EE560 : POWER ELECTRONIC CONVERTERS

A

REPORT ON

SINGLE AND THREE PHASE VOLTAGE SOURCE INVERTERS

INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI (ASSAM)

SUBMITTED BY

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1. Introduction

Dc-to-ac converters are known as inverters. The function of an inverter is to change a DC input voltage to a symmetric ac output voltage of desired magnitude and frequency . The output voltage could be fixed or variable at a fixed or variable frequency. A variable output voltage can be obtained by varying the input DC voltage and maintaining the gain of the inverter constant. On the other hand, if the DC input voltage is fixed and it is not controllable, a variable output voltage can be obtained by varying the gain of the inverter, which is normally accomplished by pulse-width-modulation (PWM) control within the inverter. The inverter gain may be defined as the ratio of the ac output voltage to DC input voltage.

A Sinusoidal Pulse Width Modulation (SPWM) Voltage Source Inverter is a key component in modern power electronics and motor drive systems. It is used to convert direct current (DC) power into alternating current (AC) power, typically for applications like motor drives, renewable energy systems, and uninterruptible power supplies. SPWM is a control technique that modulates the width of pulses in the inverter's output to generate a nearly sinusoidal AC voltage. This modulation strategy helps reduce harmonic distortion and achieve a smooth output waveform, making it suitable for various AC voltage generation tasks. SPWM inverters are widely employed in industries and applications where high-quality AC power is essential.

2. Single phase full bridge inverter

A single phase bridge VSI consists of four choppers. When the switches S_1 and S_2 are turned on at a time, then the input voltage (V_{in}) appears across the load. If the switches S_3 and S_4 are turned on at the same time, the voltage across the load is reversed ($-V_{in}$)

Circuit Diagram is given below:

Single-phase Sinusoidal Pulse Width Modulation (SPWM) voltage source inverters are commonly used in various applications to convert DC power into AC power.

Basic Principle: The main purpose of an inverter is to convert a DC voltage source into an AC voltage source. In the case of single-phase SPWM, the output waveform is a sinusoidal AC voltage.

Switching Devices: Typically, power electronic devices like MOSFETs or IGBTs are used as switching devices in the inverter. These devices control the flow of current from the DC source to the load.

PWM Technique: SPWM uses Pulse Width Modulation to generate an AC output voltage that

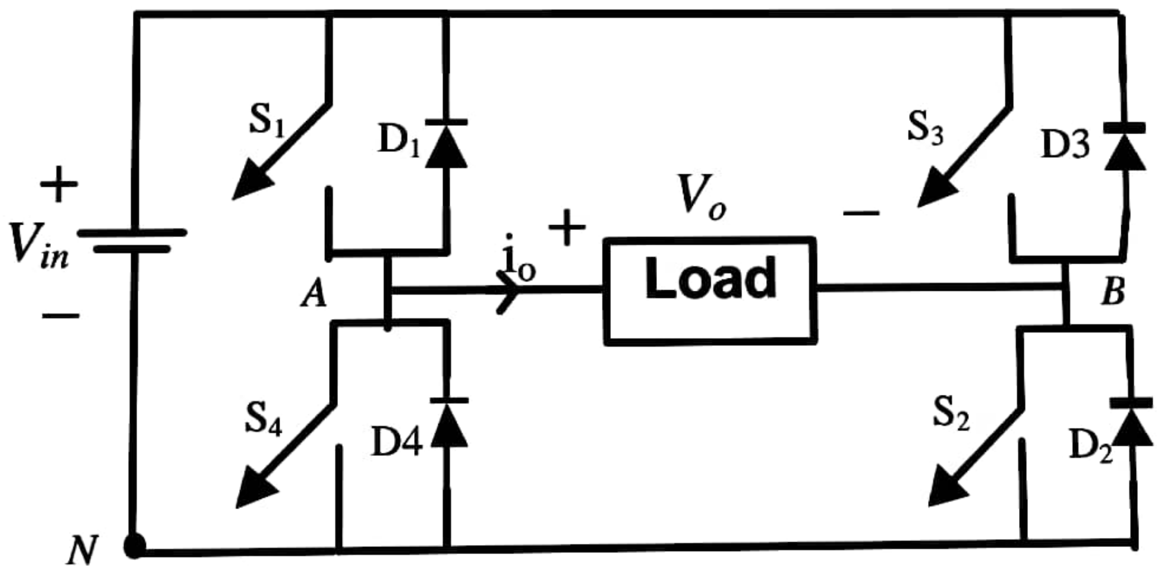

Figure 1: Single phase full bridge voltage source inverter

approximates a sine wave. The technique involves switching the inverter's devices on and off at a high frequency (carrier frequency), and the width of the pulses is modulated to achieve the desired output waveform.

Reference Signal: The reference signal is a sine wave that represents the desired AC output voltage. This reference signal is compared to a high-frequency triangular waveform (carrier waveform).

Comparison and Generation of Pulses: The reference signal is compared to the triangular waveform. Depending on the instantaneous values of these signals, the switching devices are controlled to generate the required pulse width. If the reference signal is higher than the triangular waveform, the corresponding switch is turned on; otherwise, it's turned off.

Output Voltage and Frequency Control: By adjusting the reference signal's amplitude and frequency, you can control the output voltage magnitude and frequency to match the desired AC requirements.

Harmonics: Depending on the modulation index and the switching frequency, harmonics can be present in the output waveform. These harmonics can be mitigated by adjusting the modulation index or using higher switching frequencies.

PWM with Bipolar voltage switching

Comparision with spwm:

The reference signal is compared with the triangular carrier signal to generate the switching pulses.

The switching pulses for each device in the inverter are generated based on the comparison between referrence and Carrier signals. The devices (typically MOSFETs or IGBTs) are switched on and off accordingly to create the PWM waveform.

During wt = 0 to π

if $v_{control} > v_{tri}$ switches s_1 and s_2 on , $V_o = V_{in}$

if $v_{control} < v_{tri}$ switches s_3 and s_4 on , $V_o = -V_{in}$

During wt = $\pi to 2\pi$

if $|v_{control}| > |v_{tri}|$ switches s_3 and s_4 on , $V_o = -V_{in}$

if $|v_{control}| < |v_{tri}|$ switches s_1 and s_2 on, $V_o = V_{in}$

PWM with Unipolar voltage switching:

In PWM with unipolar voltage switching , the switches in the two legs of the full bridge inverter are not switched at a time. Here leg 1 and 2 of inverter are controlled by comparing v_{tri} with v_{ref} and $-v_{ref}$ respectively. The comparision of v_{ref} with triangular waveforms results in the following logic signals to control the switches in leg 1:

$v_{ref} > v_{tri}$ switch S_1 ON and $v_{AN} = V_{in}$

$v_{ref} < v_{tri}$ switch S_4 ON and $v_{AN} = 0$

For controlling the leg 2 switches , $-v_{ref}$ is compared with the same triangular waveform, which yields the following :

$-v_{ref} > v_{tri}$ switch S_3 ON and $v_{BN} = V_{in}$

$-v_{ref} < v_{tri}$ switch S_2 ON and $v_{BN} = 0$

The fundamental frequency component in the output voltage can be obtained by

$V_{o1} = m_a V_{in} sin(wt)$

Applications: Single-phase SPWM voltage source inverters find applications in various areas like uninterruptible power supplies (UPS), motor drives, renewable energy systems, and more, where precise control of AC voltage is needed.

Advantages: SPWM provides good waveform quality with relatively simple control, and it's suitable for low to moderate power applications.

Disadvantages: It may suffer from high switching losses at high frequencies, and it's less efficient than other modulation techniques like Sine Triangle PWM at low modulation indices.

The PWM-generated pulses result in a staircase-like waveform. To smooth this into a sinusoidal waveform, an output filter (typically an LC filter) is used. This filter attenuates the high-frequency components, leaving the fundamental frequency (desired sine wave) at the output.

3. Analogy of Bipolar and Unipolar SPWM :

Analogies can help explain the differences between bipolar and unipolar Sinusoidal Pulse Width Modulation (SPWM):

Bipolar SPWM is like a seesaw: In bipolar SPWM, the voltage or current waveform swings both above and below a reference level (usually zero). It's akin to a seesaw that tilts in both directions, with positive and negative swings.

Unipolar SPWM is like a swinging gate: In unipolar SPWM, the waveform only swings above or below the reference level, but not both simultaneously. It's similar to a gate that swings in one direction, staying on one side of the reference point.

Bipolar SPWM is like a balanced scale: In bipolar SPWM, the output waveform oscillates above and below a reference level, creating both positive and negative voltage or current cycles. This is akin to a balanced scale that tips in both directions.

Unipolar SPWM is like a pendulum: In unipolar SPWM, the waveform oscillates only in one direction, either above or below the reference level, but not both simultaneously. This is similar to a pendulum that swings back and forth on one side of its resting position.

