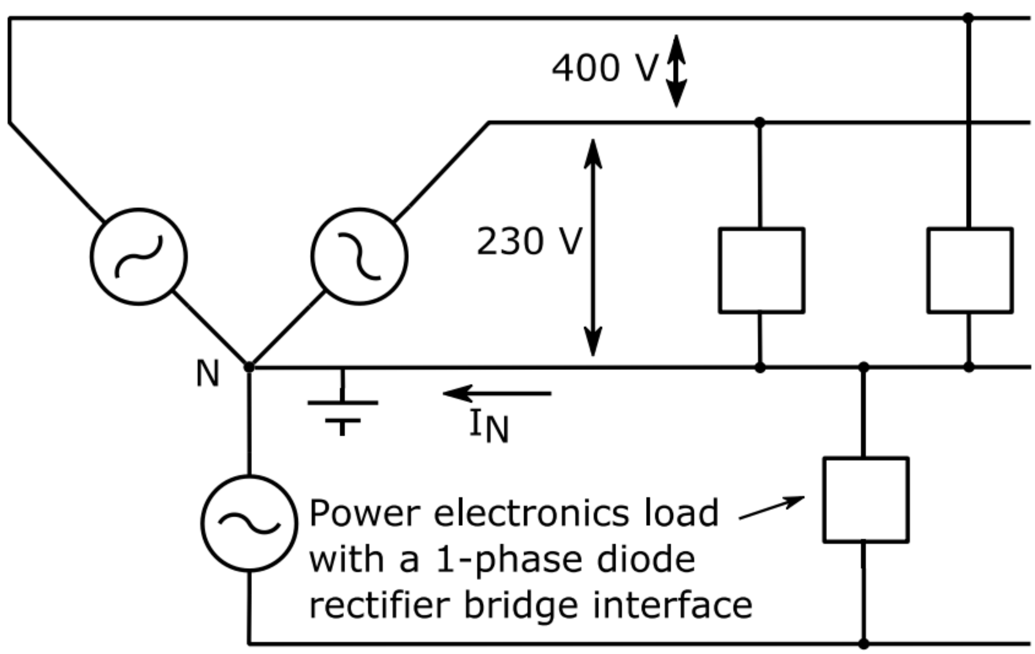
Muhammad Dayyan Hussain Khan ELEC-E8403
101423382 Converter Techniques

PLECS Simulation Assignment 01

1. Neutral Current in a 3-Phase Distribution system due to 1-Phase Power Electronics Loads



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1. **Obtain the neutral current i_N waveform.**

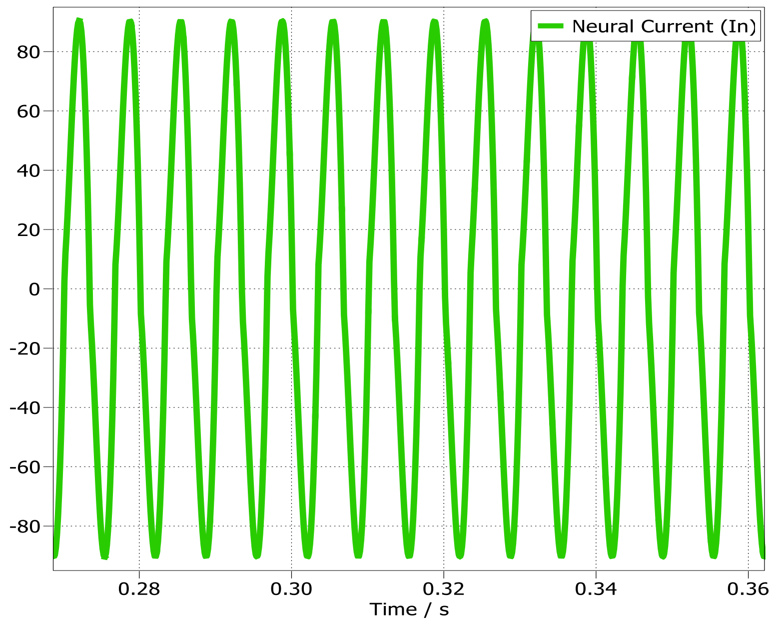


Figure 1: This graph shows the Neutral Current Waveform with an RMS Value of 63.26 Ampere

2. **By means of Fourier analysis of i_N, calculate its harmonic components as a ratio of I_{s1} (where I_{s1} = rms value of the fundamental frequency component of the phase current).**

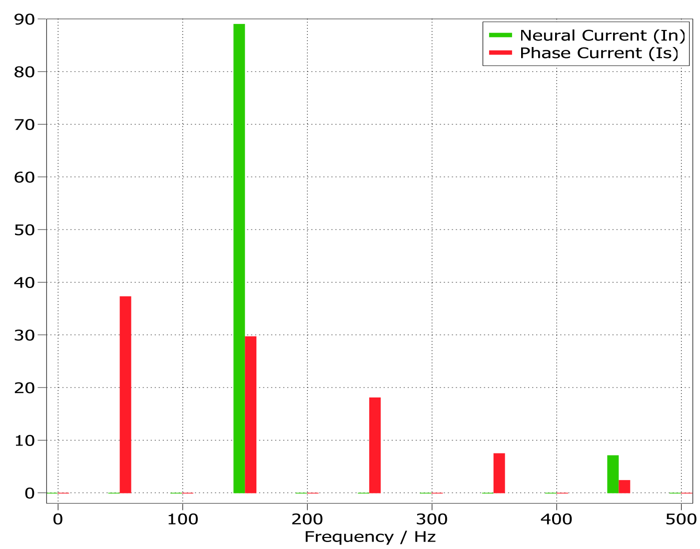


Figure 2: Fourier Spectrum for Neutral Current (In) and Phase Current (Is)

In this section, we describe the methodology used to calculate the ratios of harmonic components to the fundamental frequency component (**I_{S1} = 36.54 A**) of the current waveform i_N using Fourier analysis. The calculations were performed within the PLECS simulation environment. For each of the harmonic component the values are as follows:

S.No	No of Harmonics	Neutral Current Value	Ratio to I_{S1}
1	50 Hz	2.89×10^{-8} A	7.90×10^{-10}
2	100 Hz	6.22×10^{-8} A	1.70×10^{-9}
3	150 Hz	62.91 A	1.72
4	200 Hz	5.31×10^{-8} A	1.45×10^{-9}
5	250 Hz	2.01×10^{-8} A	5.50×10^{-10}
6	300 Hz	5.25×10^{-8} A	1.43×10^{-9}
7	350 Hz	8.83×10^{-9} A	2.41×10^{-10}
8	400 Hz	8.76×10^{-9} A	2.39×10^{-10}
9	450 Hz	4.99 A	0.13
10	500 Hz	7.91×10^{-9} A	2.16×10^{-10}

The values obtained from calculating the harmonic components of the neutral current as a ratio of **I_{S1}** offer crucial insights into the system's performance and stability. Particularly noteworthy is the significance of the third harmonic ratio, as a high value indicates notable distortion at this specific harmonic frequency. The prominence of the third harmonic is often attributed to various non-linear loads such as power electronics devices and certain types of lighting. A high third harmonic ratio suggests significant harmonic distortion, which can lead to voltage waveform distortion, increased losses, and potential interference with sensitive equipment. Therefore, attention to mitigating the effects of the third harmonic is imperative for maintaining power quality and system reliability. Analyzing and addressing the factors contributing to the high third harmonic ratio are essential steps in optimizing the system's performance and ensuring compliance with regulatory standards.

3. **Calculate I_N/I_s where I_N is the RMS value of the neutral current and I_s is the RMS value of the phase current.**

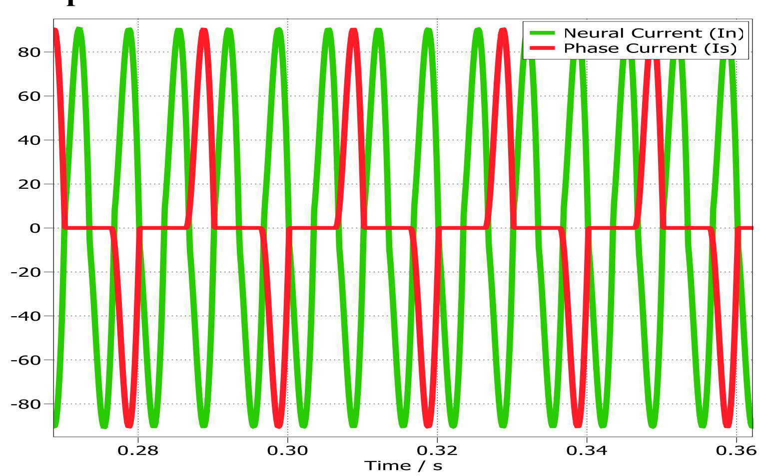


Figure 3: The Current Waveforms for In and Is

The RMS value of I_N = 63.17 A and I_s = 36.51 A. The ratio for both can be calculated as:

Ratio of I_N/I_s = 63.17/36.51 = **1.73**

The calculated ratio of approximately 1.73 indicates that the RMS value of the neutral current is approximately 1.73 times higher than the RMS value of the phase current. This ratio suggests a significant presence of neutral current relative to the phase currents in the three-phase electrical system. While a ratio of 1 would imply perfect balance between phase currents and no neutral current, a value greater than 1.0 indicates some degree of imbalance or non-sinusoidal behavior in the system. Understanding and addressing the factors contributing to this ratio can help in optimizing system performance, ensuring proper equipment sizing, and minimizing risks associated with phase imbalances and excessive neutral current flow.

