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Question 1A

For six step modulation, the peak voltage fundamental component is given by equation 1.

$$V_{ph} = \frac{2}{\pi} \cdot V_d \tag{1}$$

Substituting in the DC-link voltage of 500V:

$$V_{ph} = \frac{2}{\pi} \cdot 500 = 318.31V$$

With six-step modulation, the output frequency can be modified, but the output voltage is fixed and can only be varied by a change in the DC-link voltage. Therefore, this modulation strategy is not suitable to achieve the required output voltage fundamental component of 280V.

For sinusoidal pulse-width modulation (SPWM), the peak voltage fundamental component is given by equation 2.

$$V_{ph} = \frac{1}{2} \cdot V_d \tag{2}$$

Substituting in the DC-link voltage of 500V:

$$V_{ph} = \frac{1}{2} \cdot 500 = 250V$$

With sinusoidal PWM, the output voltage fundamental component can be reduced by under-modulating the input amplitude, or increased by over-modulating the input amplitude.

Since the output voltage with an amplitude modulation index of 1 is only 250V, sinusoidal PWM will need to be over-modulated to achieve a fundamental component of 280V.

Therefore, over-modulated Sinusoidal PWM signal will be used, where an amplitude modulation index of 1.25 was found to produce the correct fundamental component amplitude.

Question 1B

The phase voltage and current for output phases A, B & C are shown in figure 1.

