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# EE 463 Term Project Fall 2018

## Controlled Rectifiers

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# 1. Introduction

A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one direction. Controlled rectifiers are used to control output DC voltage. In this project, we have analyzed three phase both fully and half controlled rectifiers. Secondly, we have analyzed DC motor drive. Finally, we have analyzed different rectifier topologies. We have simulated the circuits in Simulink. We have commented about them by using theoretical background from EE463.

# 2. Test Results

## 1st Question

**a. Half controlled rectifier**

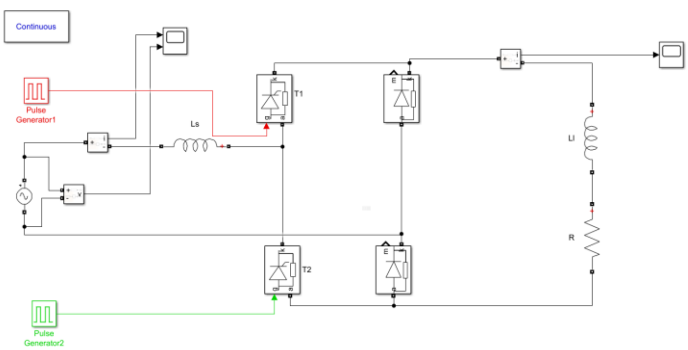
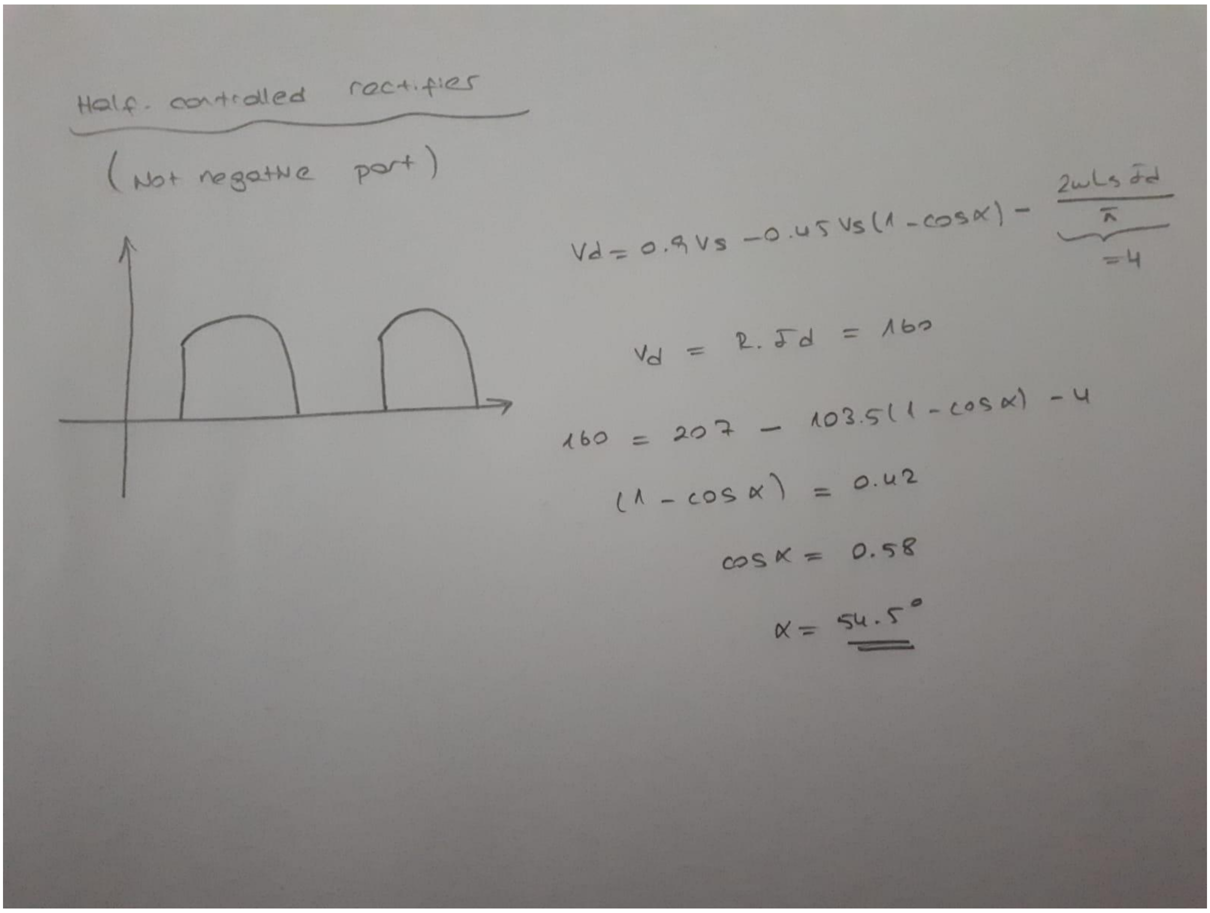



Figure 1: The circuit schematic of single phase half controlled rectifier



Half-controlled rectifier

(Not negative part)

$$V_d = 0.9 V_s - 0.45 V_s (1-\cos\alpha) - \underbrace{\frac{2\omega L_s I_d}{\pi}}_{=4}$$

