MIDDLE EAST TECHNICAL UNIVERSITY
Department of Electrical and Electronics Engineering

5670463 – STATIC POWER CONVERSION I
Software Project II
Fall2018

Participants:

Nevzat S. Şenyayla – 2263796
Sonay Ulukaya – 2094597

Table of Contents

INTRODUCTION

In this project, we will deal with different types of rectifiers. The topic of this project is Controlled Rectifiers. Controlled rectifiers are the AC to DC converters which are used to convert a fixed voltage AC voltage into variable DC voltage. In the following pages, firstly, single phase fully controlled, and half controlled rectifiers will be analyzed and compared. Then, we will study on three phase full bridge diode rectifier which are used in DC Motor Drive. Finally, we will look at the alternative rectifier topologies. For this project, 12-pulse rectifier is given to us and we will compare it with full bridge diode rectifier. For simulation results, we will use MATLAB Simulink.

QUESTION 1

QUESTION 1.a

In this question it is asked to find the firing angle of both the given topologies to take an average current of 40A. If the necessary calculations are made, in order to find the firing angles of both topologies,

$$|Z_{load}| = \sqrt{4^2 + 0.2^2} = 4{,}00499\ \Omega$$

$$V_{avg.} = I_{avg.} \times |Z_{load}| = 40 \times 4.00499 = 160{,}19987\ V$$

The equation used for the Fully-Controlled Rectifier is:

$$V_{avg.} = \frac{2\sqrt{2}}{\pi}.V_d.\cos\alpha - \frac{2\omega L_s I_d}{\pi}$$

If the Id is taken into consideration as 40A which is the desired average current,

$$160{,}19987 = \frac{2\sqrt{2}}{\pi}.230.\cos\alpha - \frac{2.2\pi.50.0.5.10^{-3}.40}{\pi}$$

$$\cos\alpha = 0{,}79295$$

$$\alpha = \cos^{-1}(0{,}79295) = 37.53\,°$$

The equation used for the Half-Controlled Rectifier is:

$$V_{avg.} = \frac{\sqrt{2}}{\pi}.V_d\,(1 + \cos\alpha) - \frac{2\omega L_s I_d}{\pi}$$

If the Id is taken into consideration as 40A which is the desired average current,

$$160.19987 = \frac{\sqrt{2}}{\pi}.230(1 + \cos\alpha) - \frac{2.2\pi.50.0.5.10^{-3}.40}{\pi}$$

$$\cos\alpha = 0{,}58591$$

$$\alpha = \cos^{-1}(0{,}58591) = 54.13\,°$$

The designed Simulink schematics of both the Full-Controlled and the Half-controlled rectifiers are given below in the figures.

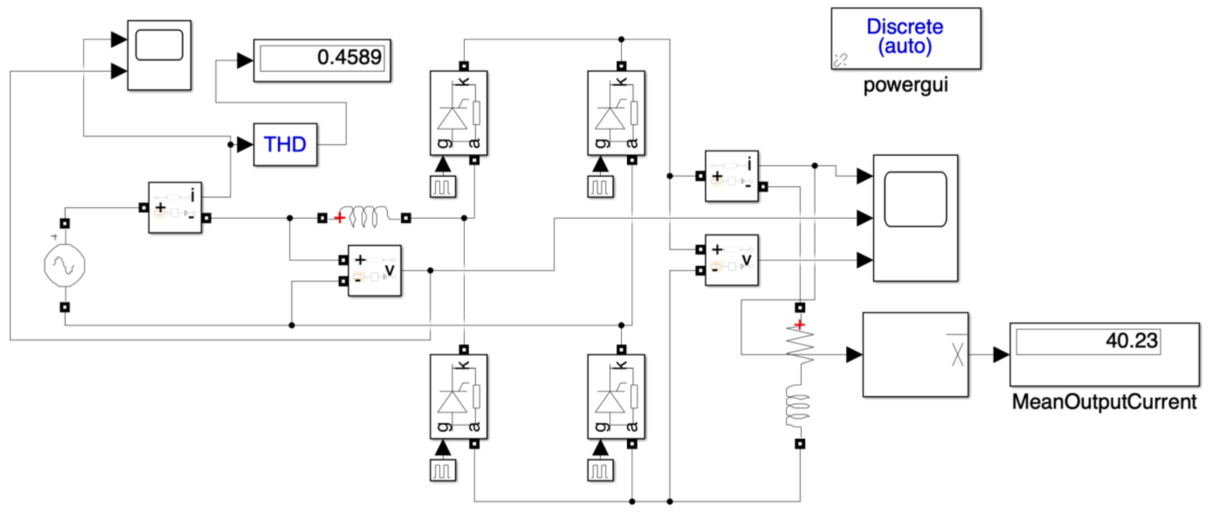

Figure 1: The Schematic of the Full-Controlled Rectifier

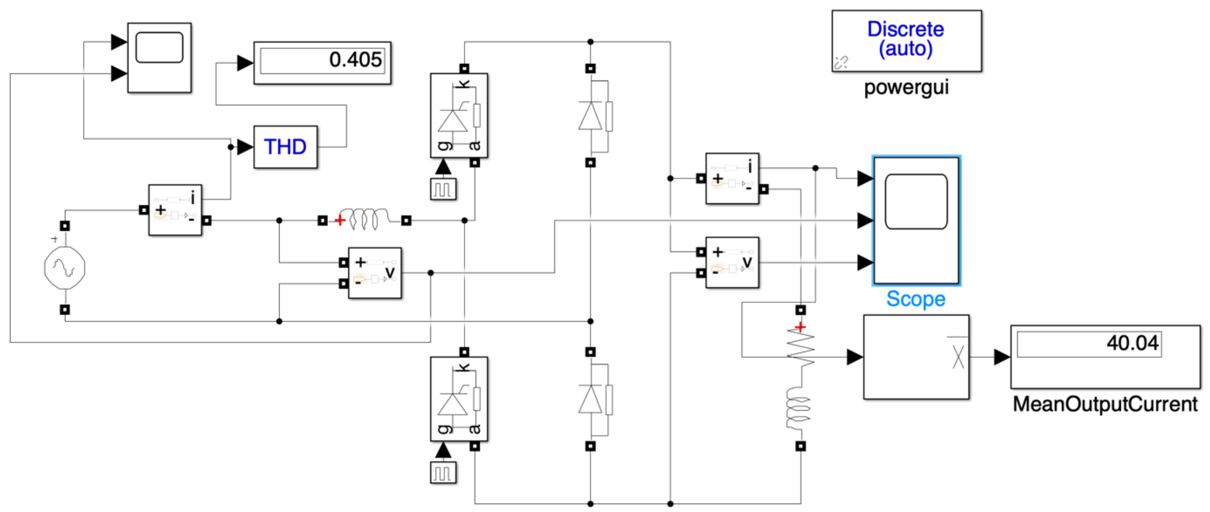

Figure 2: The Schematic of the Half-Controlled Rectifier

The graph of the input voltage (blue lines), rectified voltage (orange lines) and the output current (yellow lines) are represented in the simulations. The average output current is measured and represented in the figures 1 and 2 for the Full-Controlled and Half-Controlled Rectifiers respectively.

