IGEE 401 Power Electronics

Lab Report 4 DC-AC Converter

Group 213

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1.1 Objectives

The objective of this experiment is to study by simulating the operation of single-phase voltage source DC-AC converters (inverters), also known as VSIs, in open loop. Additionally, the goal of this lab is to become familiar with Sinusoidal Pulse Width Modulation (SPWM) techniques, specifically the Bipolar and the Unipolar SPWM.

1.2 Preliminary Calculations

1). Calculate the R and L elements of a load that consumes 2.5 kVA with pf = 0.8 when supplied with 120 V/ 60 Hz.

$$P = 2500 \times 0.8 = 2000\ W$$

$$I = \frac{S}{V} = \frac{2500}{120} = 20.83\ A$$

$$R = \frac{P}{I^2} = \frac{2000}{20.83^2} = 4.61\ \Omega$$

$$X = \frac{Q}{I^2} = \frac{1500}{20.83^2} = 3.457\Omega$$

$$X = 2\pi f L$$

$$L = \frac{3.457}{2\pi \cdot 60} = 9.17\ mH$$

2). Compute the modulation index required for a full-bridge voltage source inverter with a DC bus voltage of 200 V to supply 120 V/ 60 Hz in the output.

$$m_a = \frac{\hat{V}_{out}}{V_d} = \frac{120 \cdot \sqrt{2}}{200} = 0.8485$$

3). Calculate the magnitude of the DC component and of the lowest order harmonics in the DC side current of the VSI when it supplies rated power (2.5 kVA and pf = 0.8)

$$I_{dc} = \frac{2000}{200} = 10\ A$$

$$i_{d2} = \sqrt{2} I_d = \sqrt{2} \cdot 10 = 14.14\ A$$

1.3 Simulations

c). The modulating signal and the carrier signal are shown in the figure below. When the modulating signal is greater than the triangle carrier signal(when the comparator signal is 1), gate A is on. When the modulating signal is smaller than the triangle carrier signal(when the comparator signal is 0), gate B is on.

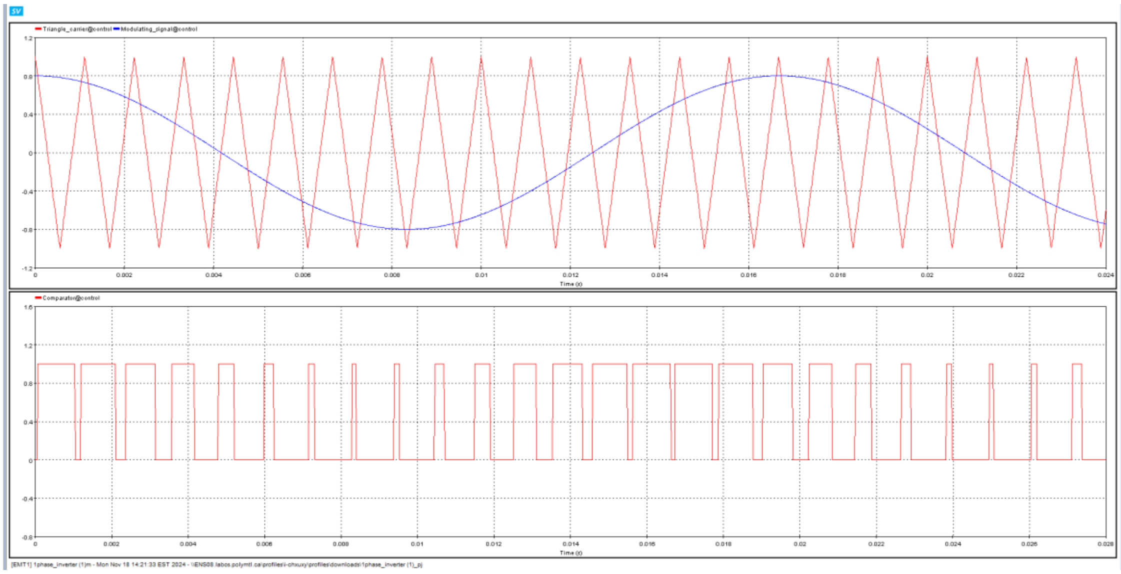

Figure 1 Superimposed diagram of modulating signal and the carrier signal and comparator signal diagram

d). The input (DC) current, load current and load voltage for both VSIs are shown in the figure below. The full bridge DC source current is twice the value of the half-bridge DC current. The full bridge VSI delivers twice the voltage as half-bridge VSI. They have the same load current and load voltage.

