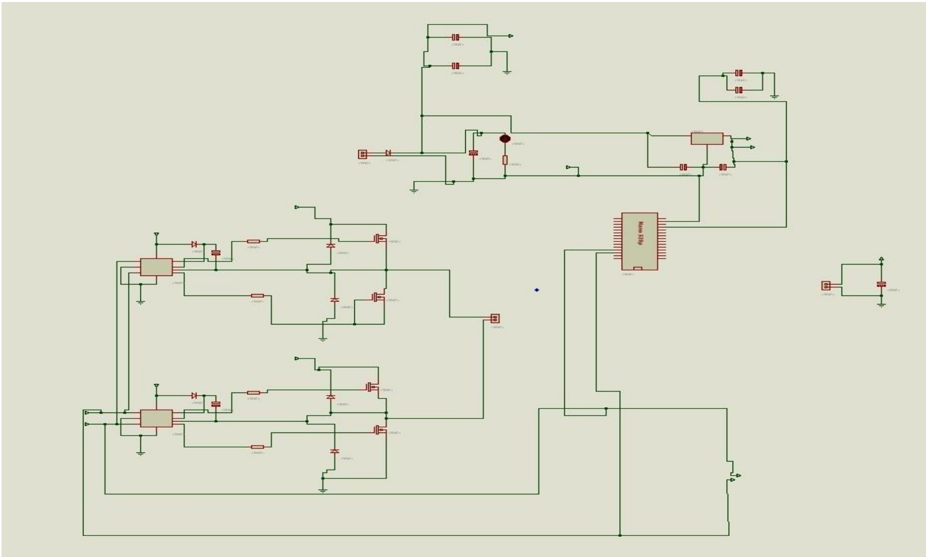

Figure 26: Simulation of H-Bridge

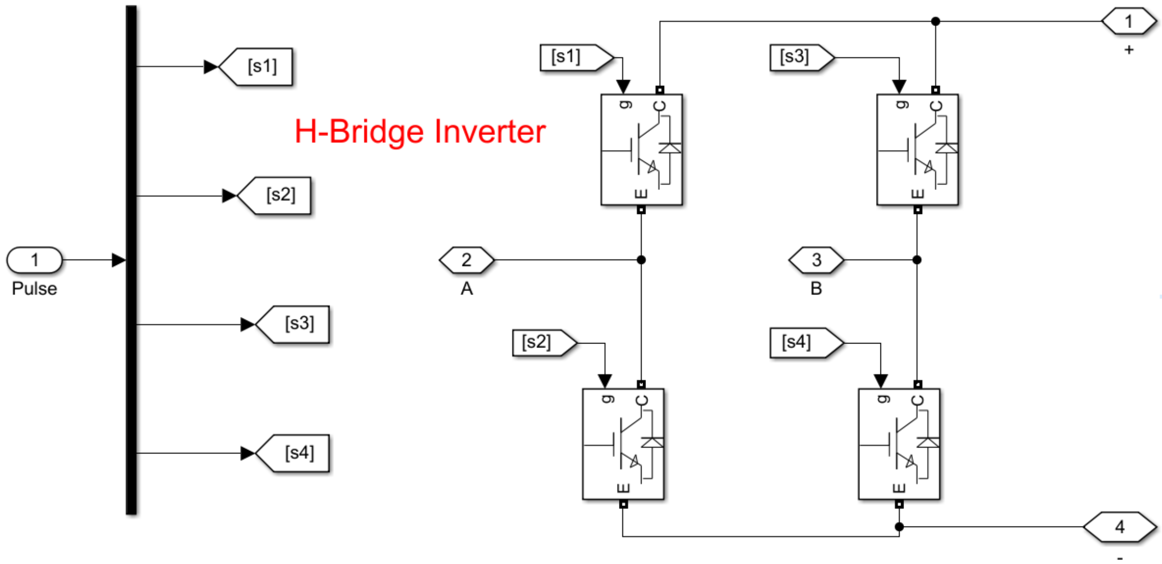

Figure 27: Simulation on Simulink

4.10 Simulink pulses and carrier signal generate SPWM

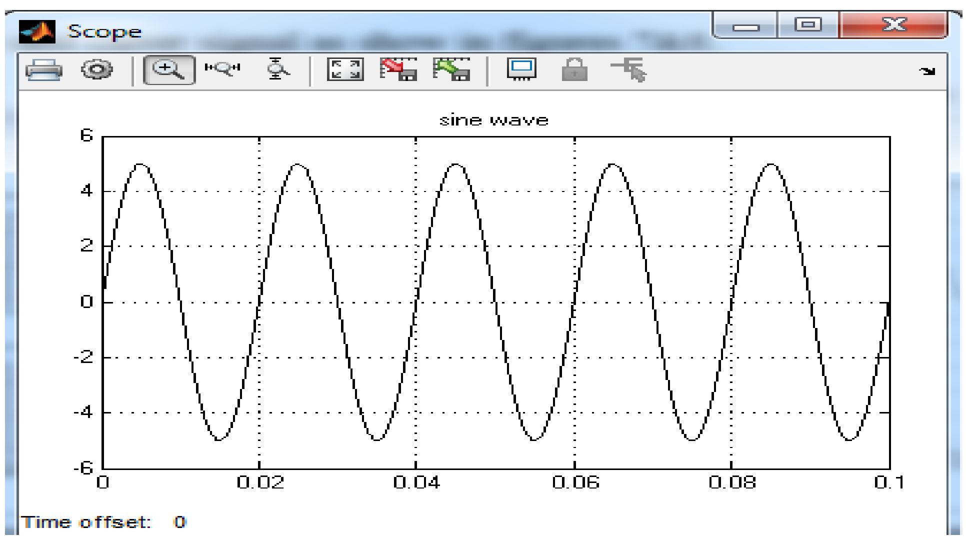

Figure 28: Simulink sine wave generate SPWM

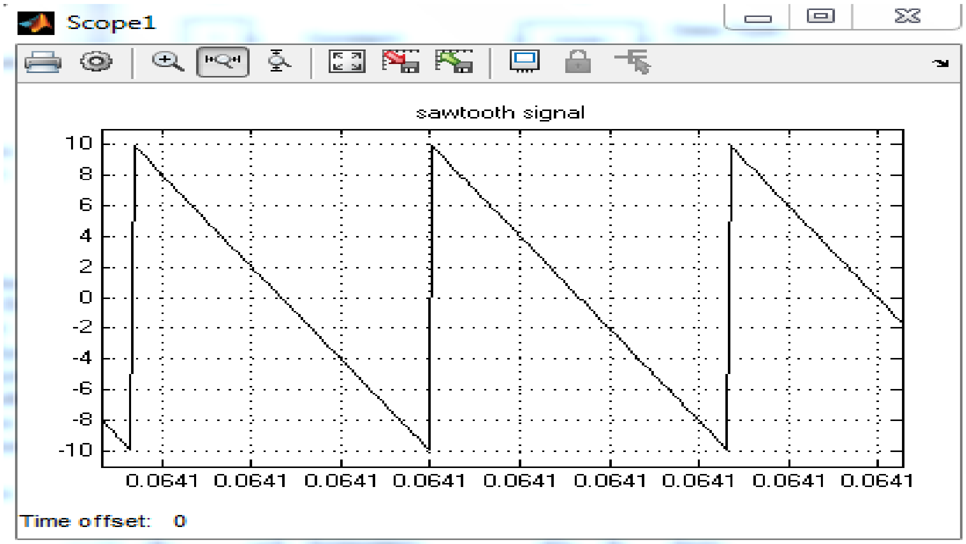

Figure 29: Simulink Carrier Signal

Figure 30: SPWM after comparing both signal

4.9.1 Simulink Output Waveform without Filter

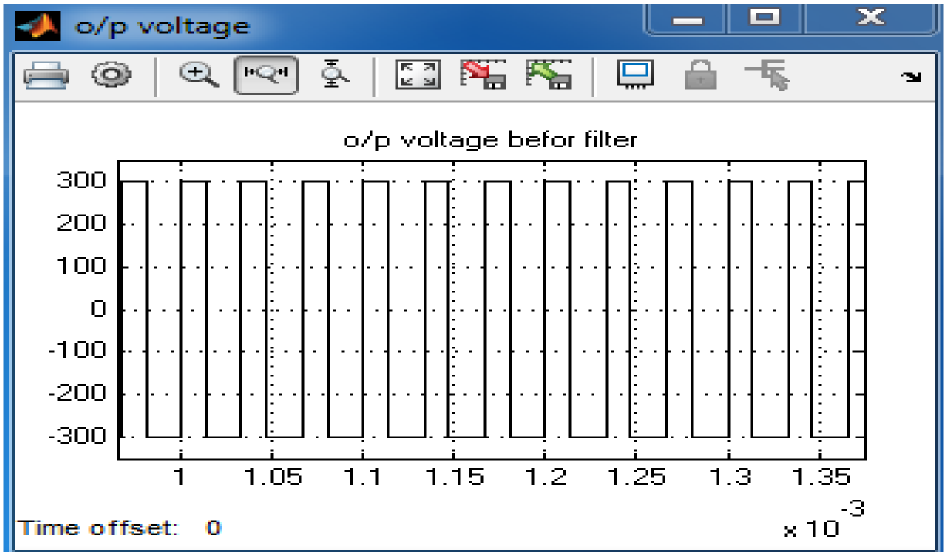