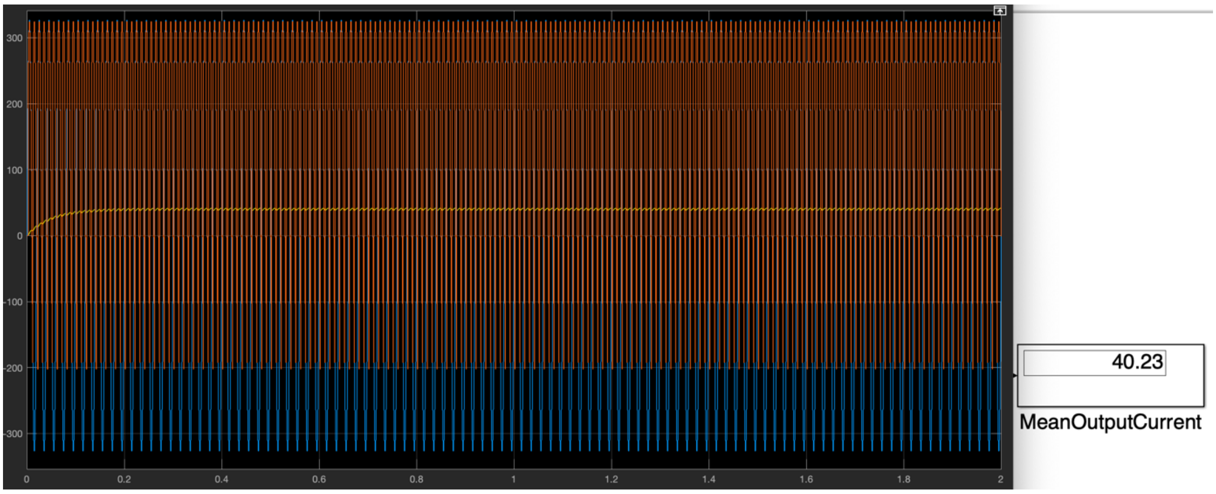

Figure 3: The Average Output Current After the Simulations of Full-Controlled Rectifier

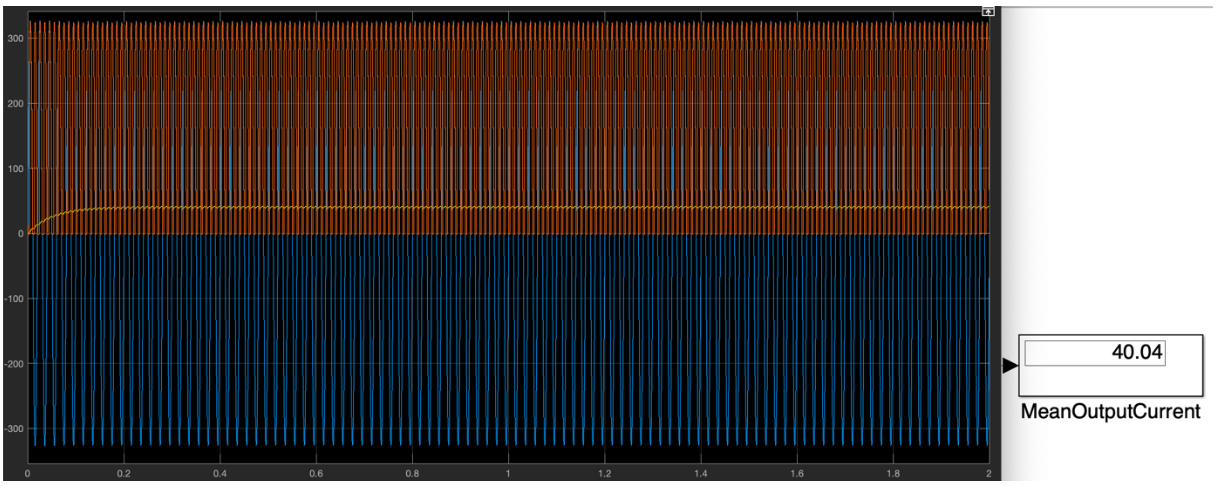

Figure 4: The Average Output Current After the Simulations of Half-Controlled Rectifier

As one can clearly understand when the analytical calculations and the simulation results are compared, the mathematical calculations are verified in the simulations.

QUESTION 1.b

In this part of the question, it is asked to simulate the schematics of the controlled rectifiers and plot the V_s and I_s waveforms on the same graph and find the THD of both the topologies. The desired result graphs are represented in the figures as follows:

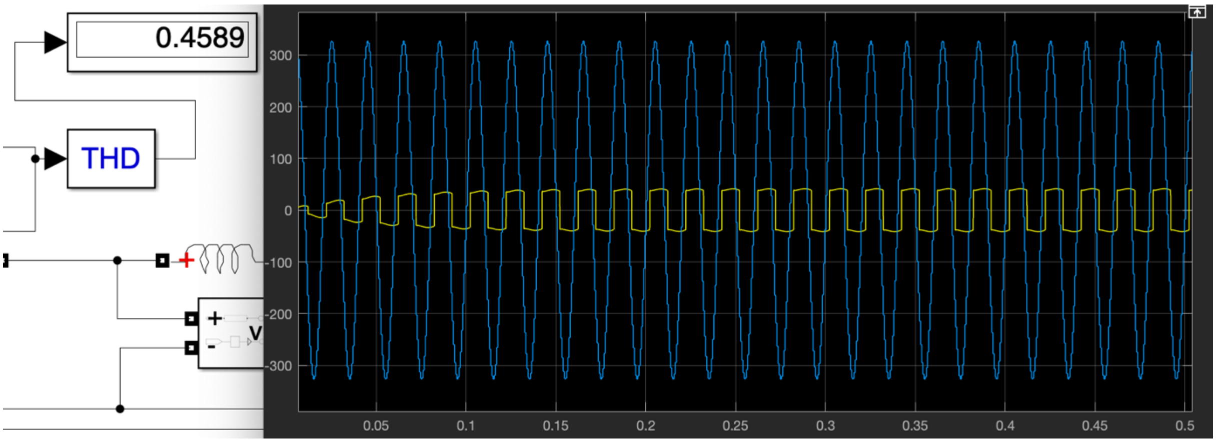

Figure 5: The V_s, I_s and THD *Waveforms After the Simulations of Full-Controlled Rectifier*

