dSPACE Based Inverter Design and Implementation

A Project report submitted in partial fulfilment

of the requirements for the degree of B. Tech in Electrical Engineering

By

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Under the supervision of

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CERTIFICATE

<u>To whom it may concern</u>

This is to certify that the project work entitled **"dSPACE Based Inverter Design and Implementation"** is the bona fide work carried out by **Krishnendu Mondal (11701614024)** students of B.Tech in the Dept. of Electrical Engineering, RCC Institute of Information Technology (RCCIIT), Canal South Road, Beliaghata, Kolkata-700015, affiliated to Maulana Abul Kalam Azad University of Technology (MAKAUT), West Bengal, India, during the academic year 2017-18, in partial fulfilment of the requirements for the degree of Bachelor of Technology in Electrical Engineering and that this project has not submitted previously for the award of any other degree, diploma and fellowship.

_____   _____

Signature of the Guide   Signature of the HOD
 Name: Name:
 Designation   Designation

_____

Signature of the External Examiner
Name:
Designation:

ACKNOWLEDGEMENTS

It is my great fortune that I have got opportunity to carry out this project work under the supervision of Dr. Shilpi Bhattacharya in the Department of Electrical Engineering, RCC Institute of Information Technology (RCCIIT), Canal South Road, Beliaghata, Kolkata-700015, affiliated to Maulana Abul Kalam Azad University of Technology (MAKAUT), West Bengal, India. I express my sincere thanks and deepest sense of gratitude to my guide for his constant support, unparalleled guidance and limitless encouragement. I wish to convey my gratitude to Prof. (Dr.) Alok Kole, HOD, Department of Electrical Engineering, RCCIIT and to the authority of RCCIIT for providing all kinds of infrastructural facility towards the research work. I would also like to convey my gratitude to all the faculty members and staffs of the Department of Electrical Engineering, RCCIIT for their whole-hearted cooperation to make this work turn into reality.

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Signature of the Student

Krishnendu Mondal (11701614024)

Place:

Date:

Abstract

This project presents prototype development of a single-phase full-bridge inverter hardware and control using dSPACE RTI 1202 Microlab box real time interface with Matlab/Simulink software. The closed loop single-phase inverter using a simple voltage control loop wherein the error between the inverter output voltage and a desired reference rms output voltage is used to generate the control pulses for the power devices of the inverter. The project has two parts: a) Inverter MATLAB Simulink model development and testing in software b) Development of hardware of the inverter and implementation. The generated PWM signals in Matlab Simulink from the voltage command of the load side are also obtained in real time using dSPACE 1202 Microlab box. These signals are then applied to the gate of the power devices through proper driver circuits etc. The results obtained after implementing the entire set-up in the lab and are presented here. This project also presents the design of the inverter: the power devices, the transformer, filter etc. then analyse the output waveforms for various values of the elements used in the circuit and hence study the system response and instabilities.

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Abstract

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List of Acronyms:

MOSFET- Metal Oxide Semiconductor Field Effect Transistor

dSPACE- Digital Signal Processor for Applied and Control Engineering

DC-Direct Current

AC- Alternating Current

UPS- uninterruptible power supply

PWM- Pulse Width Modulation

SPWM- Sinusoidal Pulse Width Modulation

PFC- power factor correction

THD- Total Harmonic Distortion

MATLAB-MATrix LABoratory

Chapter 1: Introduction

Inverter

An inverter is basically a device that converts electrical energy of DC form into that of AC. The purpose of DC-AC inverter is to take DC power from a battery source and converts it to AC. For example the household inverter receives DC supply from 12V or 24V battery and then inverter converts it to 240V AC with a desirable frequency of 50Hz or 60Hz. These DC-AC inverters have been widely used for industrial applications such as uninterruptible power supply (UPS), AC motor drives. Recently, the inverters are also playing an important role in various renewable energy applications as these are used for grid connection of Wind Energy System or Photovoltaic System. In addition to this, the control strategies used in the inverters are also similar to those in DC-DC converters. Both current-mode control and voltage-mode control are employed in practical applications.
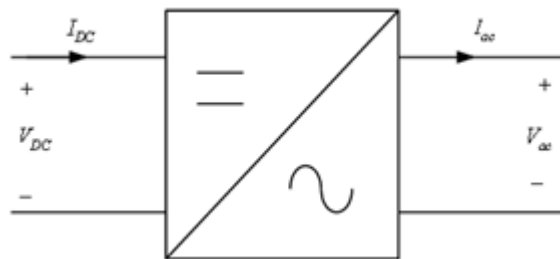
Figure 1: DC input to AC output in Inverter

The DC-AC inverters usually operate on Pulse Width Modulation (PWM) technique. The PWM is a very advance and useful technique in which width of the Gate pulses are controlled by various mechanisms. PWM inverter is used to keep the output voltage of the inverter at the rated voltage (depending on the user's choice) irrespective of the output load .In a conventional inverter the output voltage changes according to the changes in the load. To nullify this effect of the changing loads, the PWM inverter correct the output voltage by changing the width of the pulses and the output AC depends on the switching frequency and pulse width which is adjusted according to the value of the load connected at the output so as to provide constant rated output. The inverters usually operate in a pulse width modulated (PWM) way and switch between different circuit topologies, which means that the inverter is a nonlinear, specifically piecewise smooth system. In addition to this, the control strategies used in the inverters are also similar to those in DC-DC converters. Both current-mode control and voltage-mode control are employed in practical applications. In the last decade, studies of complex behaviour in switching power converters have gained increasingly more attention from both the academic community and industry. Various kinds of nonlinear phenomena such as bifurcation, chaos, border collision and coexisting attractors, have been revealed. Previous work has mainly focused on DC power supply systems including DC-DC converters and AC-DC power factor correction (PFC) converters.

Chapter 2: Theory

Based on the type of output source inverters are of 3 types:-

- **Voltage Source Inverter**: The type of inverter where the independently controlled ac output is a voltage waveform. The output voltage waveform is mostly remaining unaffected by the load. Due to this property, the VSI have many industrial applications such as adjustable speed drives (ASD) and also in Power system for FACTS (Flexible AC Transmission).
- **Current Source Inverter**: The type of inverter where the independently controlled ac output is a current waveform. The output current waveform is mostly remaining unaffected by the load. These are widely used in medium voltage industrial applications, where high quality waveform is required.
- **Combination of voltage control and current control:** In this inverter Voltage-Controlled PWM Inverter (VCPI) unit as a master is developed to keep a constant sinusoidal wave output voltage. The Current-Controlled PWM Inverter (CCPI) units as a slave are controlled to track the distributive current. The power distribution centre (PDC) performs the function of distributing the output current of each active unit.

Based on the type of operation inverter are of 3 types:-

- **Single Phase Full wave Bridge Inverter:** It consists of two arms with two semiconductor switches on both arms with anti-parallel freewheeling diodes for discharging the reverse current. In case of resistive-inductive load, the reverse load current flow through these diodes. These diodes provide an alternate path to inductive current which continue so flow during the Turn OFF condition.

Figure 2: Single Phase Full Wave Bridge Inverter

- **3 Phase Bridge type Inverter:** It consists of 3 arms with two semiconductor switches on each arms with anti-parallel freewheeling diodes for discharging the reverse current. In case of resistive-inductive load, the reverse load current flow through these diodes. These diodes provide an alternate path to inductive current whic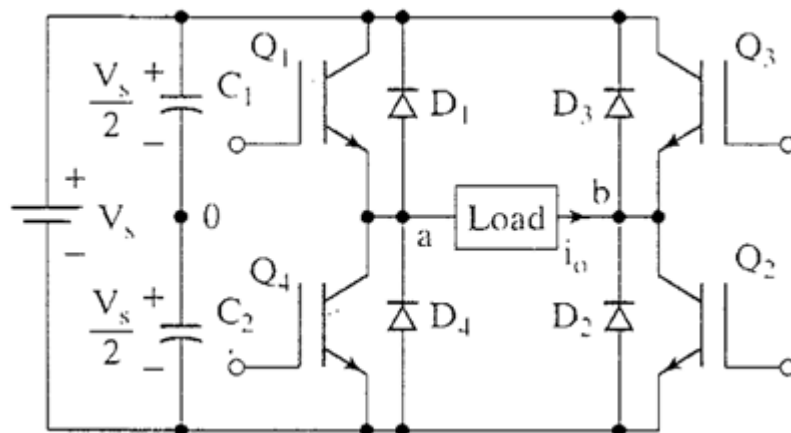h continue so flow during the Turn OFF condition. The output from this inverter is to be fed to a 3-phase balanced load. Figure below shows the power circuit of the three-phase inverter.
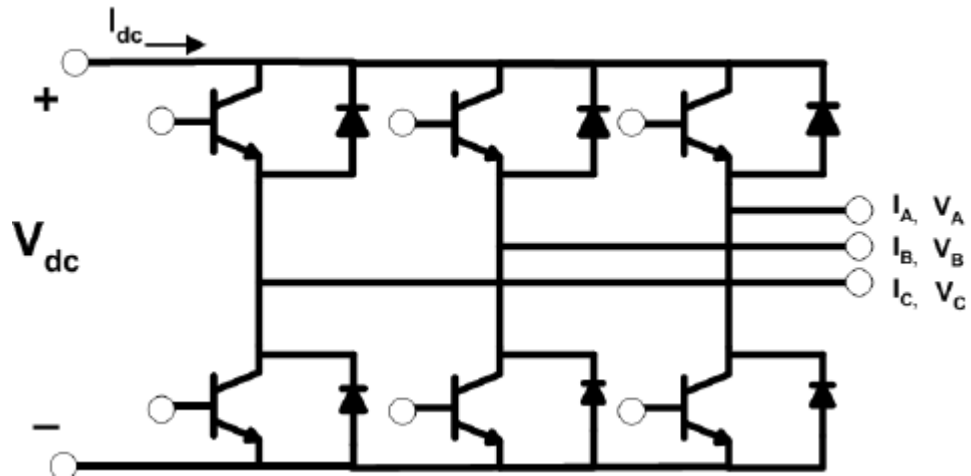
Figure 3: 3-Phase Full Wave Bridge Inverter