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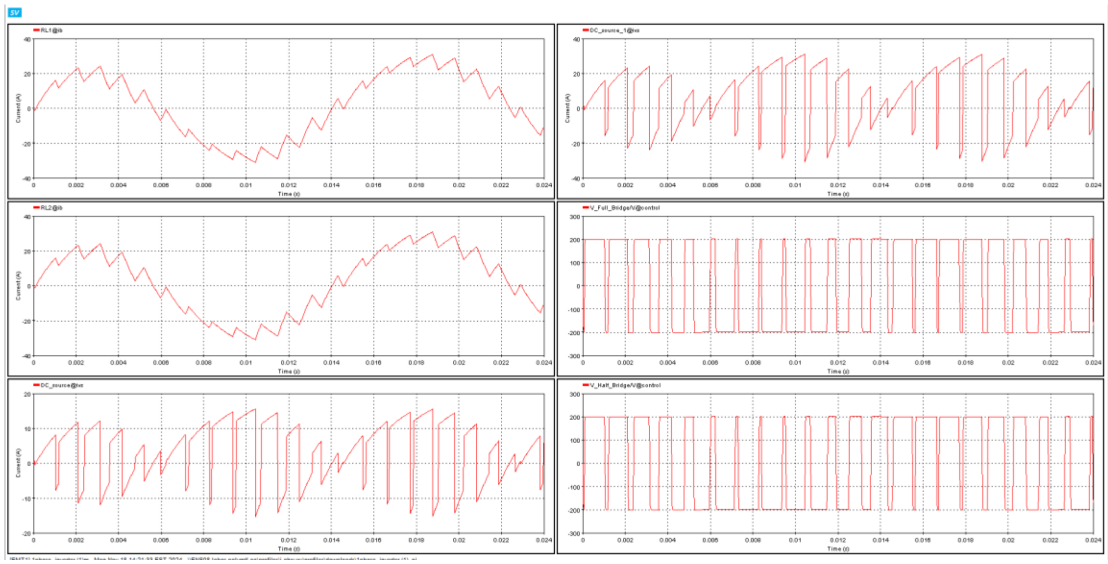

Figure 2 Input (DC) current, load current and load(AC) voltages of the two VSIs

e). The harmonic spectra of the input (DC) current and load (AC) voltage of the two VSIs are shown in the figure below. Load voltage harmonic spectra appear to be similar. The full bridge input current spectra are twice the value of half bridge.