$$V_d = R \cdot I_d = 160$$

$$160 = 207 - 103.5(1-\cos\alpha) - 4$$

$$(1-\cos\alpha) = 0.42$$

$$\cos\alpha = 0.58$$

$$\alpha = \underline{\underline{54.5^\circ}}$$

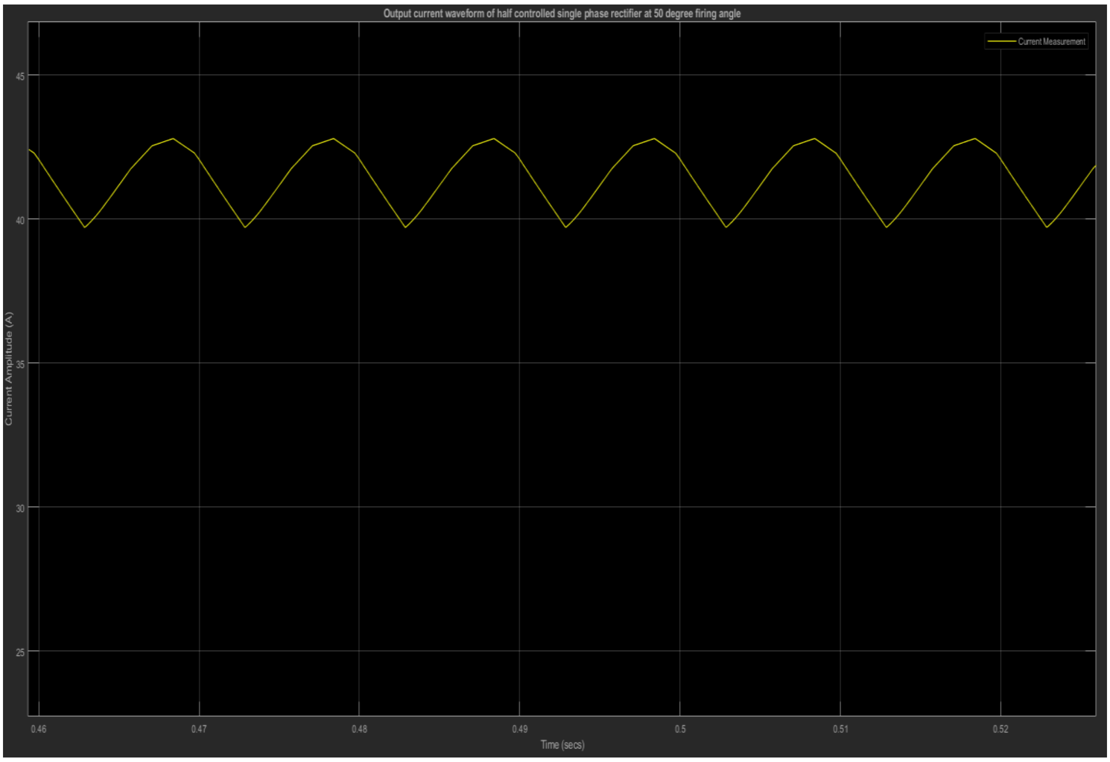
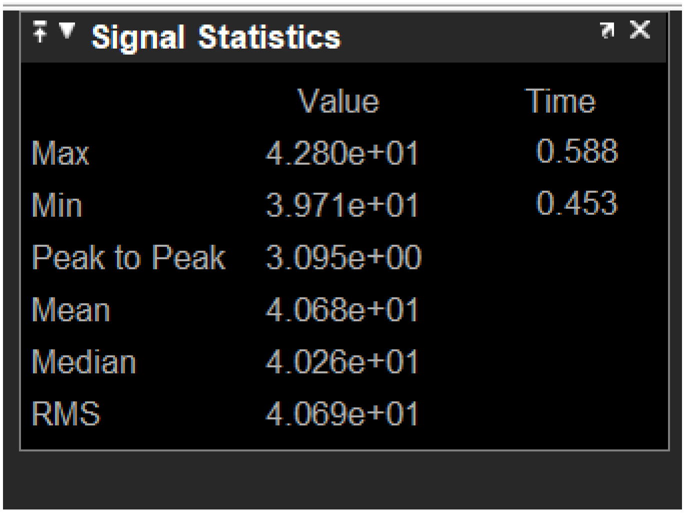



Figure 2: The output current waveform of half controlled rectifier at 54.5$^0$ firing angle



Signal Statistics

| | Value | Time |
|---|---|---|
| Max | 4.280e+01 | 0.588 |
| Min | 3.971e+01 | 0.453 |
| Peak to Peak | 3.095e+00 | |
| Mean | 4.068e+01 | |
| Median | 4.026e+01 | |
| RMS | 4.069e+01 | |