4. **Verify that in steady state:**

$$I_N = \sqrt{\sum_{h=3,9,15,21} (3I_{sh})^2} \approx 3I_{S3}$$

In steady state the value of I_N = 63.17A and the value of third harmonic of I_{S3} = 20.97A. So accordingly:

$$\mathbf{I_N = 3 * I_{S3}}$$

$$\mathbf{63.17 = 3 * 20.97}$$

$$\mathbf{63.17 = 62.91}$$

(Which is approximately equal and verified)

The relationship $I_N=3\times I_{s3}$ in a balanced three-phase system is primarily due to the symmetrical distribution of loads across the phases and the presence of harmonic currents, particularly the third harmonic component. In such systems, the neutral current is mainly composed of the third harmonic component of the phase currents, as the fundamental frequency components cancel out. Therefore, the neutral current magnitude is approximately three times that of the third harmonic component of the phase currents. This relationship underscores the importance of properly sizing the neutral conductor to accommodate harmonic currents, ensuring system reliability and safety.

5. Observe the effect of load unbalance on the neutral current by removing load R_{load} entirely in one of the phases.

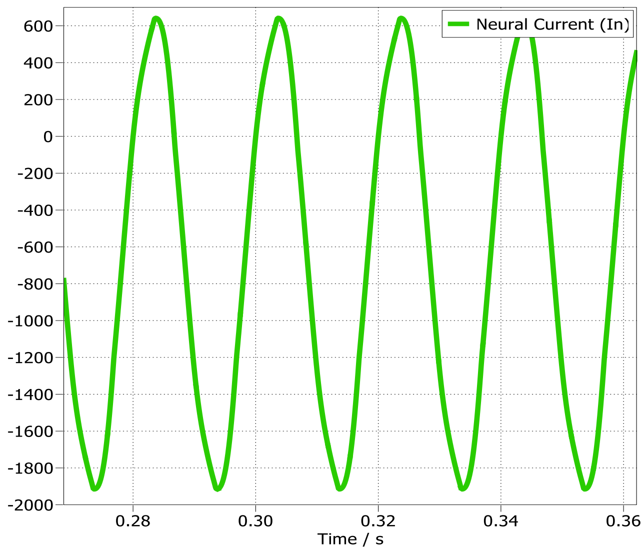
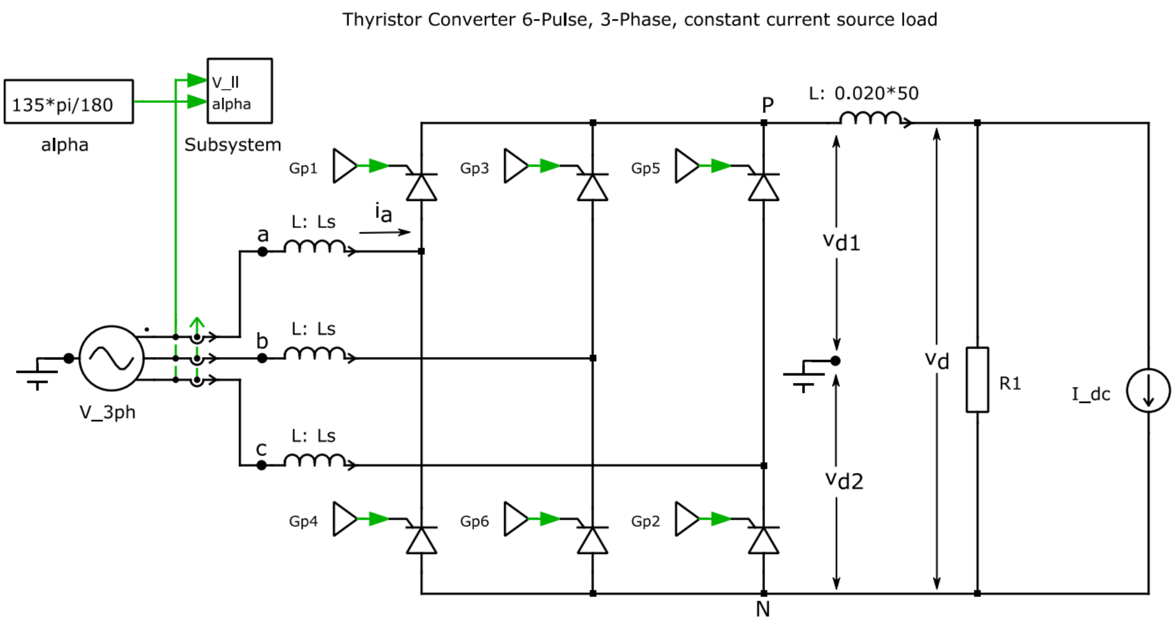


Figure 4: The effect of Load Unbalance on the Neutral Current with In = 1098.56A

With the neutral current now becoming 1098.56 A, a significant increase from its previous value, this change illustrates the profound impact of load unbalance on the neutral conductor in a three-phase system. Removing load R_{load} entirely from one phase results in an imbalance in the system, where the neutral conductor is now tasked with carrying the unbalanced current flow from the remaining phases. The substantial increase in the neutral current highlights the importance of load balancing in maintaining system stability and preventing overload conditions. This observation underscores the necessity of proper load distribution across phases to mitigate risks associated with excessive neutral current flow, ensuring the efficient and reliable operation of the electrical distribution network.

2. Basic Concepts in 3-Phase Thyristor converters



1. **Execute Thy3_Concepts to obtain v_{d1} waveforms for the three values of the delay angle α by changing the value of alpha block (Note: use radians). Calculate its average values.**

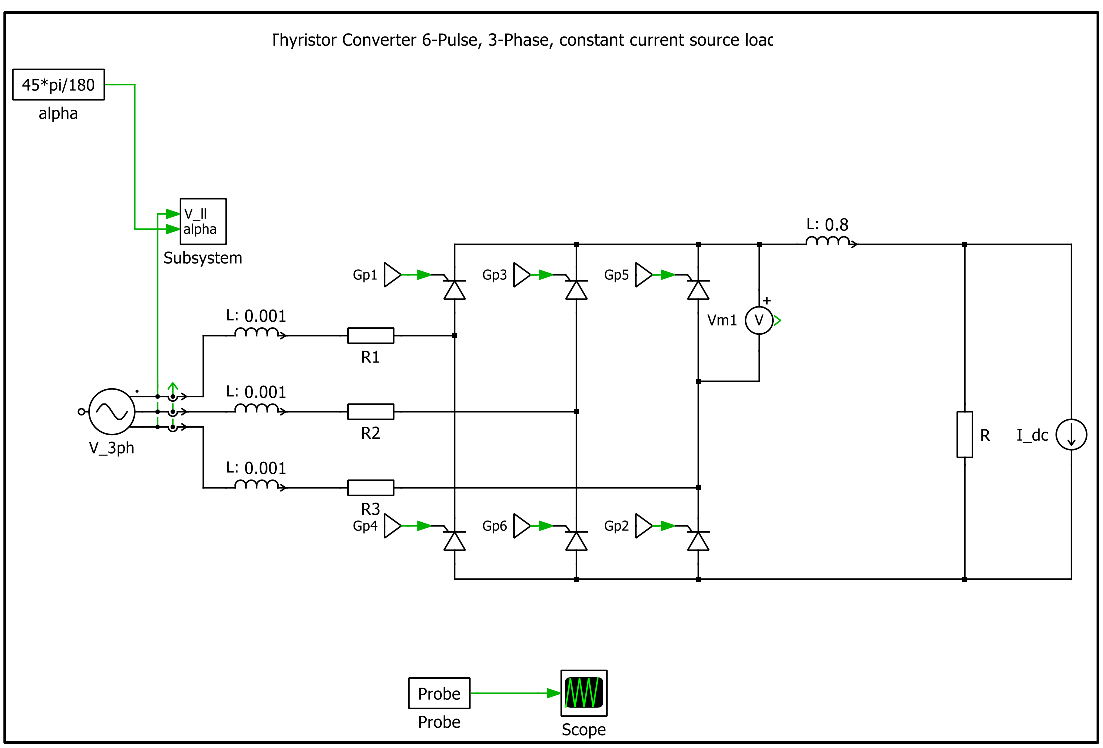


Figure 5: Circuit Diagram for calculating the Waveform for v_{d1}

For $\alpha = 45°$

The average value of v_{d1} is **226.435 Volts** at the firing angle of 45°.

