Grid Tie Inverter

Project Report

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Grid-Tie-Inverter

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The Project Report is in fulfillment of the requirements for the completion of degree of BE, Electrical Engineering from CEME, NUST.

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Declaration

This is to certify that the project titled “Grid-Tie-Inverter” is our own work. Our project has not been submitted anywhere else for evaluation. The information and material which we used from other sources has been acknowledged properly in this report.

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Correctness Certificate

Our project has been reviewed by an “English Expert”, and is free of any type of literature, structural, syntax, grammatical& spelling mistakes. The report is also in accordance with the format given by the University.

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Acknowledgements

We take this opportunity, to firstly express out gratefulness to Allah, the most beneficent & the most merciful, and to thank him for guiding us in every step of our lives. He is without any doubt, our Benefactor and Praiseworthy.

We would like to express our gratitude to our honorable supervisor & co-supervisor, and Dr.Taosif Iqbal and Dr. Usman Ali respectively for their unwavering encouragement & timely advice. Whenever we found ourselves in an indecisive state or problem, they aided us to get on the right path. This project would never have been completed without their unflinching support and reassurance.

A number of ideas generated from our numerous discussions and their feedback was incorporated in this report. Finally, we would like to thank our parents and siblings for much support and constant encouragement during the time of our graduate work.

At last, we would like to express our gratitude for our teachers & professors, who shared their knowledge with us, and taught us with the skills like matlab Programming, Circuit Designing tools etc. which were necessary to complete this project successfully.

Dedication

“We dedicate this project to our home country, Pakistan. We hope that our work will help in prosper of Pakistan. May our country progress by leaps and bounds! We also dedicate it to every person who helped us in successfully completing our work and supported us morally and practically throughout this period.”

Abstract

This project report analyzes and provides design methodology of Grid-Tie-Inverter using the Arduino mega 2560, H-bridge circuit and DC-DC converter. This study examines the development and operation of a 3-phase grid-tie inverter with feedback control system and phase-locked loop (PLL) in the stationary frame of reference (α, β) and synchronous frame of reference $(d - q)$. The result reveals an intriguing and crucial aspect of three-phase grid-tied inverters: they convert DC to AC and synchronize their voltage, current, frequency, and phase with the grid in a regulated and efficient way. Furthermore, this study demonstrates grid synchronization behavior, in which the frequency range is determined by the PLL bandwidth and the inverter power rating. As an example, under poor grid conditions, a change in PLL bandwidth might cause the inverter system to become unstable as a result of this behavior and condition is handled by grid tie inverter. The suggested grid tie inverter model may be used to investigate harmonic resonance and instability concerns. The analysis is confirmed by simulations and experiments measurements. Everyone in this country is aware of the energy catastrophe that our country is experiencing as a result of the exhaustion of energy-producing resources such as fossil energy, natural gas, and coal reserves. Renewable energy technologies are a solution that can meet our electrical demands while also being environmentally beneficial (Solar, Wind, Biomass etc.). Solar energy is by far the most abundant renewable energy resource, and our country is fortunate to have it. Renewable energy resources do not, however, produce as much electricity as human's demand. These resources are not particularly enough until we make it efficient. However, as technology advances, several strategies, such as the Maximum Power Point Technique (MPPT) and Zero-Crossing Detection (ZCD), have been developed to enhance the energy production of renewable sources of energy. As a result, the project's goal is to design a system that can efficiently produce electric energy from any renewable DC source to meet our daily energy needs, as well as energizing the National Grid if excess energy is produced for the solar cells.

Keywords

H-bridge, Grid Synchronization, Phase Lock Loop (PLL), Grid Tie Inverter (GTI), Maximum Power Point Tracking (MPPT), Zero Crossing Detection (ZCD).

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CHAPTER NO.1

GENERAL IDEA ABOUT GRID-TIE INVERTERS

1.1. Background:

Electricity powered by renewable, wind generators, or other renewable energy sources is generally in the form of Direct Current (DC), which is incompatible with any of your living area appliances. To function, all devices require alternating current (AC). This involves things like your oven, fluorescent lights, microwaves, and televisions.

To address this issue, many solar installations include a grid-tie inverter that transforms the DC from your solar panels into AC, which is then "connected" to the power system and allows you to earn an energy bill credit.

Some other points to consider would be that the energy crisis is a major challenge that all governments across the world confront. Particularly in developing nations like ours, where the crisis is impacting our financial and industrial development. People are employing generators and UPS systems in their homes, workplaces, and enterprises to cope with the energy scarcity. Even while they can provide our electrical needs, they are far more hazardous to us than we realize. Generators utilize diesel and petrol as energy, both of which are derived from fossil fuels that are rapidly decreasing, and they also emit hazardous chemicals that pollute the atmosphere and a variety of ailments in humans. Likewise, UPS systems can potentially shorten the life of the electrical gadgets that use them. To summarize, both generators and UPS are harmful to our financial and physical well-being. Furthermore, coal is the primary source of electrical generation in our country.

To address this problem, a system that can power electrical equipment using energy sources like solar and wind energy while keeping the environment and human health in mind is urgently needed.

1.2. Objectives:

In light of all considerations, our project's goals are as follows:

- To solve the energy shortages, a system operated by a DC source implementation.
- Installation of a system that can be used to replace UPS and generators in our homes and businesses.
- Establishment of an environment conscious system.
- Create a mechanism to control the inverter's output voltage.
- Developing a system that improves grid frequency stability
- Maximum power point tracking (MPPT) for efficiency

1.3. Introduction:

The "Grid Tie Inverter" is the system that achieves the purpose specified in the preceding section. A grid tie inverter is an electrical device that transforms DC electricity from renewable energy sources $(solar, geothermal, etc.)$ to AC power for electronic devices while also supplying excess power to public grids. In order to successfully and securely inject electrical energy into the grid, the ''Grid tie inverter'' must precisely match the voltage and phase of the grid sinusoidal AC power waveform. It also provides the ability to switch between standalone and grid connected in case of failure. Phase and frequency synchronization is achieved using Phase Lock Loop (PLL), feedback and LC filter. Grid tie inverter is designed using 3-phase full bridge inverter which converts direct current into alternating current. We have chosen LC filter because it provides good regulation, Ripple factor is low and is independent of load and it is suitable for both High and Low load. Advantages of grid tie inverter are that this is the most traditional inverter topology. It has easy accessibility of troubleshooting & maintenance. System design and implementation is easy. The major components of a grid tie inverter are as follows:

- Direct Current---Direct Current converter.
- Maximum Power Point Tracking (MPPT)
- Direct Current---Alternative Current inverter.
- Filtering Circuit.

- Synchronization Circuit.

1.4. DC-to-DC Converter Stage:

A DC / DC converter is a device that changes the voltage level of a DC power supply from one point level to another. A digital power converter is what it is. The levels of power range from extremely high (high voltage transmission) to extremely low (low voltage transmission) (small battery). It's similar to an AC transformer in the DC spectrum. Because they are thought to have minimal power loss, power converters are widely used in electronic circuits. The Power Optimizer is a DC/DC converter that maximizes the energy collection from solar panels, wind turbines, and other DC-powered renewable energy sources. DC / DC converters are found in portable electronic devices such as cell phones and laptop computers, the majority of which are powered by batteries. Typical electronic devices include a vast number of sub circuits, each with its own voltage needs that varies from those of batteries and external power sources (which may be higher or lower than the supply voltage). The voltage also reduces when the energy stored in the storage battery runs out. Instead of requiring a large number of batteries to get the same effect, the switched DC-DC converter allows you to enhance the voltage from a partially decreased battery voltage while also saving space.

1.5. Renewable energy resources:

Renewable energy now accounts for roughly 22% of worldwide power output, but it is predicted to quadruple in the next 15 years, owing to the rapid expansion of variable renewable energy sources such as solar photovoltaic and wind. There are a variety of technical choices for integrating variable renewable energy into power systems. Furthermore, significant advancements in wind and solar technology enable them to be employed in more circumstances. In the long run, however, power systems with substantial proportions of variable renewable power generation will necessitate a technological and economic rethinking of standard designs, operations, and planning approaches. Biomass accounts for more than half of all worldwide renewable energy usage today. Despite the fact that this crucial renewable energy resource is found in practically every country, recent technological advancements in biomass growing, pre-treatment, collection, and transportation have expanded the availability of sustainable and high-energy-content feedstock at accessible rates.

1.6. MPPT (Maximum power point Tracking):

MPPT is a network-connected inverter technology that can extract maximum power under all situations. MPPT is critical to the functioning of any restricted power system or source. We draw the voltage current characteristic and find the power at each point in MPPT to get the most power out of the source. The most efficient point on the V-I graph is MPPT.

Solar panels, wind turbines, and other kinds of MPPT play an important role. To do so, we'll need to create an algorithm that measures or checks voltage and current at each location and tracks the most efficient one.

Voltage and Current cannot be maximized simultaneously.

- Power maximized at the maximum power point (MPP).
- Maximum power point (MPP) Changes.
  1. With solar exposure
  2. With temperature
  3. With renewable energy source equipment age
  4. MPPT must be tracked continuously

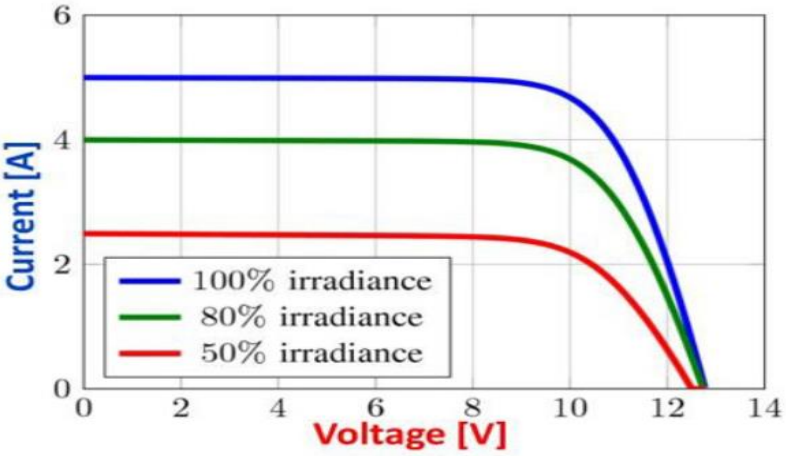


Figure 1: Current vs. Voltage waveform

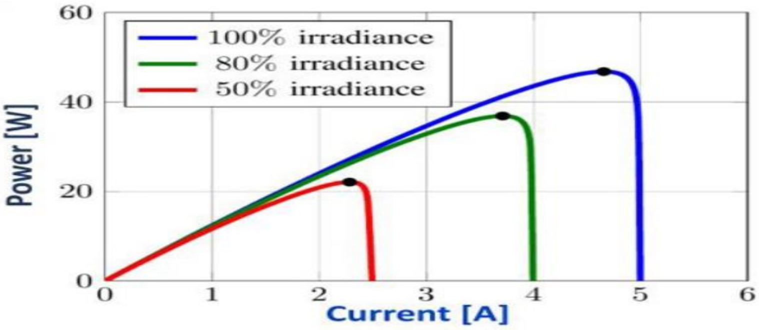


Figure 2: MPPT vs. current

1.6. DC to AC inverter stage:

After the $\boldsymbol{DC}$ to $\boldsymbol{DC}$ conversion, a $\boldsymbol{DC}$ to $\boldsymbol{AC}$ inverter step is necessary to synchronize the AC with the network's frequency, phase, and amplitude. They are classed based on the design of their power supply and power circuit. As a result, they are divided into two categories: voltage source inverters and current source inverters $(\boldsymbol{CSI})$. The $\boldsymbol{VSI}$ inverter features a low impedance $\boldsymbol{DC}$ voltage source at the inverter's input terminals. High-impedance $\boldsymbol{DC}$ sources are used in $\boldsymbol{CSI}$-type inverters.

1.7. LC filters:

There may be a lot of ripple in the output after converting the input to alternating current (AC), but the aim is to achieve a full sinusoidal signal with a frequency of 50Hz. Because the charge flows back and forth between the plates of the capacitor and via the inductance, it is also known as an oscillator circuit. The energy oscillates between the capacitor and the inductor until it is stopped by the component's internal resistance and the connecting wire. The movement of the pendulum swinging back and forth, or the movement of water flowing back and forth in the tank, is comparable to how this cycle works. As a result, it's known as a tuning circuit or a tank circuit. This circuit can store energy at the resonant frequency and works as an electrical resonator.

To increase the quality of the output voltage and make it as close to a sine wave as feasible, we utilize a filtering circuit at the output of the $DC - AC$ converter in the GTI.

Filter topologies are classified into two types:

- Passive Filters: Passive electrical components such as resistors, capacitors, and inductors are used to create these filters.
- Active Filters: These filters are made up of active electrical components such as transistors, operational amplifiers, and other similar devices. They can also utilize resistors and capacitors, but inductors are not allowed.

1.8. Synchronization Circuit:

We need a circuit to send the power from the inverter to the grid since grid tie inverters are meant to activate (give electricity) to the grid. The synchronization circuit is the name for this circuit.

To connect the inverter to the grid, numerous synchronization mechanisms are employed, some of which are listed below:

- **Zero Crossing Detection (ZCD):** One of the most essential synchronization methods is Zero Crossing Detection. We employed operational amplifiers in ZCD to compare the amplitude and phase difference with a zero reference and calculate the difference before synchronizing it.
- **Phase Locked Loop (PLL):** A phase locking approach in which output signals are compared to reference signals and an error signal is generated. The oscillator, which is a component of PLL, is also used to modify the frequency and match the phase.
- **Synchronous Reference Frame (SRF):** We synced the waveforms in synchronous Reference Frame by transforming our analogue system into a digital signal and generating two signals that are 90 degrees out of phase.

CHAPTER NO. 2

OUR DESIGN AND CALCULATIONS

2.1. DC to DC conversion stage design:

Different Topologies of dc to dc converters

The power converters are designed in a variety of topologies. The most well-known of them are listed below:

- Boost Converter (Step Up)
- Buck Converter (Step Down)

Each of these designs has its own set of benefits and drawbacks. But in our case we need a boost inverter which could convert low voltage to high voltage which could be further converted to 220V AC and could be connected with the grid.

There are several topologies for the DC-DC Converter if we used high frequency transformer as an isolated circuit or as booster some of which are mentioned below:

- **Push-Pull Converter Topology:** Two transistors are coupled in a Push-Pull circuit. The voltage is provided via a high frequency transformer's center-tapped winding and transistors at the transformer's ends. Because of its relatively steady and low-noise current output, this topology is commonly employed in high-power applications.

- **Interleaved Boost Converter Topology:** When it comes to low power applications (KWs). The Interleaved Boost architecture is also one of the most essential topologies It also contains two transistors with 180-degree out-of-phase PWMs. It has the excellent advantage of not requiring center-tapped transformers. The main benefit of an Interleaved Boost Converter is that it decreases ripples in both the input and output circuits by splitting current into two pathways. It also increased the efficiency of the $DC - DC$ converter, lowering I^2R and inductor losses.

- **Fly back Converter Topology:** Fly back converter topology is also one of the important topology. It can be used as both for Buck and Boost converter. It only required one transistor. The voltage is given in one side of winding and transistor at other side. It also does not require center-tapped transformers. Most of the time this topology is use as an isolation purpose mean with unity turn ratio.

Boost Converter (Step up):

One of the most basic forms of switch mode converters is the boost converter. It takes an input voltage and amplifies or amplifies it, as the name indicates. Only an inductor, a solid state switch (typically a MOSFET, because they are so excellent these days), a diode, and a capacitor are used in this circuit. As a MOSFET switch, a periodic square wave source is also required.