Figure 31: Output of H-bridge inverter

4.10 Hardware Part

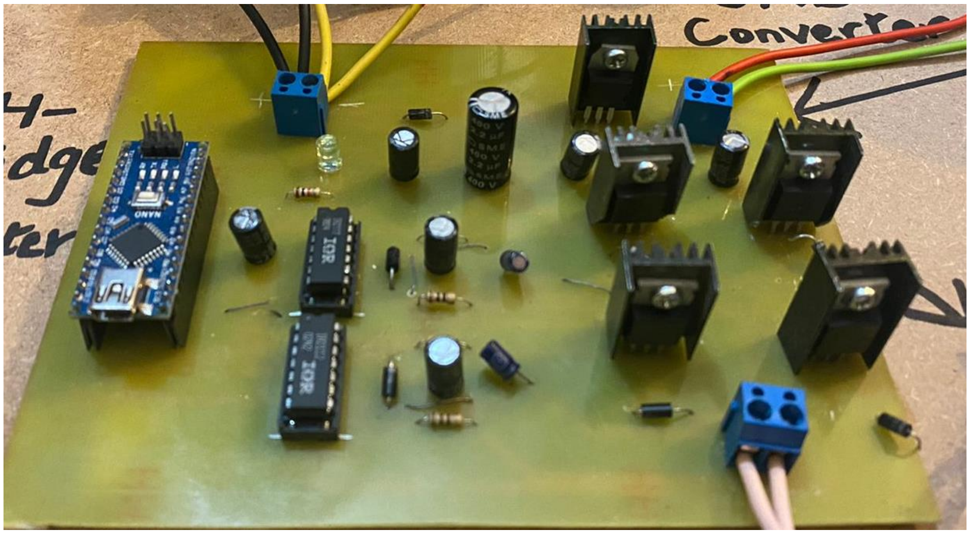

Figure 32: Hardware Model H-bridge Inverter

4.10.1 3D Model

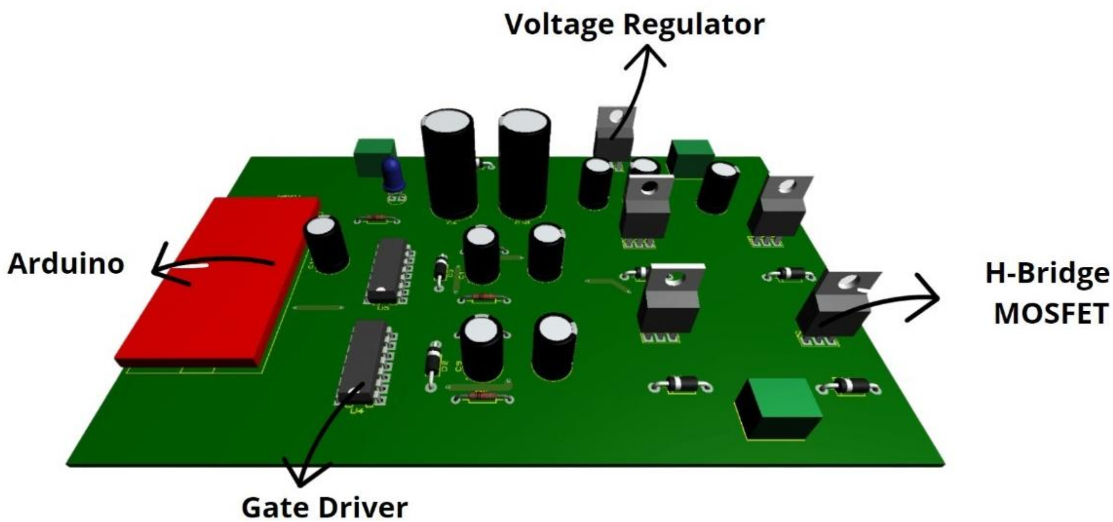

Figure 33: 3D model OF H-bridge inverter

4.10.2 PCB LAYOUT

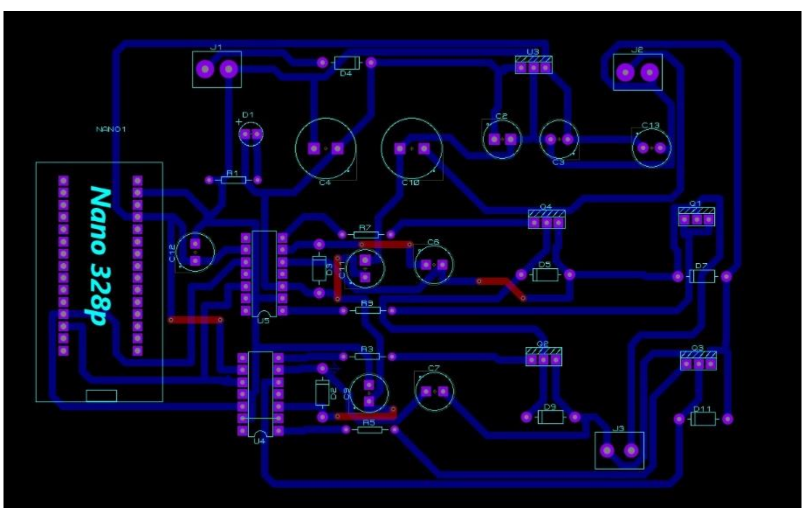

Figure 34: PCB layout H-bridge Inverter

4.11 CONCLUSION

The first characteristics of this system are the parameters of the DC-AC inverter, such as switching type diode, transistor, or thyristor. Second, PWM properties such as amplitude and frequency are important. Finally, filter and load characteristics are reviewed, as well as types such as LCL filter and R load. The DC to AC PWM inverter was modelled using MOSFETS with 50kHz frequency switching for 400~500 VDC input. The simulation of this proposed voltage regulation model was done with the intention of validating the system. The simulation results show that the suggested system can be used successfully in a variety of applications that meet the specifications of the proposed system.