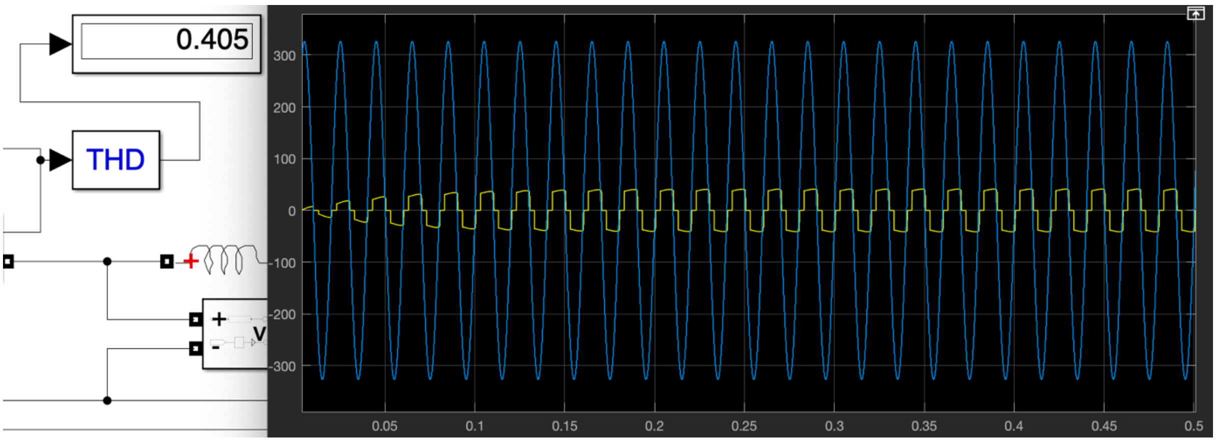

Figure 6: The V_s, I_s and THD *Waveforms After the Simulations of Half-Controlled Rectifier*

QUESTION 1.c

The Full-Controlled Rectifiers are able to enable the designer to operate in the inverter mode of operation if an active element is connected to its DC side. However, the Half-Controlled Rectifiers are not able to do this because of the diodes connected instead of the thyristors in the rectifier topology. As it was learnt in the theoretical classes, the Half-Controlled Rectifiers act like there is a free-wheeling diode connected in parallel with the rectifier circuitry.

Besides, in the Half-Controlled Rectifier, the output voltage cannot be negative because of the diodes located instead of the thyristors. However, in the Full-Controlled Rectifier, the output voltage can obtain negative values. The Half-Controlled Rectifier topology can only be used when a positive DC voltage operation is going to be conducted. If it is considered from a different point of view, the negative voltage obtain ability in the Fully-Controlled Rectifier could be a disadvantage because some elements are sensitive for the applied negative voltage.

As one can understand from the simulation results' graphs, the starting point of both the topologies are the same because of the phase difference between the first and the second party that are been in conduction during the operation. In the positive applied voltage, the α applied thyristor is in conduction and in the negative applied voltage the (α+180) is in conduction. Because of this, the voltage waveforms are beginning the same in the simulations.

QUESTION 2

QUESTION 2.a

In this question it was asked to drive a DC motor with armature resistance and inductance and analyze its results. The schematic of the relative circuit is designed in Simulink. The sample time is taken as 50.10^{-7} in Simulink. The steady state operation begins from the middle of the second 4, however the time interval is taken as 10 seconds to analyze deeply. Designed circuit is given in Figure 7 below:

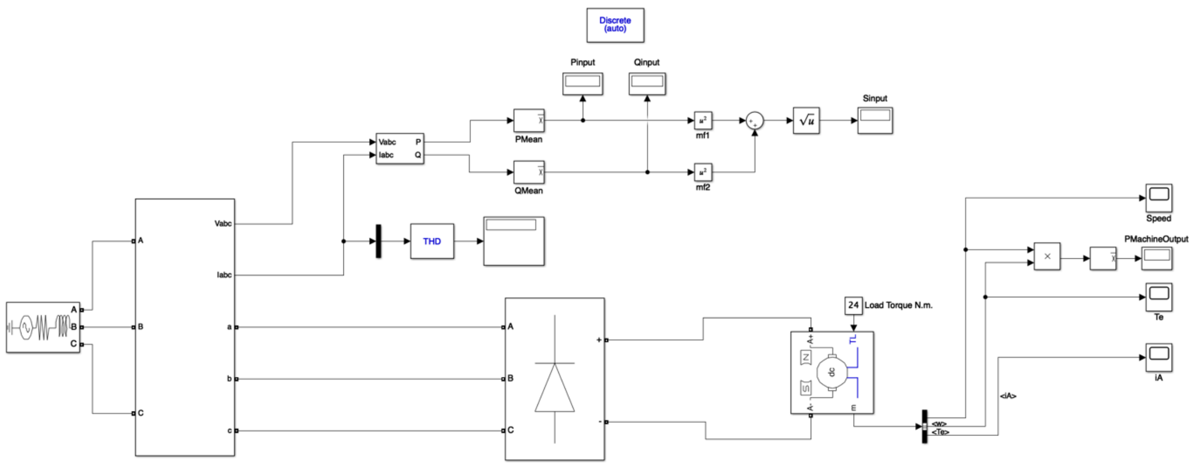

Figure 7: The Designed Schematic of the Motor Drive Circuit

All the values from the circuit can be obtained such as the THD of the line current, the input power by means of P, Q and S, the Electrical Torque (T_e), the Armature Current (I_a) and Speed. The obtained graphs are given as follows:

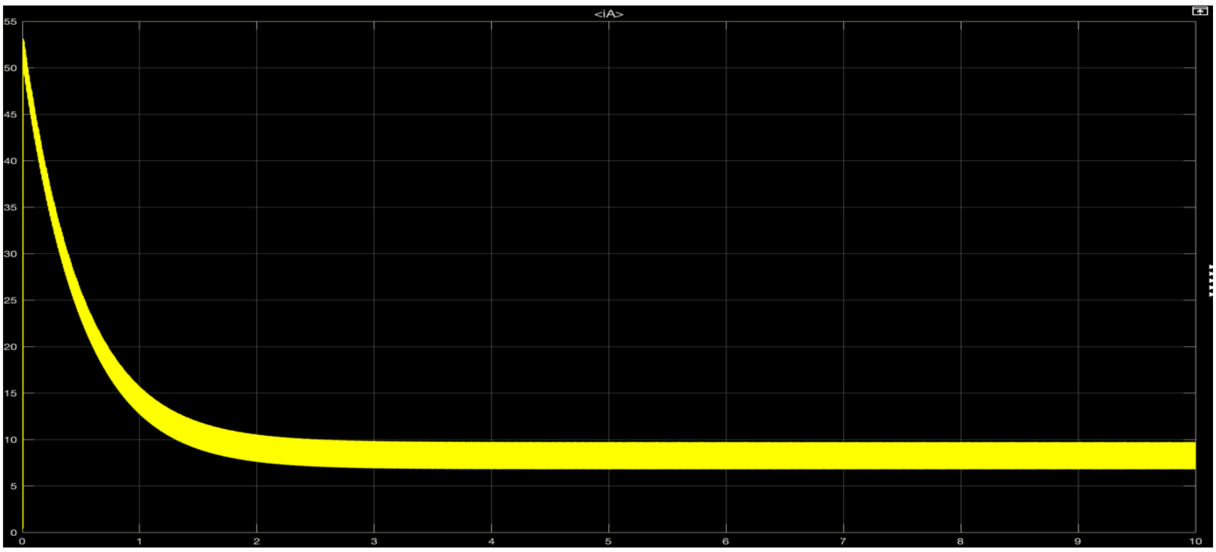

Figure 8: The Armature Current Graph of the Motor Drive Circuit

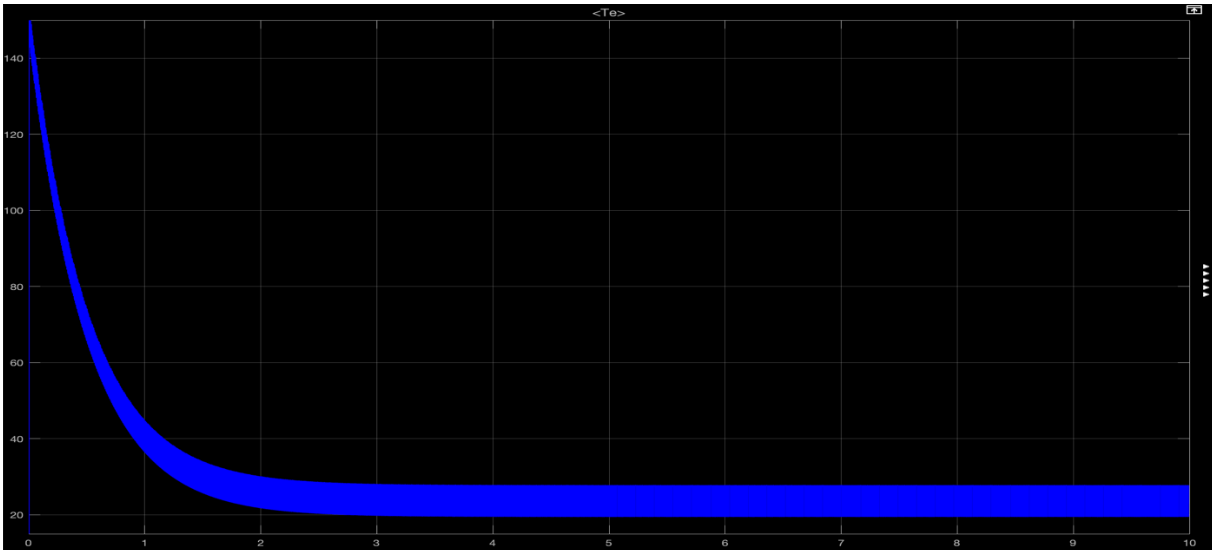

Figure 9: The Electrical Torque Graph of the Motor Drive Circuit

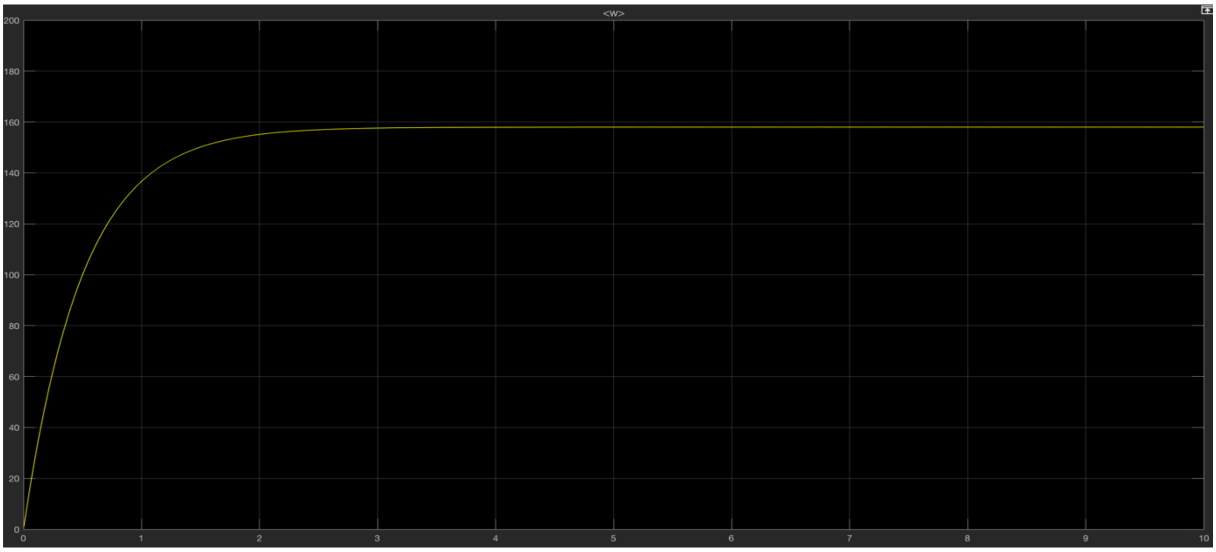

Figure 10: The Speed Graph of the Motor Drive Circuit

QUESTION 2.b

In the steady state operation, the electrical torque is measured from the Signal Statistics tool and has an average value of 24Nm, a Peak-to-Peak value is 8.313Nm and has a period of 3.333ms and a frequency of 300Hz. As one can clearly understand, the ripple is quite enough to disturb the practical applications.

Frequency is resulted as it was expected because since there are 6 switching components, the nominal frequency from the grid should be 6 times bigger than that. The line current THD is given in the figure below and indicated with an arrow:

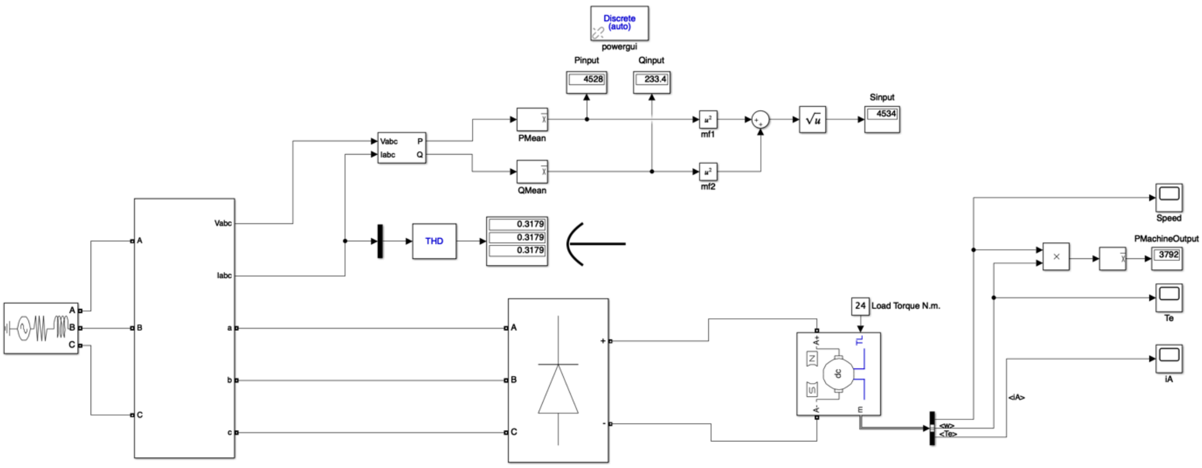

Figure 11: The Line Current THD of the Motor Drive Circuit

QUESTION 2.c

In this part two methods are proposed in order to keep the ripple below 10% of the average torque. The average torque is measured as 24Nm as it was stated above. The 10% value of it is 2.4Nm. The rippled torque is not desired in the practical applications due to the operation disturbance that can be occurred. Since the series inductance acts like a current source, it can tolerate the ripple factor of the current coming from the output stage of the bridge. Like the inductance, the shunt capacitance acts like a voltage source in order to tolerate the rippled current coming from the bridge. The overall efficiency of the operation can be controlled by those methods and power factor of the system. These are the advantages of these proposed methods.