4. Simulation of single phase voltage source inverter :

For bipolar pulse width modulation

Specifications: input voltage = 90 V , peak to peak voltage of triangular signal = 2V , frequency of triangular signal = 5Khz , frequency of sinusoidal signal = 50 Hz

For Resistive Load : R = 2.4 ohm

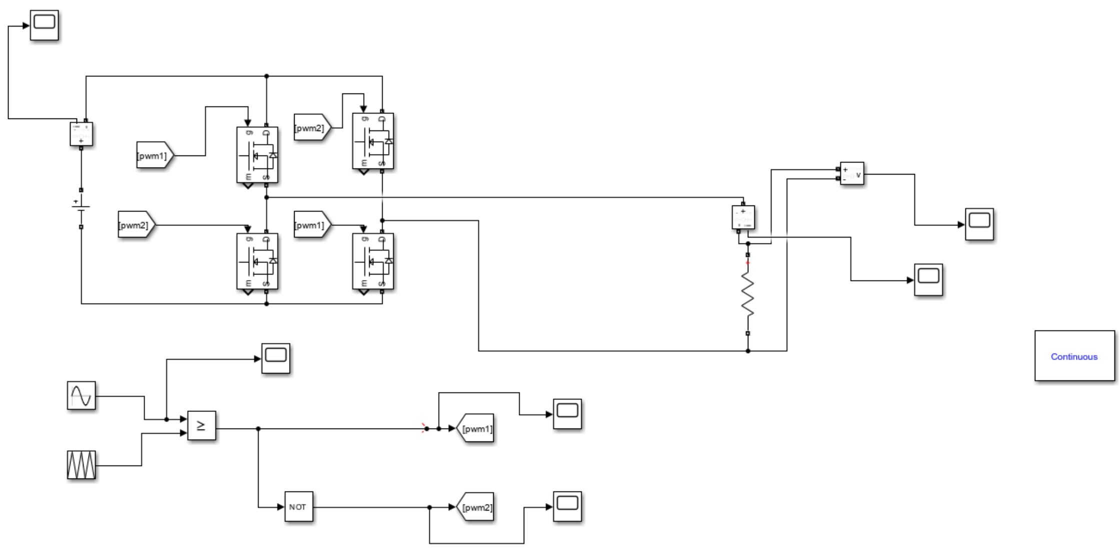

Figure 2: Single phase full bridge voltage source inverter

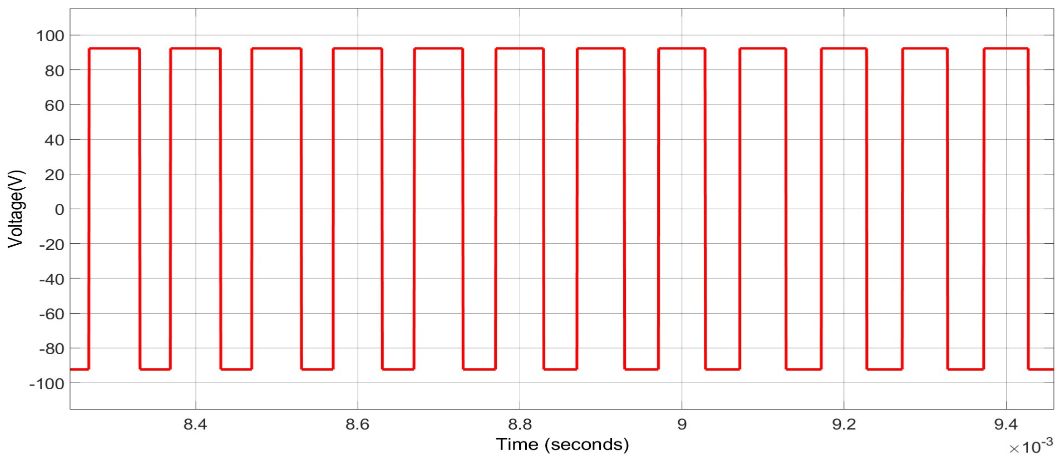

Figure 3: output voltage

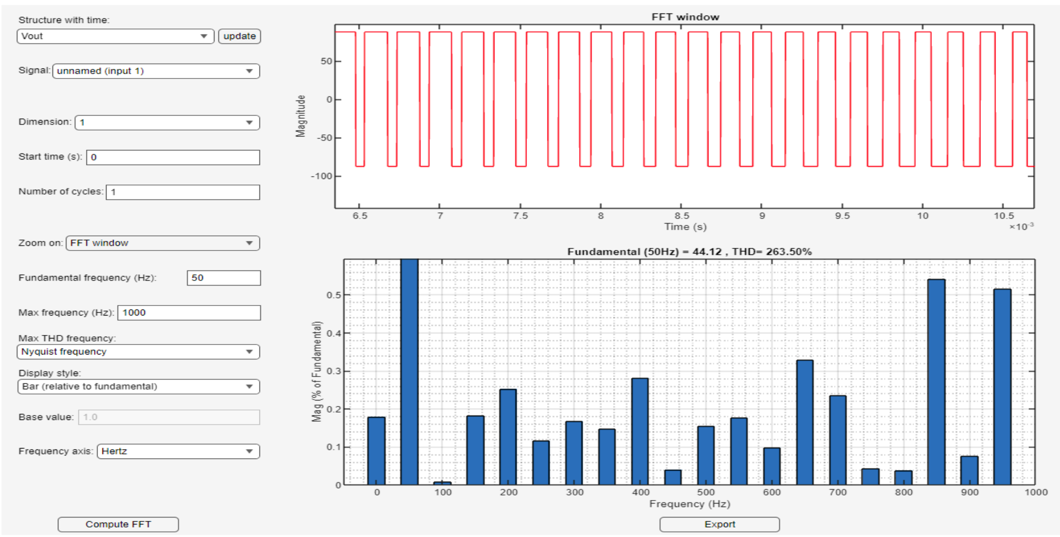

Figure 4: harmonic analysis of load voltage

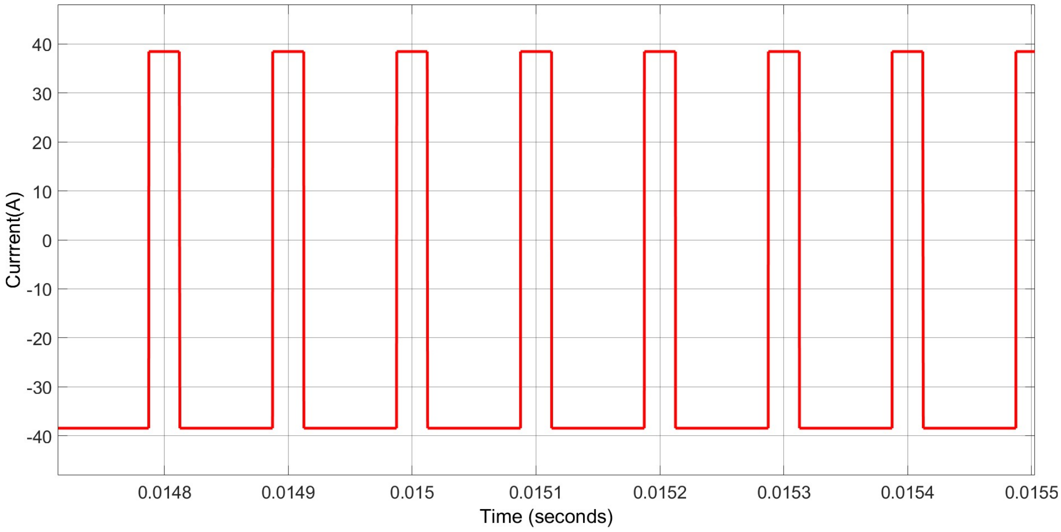

Figure 5: output current

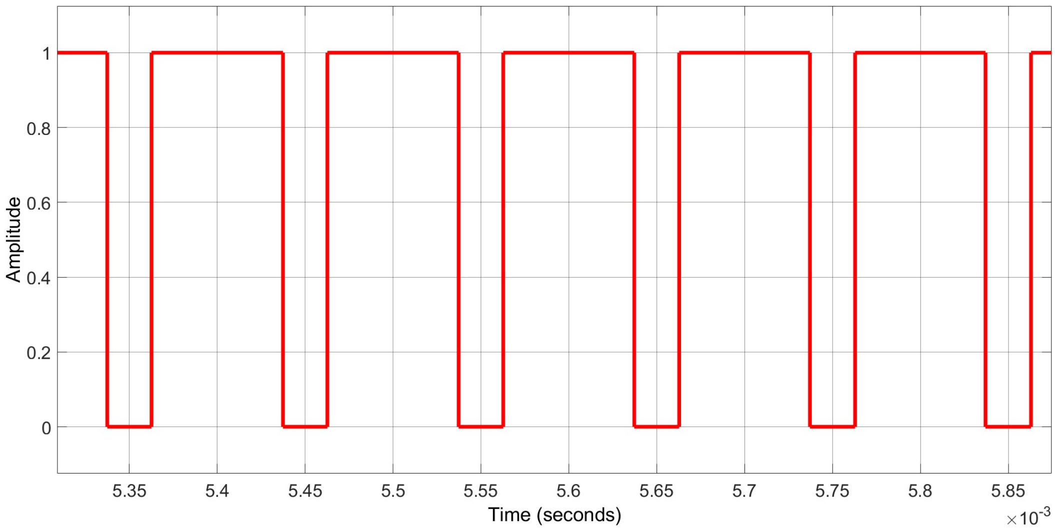