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Chapter 5: Low Pass Filter

5.1 Introduction:

These days, obtaining electrical energy from renewable sources is highly common, and renewable energy producing applications are rapidly evolving. The majority of power plants generate electricity using an Alternating Current (AC) voltage source. As a result, an AC/DC/AC conversion step is required to link such resources to the utility grid. A converter is required in the AC/DC stage, while an inverter is used in the DC/AC stage. As this has been recognized having good efficiency , greater reliability, faster dynamic reaction, so the industry has used (VSI) in primarily industrial applications.

The filter must be applied to the VSI output to restrict the harmonics of current that are sent to the system of grid. As a result, to filter the output voltage of VSI which is not sinusoidal in nature is very critical. It is used to enhance the waveform and convert to sinusoidal. The most appropriate type of filter for this application is a passive ac low pass filter. To build a perfect low pass filter, it must create (THDi) current that should be according with the power quality standard of **(IEEE-519).** The THD current is restricted to 5% according to the IEEE-519 standard. The approach utilized to create an ac low pass filter is a critical criterion for achieving the best results with the simplest procedure.

The approach of transfer function, method of calculation, method of bode plot are all options for building an ac low pass filter.

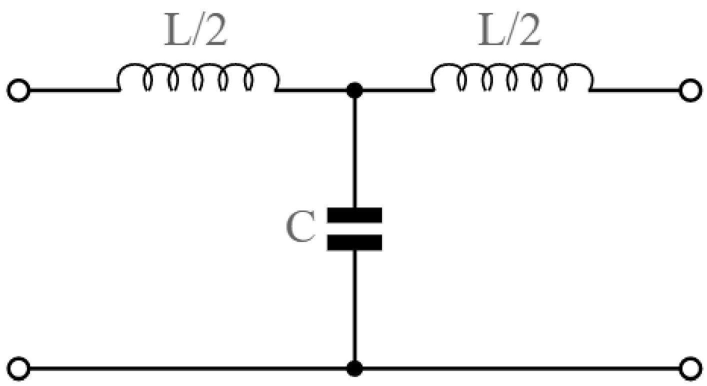

Figure 35: LCL low pass filter

5.2 Problem Statements

Power quality standards from industrial power users have become more demanding as a result of technological improvements in industrial control operations. The main issue in electrical power system related to quality of power is Harmonics which has to be solved. Harmonics are one of the most critical power quality issues to consider when developing an ac low pass filter. When developing ac low pass filters, it's challenging to come up with a design that meets IEEE-519 (THDi< 5%)'s THD current criterion. Aside from that, among the various approaches accessible, such as the calculation method, there must be the simplest method for designing an ac low pass filter.

$$V_{o,rms} = m_a \frac{V_{dc}}{\sqrt{2}}$$

Equation 15

Here the above equation (15) gives the Vrms.

The output harmonics of the inverter are represented as sidebands, whose waveforms occur in multiples of the switching frequency around the center. The output current harmonics are defined using the Fourier series approach in the equation (16) below. Where In is the output current term with a non-fundamental frequency and Il is the output current term with a fundamental frequency.

$$THD_I = \frac{\sqrt{\sum_{n=2}^{\infty}(I_{n,rms})^2}}{I_{l,rms}}$$

Equation 16

5.2.1 Low-pass LCL Filter Design

The LCL low-pass passive filters are a simple approach for decreasing inverter output harmonics. As illustrated in a 3RD order low pass filter is represented by an LC circuit, in which the inductor is shunted by the capacitor. The LCL filter transfer function is expressed which are obtained from the voltage divider rule.

The use of an LC-filter reduces the inverter system's cost and losses. Filter inductance is calculated using Equation 17. The ripple current which would be maximum was set to be between 5% and 20% of the rated current. 20% is the normal maximum ripple of rated current.

$$L = \frac{1}{8}\frac{V_{DC}}{\Delta_{ripple,\max} f_{sw}}$$

Equation 17

The power (reactive) which is absorbed by the capacitor of the filter determines the filter capacitance; Equation 18 describes it. Its value was chosen to be less than 5% since it is the reactive power factor.

$$C_f = \frac{\alpha P_{rated}}{2\pi f_{line} V_{rated}^{\ 2}}$$

Equation 18

Equation 19 defines the resonance frequency of LCL filter.