In order to keep the ripple below 2.4Nm, as a first method a series armature inductance is added to the DC motor i.e. the value of armature inductance parameter is increased and as the second method a shunt capacitor is used for the DC motor component. With the series armature inductance whose value is 0.1H and the shunt capacitor with 0.1F the ripple values are 0.942Nm and 0.0195Nm respectively. The relative schematics and the graphs of the results are given in the figures:

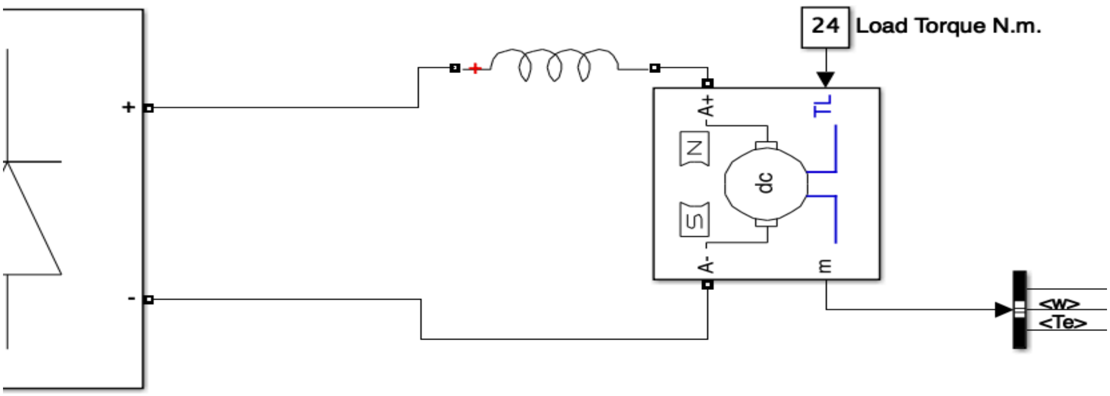

Figure 12: The Schematic of the Motor Drive Circuit with 0.1H Armature Inductance

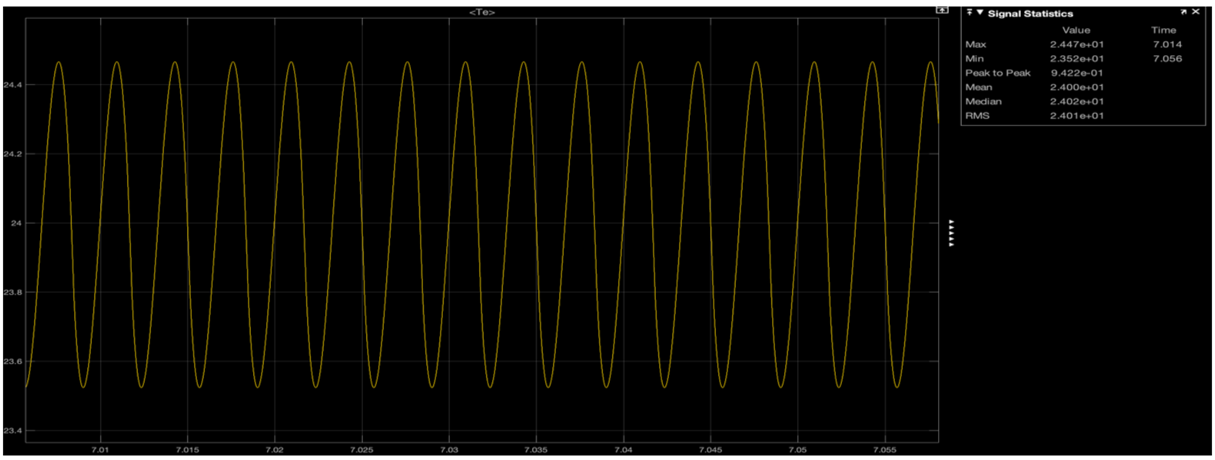

Figure 13: The Ripple Torque of the Motor Drive Circuit with 0.1H Armature Inductance

