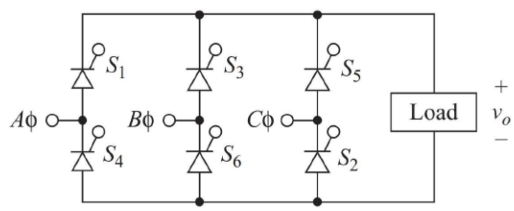
Controlled three-phase rectifier - Simulation

- 1) Simulate the following circuit. The load is composed by $R = 1\ \Omega, L = 0.1\ \mathrm{H}, V_{dc} = 7\ \mathrm{kV}$, and a paral·lel capacitor of 2700uF. The grid voltage is 6 kV rms.
- 2) Measure AC voltages and currents and DC voltage and current.
- 3) Calculate the AC power and DC power.
- 4) Start the converter with $\alpha = 0°$and at $t = 0.4$ s change it to $\alpha = 20°$ and at $t = 0.8$ s change it to $\alpha = 50°$. Explain what happens with the DC current in those cases.



Question 1: Simulate the following circuit.

Load consists of:

- **Resistance (R)**: 1 Ω
- **Inductance (L)**: 0.1 H
- **Capacitance (C)**: 2700 µF

The main parameter that affects the output voltage waveform and its DC component in controlled rectifier is a delay angle – alpha.

Thyristors are triggered at appropriate times that we specify specified. The delay angle represents an interval between two time instances: when thyristor becomes forward-biased and when the gate signal is applied.

Star (or Y) configuration for a AC three-phase system.

For Questions 2 and 3 i use alpha = 0.

Question 2: Measure AC voltages and currents and DC voltage and current.

DC (OUTPUT) VOLTAGE AND CURRENT:

The drop in output current from 800 A to 600 A in the first 0.02 seconds is primarily due to the inductor's opposition to rapid changes in current. The inductor introduces a transient effect that causes the current to gradually decrease or stabilize over time. Also the capacitor charges.