Figure 3: Data Statistics for output current waveform at 54.5$^0$ firing angle

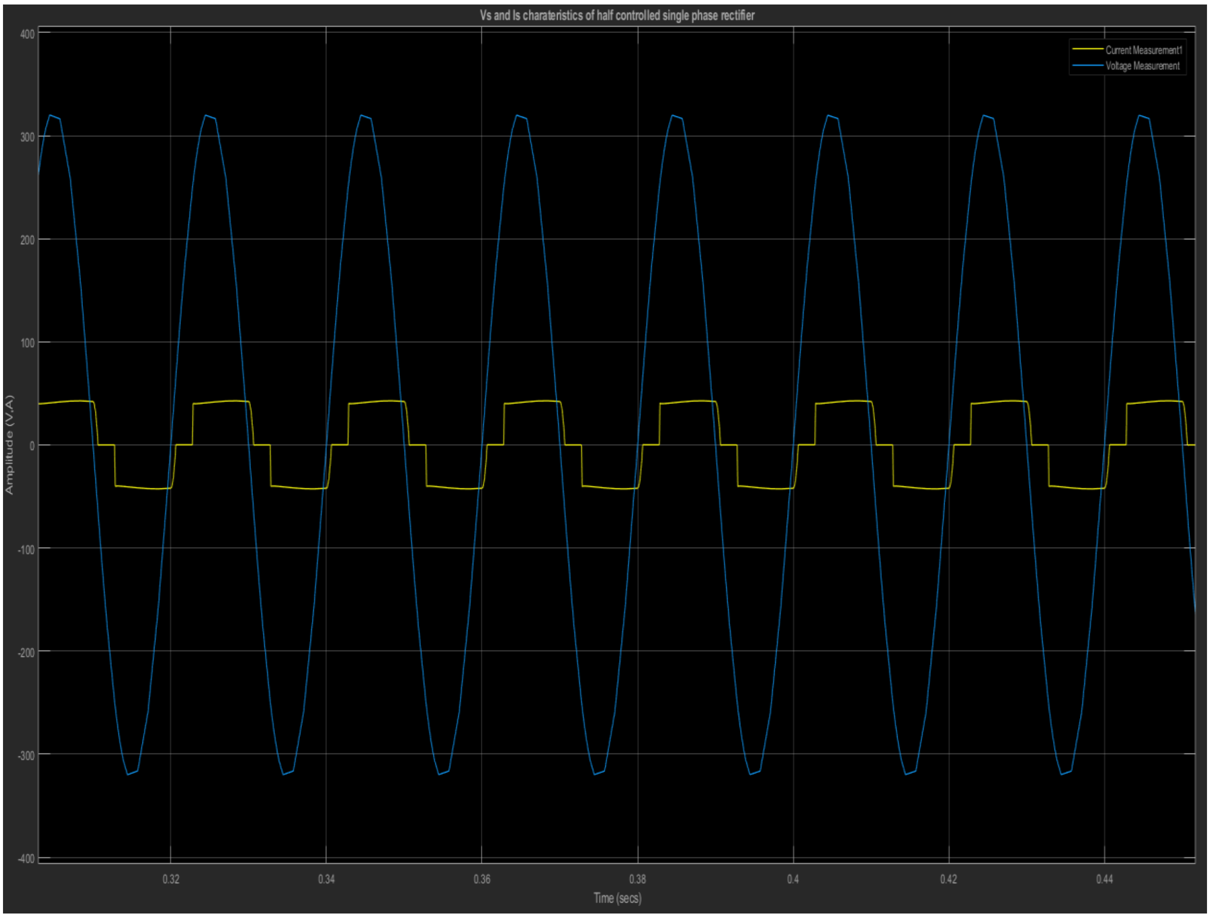



Figure 4: Vs and Is characteristics of half controlled rectifier

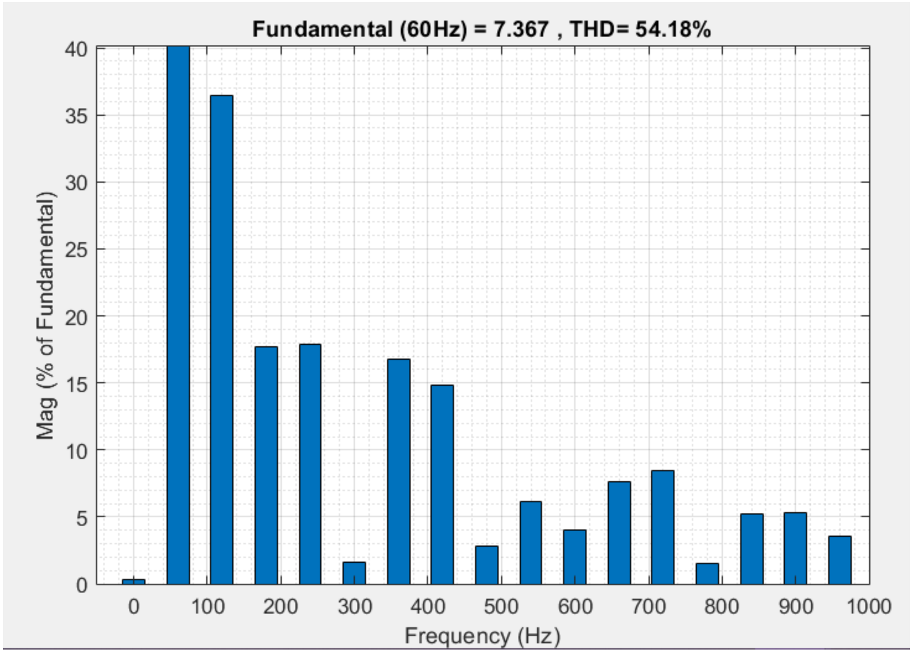



Figure 5: THD value for Is

## b. Fully controlled rectifier

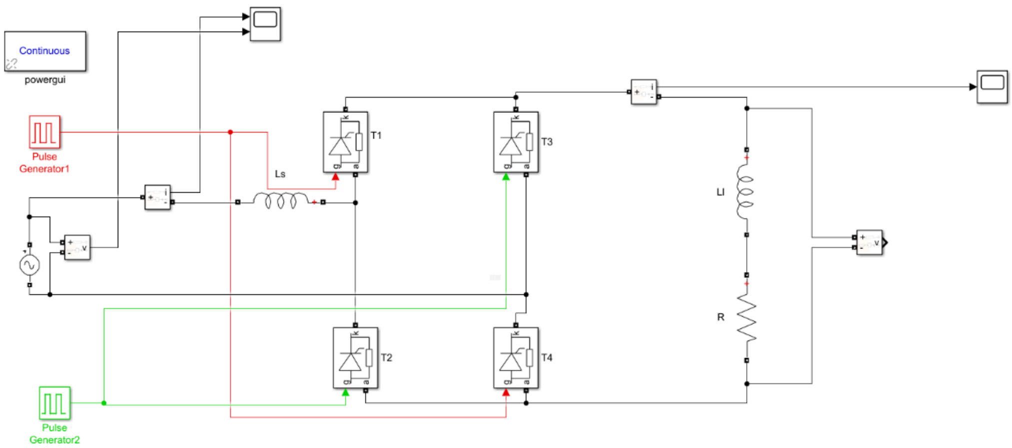
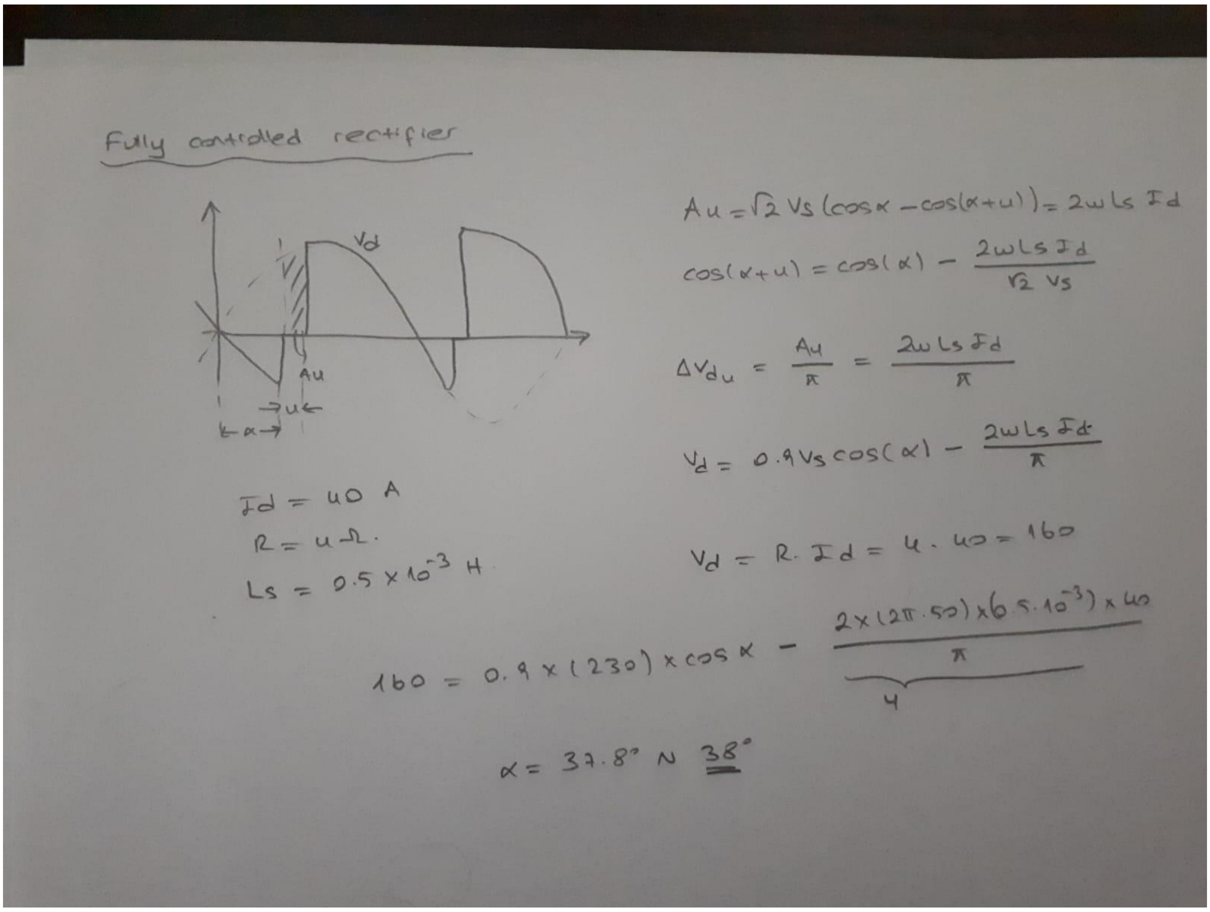