- **Multiphase Inverters:** Multi-phase inverters gives strong benefit over 3-phase inverters as it increases the current per phase without increasing the voltage per phase lowering harmonics and has high reliability. The multiphase drives are best suitable for high power application ship propulsion and electrical or hybrid vehicles.
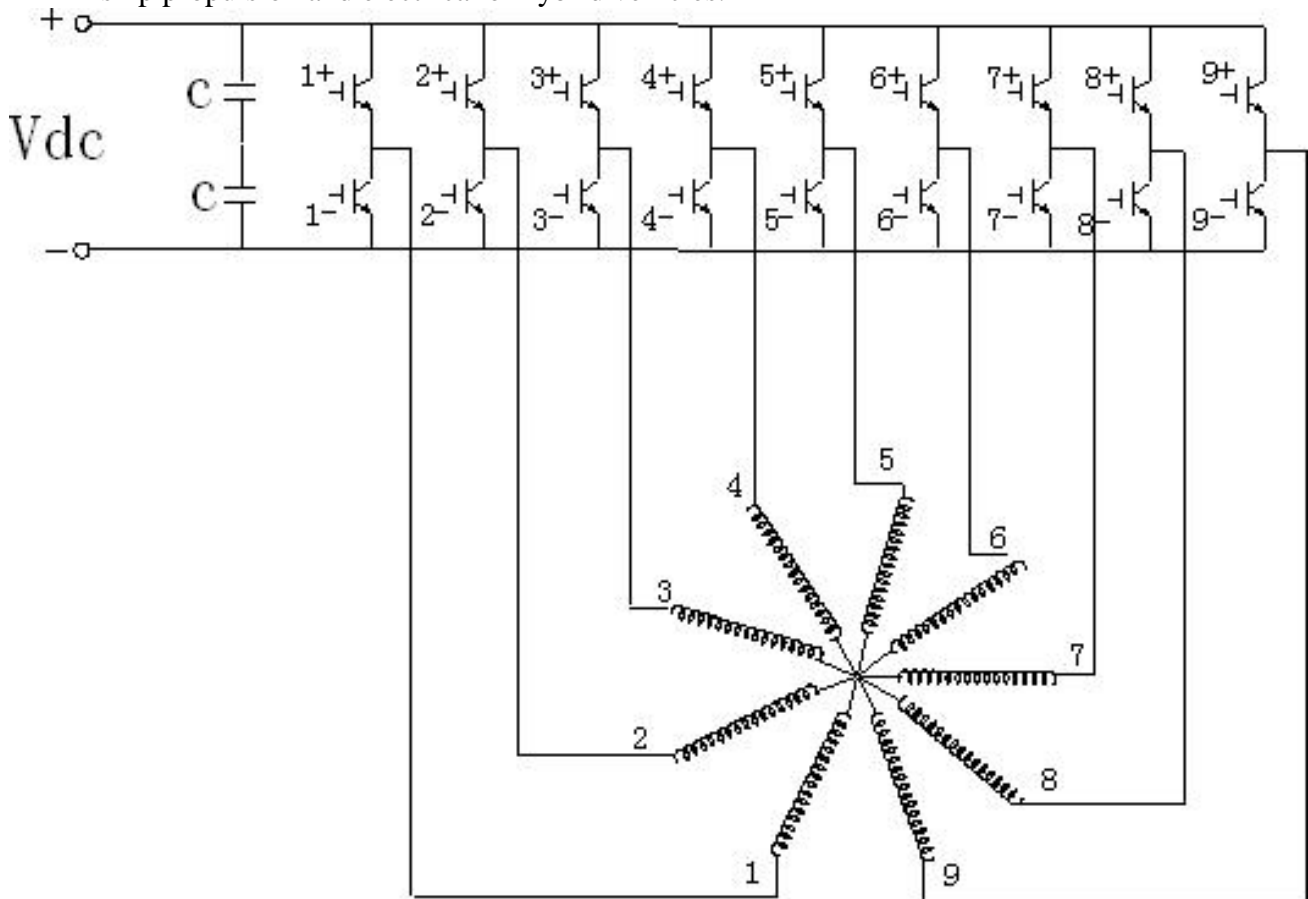

Figure 4: Multi-Phase Full Wave Bridge Inverter

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Pulse Width Modulation (PWM)

The Pulse Width Modulation (PWM) is a technique which is characterized by the generation of constant amplitude pulse by modulating the pulse duration by modulating the duty cycle. Analog PWM control requires the generation of both reference and carrier signals that are feed into the comparator and based on some logical output, the final output is generated. The reference signal is the desired signal output maybe sinusoidal or square wave, while the carrier signal is either a saw-tooth or triangular wave at a frequency significantly greater than the reference. There are several types of PWM techniques and so we get different output and the choice of the inverter depends on cost, noise and efficiency.

There are generally three types of inverter based on modulation technique for general purpose-
- Square Wave Inverter
- Modified Square Wave Inverter
- True Sine Wave Inverter

- **Square Wave Inverter:** This is the basic type of inverter. Its output is a alternating square wave. The harmonic content in this wave is very large. This inverter is not efficient and can give serious damage to some of the electronic equipment. But due to low cost, it has some limited number of applications in household appliances.
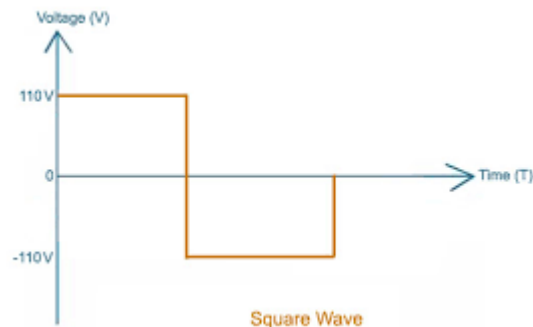

Figure 5: Square Wave Inverter Output

- **Modified Square Wave Inverter:** A modified sine wave inverter has a waveform more like a square wave, but with an extra step or so. Because the modified sine wave is noisier and rougher than a pure sine wave, clocks and timers may run faster or not work at all. A modified sine wave inverter will work fine with most equipment, although the efficiency or power will be reduced with some. But with most of the household appliances it works well.
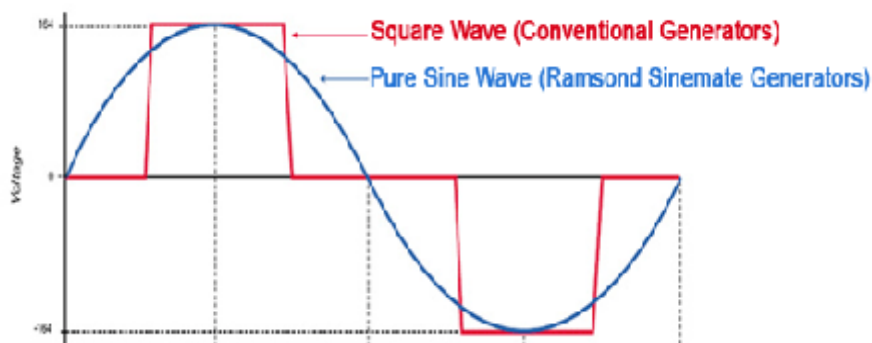

Figure 6: Modified Square Wave Inverter Output

- **True Sine Wave Inverter**: This type of inverter provides output voltage waveform which is very similar to the voltage waveform that is received from the Grid. The sine wave has very little harmonic distortion resulting in a very clean supply and makes it ideal for running electronic systems such as computers, digital fx racks and other sensitive equipment without causing problems or noise. Things like mains battery chargers also run better on pure sine wave converters.
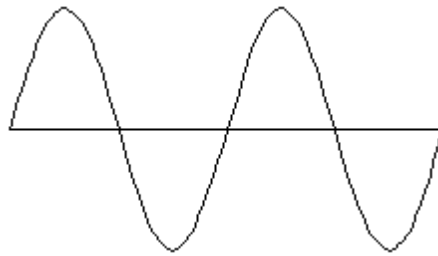

Figure 7: True Sine Wave Inverter Output

Benefits of using True Sine Wave Inverter

- Most of the electrical and electronic equipments are designed for the sine wave.
- Some appliances such as variable motor, refrigerator, microwave will not be able to provide rated output without sine wave.
- Electronic clocks are designed for the sine wave.
- Harmonic content is less.

SPWM based Single Phase True sine Wave Inverter

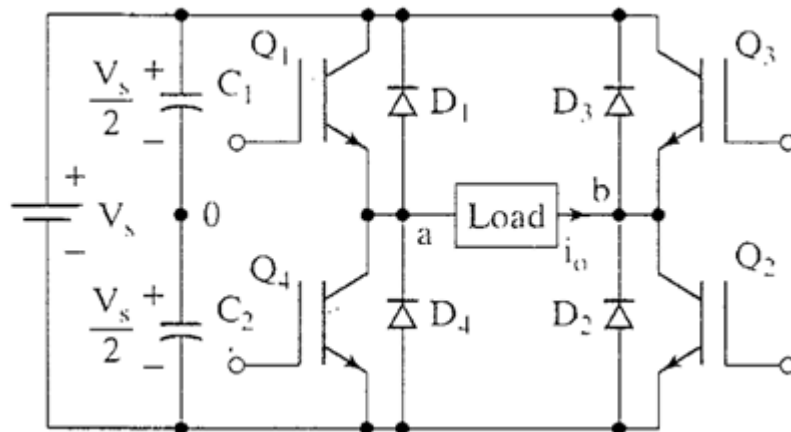**Circuit Diagram of inverter:-**

Figure 8: Basic Single Phase Inverter

When the switches S1 and S2 are turned on simultaneously for a duration $0 \leq t \leq T1$, the input voltage Vin appears across the load and the current flows from point a to b.
Q1 – Q2 ON, Q3 – Q4 OFF ==> $v \, o = Vs$
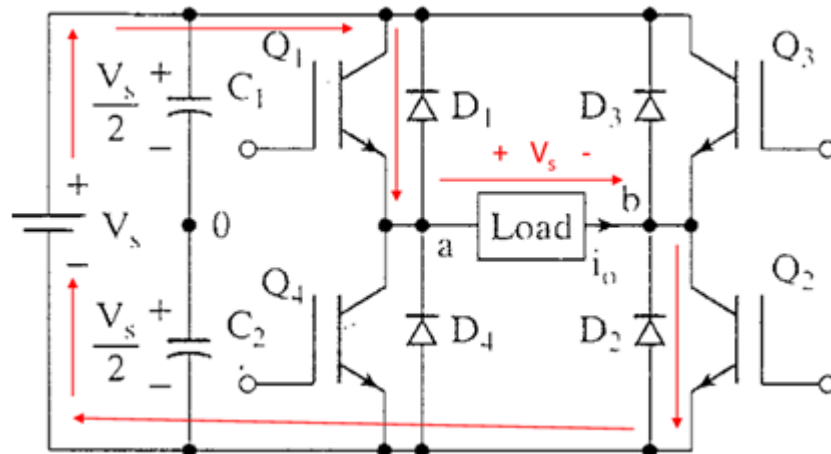
If the switches S3 and S4 turned on duration $T1 \leq t \leq T2$, the voltage across the load the load is reversed and the current through the load flows from point b to a.
Q1 – Q2 OFF, Q3 – Q4 ON ==> $v \, o = -Vs$
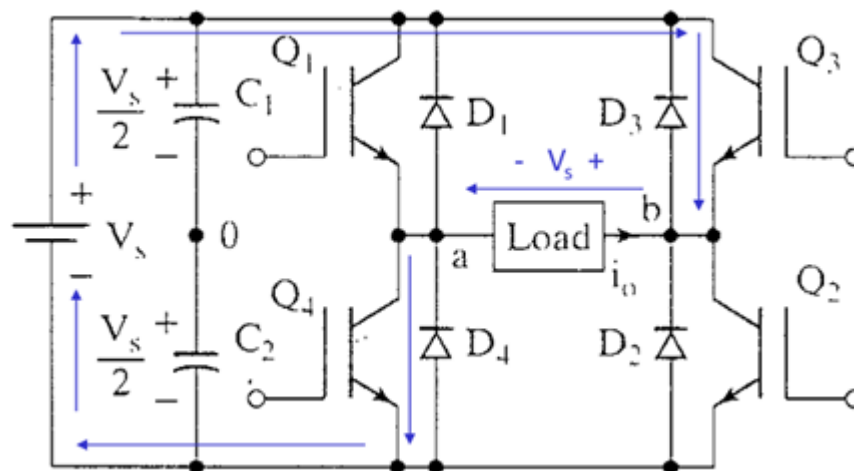
Switching Sequence with output voltage:-