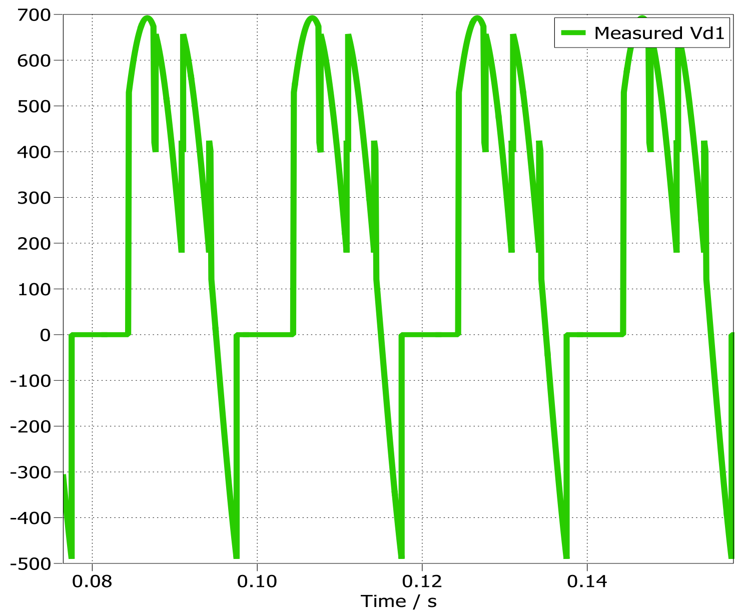


Figure 6: Waveform for v_{d1} at $\alpha = 45°$

For $\alpha = 90°$

The average value of v_{d1} is **67.19** Volts at the firing angle of 90°.

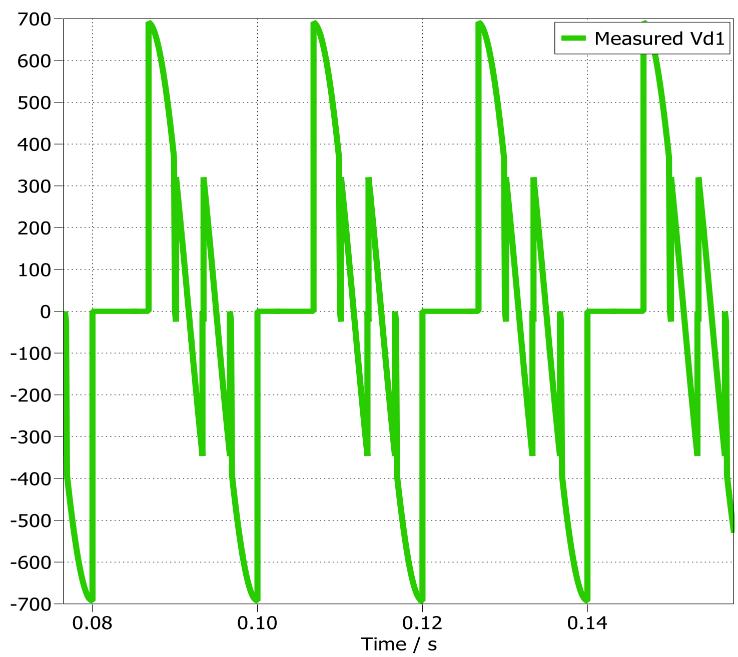


Figure 7: Waveform for v_{d1} at $\alpha = 90°$

For $\alpha = 135°$

The average value of v_{d1} is **-161.38 Volts** at the firing angle of 135°.

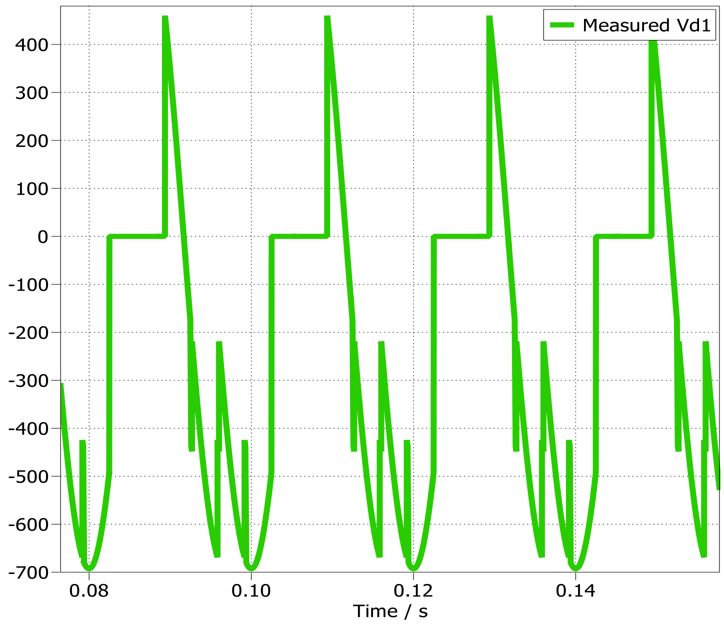


Figure 8: Waveform for v_{d1} at $\alpha = 135°$

2. Obtain v_{d2} waveforms like in Problem 1. Calculate its average values.

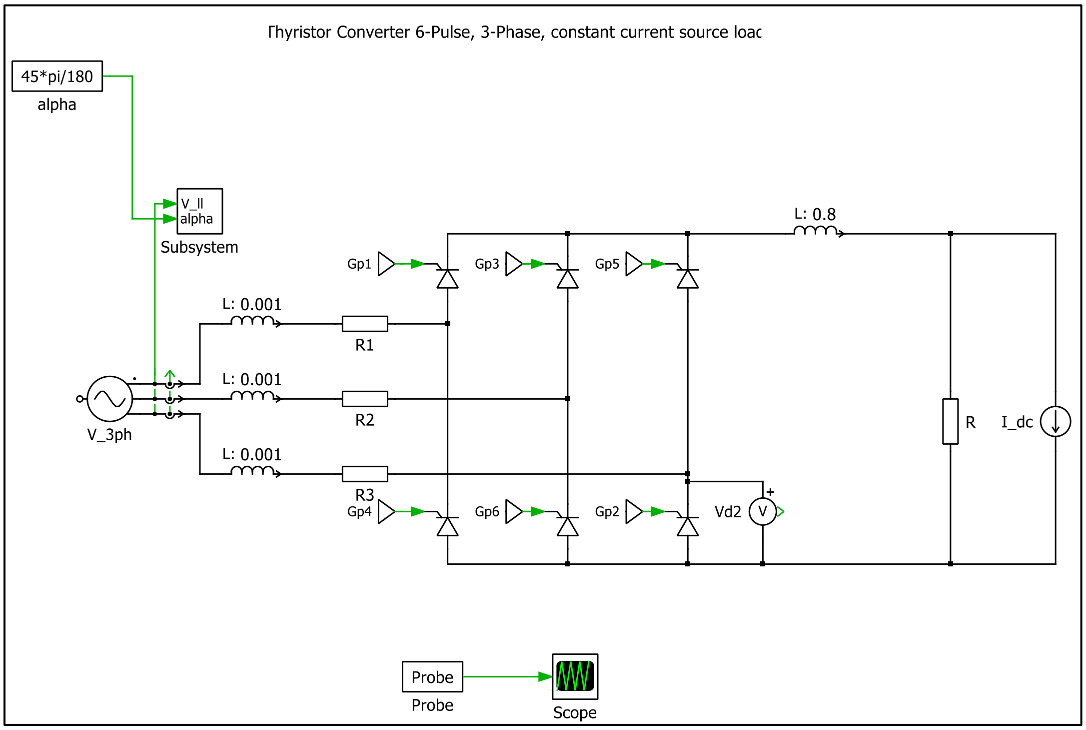


Figure 9: Circuit Diagram for calculating the Waveform for v_{d2}

For $\alpha = 45°$

The average value of v_{d2} is **226.24 Volts** at the firing angle of 45°.

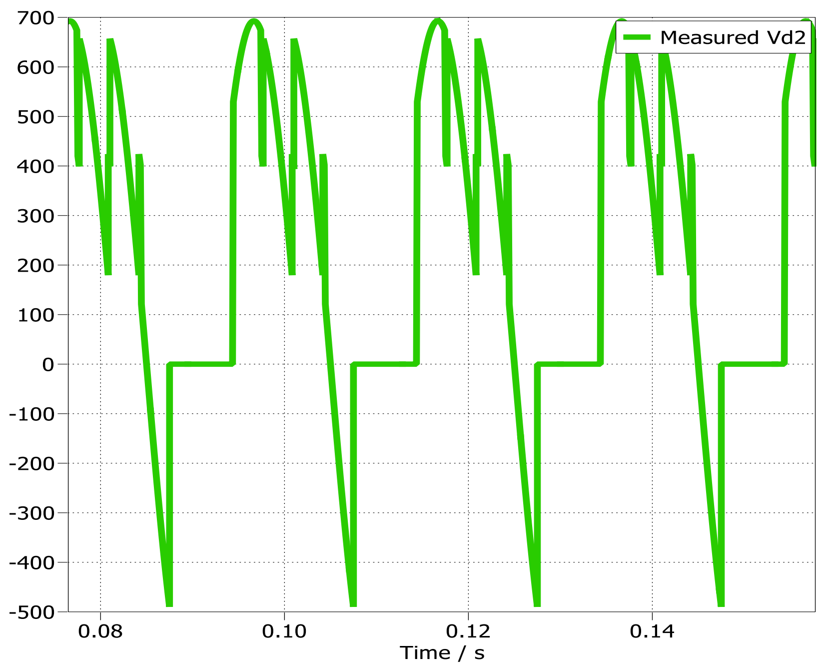


Figure 10: Waveform for v_{d2} at $\alpha = 45°$

For $\alpha = 90°$

The average value of v_{d2} is **-76.71** Volts at the firing angle of 90°.