Figure 6: The circuit schematic of fully controlled rectifier



Fully controlled rectifier



$$A_u = \sqrt{2}\,V_s\left(\cos\alpha - \cos(\alpha+u)\right) = 2\omega L_s I_d$$

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

$$\Delta V_{d_u} = \frac{A_u}{\pi} = \frac{2\omega L_s I_d}{\pi}$$

$$V_d = 0.9 V_s \cos(\alpha) - \frac{2\omega L_s I_d}{\pi}$$

$I_d = 40$ A

$R = 4\,\Omega$.

$L_s = 0.5\times10^{-3}$ H

$$V_d = R \cdot I_d = 4 \cdot 40 = 160$$

$$160 = 0.9\times(230)\times\cos\alpha - \underbrace{\frac{2\times(2\pi\cdot 50)\times(6.5\cdot10^{-3})\times 40}{\pi}}_{4}$$

$$\alpha = 37.8^\circ \sim \underline{38^\circ}$$

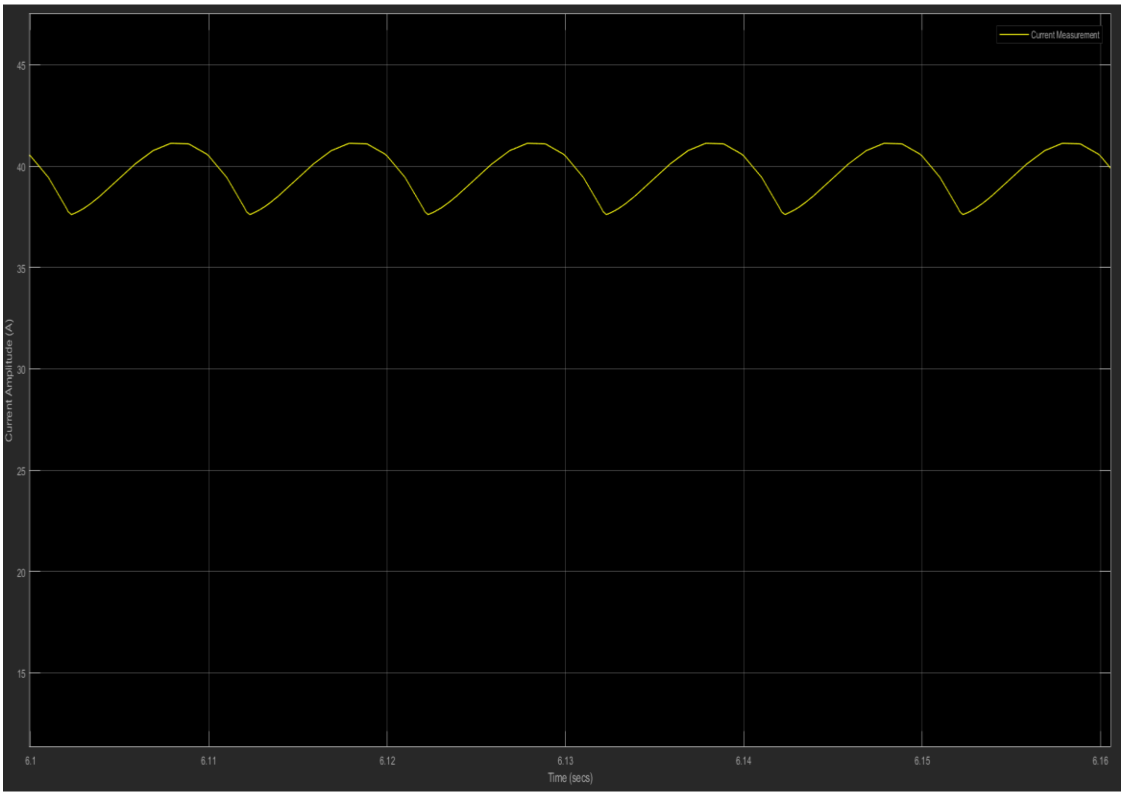
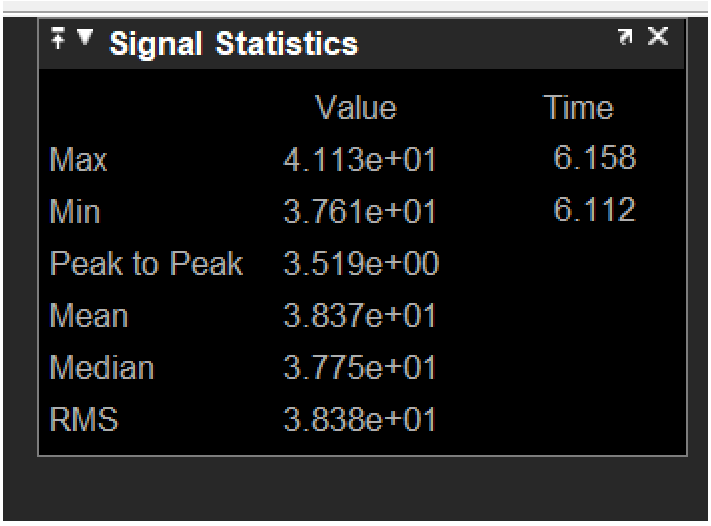