Q1	Q2	Q3	Q4	V_a	V_b	V_{ab}
ON	OFF	OFF	ON	$V_S/2$	$=V_S/2$	V_S
OFF	ON	ON	OFF	$+V_S/2$	$+V_S/2$	V_S
ON	OFF	ON	OFF	$V_S/2$	$-V_S/2$	0
OFF	ON	OFF	ON	$-V_S/2$	$+V_S/2$	0

Table 1: Switching States

The most common and popular technique for generating True Sine Wave is Sinusoidal Pulse Width Modulation (SPWM). This SPWM technique involves generation of a digital waveform, for which the duty cycle can be modulated in such a way so that the average voltage waveform corresponds to a pure sine wave. The simplest way of producing the SPWM signal is through comparing a low power sine wave reference with a high frequency triangular wave. This SPWM signal can be used to control switches. Through a filter, the output of Full Wave Bridge Inverter with SPWM signal will generate a wave approximately equal to a sine wave. This technique produces a much more similar AC waveform than that of others.
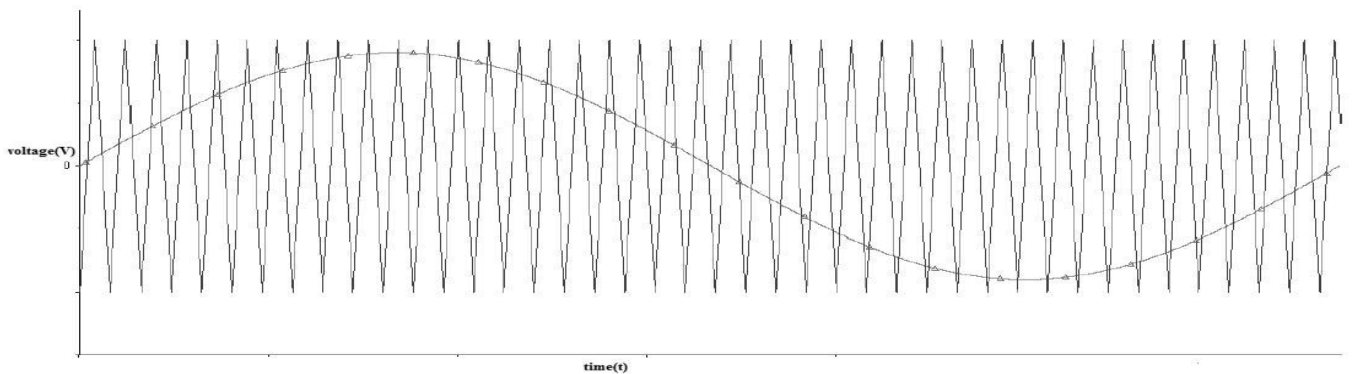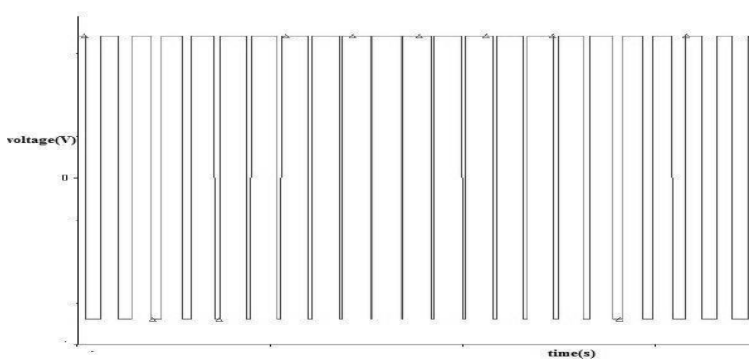

Figure 9: SPWM comparison Signals

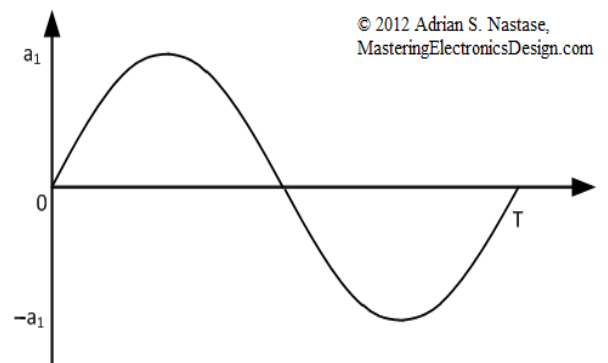**Figure 10: Unfiltered SPWM output**

Figure 11: Filtered SPWM Output

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Let the modulating signal is a sinusoidal of amplitude Am, and the amplitude of the triangular carrier is Ac, the ratio m=Am/Ac is known as Modulation Index (MI). Note that controlling the MI controls the amplitude of the applied output voltage with a sufficiently high carrier frequency. A higher carrier frequency results in substantial number of switching per cycle and hence increased power loss.
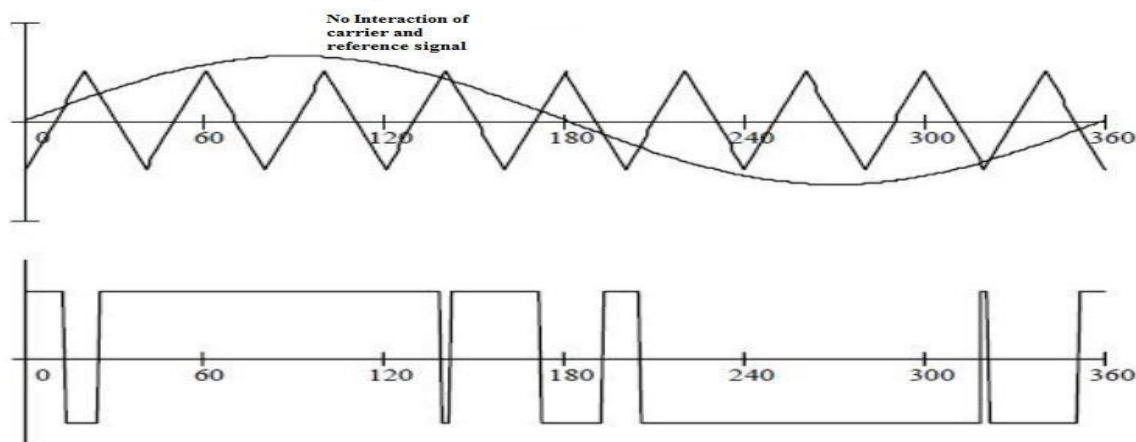

Figure 12: Overmodulation

The inverting process works well for m<1 and for m>1, there are periods of the triangle wave in which there is no intersection of carrier and the signal as shown in the fig. However , a certain amount of this "overmodulation" is often allowed in the interest of obtaining a large AC voltage magnitude even though the spectral content of the voltage is poor.

Advantages of SPWM

- Low power consumption.
- High energy efficient up to 90%
- High power handling capability
- No temperature variation-and ageing-caused drifting or degradation in linearity
- Easy to implement and control
- Compatible with today's digital microprocessors

Disadvantages of SPWM

- Attenuation of the wanted fundamental component of the waveform
- Drastically increased switching frequencies that leads to greater stresses on associated switching devices and therefore derating of those devices.
- Generation of high-frequency harmonic components.

LCL Filter

An LCL filter is often used to interconnect an inverter to the utility grid in order to filter the harmonics produced by the inverter. Simple type of filter that can be used is a series inductor but its harmonic attenuation is not very pronounced; high voltage drop is produced and the size of the inductor becomes bulky. High order LCL filter is used as replacement of conventional L filter for smoothing output current and voltage of the inverter. Higher attenuation along with cost saving. Overall weight and size reduction of the filter components, higher attenuation for the pulsating input signal to suppress harmonics and noise along with cost saving is achieved. Good performance can be obtained using small value of inductors and capacitors. In order to design effective LCL filter, it is necessary to have an appropriate mathematical model of the filter. Several characteristics must be considered in designing an LCL filter such as current ripple, filter size, and switching ripple attenuation. The reactive power requirements may cause a resonance of the capacitor interacting with the grid. Therefore passive or active damping must be added by including resistor with capacitor in series.
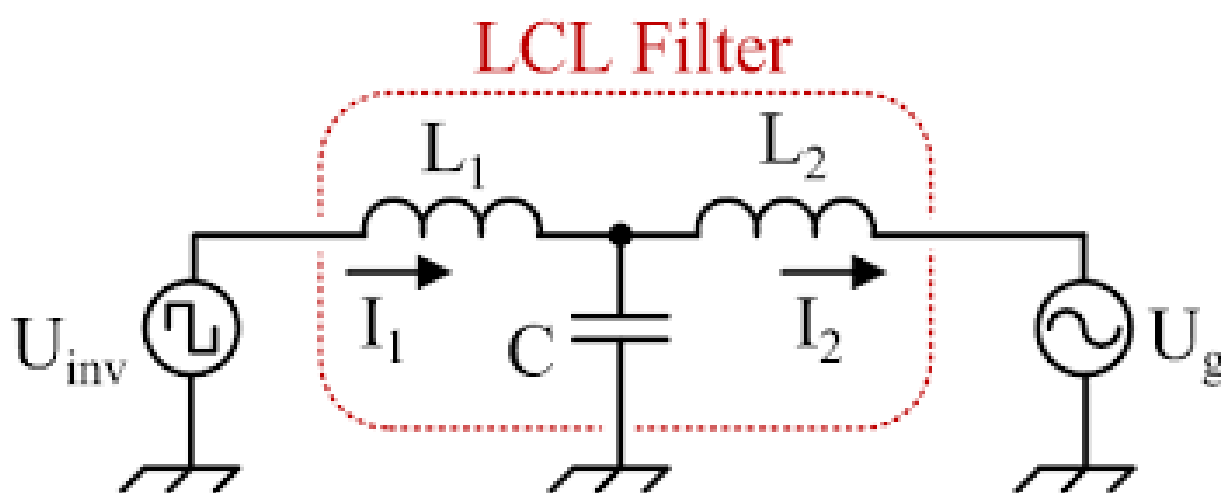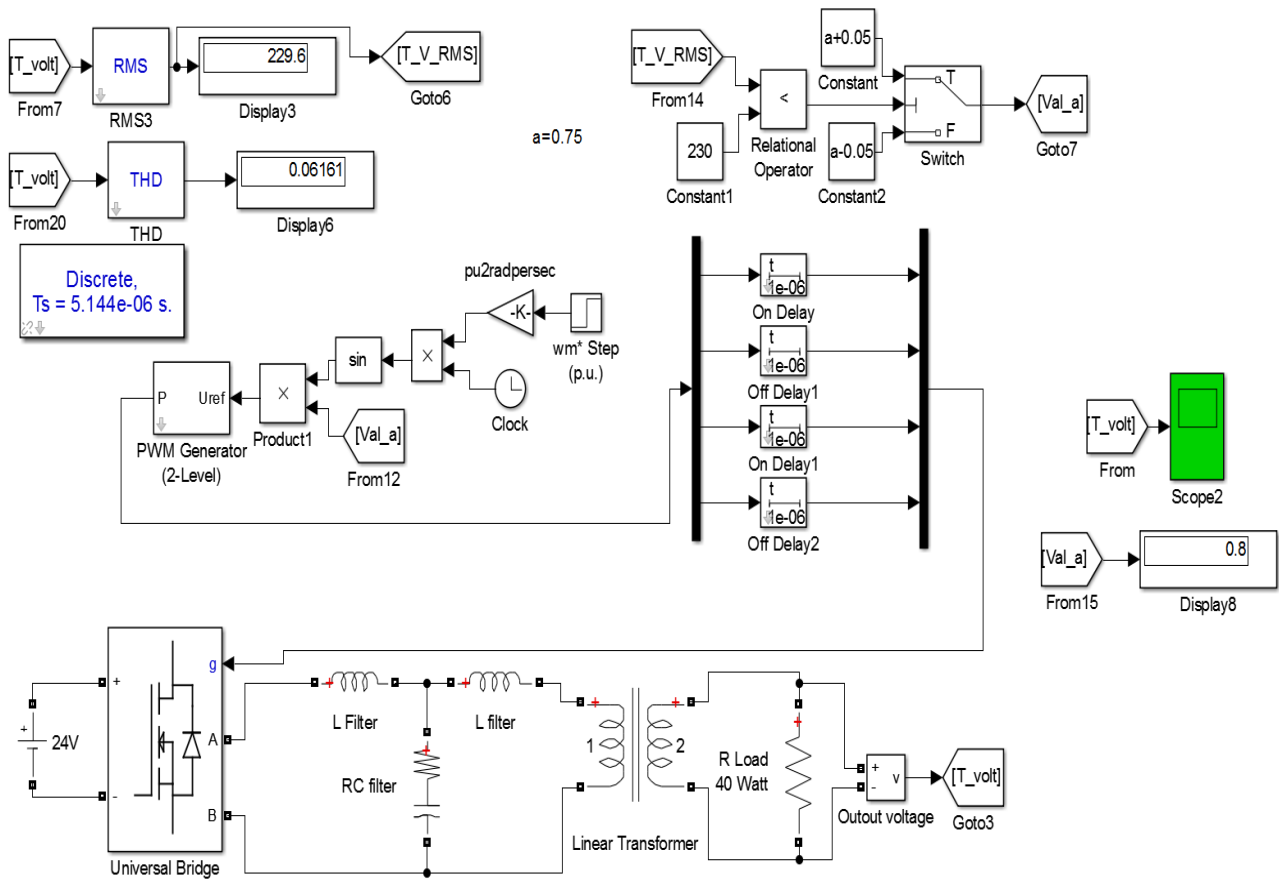