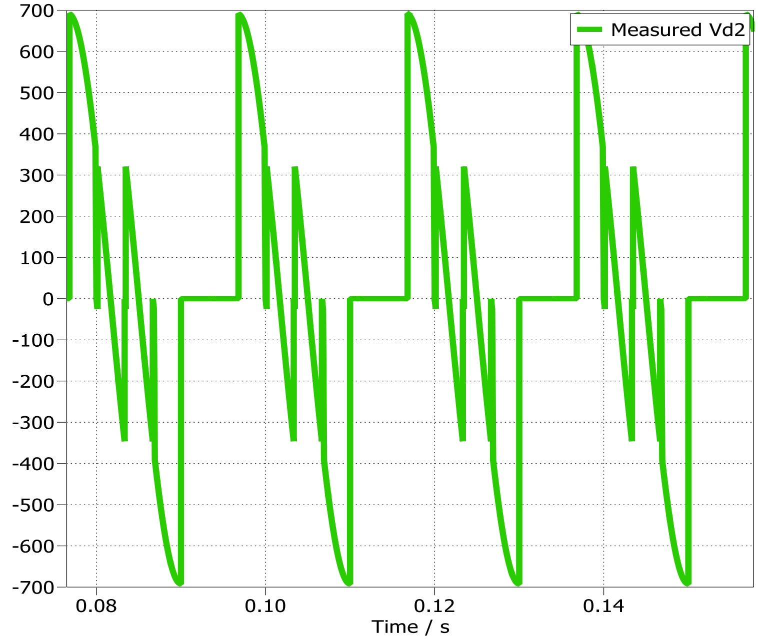


Figure 11: Waveform for v_{d2} at $\alpha = 90°$

For $\alpha = 135°$

The average value of v_{d1} is **-297.18 Volts** at the firing angle of 135°.

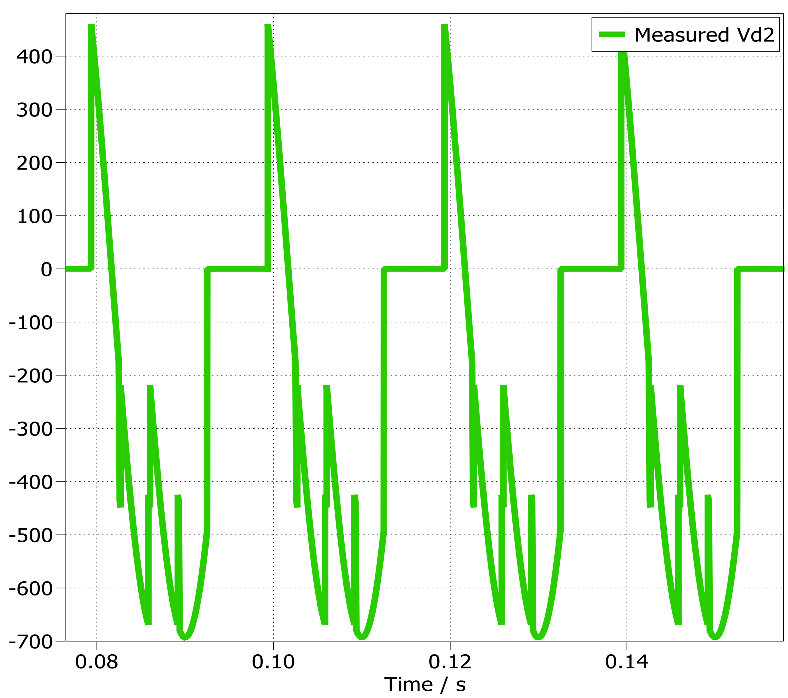


Figure 12: Waveform for $vd2$ at $\alpha = 135°$

3. **Obtain v_d waveform. Calculate the average value of the dc-side voltage for the three values of the delay angle α.**

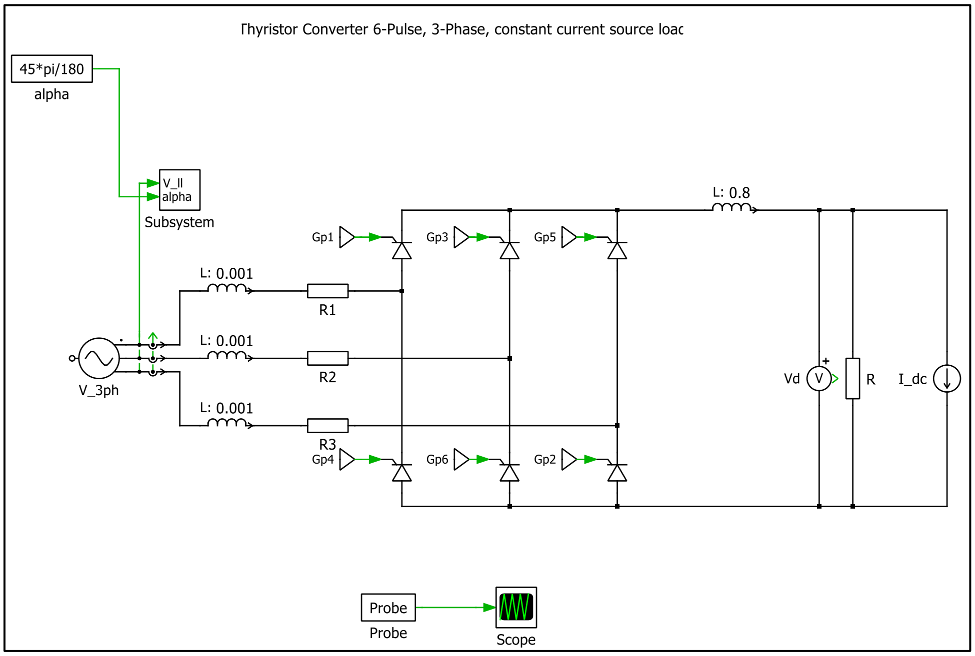


Figure 13: Circuit Diagram for calculating the Waveform for v_d

<u>For $\alpha = 45°$</u>

The average value of v_d is **453.92 Volts** at the firing angle of 45°

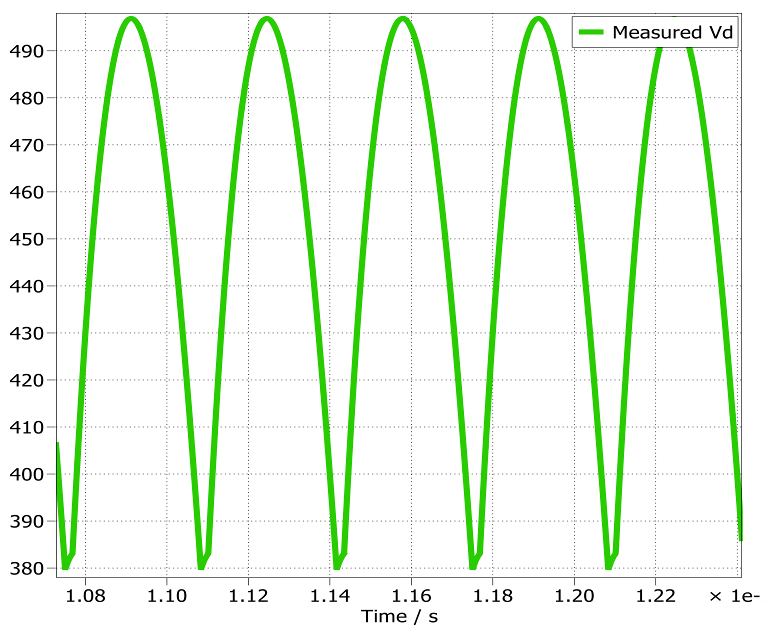


Figure 14: Waveform for v_d at $\alpha = 45°$

For $\alpha = 90°$

The average value of v_{d1} is **-13.69 Volts** at the firing angle of 90°.