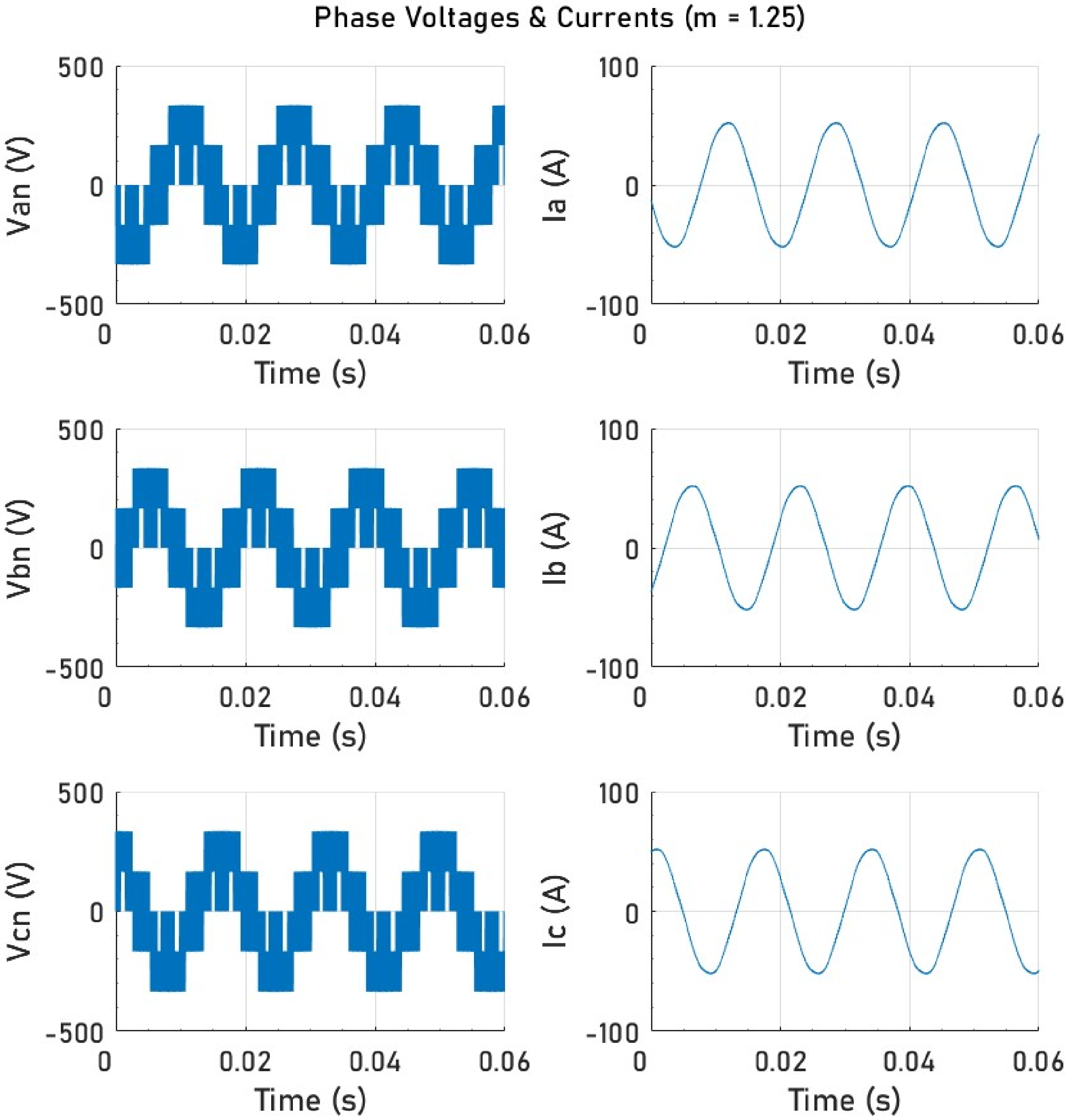

Figure 1: Phase voltages and currents

By applying a Fourier transform to Van, the harmonic spectrum of the output voltage can be generated, as seen in figure 2. The fundamental component of the signal has an amplitude of 280V, verifying that the chosen modulation strategy is correct.

