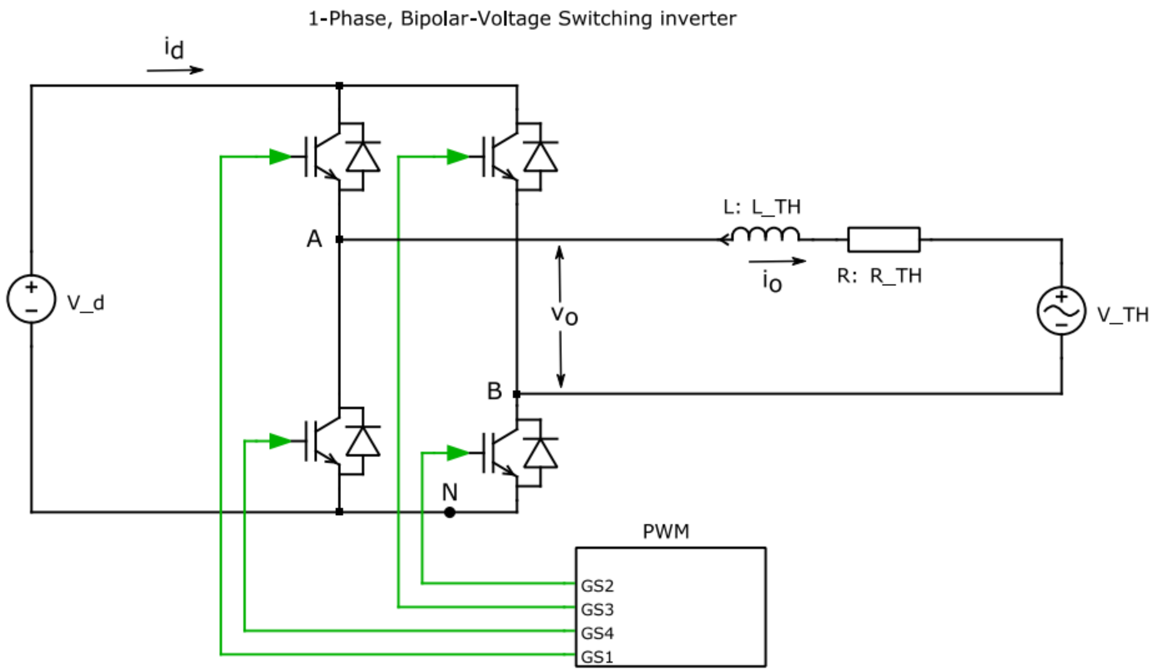
Muhammad Dayyan Hussain Khan
101423382

PLECS Simulation Assignment 02

4. 1-Phase, Bipolar-Voltage Switching Inverter



1. Obtain the following waveforms using 1Phbsinv:

a) v_o and i_o.

v_o and i_o waveforms depict the output voltage and current of the inverter system, respectively, under the given operating conditions.

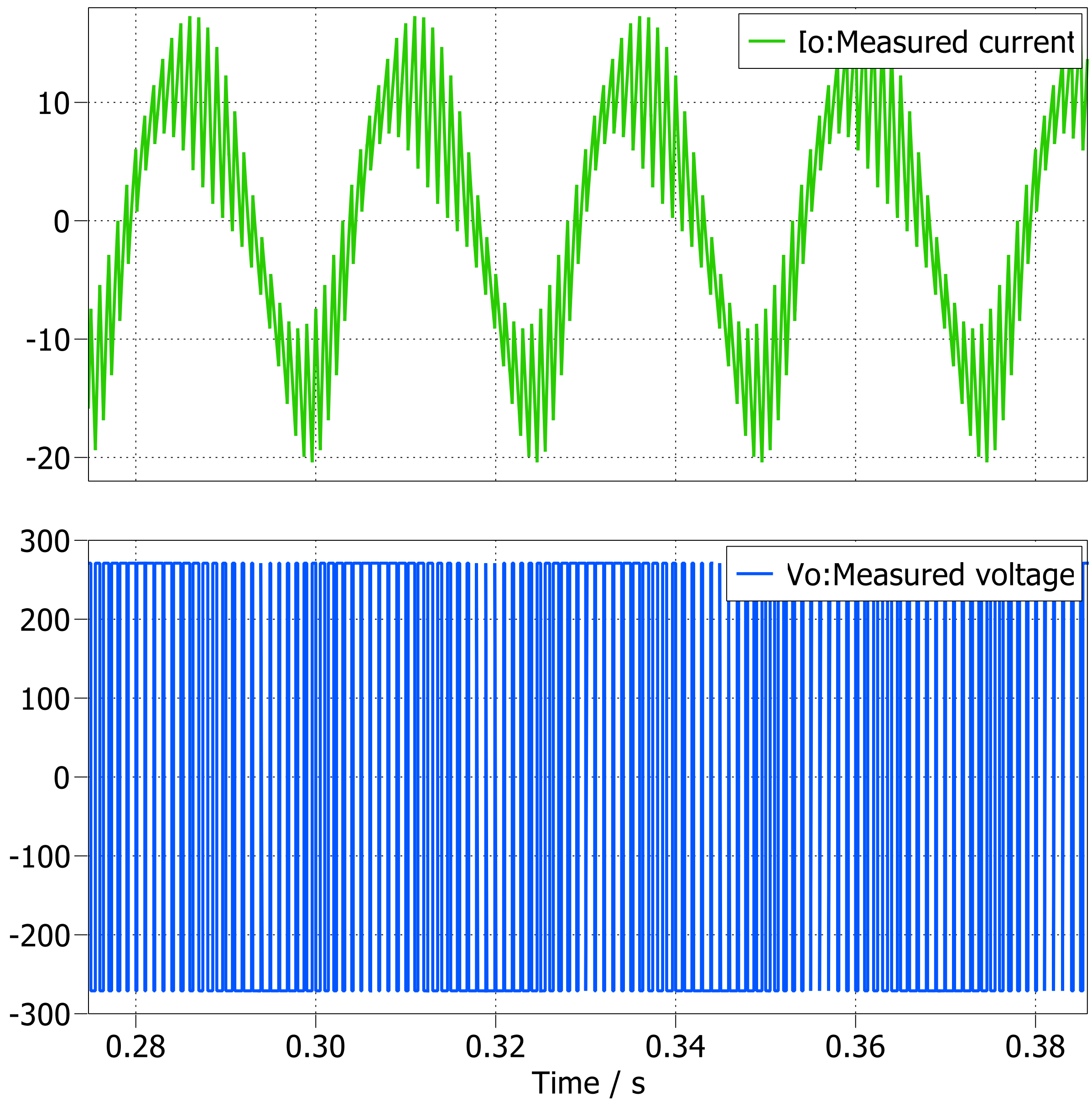


Figure 1: The waveforms for Vo and Io

b) v_o and i_d.

v_o represents the output voltage waveform after modulation, while i_d denotes the inductor current waveform, showing the current flow through the inductor.

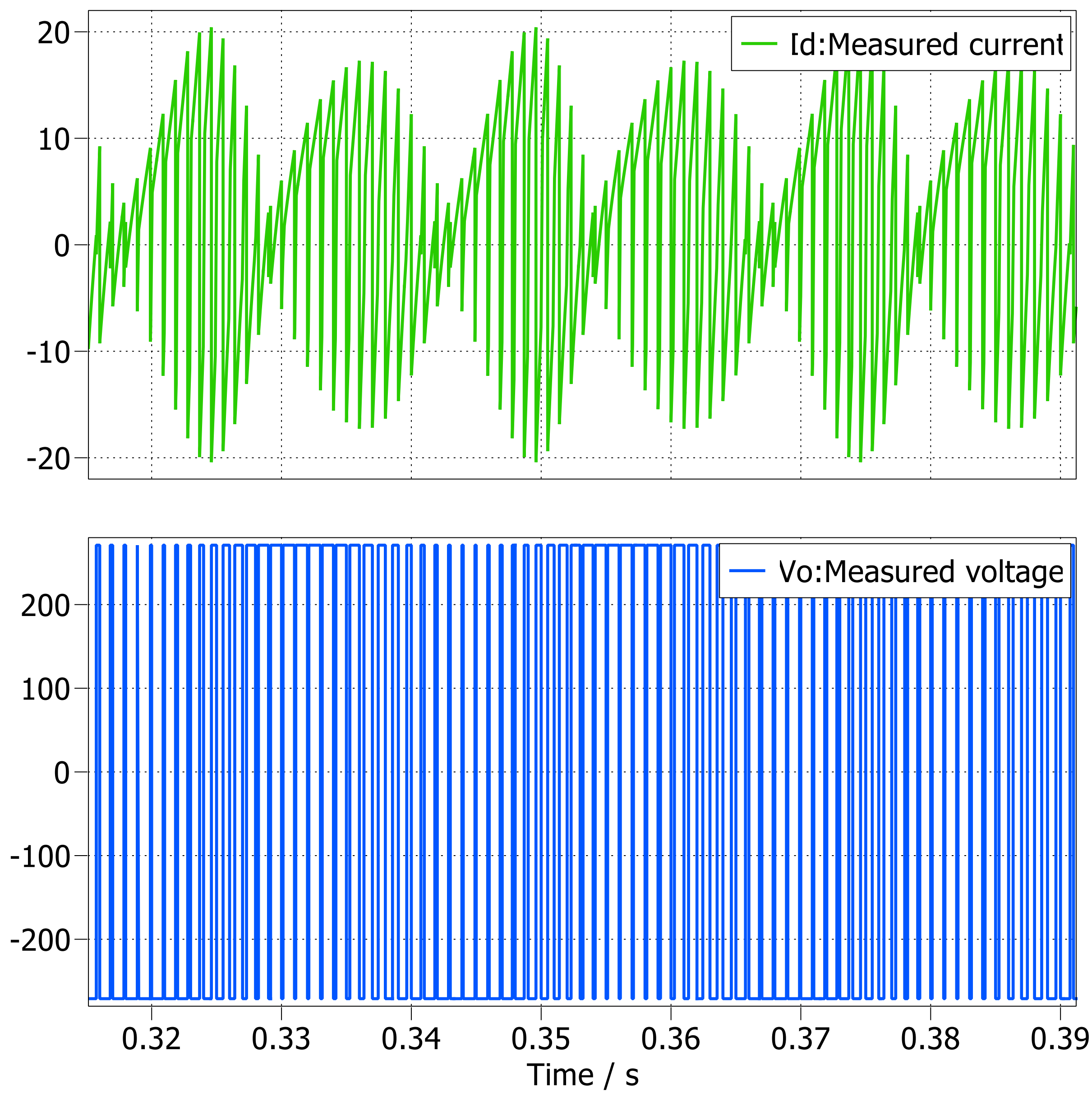


Figure 2: The waveforms for V_o and I_d

c) v_o, i_o and p_o

po waveform illustrates the power delivered by the inverter system, indicating instantaneous power consumption or generation.

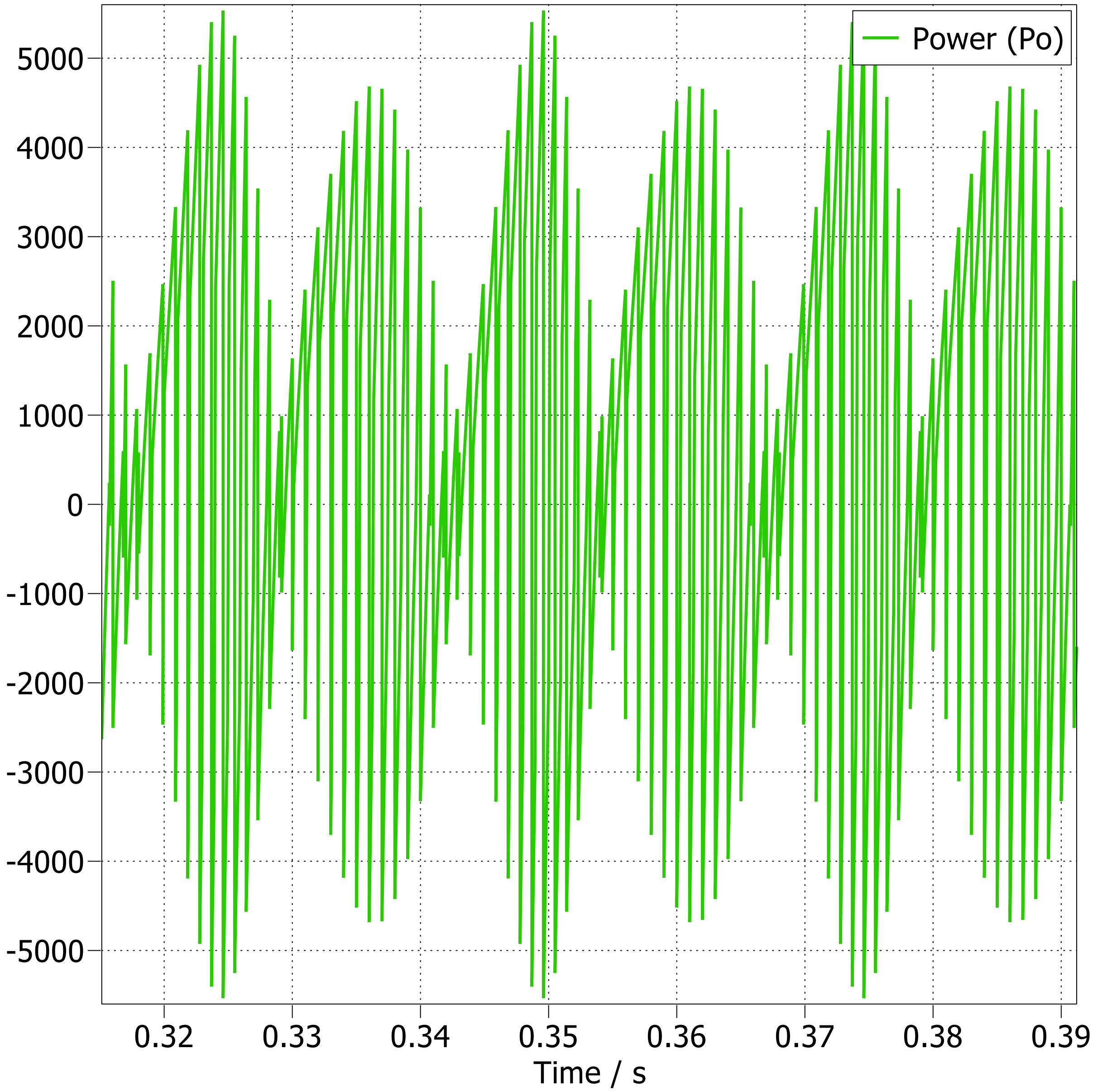


Figure 3: The waveforms for P_o.

2. Obtain v_{o1} by means of Fourier analysis of the v_o waveform. Compare v_{o1} with its precalculated nominal value.

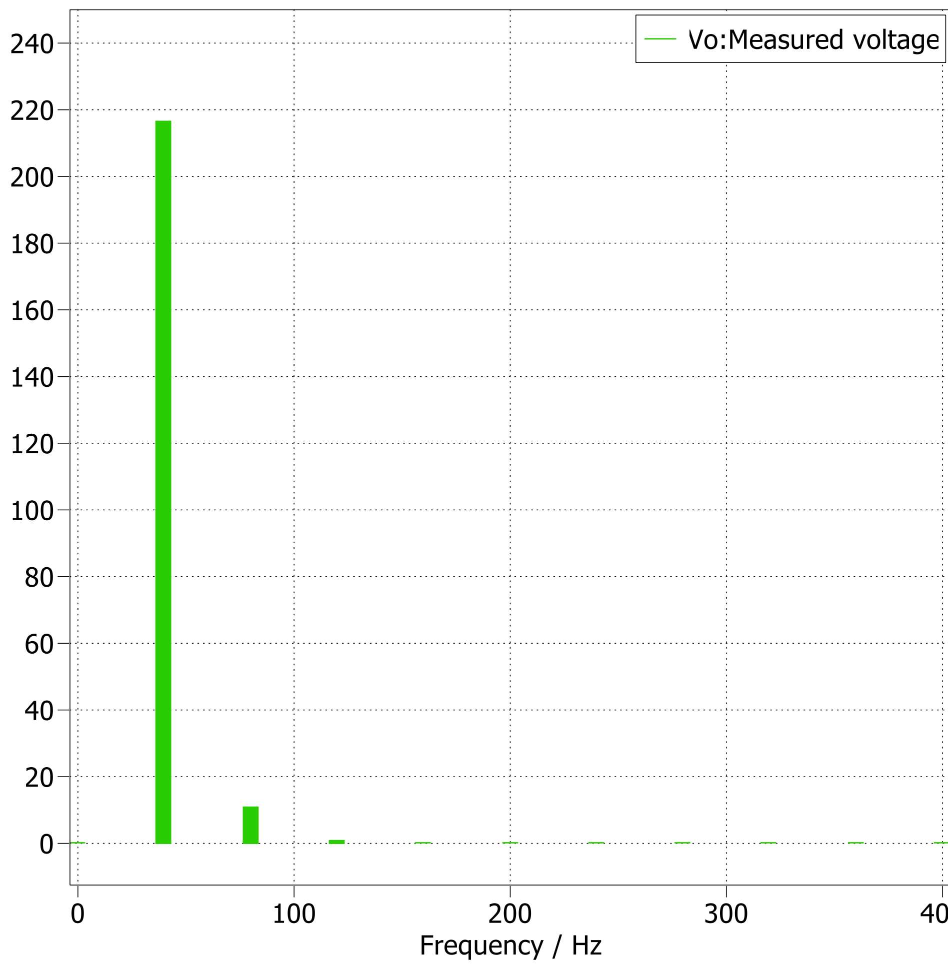


Figure 4: Fourier Analysis of V_o Waveform

Upon conducting the Fourier analysis of $\boldsymbol{v_o}$, the obtained fundamental component $\boldsymbol{v_{An1}}$ matches the precalculated nominal value of **153.11 V,** it signifies that the inverter is operating within the expected parameters and is delivering the specified output current accurately.