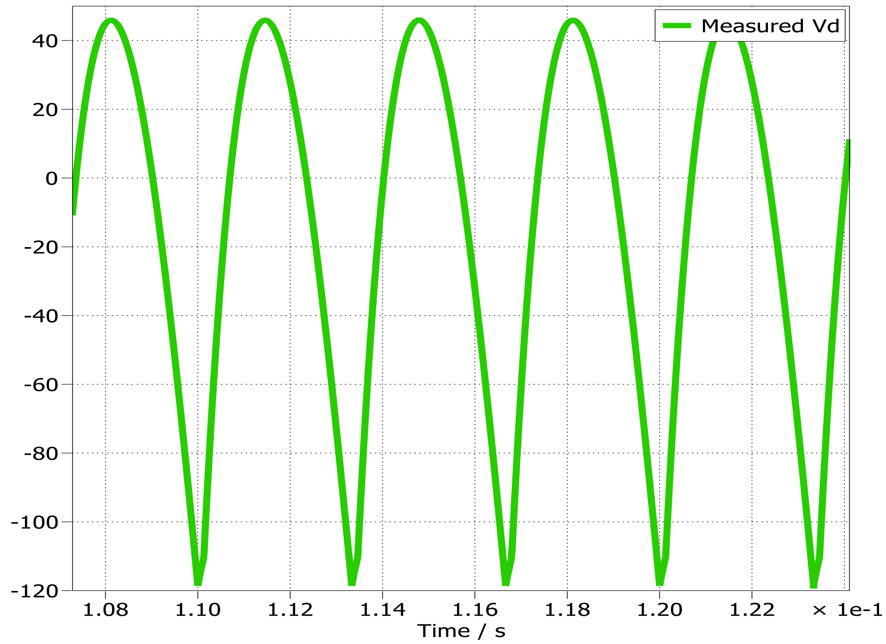


Figure 15: Waveform for vd at $\alpha = 90°$

For $\alpha = 135°$

The average value of v_{d1} is **-481.207 Volts** at the firing angle of 135°.

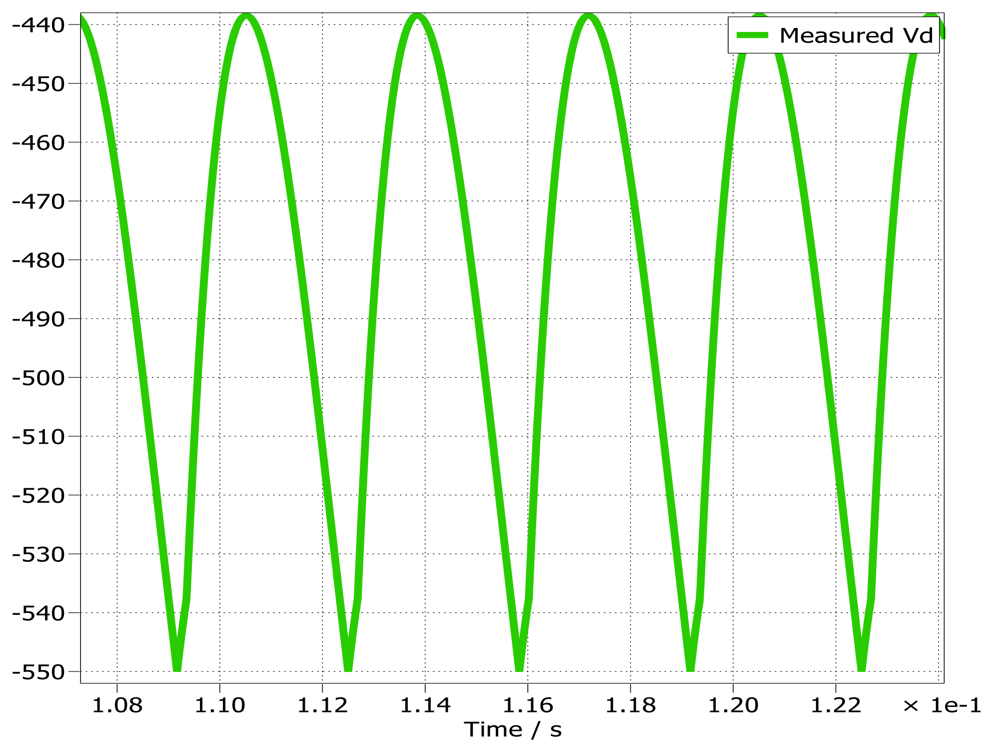


Figure 16: Waveform for vd at $\alpha = 135°$

4. **Obtain v_a and i_a waveforms. Calculate the displacement input power factor for the three values of the delay angle α.**

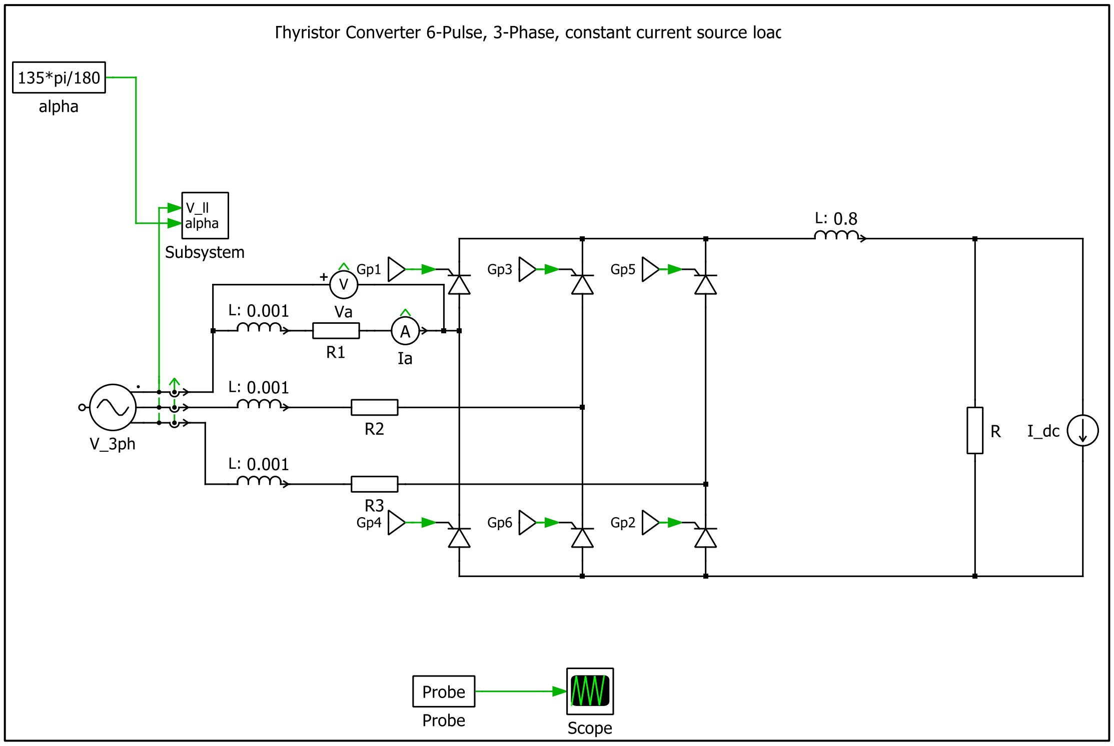


Figure 17: Circuit Diagram for calculating the Waveform for v_a and i_a

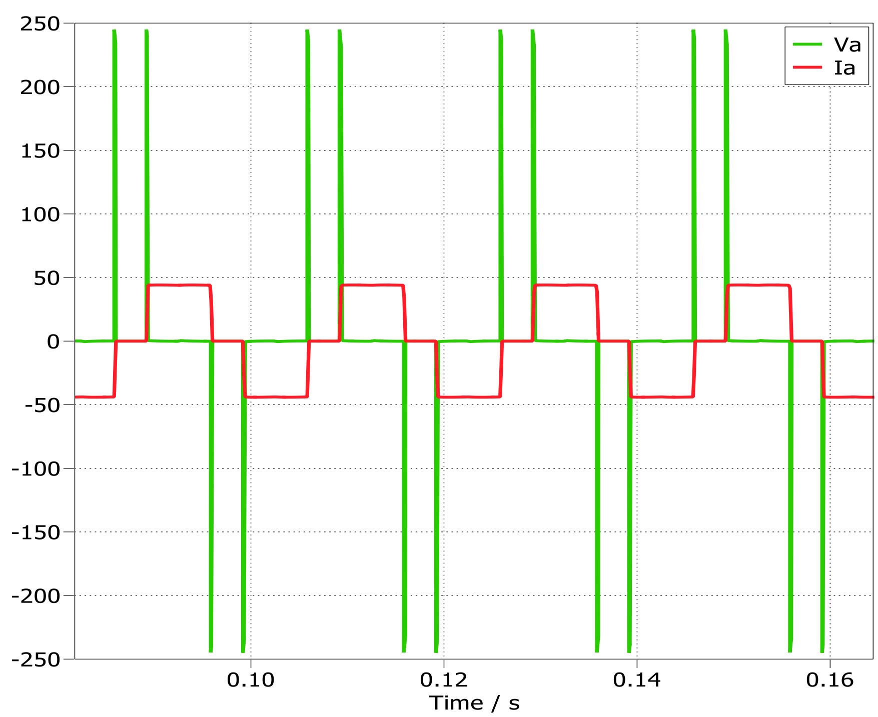


Figure 18: Waveforms for v_a and i_a

To calculate the displacement input power factor for the three values of the delay angle α (45°, 90°, and 135°), we need to use the formula:

$$\text{Displacement Power Factor} = \cos\left(\alpha+\frac{\mu}{2}\right)$$

Where:

$\boldsymbol{\alpha}$ is the delay angle in degrees.

