MIDDLE EAST TECHNICAL UNIVERSITY

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

EE463

Project-1 Report

SINGLE PHASE DIODE RECTIFIERS

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1

For increasing simulation speed, generally discrete modelling is used for continuous signal. If continuous signal is used in simulation, correct result is obtained however simulation takes a lot of time. However, if select the big step size, simulation time is small, but result may be wrong. Therefore, discrete modelling should be use. However, step size is selected very carefully.

In first question firstly step size is selected 1.5 msec. Simulation time is very small. However, voltage waveform is not as waited. Then 10 µsec is selected. In this case simulation takes larger time than before case. However, result is much better than before. Finally, 1 µsec is used for step size. This result is almost same to the case before. However, result is seen like almost continuous. Simulation results are given in the Figure 1-2-3.

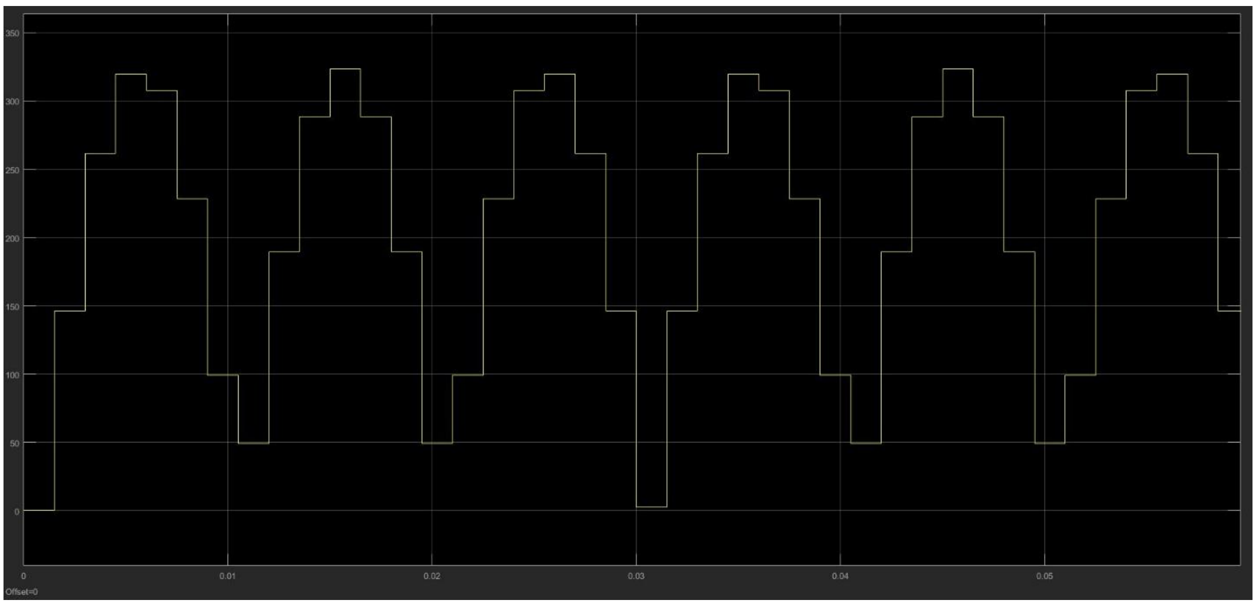

Figure 1: Voltage waveform of the resistive load with step size 1.5msec

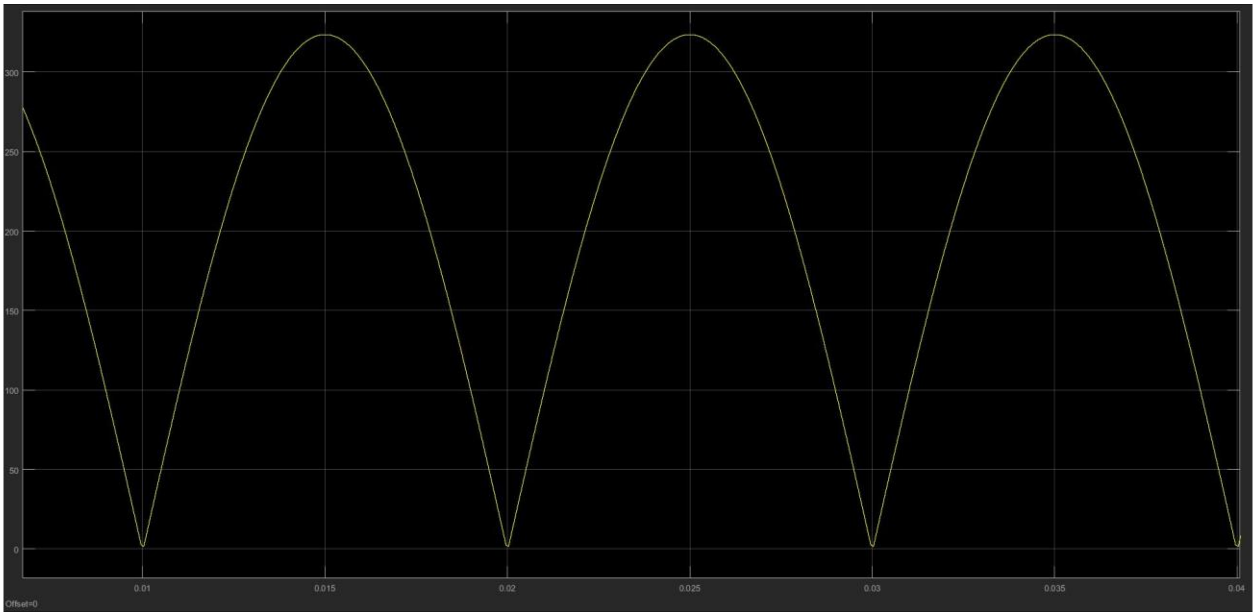

Figure 2: Voltage waveform of the resistive load with step size 10μsec

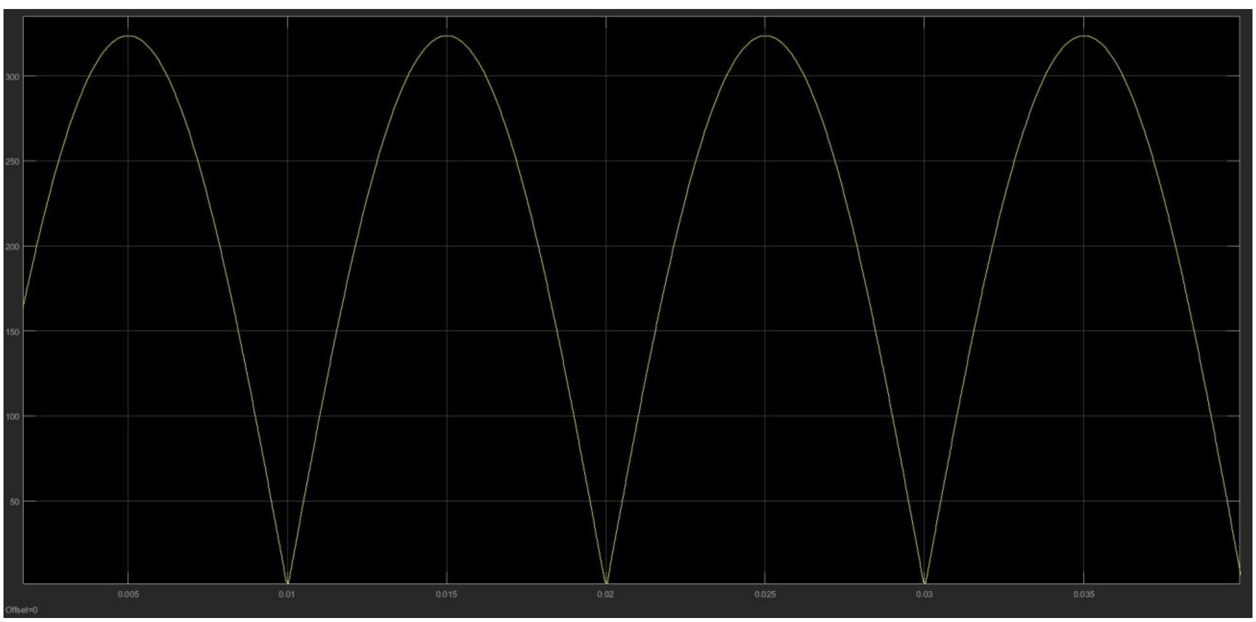

Figure 3: Voltage waveform of the resistive load with step size 1μsec

2.1

You can see the voltage and current waveforms of the different load circuits following figures.