3. Using the results of Problem 2, obtain the ripple component v_{ripple} waveform in the output voltage.

Initially, we derive the peak value and phase angle of the fundamental waveform from the Fourier Transform of $\boldsymbol{v_o}$ which yields values of 216.52 for the peak and 22.7 degrees for the phase angle. Subsequently, we create the fundamental waveform and subtract it from the original waveform of $\boldsymbol{v_o}$ to derive the ripple waveform of $\boldsymbol{v_o}$.

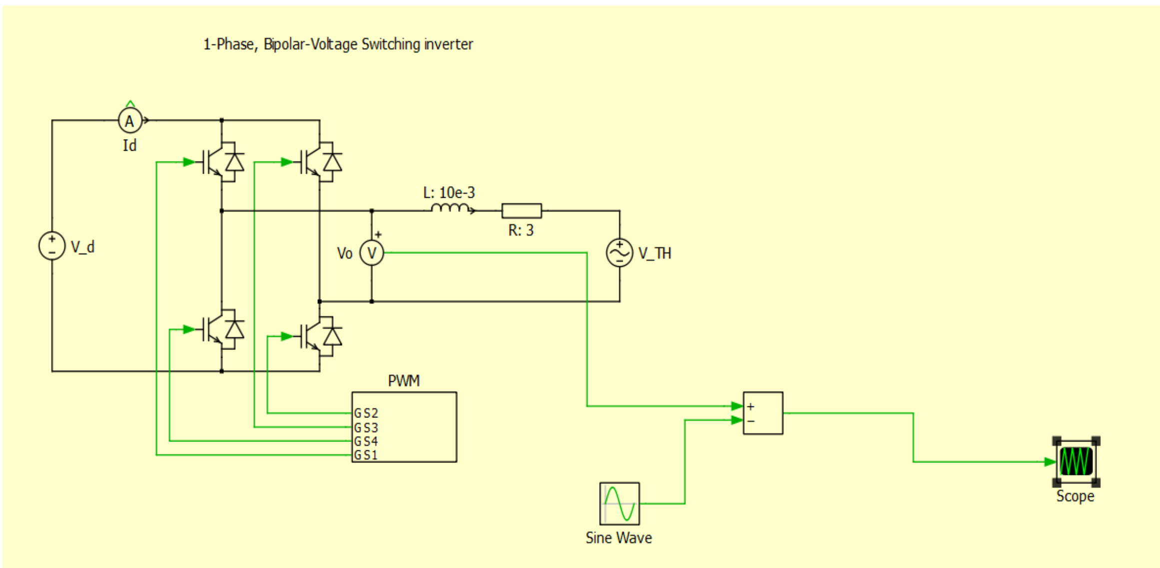


Figure 6: Circuit Diagram for Calculating V_{ripple}

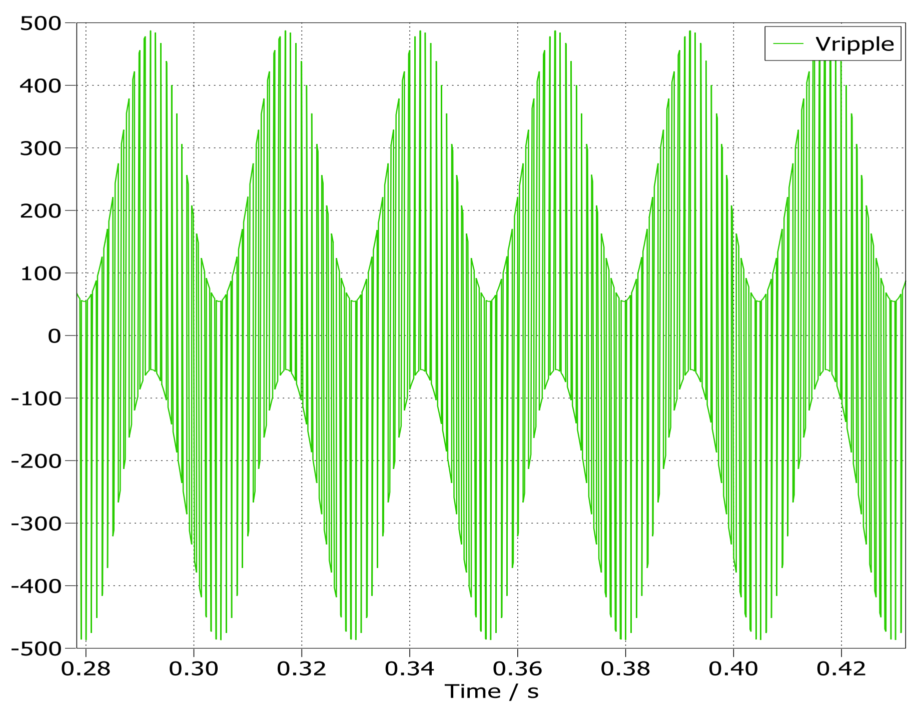


Figure 5: Waveform for V_{ripple}

4. **Obtain i_{o1} by means of Fourier analysis of the i_o waveform. Compare i_{o1} with its precalculated nominal value.**

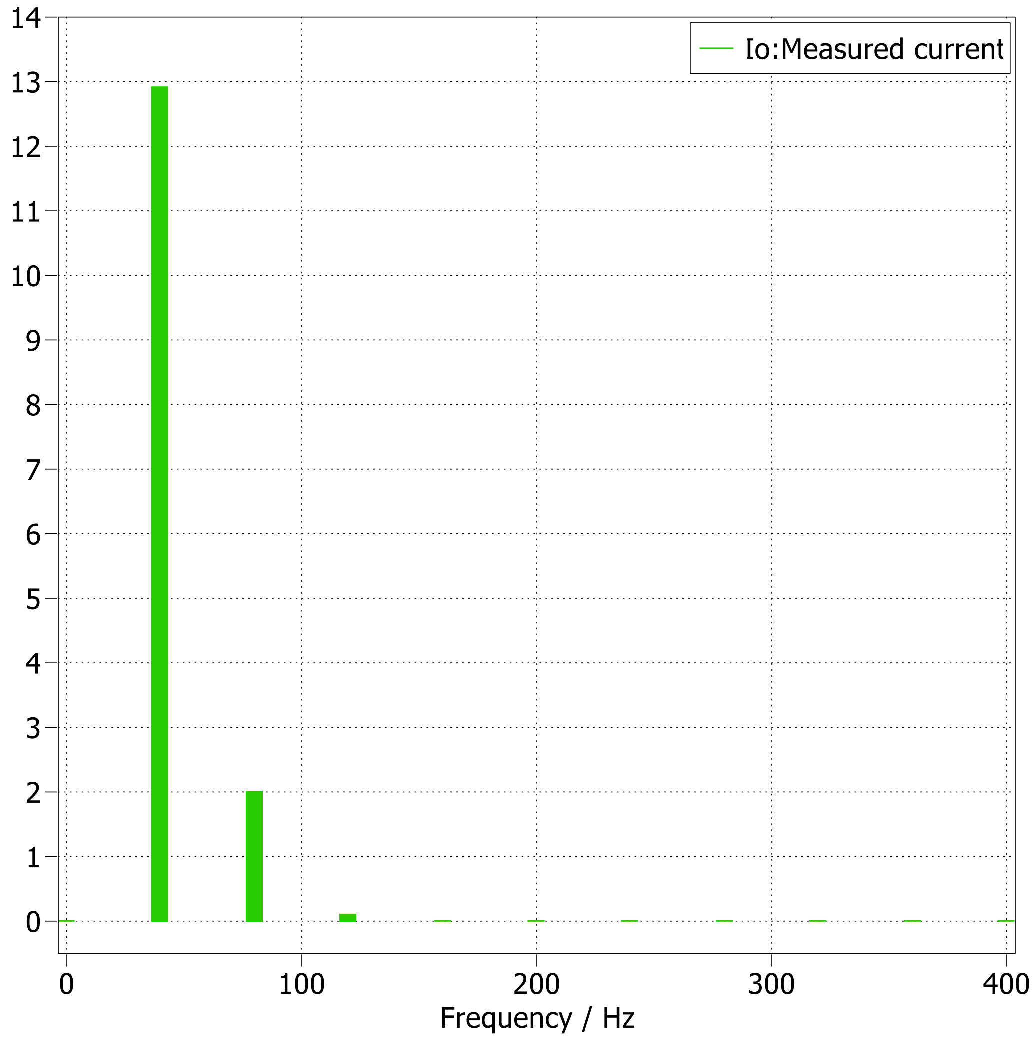


Figure 7: Fourier Analysis of I_o Waveform

Upon conducting the Fourier analysis of i_o, the obtained fundamental component i_{A1} **is** almost **9.12 A** as compared to the precalculated nominal value of **10 A,** it signifies that the inverter is operating within the expected parameters and is delivering the specified output current somehow accurately.

5. **Using the results of Problem 4, obtain the ripple component i_{ripple} in the output current.**

Initially, we derive the peak value and phase angle of the fundamental waveform from the Fourier Transform of $\boldsymbol{i_o}$ which yields values of 12.91 for the peak and -36 degrees for the phase angle. Subsequently, we create the fundamental waveform and subtract it from the original waveform of $\boldsymbol{i_o}$ to derive the ripple waveform of $\boldsymbol{i_o}$.

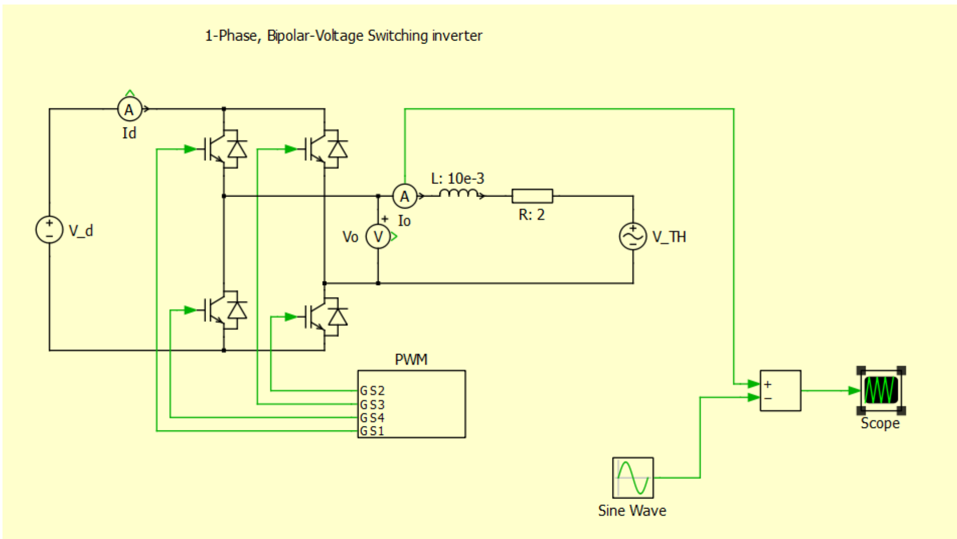


Figure 9: Circuit diagram for calculating I_{ripple}

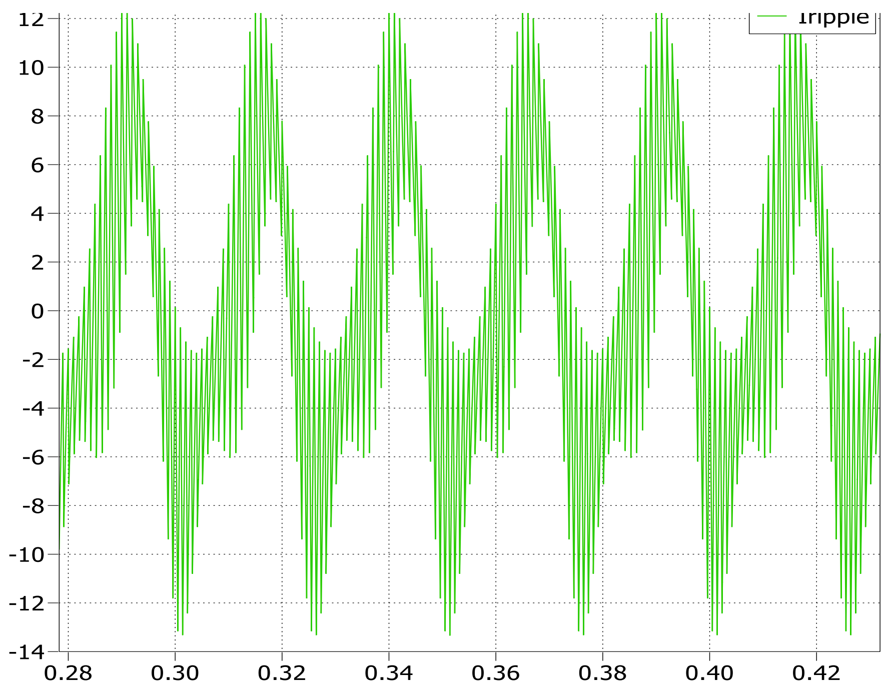


Figure 8; Waveform for I_{ripple}

6. Obtain $i_{d(avg)}$ and i_d (the component of the 2nd harmonic frequency) by means of the Fourier analysis of the i_d waveform. Compare them with their precalculated nominal values.

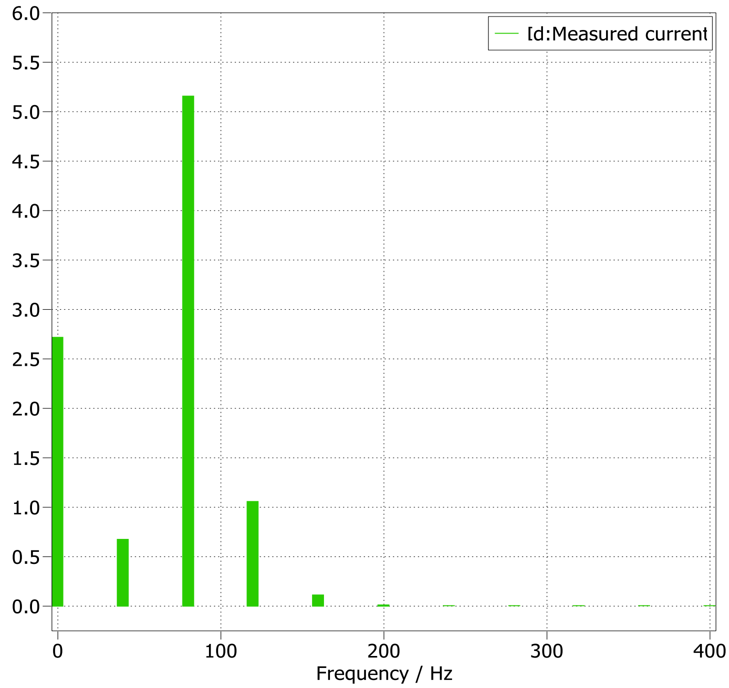


Figure 10: Fourier Analysis of Id Waveform

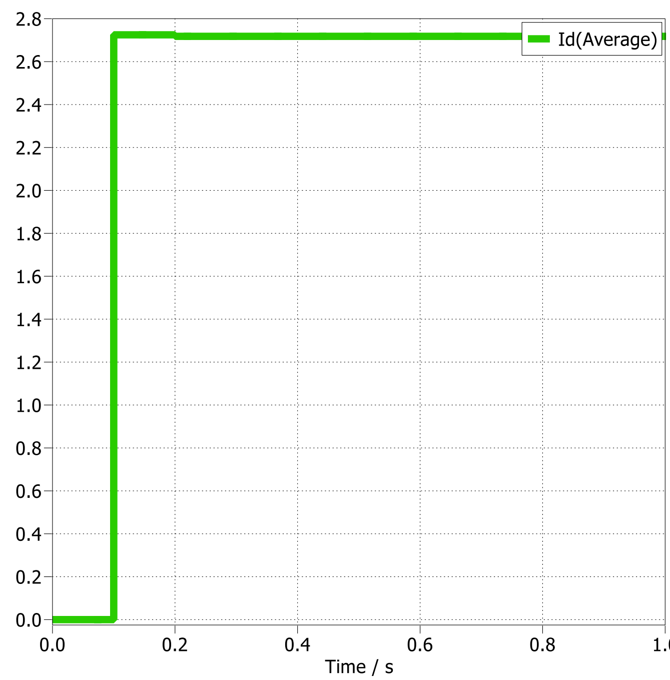


Figure 11: The Waveform for $i_{d(avg)}$

The average value of $\boldsymbol{i_{d(avg)}}$ is around **2.71 A**, while the amplitude of the second harmonic frequency component is specified as **3.64 A (RMS)**. The fundamental component of $\boldsymbol{i_d}$ represents the steady-state current flowing through the inverter system, crucial for understanding the system's average behavior. Meanwhile, the second harmonic frequency component $\boldsymbol{i_{d2}}$ indicates the presence of harmonic distortion in the input current waveform, which can lead to undesirable effects such as increased losses and reduced efficiency in the system.The discrepancy between the average value of $\boldsymbol{i_{d(avg)}}$ and the amplitude of $\boldsymbol{i_{d2}}$ suggests the presence of harmonic distortion in the input current waveform, indicating potential issues such as non-linear loads or impedance mismatches in the system. Addressing these issues may involve implementing filtering techniques, optimizing component sizing, or adjusting control algorithms to mitigate harmonic distortion and improve the overall performance of the inverter system.