Figure 7: The output current waveform of fully controlled rectifier at $38^0$ firing angle



**Signal Statistics**

| | Value | Time |
|---|---|---|
| Max | 4.113e+01 | 6.158 |
| Min | 3.761e+01 | 6.112 |
| Peak to Peak | 3.519e+00 | |
| Mean | 3.837e+01 | |
| Median | 3.775e+01 | |
| RMS | 3.838e+01 | |

Figure 8: Data statistics of output current waveform at $38^0$ firing angle

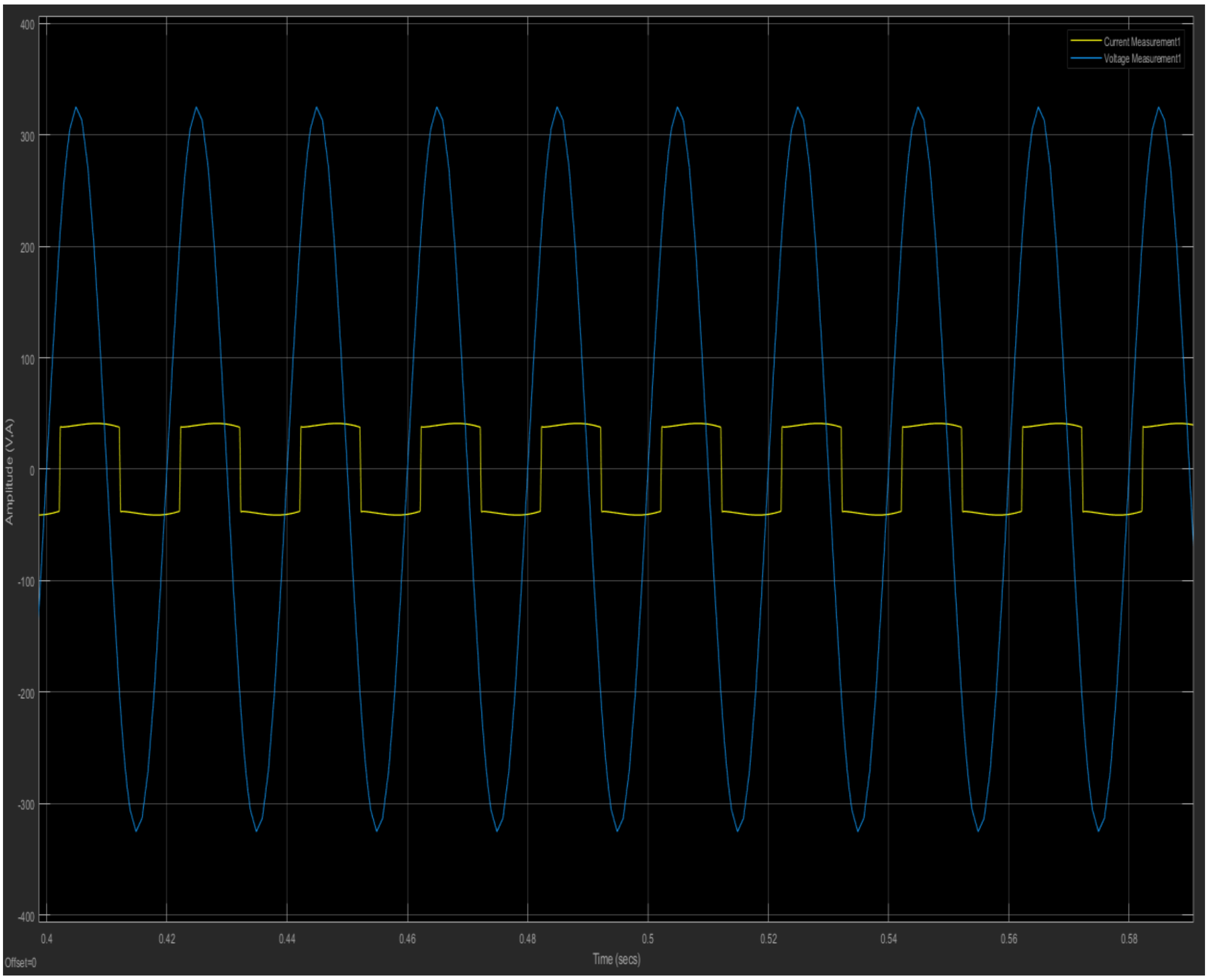



Figure 9: Vs -Is characteristics of fully controlled rectifier

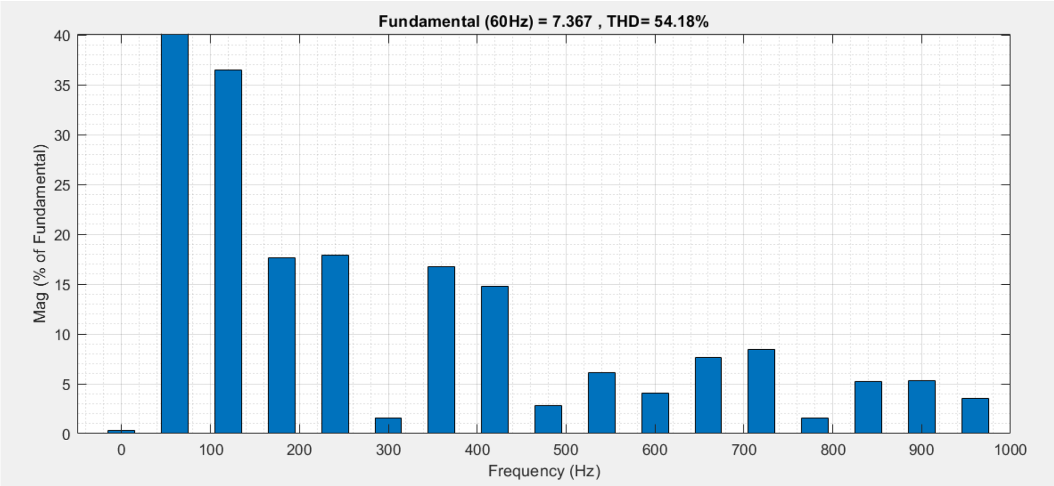



Figure 10: THD value of Is

**c.** Half controlled rectifiers operates only for positive voltages for example, rectifiers for electromagnets and they have less cost. Fully controlled rectifiers can operate both negative and positive voltages for example, DC motor drives. Moreover, fully controlled rectifiers are able to operate in inverter mode by connecting an active element to DC side.