Figure 13: Circuit diagram of a LCL filter

Chapter 3: Simulink Model

L (toward inverter) = 43uH
R=1Ω, **C**=94uF
L (towards transformer) = 106uH
Carrier frequency = 30 KHz
Transformer rating: L.V. Side = 0- 12V, 72VA, 50Hz
                             H.V. Side = 0-220-230V
Load: 10/40/50W, 230 V, 50Hz Resistive type load
In this circuit a battery of 24 volt is used and a MOSFET based inverter is used in bipolar modulation mode. The output of the inverter is fed to an LCL filter to convert the pulsating signal to pure sin. Then the voltage is stepped up using a step-up transformer to 230V. The output is fed to a load and the output voltage is measured using a voltage measurement block. The RMS value of the voltage (T_V_RMS) is compared using a relational operator. The relational operator sends a signal '1' to the switch if T_V_RMS is < 230 and sends a signal '0' to the switch if T_V_RMS is > 230. The switch is used to switch between 2 input signals on certain condition and at a time only one input is connected to the output. The threshold of the switch is set to 0.5. The switch will connect to 'Input 1' if the signal from the relational operator is greater than 0.5 and will connect to input 2 if the output from the relational operator is less than 0.5. 'Input 1' is connected to a block that will increase the value of 'a' (=0.75) by 0.05 and 'Input 2' is connected to a block that will increase the value of 'a' by 0.05. So the output value of the switch will be either 0.7 or 0.8 depending on the condition. This value is multiplied to the sin wave that is used to compare to the carrier frequency to generate SPWM gate pulse for the inverter. This is done to change the pulse width of the SPWM pulse which will change the output voltage. It is done to keep the output voltage nearly constant to 230V. The discrete time delay is used to delay the gate pulses of the MOSFET so that the MOSFET on each branch doesn't get short circuited due to on-off delay. This design helps to keep the output voltage of the inverter constant for variable load ranging from 0-60 Watt (preferring not to load the transformer beyond 80% of its rated VA).

WAVEFORM (simulink scope):

Figure 14: Inverter output voltage for 10 Watt Load

Figure 15: Inverter output voltage for 40 Watt Load

Figure 16: Inverter output voltage for 40 Watt Load

Results:

For 10 Watt load: Voltage regulation = ±(0.8 – 0.6) % ,   THD = (5.6 – 7.5) %
For 40 Watt load: Voltage regulation = ±(0.76 – 0.45) %, THD = (4.5– 6.6) %
For 40 Watt load: Voltage regulation = ±(0.68 – 0.39) %, THD = (4.2 – 6.5) %

Proposed model:
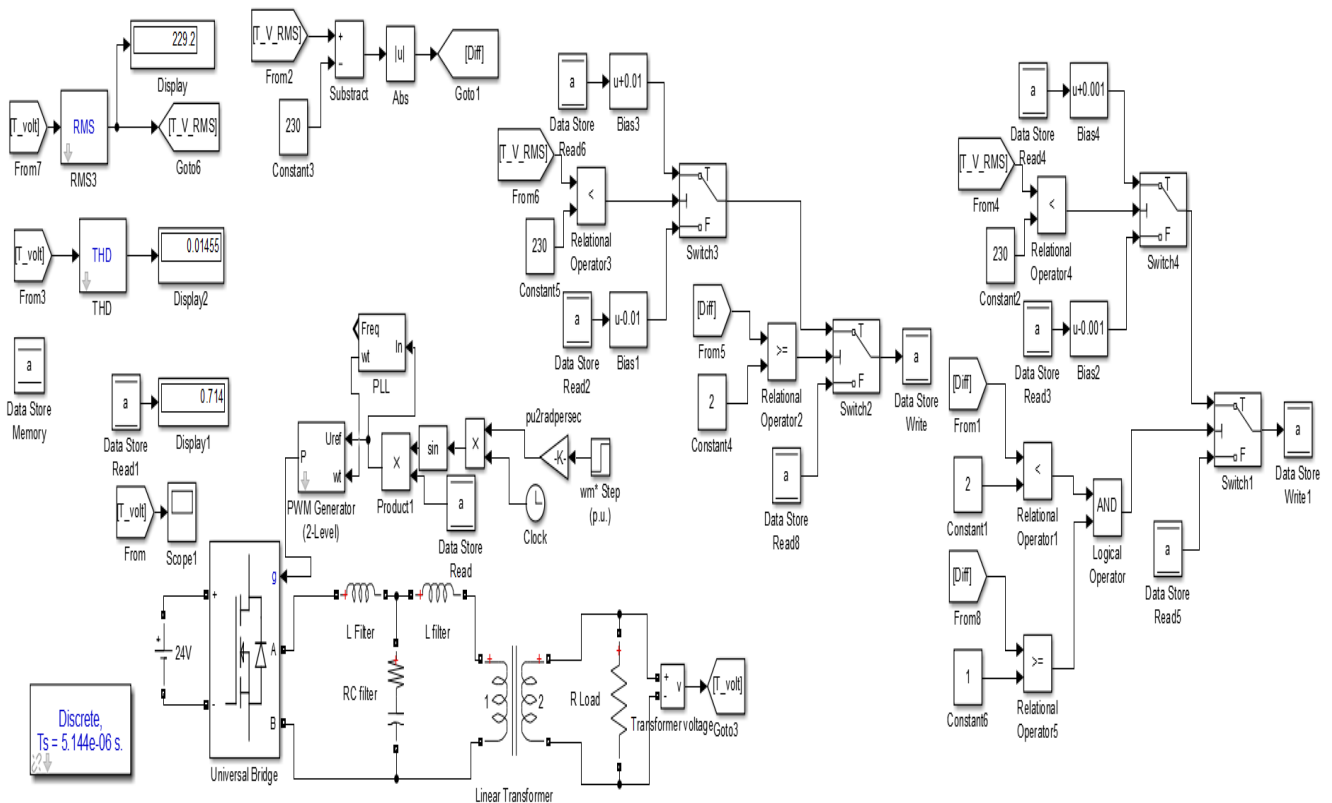
L (toward inverter) = 43uH
R=1Ω, **C=94uF**
L (towards transformer) = 106uH
Carrier frequency = 30 KHz
Transformer rating: L.V. Side= 0- 12V, 72VA, 50Hz
                                    H.V. Side= 0-220-230V
Load: 10/40/50W, 230 V, 50Hz Resistive type load

Here everything is same as the previous model only the control circuit is modified. A memory block is used which stores the value of 'a'(=0.5) and then the primary control circuit increases or decreases the value depending on the output voltage by 0.01 after every 1 millisecond until the output voltage is within 230±2 V. Then there is a secondary control circuit which increases or decreases the value of 'a' by 0.001 after every 1 millisecond until the output voltage is within 230±1 V. The control circuit takes 15 - 20 milliseconds to reach 230V.