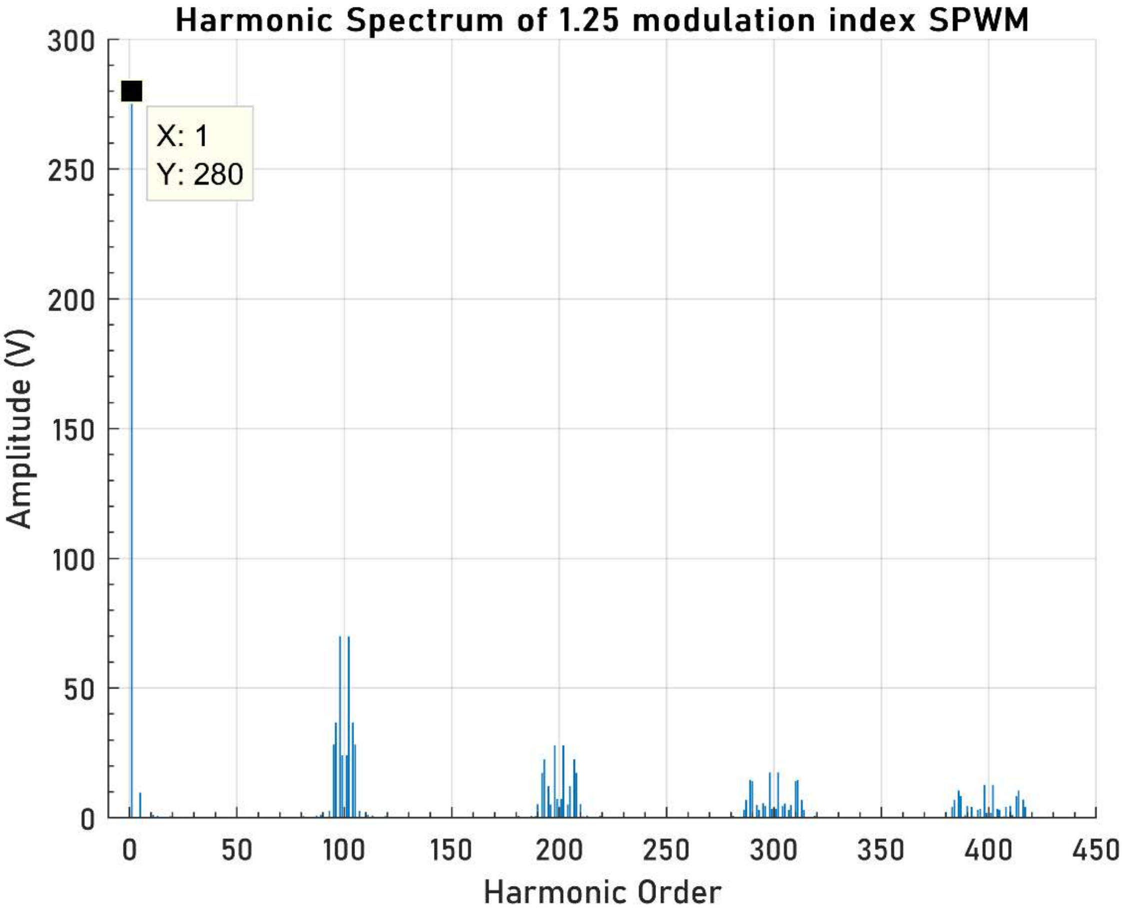

Figure 2: Harmonic spectrum of Van.

QUESTION 1C

The diode currents for phase A of the inverter and the switch gate signal are shown in figure 3.