# 2nd Question

## a)

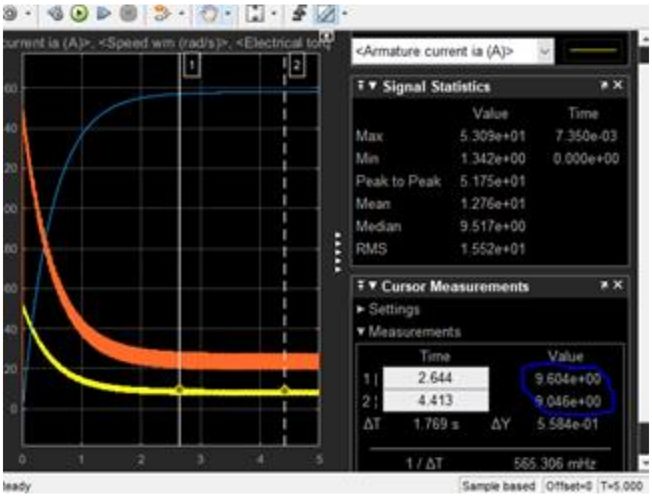



Figure 11: Armature Current of the Motor

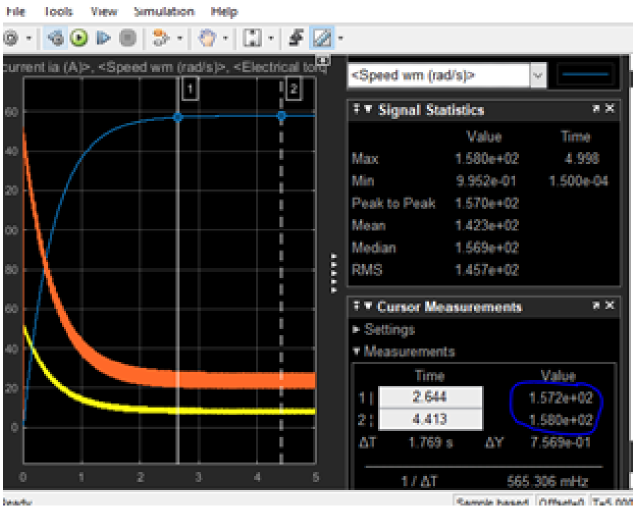



Figure 12: Speed of the Motor

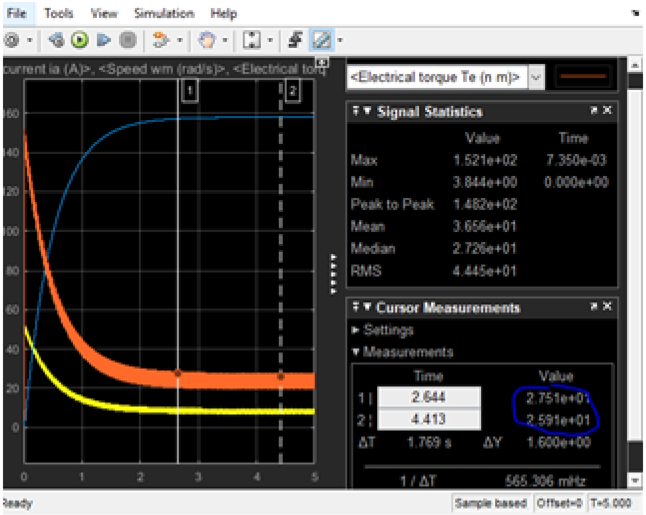



Figure 13: Torque of the Motor

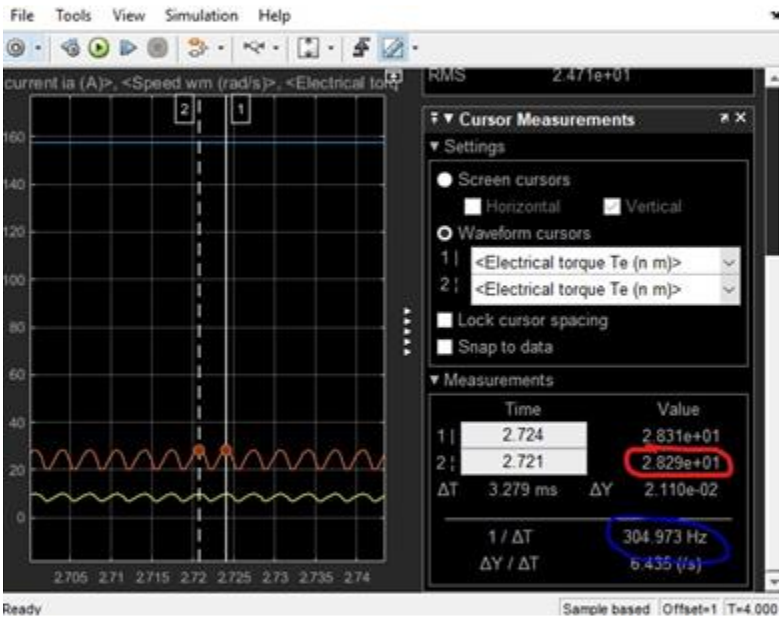



Figure 14: Torque Ripple Characteristic

# b)

- Torque ripple frequency is 300 Hz as seen in figure 14 because we have used six pulse rectifier i.e 6x50=300 Hz.
- Torque ripple magnitude is 8 N.m as seen in figure 14. Also as given in figure 13, the mean torque is 28 N.m. That is, torque ripple is 28.5% which is two high because torque ripple prevents a smooth motor rotation.
- THD of the line current is 0.387 as seen in figure 15.