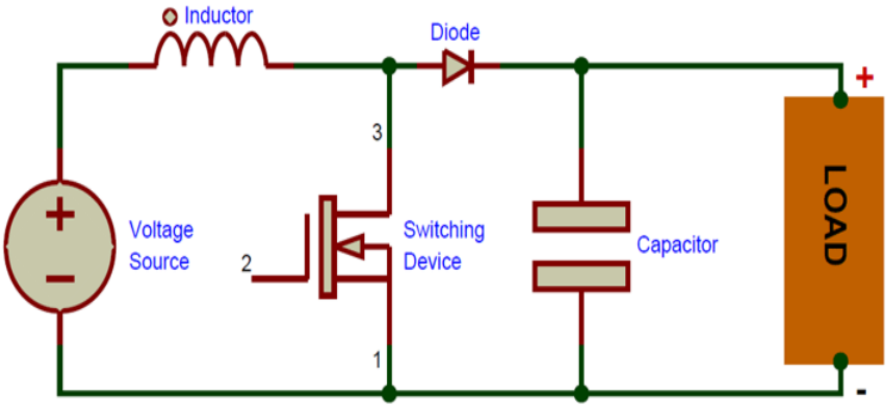


Figure 3: Boost converter

Working Principle of Boost Converter?

To comprehend how boost converters function, you must first perceive how inductors, MOSFETs, diodes, and capacitors function.

With this knowledge, you may examine the boost converter's working in detail.

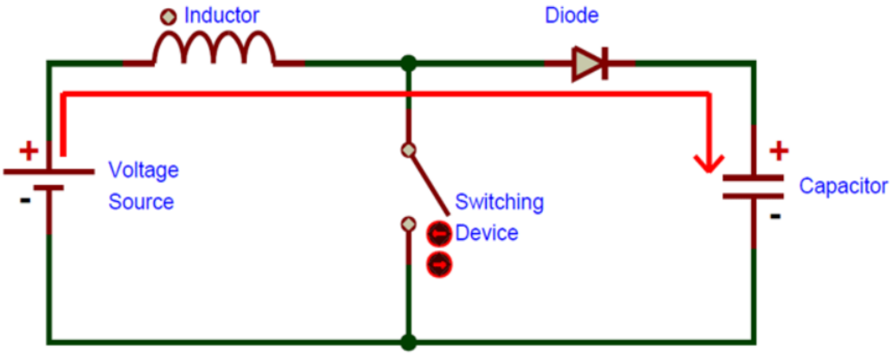


Figure 4: Diode Characteristics

Step1:

It doesn't happen very often around here. To charge the output capacitor, the input voltage is lowered by one diode drop.

Step2:

Then switch on the electricity. The MOSFET switches on when the signal source reaches high. All of the current flows via the MOSFET because of the inductor. The output capacitor will remain charged since it cannot be discharged across the newly reverse-biased diode. However, because the inductance delays the current increase, the power supply does not instantaneously short circuit. Around the inductor, a magnetic field is also created. Polarization of the voltage across the inductor is required.

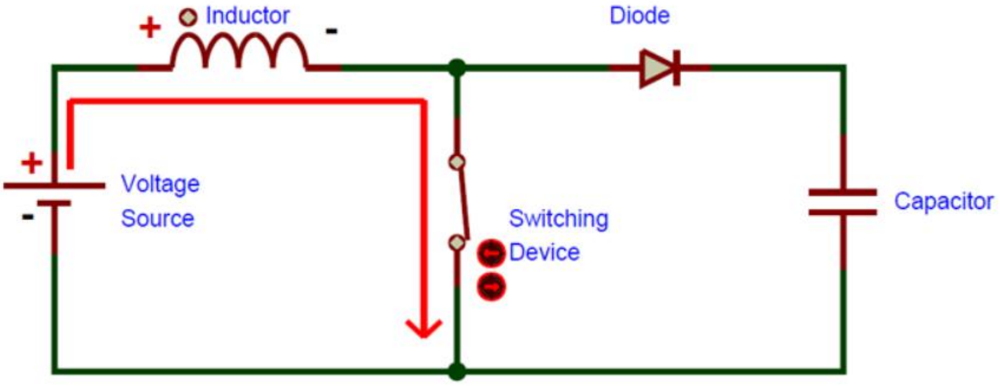


Figure 5: Switching characteristics of MOSFET

When the MOSFET is turned off, the current to the inductor is promptly shut off.

By charging the output capacitor to a higher voltage than before, we were able to elevate the low DC voltage to a higher voltage. Continuous current flow must be ensured through inductance. Sudden power spikes irritate me. That is why he is bothered by power disruptions. The magnetic field's energy is employed to generate a very high voltage with the polarity opposite that of the voltage necessary to keep the current flowing. When the other components of the circuit are ignored and just the sign of polarity is focused on, the inductor operates as a voltage source in series with the voltage supply. This means that the diode's anode is forward biased to a higher voltage than the cathode (remember that the cap was previously charged to supply the voltage first).

By charging the output capacitor to a higher voltage than before, we were able to elevate the low DC voltage to a higher voltage.

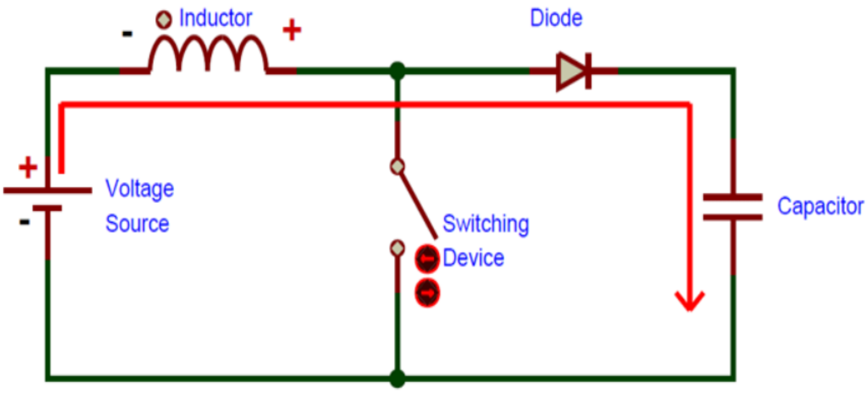


Figure 6: Charging of capacitor in boost converter

These stages (depending on the frequency of the oscillator) are repeated thousands of times to stabilize the output voltage under load.

Fine detail of Boost Converter Operation

Many of you have already expressed your dissatisfaction with this too simplistic comment. Many details have been omitted; however it was necessary to make the working of the boost converter as clear as possible. You may go on to the next degree of complexity now that you've comprehended this concept.

1. **Oscillator**

   There is no complete inductor and the MOSFET output switch cannot be left on indefinitely, Saturation current exists. Short circuits, scorched inductor insulation, MOSFET failures, and other problems can occur if the MOSFET switch is left on for more than a few hundred microseconds. Determine how long it takes to achieve an available current (such as 1 amp) using an inductor knowledge and change the oscillator on-time appropriately. As a result, the current curve is referred to as a saw-tooth because it mimics the inductance of a saw-edge.

2. **MOSFETs**

   If you look closely, the MOSFET in Step 3 shows a voltage equal to the supply voltage plus the coil voltage. This necessitates a MOSFET with a high voltage rating, as well as a high on-resistance. MOSFET breakdown voltage and on-resistance are tradeoffs in boost converter design. As we have learned through bitter experience, switching MOSFETs in boost converters are typically vulnerable. The breakdown voltage of the MOSFET, not the design, determines the boost converter's maximum output voltage.

3. **Inductor**

Obviously, regular inductors don't work. The inductor used during boost conversion must have a high magnetic permeability core that can handle high currents and allow high inductance for each size.

Boost Converter Design

Step-1

First, you need to fully understand the cargo requirements. When first building a boost converter that knows the output voltage and output current separately (based on personal experience), it is highly recommended that our output power be the result.

Step-2

To get the required average input current, divide the output power by the input voltage (which also needs to be determined). Increase the input current by 40% to compensate for ripple. To this new level, the maximum input current has been raised. Also, because the lowest input current is 0.8 times the average input current, multiply the average input current by 0.8. Now that you know what the peak and minimum currents are, you can subtract them to obtain the overall change in current.

Step-3

Now we compute the converter's duty cycle, which is the ratio of the oscillator's on and off timings.

This textbook formula calculates duty cycle:

$$\boldsymbol{Duty\ Cycle} = \frac{(\boldsymbol{V_{out}} - \boldsymbol{V_{in}})}{\boldsymbol{V_{out}}}$$

This should give us a decimal value that is more than 0 but less than 0.999.

Step-4

Next, set the oscillator frequency. This can be determined by programming with Arduino Mega2560. Once the frequency is decided, you can move the frequency back and forth to know the time. After this period, multiply the duty cycle value to get the on-time.

$$\boldsymbol{T_{on}} = \boldsymbol{T} \times \boldsymbol{Duty\ Cycle}$$

Step-5

We can combine these data into the formula for the inductor, which has been rearranged a little, because we know the turn on time, input voltage, and current change:

$$\boldsymbol{L} = \frac{\boldsymbol{V} \times \boldsymbol{dt}}{\boldsymbol{dI}}$$

Where $\boldsymbol{V}$ is the input voltage, $\boldsymbol{dt}$ is the time difference, and $\boldsymbol{dI}$ is the current difference.

Continuous mode

Because the rate of change of the current flowing through the inductor is proportional to the voltage across it, the (average) DC voltage across the inductor must be zero at steady state for the inductor to revert to its original state after each cycle (explained in more detail below).

$$\boldsymbol{V_{in} = (1 - D)V_0}$$

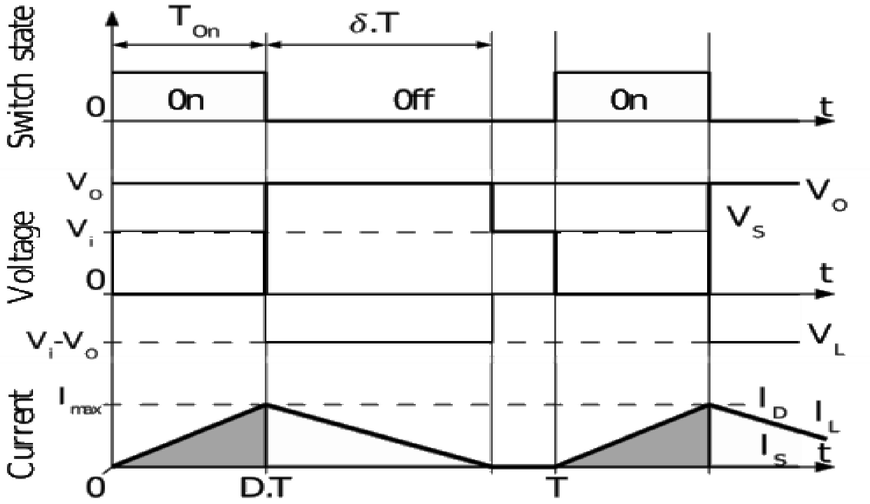


Figure 7: current, voltage, and switching waveform in ON state

Where D is Duty Cycle of waveform driving the switch.

Switch S shuts in the on state, causing an input voltage (V_{in}) to be applied to the inductor, causing a change (I_L) to be applied to the inductor for a period of time (t) according to the formula:

$$\boldsymbol{\frac{\Delta I_L}{\Delta t} = \frac{V_i}{L}}$$

Where L is the inductor value

At the end of the on-state, the increase of $\boldsymbol{I_L}$ is therefore:

$$\boldsymbol{\Delta I_{L_{on}} = \frac{1}{L}\int_0^{DT} V_{in} dt = \frac{DT}{L} V_{in}}$$

Switch S is open in the off state, allowing the inductor current to pass to the load. Changes in $I_L$when a diode has a zero voltage loss and a big enough capacitor to maintain its voltage constant.

$$V_{in} - V_{out} = L\frac{dI_L}{dt}$$

Therefore, the variation of I_L during the off-period is:

$$\Delta I_{L_{off}} = \frac{1}{L}\int_{DT}^{T}\frac{(V_{in} - V_o)}{L}dt = \frac{(V_{in} - V_o)(1 - D)T}{L}$$

Because the inductor current must be constant at both the beginning and finish of the commutation cycle, this means that the overall change (the sum of the changes) is zero at the moment:

$$\Delta I_{L_{on}} + \Delta I_{L_{off}} = 0$$

$$\frac{DT}{L}V_{in} + \frac{(V_{in} - V_o)(1 - D)T}{L} = 0$$

This can be written as

$$\frac{V_{out}}{V_{in}} = \frac{1}{1 - D}$$

<u>Discontinuous mode:</u>

If the current's ripple amplitude is too large, the inductor may be entirely drained before the commutation cycle is completed. This is very frequent under light loads. The current through the inductor in this scenario drops to zero for a portion of the time.

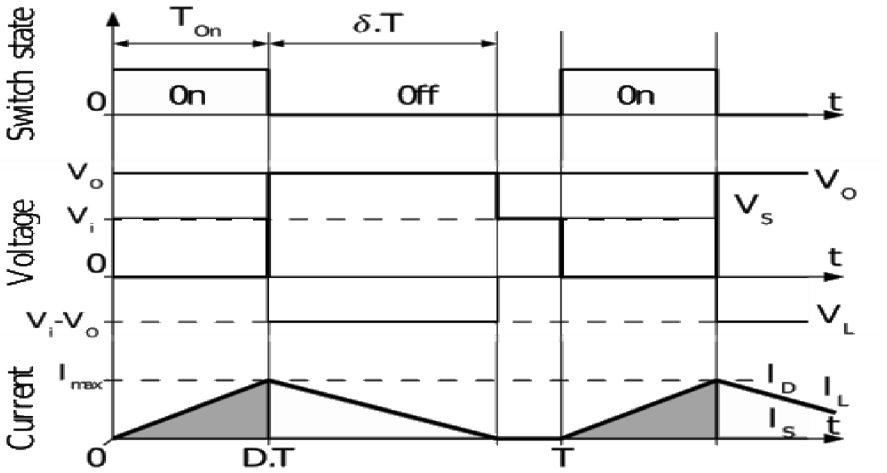


Figure 8: current, voltage, and switching waveform in OFF state

In the discontinuous mode output gain can be written as follows:

$$I_0 = 1 + \frac{V_i D^2 T}{2LI_0}$$

This equation is far more difficult to solve than the equation for continuous mode output voltage gain. Moreover, in discontinuity operation, not only the duty cycle, but also the inductor value, commutation time, and output current influence the amplification of the output voltage.

2.2. Driver Circuit:

Arduino provides an output voltage of 5 volts. Which is not sufficient enough to turn on the power MOSFET or IGBT. So we have to use a proper gate driver circuit to turn on power MOSFET or IGBT. Use of driver circuit provides following advantages.

- Low voltage compatibility. We can apply a signal as low as 1.25 volts at the input of the gate driver and we will be able to turn on our IGBT
- Transient Protection. Protects Arduino from damage from Back current.
- Allows fast switching and reduces switching losses.

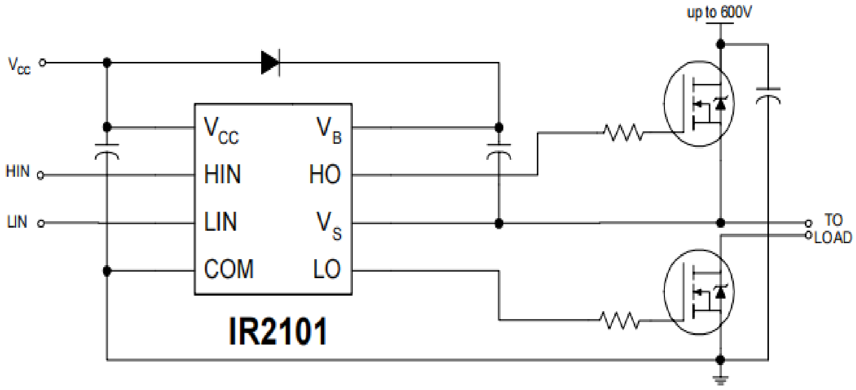


Figure 9: Typical Driver Circuit

IR2101:

Driver IC used is IR2101. It's an IGBT driver for a large capacity and rating MOSFET. It features two separate output channels, one on the high side and one on the low side. It has following features.