7. **Using the results of Problem 6, obtain the high frequency ripple component *id,ripple* in the input dc current. Calculate its rms value.**

We can calculate the high frequency ripple component $i_{d(ripple)}$ using the following equation:

$$i_{d(ripple)} = i_d - i_{d(avg)}$$

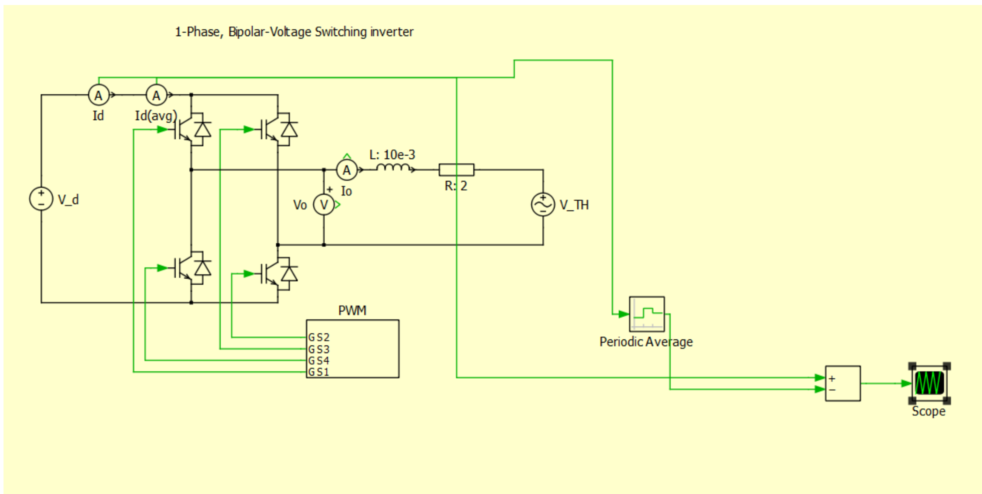


Figure 13: Circuit Diagram for calculating id, ripple

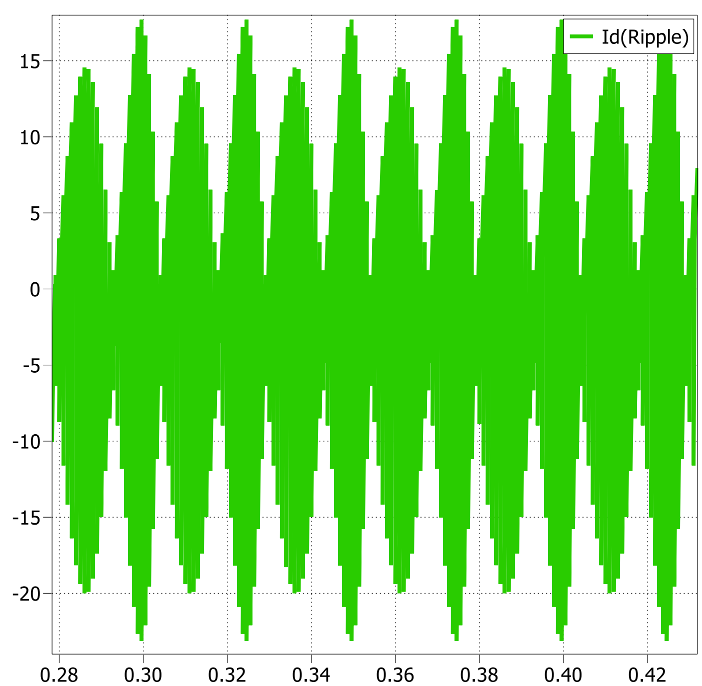
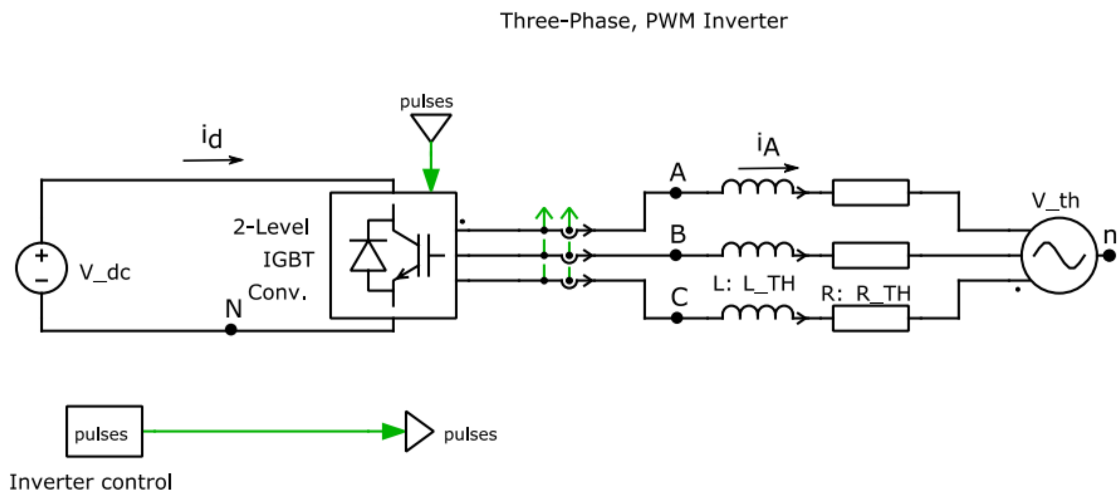


Figure 12: waveform for high frequency ripple component with an RMS value of 9.37 A

5. Three-Phase, PWM Inverter



1. Obtain the following waveforms:

a) v_{AN} and i_A.

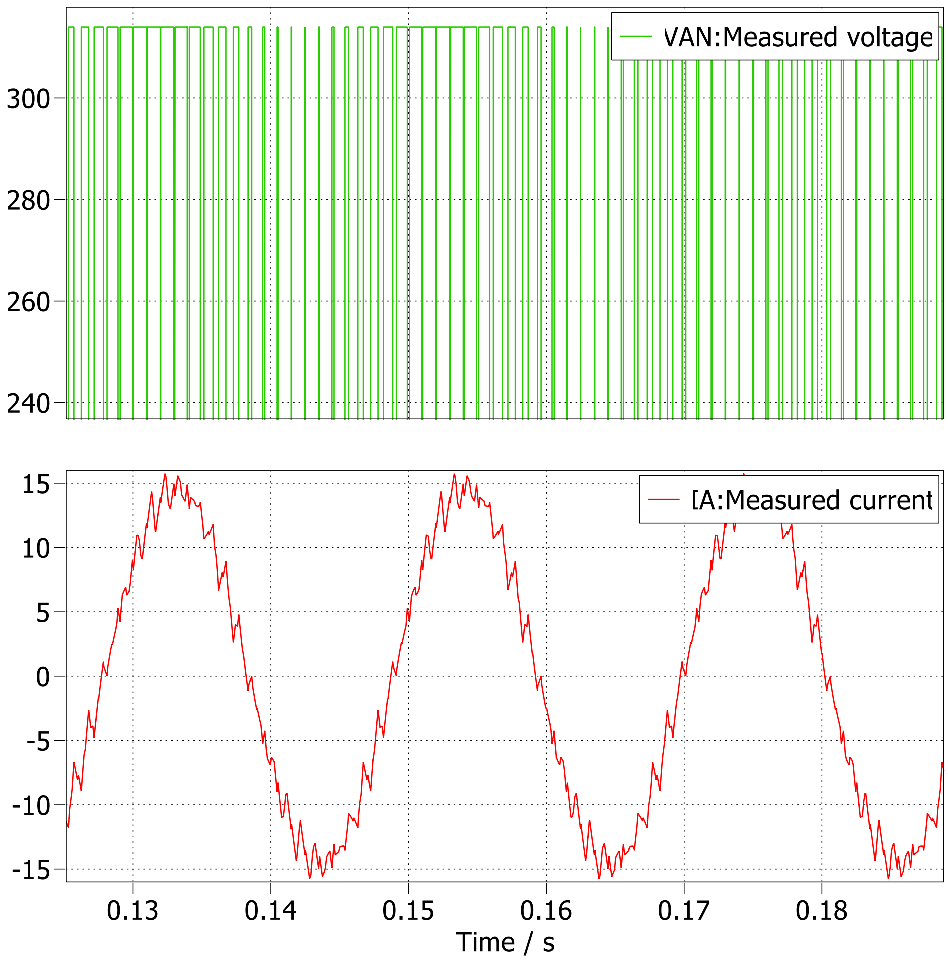


Figure 14: The waveforms for V_{AN} and I_A

b) v_{an} and i_A.

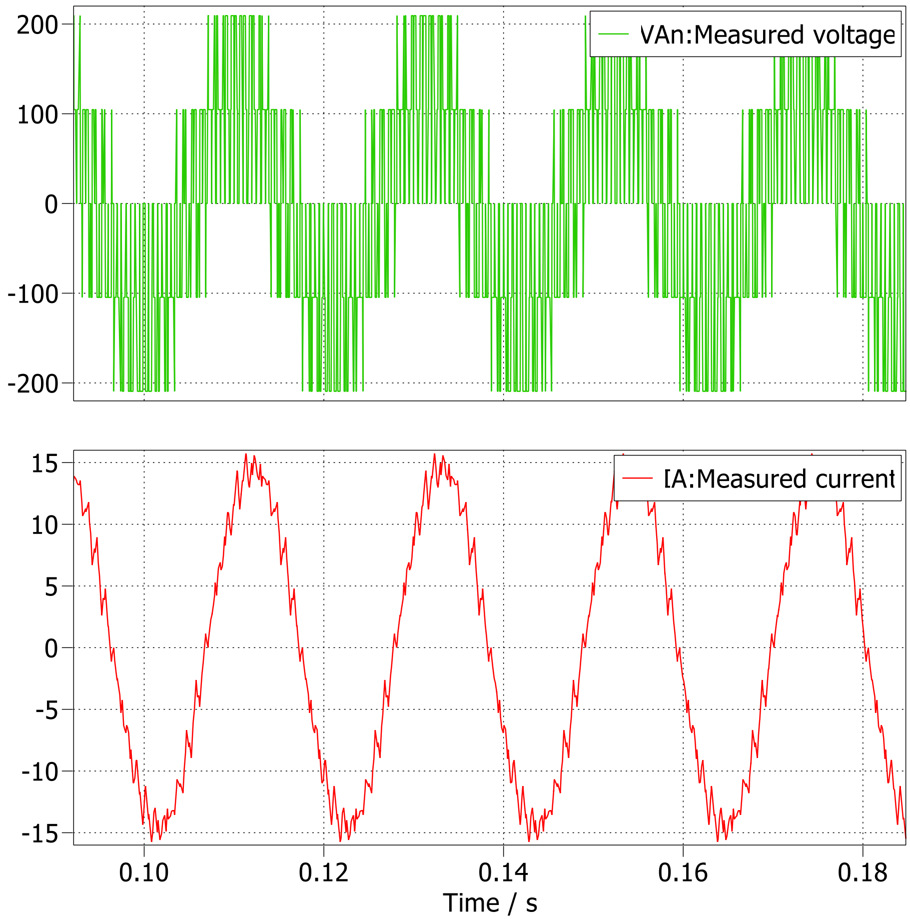


Figure 15: The waveforms for V_{An} and I_A

c) v_{AN} **and** i_d**.**

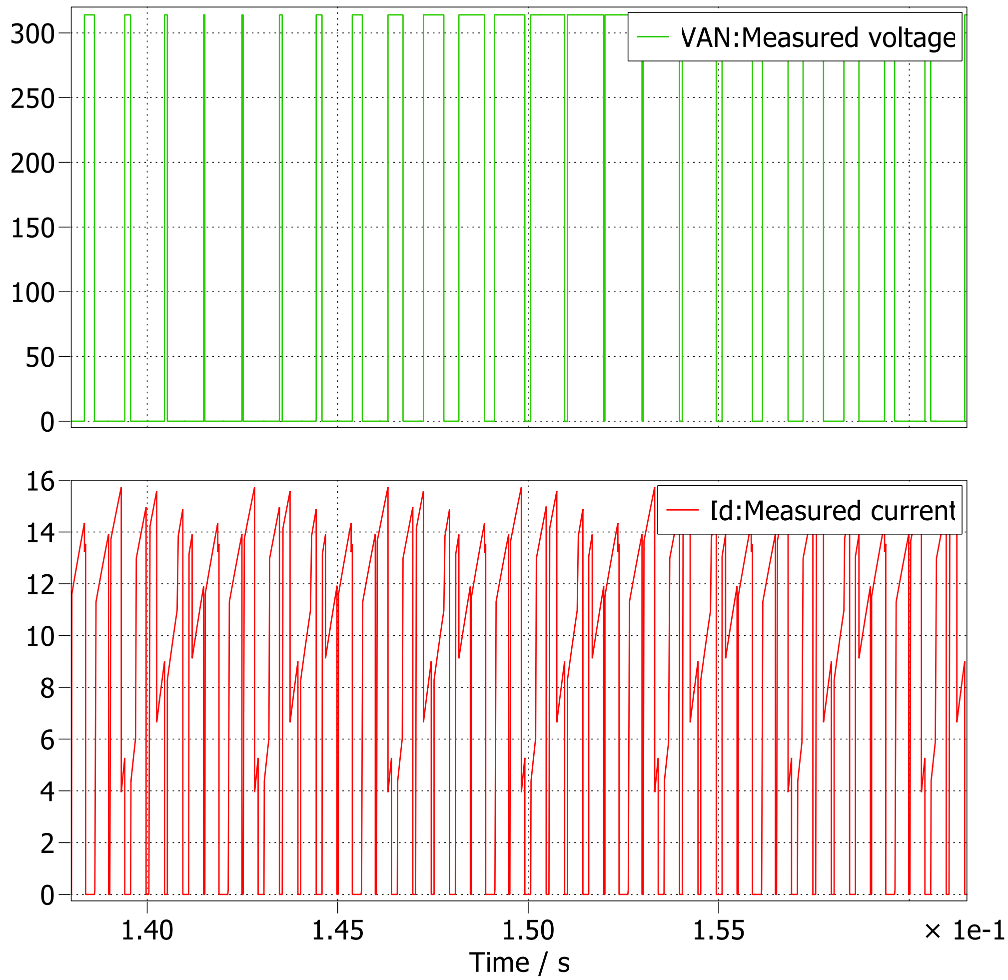


Figure 16: The waveforms for V_{AN} and I_d

2. **Obtain v_{An1} by means of Fourier analysis of the v_{An} waveform. Compare v_{An1} with its precalculated nominal value.**

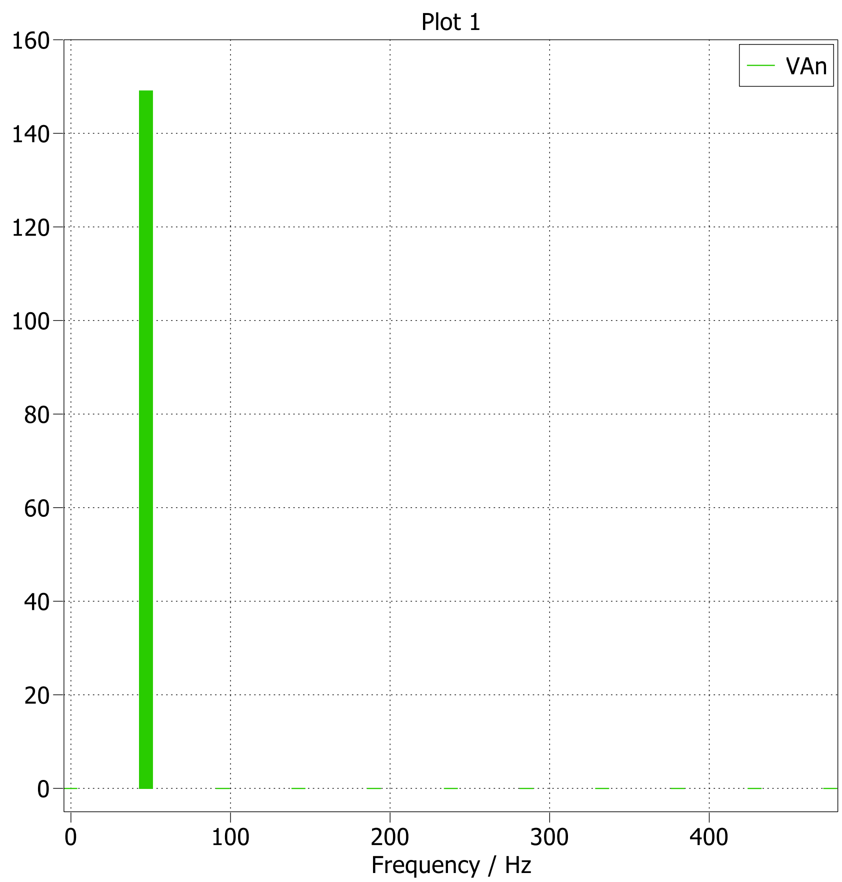


Figure 17: Fourier Analysis of V_{An}

Upon conducting the Fourier analysis of v_{An}, the obtained fundamental component v_{An1} matches the precalculated nominal value of **105.39 V,** it signifies that the inverter is operating within the expected parameters and is delivering the specified output current accurately.

3. Using the results of Problem 2, obtain the ripple component v_{ripple} waveform in the output voltage.

Initially, we derive the peak value and phase angle of the fundamental waveform from the Fourier Transform of $\boldsymbol{v_o}$ which yields values of 149.04 for the peak and 180 degrees for the phase angle. Subsequently, we create the fundamental waveform and subtract it from the original waveform of $\boldsymbol{v_o}$ to derive the ripple waveform of $\boldsymbol{v_o}$.