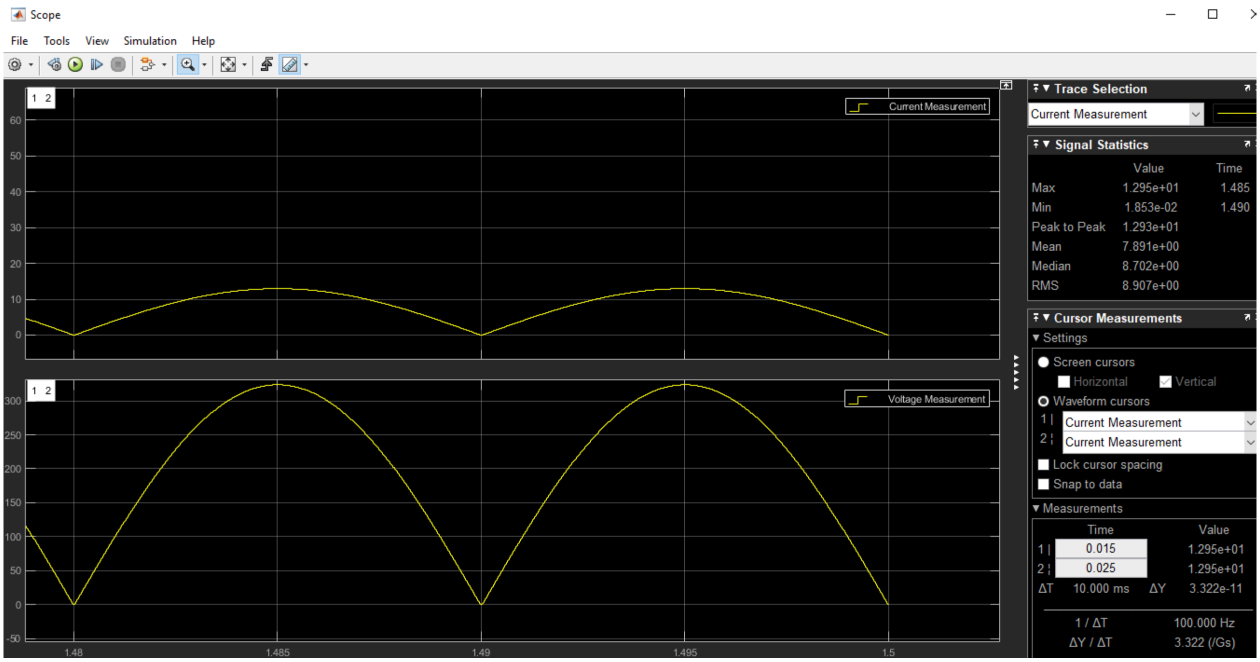

Figure 4: Voltage and current waveforms of the resistive load

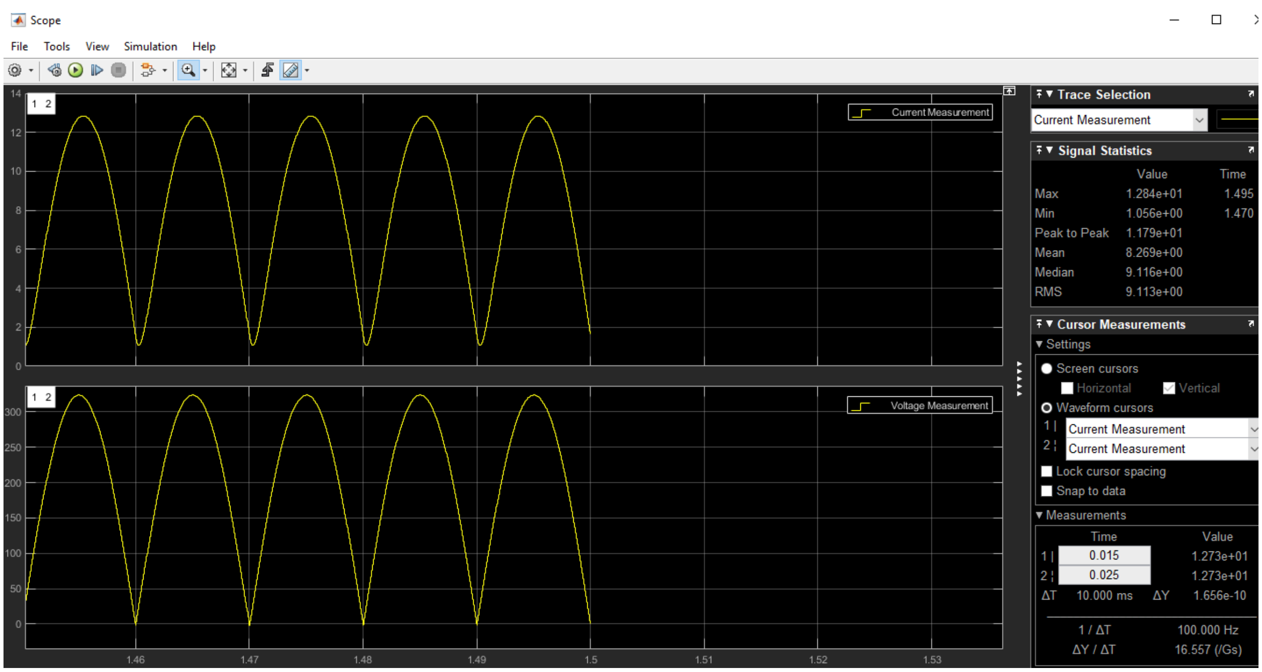

Figure 5: Voltage and current waveforms of the inductive load with L=10mH

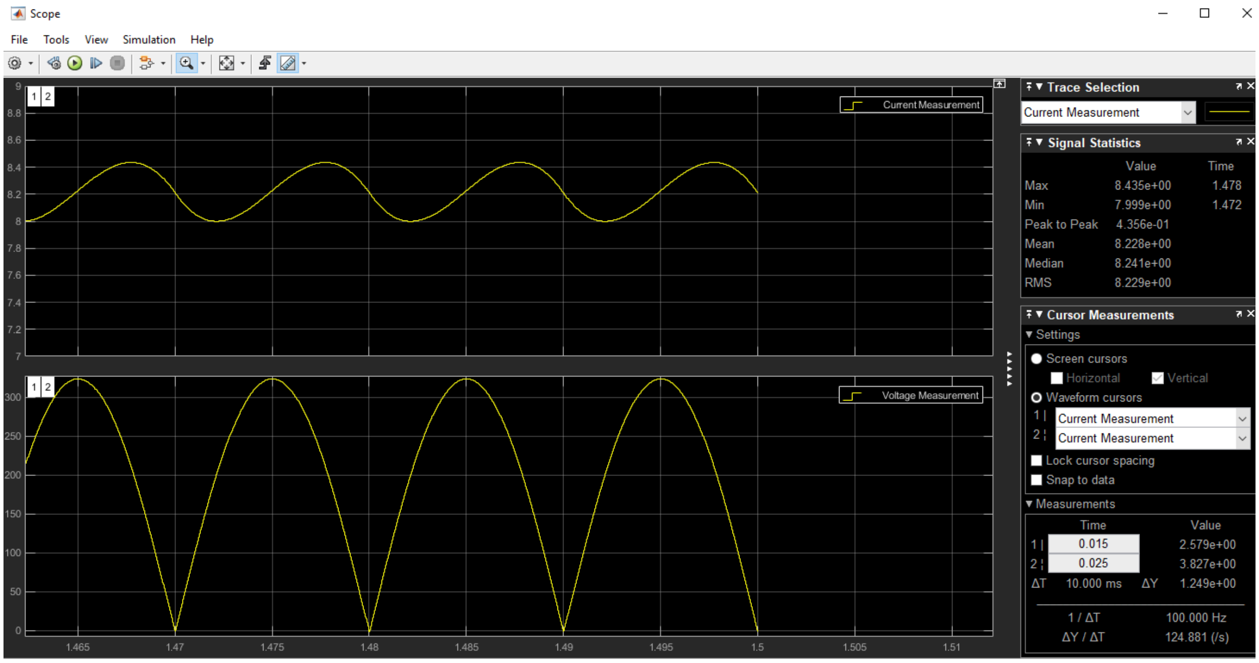