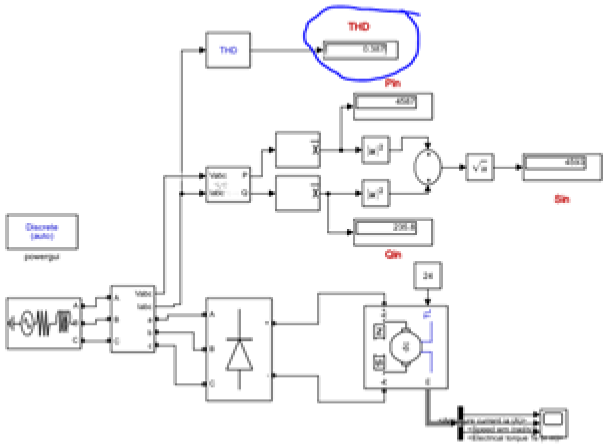



Figure 15: THD of the Line Current

**c)** We need to make the torque ripple magnitude at most 2.8 N.m for 10% average torque.

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- As a first method, we can connect a parallel 1mF capacitor two the motor as given figure 16. As seen in figure 17, torque ripple magnitude is decreased to 2.2/24=%9.2. However, it also decreased the average torque to 24 N.m which is a disadvantage. Also, a 1mF power capacitor is expensive.

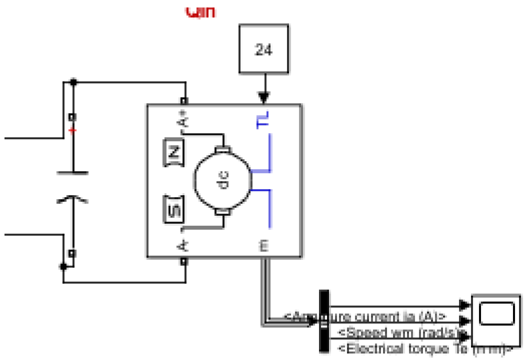
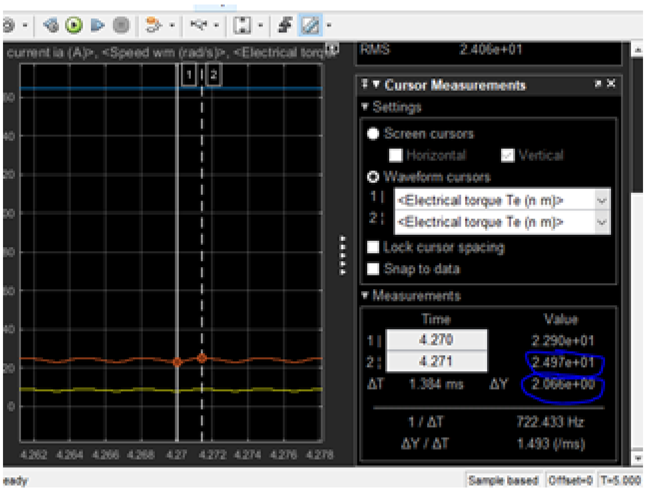



Figure 16: Parallel Capacitor Connection to the Motor

Figure 17: Torque Ripple Characteristics with Parallel Capacitor Connection to the Motor




- As a second method, we have used a higher armature inductance which is 0.1 H. As seen in figure 18, torque ripple magnitude is decreased to 1/24=%9.2. However, it also decreased the average torque to 24 N.m which is a disadvantage. Also, changing the armature inductance would be a though process.

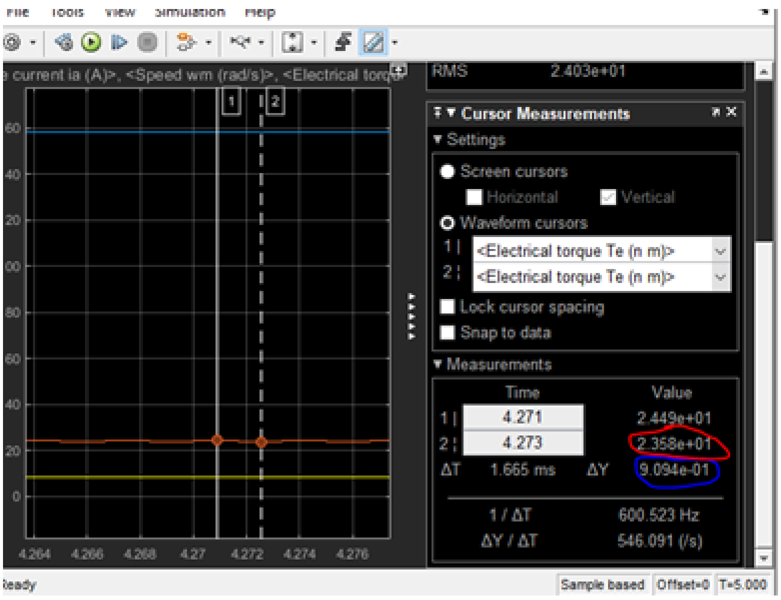



Figure 18: Torque Ripple Characteristics with 0.1 H armature inductance

**d)** Input power is 4529 W as seen in figure 19, and output power is 3792 W as seen in figure 20. Thus, overall drive efficiency is 83.7%. There are three different loss sources in this circuit. The first loss source is the source resistance. The second loss source is the diodes' on resistance. The third loss source is the motor armature resistance.

Figure 19: Input Power


Figure 20: Output Power


Table1: Power Loss

| | P (W) | Loss (W) | Loss(%) |
|---|---|---|---|
| **Input Power** | **4529** | **0** | **0** |
| **Bridge Output Power** | **4500** | **29** | **0.64** |
| **Motor Output Power** | **3792** | **708** | **15.6** |

# 3rd Question

**a)** The configuration is twelve pulse rectifier. The six pulse rectifiers can be able to eliminate 3th 9th 15th harmonics. Twelve pulse rectifiers consist of two six pulse rectifiers with delta wye connection. The reason for delta wye connection is to obtain $30^0$ shift between two six pulse rectifiers. Those rectifiers can reduce the voltage ripple on DC side, and can eliminate the harmonics except

(12k+1) and (12k-1) on AC side. Because of eliminating current harmonics, these rectifiers are used in HVDC systems.