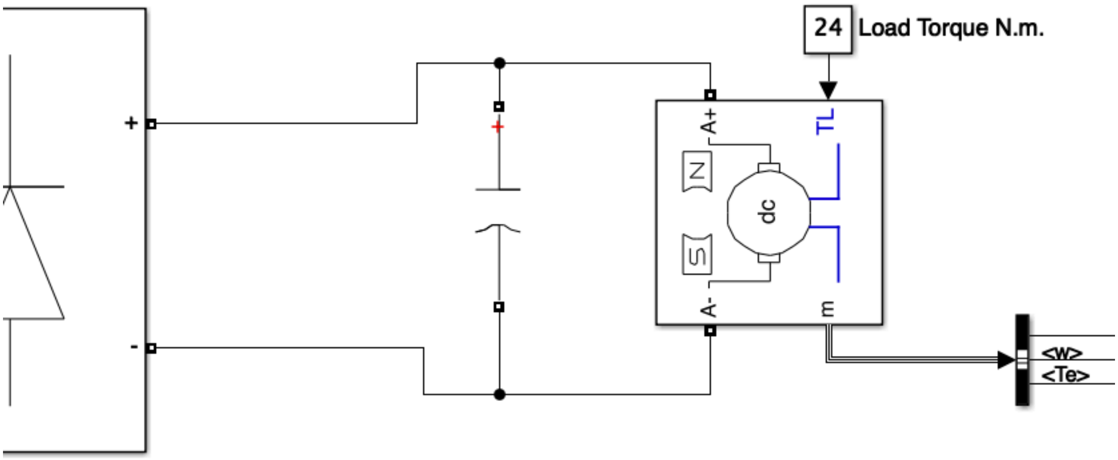

Figure 14: The Schematic of the Motor Drive Circuit with 0.1F Shunt Capacitance

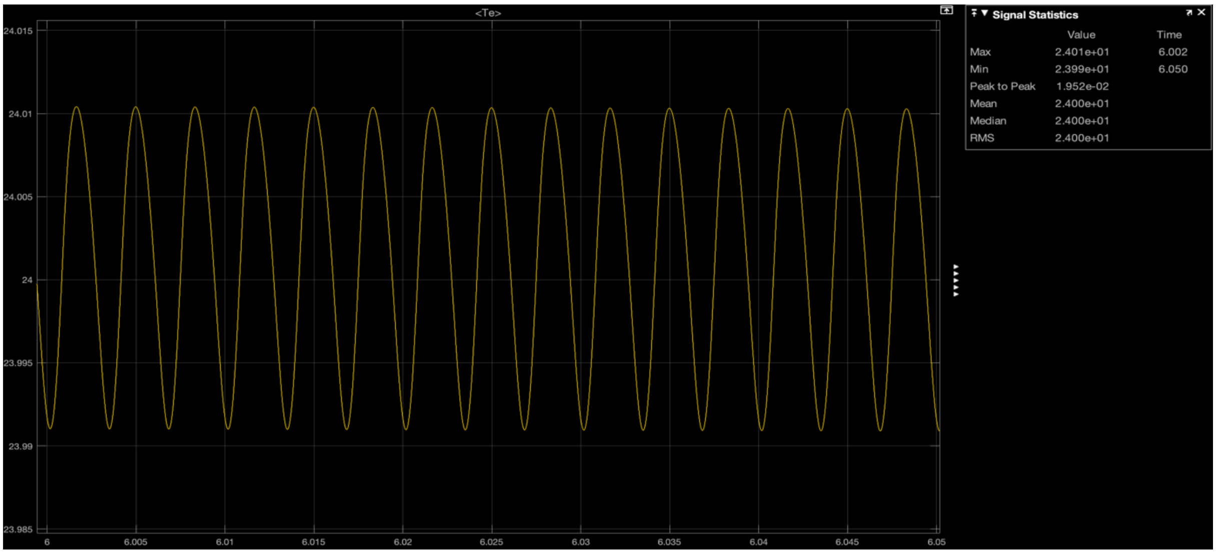

Figure 15: The Ripple Torque of the Motor Drive Circuit with 0.1F Shunt Capacitance

QUESTION 2.d

As it was represented in Figure 11, both the input and output powers can be obtained from the designed circuit. The resulted power values are given in the following figure again:

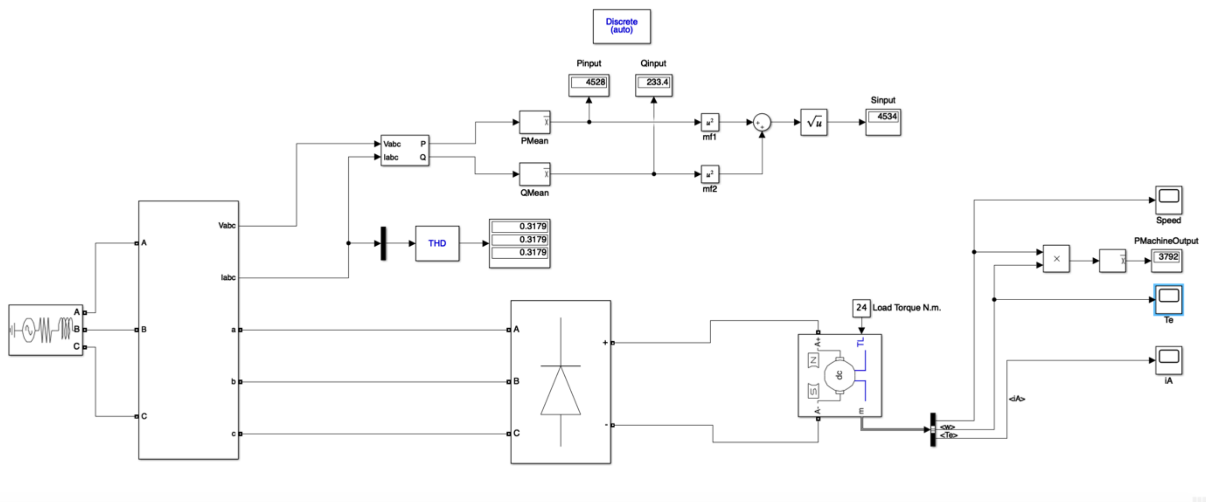

Figure 16: The Power Values of the Motor Drive Circuit

Input values of the power are P=4528W, Q=233.4Var and S=4534VA. Power at the output stage of the motor is 3792W. The efficiency of the motor driving operation is 83.75%. Losses on the motor drive operation is due to the armature resistance.

The power at the output of the Bridge is 4504W. The efficiency of the bridge is 99.46%. It is not seen in the figure however measured thanks to a series ammeter, parallel voltmeter, product tool, mean tool and display respectively. The losses at the output stage of the bridge is due to the diode resistances.

Table 1: The Table for the Analysis of the Power of the System

	Active Power (W)	Efficiency (η in %)
Input Stage	4528	100%
Bridge Output Stage	4504	99.46%
Motor Output Stage	3792	83.75%

QUESTION 3

QUESTION 3.a

The name of the topology is 12-pulse rectifier. A twelve-pulse bridge consists of two six-pulse bridge circuits connected in series, with their AC connections fed from a supply transformer with two secondary windings and one delta-connected primary winding. One secondary winding is connected in star and the other in delta. Star connected secondary feeds the upper 3-phase diode bridge rectifier, whereas the delta-connected secondary is connected to lower 3-phase diode bridge rectifier. Because of delta-wye (star) connection in secondary windings, there is a 30° phase shift between the two bridges. This results in total 12 pulse at the load. For very high-power rectifiers the twelve-pulse bridge connection is usually used. It is mainly used in HVDC systems with series devices. By using a 12-pulse rectifier, we can achieve less harmonics and this results in lower THD.

For a different variation in the 12-pulse rectifiers, thyristors can be used instead of diodes. When thyristors are used, average voltage of output will decrease depending on firing angle compared to using diodes. Moreover, thyristor rectifiers are partially controlled, whereas diodes are not controlled. We can control output voltage by just changing the firing angle of thyristor. Thus, thyristors are good devices for controlling purpose.

For another version of 12-pulse rectifier instead of delta-connected primary winding, wye-connection is used in primary side. There is a phase shift between primary side (wye connection) and secondary side (delta connection) by 30°.

QUESTION 3.b

To obtain the same average output voltage and average load current values, we applied input voltage as 800V line-to-line RMS for full bridge diode rectifier whereas for 12-pulse rectifier we applied input voltage as 400V line-to-line RMS. Thus, compared to 12-pulse rectifier, full-bridge rectifier should have higher input voltage to obtain same average values. Furthermore, we can think the three-phase full bridge rectifier as the 6-pulse rectifier. As the number of pulses per cycle is increased, the output DC waveform gets improved, so the quality of output voltage waveform would definitely be improved with low ripple. As the pulse number increases, the harmonics present in the input decreases and the Total Harmonic Distortion (THD) reduces. This means that the higher the number of rectifier pulses, the lower the line current distortion is. In 12-pulse rectifiers, power factor will improve, and total harmonic distortion can be reduced compared with full bridge rectifiers. On te other hand, 12-pulse rectifier has higher cost compared to full bridge rectifier due to diode numbers and transformers.