$$fc = \frac{1}{\pi\sqrt{L\,C}}\ Hz$$

Equation 19

5.3 Simulation Results

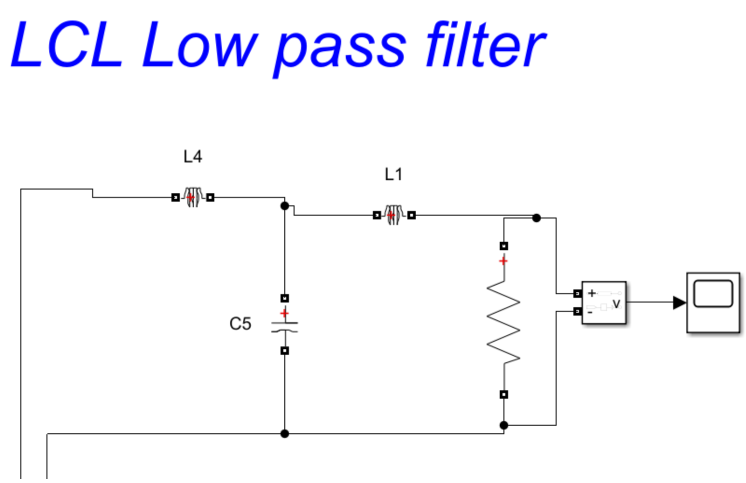

Figure 36: Simulink model of LC low pass filter

5.3.1 Hardware design of LCL filter

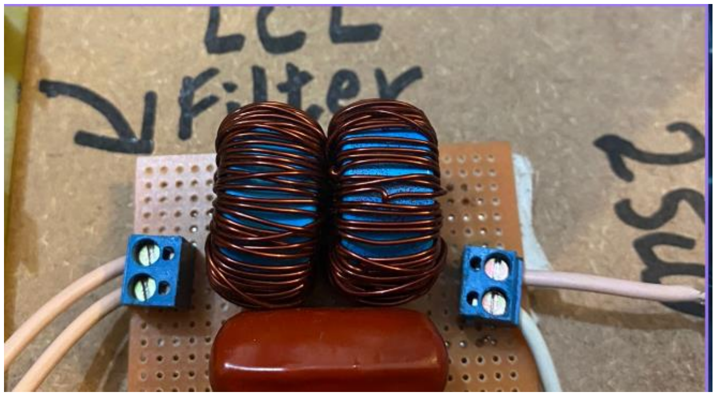

Figure 37: Hardware of LCL low pass Filter

5.3.2 Results with LCL filter

The cut-off frequency was determined to be 5KHz based on the test done without using filter .

Below Table shows the values of the filter(LCL) .

Table 1: LCL filter

Cut off fc	L (µH)	C (µF)
5KHz	4.5	100

The comparison of waveform of output voltage and current is shown (with and without filter). The output with the filter is sinusoidal but the signal without the filter is in boxes form, as can be seen in the two pictures.