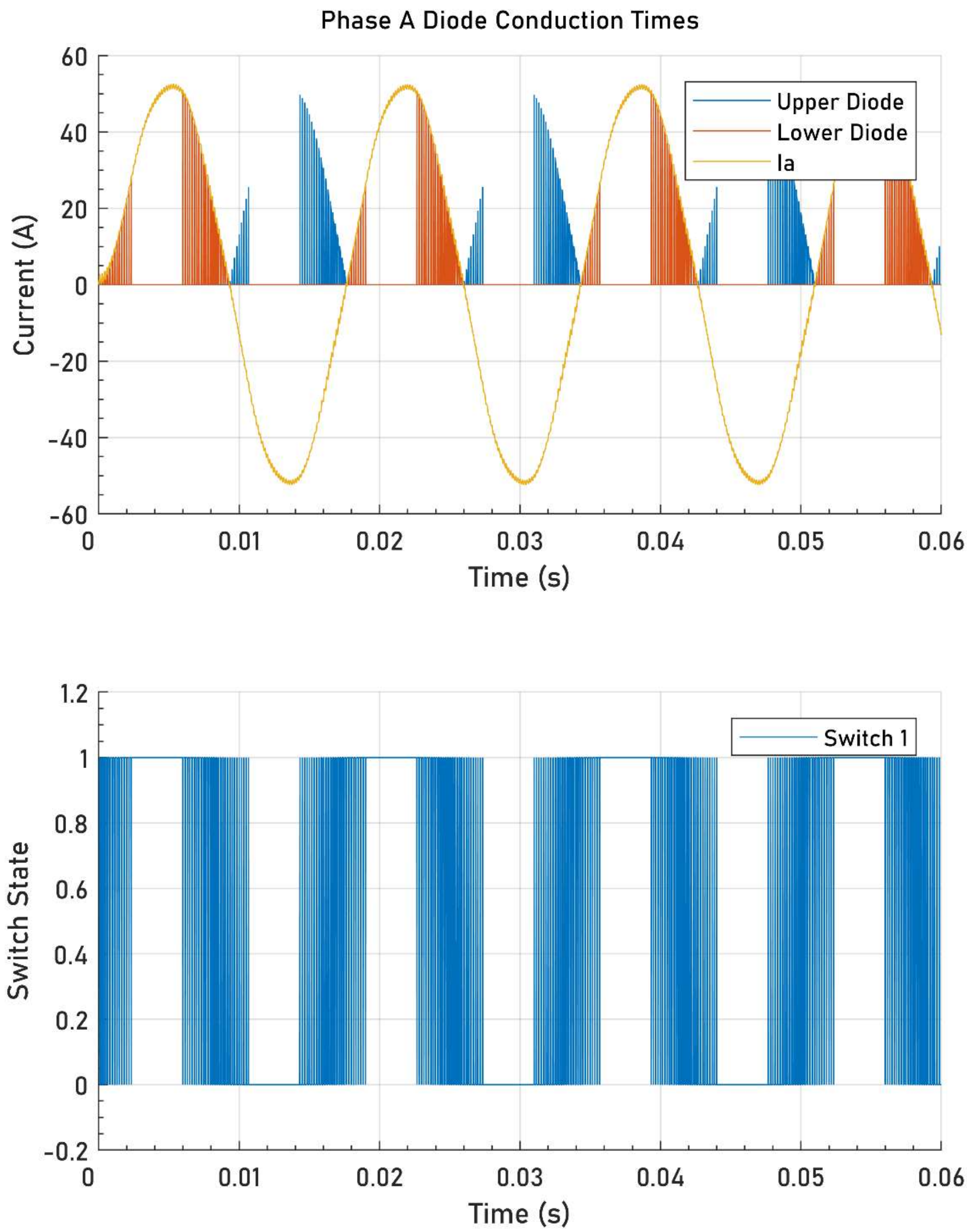

Figure 3: Diode conduction.

When switch SA+ switches off (and SA- turns on), the current Ia will continue to flow, forcing diode DA- into conduction, until the energy in the inductor is dissipated through the resistor and the other switches/diodes.

Due to using over-modulated sinusoidal PWM as the modulation strategy, there will be a region of the signal where the input signal will be fully saturated, causing the gate signal to by fully on. This prevents the phase A diodes from being able to conduct, which is why in figure 3, there is region of the gate signal that is constantly high/low, which corresponds to a region of zero diode current.

The effect of the other two phases switching is what causes the first diode conduction time to be shorter than the second.

A detailed view of the diode conduction time is shown in figure 4.

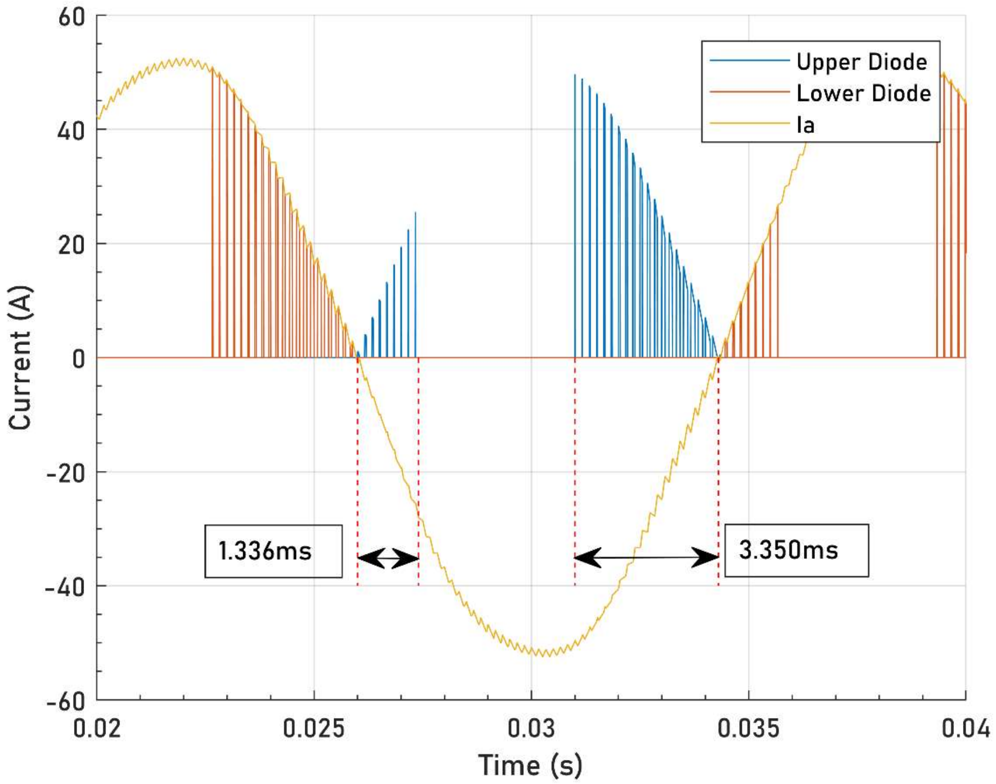

Figure 4: Detailed graph of diode conduction time.

