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ELEC-E8412
Power Electronics

Simulation Assignment 01

1. Simulate a single-phase controlled full wave rectifier with following specifications:

   - AC voltage source: amplitude 230 V, frequency 50 Hz
   - R-L Load: 10 Ω and L=10 mH
   - Delay angle: α=60°

   a. Measure the output waveforms and explain the results.

   b. Add the capacitor filters (with C1= 5 mF and C2= 10 mF) in the output side and compare the results. What is the peak-to-peak ripple of output voltage in each case?

Solution:

a) The circuit diagram for a single phase controlled full wave rectifier can be seen below:

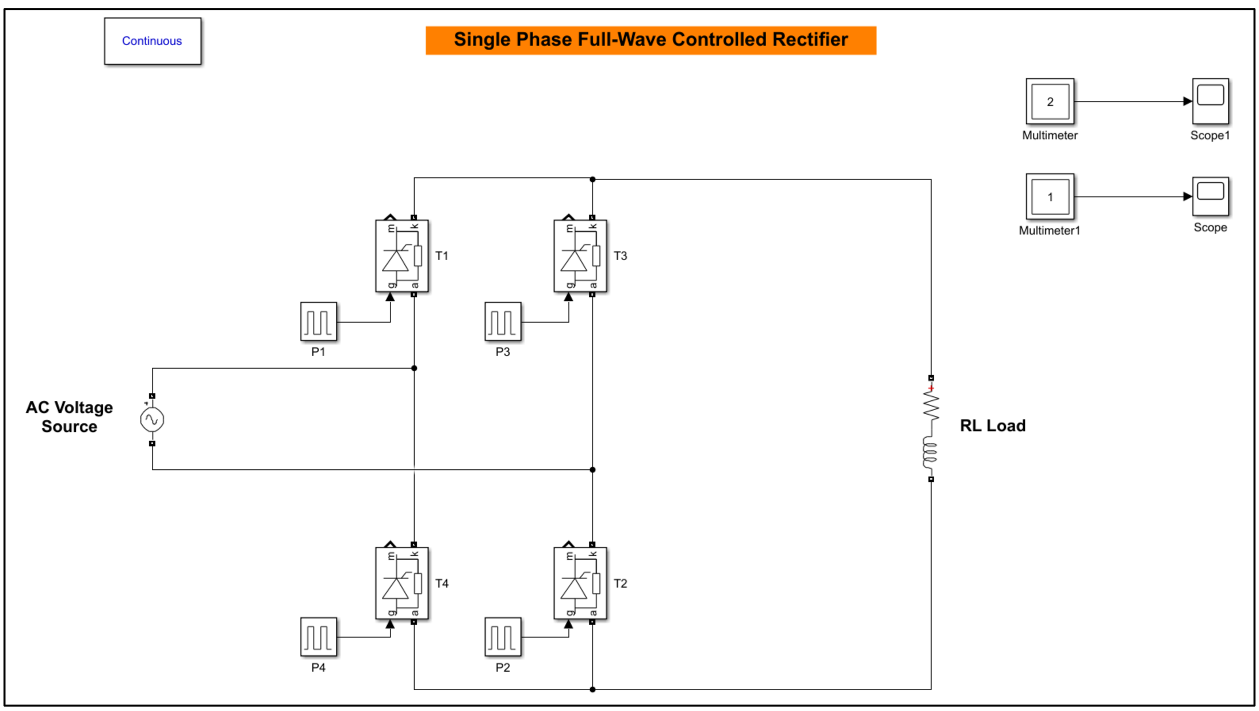

Figure 1: Single Phase Controlled Rectifier with RL Load

The output Voltage and Current Waveform for this circuit can be seen below:

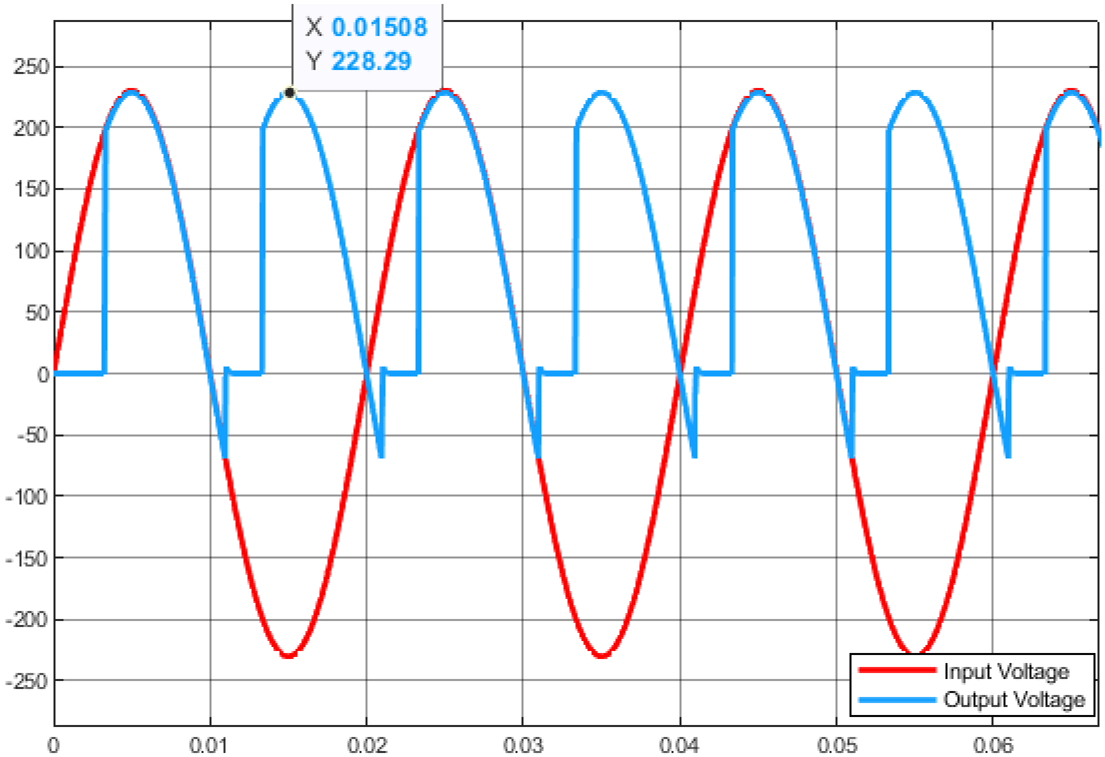

Figure 2: Voltage Waveform for Single Phase Controlled Rectifier with RL Load

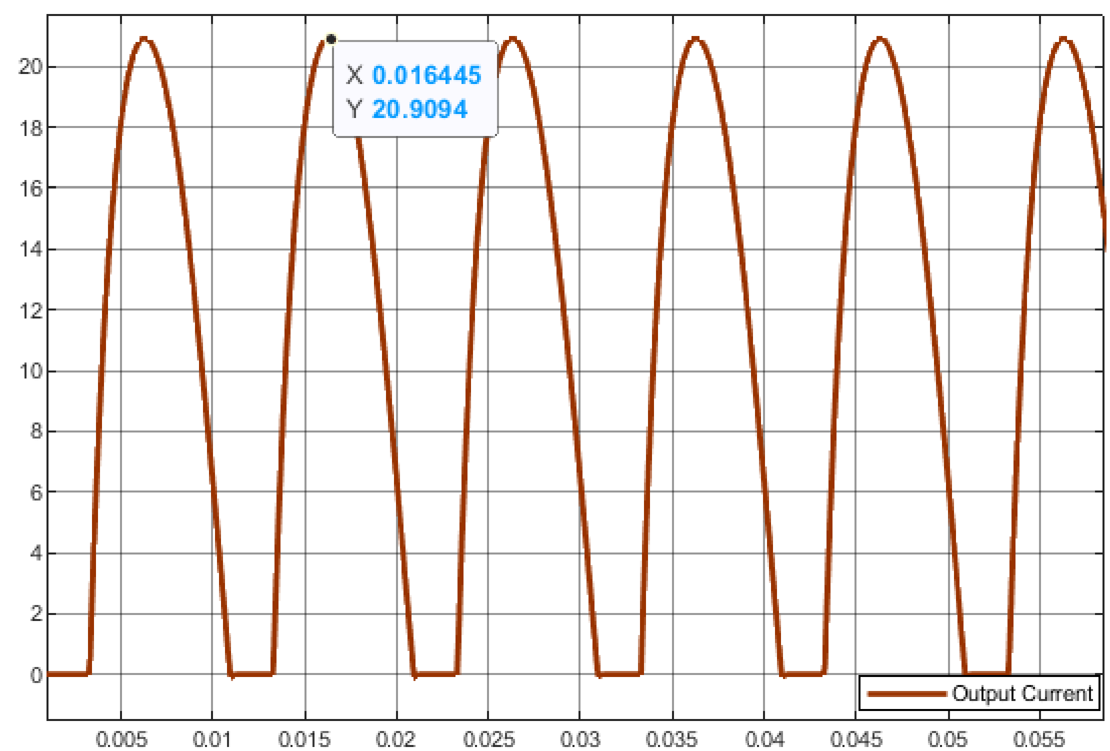

Figure 3: Current Waveform for Single Phase Controlled Rectifier with RL Load

In the context of a controlled rectifier simulation with an RL load, it's important to understand the waveforms of voltage and current across the load. The RL load consists of a resistor (R) and an inductor (L), which affect the waveform behavior differently.

1. **<u>Voltage Across RL Load:</u>**

- The voltage waveform across the RL load is determined by the controlled rectifier. This waveform is typically pulsating DC.
- When the rectifier switches are turned on (thyristors or diodes), the voltage across the load is almost equal to the instantaneous input voltage, which is a sinusoidal AC waveform in our case.
- When the rectifier switches are turned off, the voltage across the load drops to zero. This results in a pulsating DC waveform, which is a series of DC pulses with zero voltage in between.
- The ripple voltage (the variation in voltage between the maximum and minimum values) is more prominent in RL loads compared to purely resistive loads.

2. **<u>Current Through RL Load:</u>**

- The current waveform through the RL load lags the voltage waveform due to the presence of the inductor.
- Initially, when the rectifier switches are turned on, the current through the RL load rises gradually. This is because of the inductor's property to resist abrupt changes in current (inductive reactance).
- When the rectifier switches are turned off, the current gradually decreases, and the inductor helps maintain some current flow in the circuit, resisting rapid current reduction.
- The shape of the current waveform may exhibit a phase shift or lag with respect to the voltage waveform, and this lag is determined by the value of the inductance (L) and the frequency of the AC source. The greater the inductance, the more pronounced the lag.

In summary, the waveform for an RL load in a controlled rectifier will exhibit a pulsating DC voltage with a ripple due to the presence of the inductor. The current waveform will lag the voltage waveform due to the inductance, resulting in a delay in the rise and fall of current with respect to the voltage.

b) The circuit diagram for a single phase controlled full wave rectifier with capacitor filters can be seen below:

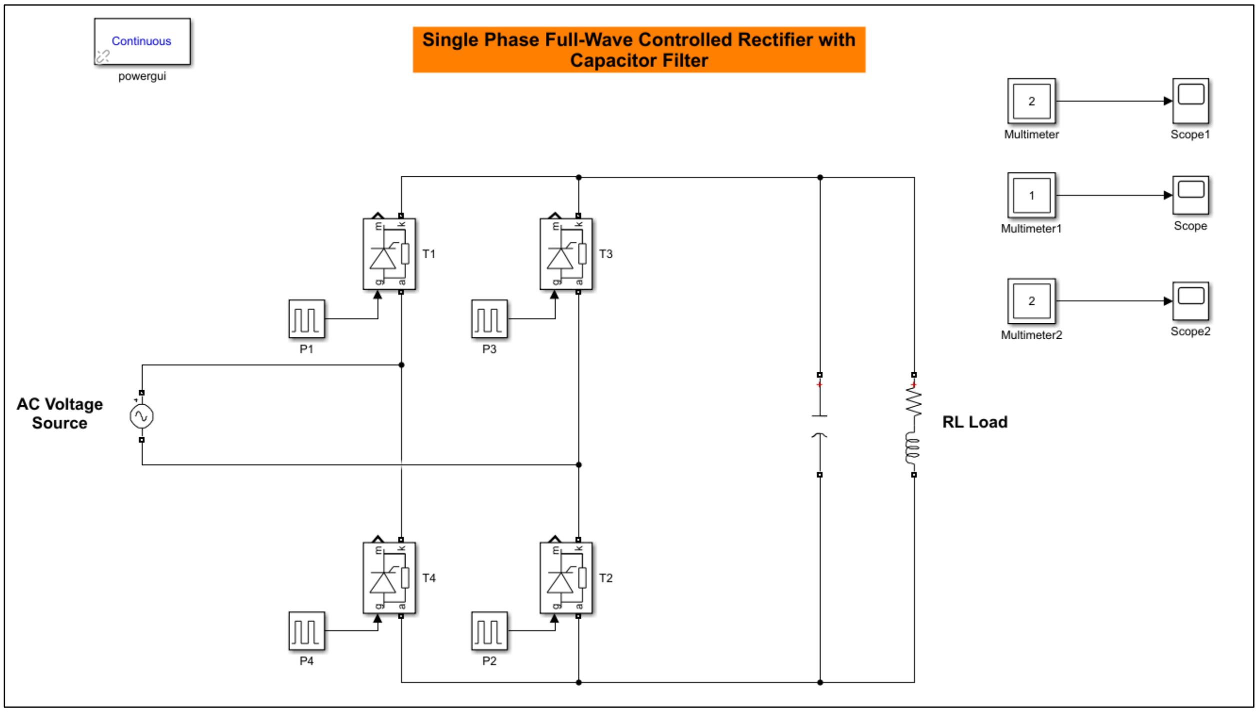

Figure 4: Single Phase Controlled Rectifier with RL Load and Capacitor Filter

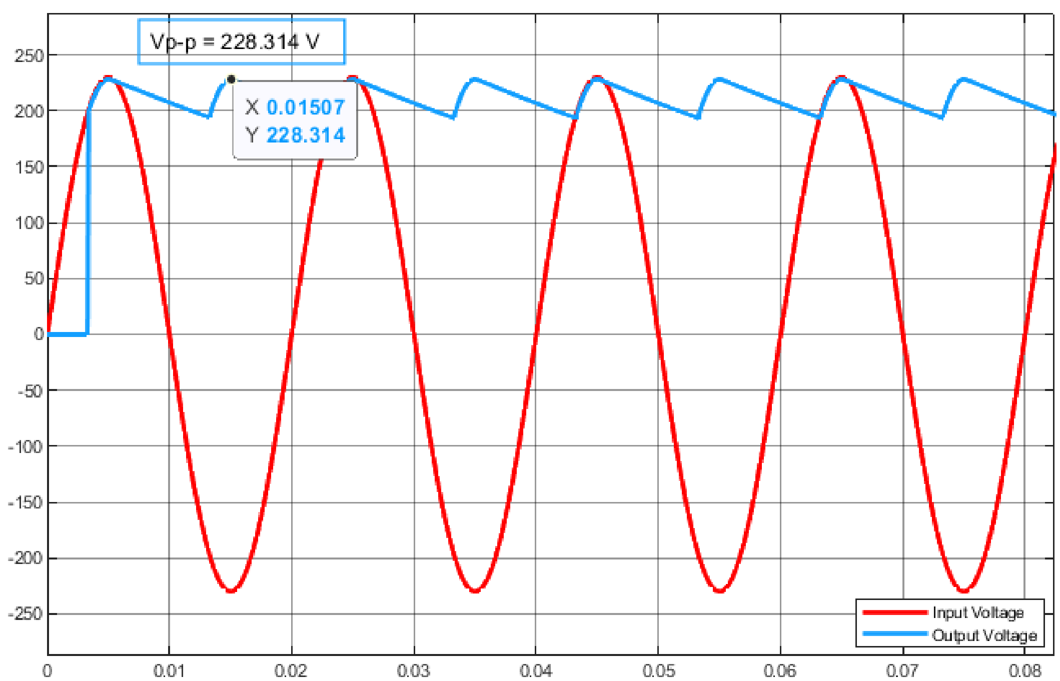

Figure 5: Peak to Peak Ripple Output Voltage for C = 5mF

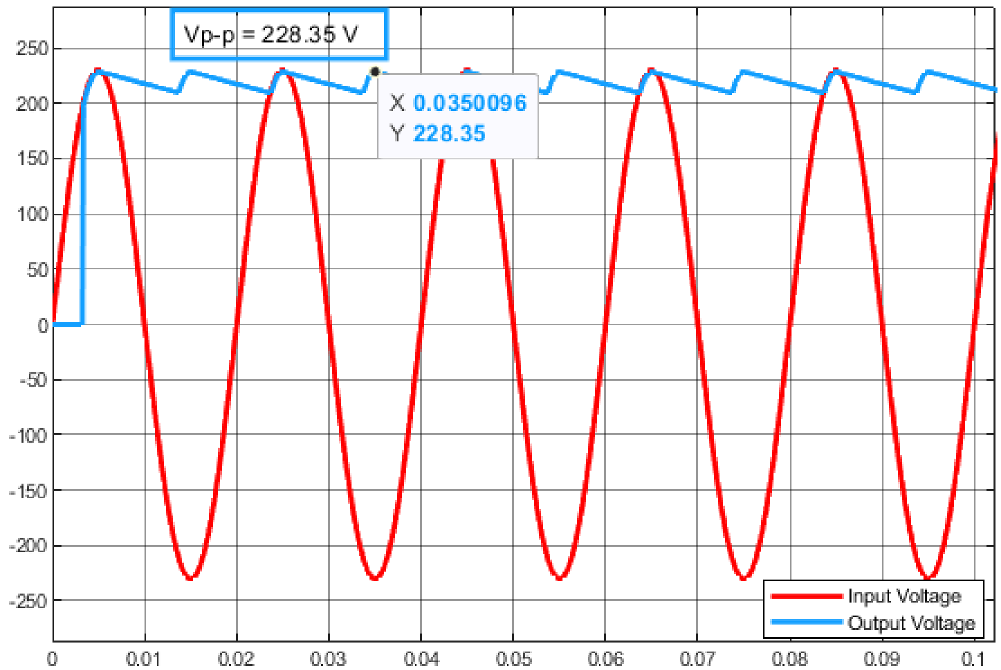

Figure 5: Peak to Peak Ripple Output Voltage for C = 10mF

Adding capacitor filters to the output of a controlled rectifier is a fundamental technique to smoothen the pulsating DC voltage generated by the rectifier. In this context, capacitors serve as energy storage devices that help reduce the ripple in the output voltage. During the "on" phase of the rectifier, when the voltage is at its peak, capacitors charge as they store energy. Subsequently, during the "off" phase of the rectifier when the voltage drops, capacitors discharge, releasing the stored energy. This continuous charging and discharging action results in a more constant DC voltage across the load, significantly reducing the ripple.

The peak-to-peak ripple voltage in the output can be calculated using the formula:

$$V_{ripple} = V_m / (2 * f * R * C)$$

Where,

Vm is the peak value of the rectified voltage.

f is the frequency of the AC source.

R is the load resistance.

C is the capacitance of the capacitor filter.

In practice, a larger capacitor (C2 = 10mF) generally results in a smaller ripple voltage due to its higher capacitance, which enables it to store more energy and smooth out the voltage more effectively.

2. Simulate a three-phase controlled rectifier with following specifications:

- AC voltage source: phase to phase voltage 400 Vrms, frequency 50 Hz
- R Load: 5 kΩ
- Delay angle: α=30°

a. Calculate the phase delay of each thyristor.

b. Measure the output waveforms and show the results.

c. Show the ac-side and dc-side voltages in the same scope and explain the result.

Solution:

The circuit diagram for a three-phase controlled full wave rectifier can be seen below:

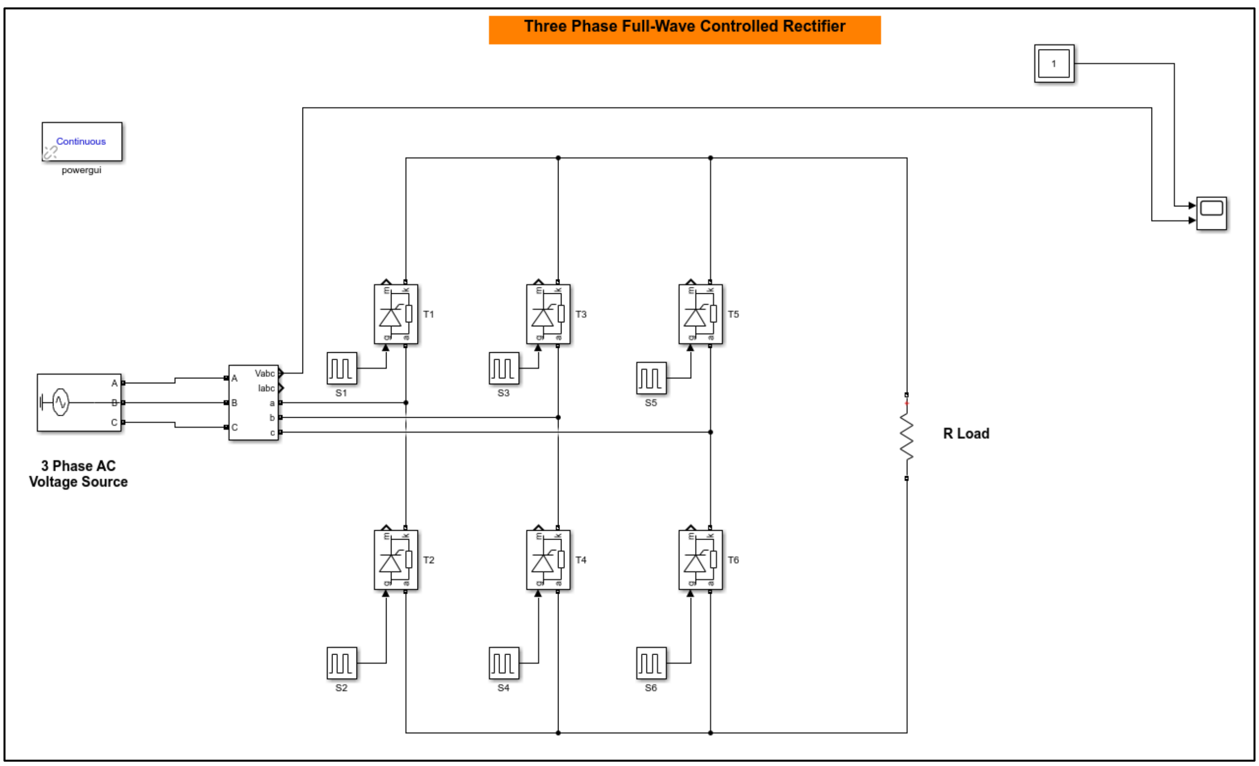

Figure 6: Three Phase Full Wave Controlled Rectifier

The phase delay of each thyristor in a three-phase controlled rectifier is essential for understanding how the thyristors are triggered in each phase to achieve the desired output. The phase delay determines the conduction angle for each thyristor, allowing them to control the rectification process effectively.

In a three-phase controlled rectifier, there are six thyristors, typically arranged in a bridge configuration. Thyristors are semiconductor devices that can be turned on (triggered) and off, allowing or blocking the flow of current. To control the rectification, these thyristors are triggered with a certain delay from the zero-crossing of the AC waveform. This delay is known as the phase delay or conduction angle (α).

Calculating the Phase Delay Angles for each Thyristor

Given: AC voltage source with 400 V_{rms} and a frequency of 50 Hz, R Load of 5 kΩ, and a delay angle (α) of 30°.

Since there are six thyristors in a three-phase controlled rectifier (T1, T2, T3, T4, T5, and T6), they are triggered at different points in the AC waveform. The phase delay for each thyristor can be calculated as follows:

- $SCR_1 = \frac{(\alpha+30)T}{360} = \frac{(30+30)\ 0.02}{360} = 0.0033$ sec
- $SCR_6 = \frac{(\alpha+30+60)T}{360} = \frac{(30+30+60)\ 0.02}{360} = 0.0066$ sec
- $SCR_3 = \frac{(\alpha+30+60+60)T}{360} = \frac{(30+30+60+60)\ 0.02}{360} = 0.01$ sec
- $SCR_2 = \frac{(\alpha+30+60+60+60)T}{360} = \frac{(30+30+60+60+60)\ 0.02}{360} = 0.0133$ sec
- $SCR_5 = \frac{(\alpha+30+60+60+60+60)T}{360} = \frac{(30+30+60+60+60+60)\ 0.02}{360} = 0.0166$ sec
- $SCR_4 = \frac{(\alpha+30+60+60+60+60+60)T}{360} = \frac{(30+30+60+60+60+60+60)\ 0.02}{360} = 0.02$ sec

The phase delay calculation ensures that each thyristor is triggered at the appropriate time within the AC waveform to achieve controlled rectification. This balanced triggering sequence ensures that all three phases of the AC source are rectified in a synchronized manner, which is critical for power quality and efficiency.

In summary, the phase delay calculation is a crucial step in the design and operation of a three-phase controlled rectifier. It allows you to control the firing of the thyristors at specific points in the AC cycle, achieving the desired rectification and controlling the output voltage as required. The balanced triggering sequence ensures efficient and synchronized rectification across all phases.