1. It can support up to 600 volts' operations.
2. It provides protection against transient.
3. Compatible inputs are 3.3, 5, 15 volts.
4. It can provide output from 10 to 20 volts.
5. Outputs are in phase with the inputs.
6. Under voltage lockout.
7. It has two packages. Out of which 8-Leas PDIP package has been used.

8. IR2101 is an 8 pin IC with the following Lead Assignment.

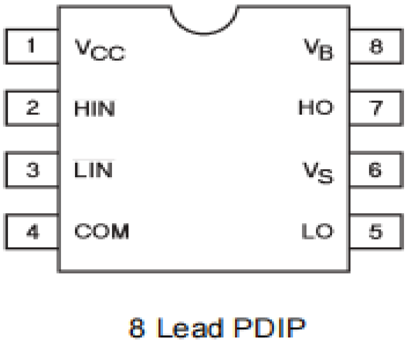


Figure 11: IR2101 Pin Configuration

2.3. DC-AC inverter design:

A three-phase inverter for the input voltage is necessary to generate a three-phase output from a circuit that employs dc as the power source. The inverter is constructed from switching devices, and hence the manner in which the inverter switches.

Switching function

Between the source and the load, there are multiple switching devices, the number of which varies depending on the kind of circuit or load. In any instance, the number of switching devices is limited by complexity. Only one switch connects the input and output lines in even the most crowded circuits. The number of switching devices required for energy conversion is equal to "$m\ x\ n$" if the power converter has "n" inputs and "m" outputs. The connections between circuit "mxn" switching devices can be used to arrange them.

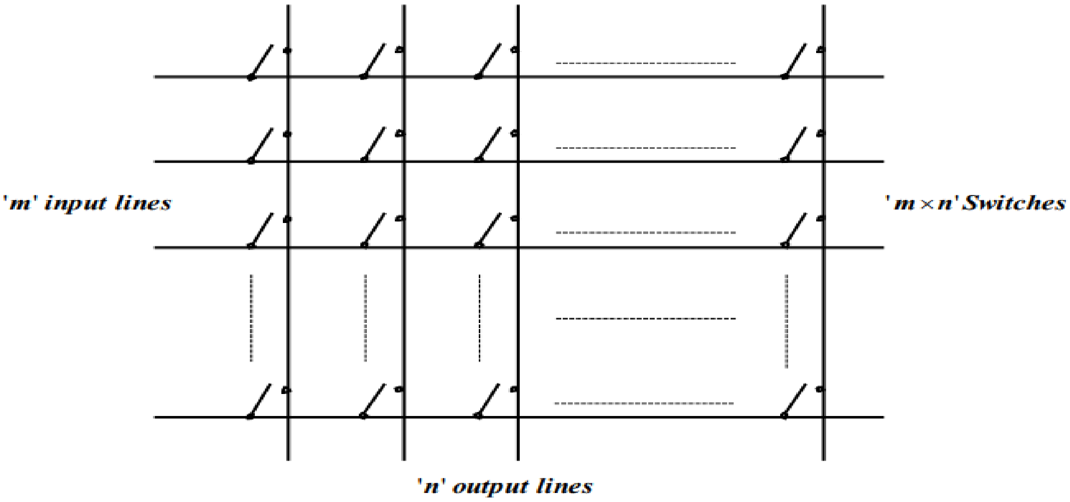


Figure 12: Switching devices

For example, single phase to dc conversion requires a total of $'2 \times 2 = 4'$ switches since phase have two ports output and dc has two ports input.

The majority of power electronic circuits are divided into two categories.

1. **Direct switch matrix circuits:** The power storage elements of these circuits are only connected to the matrix at the input and output terminals. The memory component of the source or load has been effectively implanted. A full wave rectifier with an output filter can be used with the direct switching matrix circuit.
2. **Embedded converters, often known as indirect switch matrix converters:** The energy storage devices are coupled inside the matrix structure of these circuits. In such cases, there are generally few energy storage devices, and the indirect switch is used. Matrix circuits are frequently examined as a cascade of two direct switch matrix circuits connected by storage components.

Inverters or DC-AC converters are classified as voltage source inverters (VSI) or current source inverters (CSI) depending on the kind of source and the accompanying power circuit architecture (CSI).

The goal of these topologies is to provide a three-phase voltage source with adjustable amplitude, phase, and frequency. 3-phase Converter voltage source inverters are frequently used in motor drives, active filters, and unitary power flow controllers in power systems and uninterruptible power supplies, and have programmable frequencies using various pulse width modulation (PWM) technologies. Determine the magnitude of the AC voltage as well.

The switching of the six switches in a conventional three-phase inverter is dependent on the modulation method. To recover the input dc from a single-phase or three-phase utility power source, a diode-bridge rectifier and an LC or C filter are commonly utilized.

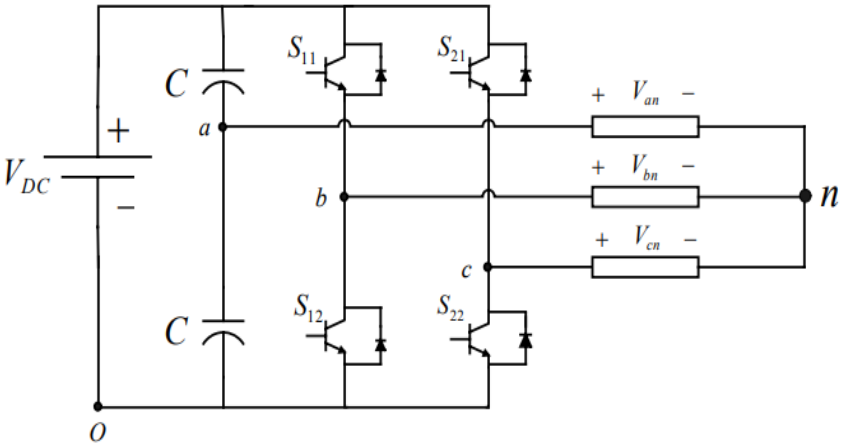


Figure 13: Three phase half bridge inverter

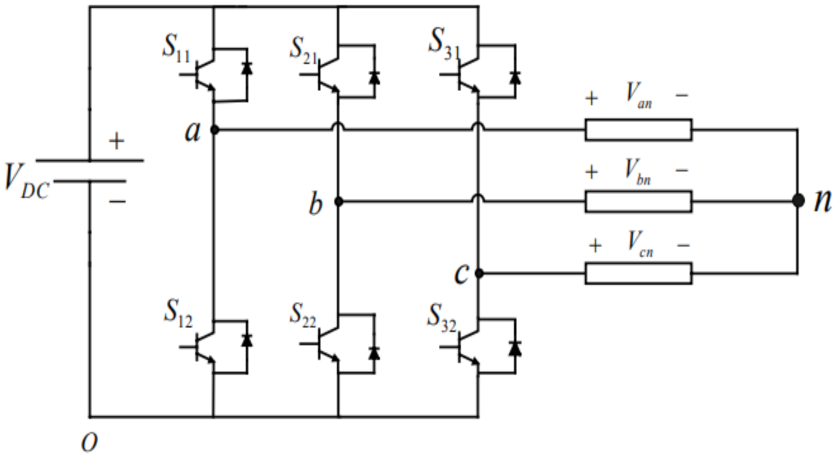


Figure 14: Three phase full bridge inverter

There are eight switch states on the inverter. The circuit meets both the KVL and the KCL; however, both switches in the same leg cannot be turned on at the same time because the input voltage would be shorted, which would violate the KVL. As a result, the natures of the two switches in the same leg are complementary.

In occurrence to the figure three phase full bridge inverter

$$S_{11} + S_{12} = 1$$

$$S_{21} + S_{22} = 1$$

$$S_{31} + S_{32} = 1$$

Table: 8 switching states

S_{11}	S_{21}	S_{31}	V_{ab}	V_{bc}	V_{ca}
0	0	0	0	0	0
0	0	1	0	$-V_{DC}$	V_{DC}
0	1	0	$-V_{DC}$	V_{DC}	0
0	1	1	$-V_{DC}$	0	$-V_{DC}$
1	0	0	V_{DC}	0	$-V_{DC}$
1	0	1	V_{DC}	$-V_{DC}$	0
1	1	0	0	V_{DC}	$-V_{DC}$
1	1	1	0	0	0

The output AC line voltage is 0 in two of the eight switching states. AC line current can flow freely in either the upper or lower component in this circumstance. There is no 0AC output line voltage in the rest of the condition. The inverter switches between states, producing a specified voltage waveform. As a result, the ac output line voltages are made up of discrete voltage values. Which are given as

$$\boldsymbol{V_{DC}},\ \mathbf{0},\ -\boldsymbol{V_{DC}}$$

Only valid values are used when the modulation technique is used to pick the states for creating the supplied waveform.

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

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

$$\frac{V_{dc}}{2}(S_{31} - S_{32}) = V_{cn} + V_{no}$$

Expressing the equation in term of modulation signals and making use of conditions

$\boldsymbol{S_{11} + S_{12} = 1, S_{21} + S_{22} = 1}$ and $\boldsymbol{S_{31} + S_{32} = 1}$

We get the new equation as

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

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

$$\frac{V_{dc}}{2}(M_{31}) = V_{cn} + V_{no}$$

Adding the equations together we get the results as

$$\frac{V_{dc}}{2}(S_{11} - S_{12} + S_{21} - S_{22} + S_{31} - S_{32}) = V_{an} + V_{bn} + V_{cn} + 3V_{no}$$

As we are dealing with balanced equation $\boldsymbol{V_{an} + V_{bn} + V_{cn} = 0}$

We are left with

$$\frac{V_{dc}}{6}(2S_{11} + 2S_{21} + 2S_{31} - 3) = V_{no}$$

Substituting for $\boldsymbol{V_{no}}$ in starting equation

$$\frac{V_{dc}}{2}(2S_{11} - S_{21} - S_{31}) = V_{an}$$

$$\frac{V_{dc}}{2}(2S_{21} - S_{21} - S_{31}) = V_{bn}$$

$$\frac{V_{dc}}{2}(2S_{31} - S_{21} - S_{11}) = V_{cn}$$

2.4. Sinusoidal PWM in Three-Phase Voltage Source Inverters

Three 120° phase-shifted sine waves at the frequency of the desired output voltage are compared to a carrier triangle with a very high frequency, similar to a single-phase voltage source inverter, and the sine wave is a sine wave, or more generally. The triangle will be bigger and lower if the so-called modulated signal is modest. The inverter's output voltage is not smooth and has a discontinuous waveform. Harmonics are more likely to occur as a result of this. The harmonics degrade the performance of the load to which these voltages are applied, hence this is not desired.

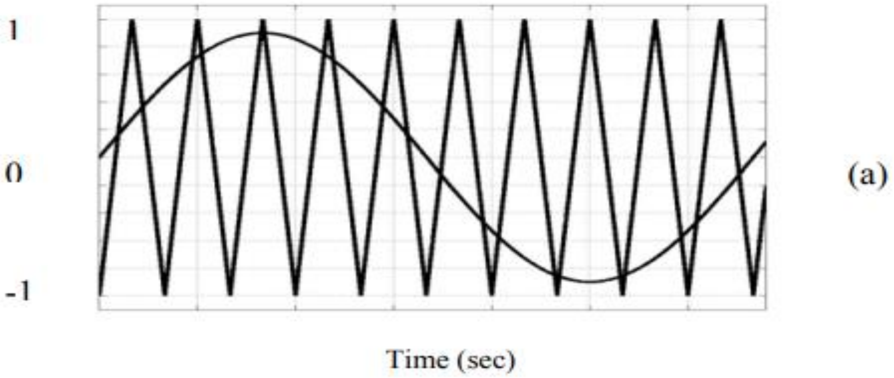


Figure 15: Reference and Carrier wave

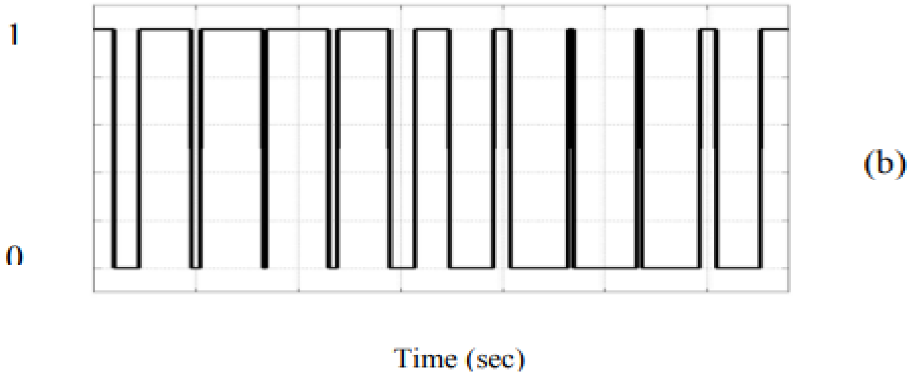


Figure 16: SPWM WAVE

The modulation signals are therefore chosen to fulfill certain criteria, such as harmonic removal and a higher fundamental component. The phase voltages may be calculated using the line voltages as follows:

$$\begin{bmatrix} V_{ab} \\ V_{bc} \\ V_{ca} \end{bmatrix} = \begin{bmatrix} V_{an} - V_{bn} \\ V_{bn} - V_{cn} \\ V_{cn} - V_{an} \end{bmatrix}$$

As a phase function of the phase-voltage vector, this may be written $[V_{an} \quad V_{bn} \quad V_{bn}]^T$ as

$$\begin{bmatrix} V_{ab} \\ V_{bc} \\ V_{ca} \end{bmatrix} = \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix}$$

Equation denotes a linear system with the vector as the unknown quantity; the phase voltages, therefore, cannot be computed via matrix inversion since the matrix is distinct. So because phase voltages add to zero, the phase load voltages may be expressed as.

$$\begin{bmatrix} V_{ab} \\ V_{bc} \\ 0 \end{bmatrix} = \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix}$$

That implies

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ 1 & 1 & 1 \end{bmatrix}^{-1} \begin{bmatrix} V_{ab} \\ V_{bc} \\ 0 \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 2 & 1 & 1 \\ -1 & 1 & 1 \\ -1 & -2 & 1 \end{bmatrix} \begin{bmatrix} V_{ab} \\ V_{bc} \\ 0 \end{bmatrix}$$

Which results in

$$V_{an} = \frac{1}{3}(2V_{ab} + V_{bc})$$

$$V_{bn} = \frac{1}{3}(V_{bc} - V_{ab})$$

$$V_{cn} = \frac{-1}{3}(2V_{bc} + V_{bc})$$

2.5. L.C. filters design:

An inverter causes high-order harmonics which cause losses in the system and instability to other devices connected to it. Due to the bipolar switching scheme, the harmonic on the output voltage of the inverter appeared near f_{sw}. The output current of the grid side inverter has ripple due to the effect of switching in the inverter. A filter is needed in order to obtain a cleaner output with lower total harmonic distortion. A Filter can be used to reduce the harmonics near the switching frequency for the inverter.

The output of the inverter bridge circuit has lots of harmonics. We need a pure sinusoidal signal. So a filter is used. The filter that was employed was an LC filter. It's a filter with a second order. Designing it is simple and straightforward. LC Filters are electric potential filters that use a collection of inductors (L) and capacitors (C) to cut or pass specified frequency-ranges.

“Capacitors block DC currents but pass AC more easily at higher frequencies. Conversely, inductors pass DC currents as they are, but pass AC less easily at higher frequencies. In other words, capacitors and inductors are passive components with completely opposite properties. By combining these components with opposite properties, noise can be cut and specific signals can be identified”. It provides 12 db per octave attenuation after f_0 which is the cut off frequency also known as the resonant frequency. The filter consists of an inductor and capacitor in series. Capacitor only allows AC signal to pass through and the inductor only allows DC signal to pass through. So a suitable combination of inductance and capacitance can be used to remove harmonics. LC filter has a gain of unity before the resonant frequency it provides a peak at the resonant frequency and after the resonant frequency it provides high attenuation. At frequency below resonant frequency the circuit will be capacitive. At frequency higher than resonant frequency the circuit will be inductive. At resonant frequency current will be maximum and impedance will be minimum.