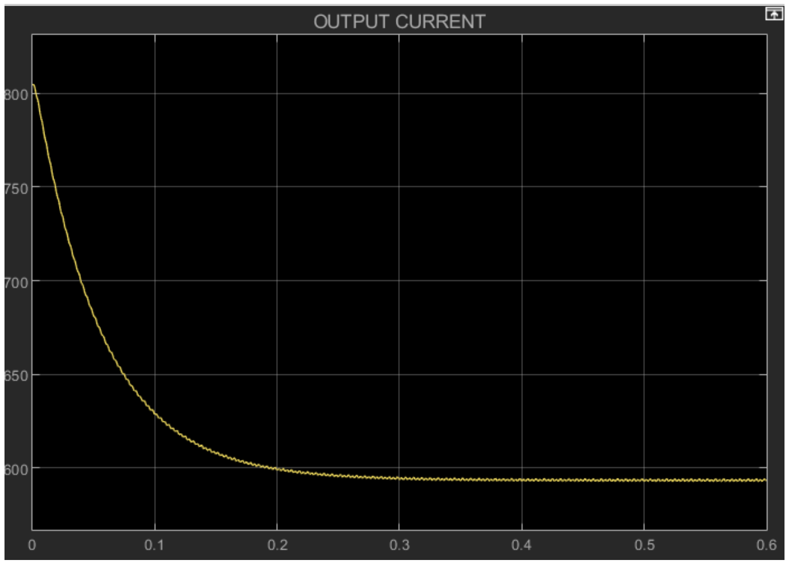


Figure 1. Output Current

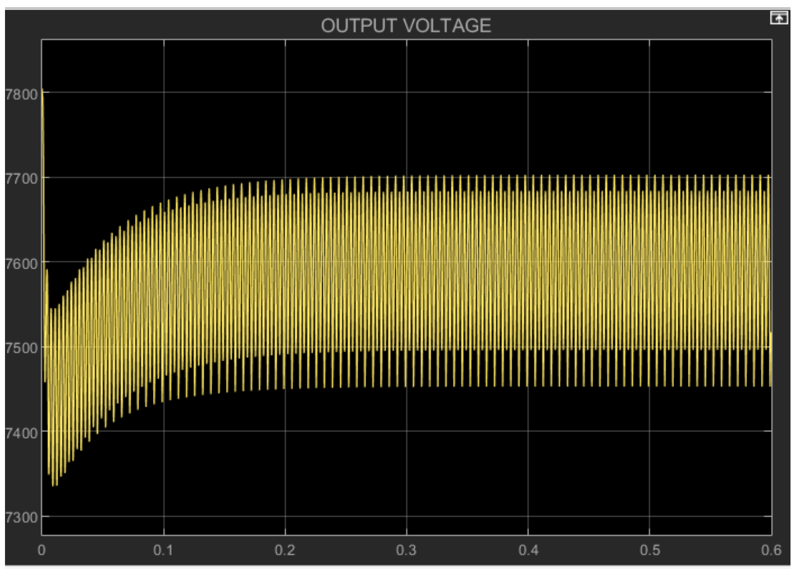


Figure 2. Output Voltage

$$I_{output,RMS} = 593{,}4\ A$$

$$U_{output,RMS} = 7594\ V$$

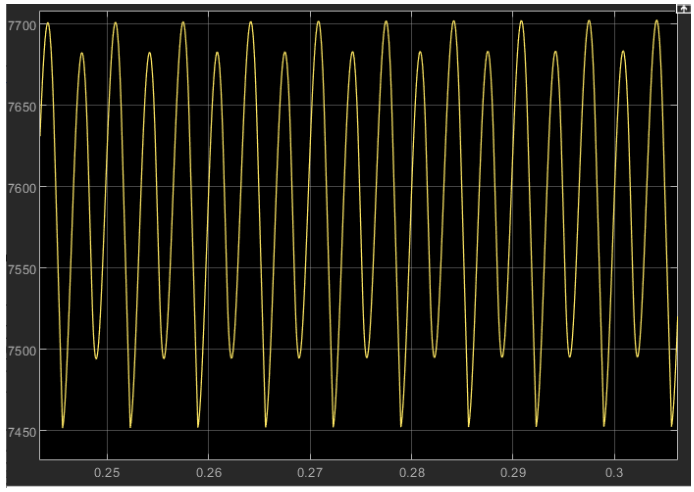


Figure 3. Load voltage zoomed

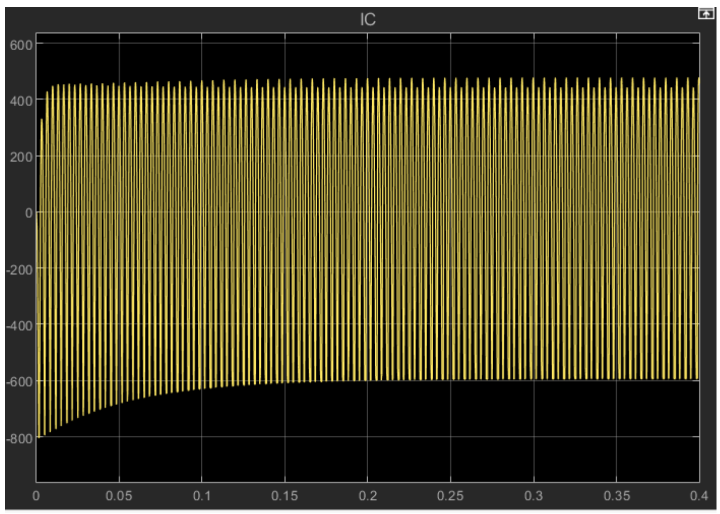


Figure 4. Capacitor Current

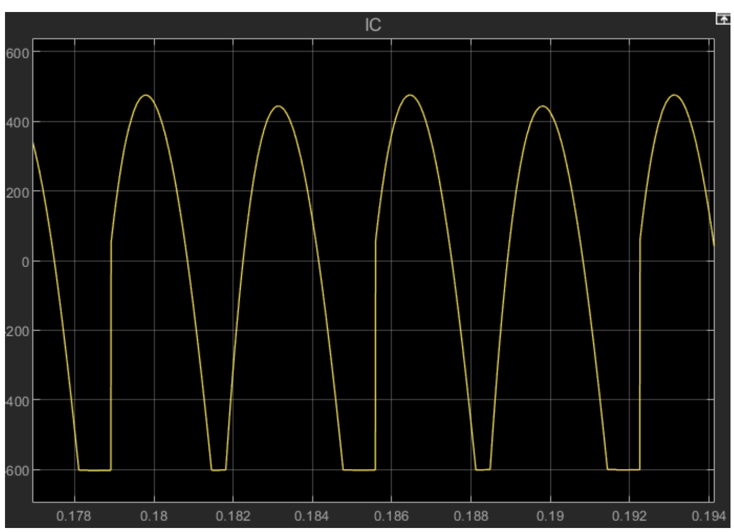


Figure 5. Capacitor Current Zoomed

In a rectifier circuit, the capacitor charges during the intervals when the rectified output voltage is higher than the voltage across the capacitor. Since the rectified voltage from the thyristors is a pulsating DC (with ripple), the charging current is not constant and depends on the voltage difference between the rectified output and the capacitor voltage. As the capacitor charges, the voltage difference reduces, causing a decrease in the charging current. This explains why the charging current is non-constant.