The short conduction time is 1.336ms, and the long conduction time is 3.350ms.

QUESTION 2A

For six step modulation, equation 1 can be used again to determine the maximum achievable fundamental component of the output voltage.

With a DC-link voltage of 500V:

$$V_{ph} = \frac{2}{\pi} \cdot 500 = 318.31V$$

This value is above out required output voltage fundamental component of 200V, and since the output voltage cannot be varied with six step modulation, another approach is needed.

For sinusoidal pulse-width modulation (SPWM), equation 2 can be used again to determine the maximum achievable fundamental components of the output voltage with an input amplitude modulation index of 1.

With a DC-link voltage of 500V:

$$V_{ph} = \frac{1}{2} \cdot 500 = 250V$$

This value is above the target value, but can be reduced by under modulating the amplitude of the input control signal, therefore sinusoidal PWM will be used to achieve an output voltage fundamental component of 200V.

There is a linear relationship between the output voltage and the input amplitude modulation index in the under-modulation region. Therefore, the required modulation index to achieve an output voltage fundamental component of 200V can be calculated using equation 3, where V_{ph} is the maximum output voltage achieved by SPWM, V_{out} is the desired output voltage, and m is the input amplitude modulation index. This relationship is visualised in figure 5.

$$V_{out} = \left(\frac{V_{ph}}{1}\right) \cdot m \qquad (3)$$

With a maximum output voltage of 250V and a desired output voltage of 200V:

$$m = \frac{200}{250} = 0.8$$

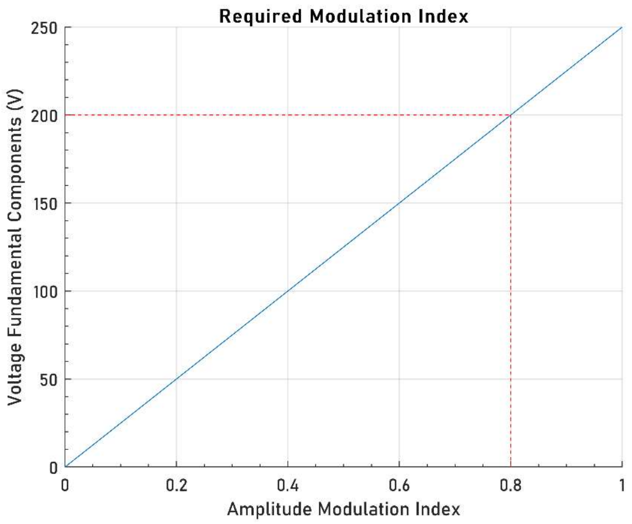

Figure 5: Under-modulation region.

Therefore, the theoretical modulation index required is 0.8, however, the addition of dead time will reduce the amplitude of the fundamental component, so the modulation index will have to be experimentally modified.

QUESTION 2B

The gate voltage of the phase-A IGBTs with an added deadtime of 1μs is shown in figure 6, with a closer look at the deadtime shown in figure 7.