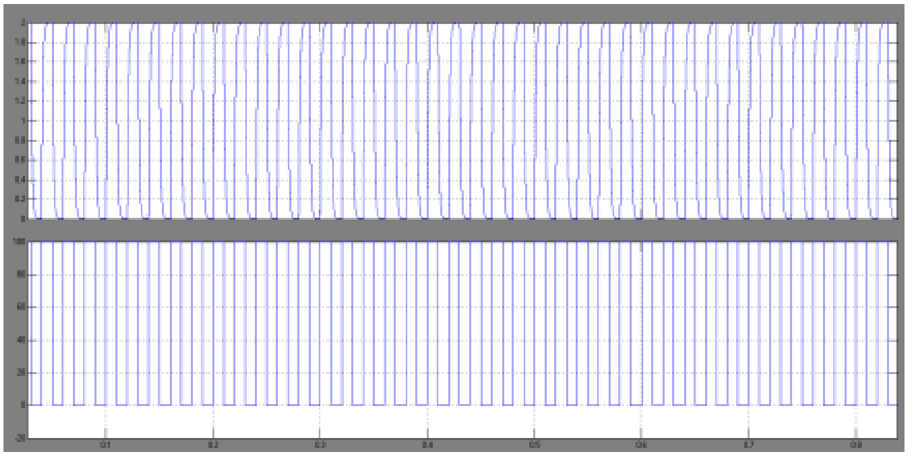

Figure 38: Waveform of the Output voltage and current of inverter without filter

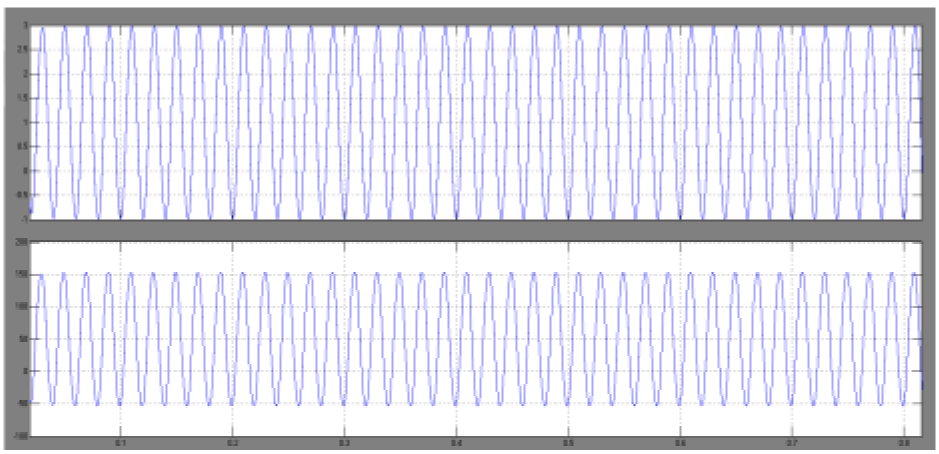

Figure 39: Waveform of the Output voltage and current of inverter with filter

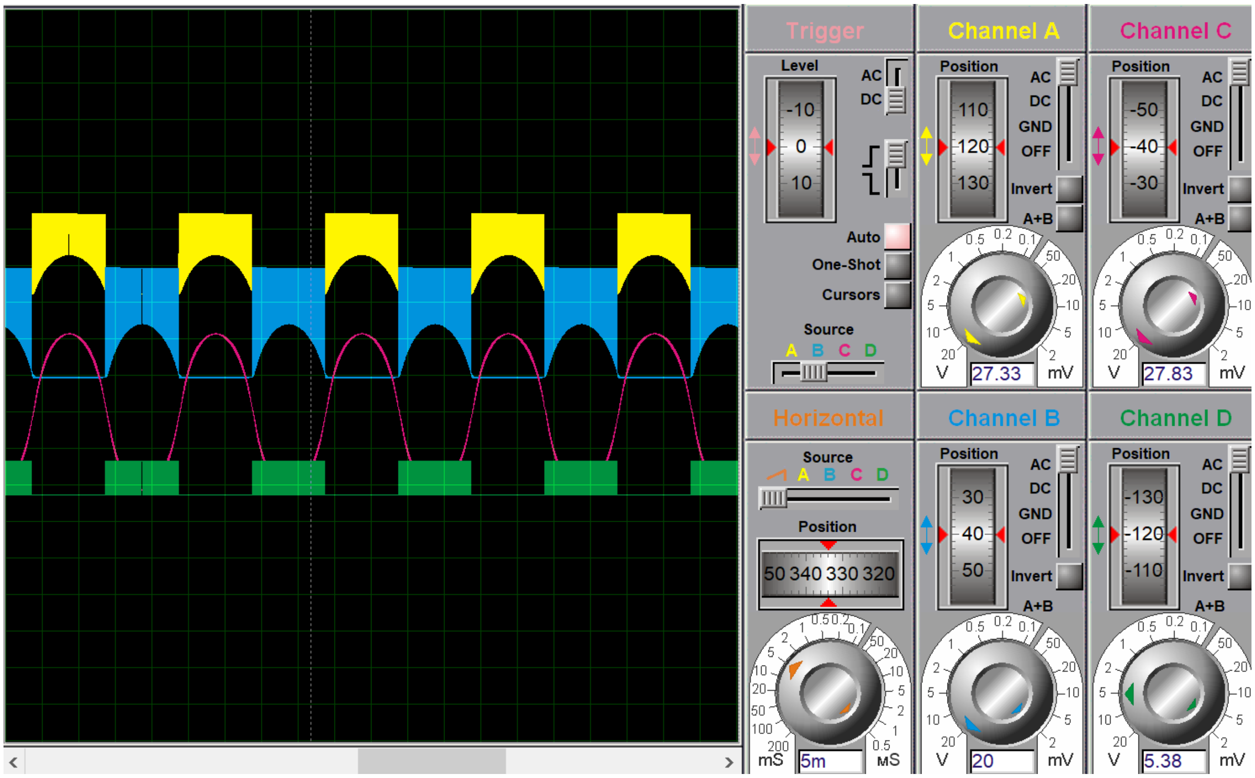

Figure 40: Output of proteus complete circuit

5.3.3 Output at load without filter

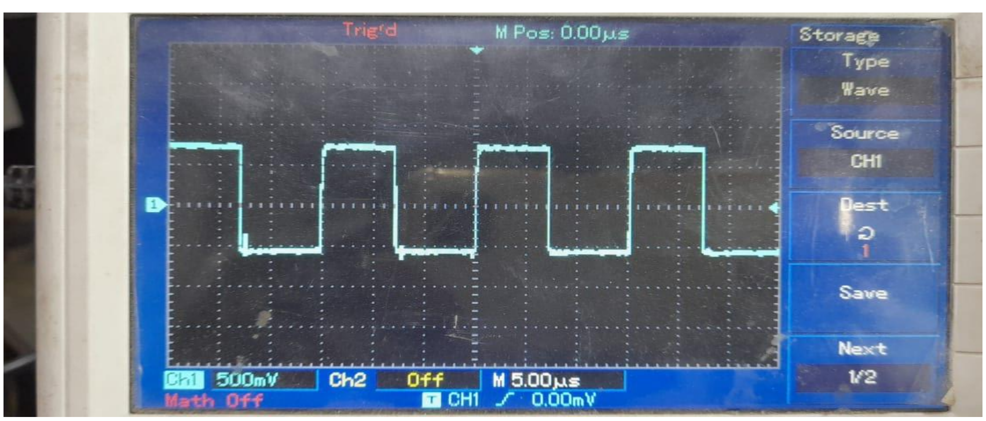

Figure 41: Result without filter

5.3.4 Final output with filter

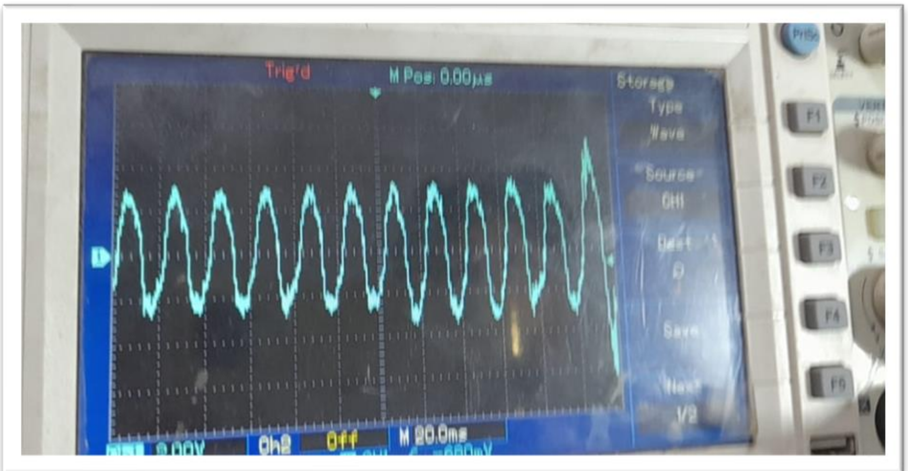

Figure 42: Result with filter

5.3.5 Future Scope and Development

To reduce the leakage inductance, we can use toroidal coil transformer instead of shell type, for more efficient high frequency transformer . In future, we can design a double layer PCB and design which would be more compact for industry point of view. Moreover, we can also work on Dual active bridge and use its bi-directional function for use in net-metering.

For future purposes, this project will be used for:

- Soft Switching
- Dynamic Modelling which describes those aspect of the system that are concerned with time and sequencing of the operations.
- EV stations
- UPS systems

References

[1] Y. Huang, J. Wang, F. Z. Peng, and D. W. Yoo, "Survey of the power conditioning system for PV power generation," 2006. doi: 10.1109/PESC.2006.1712267.

[2] T. Liu *et al.*, "Design and Implementation of High Efficiency Control Scheme of Dual Active Bridge Based 10 kV/1 MW Solid State Transformer for PV Application," *IEEE Transactions on Power Electronics*, vol. 34, no. 5, pp. 4223–4238, May 2019, doi: 10.1109/TPEL.2018.2864657.

[3] Y. Ting, S. de Haan, and B. Ferreira, "Modular single-active Bridge DC-DC converters: Efficiency optimization over a wide load range," *IEEE Industry Applications Magazine*, vol. 22, no. 5, pp. 43–52, Sep. 2016, doi: 10.1109/MIAS.2015.2459086.

[4] S. Kurm and V. Agarwal, "Dual Active Bridge Based Reduced Stage Multiport DC/AC Converter for PV-Battery Systems," in *IEEE Transactions on Industry Applications*, 2022, vol. 58, no. 2, pp. 2341–2351. doi: 10.1109/TIA.2021.3137371.