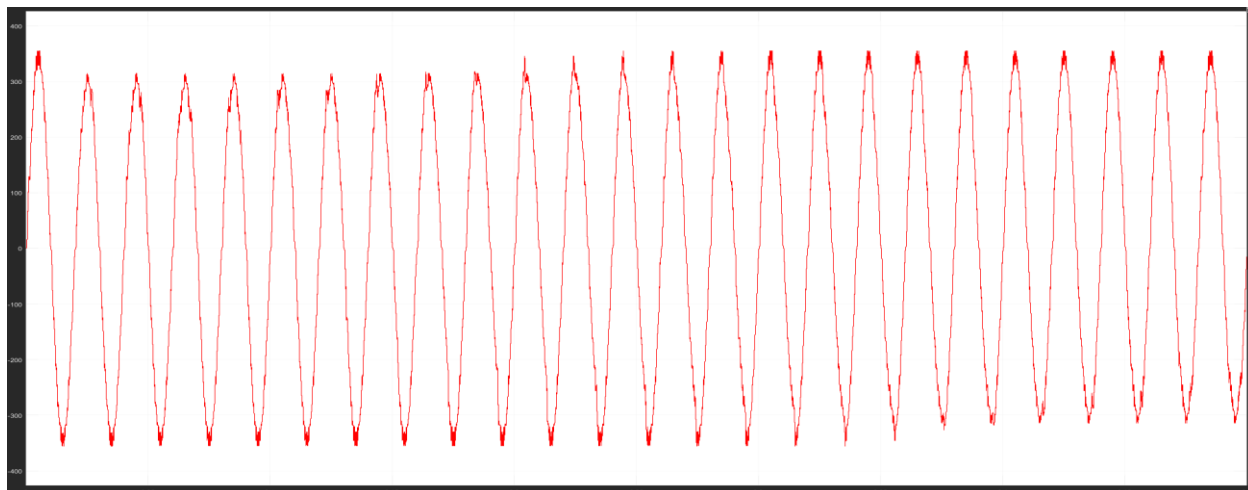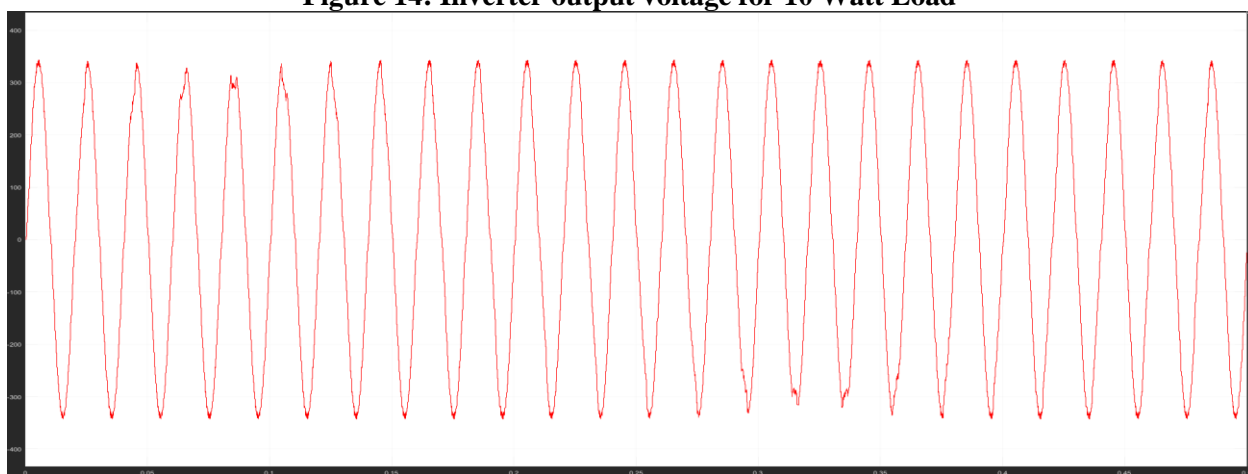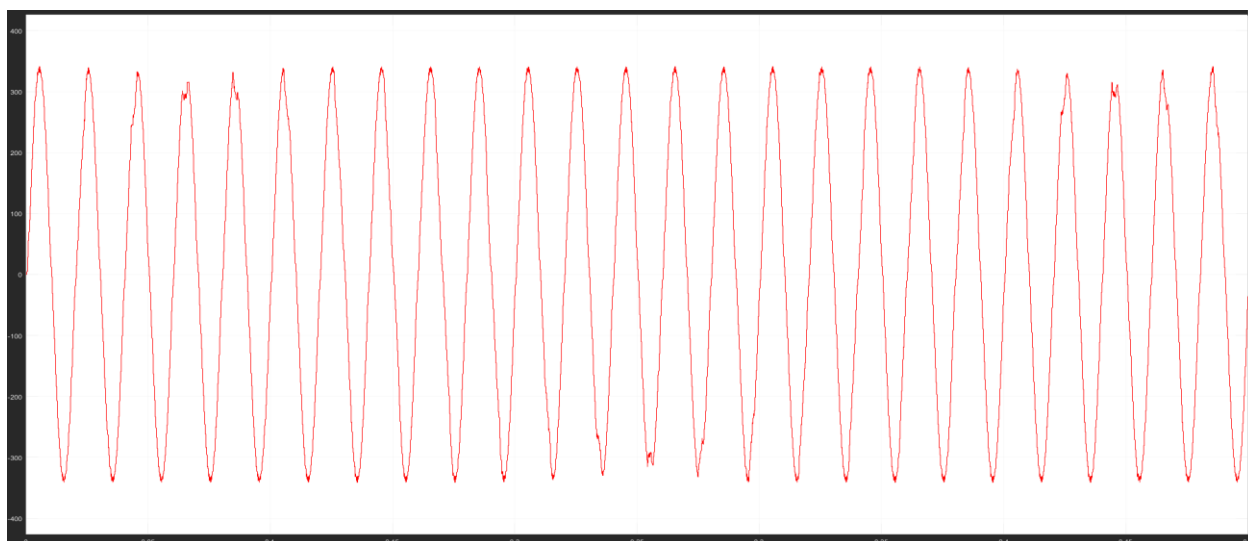# WAVEFORM (Simulink Scope):

Figure 17: Inverter output voltage for 10 Watt Load

Figure 18: Inverter output voltage for 40 Watt Load

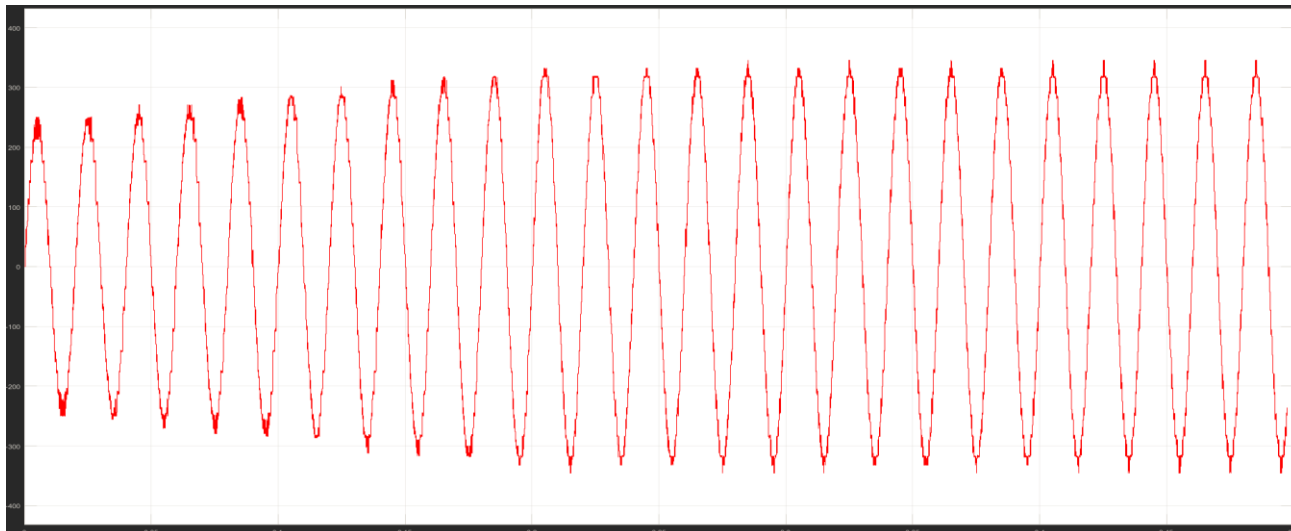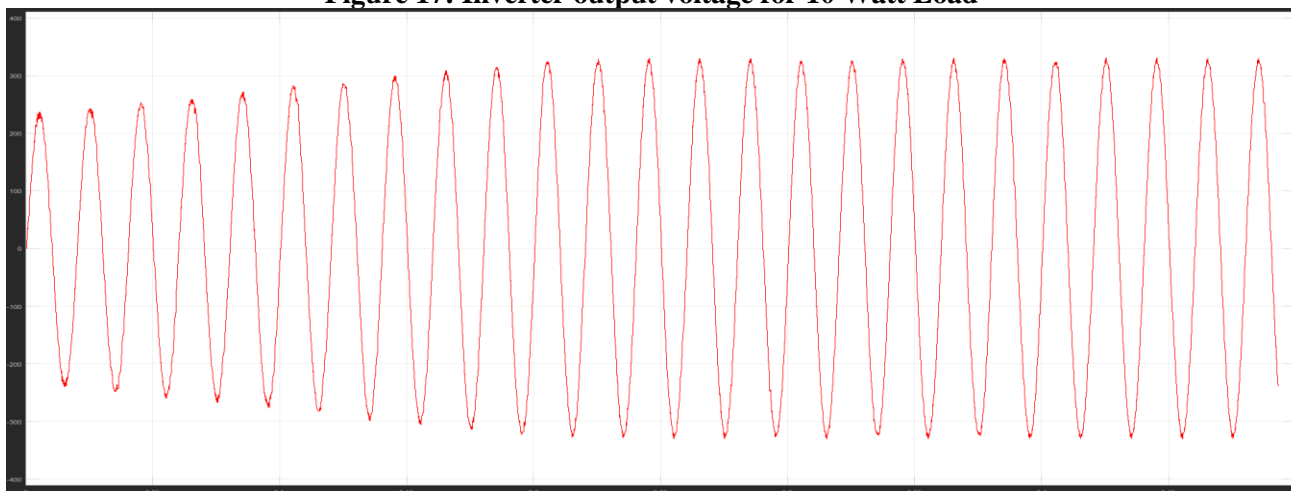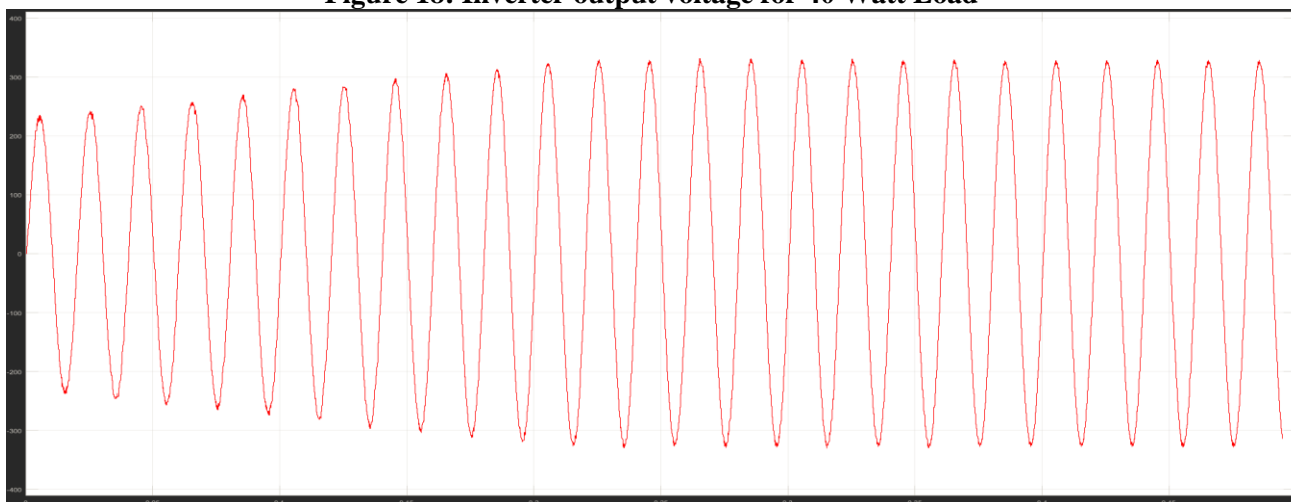**Figure 19: Inverter output voltage for 50 Watt Load**

Results:

For 10 Watt load: Voltage regulation = ±(0.04 – 0.4) % ,   THD = (4 – 5.5) %
For 40 Watt load: Voltage regulation = ±(0.04 – 0.4) %,   THD = (– 6.6) %
For 40 Watt load: Voltage regulation = ±(0.04 – 0.4) %,   THD = (4.2 – 6.5) %

Chapter 4: Components Used

This part consists of all the components we have used during this project work, it includes two parts: one is **software section** and another part is **hardware section**.