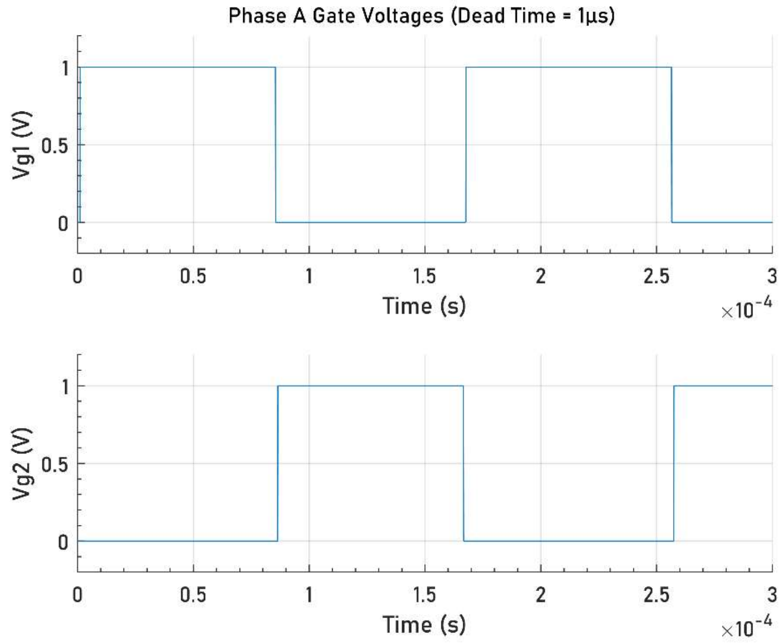

Figure 6: Phase A gate voltages with dead time.

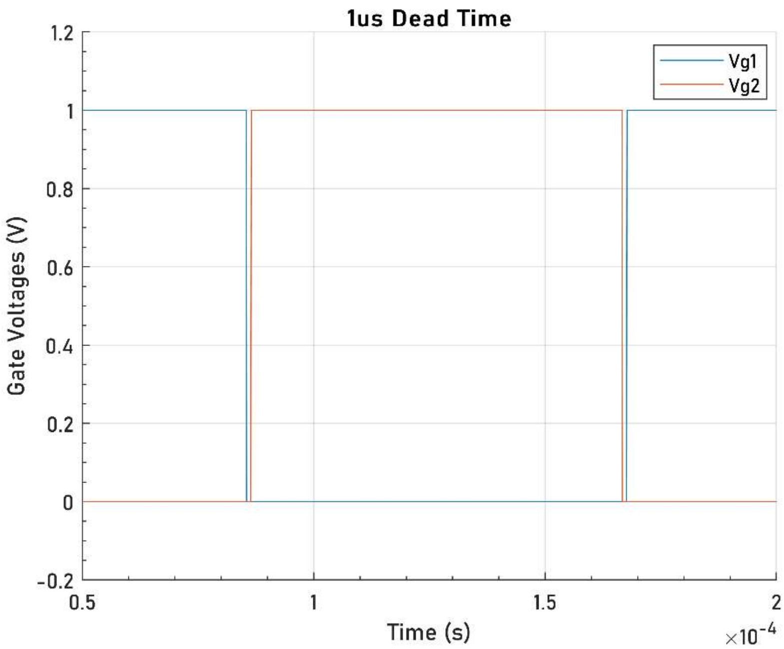

Figure 7: Dead time close up view.

The output phase voltages and currents are shown in figure 8.