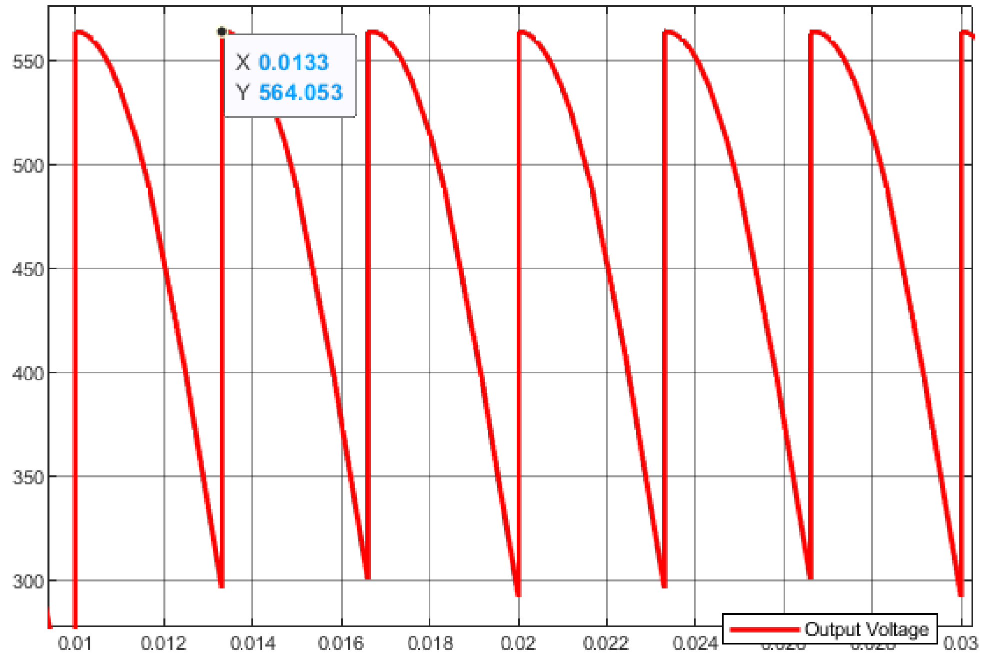

Figure 7: Output Voltage of Three Phase Full Wave Controlled Rectifier

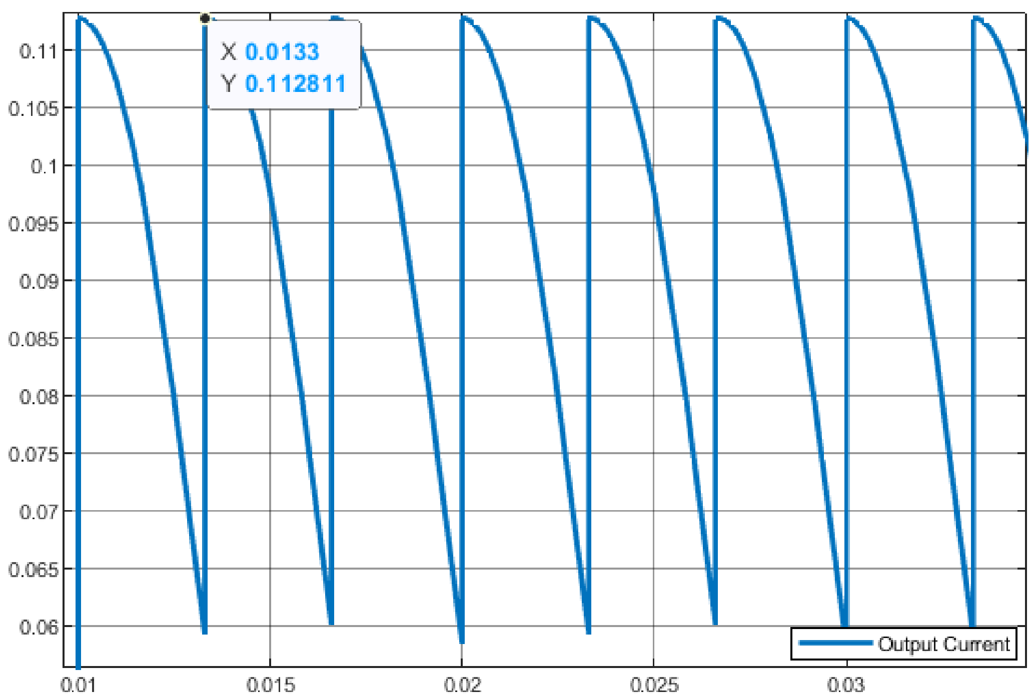

Figure 8: Output Current of Three Phase Full Wave Controlled Rectifier

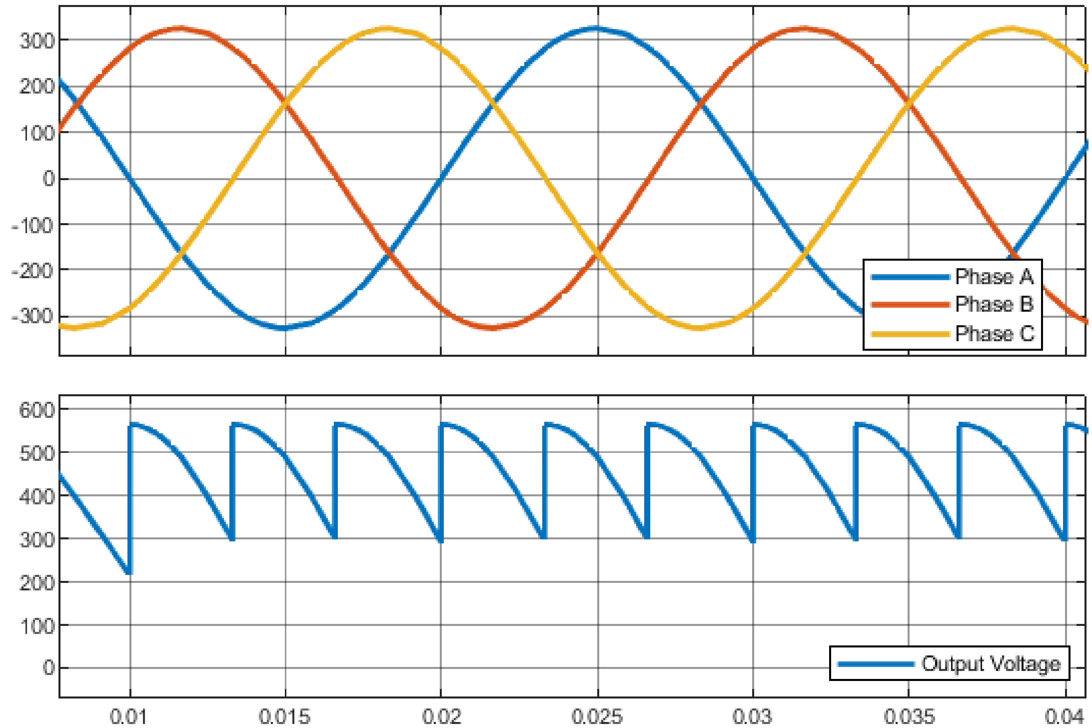

Figure 9: Comparison of AC Side and DC Side Voltages of Three Phase Full Wave Controlled Rectifier

The joint representation of AC and DC voltage waveforms in the same scope provides a comprehensive view of the rectification process:

- **AC Voltage:** The AC voltage waveform is sinusoidal and fluctuates between positive and negative values as the three-phase AC source cycles.
- **DC Voltage:** The DC voltage waveform represents the rectified output. It appears as pulsating DC voltage, characterized by ripple. This ripple results from the phase control of thyristors and any filtering components.
- **Phase Delay (α):** The phase delay, denoted by α, defines when each thyristor triggers within each phase of the AC source. For a balanced three-phase system, there's a 120° phase shift between each thyristor's conduction angle. This coordinated triggering ensures balanced rectification across all phases.

The combined waveforms reveal the dynamic relationship between AC and DC voltages. The DC voltage follows the rectification process, turning on when thyristors conduct and off when they block current. The phase delay (α) governs the thyristor triggering, leading to the characteristic ripple in the DC voltage. Minimizing the ripple in the DC voltage can be achieved by increasing the smoothing capacitance (if capacitors are employed) or selecting appropriate firing angles for thyristors. The synchronization of phase delays in the controlled rectifier ensures a balanced rectification of the three-phase AC input, resulting in a smoother and more stable DC output.