Figure 6: Switching pulse for switches S_1 and S_2

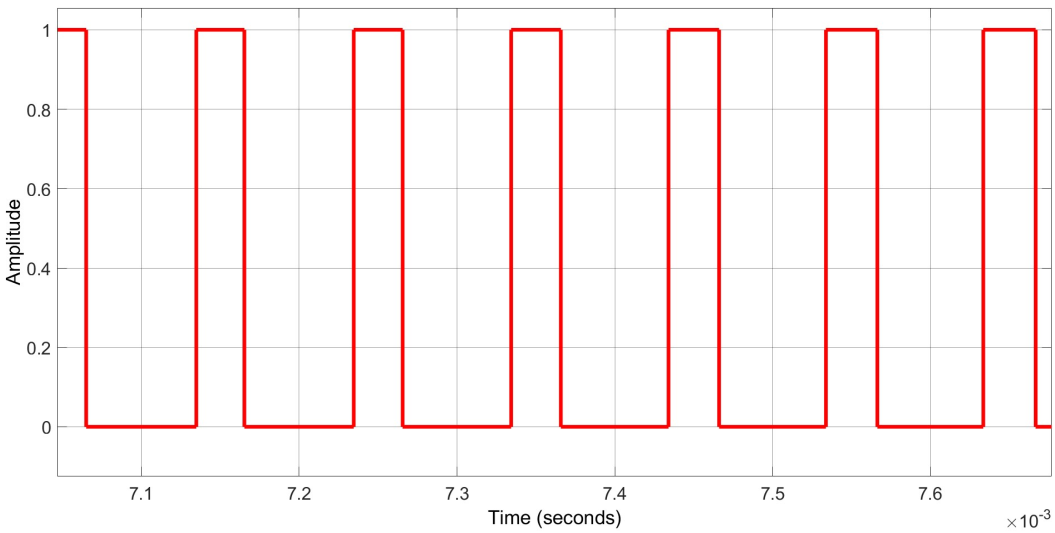

Figure 7: Switching pulse for switches S_3 and S_4

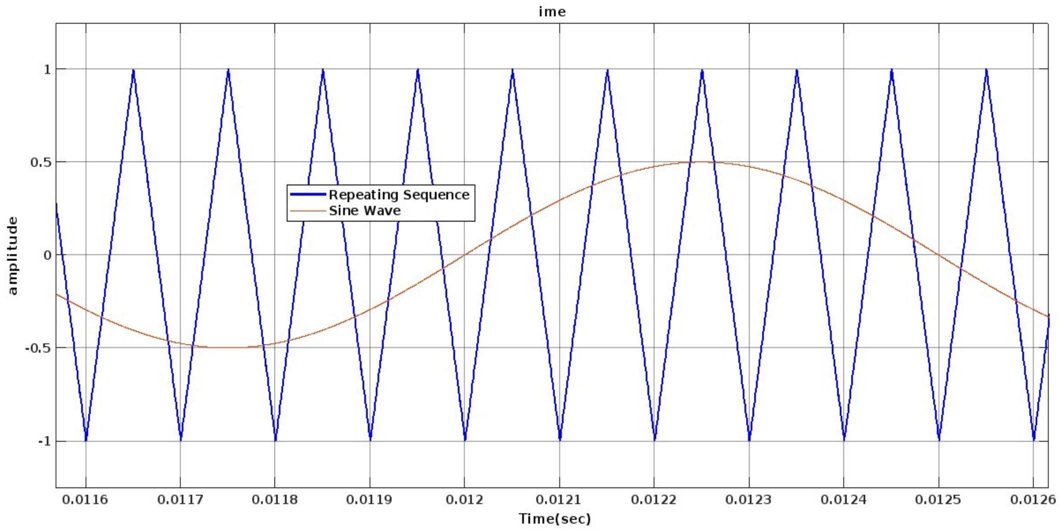

Figure 8: control and triangular signal

For Inductive Load L = 1 mH

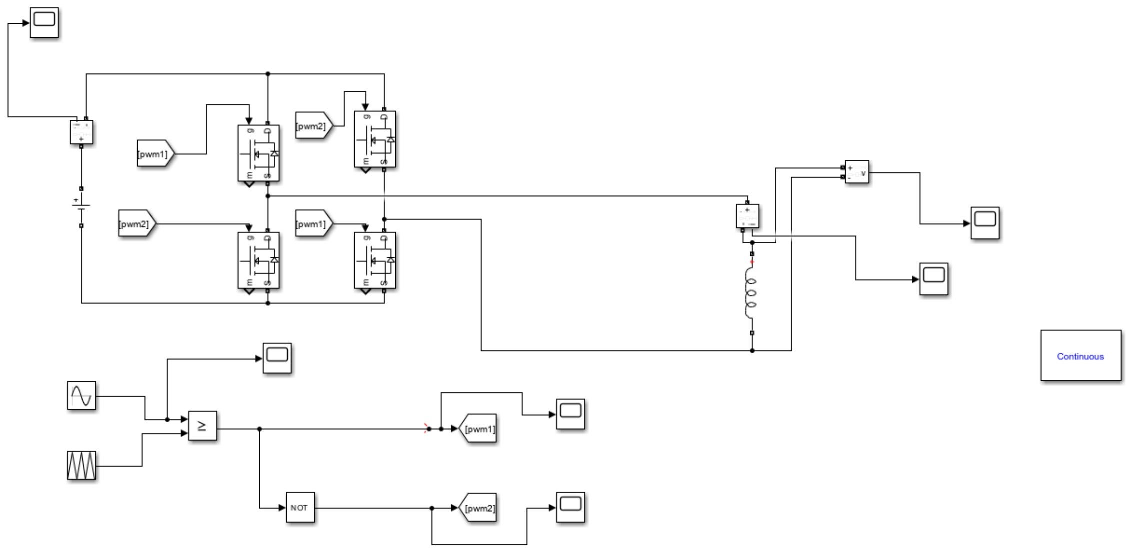

Figure 9: Single phase full bridge voltage source inverter with L load

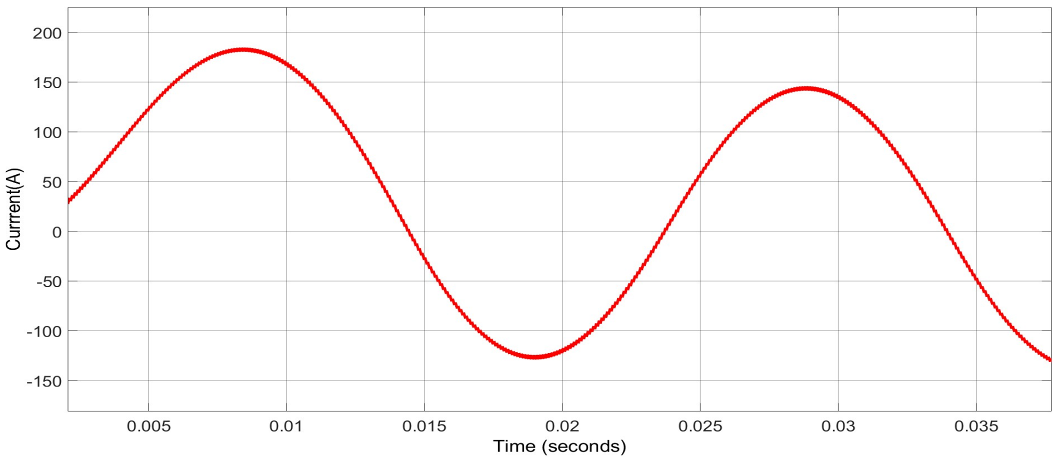

Figure 10: output current

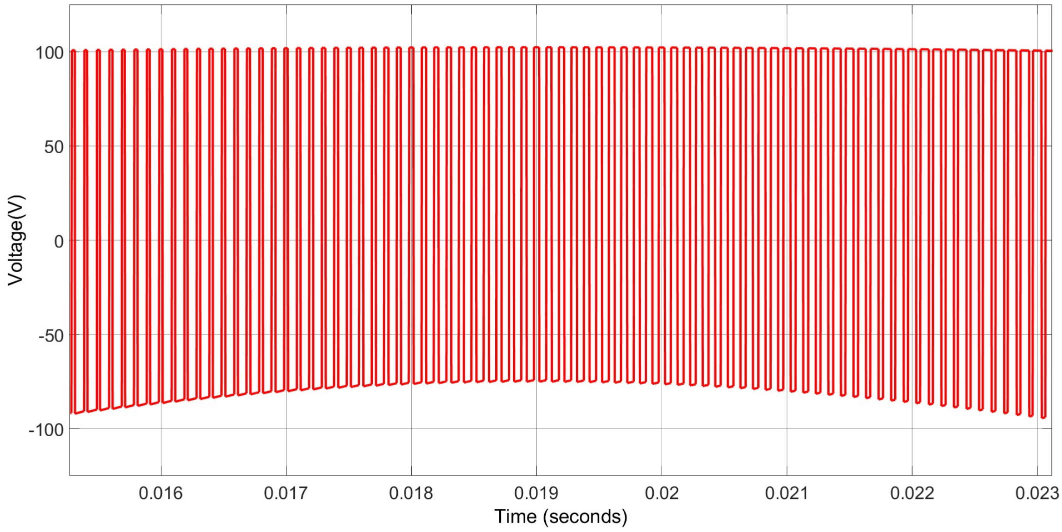

Figure 11: output voltage

For RL load

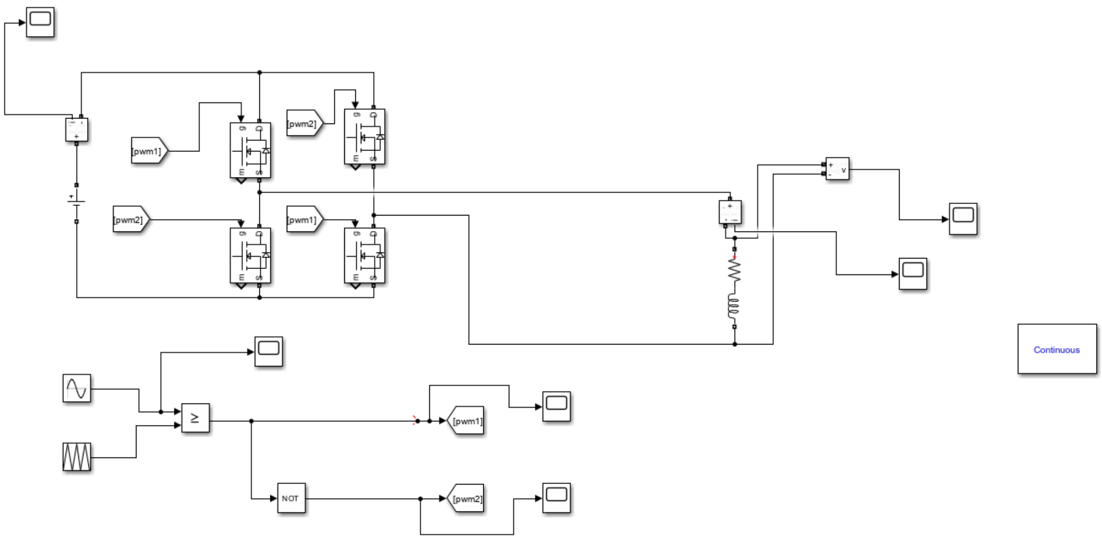

Figure 12: Single phase full bridge voltage source inverter with RL load

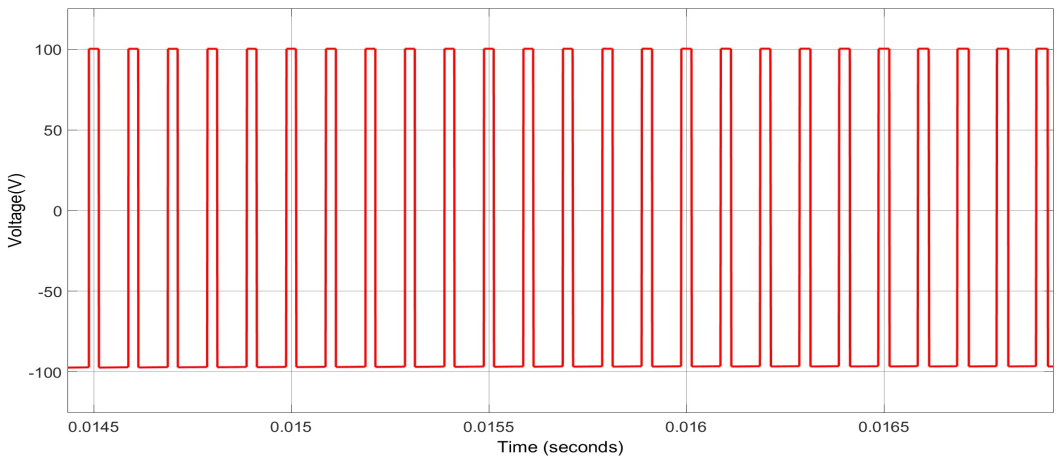