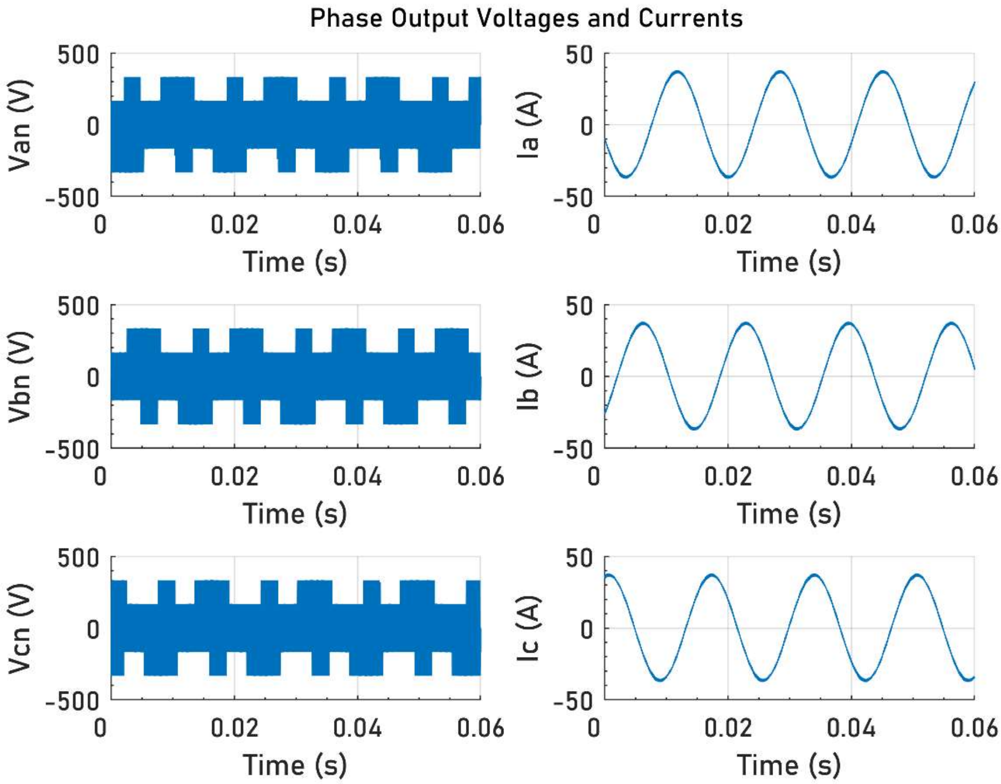

Figure 8: Output phase voltage and current.

The harmonic spectrum is shown in figure 9, using an amplitude modulation index of 0.814.

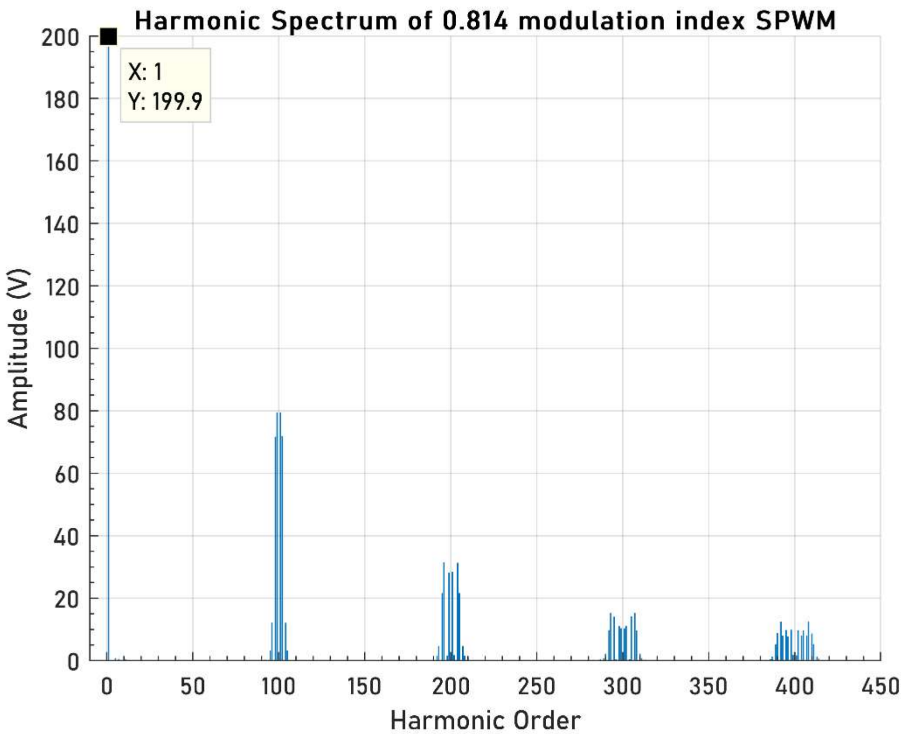

Figure 9: Harmonic spectrum with m = 0.814.