μ is the commutation angle in degrees

Let's calculate the power factor for each of the given values of α and μ:

1. **<u>For α = 45°:</u>**

   In order to the Input Displacement Power Factor, we need to calculate the commutation interval (u) we will find the Delta between V_a and I_a which comes out to be **0.000211**and then converting this into radians by multiplying it by 2πf we get **0.0565 radians** which when converted into degree becomes **3.23°**

   $PF = \cos\left(\alpha+\frac{\mu}{2}\right) = \cos\left(45+\frac{3.23}{2}\right) = 0.686$

2. **<u>For α = 90°:</u>**
   In order to the Input Displacement Power Factor, we need to calculate the commutation interval (u) we will find the Delta between V_a and I_a which comes out to be **0.000194** and then converting this into radians by multiplying it by 2πf we get **0.0405 radians** which when converted into degree becomes **2.32°**

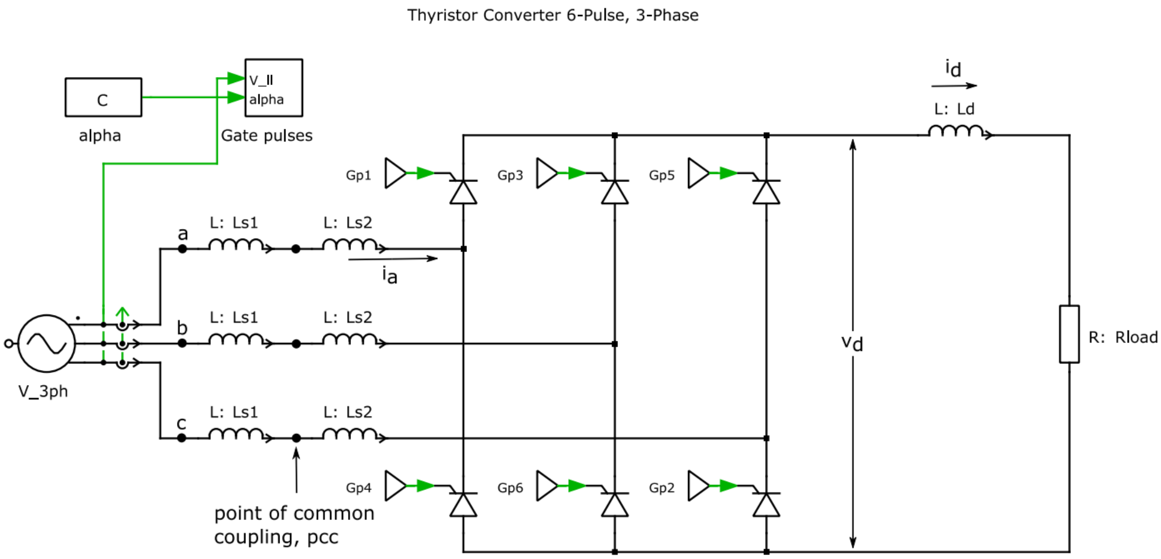
   $PF = \cos\left(\alpha+\frac{\mu}{2}\right) = \cos\left(45+\frac{2.32}{2}\right) = 0.69$

3. **<u>For α = 135°:</u>**
   In order to the Input Displacement Power Factor, we need to calculate the commutation interval (u) we will find the Delta between V_a and I_a which comes out to be **0.000147** and then converting this into radians by multiplying it by 2πf we get **0.0378 radians** which when converted into degree becomes **2.06°**

   $PF = \cos\left(\alpha+\frac{\mu}{2}\right) = \cos\left(45+\frac{2.06}{2}\right) = 0.694$

So, these are the displacement input power factors for the given values of the delay angle α

3. 3-Phase Thyristor Rectifier Bridge



1. **Obtain the following waveforms for each section respectively.**
   a) **v_a, v_d, and i_d.**
   b) **v_a and i_a.**
   c) **(v_a)pcc, (v_{ab})pcc, and i_a.**