Software Section:

This section consists of the all the software we used during this project. The softwares used are:

1. MATLAB (Simulink)
2. d-SPACE

1. MATLAB:

MATrix LABoratory is basically popular with the name MATLAB. In one sentence *MATLAB is the Language of Technical Computing*. The MATLAB platform is optimized for solving engineering and scientific problems. The matrix-based MATLAB language is the world's most natural way to express computational mathematics. Built-in graphics makes it easy to visualize and gain insights from data. A vast library of prebuilt toolboxes lets us get started right away with algorithms essential to our domain. The desktop environment invites experimentation, exploration, and discovery. These MATLAB tools and capabilities are all rigorously tested and designed to work together.

Features of Matlab:

- **Simulink:** Simulink® is a block diagram environment for multidomain simulation and Model-Based Design. It supports simulation, automatic code generation, and continuous test and verification of embedded systems.
- **Language Fundamentals:** Syntax, operators, data types, array indexing and manipulation.
- **Mathematics:** Linear algebra, differentiation and integrals, Fourier transforms, and other mathematics.
- **Graphics:** Two- and three-dimensional plots, images, animation, visualization.
- **Data Import and Analysis:** Import and export, pre-processing, visual exploration.
- **Programming Scripts and Functions:** Program files, control flow, editing, debugging.
- **App Building:** App development using App Designer, GUIDE, or a programmatic workflow.
- **Advanced Software Development:** Object-oriented programming; code performance; unit testing; external interfaces to Java®, C/C++, .NET and other languages.
- **Desktop Environment:** Preferences and settings, platform differences.
- **Supported Hardware:** Support for third-party hardware, such as webcam, Arduino®, and Raspberry Pi™ hardware. Also the MicroLab box can be used to get the real time output from the Simulink files.

About Simulink:

Simulink is a block diagram environment for multi-domain simulation and Model-Based Design. It supports simulation, automatic code generation, and continuous test and verification of embedded systems. Simulink provides a graphical editor, customizable block libraries, and solvers for modeling and simulating dynamic systems. It is integrated with MATLAB, enabling us to incorporate MATLAB algorithms into models and export simulation results to MATLAB for further analysis. To run the model in real time on a target computer, we made use of the Simulink Real- Time™ for HIL simulation, rapid control prototyping, and other real-time testing applications. In this project, our Hardware and Software part both are based on Simulink. In the software part the whole thing is simulated in Simulink and in the hardware part the control signal is also generated using the Simulink file by getting a real time output using ***MicroLab Box and dSPACE*** software.

MicroLab Box and dSPACE:

This hardware MicroLab box is a great product for the real time output using the MATLAB, and the dSPACE is the software part of this package which helps to connect the hardware section (MicroLab Box) with the user and interface it according to the user input.

About MicroLab box-

☐ Compact all-in-one development system for laboratory purposes
☐ Dual-core real-time processor at 2 GHz
☐ User-programmable FPGA
☐ More than 100 channels of high-performance I/O
☐ Dedicated electric motor control features
☐ Ethernet and CAN bus interfaces
☐ Easy I/O access via integrated connector panel

Application Areas:

MicroLab Box is a compact development system for the laboratory that combines compact size and cost-effectiveness with high performance and versatility. MicroLab Box lets to set up control, test or measurement applications quickly and easily, and helps to turn new control concepts into reality. More than 100 I/O channels of different types make MicroLab Box a versatile system that can be used in mechatronic research and development areas, such as robotics, medical engineering, electric drives control, renewable energy, vehicle engineering, or aerospace.

Key Benefits:

High computation power combined with very low I/O latencies provides a great real-time performance. A programmable FPGA gives a high degree of flexibility and let's to run even extremely fast control loops, as required in applications such as electric motor control or active noise and vibration cancellation. MicroLab Box is supported by a comprehensive dSPACE software package, including, e.g., Real-Time Interface (RTI) for Simulink for model-based I/O integration and the experiment software Control Desk®, which provides access to the real-time application during run time by means of graphical instruments.

Figure 20: MicroLab box

Technical Details: -

| Parameter		Specification
Processor	Real-time processor	• Free scale QorIQ P5020, dual-core, 2 GHz • 32 KB L1 data cache per core, 32 KB L1 instruction cache per core, 512 KB L2 cache per core, 2 MB L3 cache total
	Host communication Processor	Free scale QorIQ P1011 800 MHz for communication with host PC
Memory		• 1 GB DRAM • 128 MB flash memory
Programmable FPGA		Xilinx® Kintex®-7 XC7K325T FPGA
Analog input	Resolution and Type	• 8 14-bit channels, 10 Msps, differential; functionality: free running mode • 24 16-bit channels, 1 Msps, differential; functionality: single conversion and burst conversion mode with different trigger and interrupt options
	Input Voltage Range	-10V ... 10 V
Analog input	Resolution and Type	16 16-bit channels, 1 Msps, settling time: 1 μs
	Output Voltage Range	-10V ... 10 V
	Output Current	± 8 mA
Digital I/O		• 48 bidirectional channels, 2.5/3.3/5 V (single-ended); functionality: bit I/O, PWM generation and measurement (10 ns resolution), pulse generation and measurement (10 ns resolution), 4 x SPI Master • 12 bidirectional channels (RS422/485 type) to connect sensors with differential interfaces
Theft protection		Kensington® lock

Table 2: MicroLab Box Technical Details

Real-Time Interface (RTI) using MicroLab box:

RTI lets to concentrate fully on the actual design process and carry out fast design iterations. It extends the C code generator Simulink Coder™ (formerly Real-Time Workshop®) for the seamless, automatic implementation of your Simulink and State flow models on the real-time hardware.

Working with RTI:

To connect the model to a dSPACE I/O board, just drag the I/O module from the RTI block library onto the model and then connect it to the Simulink blocks. All settings, such as parameterization, are available by clicking the appropriate blocks. Simulink Coder™ (formerly Real- Time Workshop®) generates the model code while RTI provides blocks that implement the I/O capabilities of dSPACE systems in Simulink models, thus preparing the model for the realtime application. Your real-time model is compiled, downloaded, and started automatically on the real-time hardware, without having to write a single line of code. RTI guides through the configuration. RTI provides consistency checks, so potential errors can be identified and corrected before or during the build process.

Hardware Section:
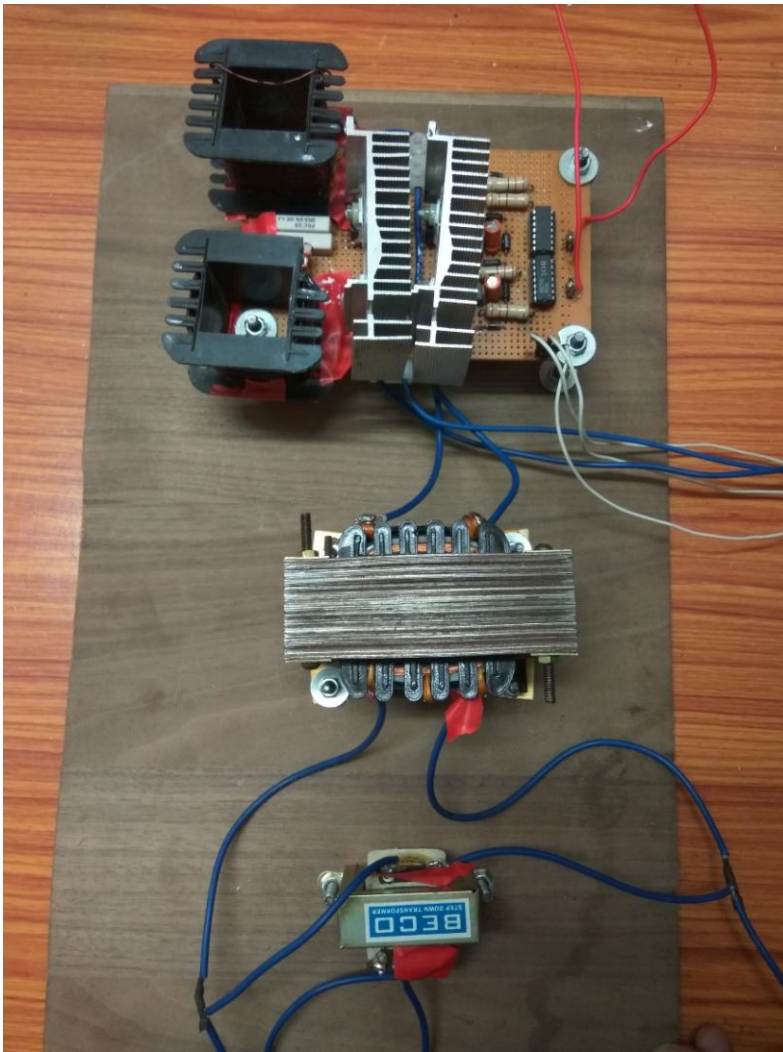
MOSFET based inverter circuit with LCL filter. Heatsink is used for the MOSFET (2 in

Step-up transformer is used for stepping up the voltage from 12 to 230V.

Step-down transformer is used for stepping down output voltage from 230V to 6V for the dSPACE to measure.
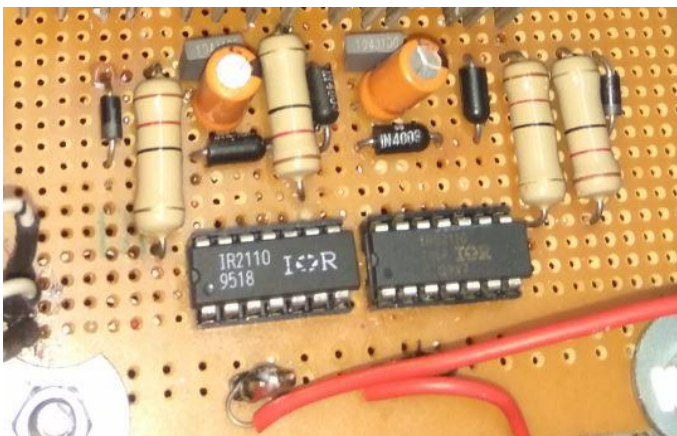
Figure 21: Hardware Circuit

Figure 22: IR2110 Based Gate Driver Circuit

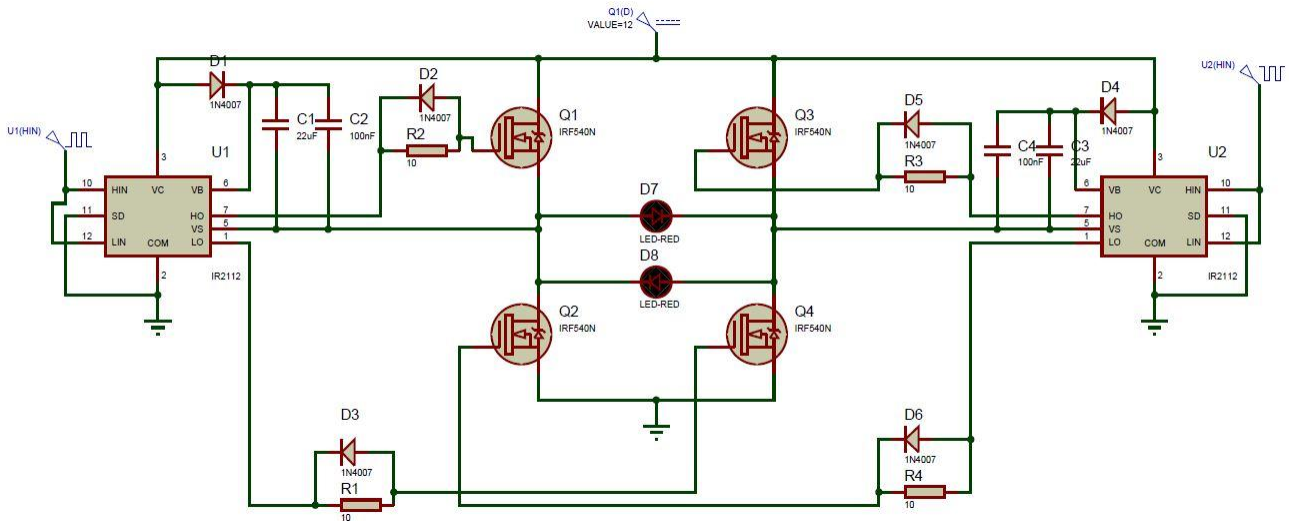**Proteus model for the MOSFET Gate Driver Circuit:**