QUESTION 2C

If the real resistive component of the load is kept constant, and load inductance is increased, the power factor will decrease. The apparent voltage across the whole load will increase as a result of the larger reactive voltage phasor. A larger load inductance will improve the circuits ability to maintain an output current through the switches dead time, resulting in a smoother output current waveform. This will increase the fundamental components of the output voltage compared to a small load inductance.

The relationship between power factor and the fundamental component of the output voltage is shown in figure 10.

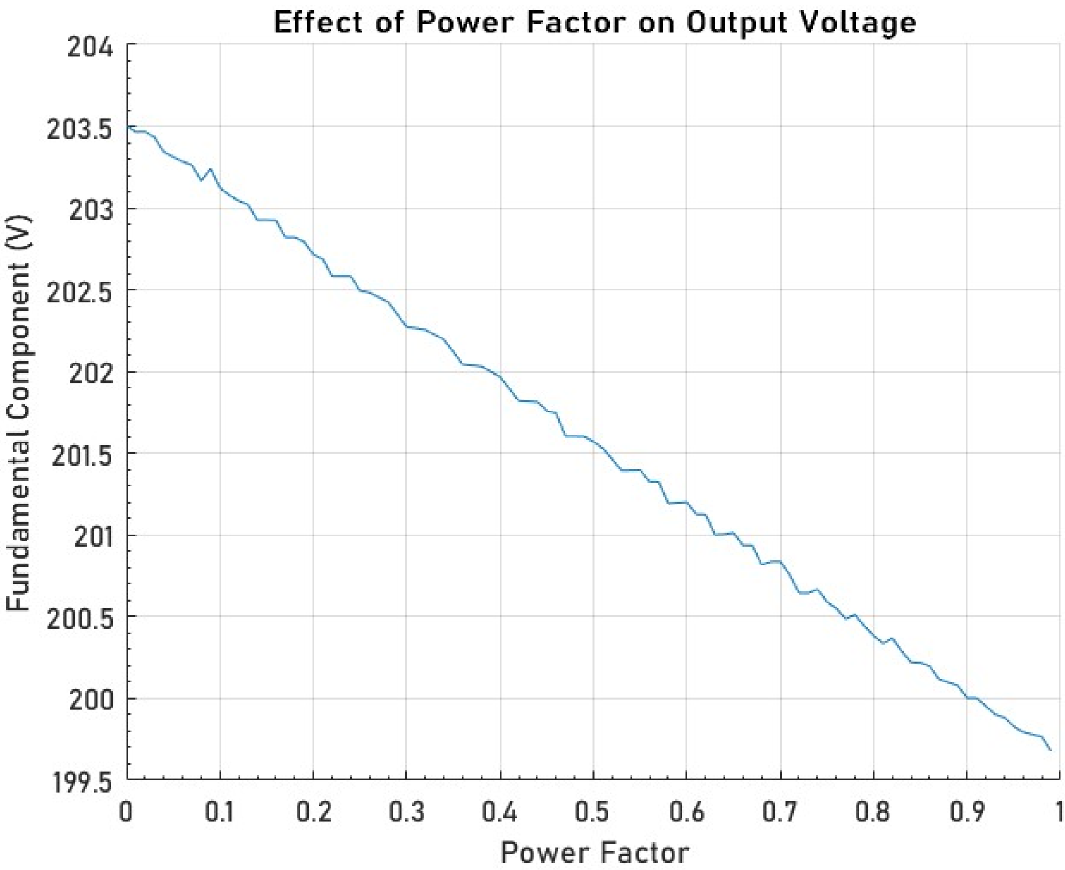

Figure 10: Relationship between power factor and output voltage.

As expected, the output voltage almost linearly decreases as the power factor is increased.