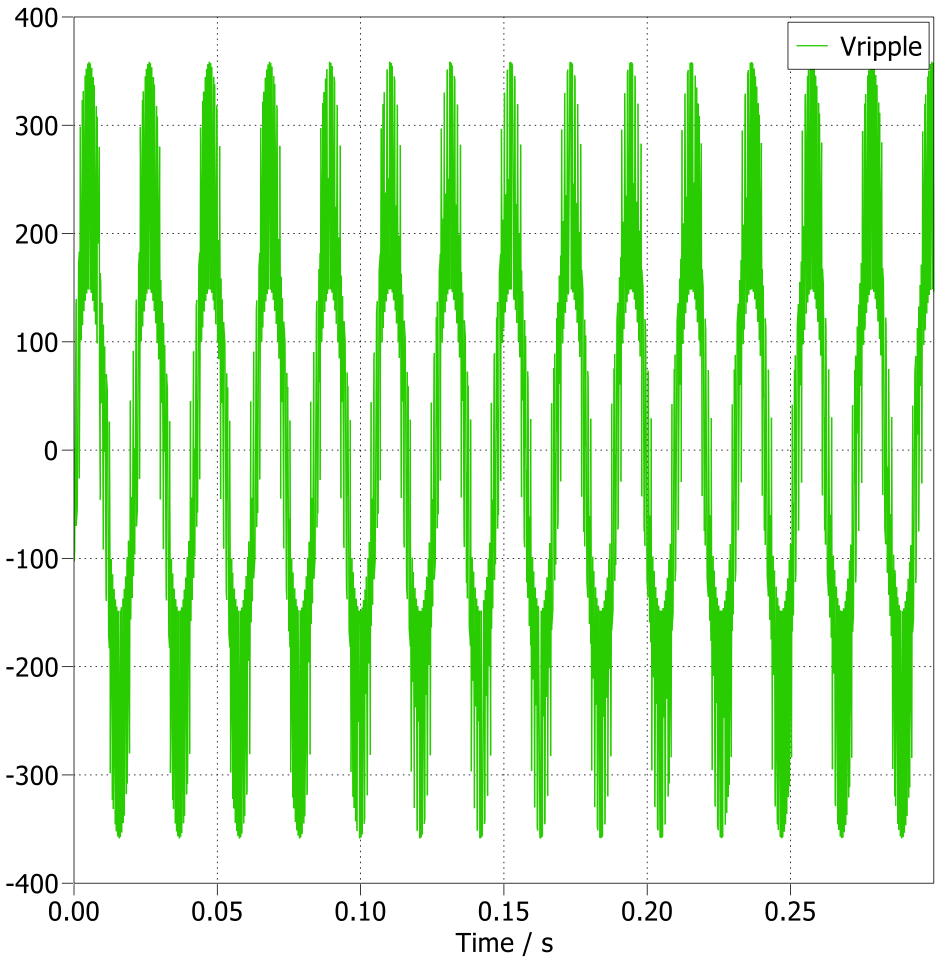


Figure 18: Waveform for V_{ripple}

4. Obtain i_{A1} by means of Fourier analysis of i_A waveform. Compare i_A with its precalculated nominal value.

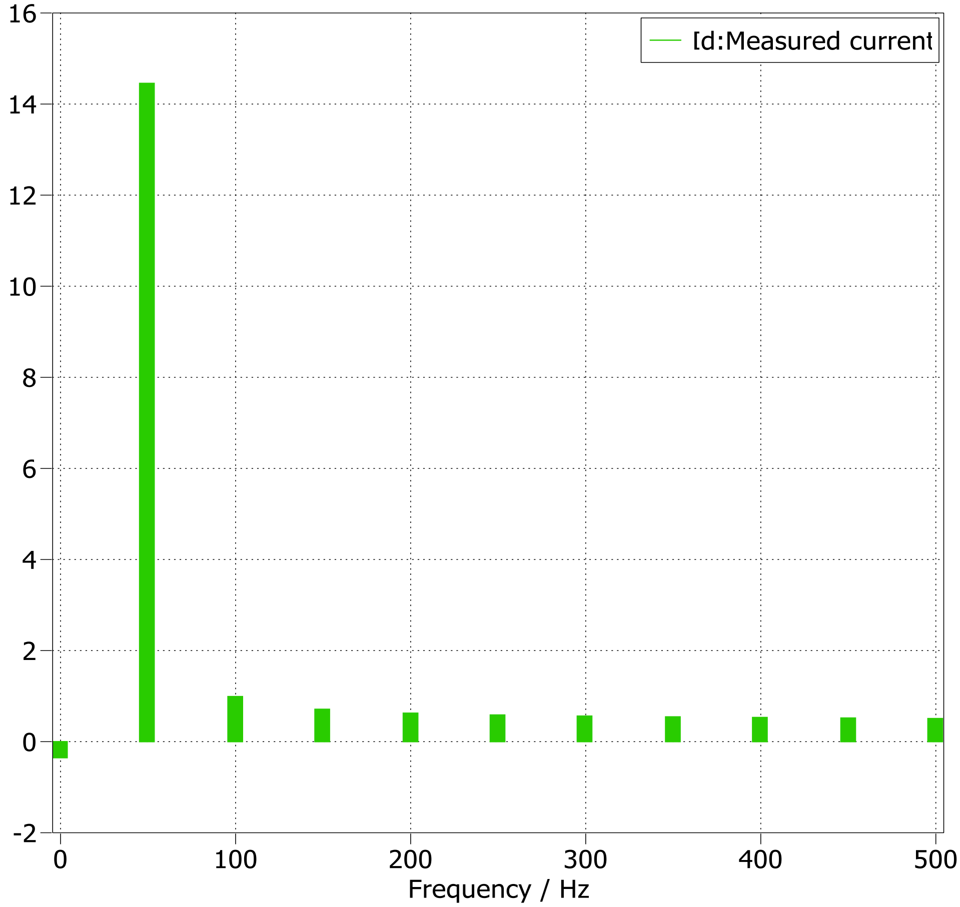


Figure 19: Fourier Transform of i_A

Upon conducting the Fourier analysis of i_A, the obtained fundamental component i_{A1} matches the precalculated nominal value of **10 A,** it signifies that the inverter is operating within the expected parameters and is delivering the specified output current accurately.

5. Using the results of Problem 4, obtain the ripple component i_{ripple} in the output current.

Initially, we derive the peak value and phase angle of the fundamental waveform from the Fourier Transform of i_o which yields values of 14.53 for the peak and -24.23 degrees for the phase angle. Subsequently, we create the fundamental waveform and subtract it from the original waveform of i_o to derive the ripple waveform of i_o .

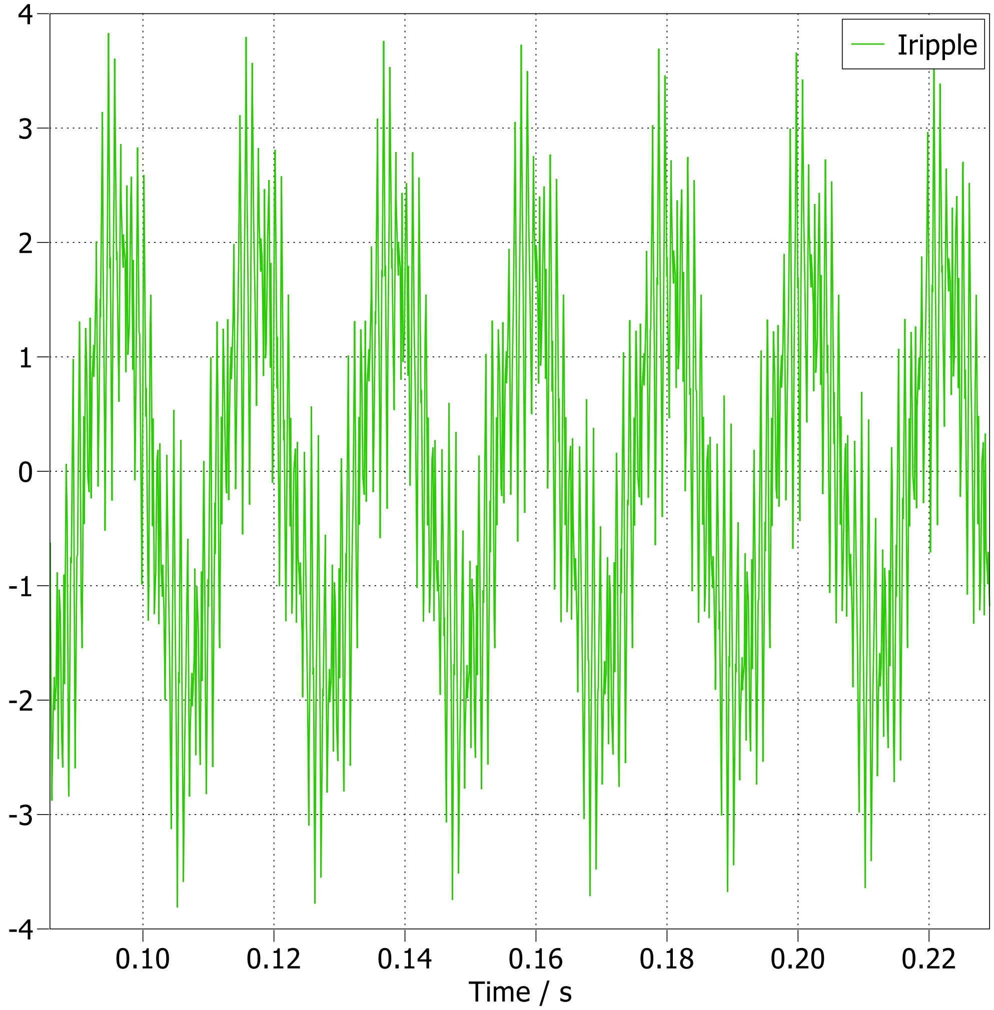


Figure 20: Waveform for I_{ripple}

6. **Obtain $i_{d(avg)}$ by means of Fourier analysis and obtain the high frequency ripple $i_{d(ripple)} = i_d - i_{d(avg)}$ in the input current.**

We can calculate the high frequency ripple component $i_{d(ripple)}$ using the following equation:

$$i_{d(ripple)} = i_d - i_{d(avg)}$$

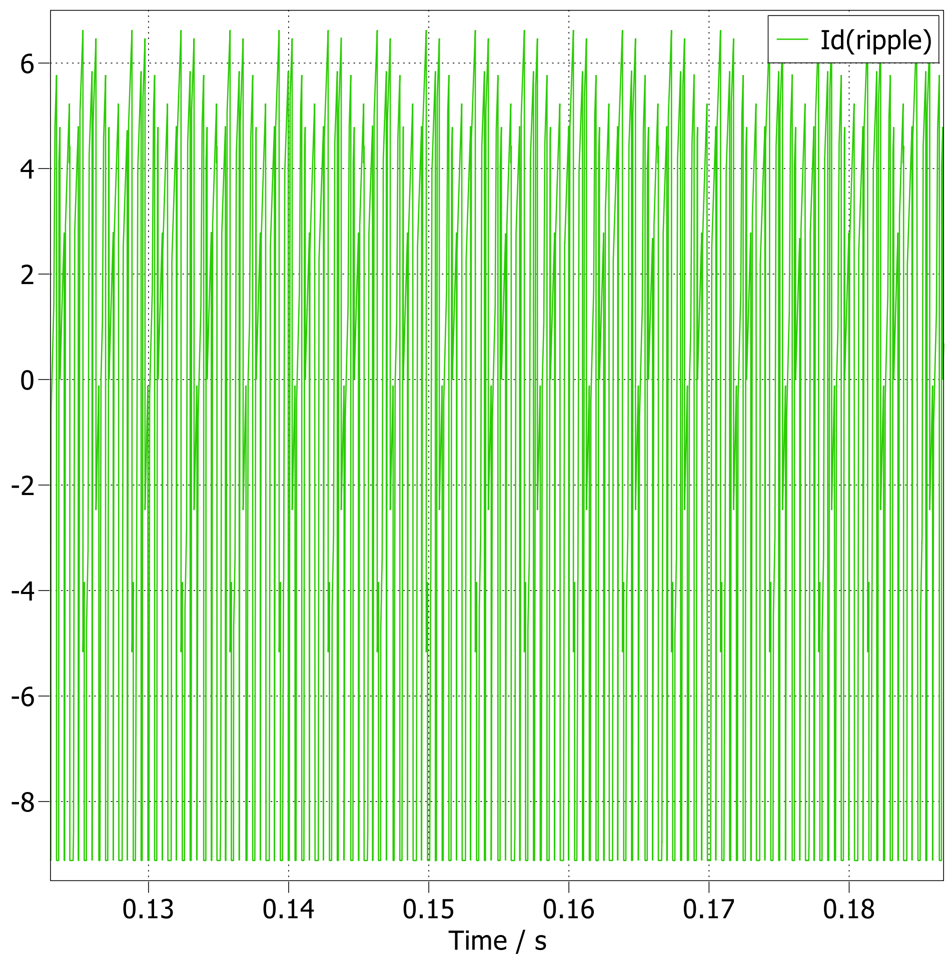


Figure 21: Waveform for High Frequency Ripple with an RMS Value of 5.54 A

7. Obtain the load neutral voltage with respect to the mid-point of the dc input voltage.

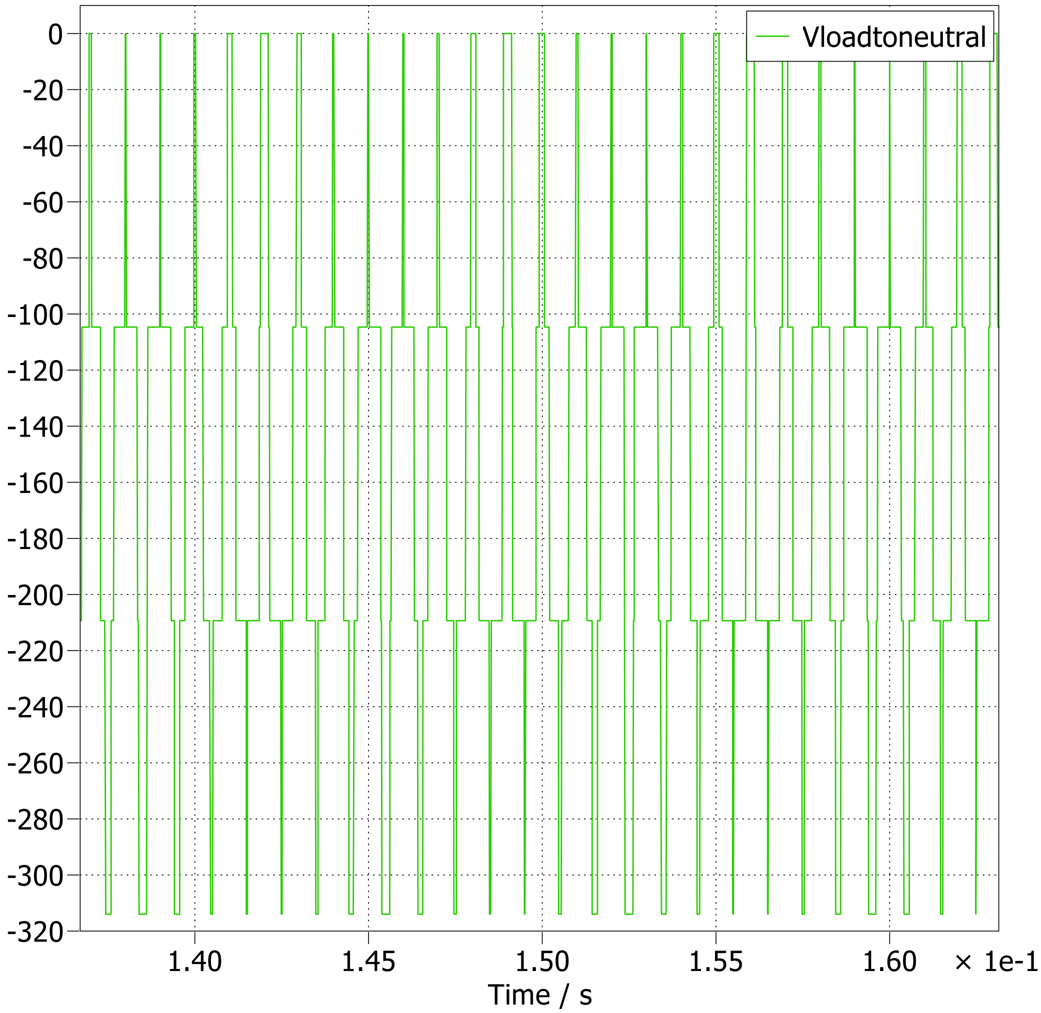
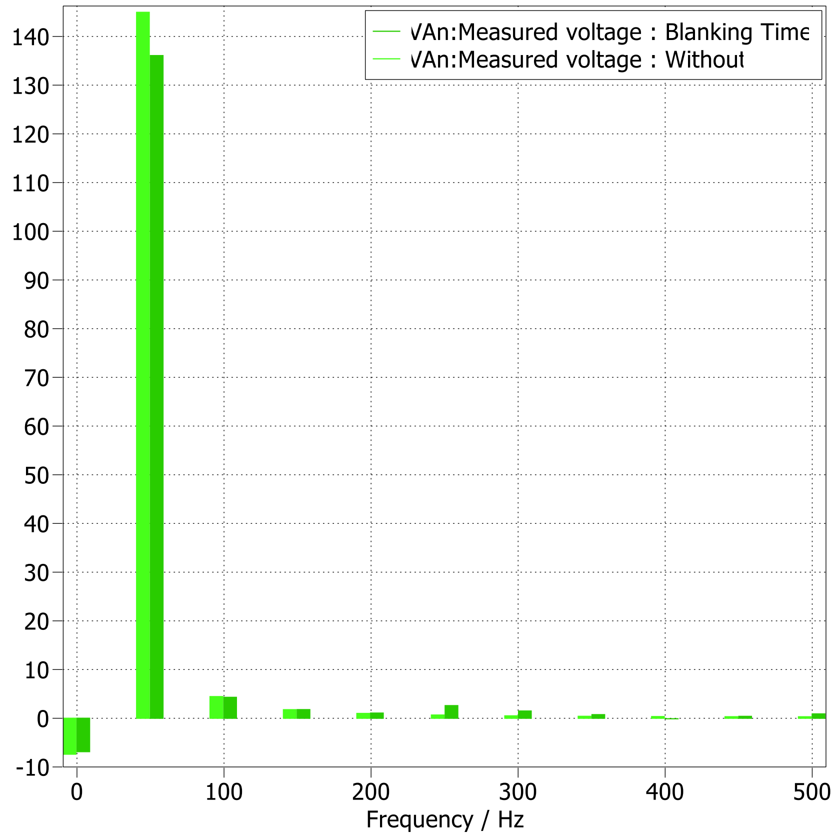