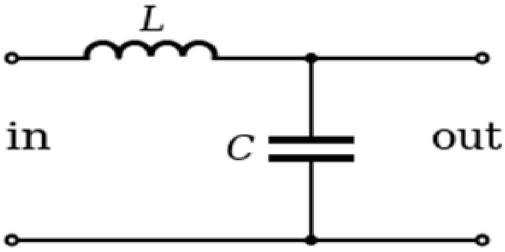


Figure 17: LC Filter

The resonant frequency also known as the cut off frequency of the LC filter is.

$$f_0 = \frac{\omega_0}{2\pi} = \frac{1}{2\pi\sqrt{LC}}$$

The LC filter's transfer function is

$$H_c(s) = \frac{1}{1 - \omega^2 LC}$$

Design:

Choosing the resonant frequency to be $60\ Hz$ and taking inductance to be 15 mH and using the formula will lead to $470\ uF$ capacitance.

A cutoff frequency is assigned to all low-pass filters. The frequency at which the output voltage is less than 70.7 percent of the input voltage.

Cut off Frequency = $60\ Hz$

Inductor value = $15\ mH$

Capacitor value = $470\ uF$

Multisim

Schematic:

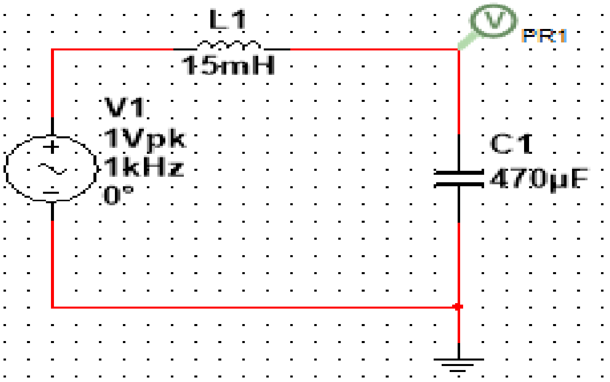


Figure 18: LC Filter Simulation

Frequency Response:

A low-pass filter (LC) allows signals underneath the cutoff frequency to pass through while negating frequencies above it. The frequency response of the filter is determined by its design. When working with filter circuits, keep in mind that the filter's behavior is determined by the filter's component values as well as the load's impedance. If the cutoff frequency equation does not account for load impedance, it is assumed that there is no load, and correct results for the real filter that feeds current to the load will not be achieved.

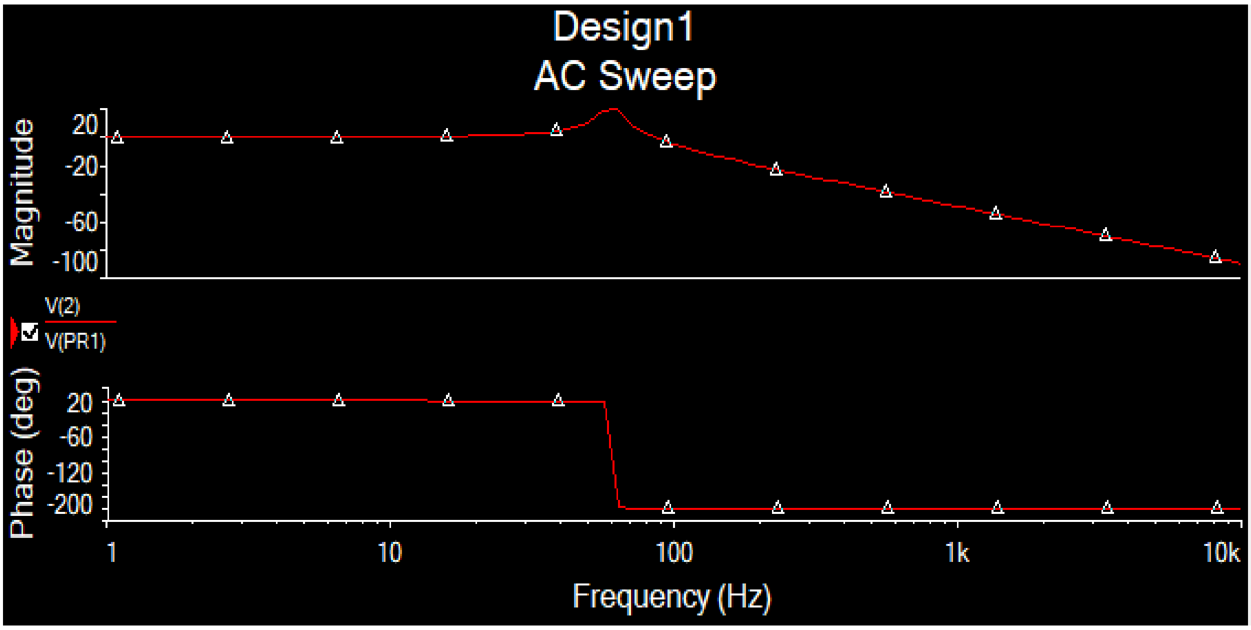


Figure 19: Frequency Response of LC Filter

2.6. Grid synchronization stage:

The current injected from the inverter has to be synchronized with the grid which requires a synchronization algorithm. The phases of the grid voltage should be provided by the algorithm, which is utilized to synchronize control factors like the D-Q transform.. The three commonly used methods are zero-crossing method, grid voltage filtering and the phase locked loop (PLL) technique. The most common and efficient technique used nowadays is the PLL technique, which has been used in the thesis. $PLLs$ are frequently used in three phase grid tie inverters, but can also be used in the single phase inverters. Recently, synchronous frame $PLLs$ are commonly used in grid tie inverters. This type of PLL is implemented in the $d - q$ synchronous rotating frame. The PLL converts the grid voltage into its orthogonal components by using $\alpha\beta \rightarrow dq$ transform. PI regulator, is used to control either the real component of the grid voltage V_d or the imaginary component of the grid voltage V_q to be zero so that the phase of the d or q component can be locked.

Current and phase angle adjustment elements make up this system. The $i_d$and $i_q$variables govern how much electricity is sent from alternative energy sources to the grid. In the current control portion (i_d and i_q), the line currents (i_a,i_b and i_c) to be sent to the grid are measured and converted to dq components. As a result, id and I q became DC values, simplifying control and filtering. The grid phase angle information is required for transformation from the abc axis frame to the dq axis frame. Then PLL determines this angle information once the grid voltages are recognized.

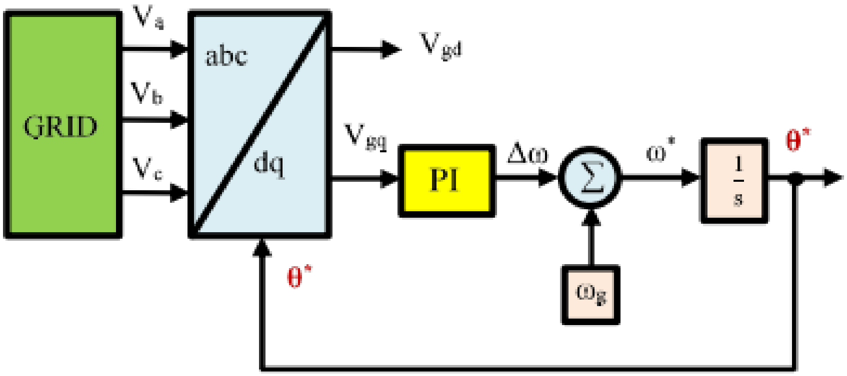


Figure 20: Block diagram of dq-PLL

The converted i_d and i_q currents are compared to reference current values ($i_{d_{ref}}$ and ($i_{q_{ref}}$), and the errors are then input into the PI controller. Voltage feedforward (V_{gd} and V_{gq}) and decoupling terms (ωL) are added to the PI controller's output to increase the PI controller's performance and eliminate grid harmonics impacts. The PLL block generates V_{gd} and V_{gq} voltages.

If an effective PLL mechanism is utilized, V_{gd} will match the grid voltage's maximum value, whereas V_{gq} will equal zero. As a consequence, the $SPWM$ algorithm's reference voltages ($V_{d_{ref}}$ and $V_{q_{ref}}$ may be derived. Using $V_{d_{ref}}$, $V_{q_{ref}}$ and DC link voltages, the SPWM algorithm generates suitable switching signals for controlling the grid-tied inverter.

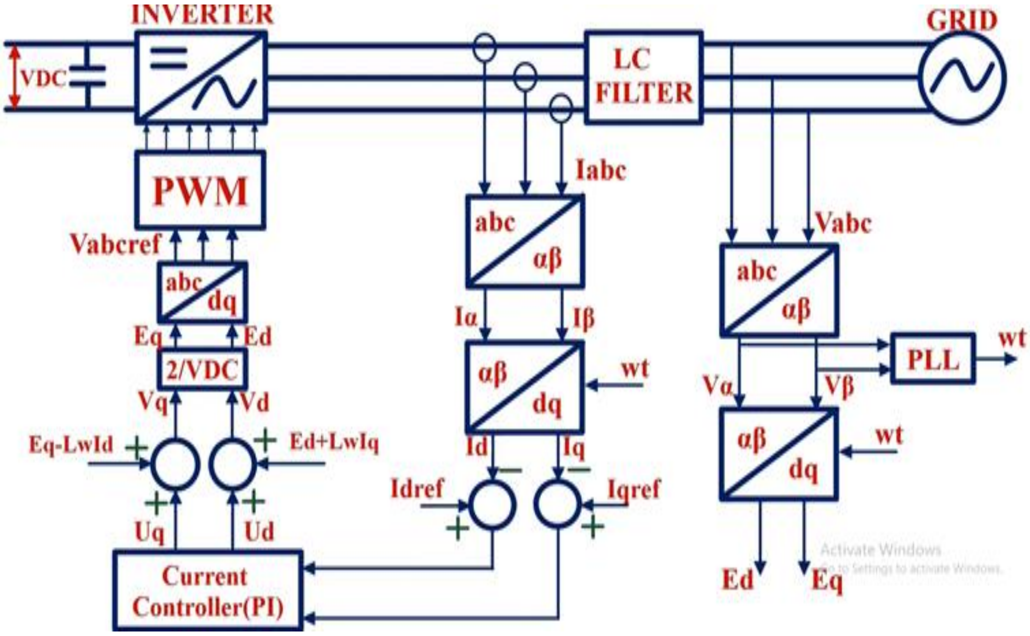


Figure 21: Current Control Loop

The phase angle of the grid voltage is established in the phase angle control section so that the inverter may work simultaneously with the grid. As a result, the inverter must be controlled using a synchronization mechanism. The phase angle of the grid voltage must be established properly and fast to ensure grid synchronization. For grid synchronization, the PLL approach is commonly employed. The $dq - PLL$ approach is recommended among the PLL methods since its structure is basic and straightforward to use.

The $dq - PLL$ works as a feedback mechanism to detect the phase angle (θ) of the grid voltages in real time. The observed three-phase grid voltages (V_a ,V_b and V_c) are first translated into rotating axis variables (V_{gd} and V_{gq}) in the $dq - PLL$ system. Furthermore, the voltages V_{gd} and V_{gq} show as DC components.

$$\begin{bmatrix} V_{gd} \\ V_{gq} \\ 0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos(\theta) & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ -\sin(\theta) & -\sin(\theta - \frac{2\pi}{3}) & -\sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

Under perfect grid circumstances, the calculated phase angle (θ) is equal to the grid phase angle(θ), as shown by the equations below; while V_{gq} is equal to zero, V_{gd} is equal to the grid voltage peak value. In other words, V_{gq} contains information about the grid's phase angle inaccuracy, whereas V_{gd} contains information about the amplitude of the grid voltage in steady state.

$$V_{gq} = V_m \sin(\theta_{grid} - \theta)$$

$$V_{gd} = V_m \cos(\theta_{grid} - \theta)$$

It is critical in the dq-control $PLL's$ technique that the resulting phase angle is locked tightly to the grid phase angle and that it has a strong filtering characteristic in terms of the system's dynamic response. For $dq-PLL$ control, a PI controller is usually utilized. The PI controller also acts as a loop filter in the system, regulating V_{gq} voltage and determining the system's behaviors.

The inverter's sinusoidal three-phase output voltage is as follows:

$$V_{ia} = Asin(\omega t)$$

$$V_{ib} = Asin(\omega t - \frac{2\pi}{3})$$

$$V_{ic} = Asin(\omega t + \frac{2\pi}{3})$$

For a three-phase stationary frame, the equation matrix is

$$\begin{bmatrix} V_{ga} \\ V_{gb} \\ V_{gc} \end{bmatrix} = \begin{bmatrix} V_{ia} - L\frac{di_a}{dt} - Ri_a \\ V_{ib} - L\frac{di_b}{dt} - Ri_b \\ V_{ic} - L\frac{di_c}{dt} - Ri_c \end{bmatrix}$$

Equation for the transformation of three phase stationary (abc) to two phase stationary $(\alpha\beta)$ would be

$$\begin{bmatrix} V_{g\alpha} \\ V_{g\beta} \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} V_{ga} \\ V_{gb} \\ V_{gc} \end{bmatrix}$$

$$= \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} V_a - L\frac{di_a}{dt} - Ri_a \\ V_b - L\frac{di_b}{dt} - Ri_b \\ V_c - L\frac{di_c}{dt} - Ri_c \end{bmatrix}$$

$$\begin{bmatrix} V_{g\alpha} \\ V_{g\beta} \end{bmatrix} = \begin{bmatrix} V_{i\alpha} - L\frac{di_\alpha}{dt} - Ri_\alpha \\ V_{i\beta} - L\frac{di_\beta}{dt} - Ri_\beta \end{bmatrix}$$

Now converting from the $\alpha\beta$ frame to the synchronous $d-q$ frame

$$\begin{bmatrix} V_{gd} \\ V_{gq} \end{bmatrix} = \begin{bmatrix} \cos(\omega t) & \sin(\omega t) \\ -\sin(\omega t) & \cos(\omega t) \end{bmatrix}\begin{bmatrix} V_{g\alpha} \\ V_{g\beta} \end{bmatrix}$$

$$\begin{bmatrix} V_{gd} \\ V_{gq} \end{bmatrix} = \begin{bmatrix} \cos(\omega t) & \sin(\omega t) \\ -\sin(\omega t) & \cos(\omega t) \end{bmatrix} \begin{bmatrix} V_{i\alpha} - L\dfrac{di_\alpha}{dt} - Ri_\alpha \\ V_{i\beta} - L\dfrac{di_\beta}{dt} - Ri_\beta \end{bmatrix}$$

$$\begin{bmatrix} V_{gd} \\ V_{gq} \end{bmatrix} = \begin{bmatrix} V_{id} \\ V_{iq} \end{bmatrix} - R\begin{bmatrix} i_d \\ i_q \end{bmatrix} - L\begin{bmatrix} \cos(\omega t) & \sin(\omega t) \\ -\sin(\omega t) & \cos(\omega t) \end{bmatrix} \begin{bmatrix} \dfrac{di_\alpha}{dt} \\ \dfrac{di_\beta}{dt} \end{bmatrix}$$

Now

$$\begin{bmatrix} \cos(\omega t) & \sin(\omega t) \\ -\sin(\omega t) & \cos(\omega t) \end{bmatrix} \begin{bmatrix} \dfrac{di_\alpha}{dt} \\ \dfrac{di_\beta}{dt} \end{bmatrix} = \frac{d}{dt}\begin{bmatrix} i_d \\ i_q \end{bmatrix} + \omega\begin{bmatrix} -i_d \\ i_q \end{bmatrix}$$

As a result, the electrical dynamics of an inverter in a d-q synchronous frame may be calculated as follows:

$$\begin{bmatrix} V_{gd} \\ V_{gq} \end{bmatrix} = \begin{bmatrix} V_{id} \\ V_{iq} \end{bmatrix} - R\begin{bmatrix} i_d \\ i_q \end{bmatrix} - L\frac{d}{dt}\begin{bmatrix} i_d \\ i_q \end{bmatrix} + \omega L\begin{bmatrix} -i_d \\ i_q \end{bmatrix}$$

$$\begin{bmatrix} V_{id} \\ V_{iq} \end{bmatrix} = \begin{bmatrix} V_{gd} \\ V_{gq} \end{bmatrix} + L\frac{d}{dt}\begin{bmatrix} i_d \\ i_q \end{bmatrix} + \omega L\begin{bmatrix} -i_d \\ i_q \end{bmatrix} + R\begin{bmatrix} i_d \\ i_q \end{bmatrix}$$

The resistance R may be realistically ignored, and the synchronous frame differential equation is reduced to

$$\frac{d}{dt}\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \frac{1}{L}\begin{bmatrix} V_{id} - V_{gd} \\ V_{iq} - V_{gq} \end{bmatrix} - \omega\begin{bmatrix} -i_d \\ i_q \end{bmatrix}$$

The dynamics of one axis current are dependent on the dynamics of the other axis current, according to this equation. This is similar to how a direct axis flux causes a quadrature axis back EMF in an electric machine.