[5] B. I. Rani, G. S. Ilango, and C. Nagamani, "Enhanced power generation from PV array under partial shading conditions by shade dispersion using Su Do Ku configuration," *IEEE Transactions on Sustainable Energy*, vol. 4, no. 3, pp. 594–601, 2013, doi: 10.1109/TSTE.2012.2230033.

[6] S. Shuvo, E. Hossain, T. Islam, A. Akib, S. Padmanaban, and M. Z. R. Khan, "Design and Hardware Implementation Considerations of Modified Multilevel Cascaded H-Bridge Inverter for Photovoltaic System," *IEEE Access*, vol. 7, pp. 16504–16524, 2019, doi: 10.1109/ACCESS.2019.2894757.

[7] P. Cortés, G. Ortiz, J. I. Yuz, J. Rodríguez, S. Vazquez, and L. G. Franquelo, "Model predictive control of an inverter with output LC filter for UPS applications," *IEEE Transactions on Industrial Electronics*, vol. 56, no. 6, pp. 1875–1883, 2009, doi: 10.1109/TIE.2009.2015750.

[8] J. Y. Lee, Y. P. Cho, H. S. Kim, and J. H. Jung, "Design methodology of passive damped LCL filter using current controller for grid-connected three-phase voltage-source inverters," *Journal of Power Electronics*, vol. 18, no. 4, pp. 1178–1189, Jul. 2018, doi: 10.6113/JPE.2018.18.4.1178.

[9] M. I. Azim, M. M. Hossain, M. M. Rana, and M. R. Rahman, “Utilization of single-phase inverters in Photovoltaic system,” Oct. 2014. doi: 10.1109/ICEEICT.2014.6919056.

[10] Institute of Electrical and Electronics Engineers, *Proceedings of the 2nd International Conference on High Voltage Engineering and Power Systems (ICHVEPS) 2019 : Bali, October 1st - 4th, 2019, Inna Grand Bali Beach Hotel, Sanur, Bali, Indonesia.*

[11] N. Singh, S. Jena, and C. K. Panigrahi, “Sliding Mode Controlled IDBHCC for Single phase LC filter PWM Inverter,” 2021. doi: 10.1109/APSIT52773.2021.9641402.

[12] C. Liu, L. Lei, Q. Chen, L. Zhang, and S. Quan, “Model predictive control of single-phase grid-connected inverter with LC filter,” in *Proceedings - 2017 32nd Youth Academic Annual Conference of Chinese Association of Automation, YAC 2017*, Jun. 2017, pp. 115–119. doi: 10.1109/YAC.2017.7967389.

[13] R. Jha, M. Forato, S. Prakash, H. Dashora, and G. Buja, “An Analysis-Supported Design of a Single Active Bridge (SAB) Converter,” *Energies (Basel)*, vol. 15, no. 2, Jan. 2022, doi: 10.3390/en15020666.