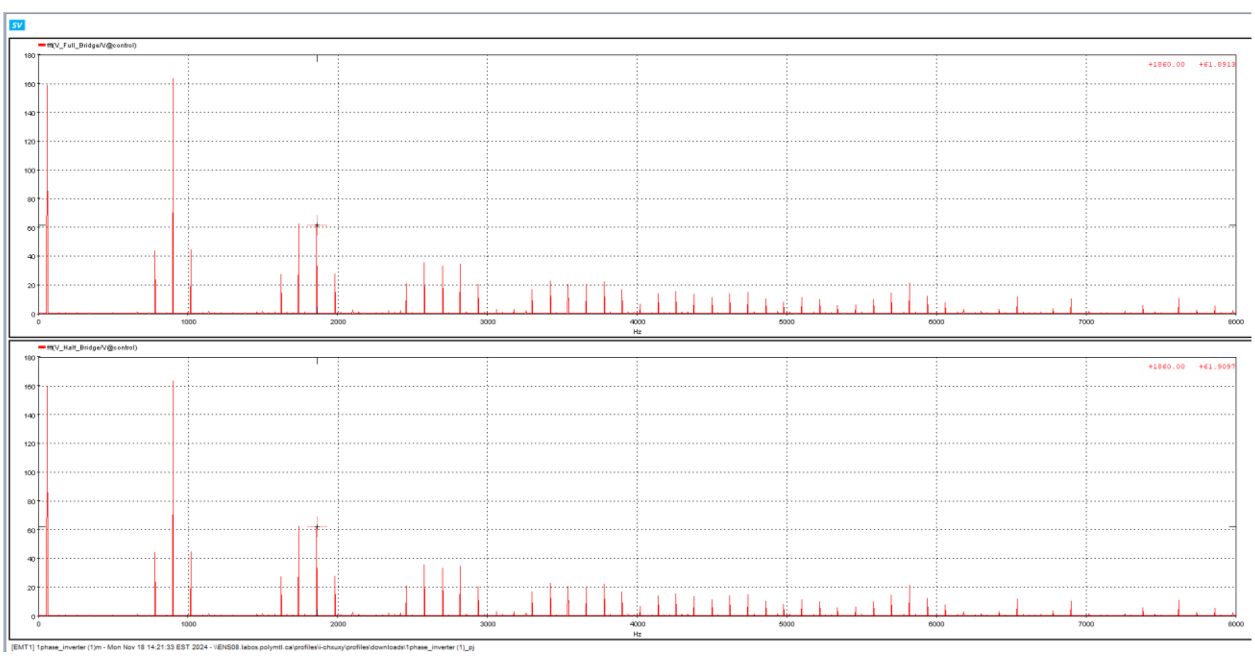

Figure 3 Voltage Harmonic Spectra of the two VSIs with a modulating index of 0.8

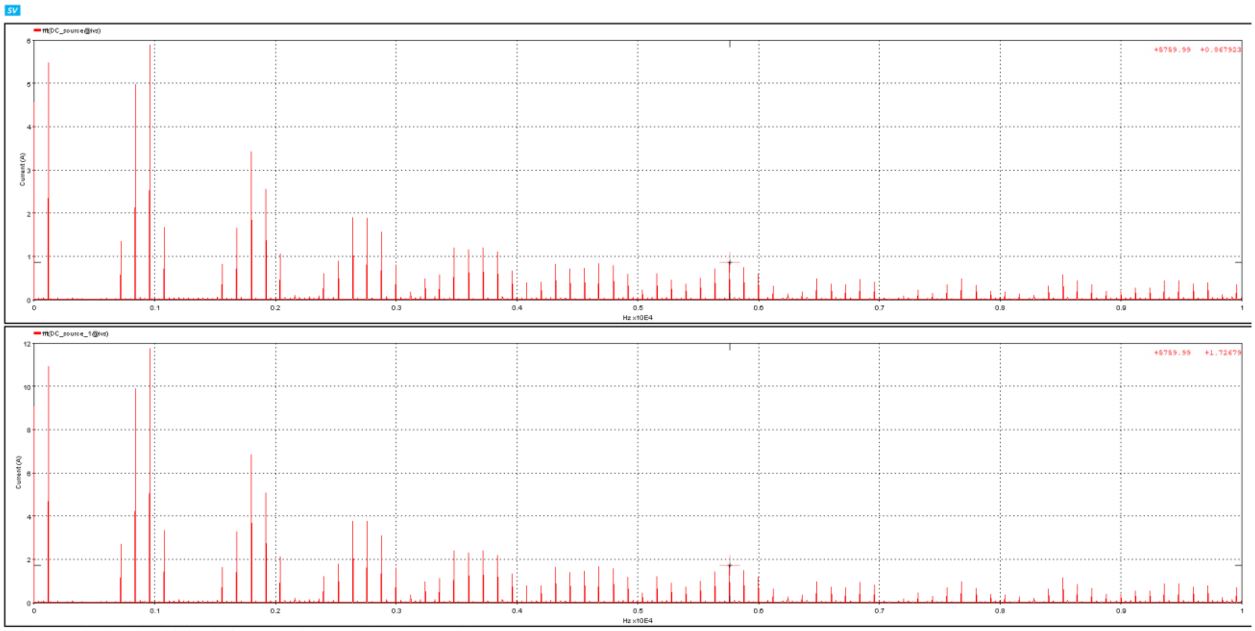

Figure 4 Current Harmonic Spectra of the two VSIs with a modulating index of 0.8

f). The current and voltage waveforms across a switch are shown in the figure below. The switch has the same current waveform. For the voltage waveform, the amplitude across the half bridge inverter is 400 V while the amplitude across the full bridge inverter is 200V.