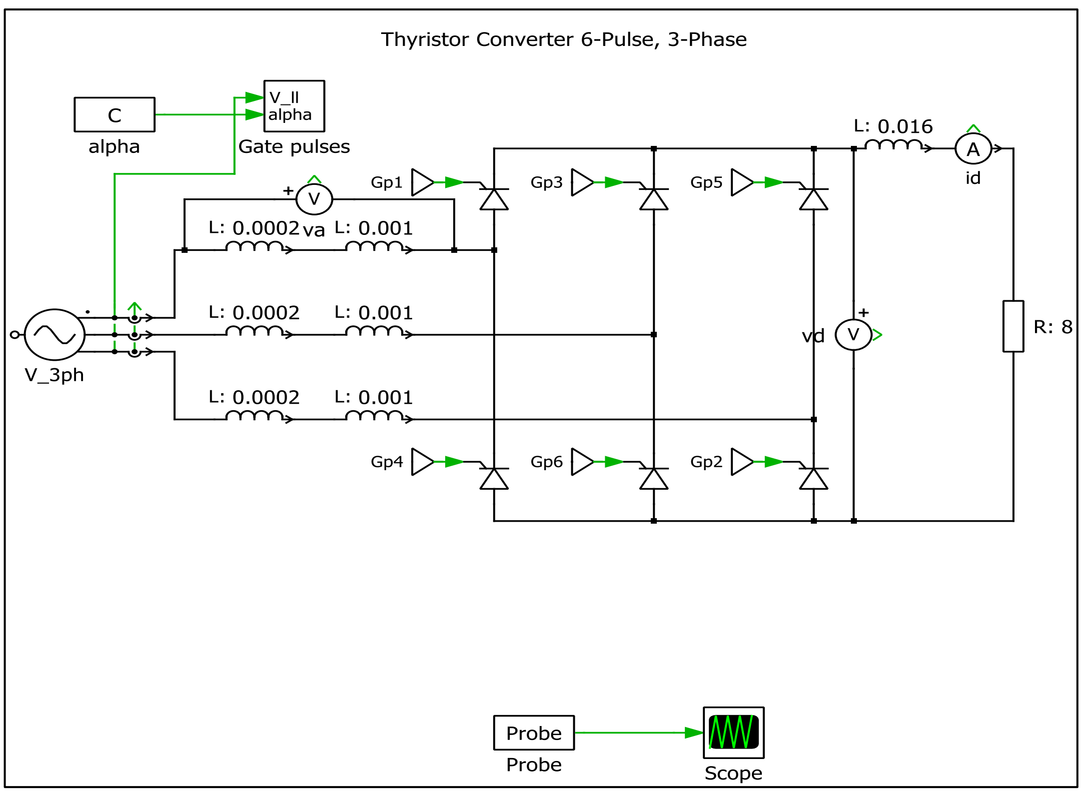


Figure 19: Circuit Diagram for calculating the Waveform for v_a, v_d and i_d

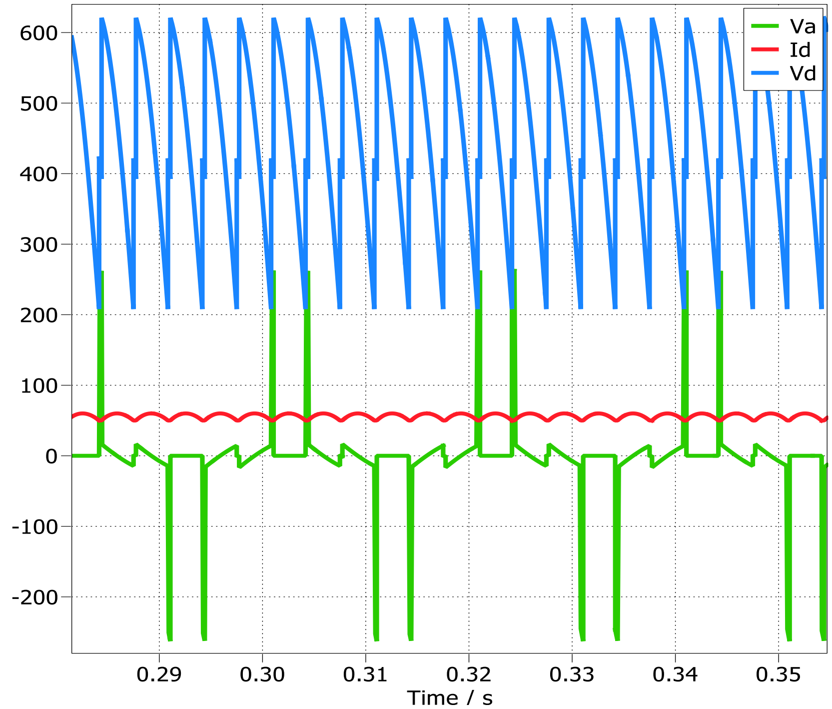


Figure 20: Waveforms for va, vd and id

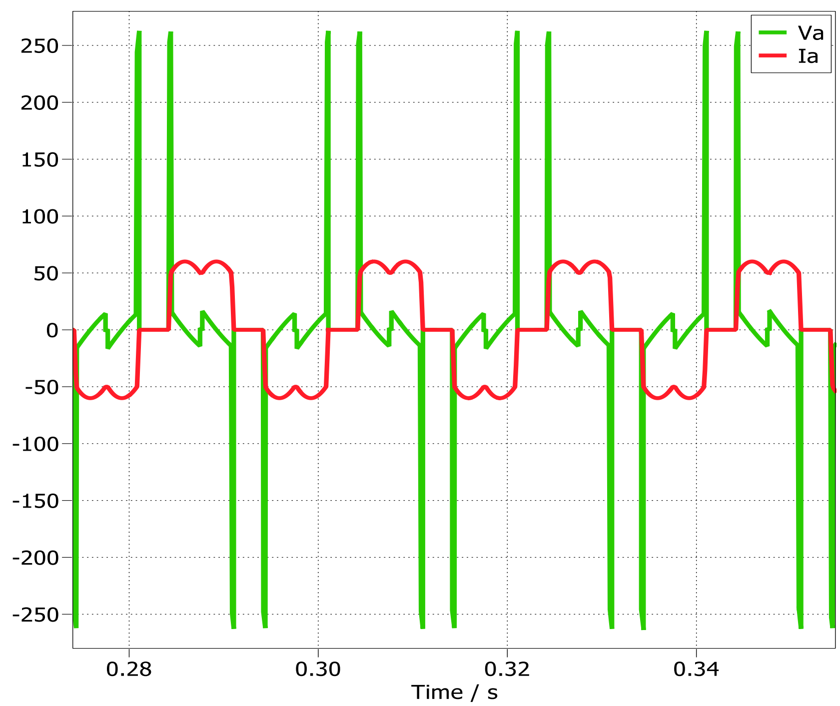


Figure 21: Waveforms for v_a and i_a

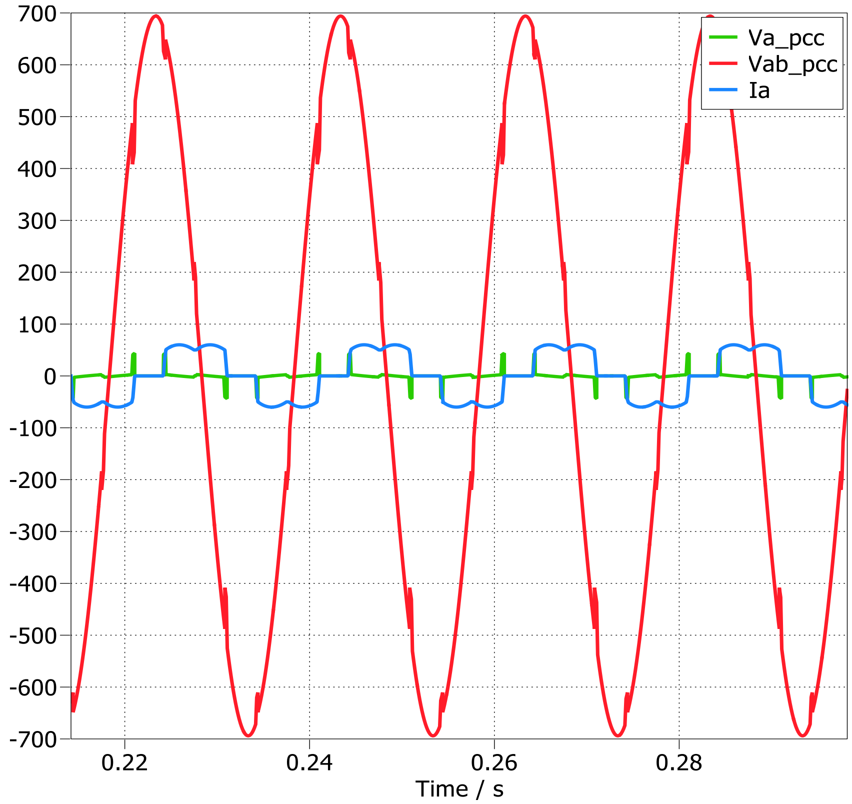


Figure 22: Waveforms for $v_{a(pcc)}$, $v_{ab(pcc)}$ and i_a

2. **From the plots, obtain the commutation interval u and i_d at the start of the commutation. Verify the following commutation equation:**

$$\cos(\alpha + u) = \cos\alpha - \frac{2\omega L_s}{\sqrt{2}V_{LL}} I_d$$

where $L_s = L_{s1} + L_{s2}$. For I_d, use the average value of i_d or its value at the start of the commutation.

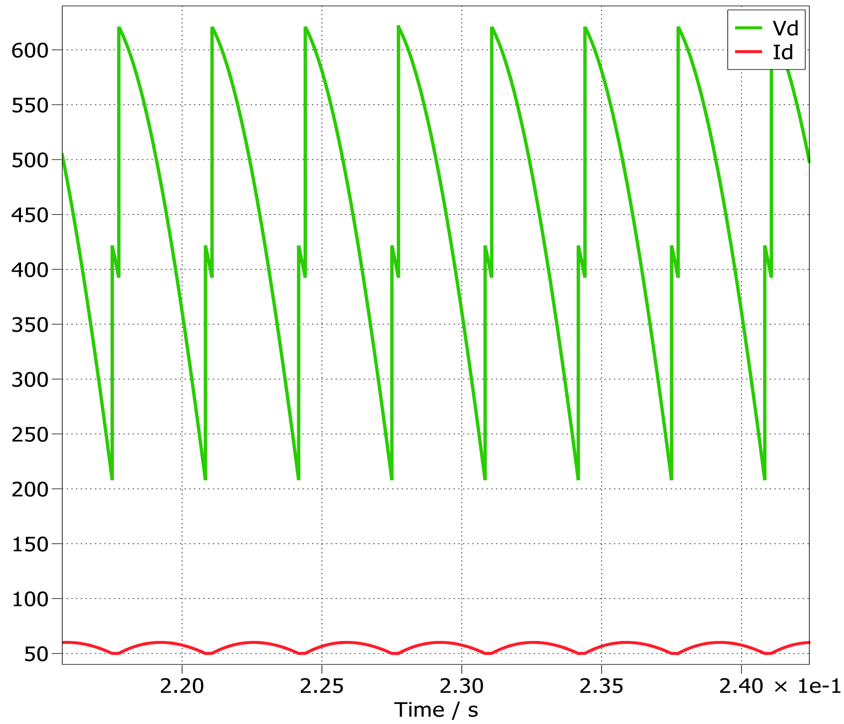


Figure 22: Waveforms for v_d and i_d

To calculate the commutation interval (u) we will find the Delta between V_d and I_d at the start of commutation which comes out to be **0.0023** and then converting this into radians by multiplying it by 2πf we get **0.072 radians** which when converted into degree becomes **4.125°**

The value of I_d at the start of the commutation is 50.23 A which has been calculated from the graph. Now we have the equation:

$$\cos(\alpha + u) = \cos(\alpha) - \frac{2\omega Ls}{\sqrt{2}V_{LL}} * I_d$$

$$\cos(45 + 4.125) = \cos(45) - \frac{2*2*\pi*50*(0.0002+0.001)}{\sqrt{2}*400} * 50.23$$

0.654 = 0.707 - 0.001332 ∗ 50.23

0.654 = 0.707 – 0.0669

0.654 = 0.640 **(Approximately Equal)**

3. By means of Fourier analysis of i_s, calculate its harmonic components as a ratio of I_{s1}.

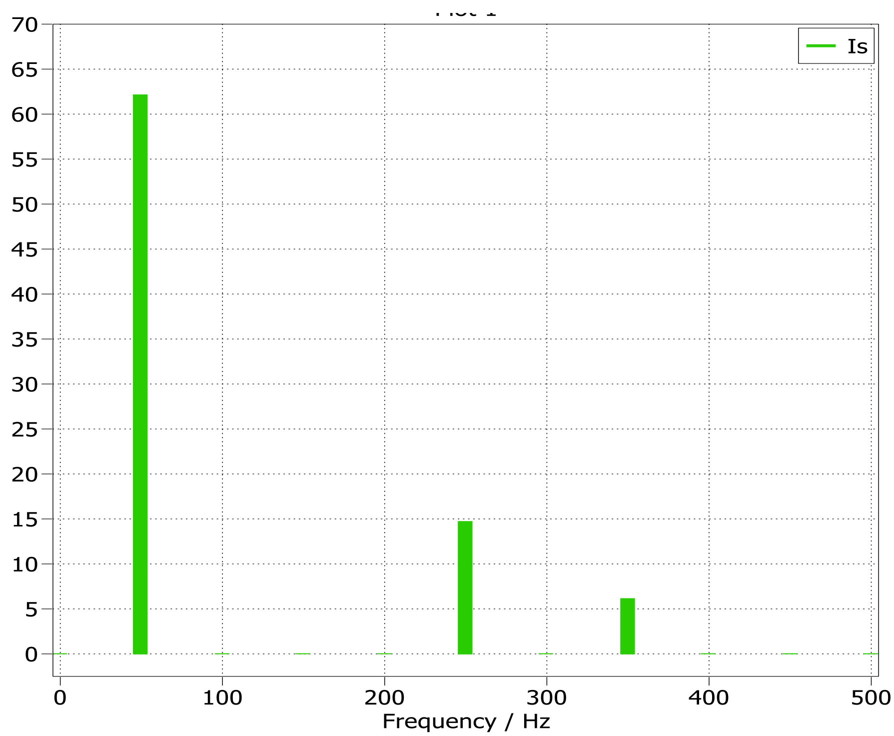


Figure 23: Fourier Transform of Is

Given the fundamental value of I_{S1}**= 62.13 A** and the harmonic components I_{S5} **= 14.704 A** and I_{S7} **= 6.13 A**, we can calculate the total harmonic distortion (THD) to assess the distortion present in the waveform.