[14] European Power Electronics and Drives Association, Politechnika Poznańska, International Power Electronics and Motion Control Conference 13 2008.09.01-03 Poznań, and EPE-PEMC 13 2008.09.01-03 Poznań, *13th International Power Electronics and Motion Control Conference, 2008 EPE-PEMC 2008 ; 1-3 Sept. 2008, [Poznań, Poland ; proceedings]*.

[15] L. Max and T. Thiringer, “Control method and snubber selection for a 5 MW wind turbine single active bridge DC/DC converter Acknowledgements.”

[16] H. H. C. Iu and B. Robert, “Control of chaos in a PWM current-mode H-bridge inverter using time-delayed feedback,” *IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications*, vol. 50, no. 8, pp. 1125–1129, Aug. 2003, doi: 10.1109/TCSI.2003.815220.

[17] C. Wu, W. H. Lau, and H. S. H. Chung, “Analytical technique for calculating the output harmonics of an H-bridge inverter with dead time,” *IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications*, vol. 46, no. 5, pp. 617–627, 1999, doi: 10.1109/81.762927.

[18] K. Park and Z. Chen, “Analysis and design of a parallel-connected single active bridge DC-DC converter for high-power wind farm applications,” 2013. doi: 10.1109/EPE.2013.6631854.

[19] P. A. Dahono, A. Purwadi, and A. Qamaruzzaman, “LC filter design method for single-phase PWM inverters,” in *Proceedings of the International Conference on Power Electronics and Drive Systems*, 1995, vol. 2, pp. 571–576. doi: 10.1109/peds.1995.405006.

[20] K. Corzine and Y. Familiant, “A new cascaded multilevel H-bridge drive,” *IEEE Transactions on Power Electronics*, vol. 17, no. 1, pp. 125–131, Jan. 2002, doi: 10.1109/63.988678.

Appendix

Code Matlab

```
function sig_ref  = fcn(t)
%% parameters for DAB SST
Tsw=2*5e-5;%%switching perod;
NRs=rem(round(t/Tsw),2);
fs=1/Tsw
%% reference signal creation
if(NRs==0)
    sig_ref=1;
else
    sig_ref=0;
end
```

code Arduino for SPWM

```
int i = 0;
int x = 0;
int OK = 0;
int sinPWM[] = {1, 2, 5, 7, 10, 12, 15, 17, 19, 22, 24, 27, 30,}

#define MOSFET1  9
#define MOSFET4  10
#define EnablePower 8  // HV power on switch
#define HVON  13 // high voltage on blinks
//int x1 = 0;  int y = 0; int z = 0;

void setup() {
  Serial.begin(9600);

  pinMode(5, OUTPUT);
  pinMode(6, OUTPUT);
  pinMode(MOSFET1, OUTPUT); // MOSFET 1
  pinMode(MOSFET4, OUTPUT);  // MOSFET 2
  pinMode(EnablePower, INPUT); // N.O. switch
  digitalWrite(EnablePower, HIGH); // pull up enabled
  pinMode(HVON, OUTPUT);
  digitalWrite(HVON, LOW);
  cli();// stop interrupts
  TCCR0A = 0; //reset the value
  TCCR0B = 0; //reset the value
  TCNT0 = 0; //reset the value
  //0b allow me to write bits in binary
  TCCR0A = 0b10100001; //phase correct pwm mode
  TCCR0B = 0b00000001; //no prescaler
  TCCR1A = 0; //reset the value
  TCCR1B = 0; //reset the value
```

```
  TCNT1 = 0; //reset the value
  OCR1A = 509; // compare match value
  TCCR1B = 0b00001001; //WGM12 bit is 1 and no prescaler

  TIMSK1 |= (1 << OCIE1A);

  sei();// enable interrupts
}
ISR(TIMER1_COMPA_vect) { // interrupt when timer 1 match with OCR1A va
lue
  if (i > 313 && OK == 0) { // final value from vector for pin 6
    i = 0; // go to first value of vector
    OK = 1; //enable pin 5
  }
  if (i > 313 && OK == 1) { // final value from vector for pin 5
    i = 0; //go to firs value of vector
    OK = 0; //enable pin 6
  }
  x = sinPWM[i]; // x take the value from vector corresponding to posi
tion i(i is zero indexed)
  i = i + 1; // go to the next position
  if (OK == 0) {
    OCR0B = 0; //make pin 5 0
    OCR0A = x; //enable pin 6 to corresponding duty cycle
  }
  if (OK == 1) {
    OCR0A = 0; //make pin 6 0
    OCR0B = x; //enable pin 5 to corresponding duty cycle
  }
}
void loop() {
  while ((digitalRead(8) == LOW))   {// && (y > 150)
    digitalWrite(MOSFET1, HIGH);   // MOSFET1 on
    digitalWrite(MOSFET4, LOW);
    delayMicroseconds(25);
    //delay(1);  // wait for 10.3 mS
    digitalWrite(MOSFET1, LOW);  // MOSFET1 off
    digitalWrite(MOSFET4, HIGH);
    delayMicroseconds(25);
    //delay(1);  // wait for 10.3 mS
    digitalWrite(MOSFET1, LOW);  // MOSFET2 off
    digitalWrite(MOSFET4, LOW);
  } // end while
}
```