Figure 6: Voltage and current waveforms of the inductive load with L=1H

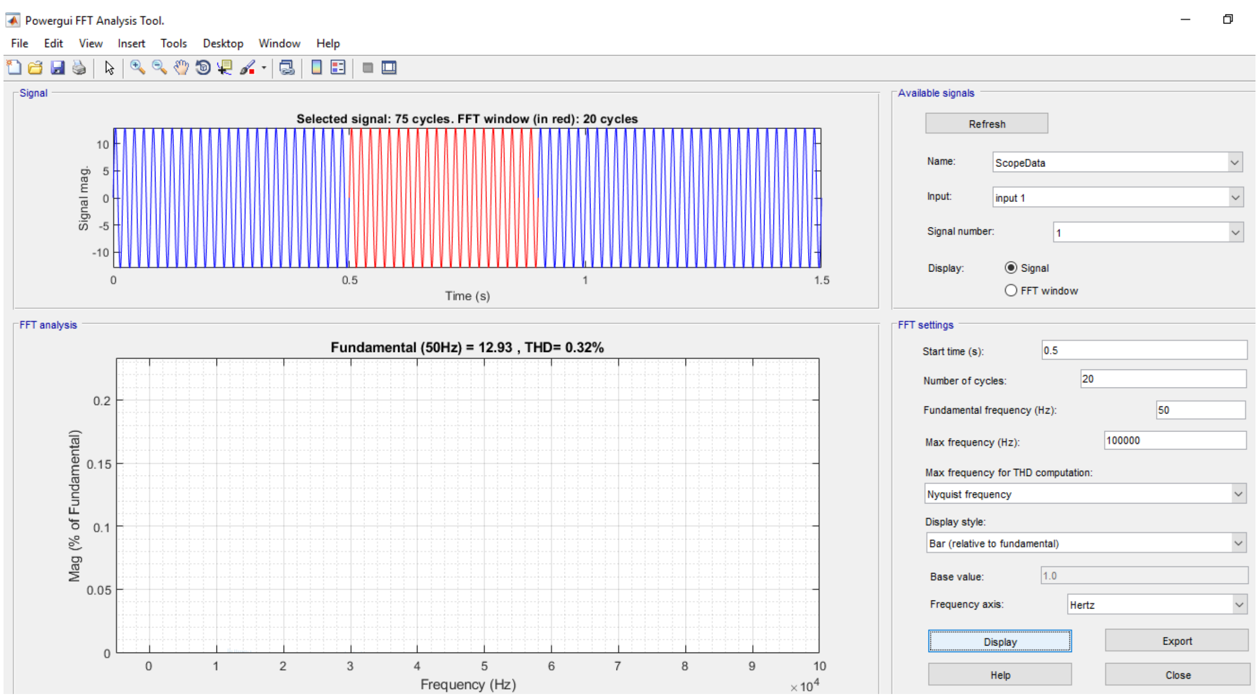

Figure 7: THD of the line current of the resistive load

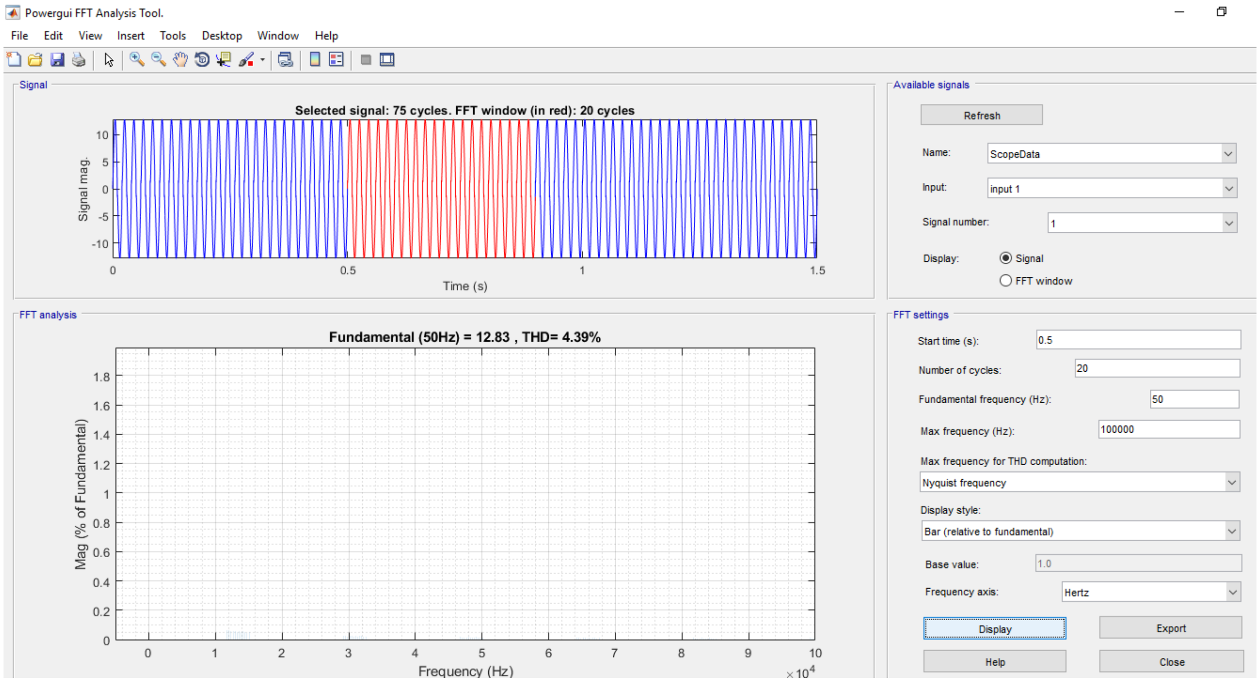

Figure 8: THD of the line current of the inductive load with L=10mH