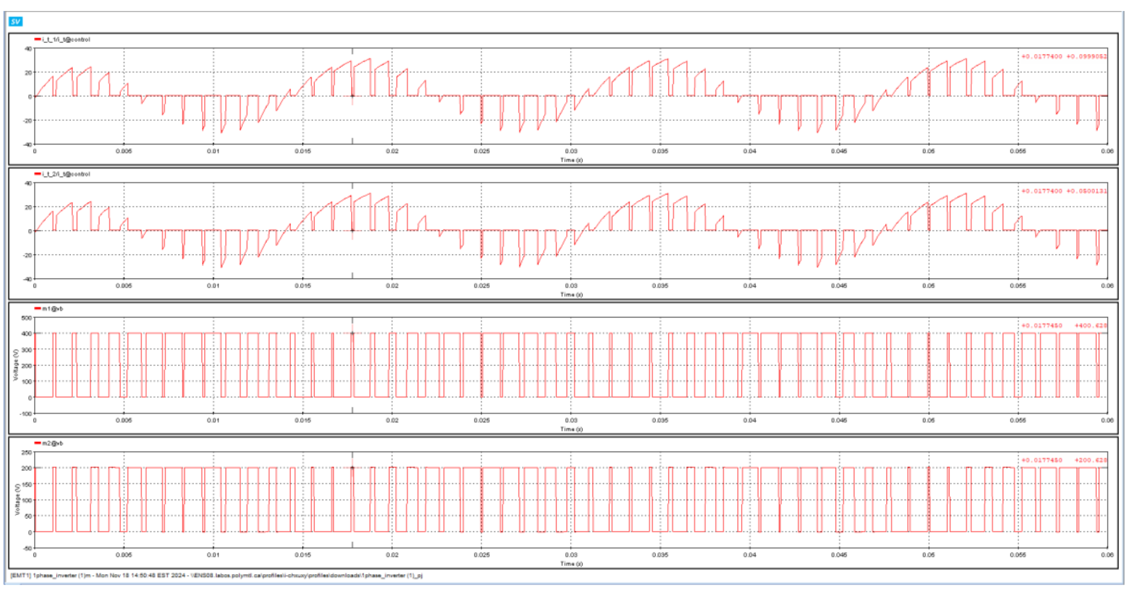

Figure 5 Current and voltage waveforms across a switch of two VSIs

g). The harmonic spectra of the DC input current and output AC voltage of the two VSIs for a modulation index equal to 0.9 and 1.2 is shown in the figures below. As the modulation index increases from m = 0.8 to m = 0.9, the fundamental amplitude grows, and relative harmonic distortion decreases, improving waveform quality. However, when over-modulation occurs m = 1.2, the waveform becomes nonlinear, leading to increased distortion and diminished efficiency.

Operating at a modulation index below or close to m = 1 achieves the best balance between waveform fidelity and harmonic suppression.