Figure 13: output voltage

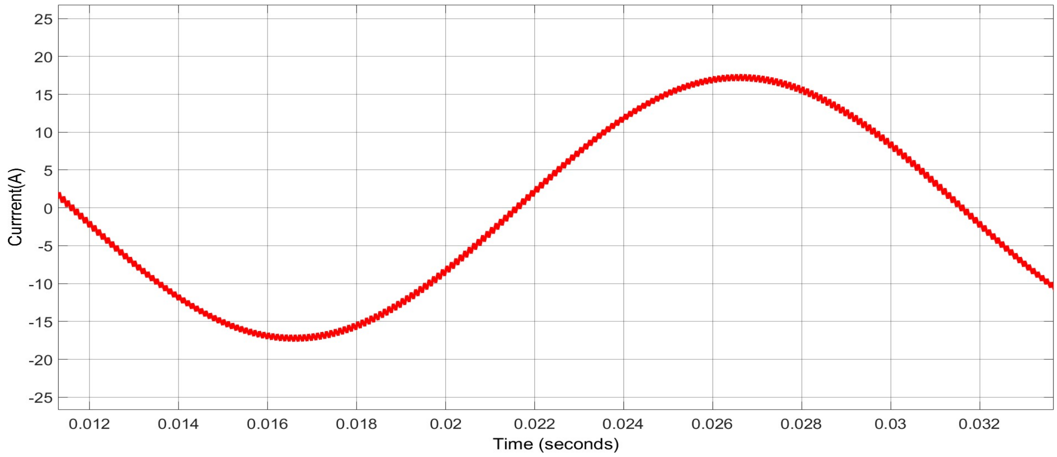

Figure 14: output current

FOR Capacitive Load

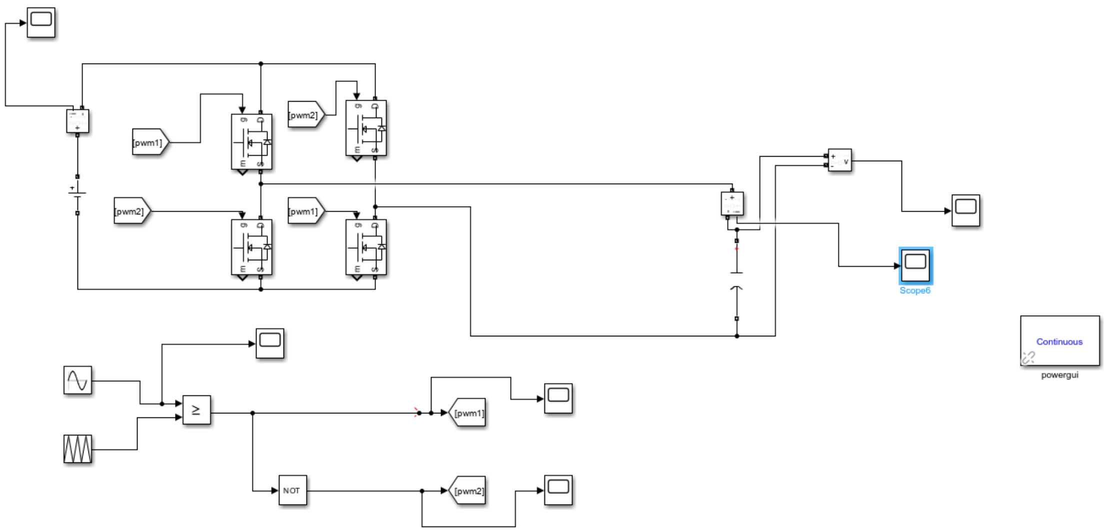

Figure 15: Single phase full bridge voltage source inverter with C load

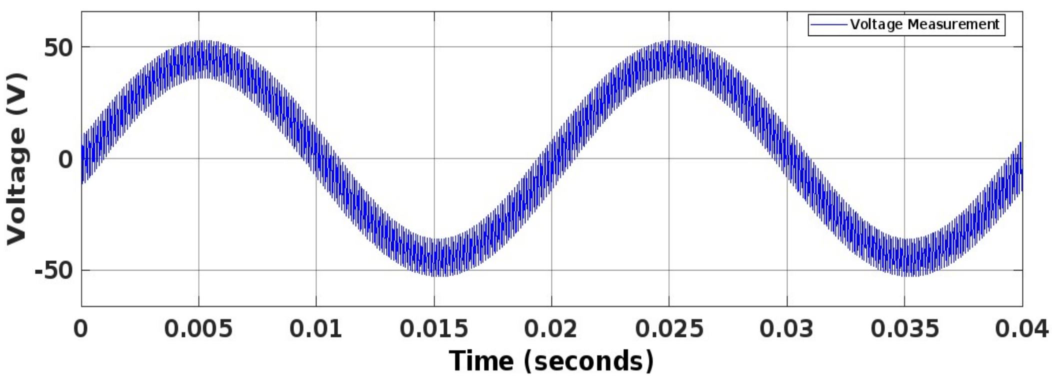

Figure 16: output voltage

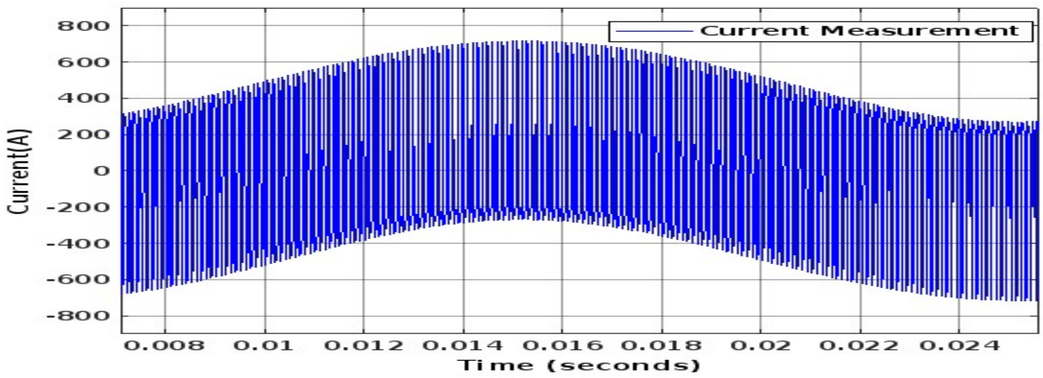

Figure 17: output current

For Unipolar pulse width modulation
Specifications: input voltage = 200 V , peak to peak voltage of triangular signal = 2V , frequency of triangular signal = 4Khz , Output fundamental frequency = 50 Hz, Reference signal = $0.4\sin(100\pi t)$
For Resistive Load : R = 52.9 ohm