Figure 22: The Load Neutral Voltage with respect to the Input of DC Input Voltage is 179.19 V (RMS)

8. **For this problem, the effect of blanking time is studied. After the inverter control block add "Blanking time" block (can be found from Control > Modulators). Set its value to 25 µs. Obtain the low order harmonics such as the 3rd, 5th, 7th, etc. in the phase-to-neutral and the line-to-line output voltages. At the fundamental frequency, obtain the amplitude and the phase of the voltages and compare them to the harmonics without the blanking time.**



	3rd Harmonic	5th Harmonic	7th Harmonic
Frequency	150 Hz	250 Hz	350 Hz
Amplitude	1.769	2.59069	0.738458
Angle	-16.1489 Degree	28.8947 Degree	179.946 Degree

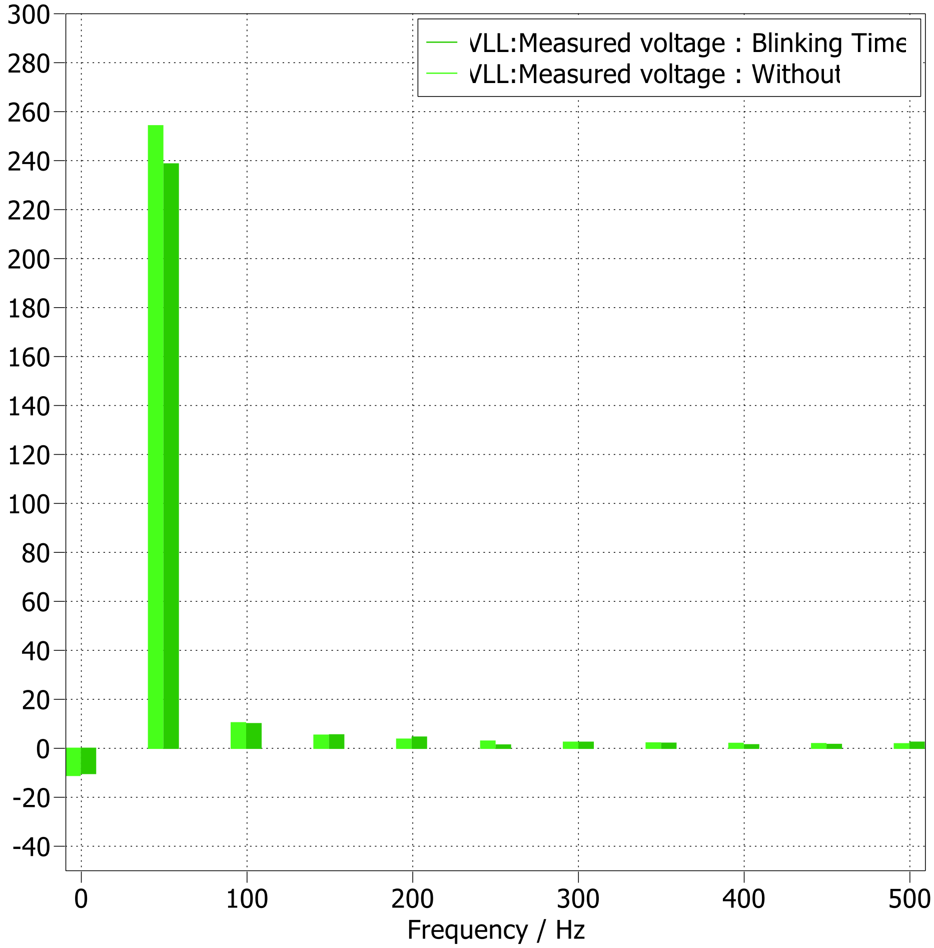


Figure 23: Fourier Transform of V_{LL} with effect of Blanking Time

	3rd Harmonic	**5th Harmonic**	**7th Harmonic**
Frequency	150 Hz	250 Hz	350 Hz
Amplitude	5.47501	1.33348	2.06709
Angle	-70.4955 Degree	19.3315 Degree	-170.947 Degree

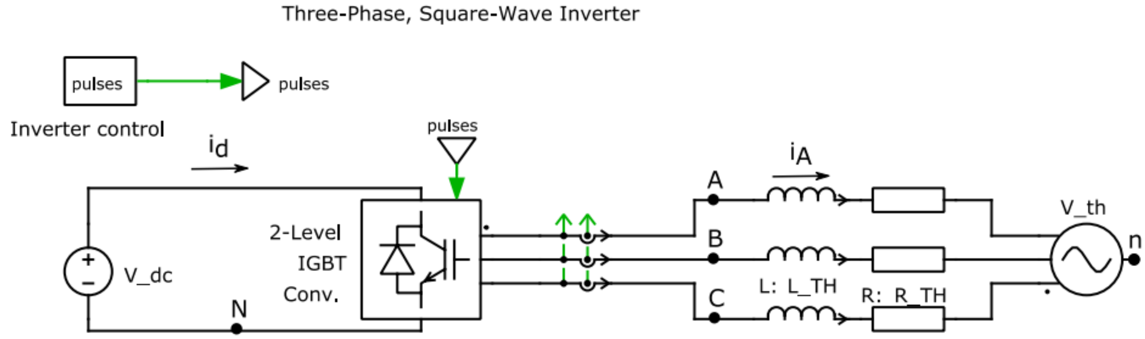
The introduction of blanking time in the three-phase PWM inverter circuit had noticeable effects on the output voltages, as indicated by the measured values. With blanking time at the fundamental frequency, the phase-to-neutral voltage $\boldsymbol{v_{An}}$decreased from **144.953 V** to **136.069 V**, and the line-to-line voltage $\boldsymbol{v_{LL}}$ decreased from **254.241 V** to **238.645 V.** This reduction in voltage magnitudes suggests that the blanking time influenced the amplitude of the output voltages. Moreover, the phase angles also experienced slight changes, with $\boldsymbol{v_{An}}$ shifting from **-4.91734°** to **-3.58125°** and $\boldsymbol{v_{LL}}$ shifting from **-36.13°** to **-34.7744°.**

Analyzing the harmonic content revealed interesting findings. At frequencies of 150 Hz, 250 Hz, and 350 Hz, $\boldsymbol{v_{An}}$ exhibited varying magnitudes and phase angles both with and without blanking time. For instance, at 150 Hz, $\boldsymbol{v_{An}}$had a magnitude of **1.769 V** and a phase angle of **-16.1489°** with blanking time, while without blanking time, it measured **2.59069 V** with a phase angle of **28.8947°.** This discrepancy suggests that the blanking time influenced the harmonic content of the phase-to-neutral voltage waveform.

Similarly, the line-to-line voltage $\boldsymbol{v_{LL}}$ showed varying magnitudes and phase angles at different frequencies with and without blanking time. At 150 Hz, $\boldsymbol{v_{LL}}$measured **5.47501 V** with a phase angle of **-70.4955°** with blanking time, while without blanking time, it measured **1.33348 V** with a phase angle of **19.3315°.** These differences highlight the impact of blanking time on the harmonic components of the output voltages, emphasizing its role in shaping the waveform characteristics and overall performance of the inverter system.

In summary, the introduction of blanking time in the PWM inverter circuit influenced the output voltage amplitudes and phase angles, as well as the harmonic content at different frequencies. This underscores the importance of considering blanking time in the design and optimization of power electronic circuits to achieve desired waveform characteristics and ensure efficient operation.

6. Three-Phase, Square-Wave Inverter



1. Obtain the following waveforms:

a. v_{AN} and i_A.

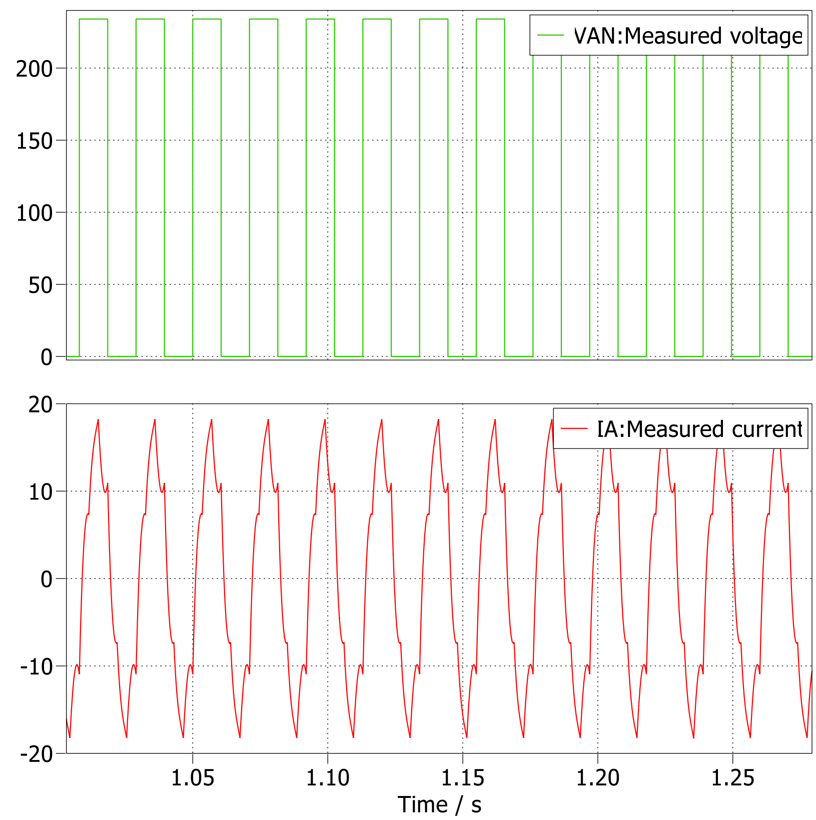


Figure 24: The Waveforms for V_{AN} and i_A

b. v_{an} and i_A.

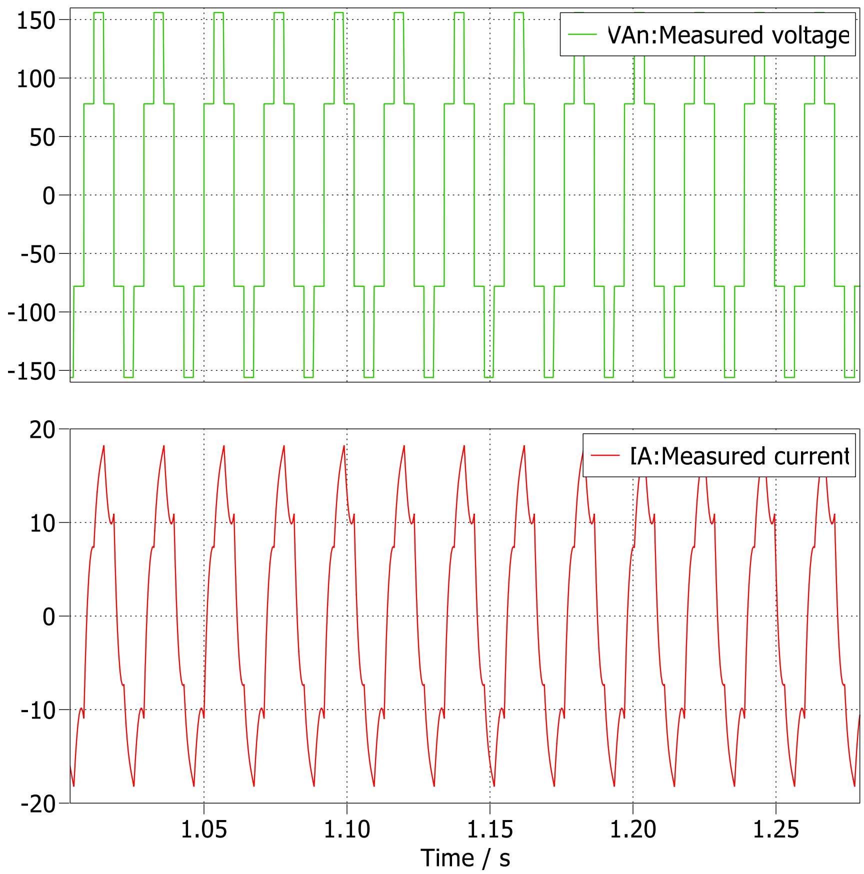


Figure 25: The Waveforms for VAn and iA

c. v_{AN} and i_d.

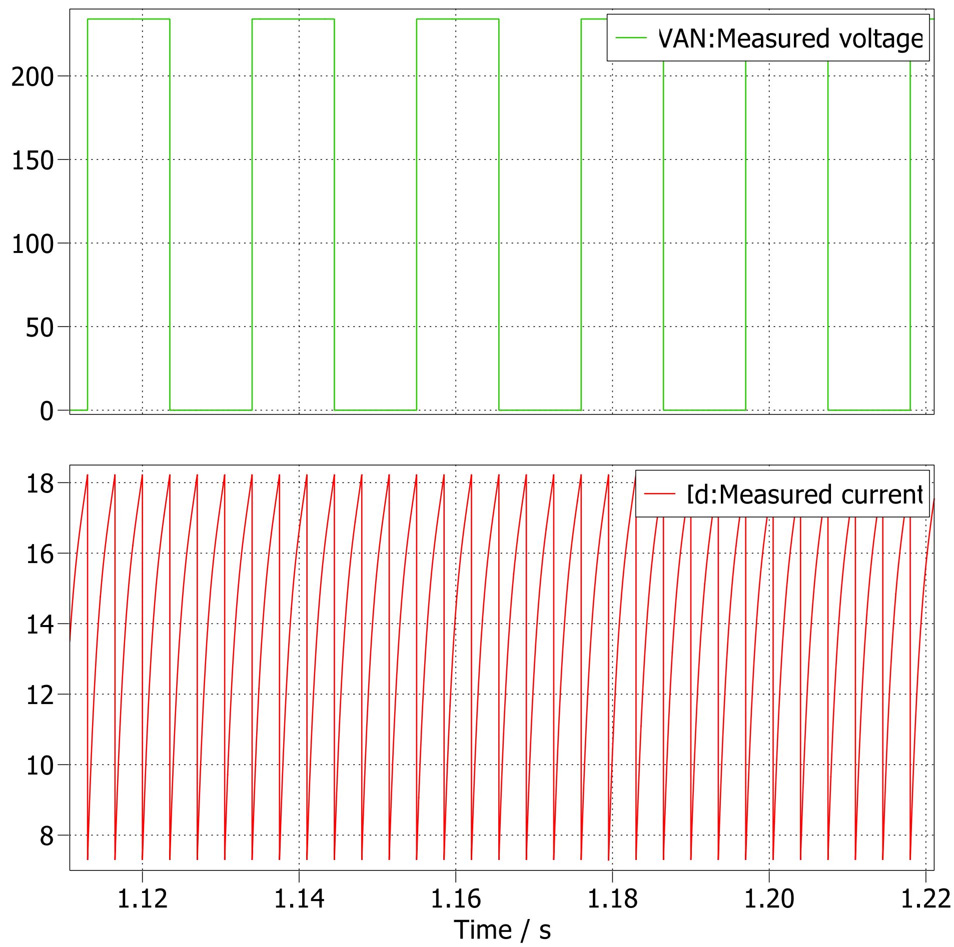


Figure 26: The Waveforms for v_{AN} and i_d

2. **Obtain v_{An1} by means of Fourier analysis of the v_{An} waveform. Compare v_{An1} with its precalculated nominal value.**

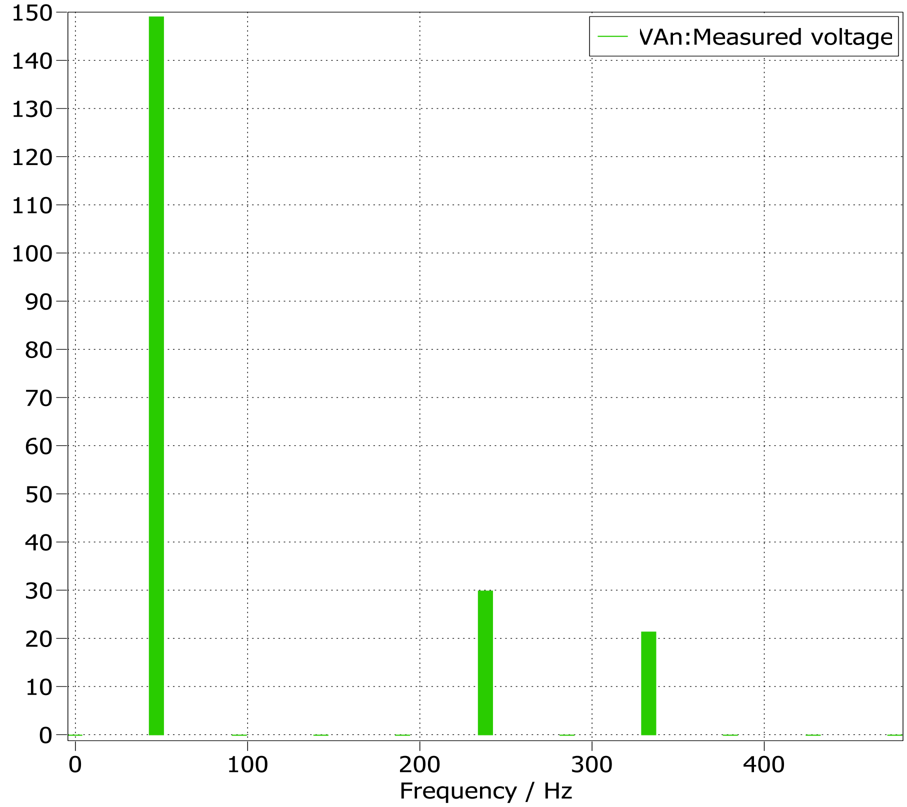


Figure 27: Fourier Analysis of V_{An}

Upon conducting the Fourier analysis of v_{An}, the obtained fundamental component v_{An1} matches the precalculated nominal value of **105.39 V,** it signifies that the inverter is operating within the expected parameters and is delivering the specified output current accurately.