A PI controller is presented to regulate the currents i_d and i_q. As a result, the input reference voltage of the inverter would be

$$\begin{bmatrix} i_{id}^* \\ i_{iq}^* \end{bmatrix} = \begin{bmatrix} i_{gd} \\ i_{gq} \end{bmatrix} + \begin{bmatrix} (k_p + \dfrac{k_i}{s})(i_d^* - i_d) \\ (k_p + \dfrac{k_i}{s})(i_q^* - i_q) \end{bmatrix} + \omega L\begin{bmatrix} -i_d \\ i_q \end{bmatrix}$$

The reference value is indicated by an asterisk.

To adjust for reactive power from the inverter using the controller, the inverter's output voltage is monitored, sensed and compared to the nominal grid voltage (240Vrms), with the error being applied to a voltage controller to form the inverter's reactive power control signal. Quadrate reference current i_q ref is created and sent to the current controller for the inverter to compensate for reactive power. As a result, the inverter supplies the grid with bidirectional power flow adjustment, which improves grid voltage stability. The inverter output voltage may fluctuate depending on the current power consumption in this method of operation. The voltage provided by the grid will affect the active or reactive power consumption of the consumer's loads. The reactive power control uses the nominal grid voltage to provide a quadrature current for regulating the voltage.

When a negative quadrature reference current is generated from the inverter control system, the inverter behaves as a capacitor, thus producing reactive power. It compensates reactive power at the grid due to excess inductive loads. The direct and quadrature currents tracking its reference the quadrature components being a non-zero magnitude, shows that the inverter is supplying reactive power to the grid. The inverter voltage and current with a phase shift indicates that power is supplied to an inductive load in the system.

CHAPTER NO. 3

HARDWARE IMPLEMENTATIONS AND COMPONENTS INFORMATION

3.1. Hardware Implementation:

The actual manifestation of this project is a physical device. It is not just a computer program. So, once we were done with our simulations it was time to bring our project in its physical form. We had divided the project into three main blocks:DC to AC Inverter, the Grid Synchronization Stage with control loop and the filter.

3.1.1 Testing On Breadboard:

❖ **PWM Generation:**

- The 3phase SPWM signals were plotted on Oscilloscope and phase difference and overlapping of adjacent signals were verified.
- Each SPWM has its corresponding Inverted signal at Output.
- The Oscilloscope Output is shown below.

Figure 22: PWM Waveform on Oscilloscope

❖ **Driver Circuit:**

- Driver Circuit amplified the 5V to 12 volts and amplitude was verified from oscilloscope.

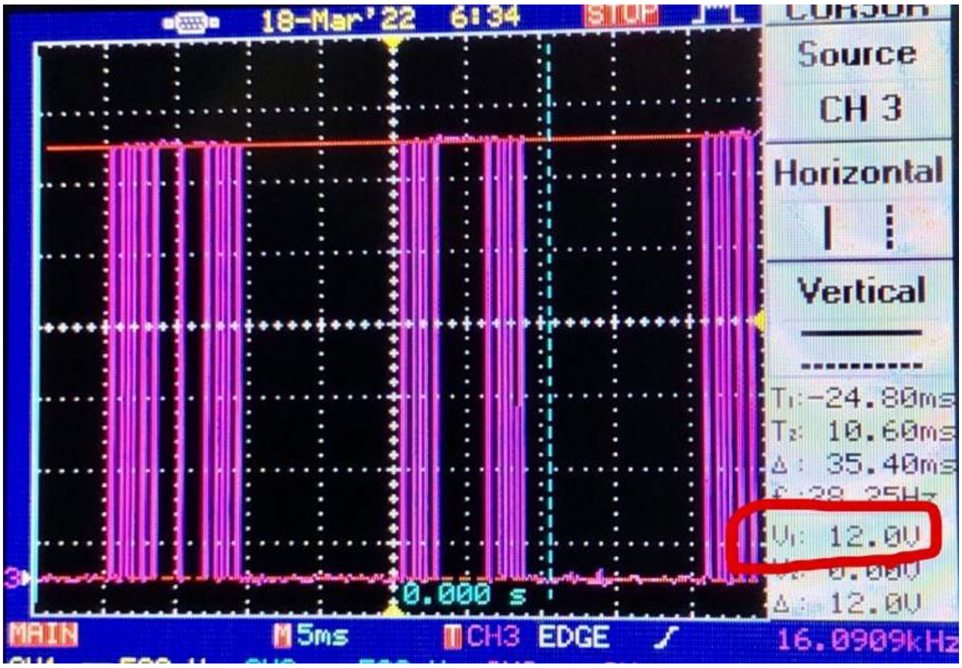


Figure 23: Output of Driver Circuit

❖ Full Bridge Inverter:

- Full bridge inverter configuration was implemented and output was recorded on bridge output node.

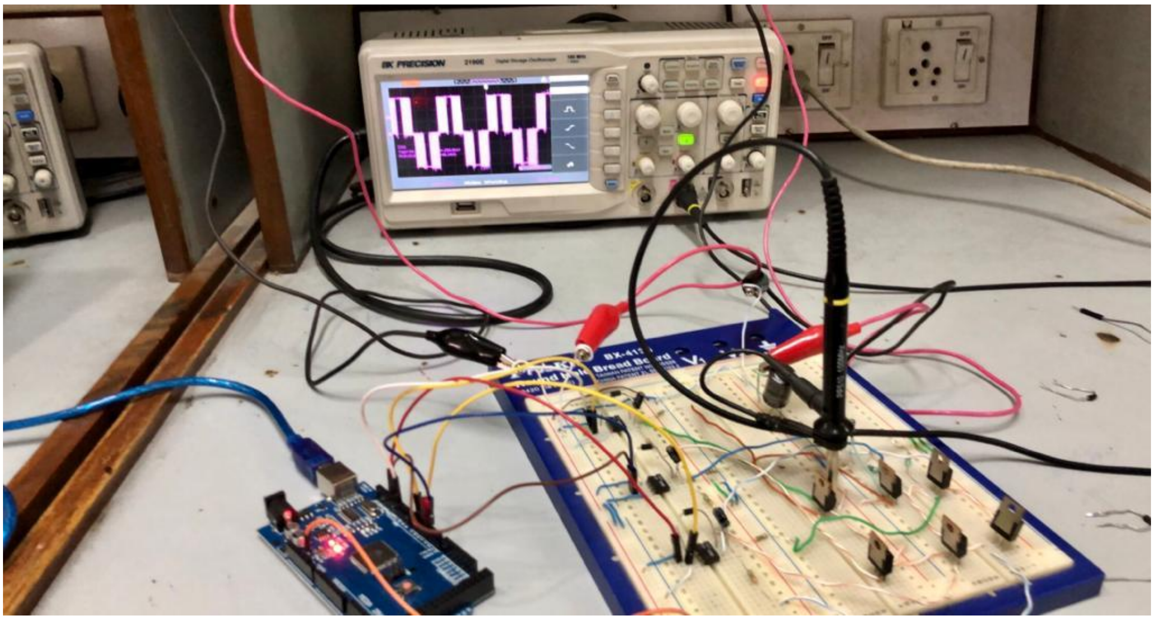


Figure 24: Inverter Output

❖ LC Filter:

- The Bridge Output was filtered to obtain synchronized Sine wave at output.
- Output Waveform of Grid Tie Inverter is shown below.

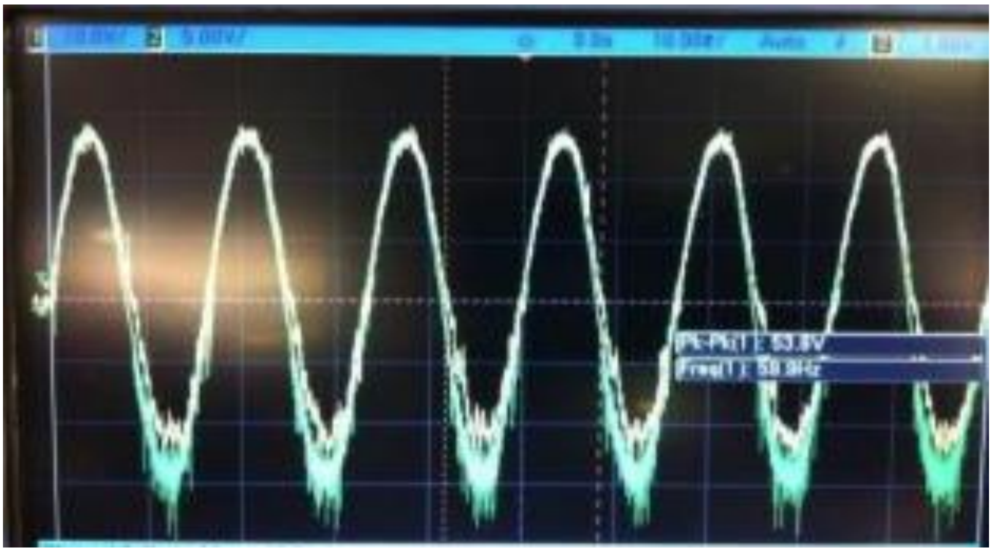


Figure 25: Filter Output

- **Experimental Setup:**

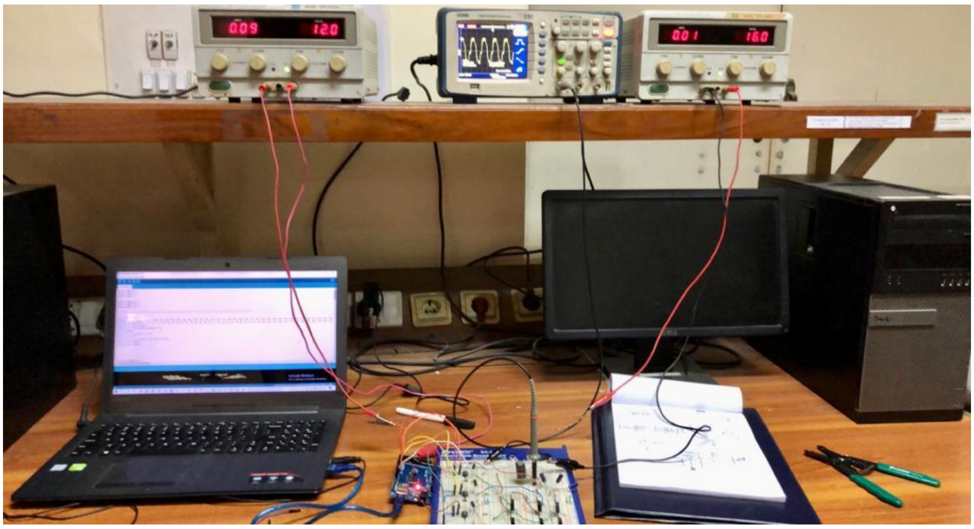


Figure 26: Experimental Hardware Setup

3.1.2 PCB Design:

We looked up a couple of PCB design software online like the kiCad, EAGLE, Altium Designer and ExpressPCB. However, at the end we decided to use KiCad as it is Open Source and features such as differential routing, length matching is available. Its clear separation of schematic and layout is bonus to using it.

- **Schematic Design:**
  - Schematic is drawn first which refers to adding symbols and drawing connections between them.
  - Footprints are also selected for each component.

- Schematic describes which components are in design and how they are connected.
- When schematic is complete and design passes electrical rules check (ERC), the design information is then transferred to board editor and layout begins.

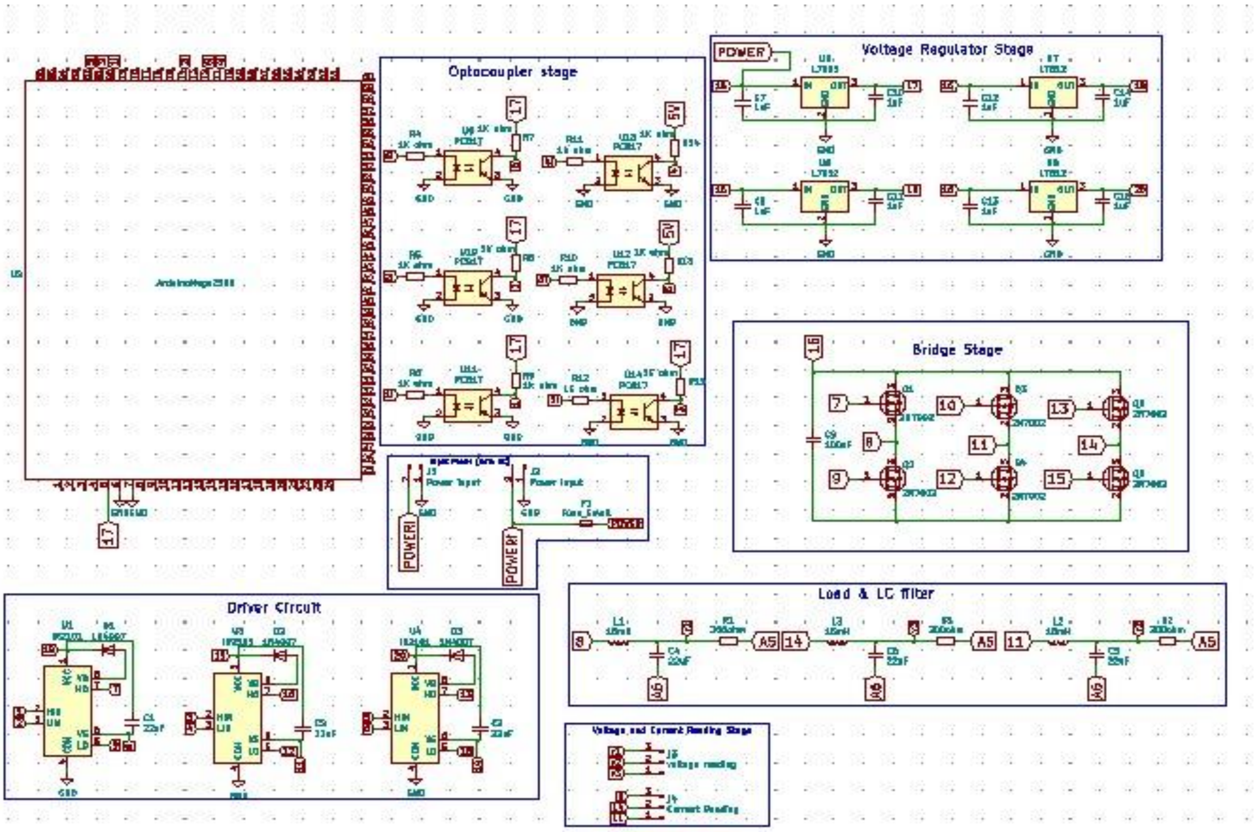


Figure 27: PCB Schematics

❖ **PCB Design Layout:**

- This process requires careful placement of each footprint on circuit board.
- After components placement copper tracks are drawn between components based on schematic connections and trace resistance.
- When board layout is complete and board passes Design Rules Check (DRC), fabricated outputs are generated.