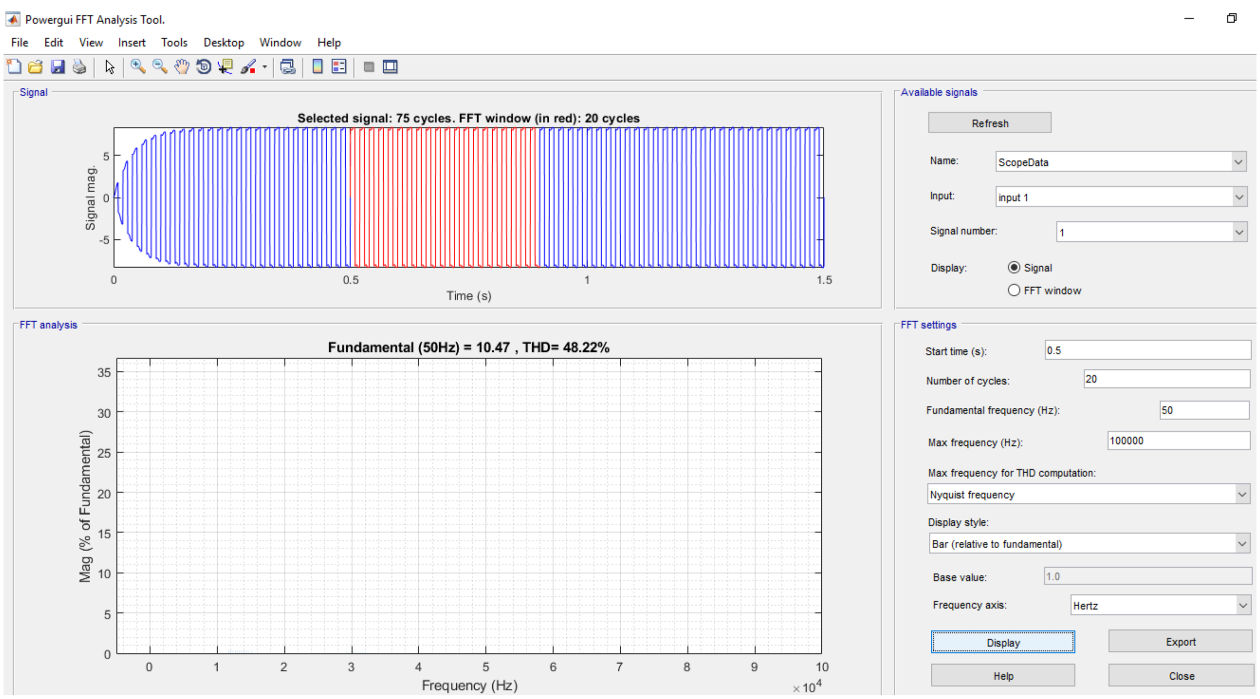

Figure 9: THD of the line current of the inductive load with L=1H

As the inductance of the load is increased, phase difference between the current and voltage is increased. Also, current waveform begins to be more DC. When there is no inductance at the load, THD of the line current is almost zero, because there are no harmonic components. As inductance increased, THD of the line current is also increased because of the harmonic components.