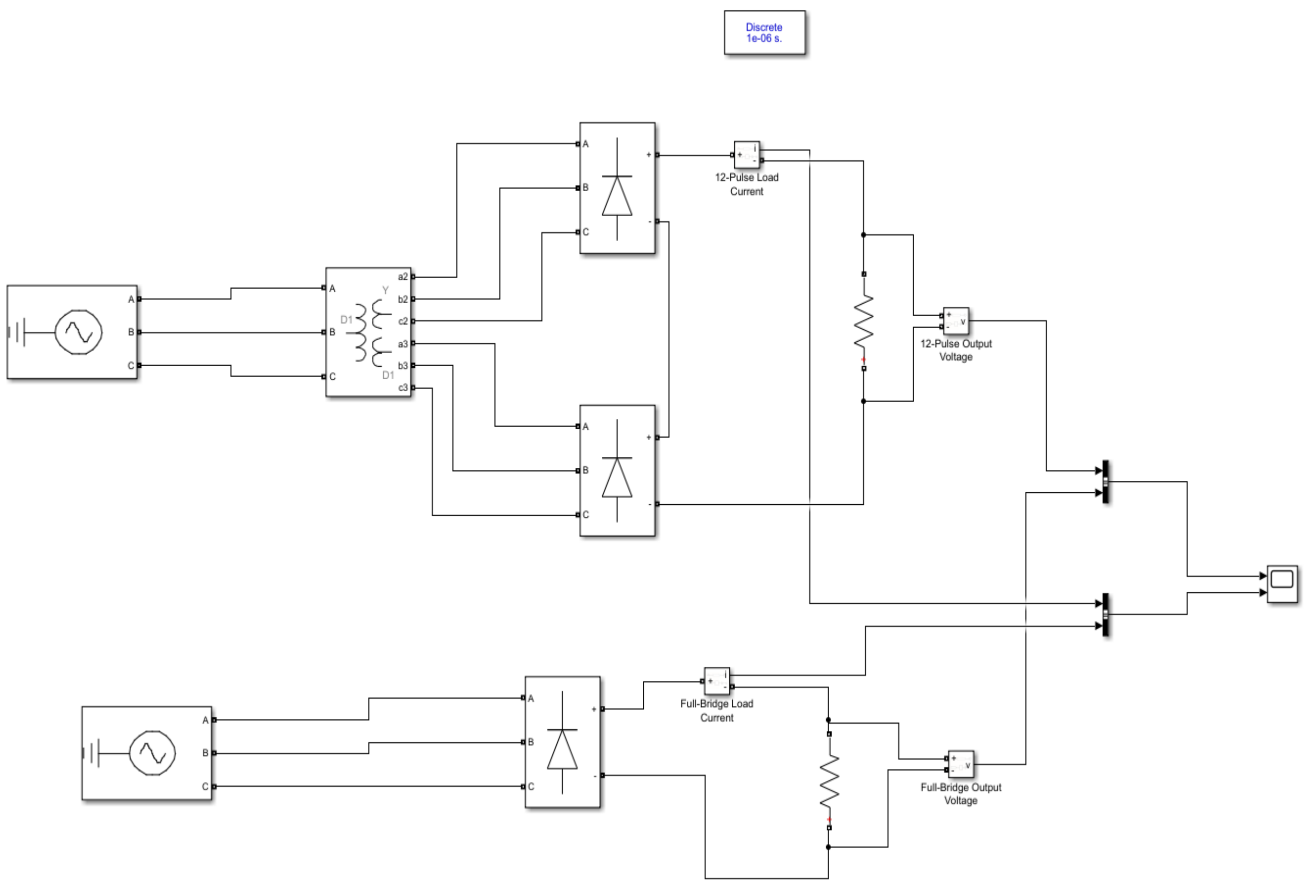

Figure 17: The circuit schematics of 12-pulse rectifier and full-bridge diode rectifier in SIMULINK

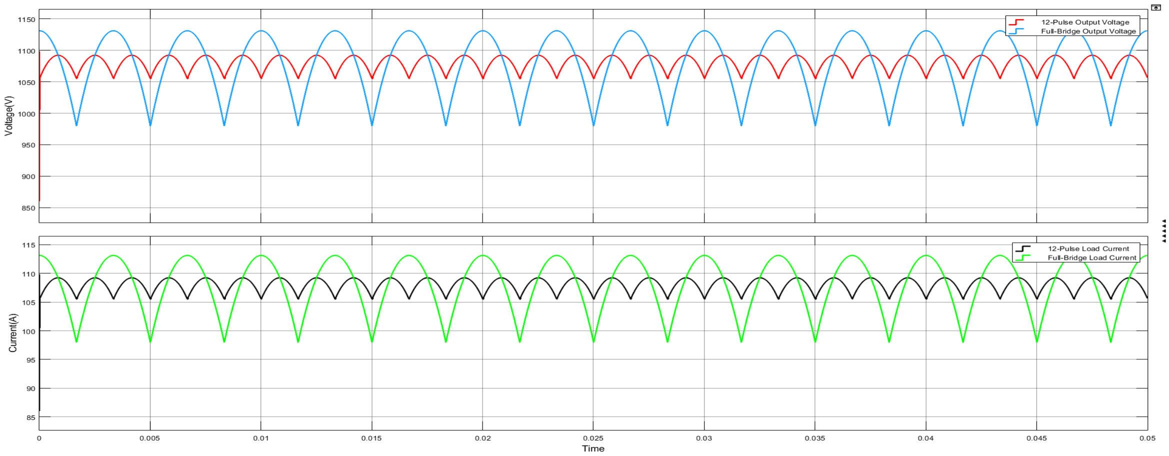

Figure 18: The graph of output voltage and load current waveforms for 12-pulse rectifier and full-bridge diode rectifier

Trace Selection

12-Pulse Output Voltage

Signal Statistics

	Value	Time
Max	1.098e+03	1.000e-06
Min	8.602e+02	0.000e+00
Peak to Peak	2.381e+02	
Mean	1.080e+03	
Median	1.083e+03	
RMS	1.080e+03	

Trace Selection

Full-Bridge Output Voltage

Signal Statistics

	Value	Time
Max	1.131e+03	0.040
Min	9.796e+02	5.000e-03
Peak to Peak	1.515e+02	
Mean	1.080e+03	
Median	1.093e+03	
RMS	1.081e+03	

Figure 19: The average output voltage values for 12-pulse rectifier and full-bridge diode rectifier

Trace Selection: 12-Pulse Load Current

Signal Statistics

	Value	Time
Max	1.098e+02	1.000e-06
Min	8.602e+01	0.000e+00
Peak to Peak	2.381e+01	
Mean	1.080e+02	
Median	1.083e+02	
RMS	1.080e+02	

Trace Selection: Full-Bridge Load Current

Signal Statistics

	Value	Time
Max	1.131e+02	0.040
Min	9.796e+01	5.000e-03
Peak to Peak	1.515e+01	
Mean	1.080e+02	
Median	1.093e+02	
RMS	1.081e+02	

Figure 20: The average load current values for 12-pulse rectifier and full-bridge diode rectifier