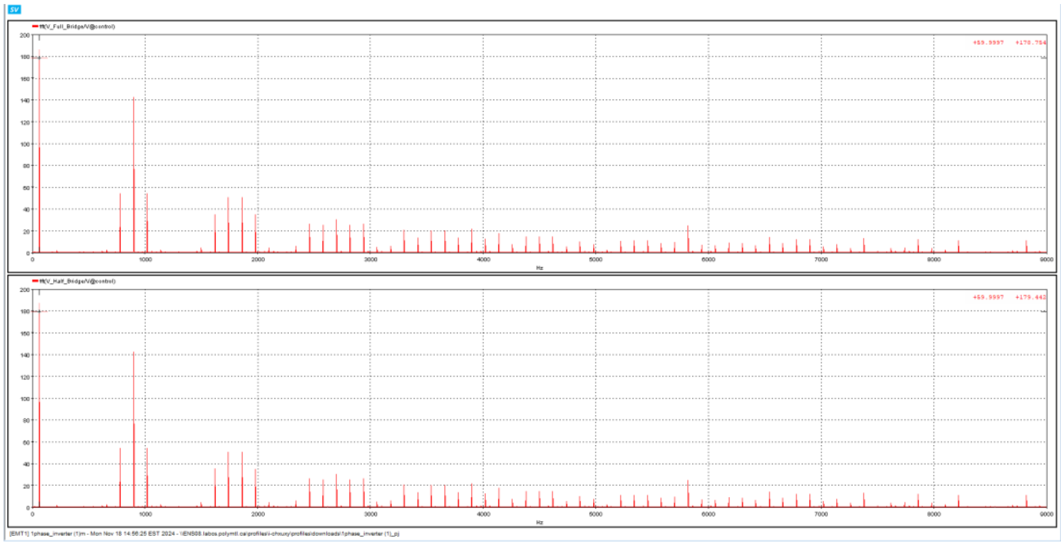

Figure 6 Harmonic Spectra of AC voltage for two VSIs at modulation index of 0.9

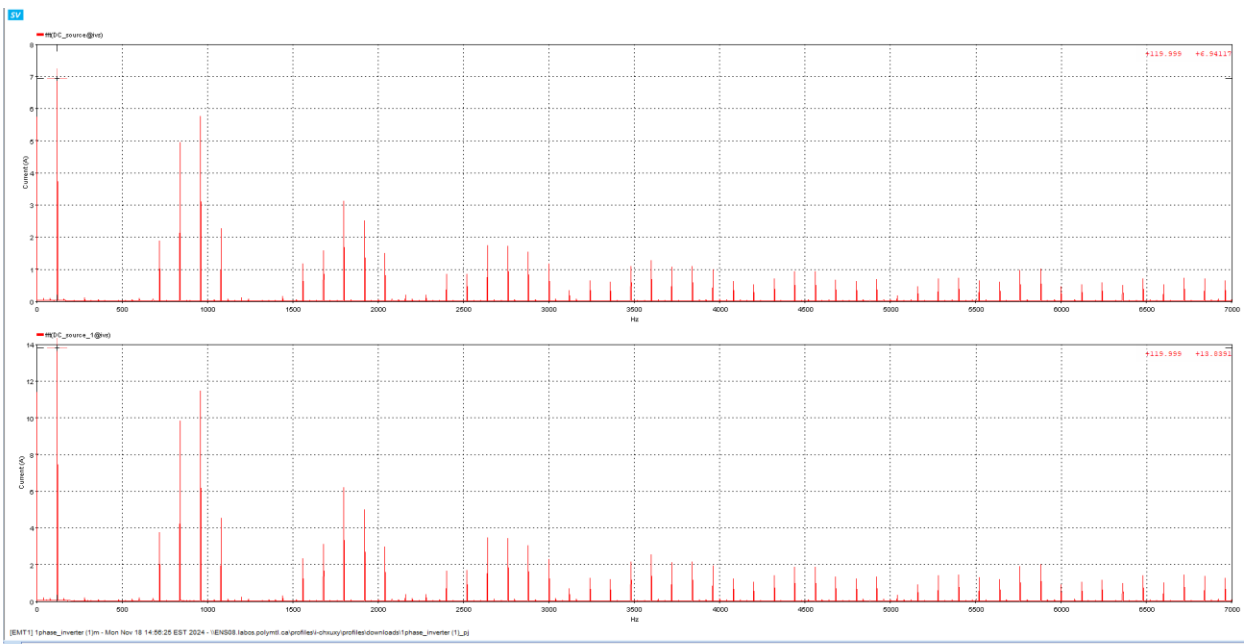

Figure 7 Harmonic Spectra of DC Current for two VSIs at modulation index of 0.9

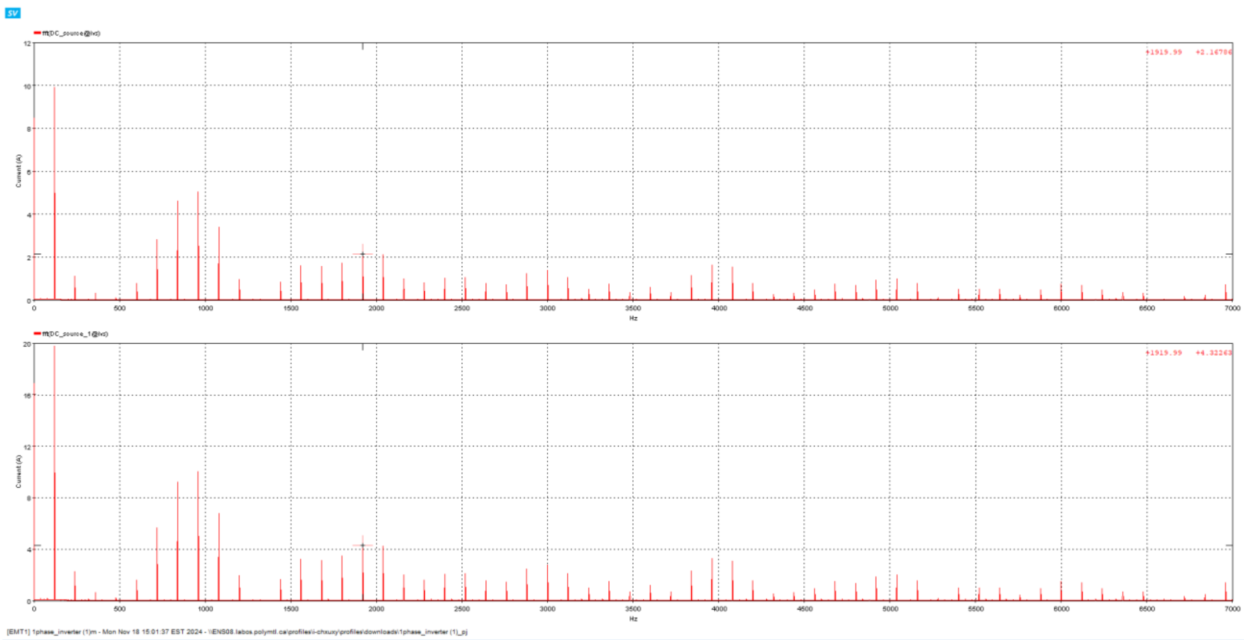

Figure 8 Harmonic Spectra of DC current for two VSIs at modulation index of 1.2

Figure 9 Harmonic Spectra of AC voltage for two VSIs DC current at modulation index of 1.2

1.4 Questions

1**). Comment on the difference of the half and full bridge inverters in terms of input/output waveforms quality and switch/diode voltage/current waveforms. (Section 3.1.d and 3.1.f)**

For the DC input current, the full-bridge inverter exhibits twice the value of the half-bridge inverter. Both inverters, however, deliver the same load current. Regarding the load voltage, both inverters output an amplitude of 200V, but the full-bridge inverter inherently delivers twice the voltage of the half-bridge inverter due to its design. All waveforms share similar shapes, which can be attributed to the use of the same modulation technique.

In terms of waveform quality, typically full-bridge inverters have better waveform quality than half-bridge inverters. However, in our simulation, due to using the same modulating technique, the waveform quality is the same.

The voltage and current waveforms present at the switches of the two VSIs have the same current waveform, but different voltage waveforms. The half-bridge inverter has an amplitude of 400V, and the full-bridge inverter has an amplitude of 200V.

2). Comment on the difference between the two single-phase VSI topologies in terms of AC/DC gains and flexibility in terms of modulation techniques that can be employed.

In terms of flexibility of modulation techniques, the full-bridge inverter supports both unipolar and bipolar SPWM. Unipolar SPWM typically results in improved waveform quality, reduced Total Harmonic Distortion (THD), and lower switching losses compared to bipolar SPWM. This added flexibility allows the full-bridge inverter to optimize performance for a broader range of applications. In contrast, the half-bridge inverter is restricted to using only bipolar SPWM, limiting its ability to achieve the same level of efficiency and waveform fidelity.