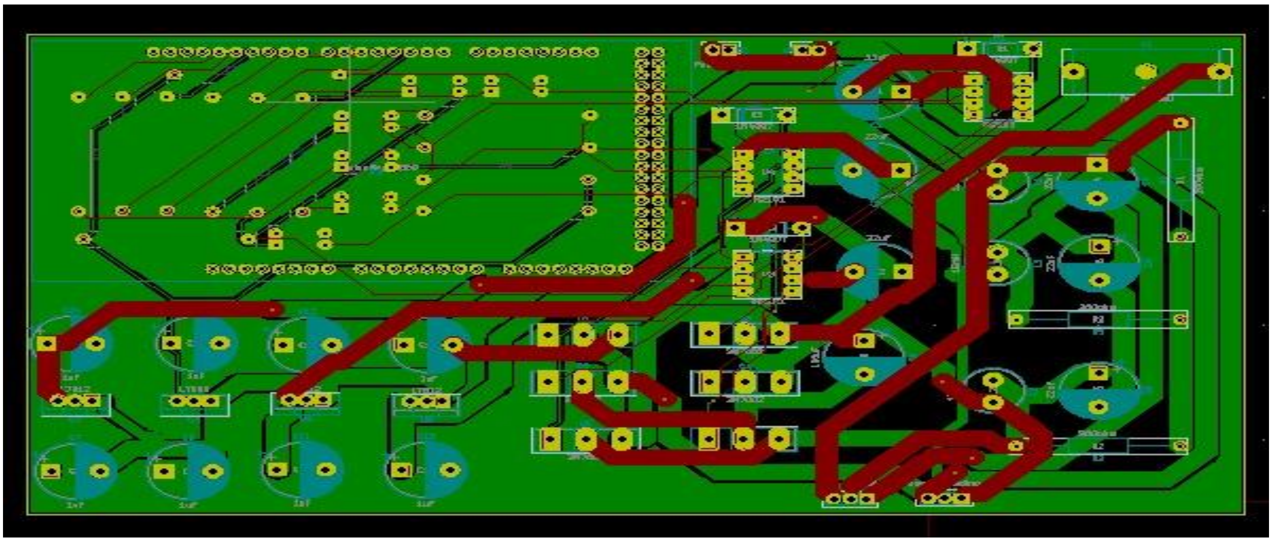


Figure 28: PCB Design Layout

- **3D view of PCB:**

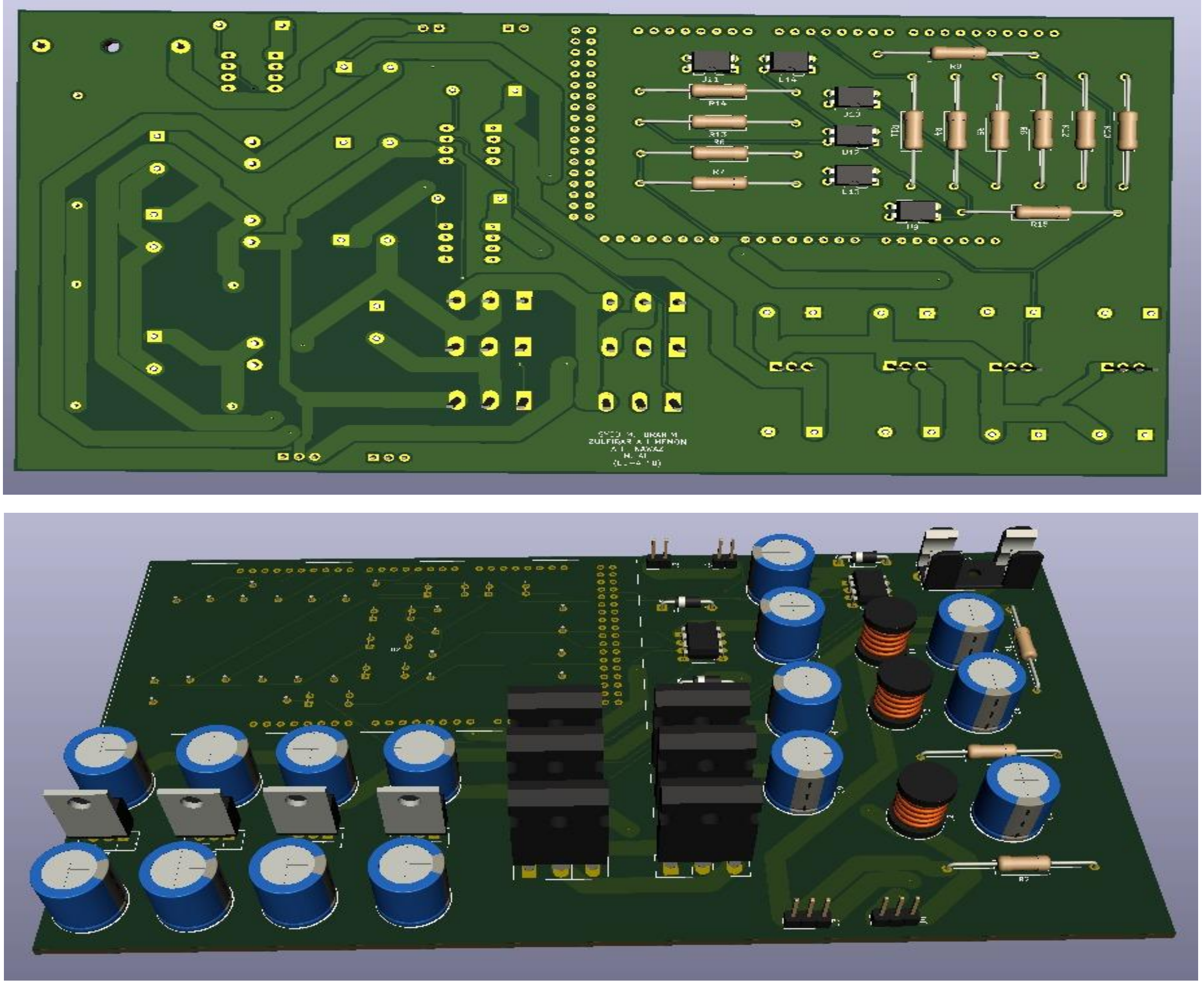
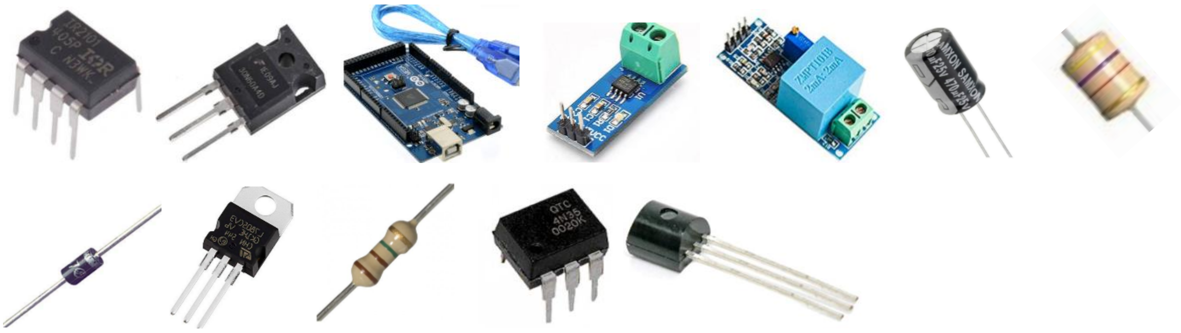


Figure 29: 3D View of PCB

3.2. Component Information

The components selection is one the most important and difficult part during hardware implementation. We bought most of components from college road which include most of our ICs, filter passive components and Microcontroller board (Arduino Mega 2560). Our components are as followed:



- Arduino Mega 2560.
- Driver IC 2101.
- IGBT 30N60.
- Current sensor ACS712.
- Voltage Sensor ZMPT101b.
- Capacitors 22uF,470Uf.
- Inductor 15mH.
- Diode.
- Voltage Regulators LM7805 and LM812.
- Resistors 200 ohm.
- Optocoupler (To isolate Arduino).
- Fuse. (DC supply side to Protect Short-circuit).

CHAPTER NO. 4

SOFTWARE IMPLEMEMTATION

4.1. MATLAB/SIMULINK IMPLEMENTATION OF GRID-TIE INVERTER

MATLAB/Simulink is one the most widely and efficient software for dealing with circuits like in Power Electronics. In MATLAB/Simulink we have complete control of different transistors like IGBTs solid-state components. We can design different digital controller with maximum optimism and dynamic performances We can also model and implement different complex topologies in it that enables design Engineers to verify, calculate and understand their designs with the help of MATLAB/Simulink software.

SIMULATION & RESULTS:

- **3 Phase Inverter:**
  - It Converts DC from renewable source to AC. It utilizes IGBT 30N60.
  - The inverter input is basically given from a DC source (Renewable source) and it converts it into three phase AC voltage and feeds to the grid synchronization circuit.

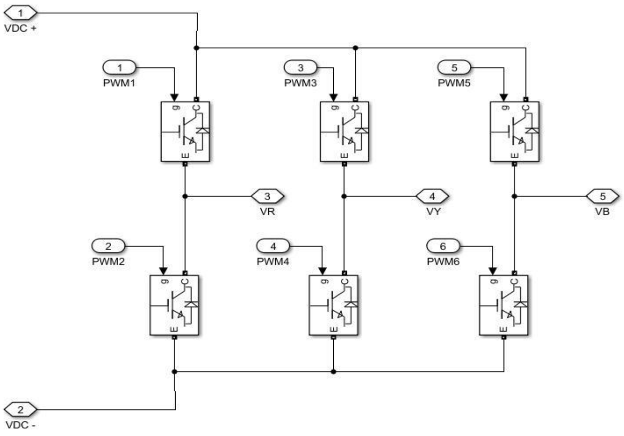


Figure 30: Inverter Circuit

- **Power Circuit with LC filter connected to grid:**

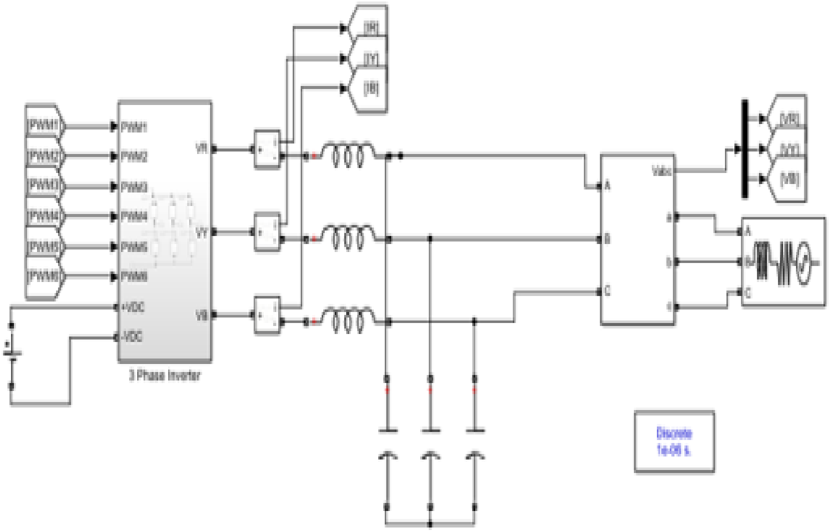


Figure 31: Grid Connected Power Circuit

- **SPWM Generation with Dead Time Compensation-Block:**
  - "Sinusoidal PWM is a modulation schemes that relies on its carrier signal hence it is often referred as carrier based PWM.It uses pre-defined modulation signals to obtain output quantity. In sinusoidal PWM, sinusoidal signal is referred as modulation signal, with the peak amplitude of the modulating signal is maintained always lower than the peak of the carrier signal used in modulation scheme".
  - SPWM is generated by comparing sinusoidal reference wave with high frequency triangular carrier wave.
  - SPWM is used to generated the switching pulses given to the gate of IGBTs used in inverter circuit. SPWM performance is tested and is better option compared to commonly used PWM or SVPWM.The dead time was incorporated resulting in more synchronous sine wave with a higher voltage, dominant total harmonic reduction and overall lower total harmonic distortion (THD) when used to drive IGBTs in inverter.
  - If Amplitude of Reference signal is greater than that of carrier wave upper switches of bridge are on or Signal is high