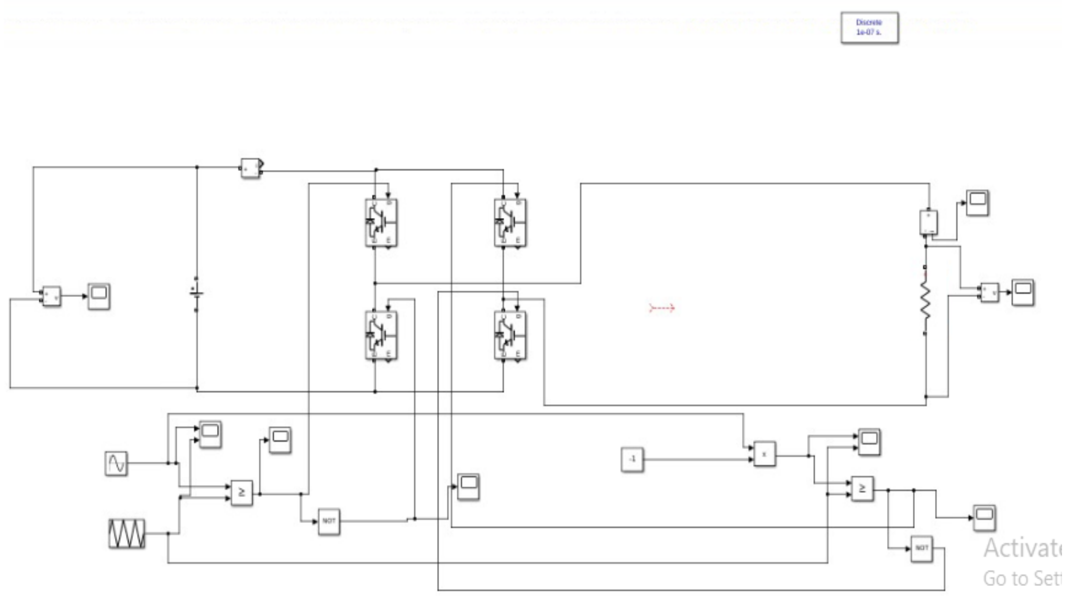

Figure 18: Circuit Diagram of single phase vsi with unipolar PWM

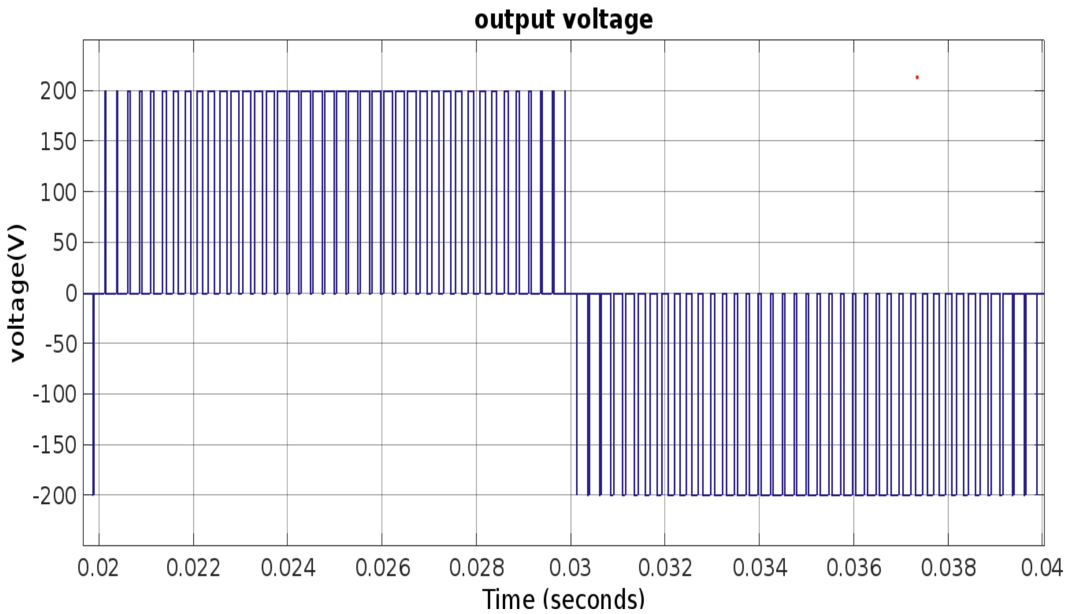

Figure 19: Output Voltage

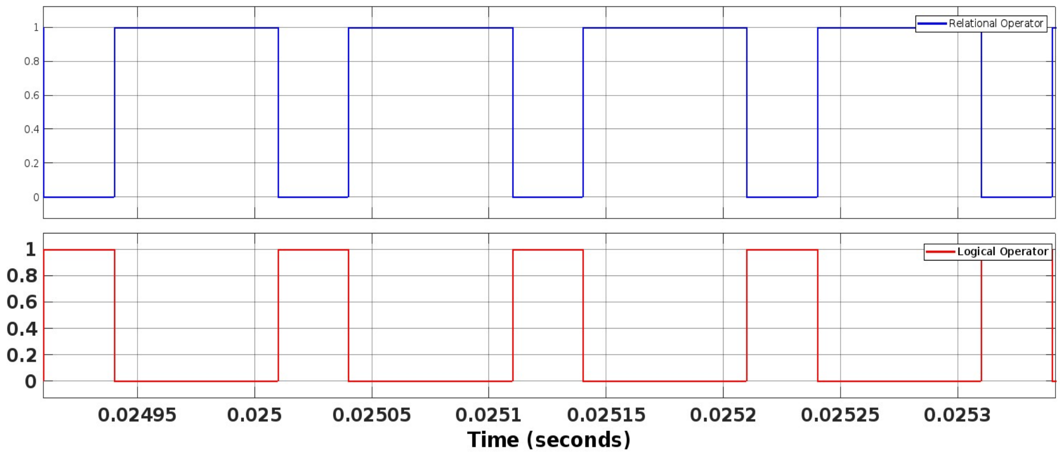

Figure 20: Switching pulse for switches S_1 and S_4

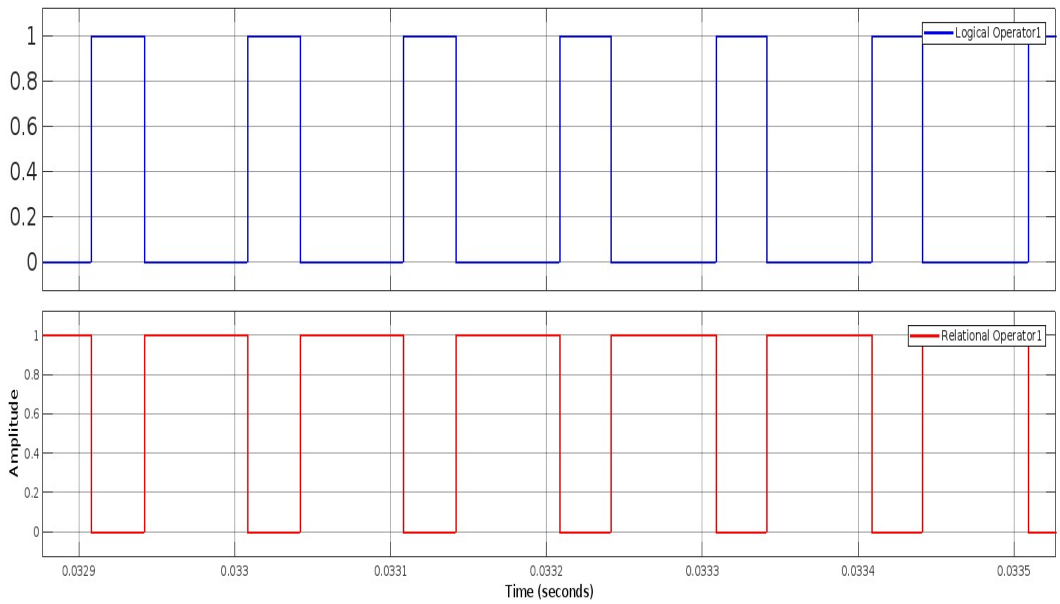

Figure 21: Switching pulse for switches S_3 and S_2

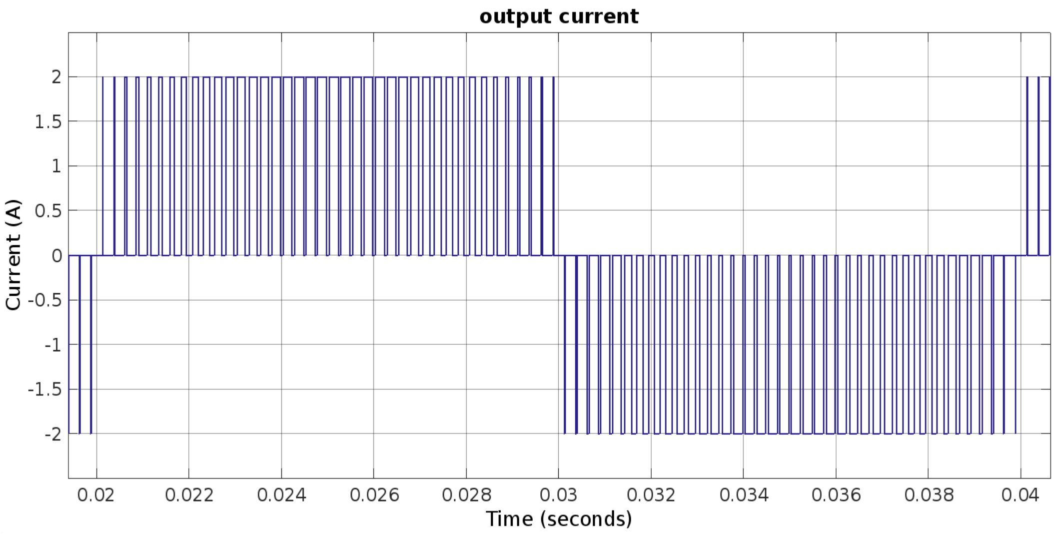

Figure 22: output current

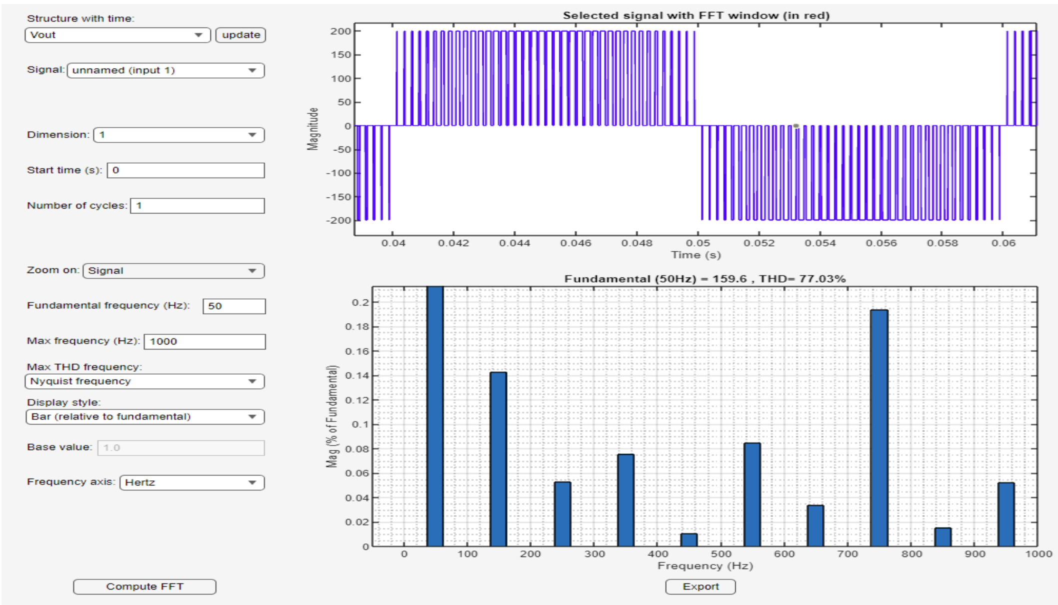

Figure 23: harmonic analysis of load voltage

For inductive load L = 10 mH

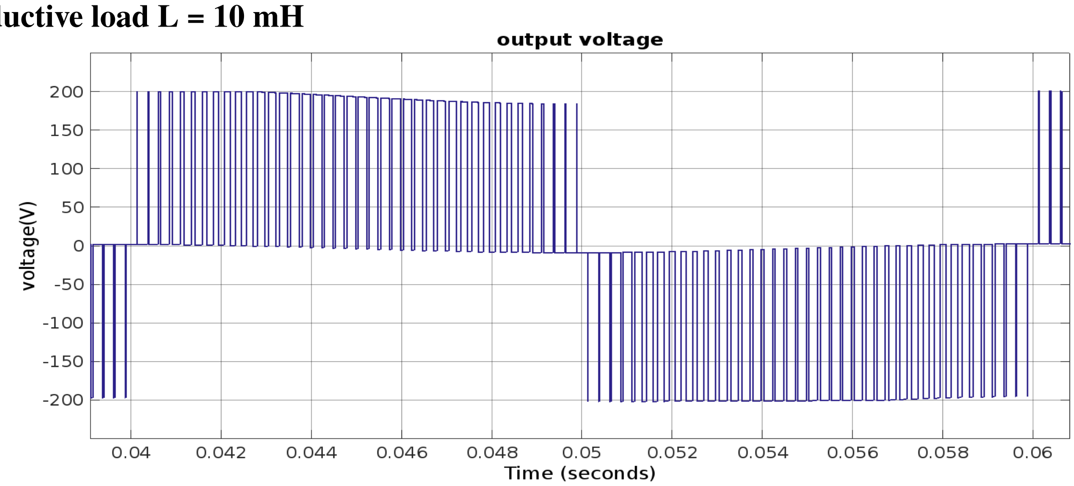

Figure 24: Output Voltage

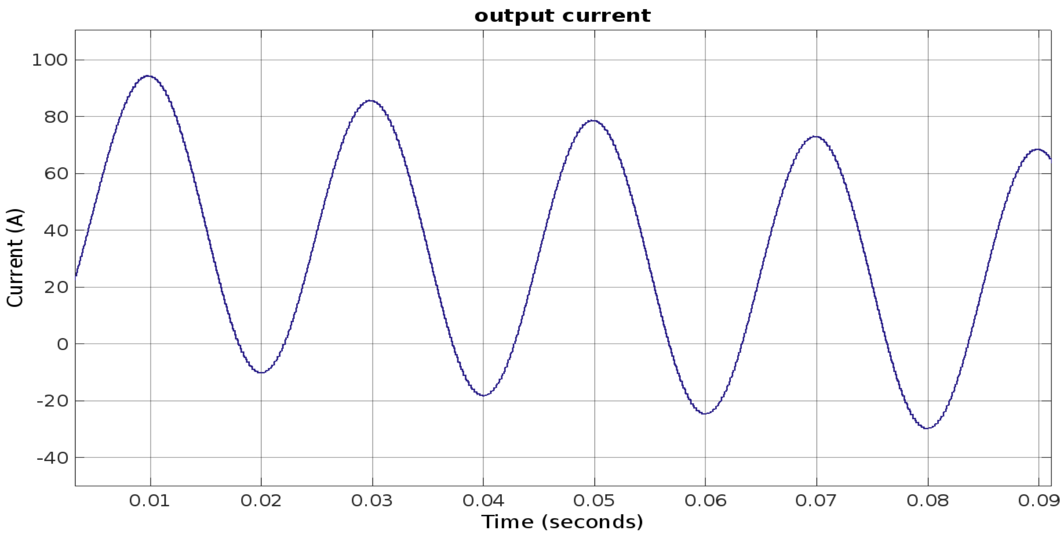

Figure 25: output current

For RL load with R=100 ohm and L = 10 mH

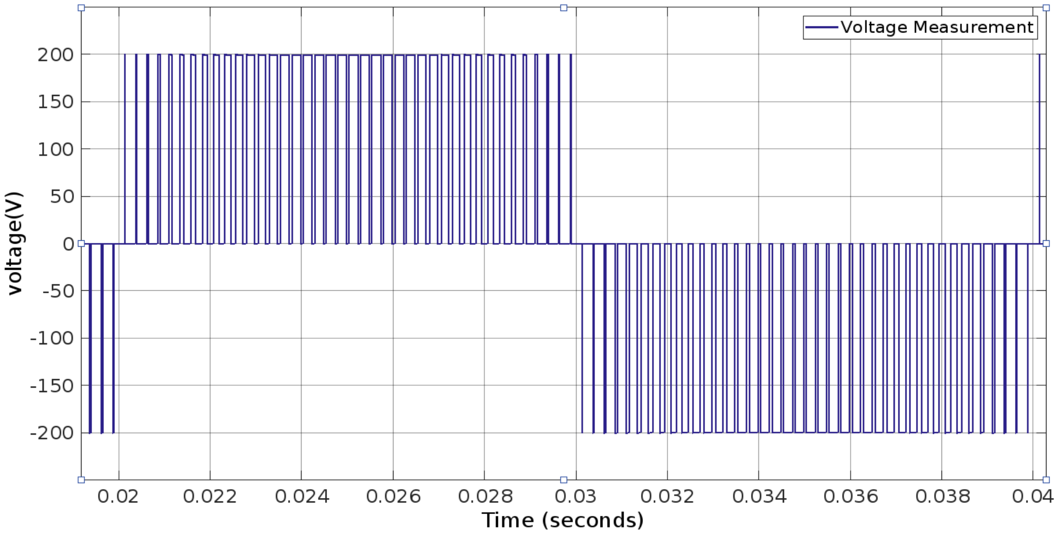

Figure 26: Output Voltage

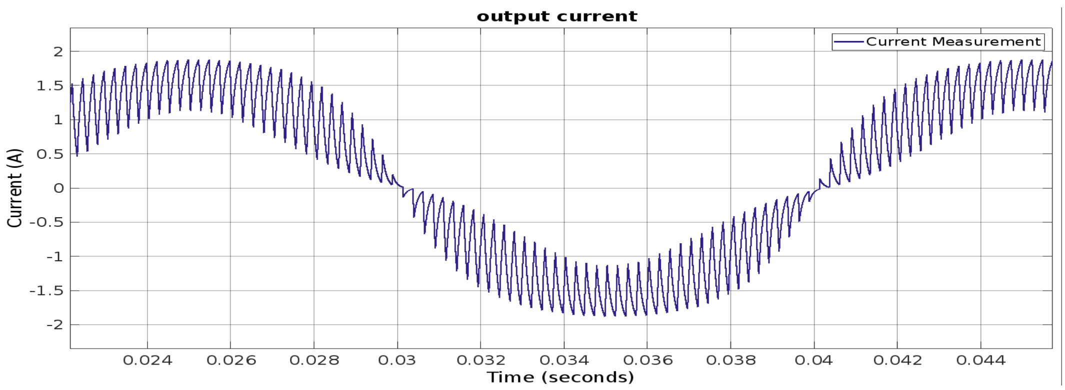

Figure 27: output current

For capacitive load C = 1 uF

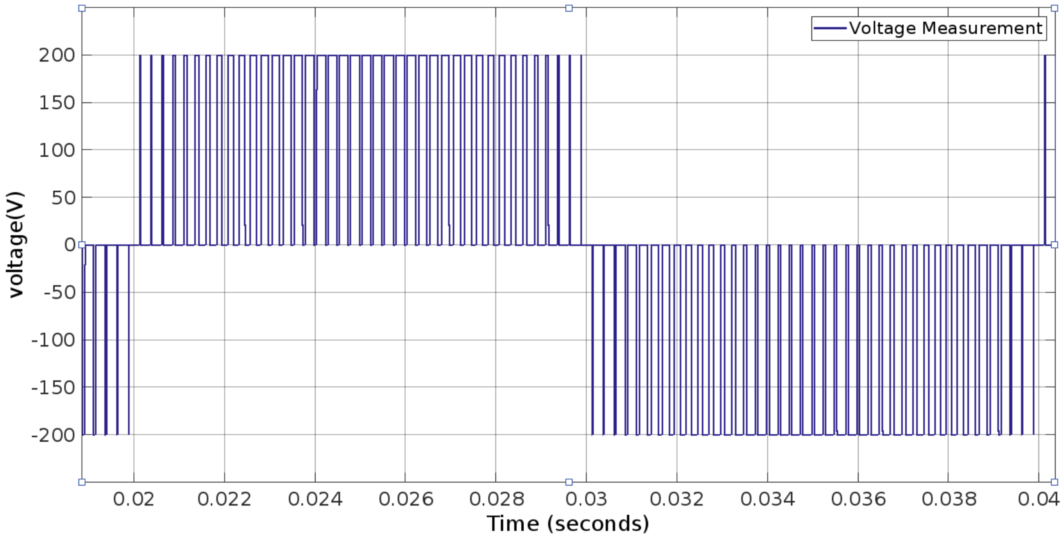

Figure 28: Output Voltage

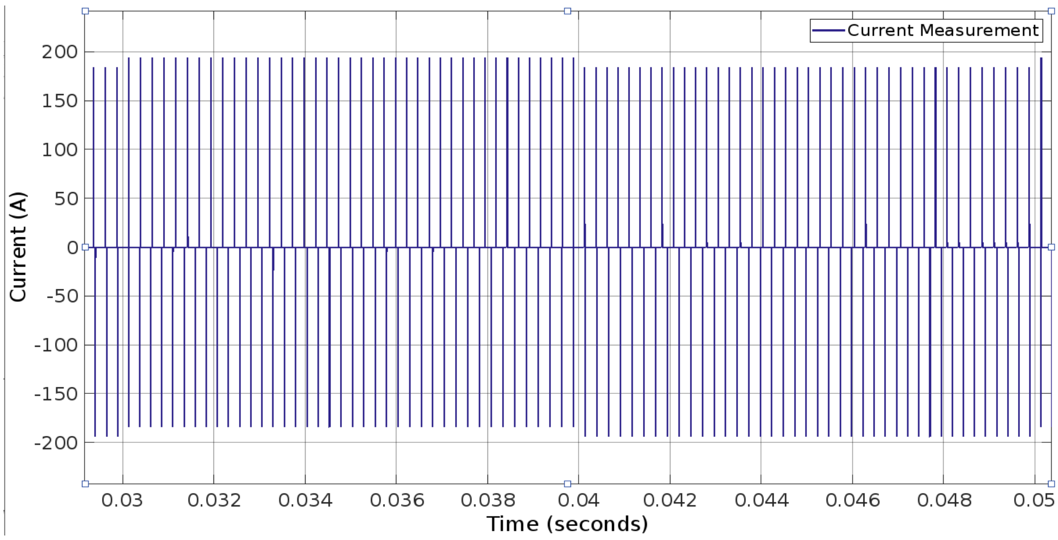

Figure 29: output current

4. Three Phase voltage source inverter :

A three-phase SPWM (Sinusoidal Pulse Width Modulation) voltage source inverter is a type of power electronics device used for converting DC (direct current) power into AC (alternating current) power in three phases. SPWM is a control technique that modulates the width of pulses in order to synthesize a sinusoidal waveform.

Here's a brief overview of how it works:

DC Source : The inverter takes a DC voltage source as its input. This could be from a rectified AC source or a DC power supply.

SPWM Control: The SPWM control algorithm generates three sets of PWM signals for the three phases based on a reference sinusoidal waveform. The width of these pulses varies to mimic the desired sinusoidal output.

Gate Drivers: Gate drivers are used to control the switching devices (typically IGBTs or MOSFETs) in the inverter. The PWM signals determine when these switches turn on and off.

Inverter Output: The switches in the inverter create a pulsed AC waveform in each phase. By adjusting the pulse width according to the SPWM control, the output closely approximates a sine wave.