3. Using the results of Problem 2, obtain the ripple component v_{ripple} waveform in the output voltage.

Initially, we derive the peak value and phase angle of the fundamental waveform from the Fourier Transform of v_o which yields values of 148.98 for the peak and -61.37 degrees for the phase angle. Subsequently, we create the fundamental waveform and subtract it from the original waveform of v_o to derive the ripple waveform of v_o.

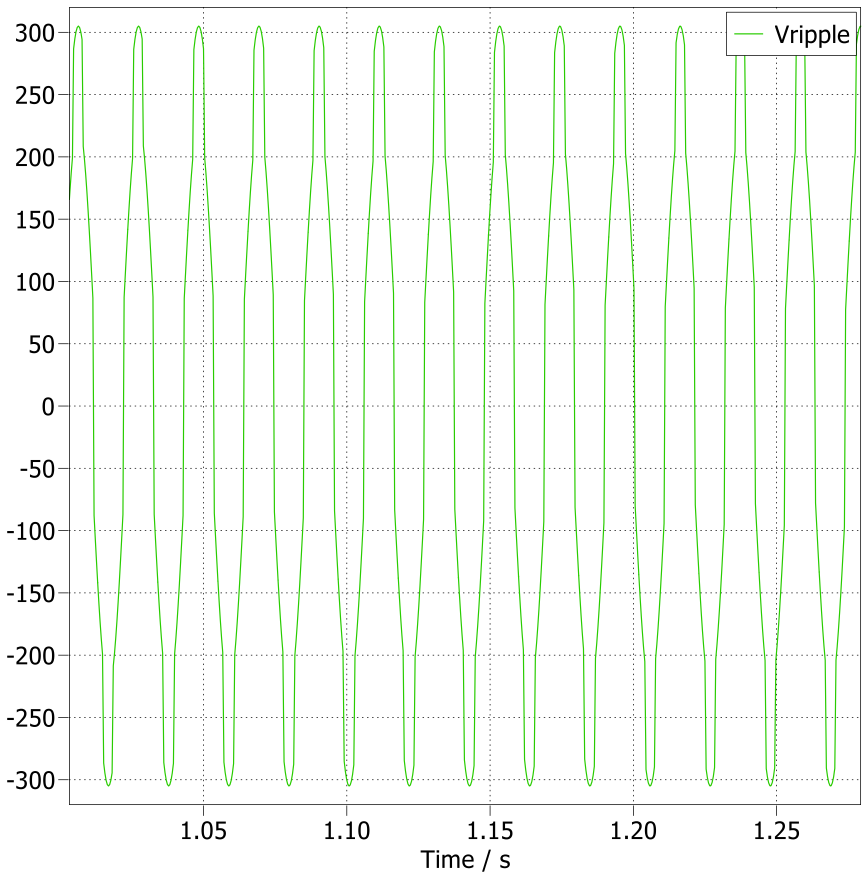


Figure 28: Waveform for Vripple

4. Obtain i_{A1} by means of Fourier analysis of i_A waveform. Compare i_{A1} with its precalculated nominal value.

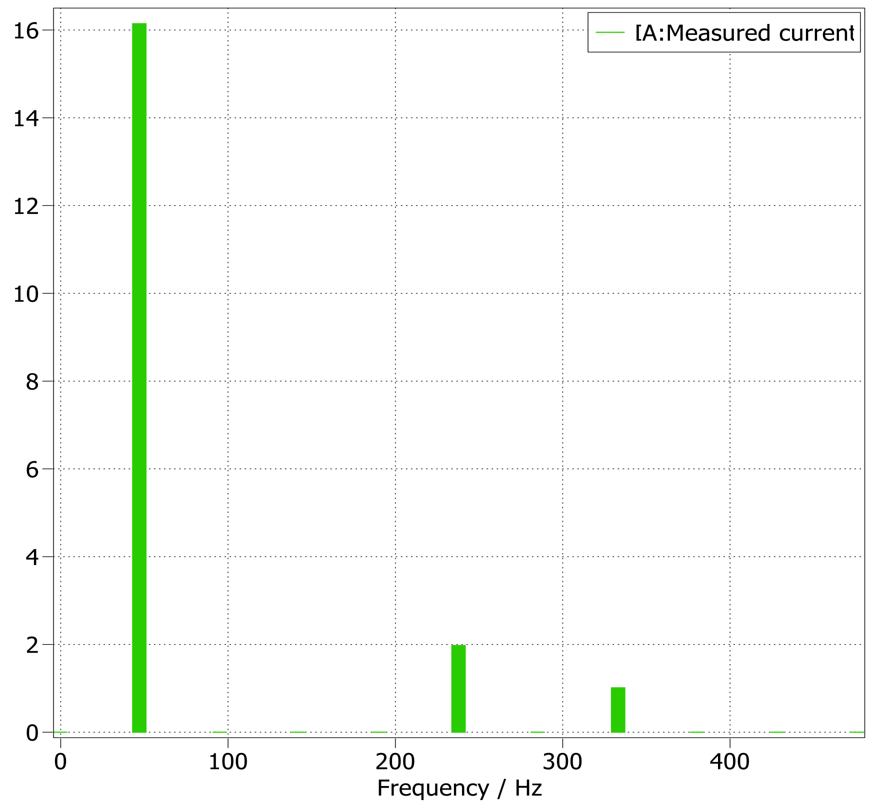


Figure 29: Fourier Analysis of i_A

Upon conducting the Fourier analysis of i_A, the obtained fundamental component i_{A1} **is** almost **11.412 A** as compared to the precalculated nominal value of **10 A,** it signifies that the inverter is operating within the expected parameters and is delivering the specified output current somehow accurately.

5. Using the results of Problem 4, obtain the ripple component i_{ripple} in the output current.

Initially, we derive the peak value and phase angle of the fundamental waveform from the Fourier Transform of i_o which yields values of 16.14 for the peak and -56.98 degrees for the phase angle. Subsequently, we create the fundamental waveform and subtract it from the original waveform of i_o to derive the ripple waveform of i_o .

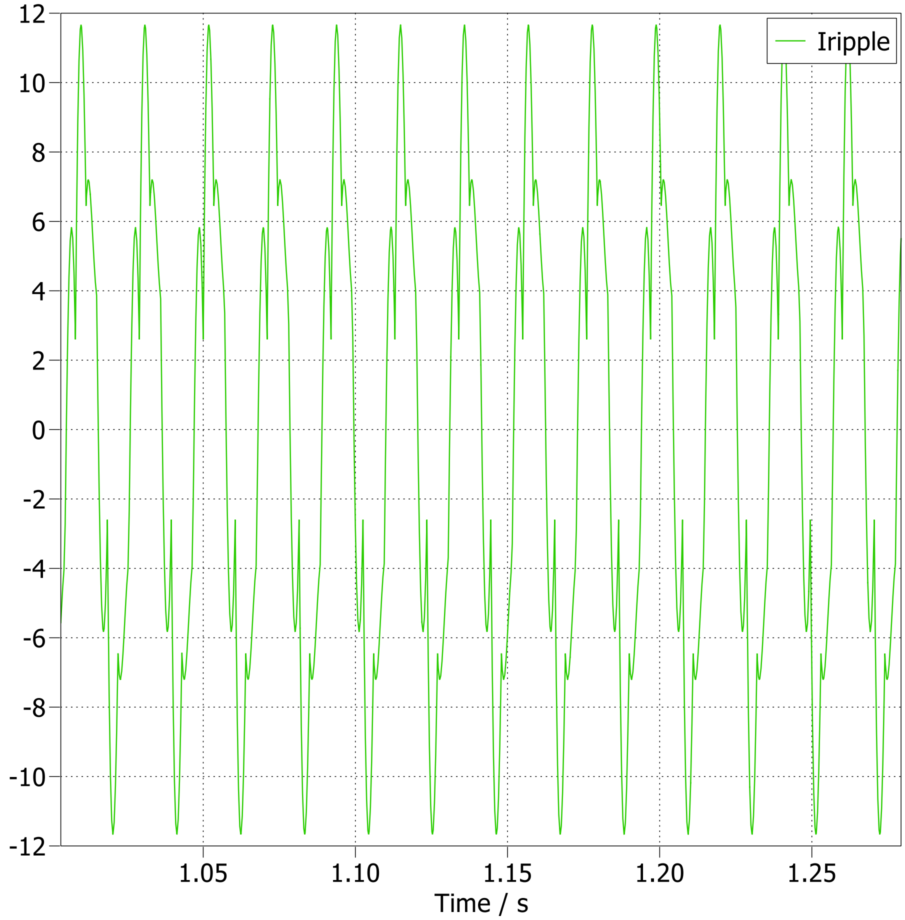


Figure 30: Waveform for Iripple

6. Obtain $i_{d(avg)}$ by means of Fourier analysis and obtain the high frequency ripple $i_{d(ripple)} = i_d - i_{d(avg)}$ in the input current.

We can calculate the high frequency ripple component $i_{d(ripple)}$ using the following equation:

$$i_{d(ripple)} = i_d - i_{d(avg)}$$

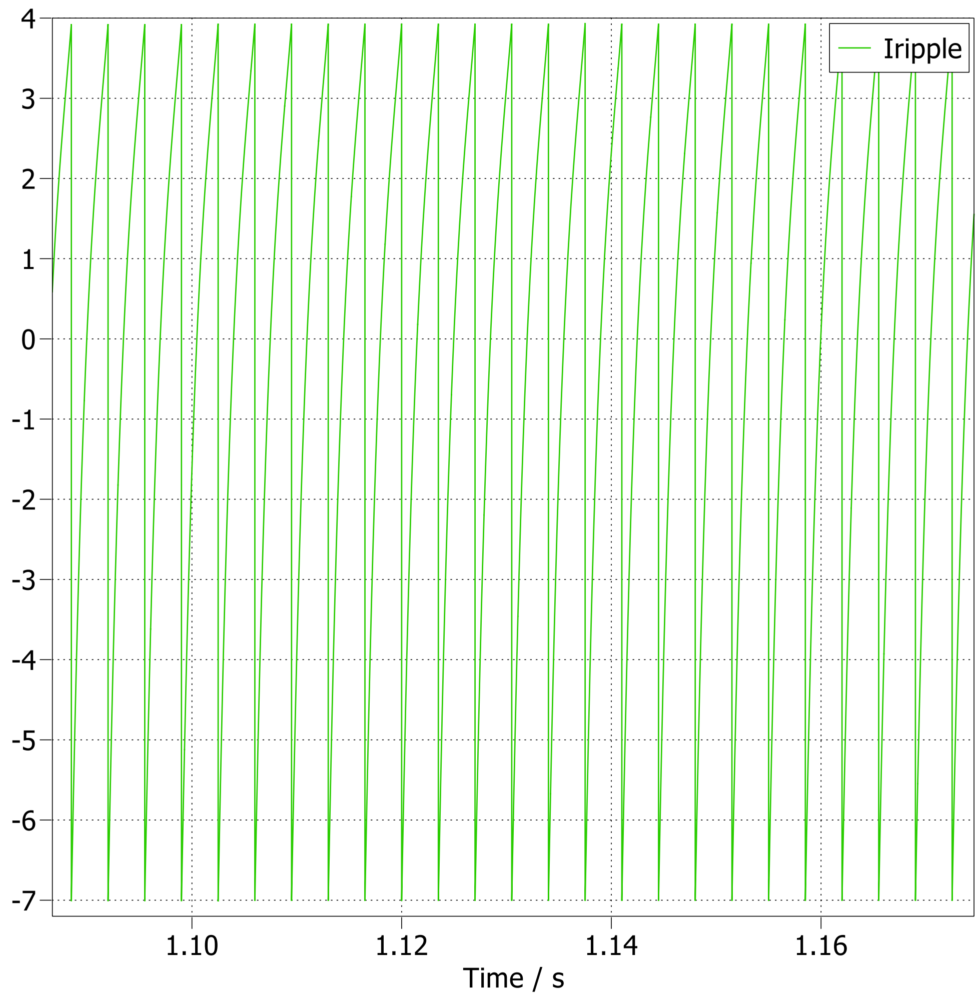


Figure 31: Waveform for High Frequency Ripple id

7. Obtain the load neutral voltage with respect to the mid-point of the dc input voltage.

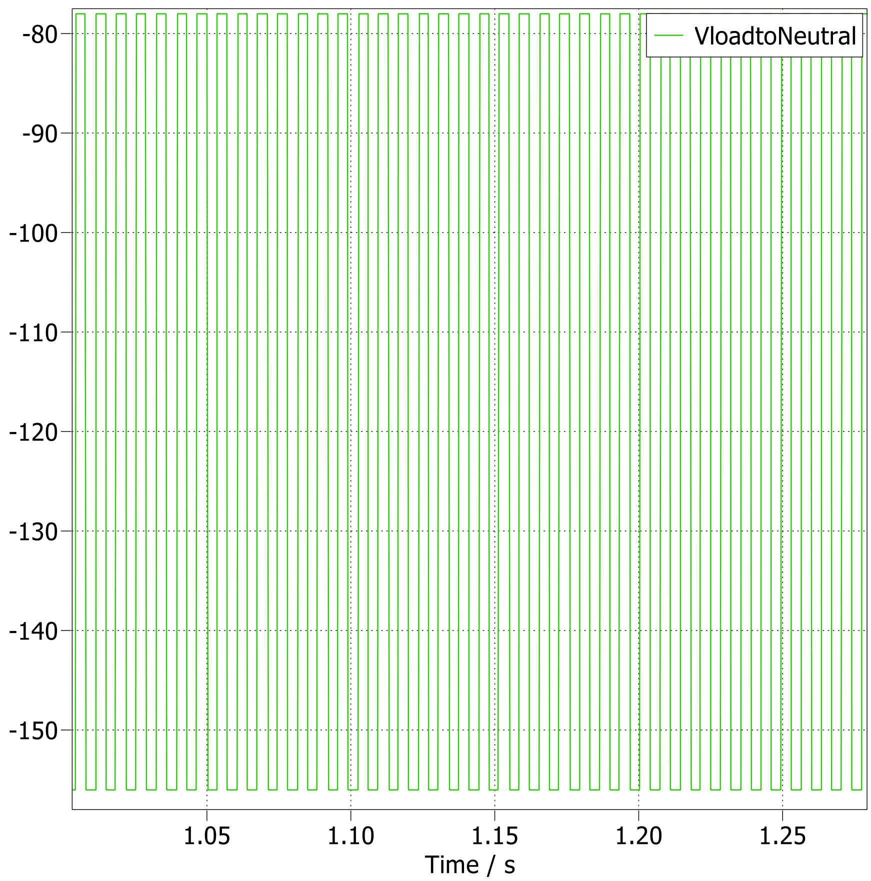
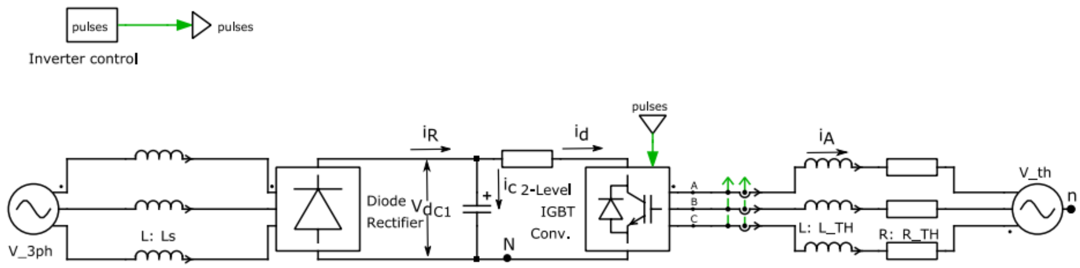


Figure 32: The Load Neutral Voltage with respect to the Input of DC Input Voltage is 123.08 V (RMS)