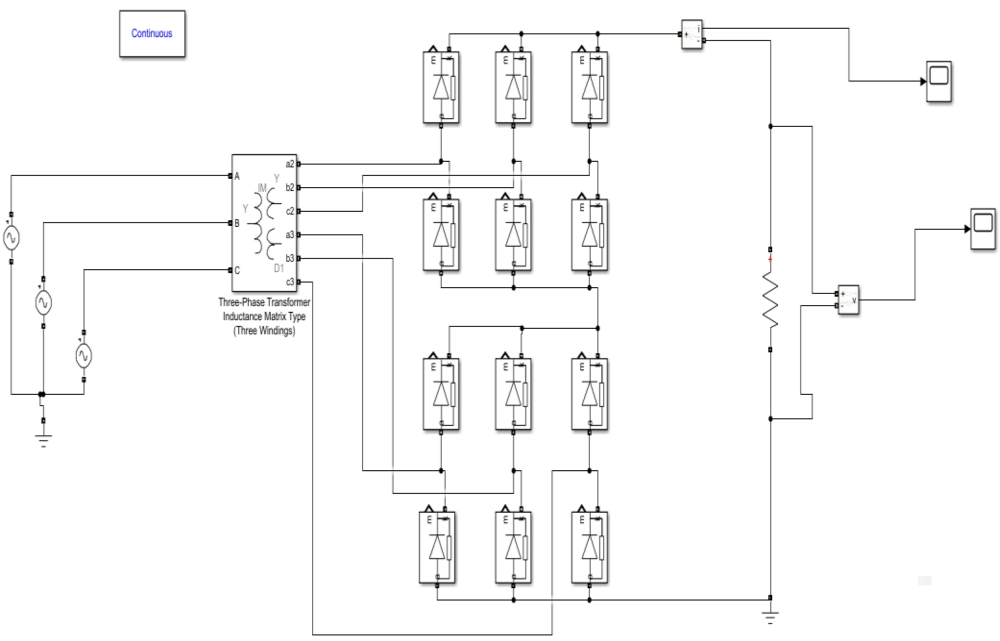



Figure 21: The circuit schematic of 12 pulse rectifier

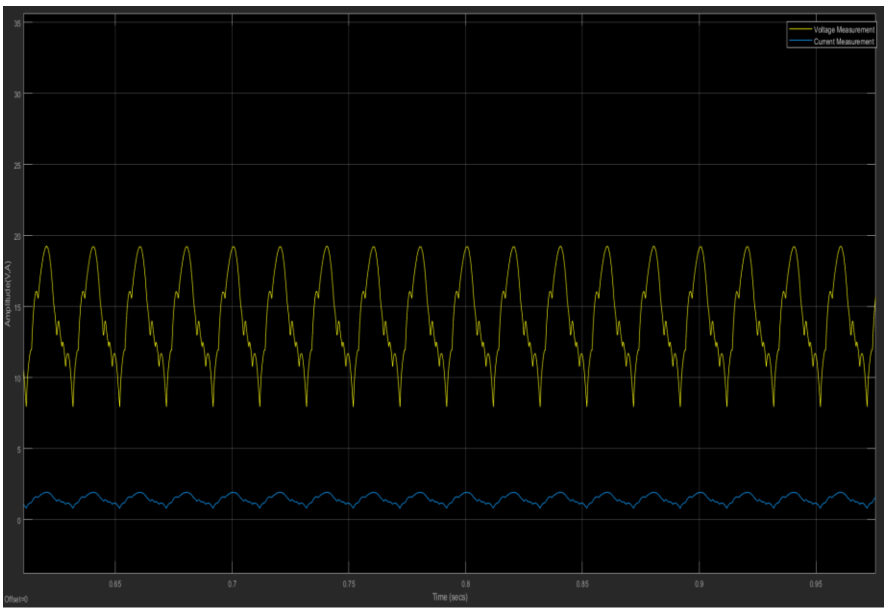



Figure 22: Load voltage and current waveform of 12 pulse rectifier

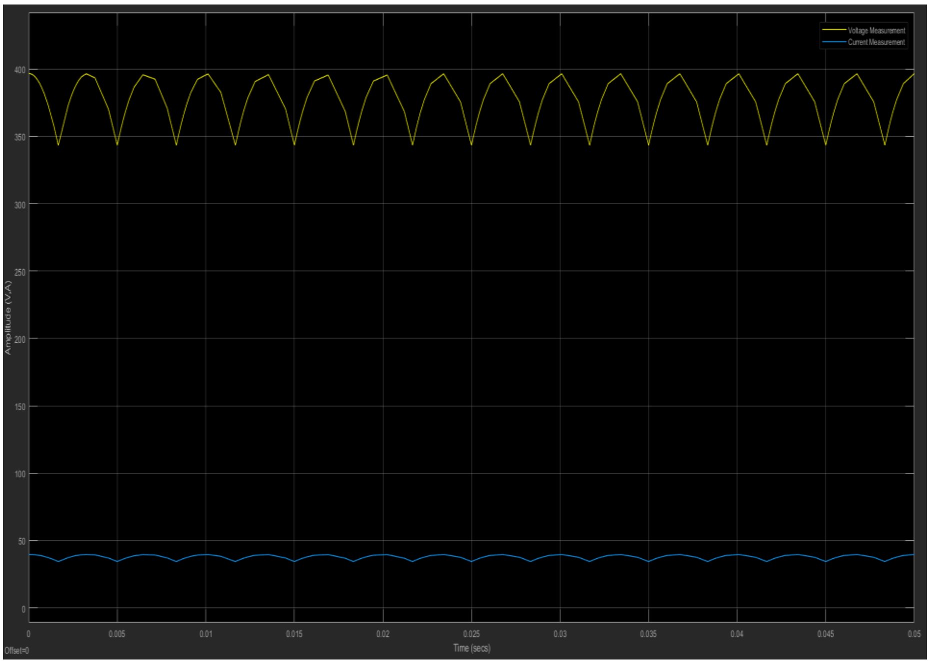



Figure 23: The load voltage and current characteristic of full bridge rectifier

The ripple output voltage must be reduced by using 12 pulse rectifier and output waveform must be more stable. Moreover, THD of current must be reduced due to elimination of harmonics.

# 3. Conclusion

In this project, we have analyzed three phase both fully and half controlled rectifiers in Simulink environment. Secondly, we have analyzed DC motor drive. We have become familiar with DC motor driving which is an essential part of power electronics area. Finally, we have analyzed 12 pulse rectifier and other types of rectifier topologies. It was a compact project which includes different power electronics area disciplines.