Figure 23: Proteus simulation circuit

Gate Driver Circuit consists of:
- IR2110
- 1N4007 Diode
- 10 Ohm Resistance
- 12V, 5V DC Source
- 22uF, 0.1uF capacitors

Inverter Circuit Consist of:
- IRF540N MOSFET
- 10 Ohm, 0.1uF Capacitor for Snubber
- Heatsink
- 24V DC Power Supply
- L (towards inverter) = 43uF, R= 1Ohm/5W, L (towards transformer) = 106uF for LCL Filter

Transformer Ratings:
- Step-up Transformer :   L.V. side- 0-12V, 6Amp
                             H.V. side- 0-220-230V, 50 Hz
- Step-down Transformer :   L.V. side- 6-0-6V, 500mA
                             H.V. side- 0-230V, 50 Hz
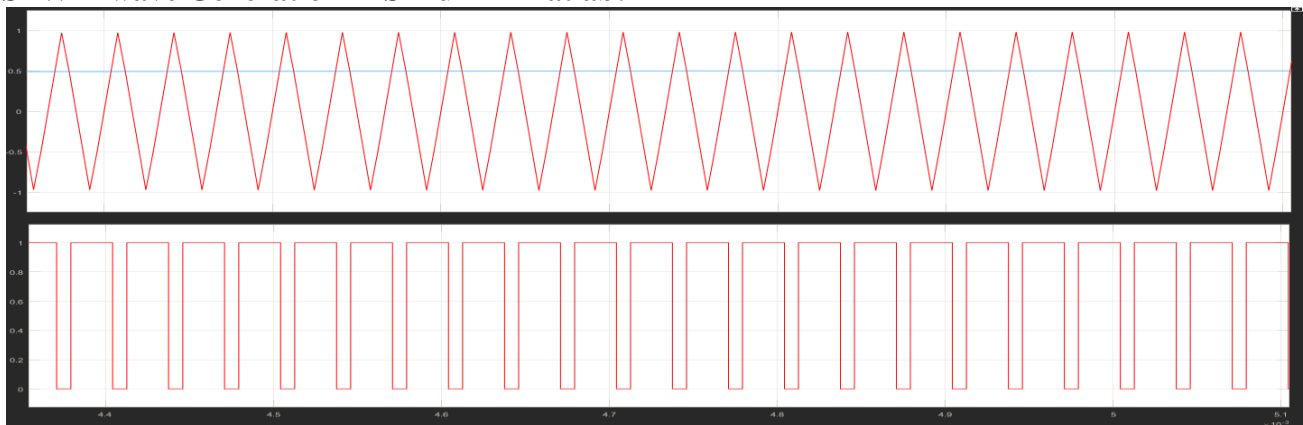
SPWM wave Generation in Simulink Matlab:

Figure 24: Simulink SPWM Generation

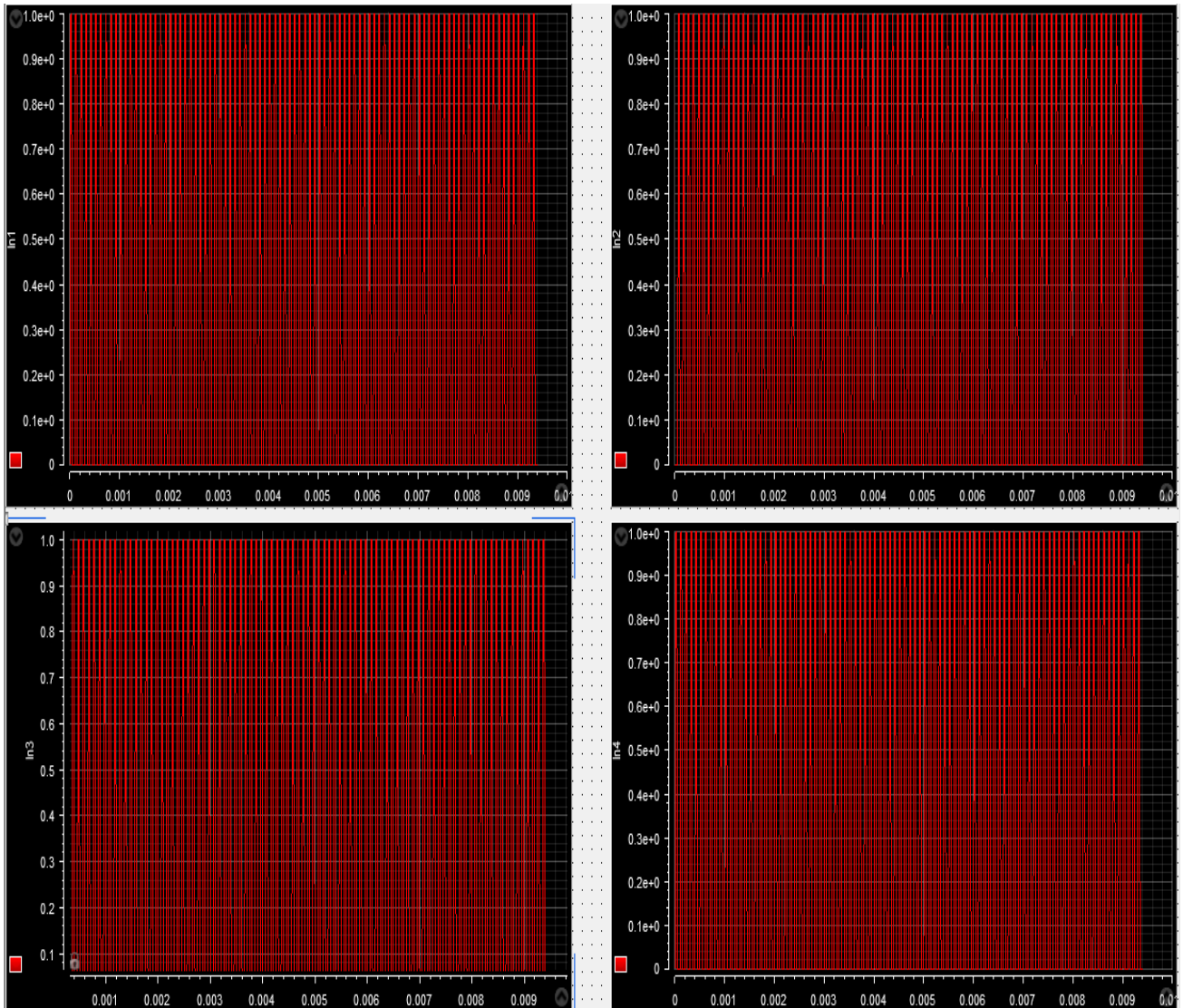**dSPACE output signals for the MOSFET :**

Figure 25: Dspace Pulse output for 4 MOSFETS

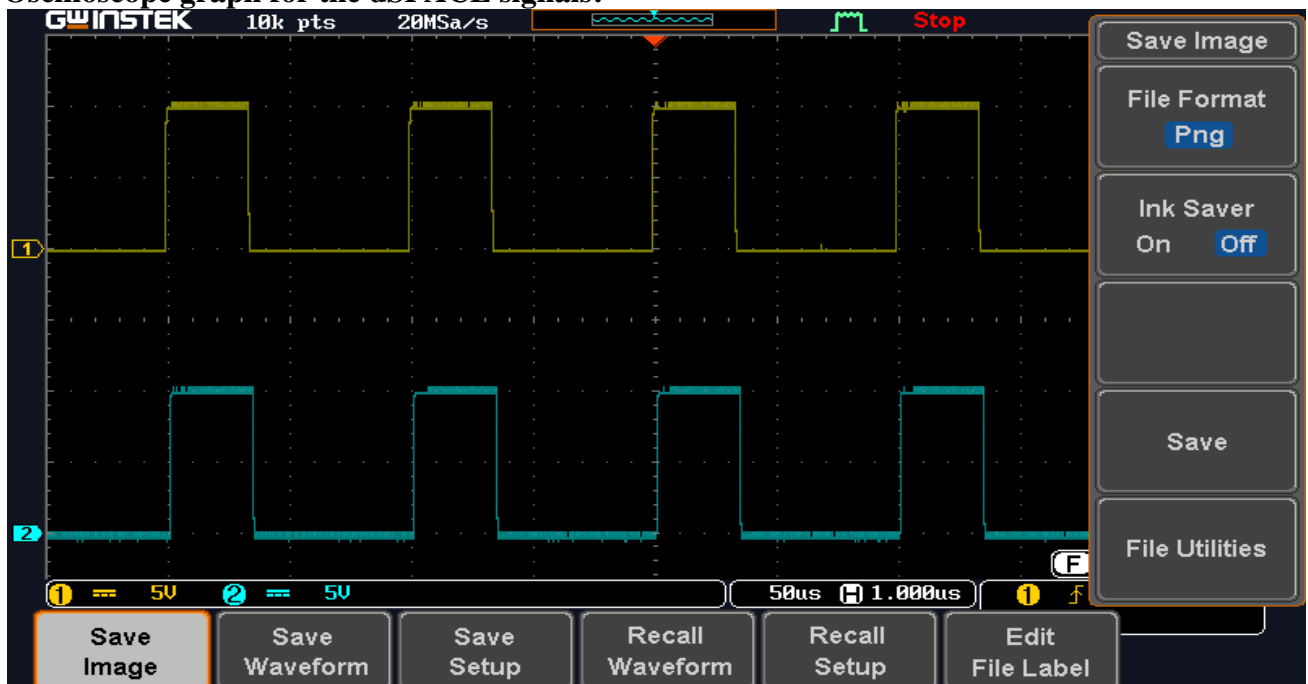**Oscilloscope graph for the dSPACE signals:**