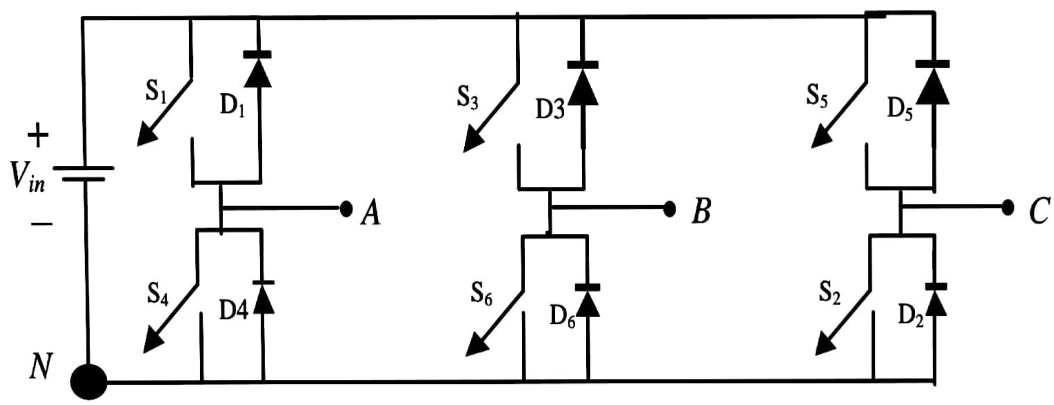

Figure 30: Three Phase Voltage source Inverter

Three-phase SPWM voltage source inverters are commonly used in various applications, including motor drives, renewable energy systems (such as wind and solar inverters), and in industrial settings where precise control of AC power is required. They offer advantages like improved power quality, reduced harmonic distortion, and better efficiency compared to other modulation techniques.

A Three-Phase Sinusoidal Pulse Width Modulation (SPWM) Voltage Source Inverter is a power electronics device that converts DC power into a controlled three-phase AC output. Here, we'll provide a detailed analysis of how it works:

Pulse Width Modulation (PWM):

SPWM techniques are used to generate a three-phase AC output with the desired frequency and magnitude. Each phase is controlled independently.

Reference Signals:

Three reference signals are generated, each representing the desired magnitude and phase of one of the three output phases. These reference signals are typically sinusoidal.

Carrier Signal: A high-frequency triangular carrier signal is generated. This signal serves as the basis for pulse width modulation.

Control of Amplitude and Frequency:

By adjusting the reference signals' amplitudes and frequencies, you can control the output voltage magnitude and frequency of each phase independently.

Advantages:

Three-phase SPWM inverters offer precise control of three-phase AC voltage and currents, making them suitable for a wide range of applications, including motor drives, industrial machinery, and grid-tied renewable energy systems.

Disadvantages: They may suffer from higher switching losses due to the three-phase operation, which can impact efficiency at high frequencies.

5. Simulation of Three phase voltage source inverter :

Specifications : input voltage = 300 V, peak to peak voltage of triangular signal = 2V, frequency of triangular signal = 5Khz, frequency of sinusoidal signal = 50 Hz