7. Three-Phase, PWM Inverter with a Three-Phase Rectifier Input



1. Obtain the following waveforms using PWMInv3_Rect:

a. i_R**,** i_c **and** i_d**.**

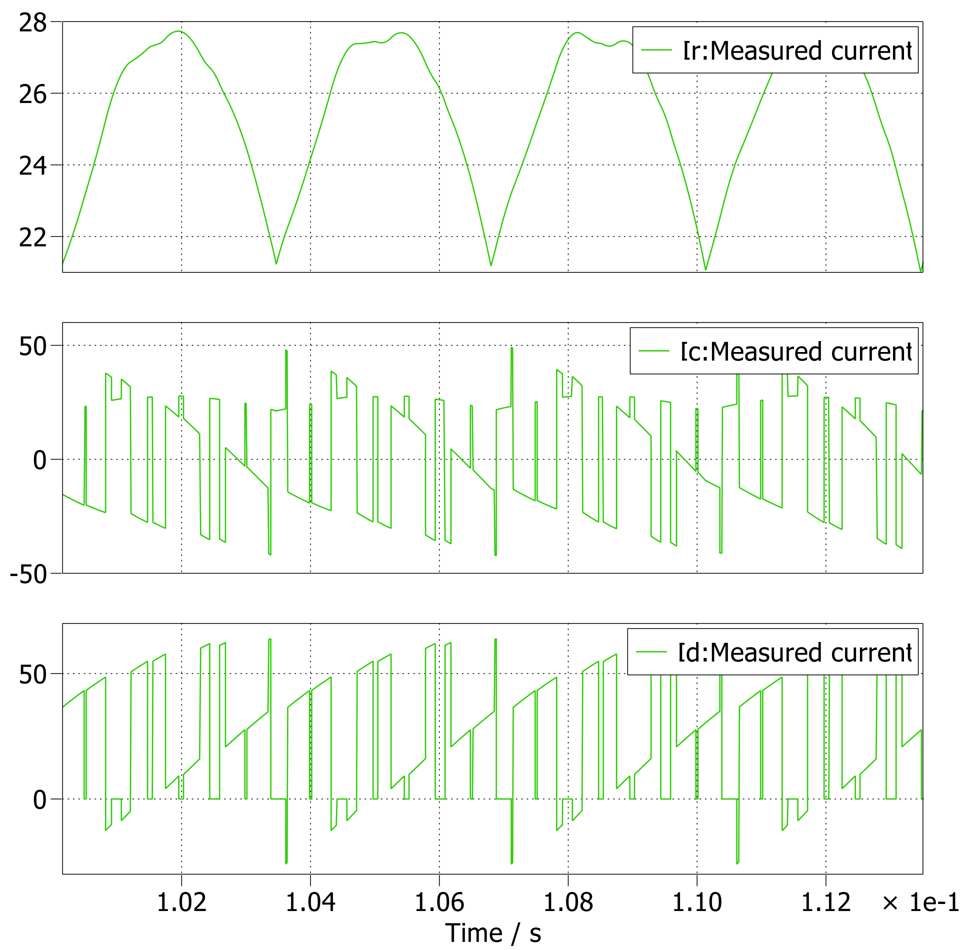


Figure 33: Waveforms for Current I_R, I_c and I_d

b. v_d**.**

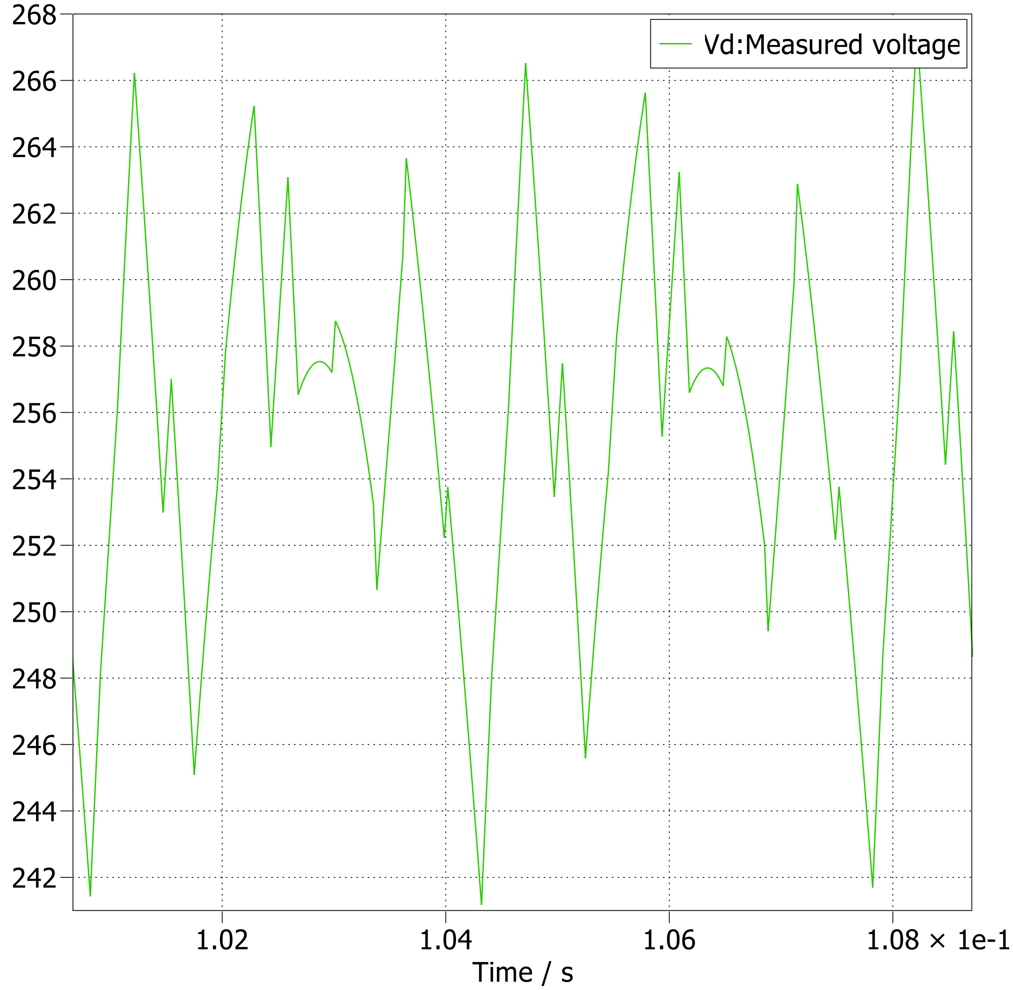


Figure 34: Waveform for Voltage V_d

2. Obtain the RMS values of the currents i_R, i_c and i_d.

	RMS Values
i_R	25.59 A
i_C	23.45 A
i_d	35.04 A

3. **Plot peak-to-peak ripple in v_d with the capacitor C_d values of 500 µF, 1000 µF and 1500 µF.**

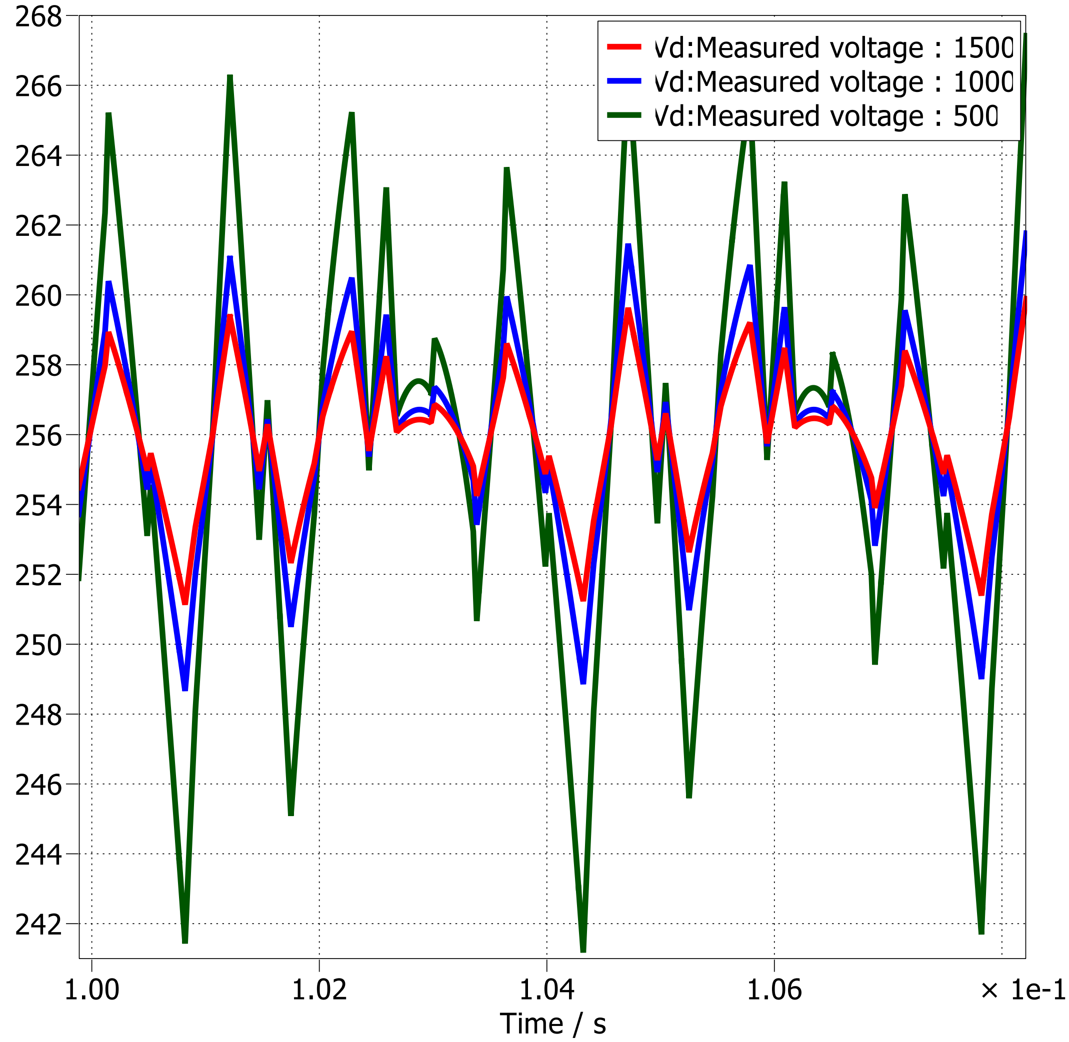


Figure 35: Peak to Peak Ripples with different values of C

4. **Change L_{TH} to 1 mH. Obtain waveforms of i_A and v_{An}. Compare to the initial value of 10mH**

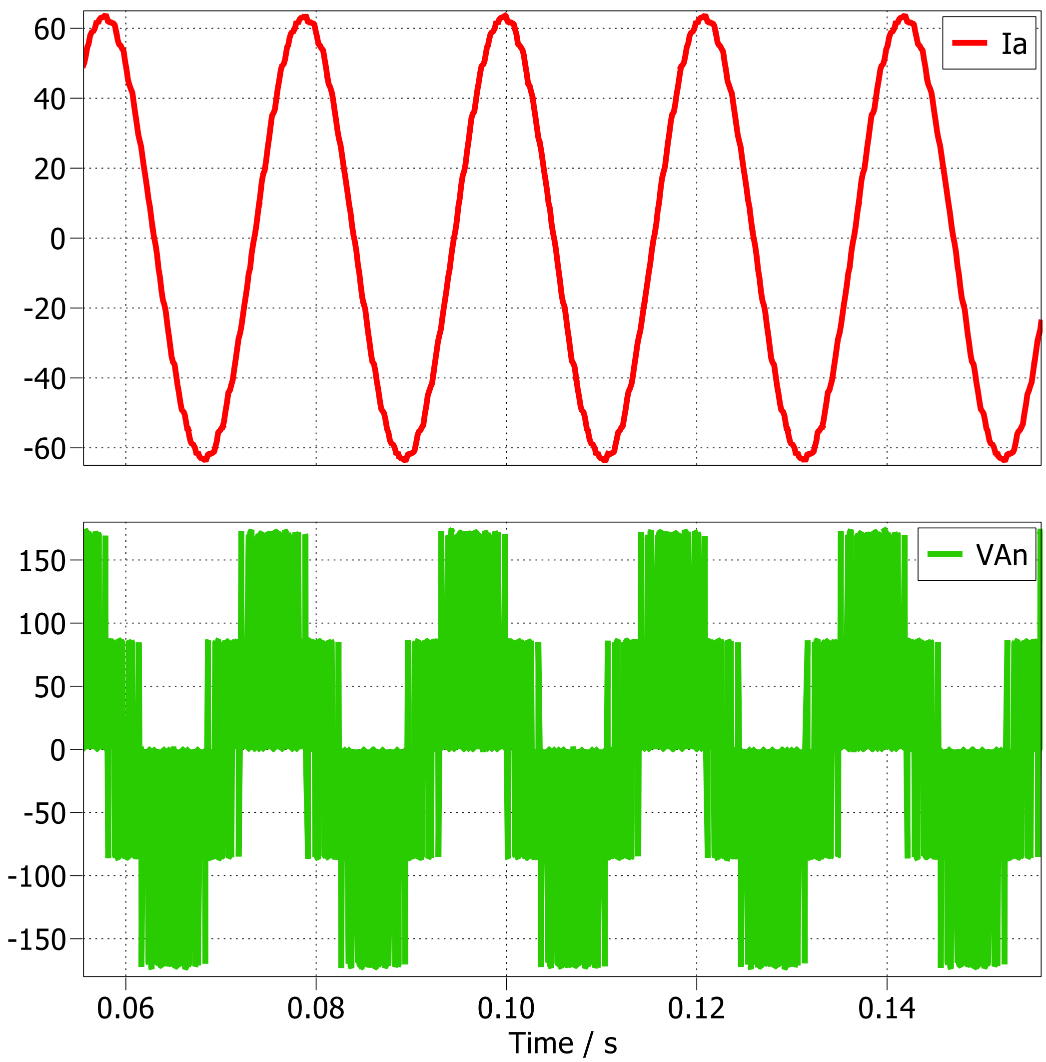


Figure 36: The Waveforms for i_A and v_{An} for L_{th} = 10mH

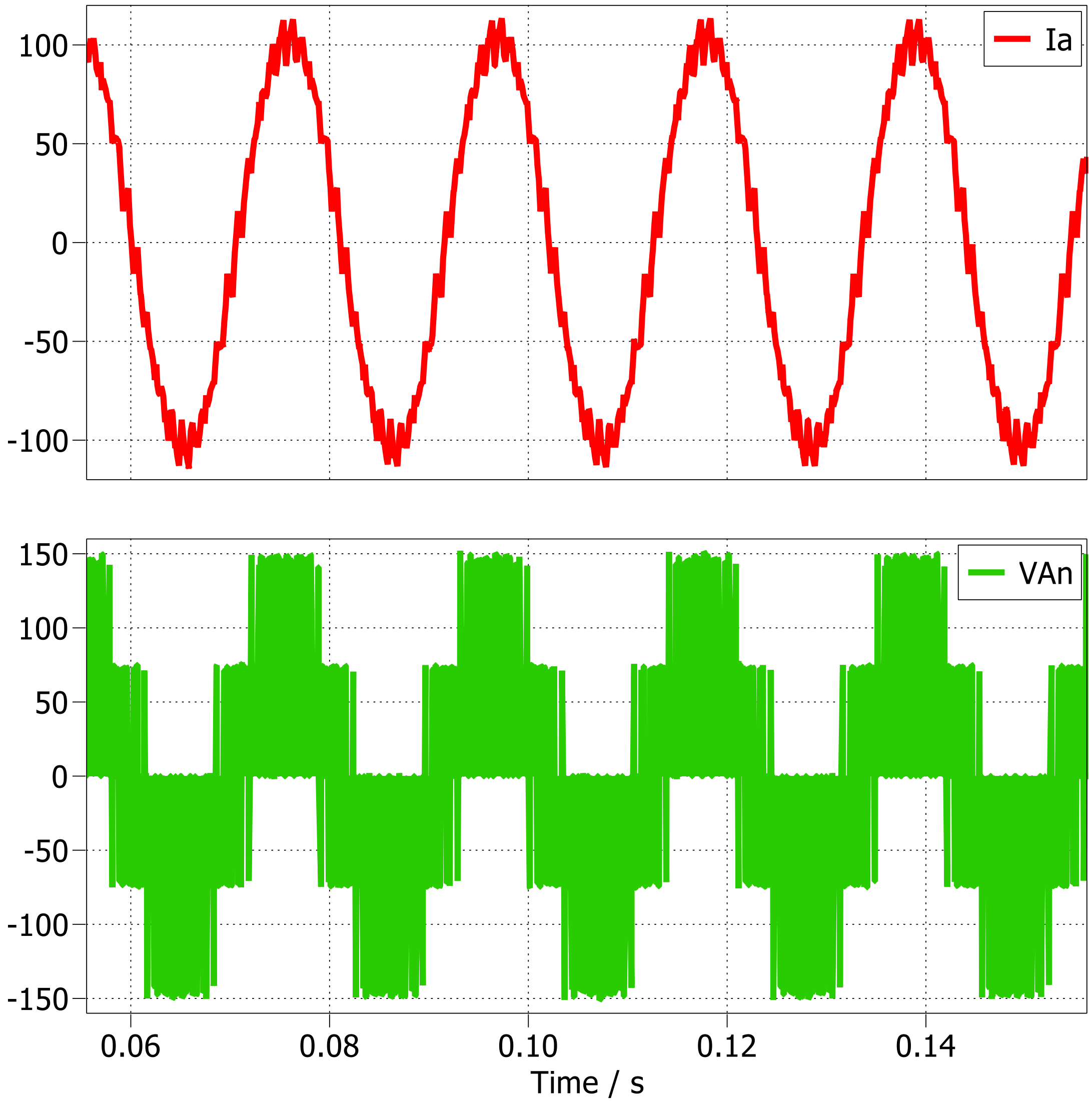
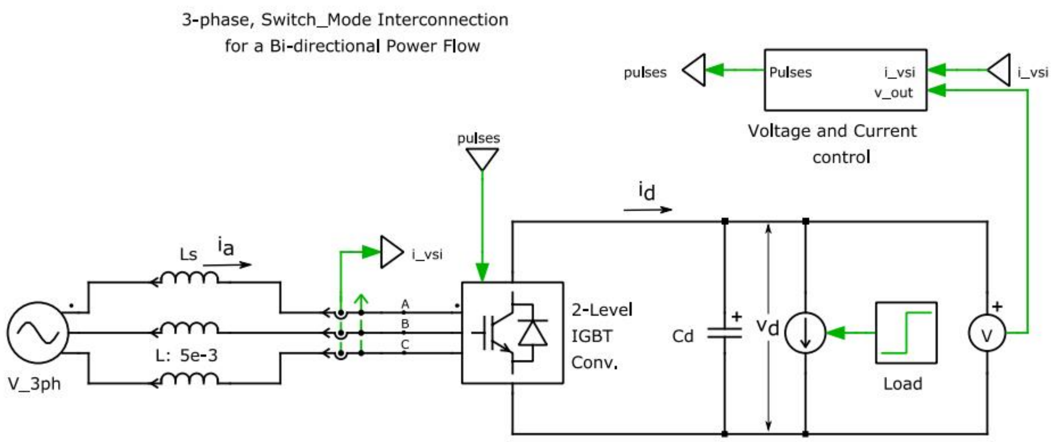