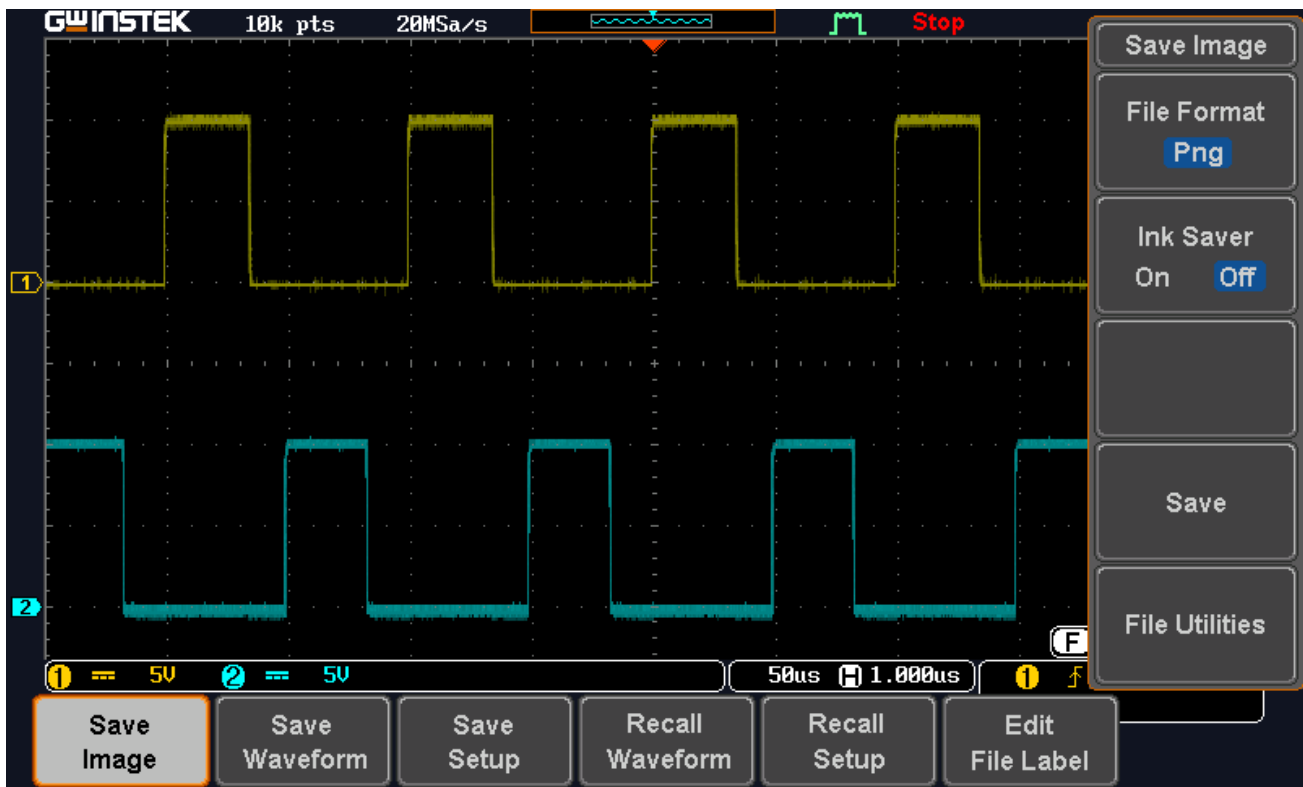**Figure 26: Pulse for MOSFET pairs 1, 4 and 2, 3**

Figure 27: Pulse for MOSFET pairs 1,2 and 3,4

The component details are given below:

1. **IRF540N MOSFET:** 100V, 33Amps, 0.044mOhm. This N-Channel enhancement mode silicon gate power field effect transistor is an advanced power MOSFET designed, tested, and guaranteed to withstand a specified level of energy in the breakdown avalanche mode of operation. All of these power MOSFETs are designed for applications such as switching regulators, switching converters, motor drivers, relay drivers, and drivers for high power bipolar switching transistors requiring high speed and low gate drive power. They can be operated directly from integrated circuits.
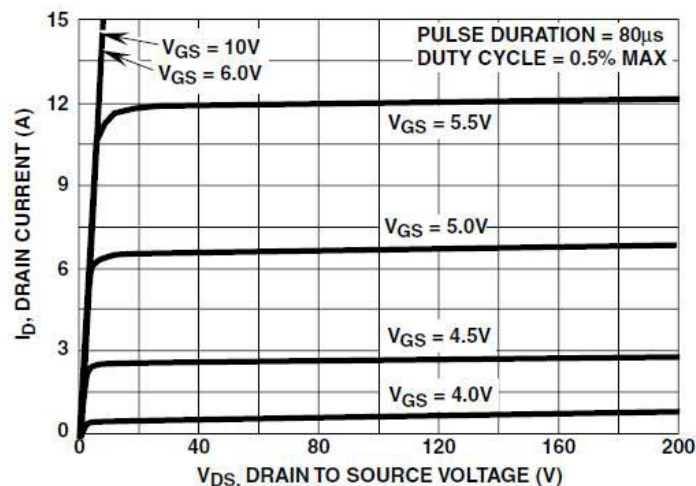
The MOSFET (Metal Oxide Semiconductor Field Effect Transistor) is a semiconductor device which is widely used for switching and amplifying electronic signals in the electronic devices. The MOSFET is a core of integrated circuit and it can be designed and fabricated in a single chip because of these very small sizes. The MOSFET is a four terminal device with source(S), gate (G), drain (D) and body (B) terminals. The body of the MOSFET is frequently connected to the source terminal so making it a three terminal device like field effect transistor. The MOSFET is very far the most common transistor and can be used in both analog and digital circuits. The MOSFET works by electronically varying the width of a channel along which charge carriers flow (electrons or holes). The charge carriers enter the channel at source and exit via the drain. The width of the channel is controlled by the voltage on an electrode is called gate which is located between source and drain. It is insulated from the channel near an extremely thin layer of metal oxide.

The MOSFET can function in two ways:

1. Depletion Mode
2. Enhancement Mode

Depletion Mode:
When there is no voltage on the gate, the channel shows its maximum conductance. As the voltage on the gate is either positive or negative, the channel conductivity decreases.

Enhancement mode:
When there is no voltage on the gate the device does not conduct. More is the voltage on the gate, the better the device can conduct.

Working Principle of MOSFET:
The aim of the MOSFET is to be able to control the voltage and current flow between the source and drain. It works almost as a switch. The working of MOSFET depends upon the MOS capacitor. The MOS capacitor is the main part of MOSFET. The semiconductor surface at the below oxide layer which is located between source and drain terminal. It can be inverted from p-type to n-type by applying a positive or negative gate voltage respectively. When we apply the positive gate voltage the holes present under the oxide layer with a repulsive force and holes are pushed downward with the substrate. The deflection region populated by the bound negative charges which are associated with the acceptor atoms. The electrons reach channel is formed. The positive voltage also attracts electrons from the n+ source and drain regions into the channel. Now, if a voltage is applied between the drain and source, the current flows freely between the source and drain and the gate voltage controls the electrons in the channel. Instead of positive voltage if we apply negative voltage, holes in the channel will be formed under the oxide layer.
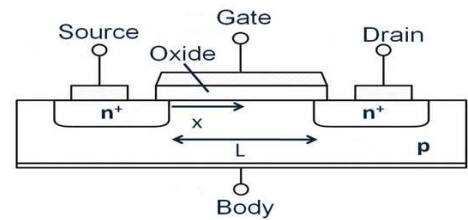
2. **IR2110 MOSFET Gate Driver IC:** The IR2110/IR2113 are high voltage, high speed power MOSFET and IGBT drivers with independent high and low side referenced output channels. Proprietary HVIC and latch immune CMOS technologies enable ruggedized monolithic construction. Logic inputs are compatible with standard CMOS or LSTTL output, down to 3.3V logic. The output drivers feature a high pulse current buffer stage designed for minimum driver cross-conduction. Propagation delays are matched to simplify use in high frequency applications. The floating channel can be used to drive an N-channel power MOSFET or IGBT in the high side configuration which operates up to 500 or 600 volts.
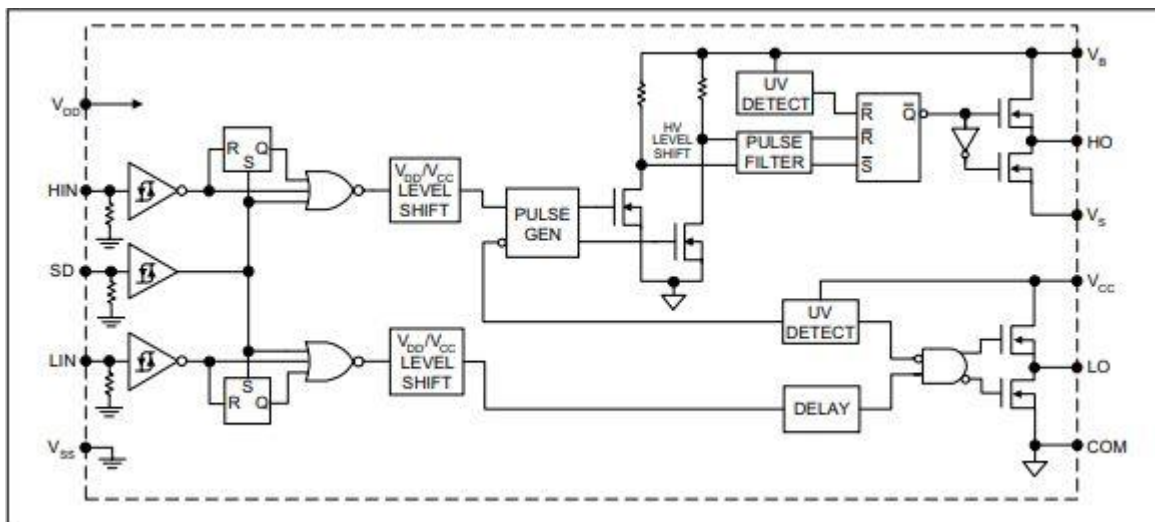
Figure 28: Functinal block diagram of IR2110

3. **Inductor design:**

   Inductor 1= 43uF (towards inverter)

   $L = (\mu_o \, \mu_r \, N^2 A) / 1$
   Here Breadth (b)= 2.7cm, Width (w)= 3.3cm, Length (l)= 3.7cm
   Area = b x w = 2.7 x 3.3 cm^2 = 8.91 cm^2 = 8.91 x 10^{-4} mm^2
   $\mu_o = 4\Pi$ x 10^{-7} H/m
   μ_r = 1 (for air core)

   $N = (L \, l \, / \, \mu_o \, \mu_r \, A)^{0.5}$ = 16 turns

   Inductor 2= 106uF (towards transformer)

   $N = (L \, l \, / \, \mu_o \, \mu_r \, A)^{0.5}$ = 57 turns

4. **Transformer Rating:**
   Step-up Transformer:
   The maximum peak voltage MOSFET can give is 24V as the battery is of 24V DC. Converting it to RMS voltage we get maximum of 17V AC. So the transformer should be selected for a L.V. side rating of less than or equal to 17 V. In the market the nearest available L.V. side rating was 12 V. The maximum current flowing through the L.V. winding is 5Amps (for 60 VA). So the L.V. winding rating is selected for 6Amps for safety purposes.

   Step-down Transformer:
   The dSPACE was capable of handling ±10V DC max. for the DAC to measure the output voltage . So the nearest value of the transformer available in the market was 6V AC (peak voltage is 6 x 1.414 = 8.5V).

Conclusion:

From the two models we can see that the output voltage regulation is better for the proposed model and also the THD is very less than the current model in use. The regulation is almost same for every type of load in the proposed model. The only problem is that the control circuit of the proposed model is bigger and is a bit slower than the current model in use. The response time can be decreased by using a faster controller that can increase the performance of the inverter and also by using filters of variable switching frequency the THD can be decreased further.