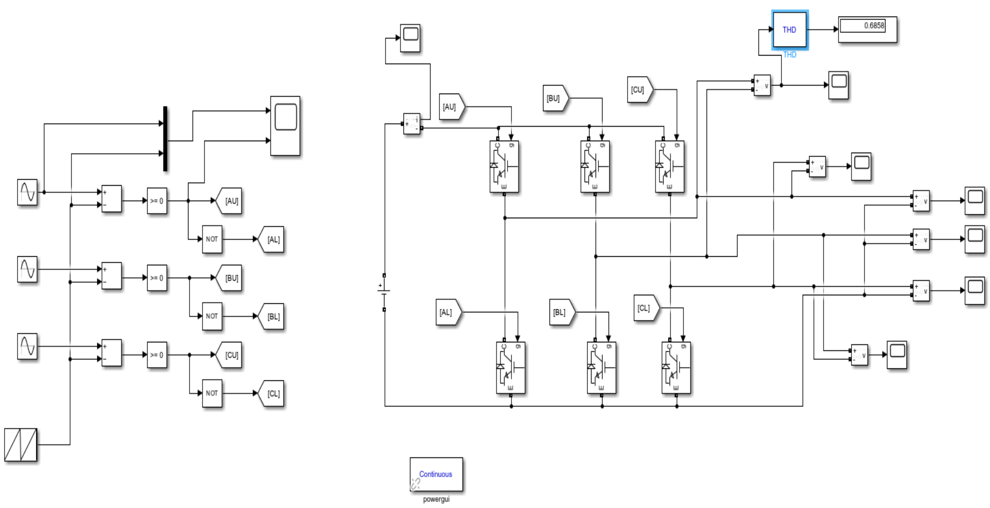

Figure 31: Three Phase voltage source inverter

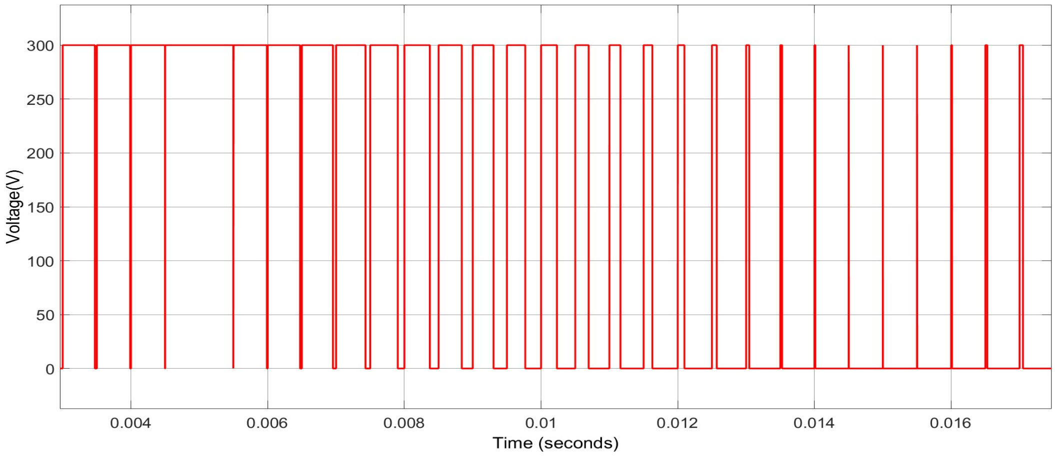

Figure 32: Phase Voltage v_{AN}

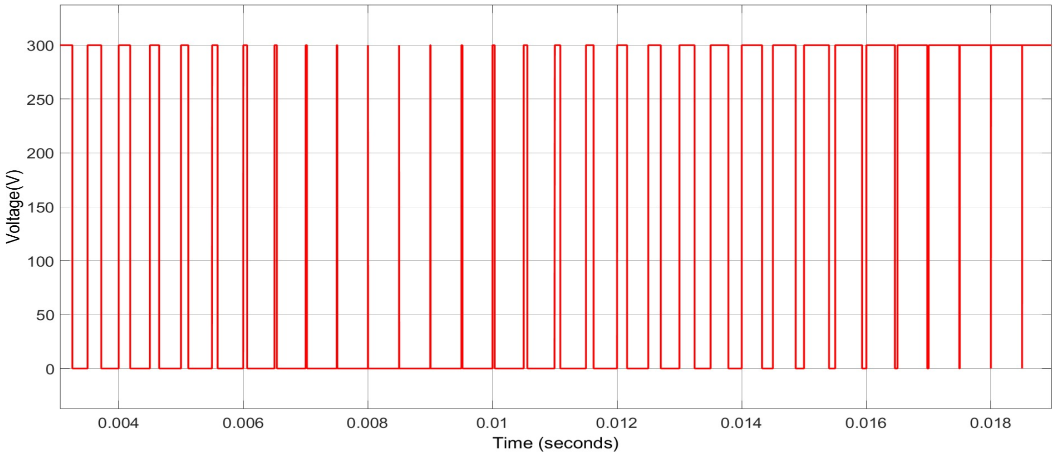

Figure 33: Phase Voltage v_{BN}

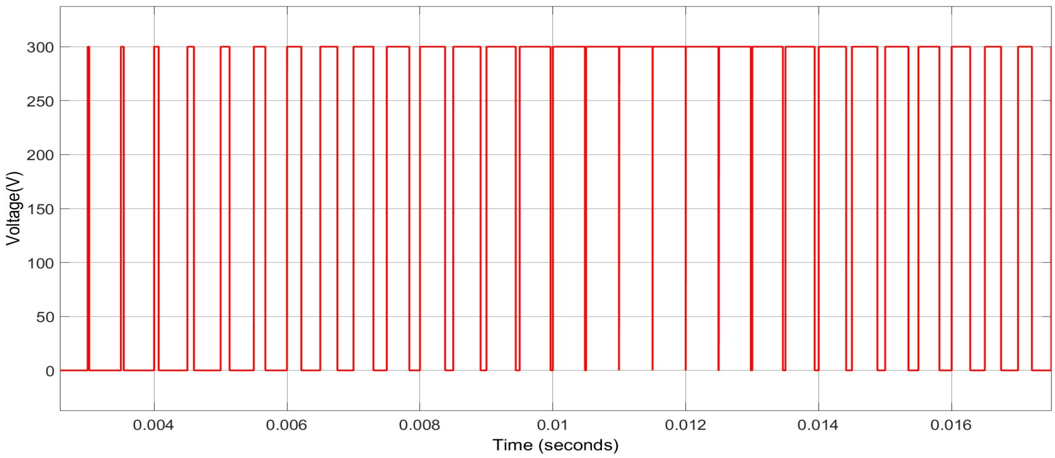

Figure 34: Phase Voltage v_{CN}

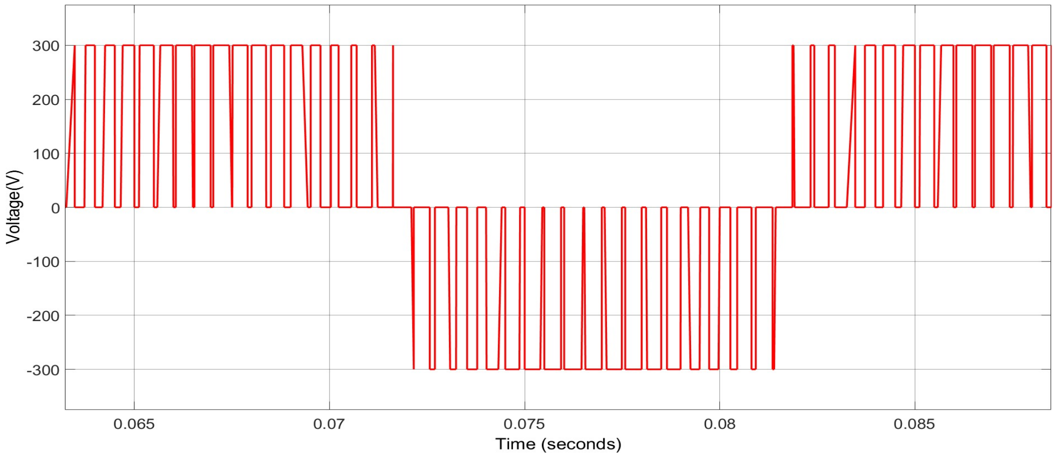

Figure 35: Line to Line Voltage v_{AB}

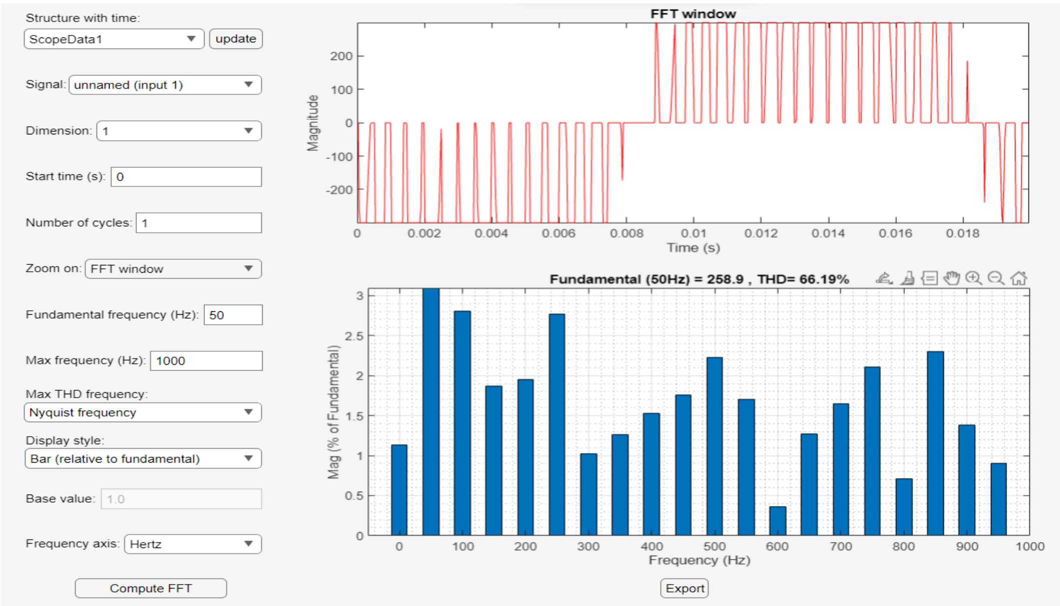

Figure 36: FFT for v_{AB}

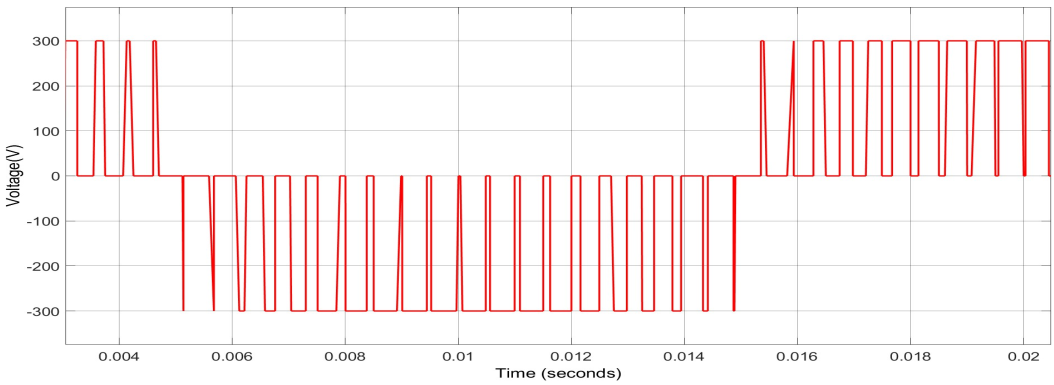

Figure 37: Line to Line Voltage v_{BC}

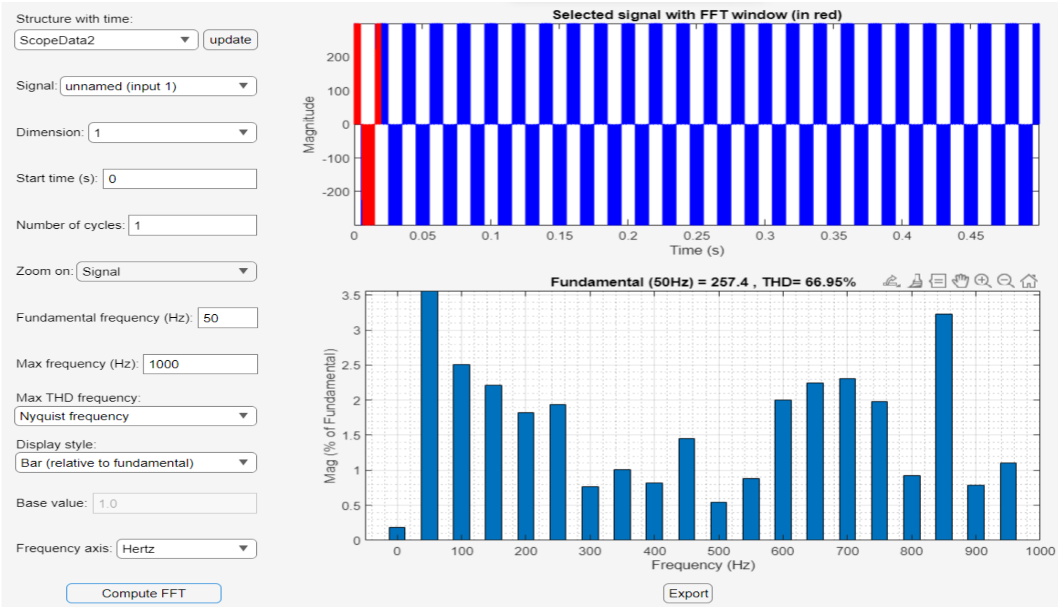

Figure 38: FFT for v_{BC}

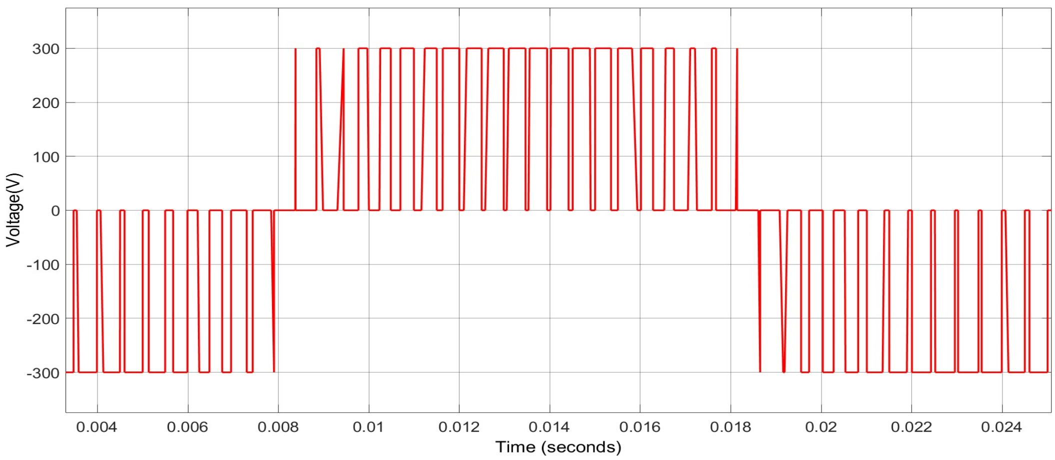

Figure 39: Line to Line Voltage v_{AB}

THD analysis of three phase SPWM voltage source inverter :

Certainly, here's a theoretical analysis of Total Harmonic Distortion (THD) in a three-phase Sinusoidal Pulse Width Modulation (SPWM) Voltage Source Inverter (VSI):
THD Formula: The THD of the output voltage waveform in a three-phase VSI is typically calculated using the formula:

$$\text{THD} = \frac{\sqrt{\sum(\text{Harmonic Voltage}^2)}}{\text{Fundamental Voltage}} \times 100\%$$

Where:

- Harmonic Voltage is the magnitude of each individual harmonic component (excluding the fundamental frequency) in the frequency domain analysis.
- Fundamental Voltage is the magnitude of the fundamental frequency component.

Harmonic Components: The harmonics in the output voltage are typically at integer multiples of the fundamental frequency (50 Hz in the case of a 50 Hz power system). So, you'll have harmonics at 100 Hz (2nd harmonic), 150 Hz (3rd harmonic), 200 Hz (4th harmonic), and so on.

Fourier Analysis :
A Fourier analysis, often performed using the Fast Fourier Transform (FFT), decomposes the three-phase output voltage waveforms into their constituent harmonic components and the fundamental frequency.

Individual Phase Analysis:
The analysis is typically done individually for each phase (A, B, C) to account for any phase imbalances.
THD Calculation:

- Calculate the THD for each phase using the THD formula.
- Calculate the average THD by averaging the THD values of the three phases.

Interpretation :

- A lower THD indicates a cleaner and more sinusoidal output voltage.
- THD should be within specified limits based on the application (e.g., grid-tied inverters often require low THD for compliance with power quality standards).

Analyzing THD is essential to ensure that the inverter generates a high-quality AC output voltage, especially in applications where low harmonic distortion is critical, such as grid-tied inverters, motor drives, and power quality-sensitive systems.

Conclusion :
The type of SPWM modulation technique used and the switching frequency can significantly impact the harmonic content and subsequently, the THD of the output voltage. Some modulation techniques are better at reducing THD than others.
In some applications, additional filters (e.g., LC filters) may be used to reduce harmonic content and improve THD.