After the rectified voltage drops below the capacitor voltage, the capacitor starts discharging into the load. The discharge current remain relatively constant for a period, because there is an inductor present in the circuit to smooth the current and load is also resistive.

AC (INPUT) VOLTAGE AND CURRENT:

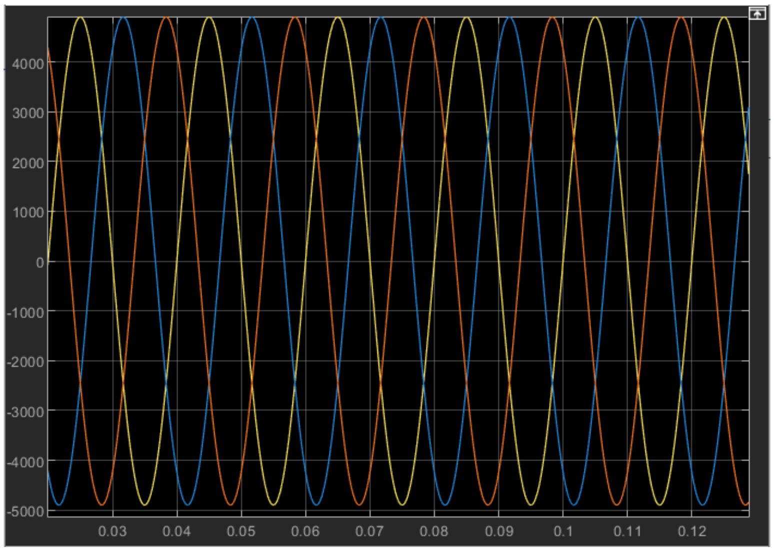


Figure 6. Input AC Voltage – all 3 phases

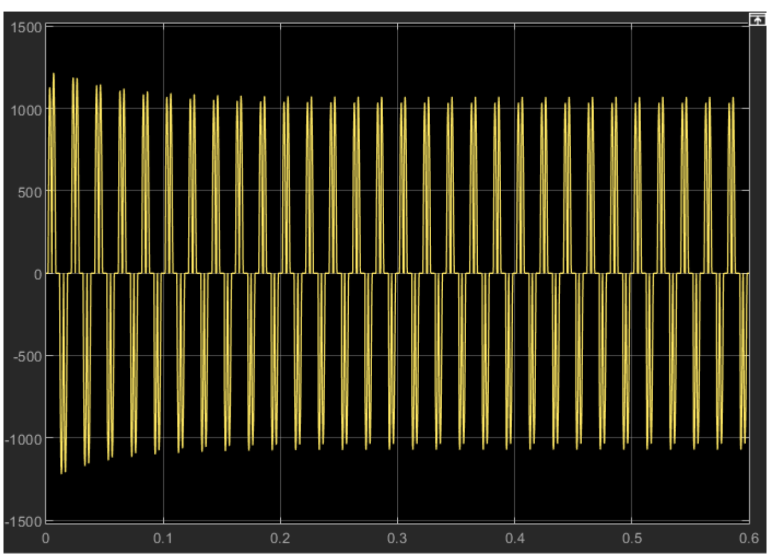


Figure 7. Input AC Current- only phase A

As can be seen on Fig. 8 there are periods when the current falls to zero before the next thyristor starts conducting. At the moment when one thyristor stops conducting (due to reaching the end of the conduction period for its corresponding phase voltage), and before the next thyristor starts conducting the current in that phase **falls to zero.** The input current follows a **pulsating pattern**, rising to a peak when the thyristors conduct and falling back to zero during the non-conducting periods. The input AC current is highly disorted and far from sinusoidal and consists of sharp pulses that correspond to the conduction periods of the thyristors.