THD is typically calculated using the following formula:

$$\mathrm{THD} = \sqrt{\frac{I_{S5}^2 + I_{S7}^2}{I_{S1}^2}}$$

Substituting the given values:

$$\mathrm{THD} = \sqrt{\frac{14.704^2 + 6.13^2}{62.13^2}}$$

So, the Total Harmonic Distortion (THD) is approximately **0.2564** or **25.64%.**

This indicates that approximately 25.64% of the total waveform's energy is due to harmonic distortion, relative to the fundamental component.

4. Calculate I_s, the input displacement power factor and the input power factor.

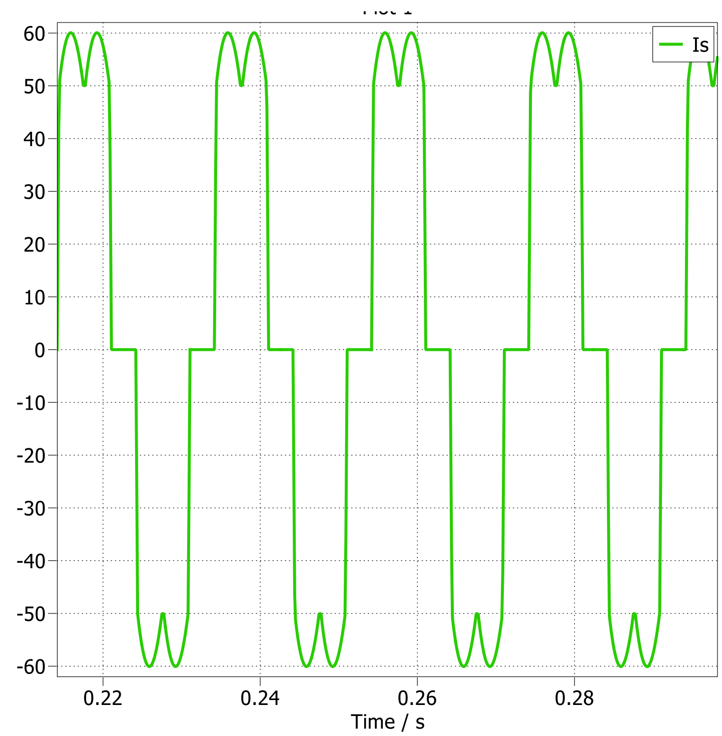


Figure 24: Waveform of Is with RMS Value of 45.80 A

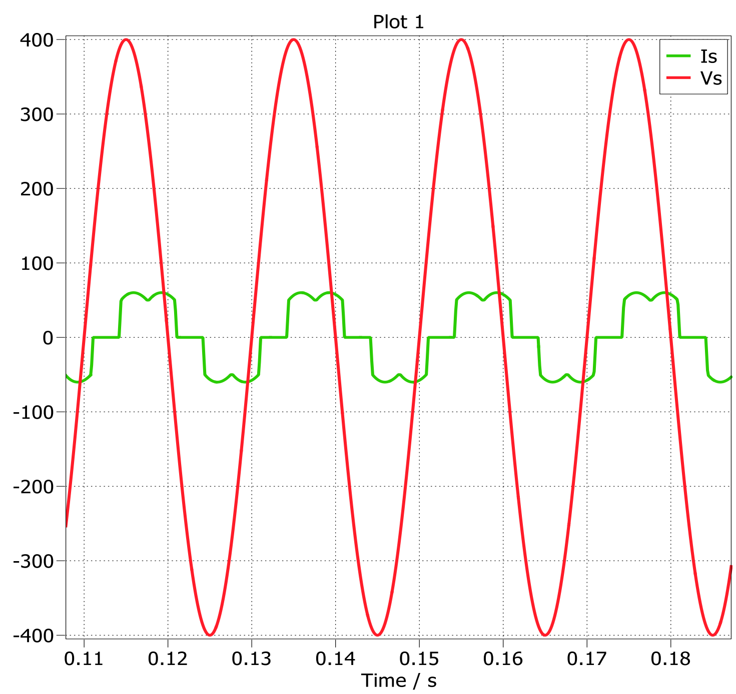


Figure 25: Waveform of Is and Vs

In order to calculate the Input Displacement Power Factor, we need to calculate the commutation interval (u) we will find the Delta between V_s and I_s which comes out to be **0.00028** and then converting this into radians by multiplying it by 2πf we get **0.0879 radians** which when converted into degree becomes **5.03°**

Displacement Input Power Factor = $\cos(\alpha + \frac{\mu}{2})$

$$= \cos(45 + \frac{5.03}{2}) = \mathbf{0.675}$$

Input Power Factor = $\cos(\pi)$

$$= \cos(5.03) = \mathbf{0.996}$$

5. **Verify the following equation:**

$$Displacement\ power\ factor \approx \cos\left(\alpha + \frac{u}{2}\right) \approx \frac{\cos\alpha + \cos(\alpha + u)}{2}$$

Displacement Power Factor = $\cos(\alpha + \frac{\mu}{2}) = \frac{\cos\alpha + \cos(\alpha+\mu)}{2}$

<u>Given:</u>

$\alpha = 45°$

$\mu = 4.125°$

Displacement Power Factor = $\cos(45 + \frac{4.125}{2}) = \frac{\cos 45 + \cos(45+4.125)}{2}$

Displacement Power Factor = $\cos(47.06) = \frac{\cos 45 + \cos(49.125)}{2}$

Displacement Power Factor = $0.681 = \frac{0.707 + 0.654}{2}$

Displacement Power Factor = 0.681 = 0.6805 **<u>(Proved)</u>**

6. **At the point of common coupling, obtain the following from the v_{pcc} waveform:**

   a. **Line-notch depth ρ (%)**

      The line-notch is the dip in voltage, occurring at a certain point due to the thyristor rectifier operation. The depth of the line-notch from the baseline to its lowest point is **5.04 Volts** and the peak voltage is **43.80 Volts.** Then the Line Notch Depth will be:

$$\rho = \frac{5.04}{43.80} \text{ x } 100 = 11.50\ \%$$

   b. **Line-notch area.**

      To calculate the line-notch area, we would need to integrate the area under the line-notch curve. This process would provide us with the line-notch area, which represents the energy loss or disturbance caused by the rectifier operation at the point of common coupling.

7. **Obtain the average dc voltage V_d. Verify that:**

$$V_d = 1.35\, V_{LL} \cos\alpha - \frac{3\omega L_s}{\pi} I_d$$

For I_d, use the average value of id or its value at the start of the commutation.

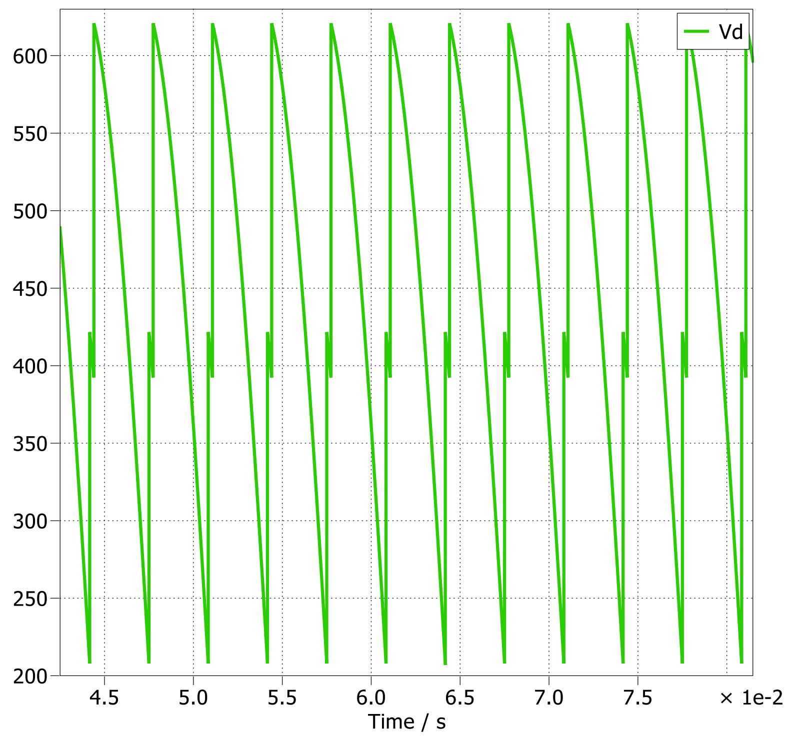


Figure 26: Waveform of V_d

The value of I_d at the start of the commutation is **50.23 A** which has been calculated from the graph in Part (2).

$$V_d = 1.35 V_{LL} \cos(\alpha) - \frac{3\omega Ls}{\pi} I_d$$

$$V_d = 1.35 * 400 * \cos(45) - \frac{3*2*\pi*50*(0.002+0.001)}{\pi} * 50.23$$

$$V_d = 381.83 - 18.08$$

$$V_d = 363.75$$