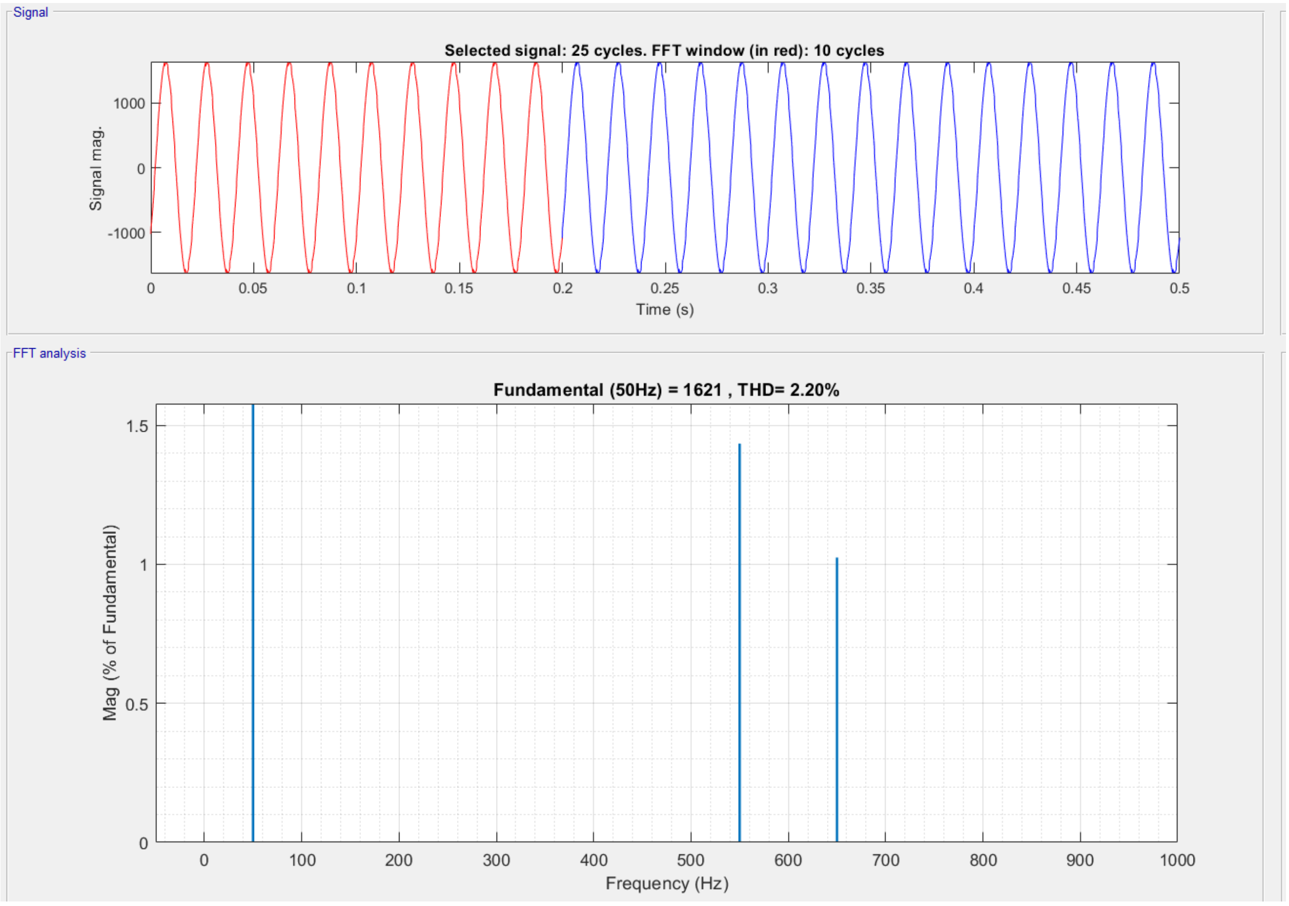

Figure 21: THD of line current for 12-pulse rectifier

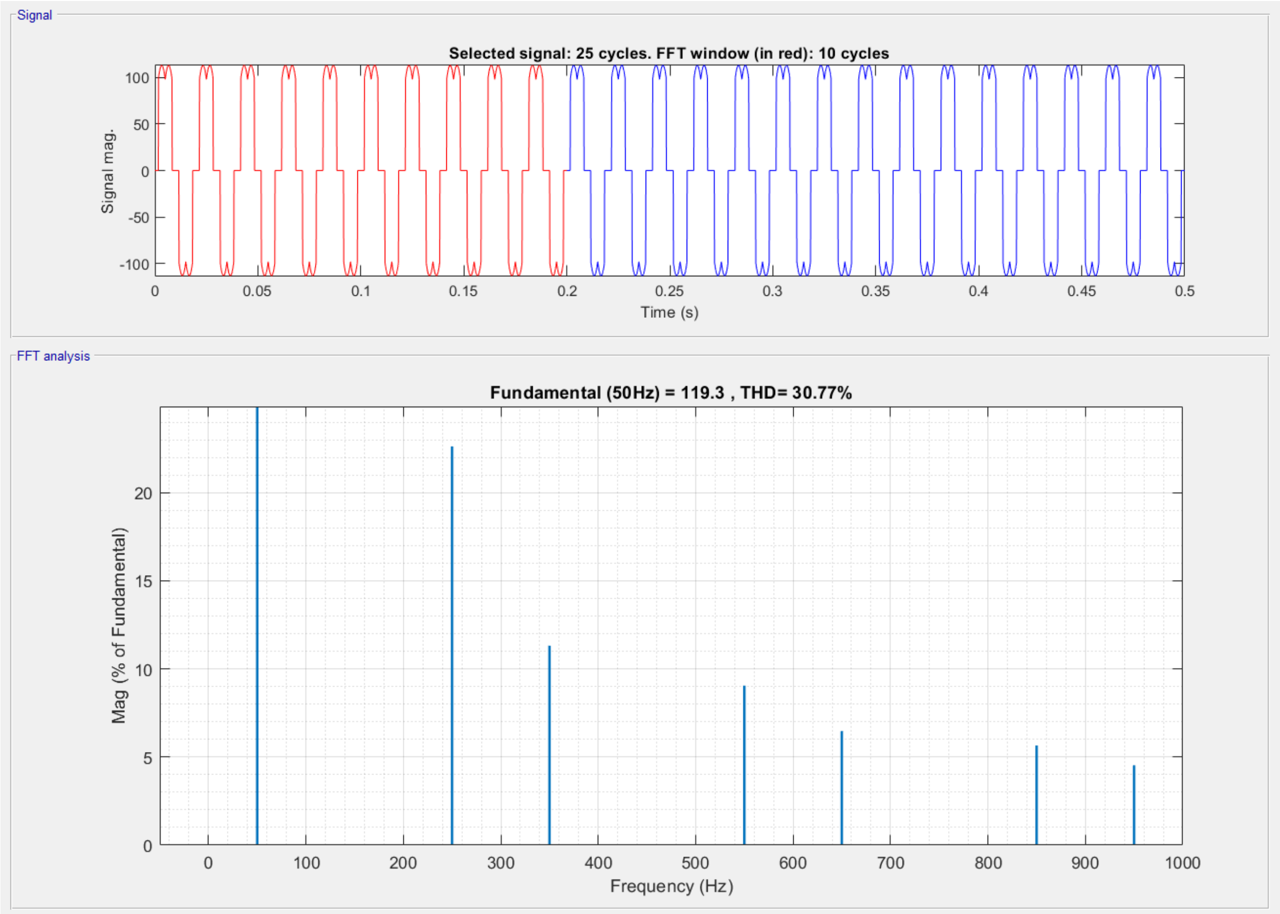

Figure 22: THD of line current for full bridge diode rectifier

CONCLUSION

To conclude all the project, the full bridge full and half controlled thyristor rectifiers are investigated, the DM Motor driving basics have learnt, and the pulse rectifiers were examined.

It was a great opportunity to design circuits to learn Simulink more, simulate those designs and see the practical responses of the theoretical knowledge.