In terms of AC/DC gains, the full-bridge inverter has twice the voltage gain of the half-bridge inverter. This is because the full-bridge topology utilizes both halves of the DC supply to generate the AC output, effectively doubling the output voltage swing.

3). Comment on the linearity of SPWM and on the effects of the over-modulation. (Section 3.1.g).

The linearity of SPWM is achieved for a modulating index from 0 up to 1. In this range, the fundamental output voltage is directly proportional to the modulation index, allowing predictable and stable operation. This linear behavior ensures minimal distortion and efficient control of the inverter output. Non-linearity happens during over-modulation (modulating index -bigger than 1). In this case, the reference sinusoidal waveform exceeds the amplitude of the triangular carrier waveform, causing portions of the sinusoidal signal to be clipped. While higher-order harmonics may decrease due to the diminishing carrier signal's influence, significant lower-order harmonics are introduced, which can degrade the overall waveform quality. This results in waveform distortion and the introduction of additional harmonics in the output voltage. There is a diminishing voltage gain for increase in modulating index. The relationship between the modulation index and the output voltage is no longer linear.

1.5 Conclusions

This lab investigated the operation of single-phase voltage source inverters (VSIs) using SPWM techniques. Full-bridge inverters demonstrated greater flexibility and higher AC voltage gains compared to half-bridge inverters. The study also highlighted the linearity of SPWM and the effects of over-modulation on voltage gain and harmonic reduction. These findings reinforce key principles of inverter design and operation.