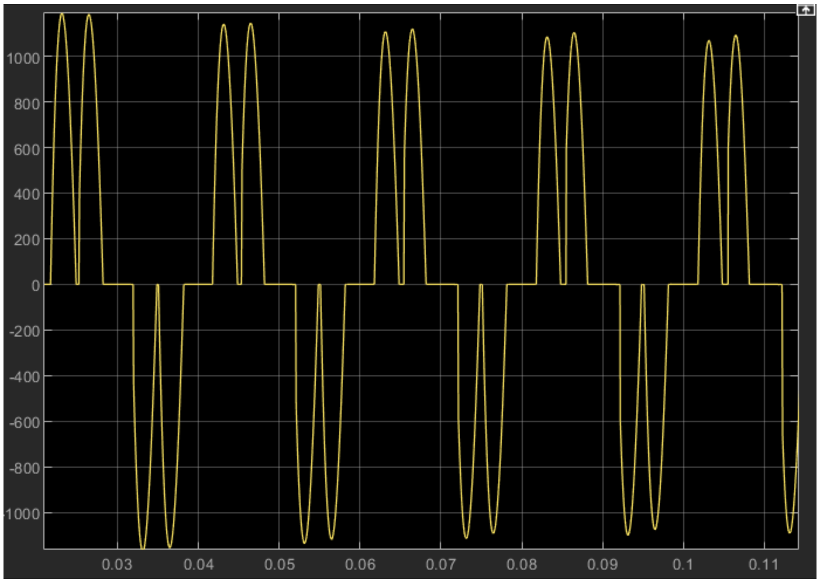


Figure 8. Input AC Current - Zoomed

Question 3: Calculate the AC power and DC power.

Answer:

Since the thyristors conducts for the full duration of their positive half-cycle (alpha = 0), the rectifier delivers **maximum DC power** to the load.

1) AC Apparent power S_{AC}:

   Apparent power is the product of the RMS voltage and the total RMS current drawn by the rectifier. The apparent power for a balanced three-phase system:

$$S = 3 \cdot U_{phase} \cdot I_{phase}$$

   In a star connection, the **line-to-line voltage** related to the **phase voltage** by:

$$U_{LL} = \sqrt{3} \cdot U_{phase}$$

   In a star connection, the **line current** is equal to the **phase current**:

$$I_{LL} = I_{phase}$$

   Finally:

$$S = \sqrt{3} \cdot U_{LL} \cdot I_{phase}$$

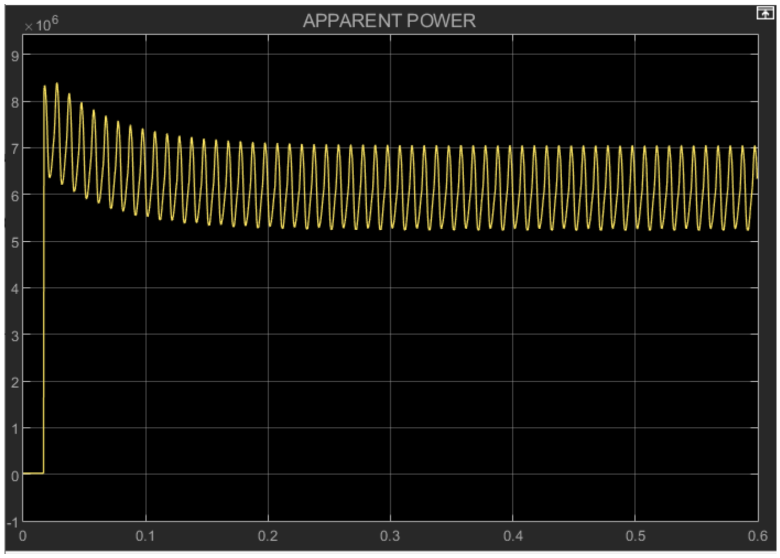


Figure 9. Apparent Power AC

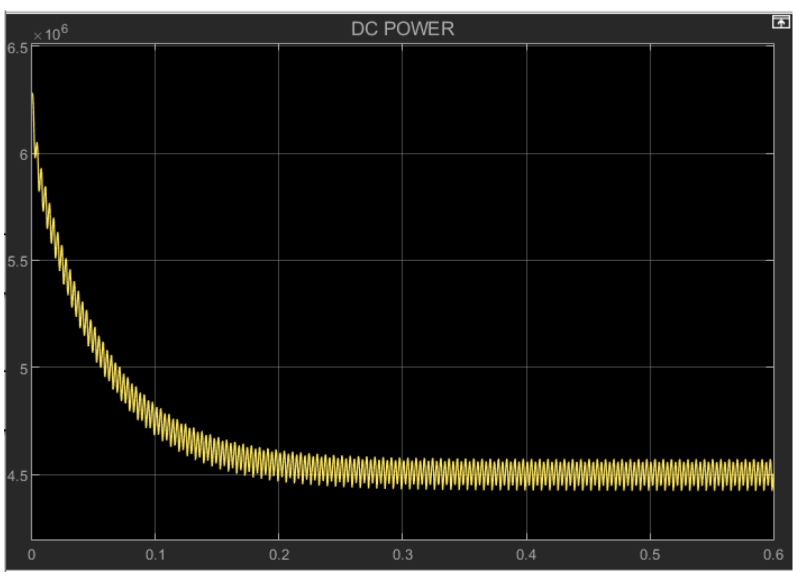
2) AC Real power Pac:

$$PF = \frac{I_{a1}^{rms}}{I_{a}^{rms}} \cos\alpha, \qquad I_{a1}^{rms} - the\ rms\ value\ of\ i_{a1} (fundamental\ component\ of\ i_a)$$

$$P = PF * S$$

This equation shows clearly that due to the nonsinusoidal waveform of the currents, the power factor of the rectifier is negatively affected by both the firing angle a and the distortion of the input current. In effect, an increase in the distortion of the current produces an increase in the value of I rms which deteriorates the power factor.

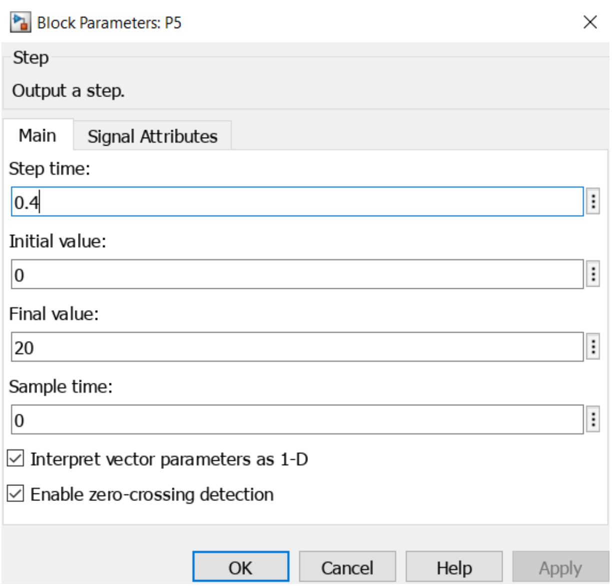
3) DC Apparent power Sdc:

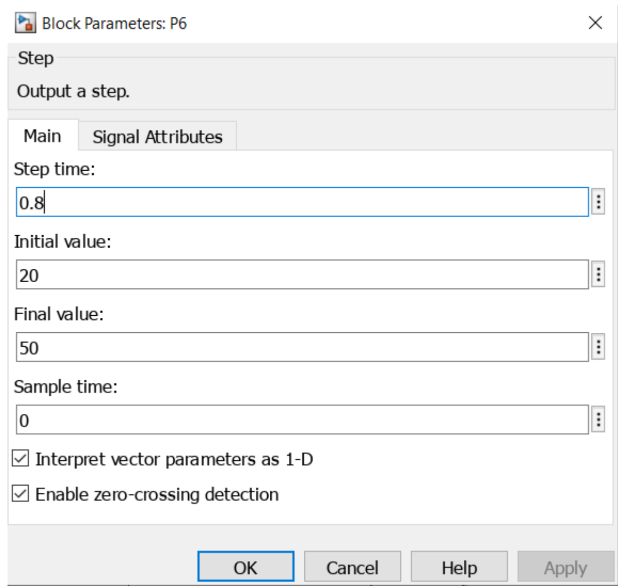


Question 3: Start the converter with (alpha = 0) and at t = 0,4s change it to (alpha = 20) and at t = 0.8 s change it to (alpha = 50). Explain what happens with the DC current in those cases.

Answer 3:

The **firing angle** determines when the thyristor will start conducting during each AC cycle. By changing alpha, we control the point in the AC waveform at which the thyristor is triggered. To do this we need to change parameters in gate triggering circuit (Step).





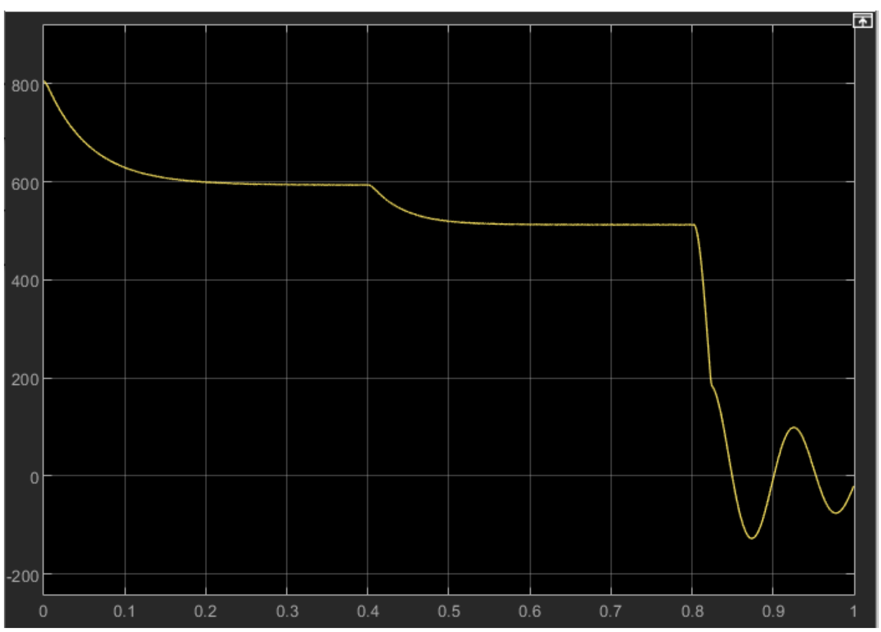


Figure 10. Load current

The firing angle (alpha) of the thyristors controls the amount of DC voltage delivered to the load, which affects the DC current.

1. Alpha = 0 from t = 0 to t = 0.04s

   At firing angle 0, the thyristors act like diodes, conducting as soon as the grid phase voltage becomes positive relative to the cathode. This will result in the maximum average DC voltage across the load. The DC current will be close to the maximum possible value because there is minimal delay in the thyristors' conduction, leading to a high rectified output voltage.
2. Alpha = 20 from t = 0.04 s to t = 0.08 s

   Increasing the alpha to 20 introduces a delay in the conduction of the thyristors. As a result, the output DC voltage decreases because the thyristors are now conducting for a shorter portion of the AC cycle. The DC current will still be relatively high but lower than when alpha = 0, as the energy transferred to the load per cycle is reduced.

3. Alpha = 50 from t = 0.08 s to t = inf

   The maximum output voltage from a 3-phase controlled rectifier can be calculated using the formula (for alpha = 50) :

$$V_o = \frac{3 \cdot \sqrt{2} \cdot \ V_{L-L}}{\pi} \cdot \cos \alpha = \frac{3 \cdot \sqrt{2} \cdot 6000}{\pi} \cos \frac{5 \cdot \pi}{18} = 5208{,}4$$

The output voltage is lower than DC voltage we have in series with R and L. That explains the disturbance.