2.2

While choosing the diodes, we considered some important parameters. Voltage and current rating are so important to select right component. These values should be higher than the nominal values of the system due to safety. We consider also these components' thermal situations. We clearly notice that discrete diode is better than the diode rectifier module according to thermal issues. Diode rectifier modules gets warm faster than discrete diodes when all conditions are same. Discrete diodes have more space to dissipate heat, so they are cooler. Also, data sheets specify the typical applications of their products. For example, our products we choose are suitable for using the rectifier circuits. Mounting is another criterion that we consider, because some diodes are fit for PCB design, not for linking the panel. Revers recovery time is important parameter for choosing diode, but not for our aim. We have 100 Hz output which means its speed is 10 ms. Almost all product is faster than that speed. It is very important for different applications like motor drive. You can reach the datasheets of the products here:

https://www.semikron.com/dl/service-support/downloads/download/semikron-datasheet-skb-25-07238690.pdf

https://www.semikron.com/dl/service-support/downloads/download/semikron-datasheet-skn-2f17-02237420.pdf

2.3

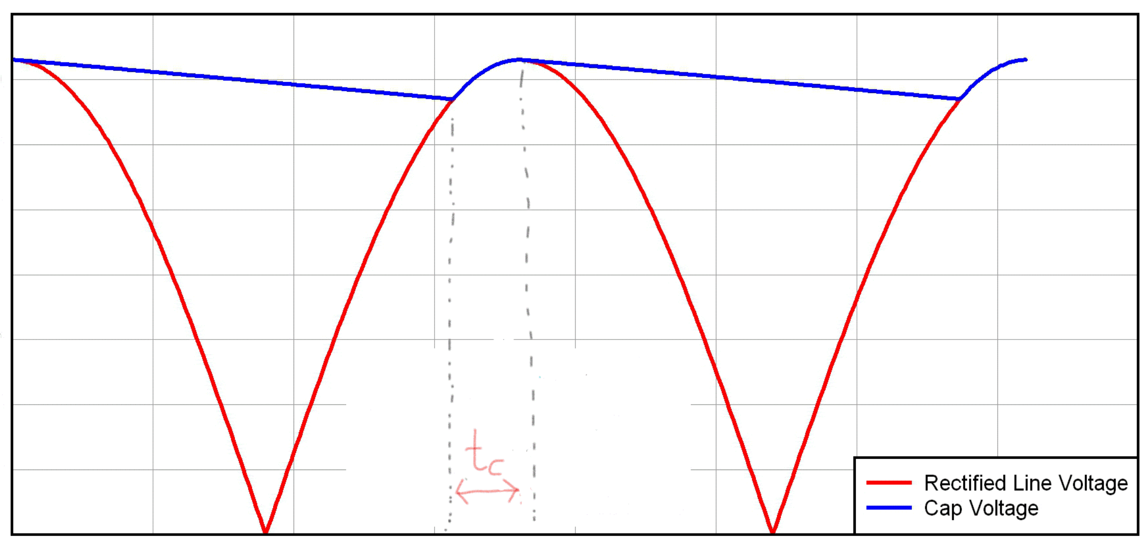

Figure 10: An example of ripple voltage

When we connect a capacitor at the load side, ripple voltage occurs as seen in Figure 10. In the given question, we are asked to keep ripple smaller than 20% of the average output voltage. We can calculate some capacitance value analytically. In the figure, capacitor is charging until the input voltage up to maximum. We can call this time 't_c'. After the time voltage up to maximum, capacitor is discharging. First, we can calculate the average voltage that is rectified by using this formula:

$$V_{avg} = \frac{V_{max}}{\sqrt{2}} * 0.9$$

The average voltage is about 207 Volts. The ripple voltage is:

$$V_{ripple} = V_{max} - V_{max} * \cos(wt_c)$$

By editing this equation, we get:

$$t_c = \frac{\arccos(1 - \frac{V_{ripple}}{V_{max}})}{w}$$

We know the ratio of the ripple voltage over the maximum voltage from the above equations. The ripple voltage should be smaller than 41.4 according to the above calculations, so we can calculate the t_c. Its value is 0.8 ms.