- **Current and voltage transformation(d-q) Blocks:**

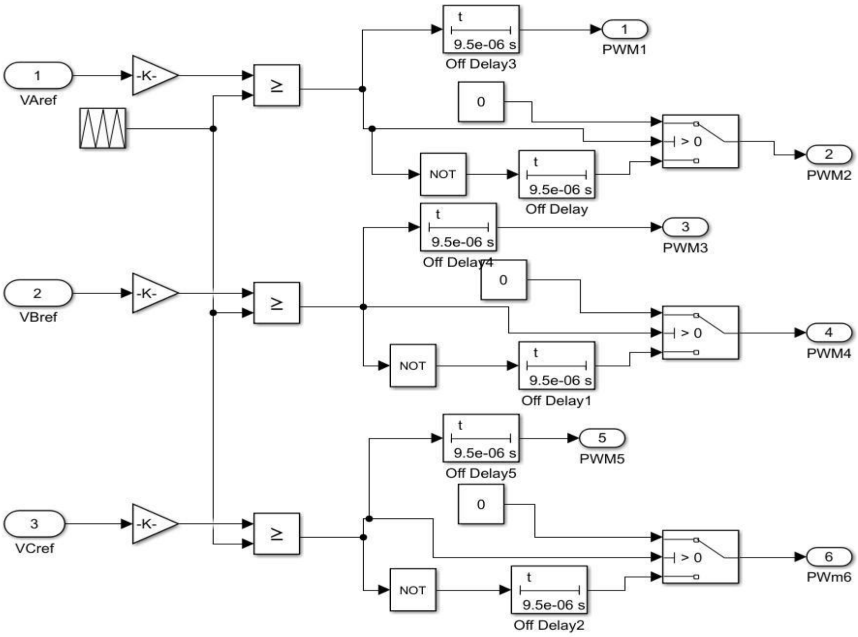


Figure 32: SPWM with dead time

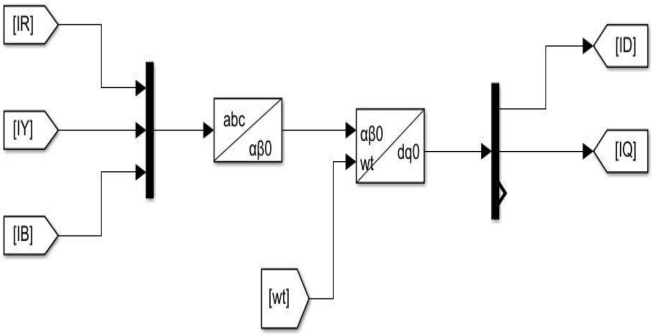


Figure 33: Current Transformation Circuit

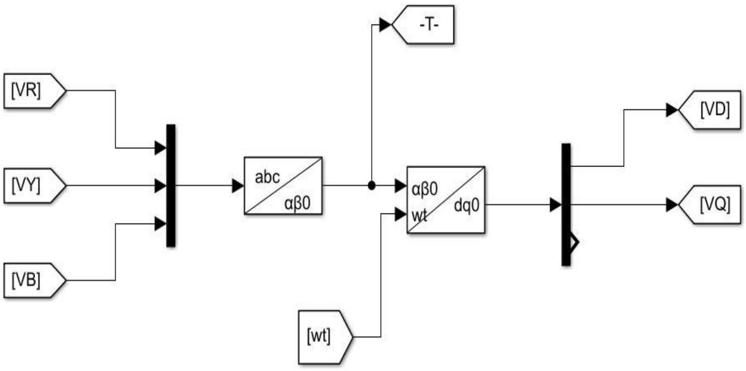


Figure 34: Voltage Transformation Circuit

- **Current Controller Blocks:**

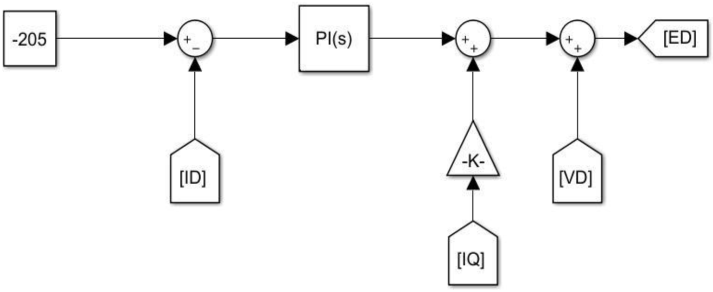


Figure 35: Active Current Controller Circuit

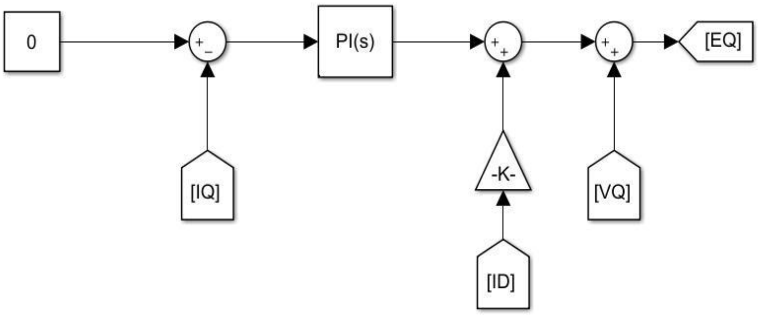


Figure 36: Reactive Current Controller Circuit

- **Inverse Transformation Block to get reference voltage for PWM generation:**

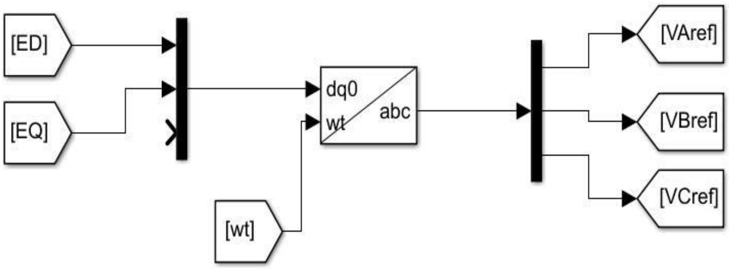


Figure 37; Reference for SPWM generation

- **Phase Lock Loop(PLL):**
  - The main purpose of PLL is to get phase (angle) of grid voltage in order to achieve perfect synchronization and main high power quality.
  - “Phase locked loop (PLL) control is an important part of the grid synchronization process”.it gives a better estimation on phase difference between grid voltage and output voltage generated by inverter.

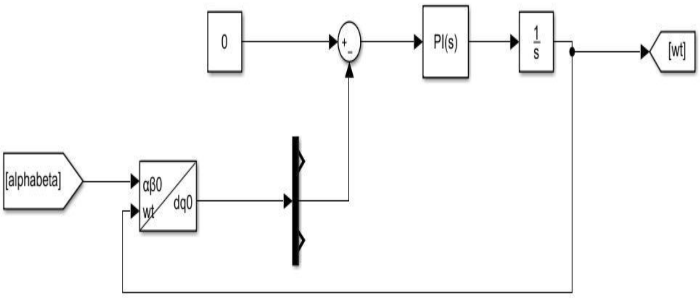
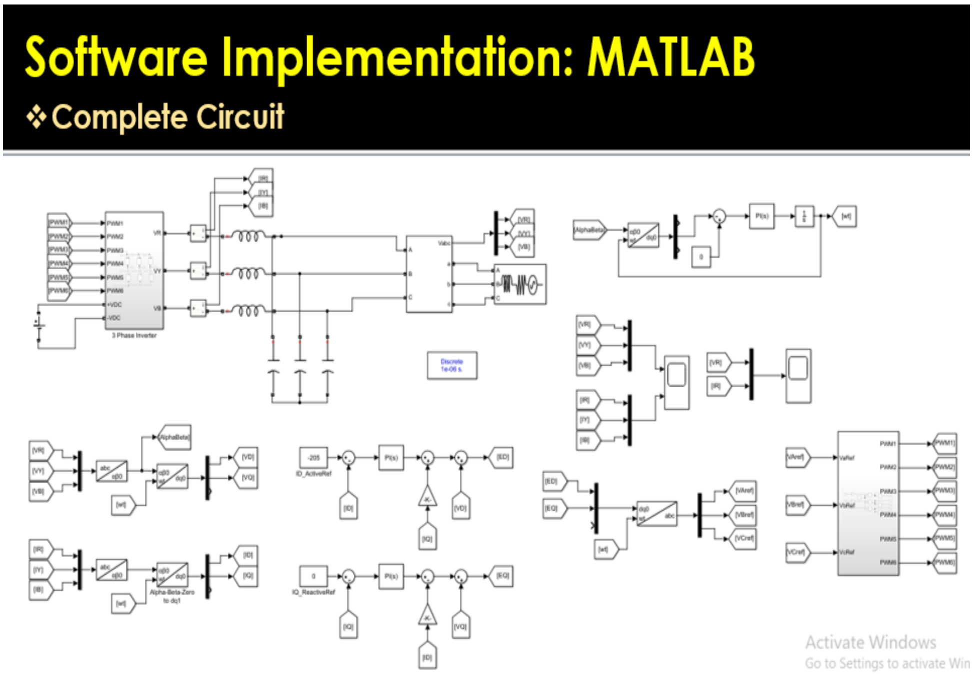


Figure 38: PLL Circuit

We simulated 100KVA three phase grid tie inverter with 800V DC input and 10k Hz switching frequency.


Software Implementation: MATLAB

❖Complete Circuit

Figure 39: Grid Tie Inverter MATLAB Circuit

Results:

- Three phase current and voltage outputs are shown respectively.
- Reference Active current is set to 205 A white reactive current is regulated to zero.
- Output Waveform shows that actual Current is same as reference Current.
- The output voltage of the inverter was filtered through the LC filter;filtered output voltage was plotted. The plot shows that the voltage is sinusoidal with no harmonics or noise components in the signal. The quadrature and direct

signal components of the voltage at the point of common coupling were plotted in per unit.

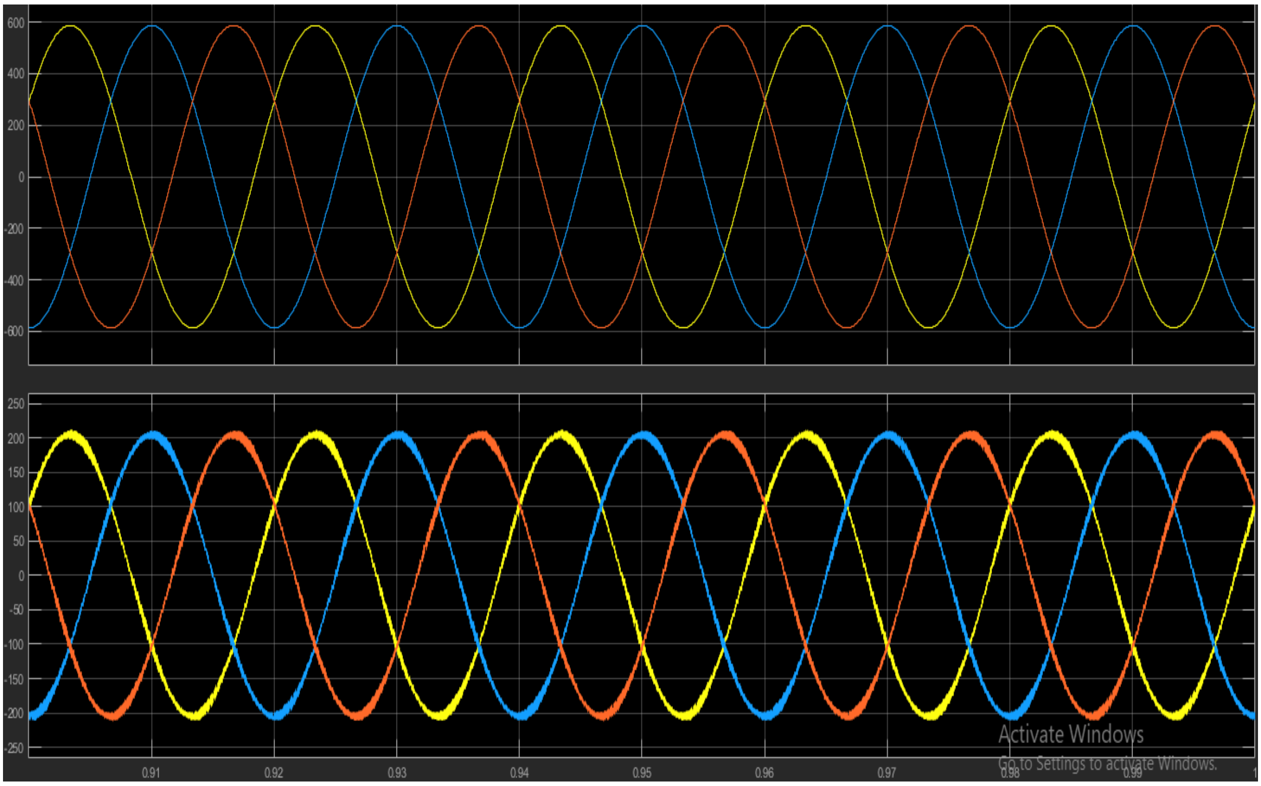


Figure 40: 3phase Current and Voltage Waveform

- Since, we are sending only active current so current and voltage of one single phase are aligned in phase, implying that they are in synchronization.
- Inverter voltage and current are in phase when the inverter is supplying active power to the load at the point of common coupling.

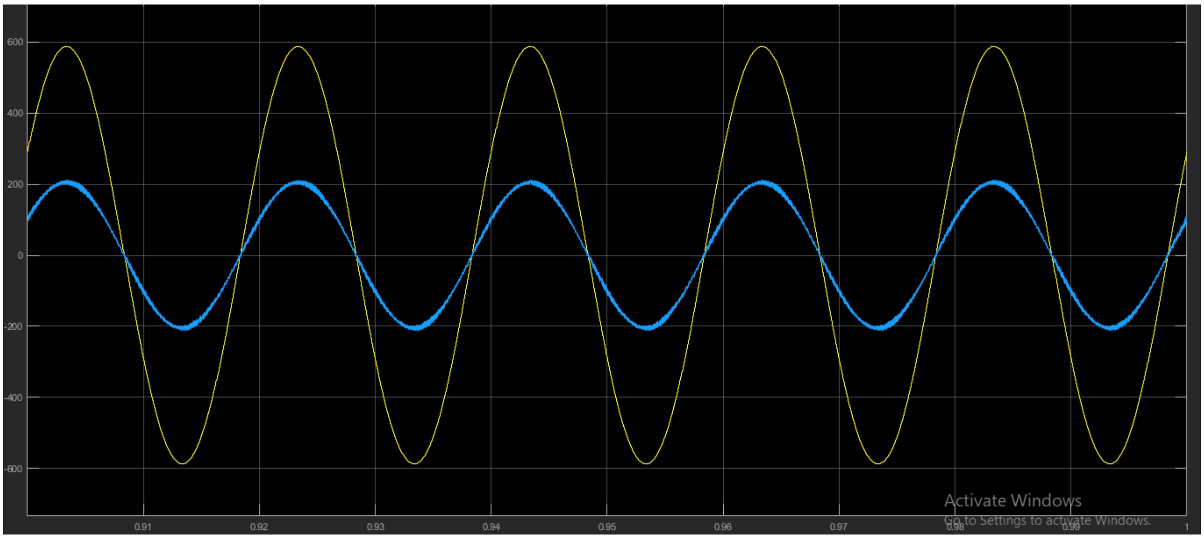


Figure 41: Single Phase Current and Voltage Waveform

- To check our design further, we regulated active current to zero and sent only reactive current to verify phase shift between and voltage and current,

- It can be seen that voltage and current are 90° out of phase.

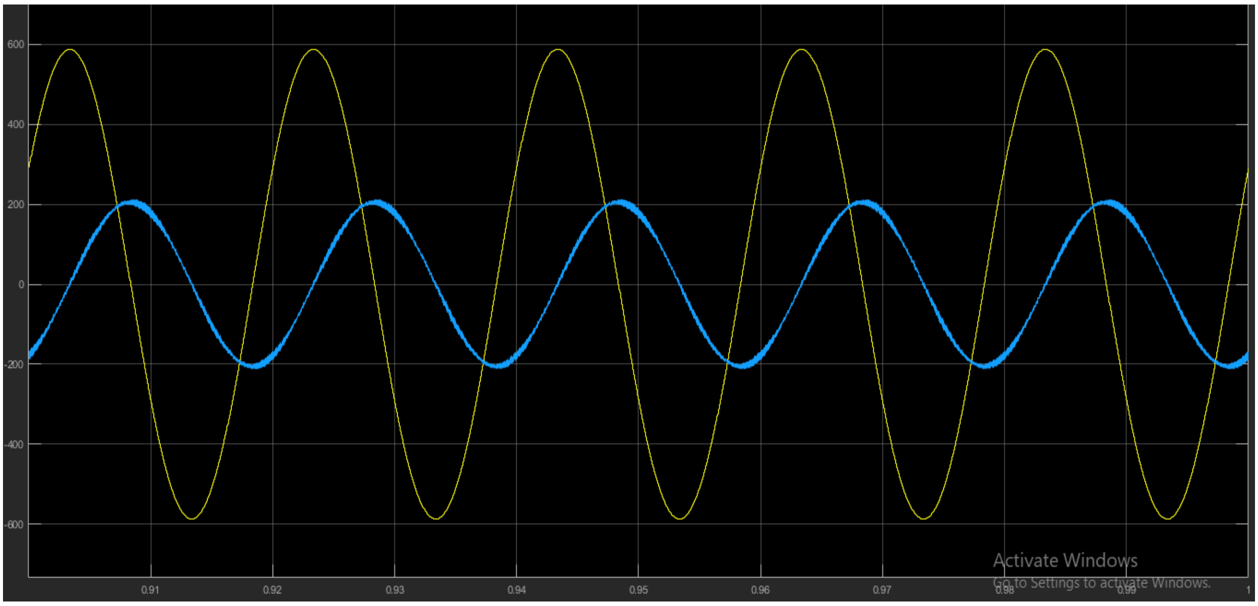


Figure 42: Single Phase Current and Voltage Waveform

PWM Signals:

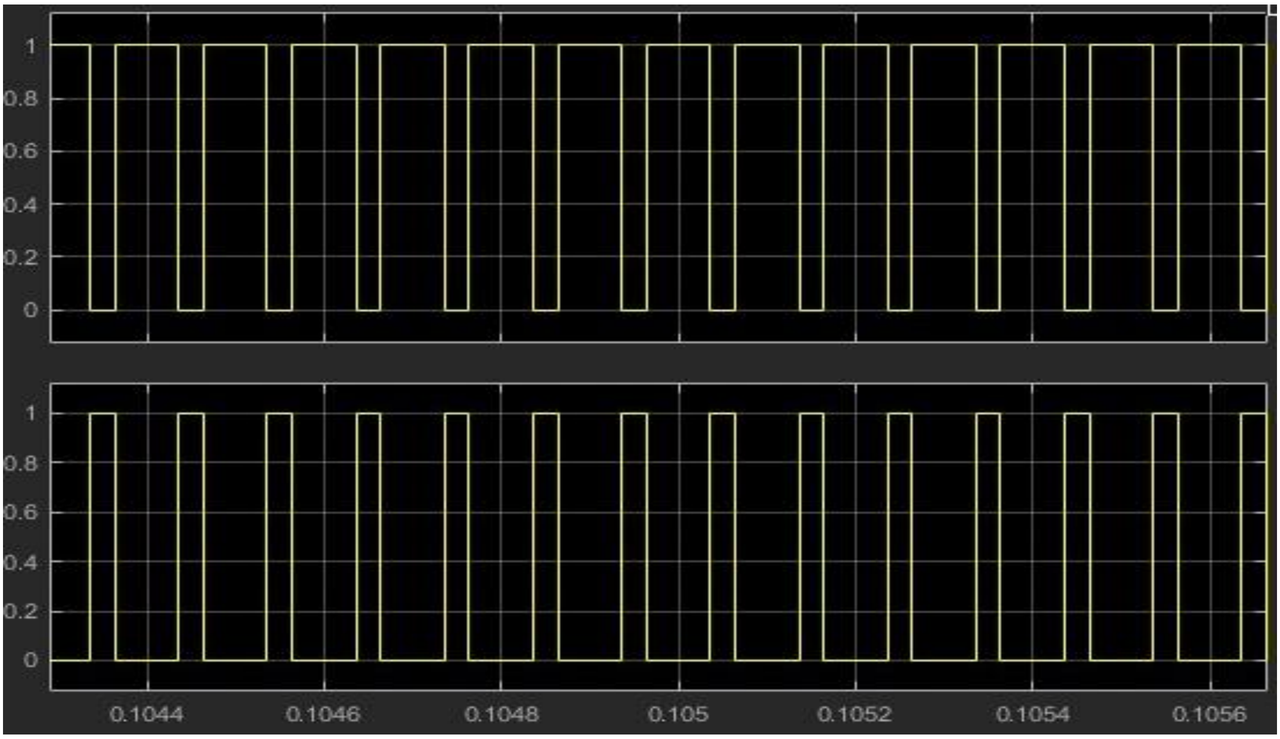


Figure 43: PWM Signals

4.2. PROTEUS IMPLEMENTATION OF GRID-TIE INVERTER SIMULATION & RESULTS:

1. 3 Phase Inverter:

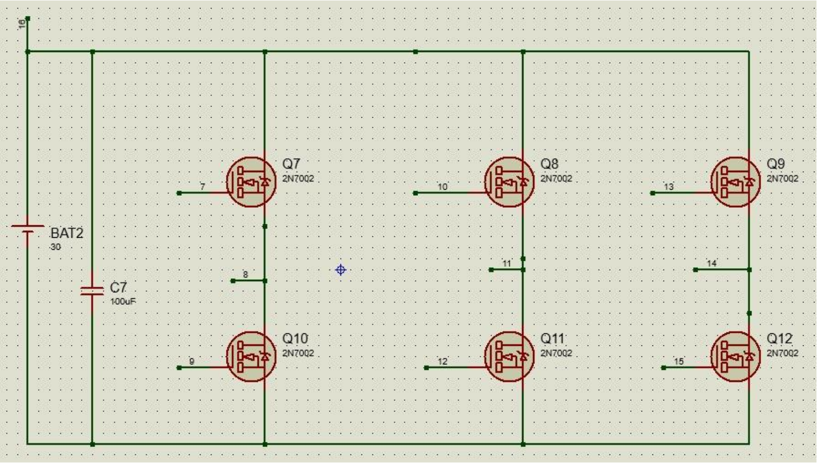


Figure 44: 3-phase Inverter

2. Driver Circuit:

- Amplifies voltage from 5V to 12V.

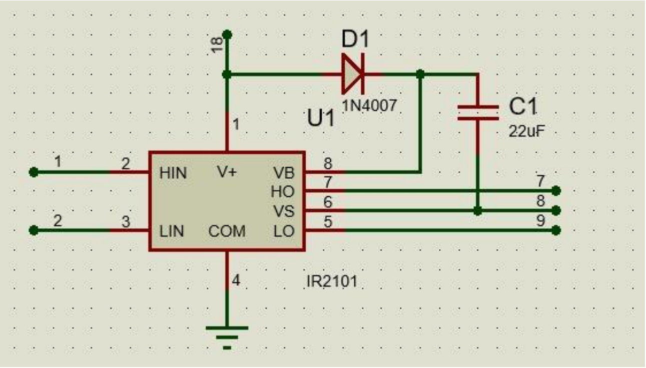


Figure 45: Driver Circuit

3. LC filter with Y-connected Load:

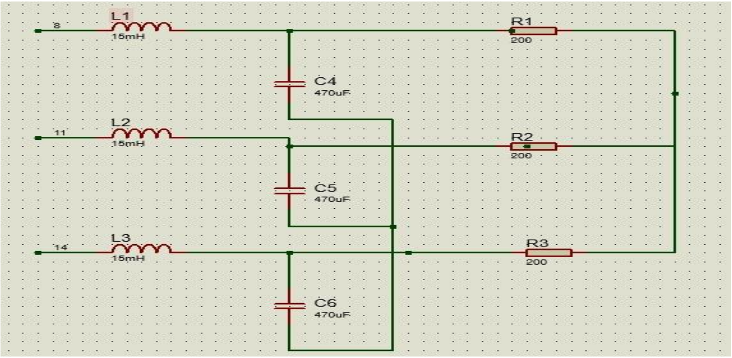


Figure 46: Filter Circuit

4. Voltage Regulator:

- Voltage regulator is mainly used to maintain constant DC voltage at output so that voltage of different magnitude can be supplied to appropriate ICs by using one power supply followed by voltage regulators. The ripples in output that were not removed by filter are blocked by voltage regulator resulting in maintaining good power quality and ripple free output.
- Voltage regulators are considered to be best option in situations were steady and reliability of output voltage is to be maintained.

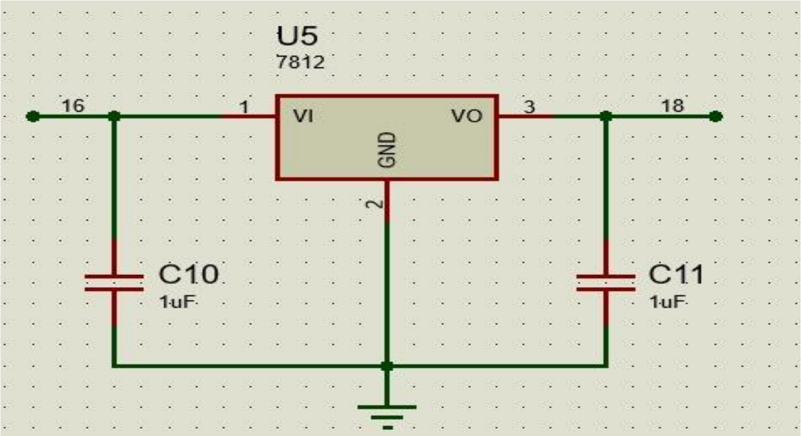


Figure 47: Voltage Regulator

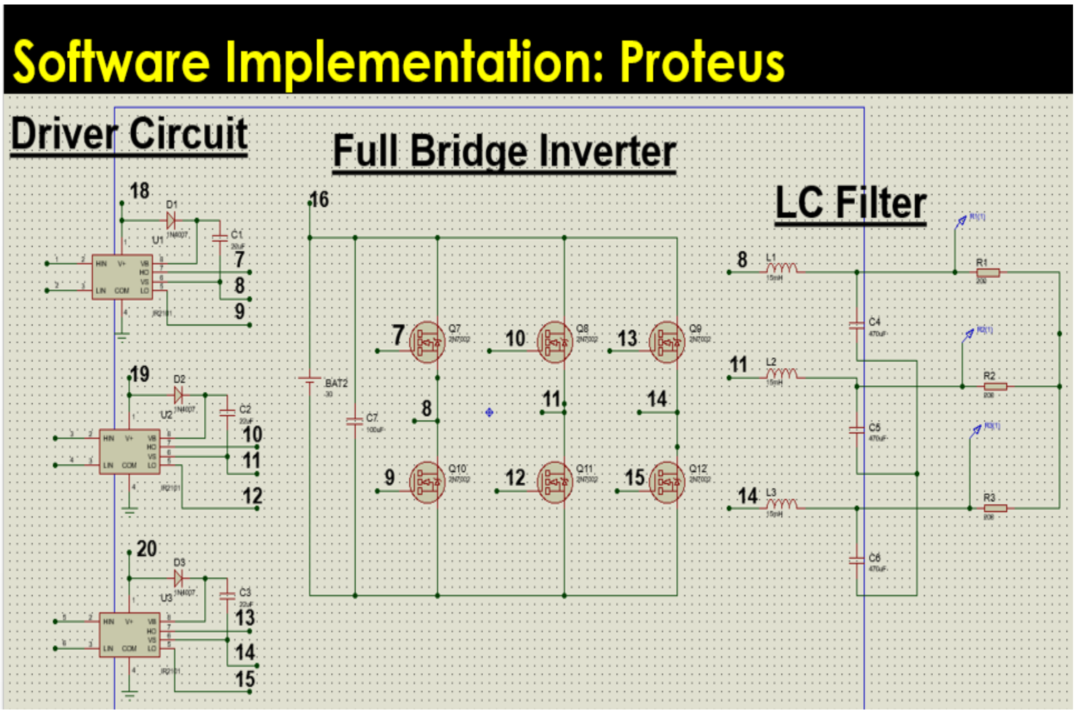


Figure 48: Proteus Circuit

Three phase Current Waveform:

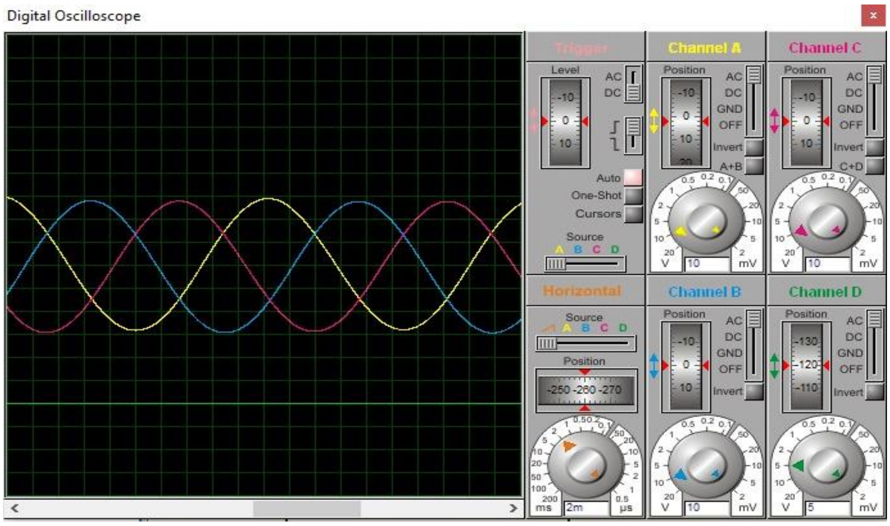
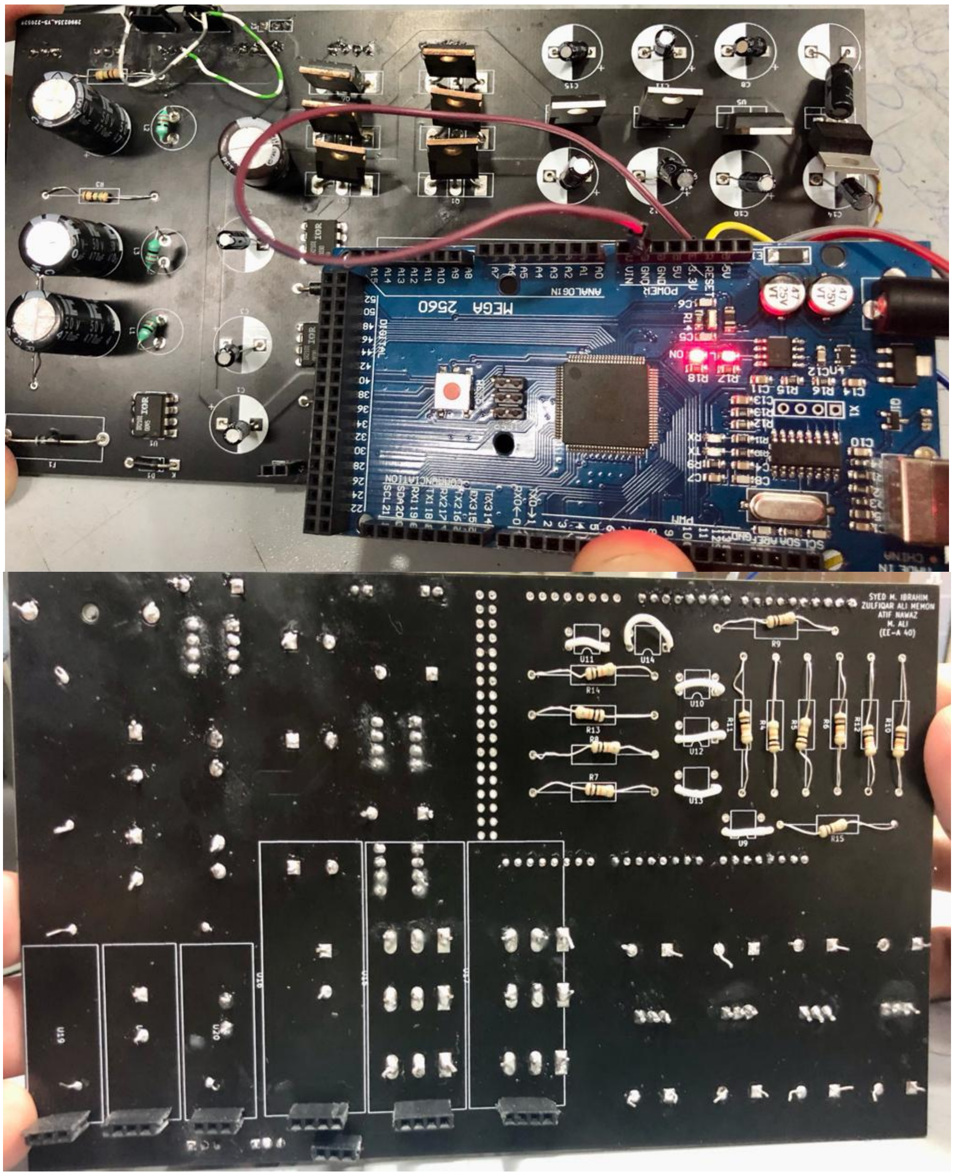


Figure 49: Output Waveform



CHAPTER NO. 5

CONCLUSIONS

This report presents the Design and implementation of Grid Tie Inverter comprising of PWM generation module, full Bridge inverter, Current control loop and Filter. “Results confirm that the GTI is capable of producing an AC waveform that is synchronized with the grid”. A grid tie inverter is an electronic device which can convert DC electricity energy from renewable energy sources (solar, wind, geothermal etc.) to AC electricity which is suitable for our electronic appliances and is also capable of injecting surplus electricity to the national grid.

A three phase SPWM controlled Grid tie inverter was first simulated on Simulink and Proteus. A $dq-PLL$ algorithm was tested to check that current follows the specified reference. LC filter was used at Bridge output to reduce harmonics with better ripple performance. All simulation and experimental results confirmed that output voltage of Grid Tie inverter was balanced with grid and frequency, amplitude and phase were perfectly synchronized with grid.

From the system design, “it can be concluded that PI controllers are best suited even for grids in which the values of grid voltage and grid frequency are changing during the operation”. From the step change in the load power, the references continued to track their desired parameters which prove that a PI controller was suitably in this application. This controller can be applied in residential PV application to support the reactive power at the grid. The proposed controller will improve the power quality at the consumer side of the grid by making the voltage at the point of coupling closer to nominal value. Inverters with reactive power support capabilities will be of great importance to grid tie energy sources with the ability to minimize blackouts.

The reason we decided to undertake the grid tied inverter as our final year project is because this device holds a great potential that can be utilized in the coming future. It also serves as switch between standalone and grid connected in case of failure. The inverter relies on solar energy as input, which is an infinite source of energy. The inverter can then supply the electrical energy for household uses. It delivers the access energy to the main grid, thus contributing to the sustainability of our energy resources and demands. The inverter can also be used for commercial use. Pakistan can greatly utilize the grid tied inverters as it provides free energy from a renewable source and is cost efficient in the long run.

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