Figure 37: The Waveforms for i_A and v_{An} for L_{th} = 1mH

8. 3-Phase, Switch-Mode Interconnection for a Bi-directional-Power-Flow



1. Obtain the v_s and i_s waveforms.

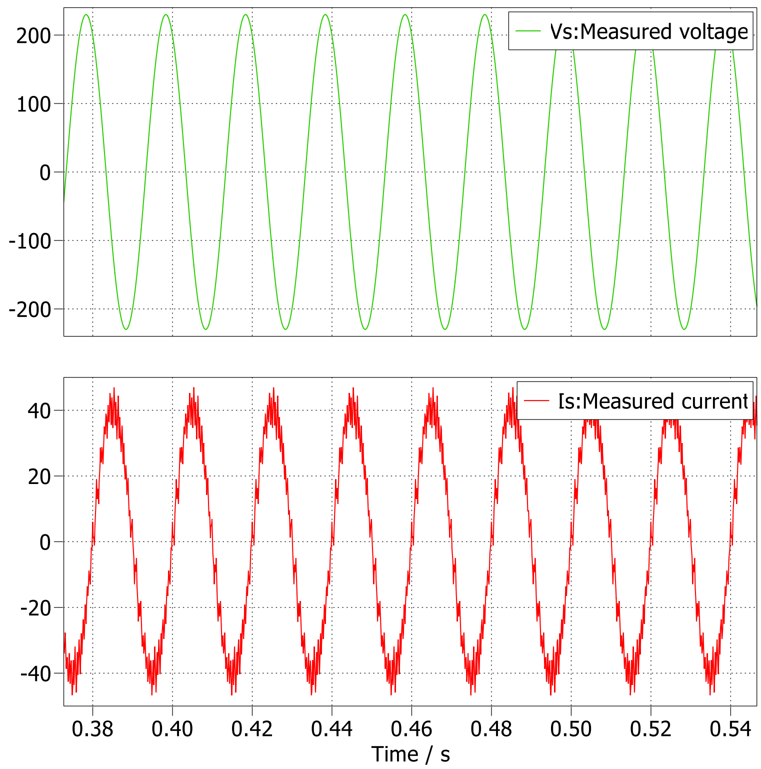


Figure 38: Waveforms for Vs and Is at 5mH

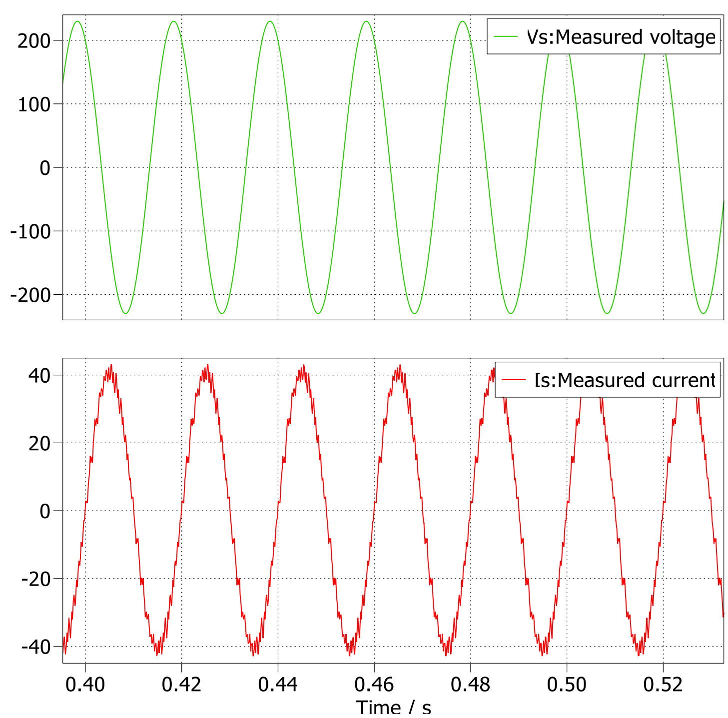


Figure 39: Waveform for Vs and Is at 10mH

2. **Obtain the maximum peak-to-peak ripple in i_s**

Initially, we derive the peak value and phase angle of the fundamental waveform from the Fourier Transform of $\boldsymbol{i_s}$ which yields values of 40.58 for the peak and -24.92 degrees for the phase angle. Subsequently, we create the fundamental waveform and subtract it from the original waveform of $\boldsymbol{i_s}$ to derive the ripple waveform of $\boldsymbol{i_s}$.

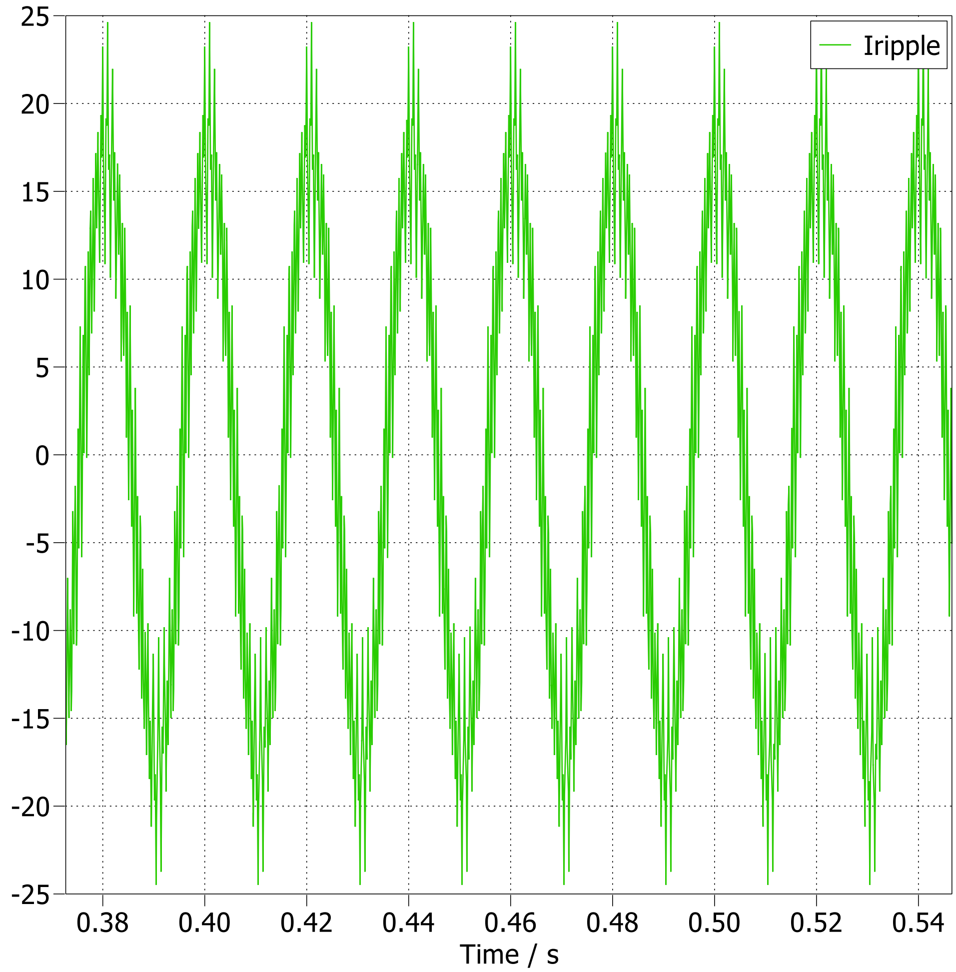


Figure 40: Maximum Peak to Peak Ripple in I_s (Ls=5mH)

From this graph the maximum ripple of this waveform is 24.63A and the minimum ripple of this ripple is -23.42 A. Therefore, the maximum peak to peak ripple is 48.05 A

Similarly, for 10mH, we derive the peak value and phase angle of the fundamental waveform from the Fourier Transform of $\boldsymbol{i_s}$ which yields values of 40.57 for the peak and 112.10 degrees for the phase angle. Subsequently, we create the fundamental waveform and subtract it from the original waveform of $\boldsymbol{i_s}$ to derive the ripple waveform of $\boldsymbol{i_s}$.

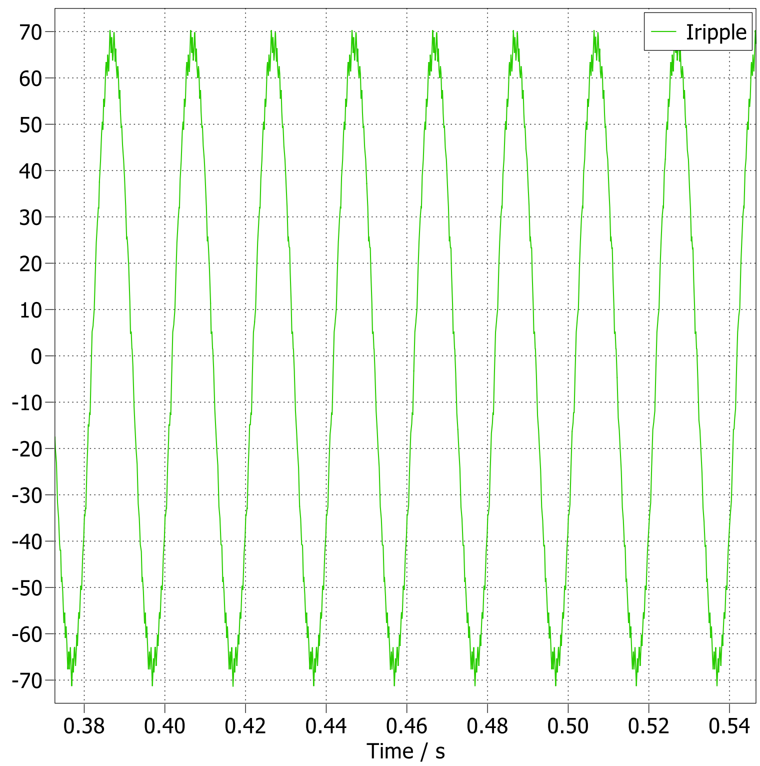


Figure 41: Maximum Peak to Peak Ripple in Is (Ls=10mH)

From this graph the maximum ripple of this waveform is 70.29A and the minimum ripple of this ripple is -71.30 A. Therefore, the maximum peak to peak ripple is 141.59 A

3. **Obtain the fundamental frequency component of the converter voltage v_{conv1}. What is the angle by which it lags v_s**

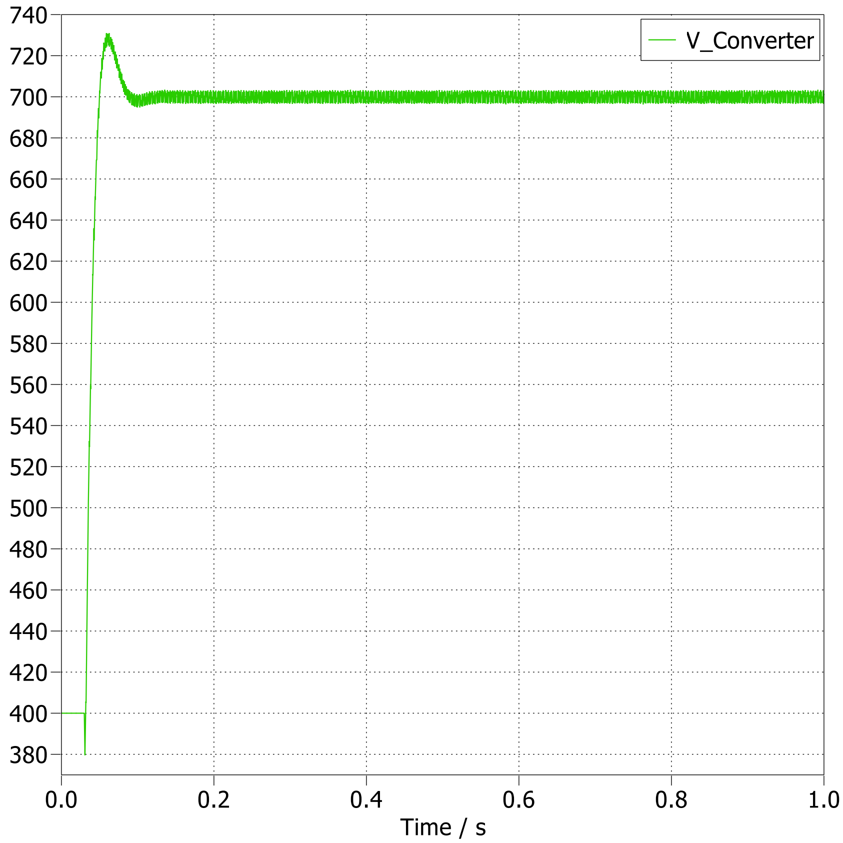


Figure 42: Waveform for V_{conv}

By analyzing the Fourier Transform for v_{conv}, we can determine the maximum peak value and phase angle of the fundamental component as approximately 61.8V and -17 degrees, respectively. The observed phase angle of the fundamental waveform v_s from the Fourier Transform is approximately 14 degrees. Consequently, it indicates that the v_{conv} lags v_s by approximately **31** degrees.

4. Obtain the waveform of the dc-side current i_d.

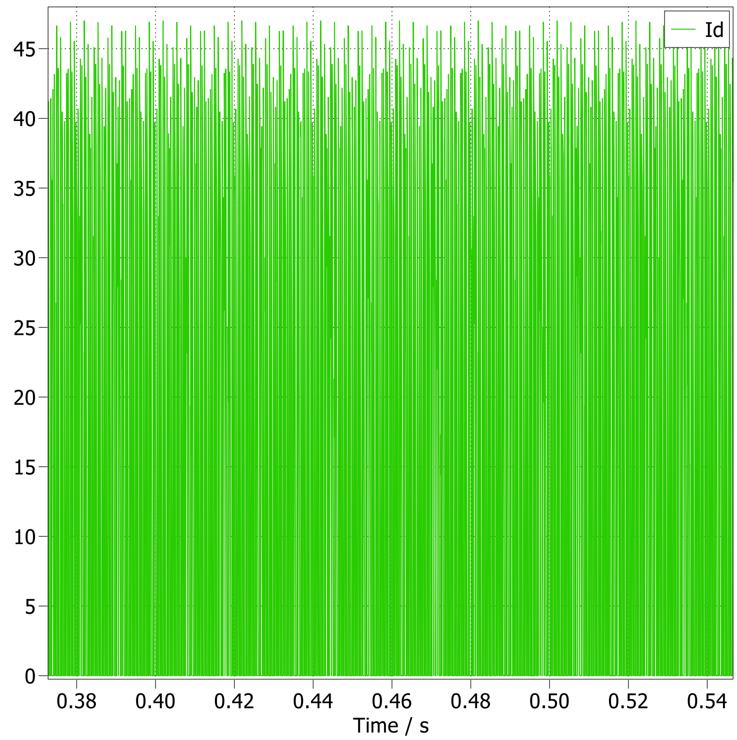


Figure 44: Id Waveform for Ls = 5mH

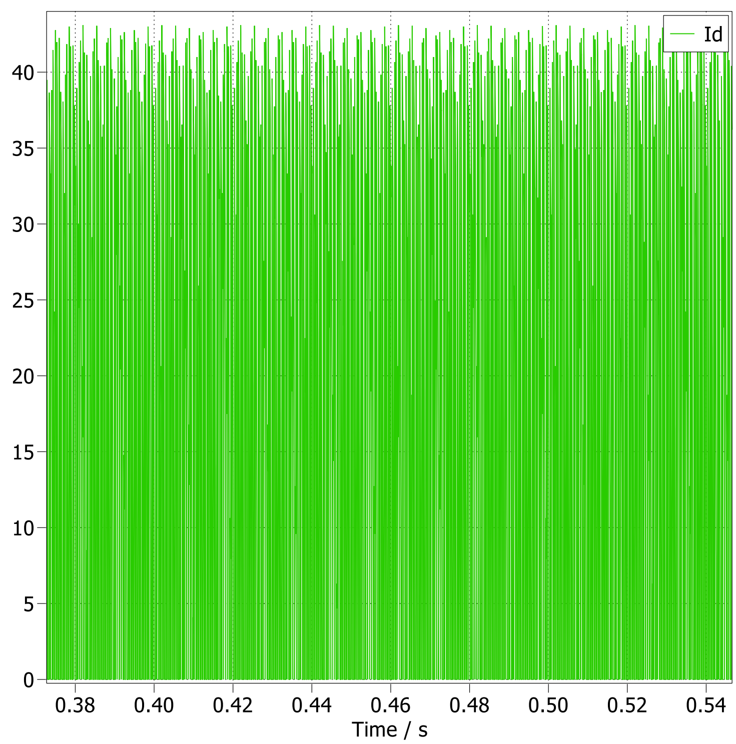


Figure 43: Id Waveform for Ls = 10mH