When the capacitor is discharging, we can use the following equation:

$$V_{max} - V_{ripple} = V_{min} = V_{final} - (V_{final} - V_{initial})e^{\frac{-t}{RC}}$$

The final value is zero because if there is no effect, capacitor voltage will be equal to zero. The initial value is equal to the V_{max} value. The equation's t value is period of the output voltage of the rectifier circuit minus charging time which is t_c.

If we take the maximum as 326 Volts, we get:

$$326 - 41.4 = 326 * e^{\frac{(10-0.8)*10^{-3}}{100C}}$$

After solving the equation, capacitor value is approximately 677μF. Because it is so specific value, we used the 680 μF capacitor in the simulation software. Besides, our aim is to reduce ripple voltage. More capacitance means that less ripple voltage. As seen in the figure 11, ripple voltage is less than 40 Volts which is acceptable design for us.

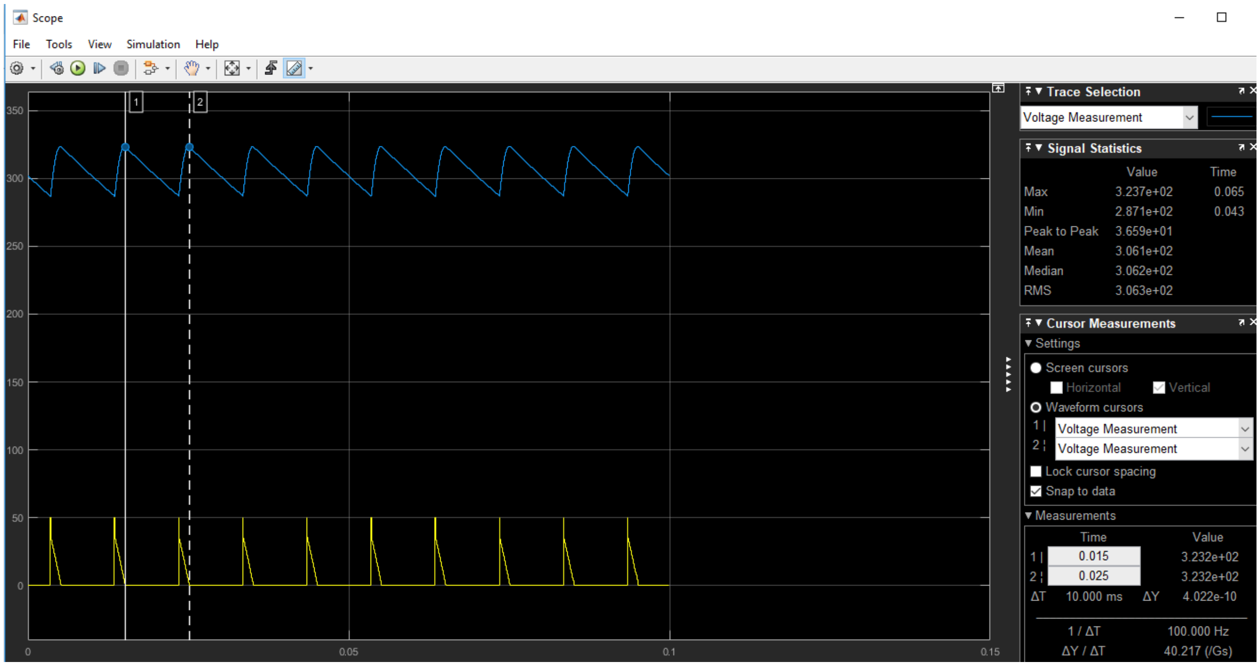

Figure 11: Simulation result of the capacitive load circuit

While selecting the capacitor, capacitance value and voltage rating are the most important parameters. We also checked their applications. Moreover, lifetime of the capacitor is another parameter for us. The link of the capacitor we choose is here:

https://www.digikey.com/product-detail/en/vishay-bc-components/MAL209534681E3/MAL209534681E3-ND/5635654

2.4

In this question, we observed the effect of the line inductance to the output voltage waveform. Theoretically, we learned that, line current cannot change immediately due to inductance of the line. That changing time, all diodes are open, and we call it commutation process. During that time, output voltage does not change. When the commutation time is over, output voltage is change suddenly as seen in figure 12.

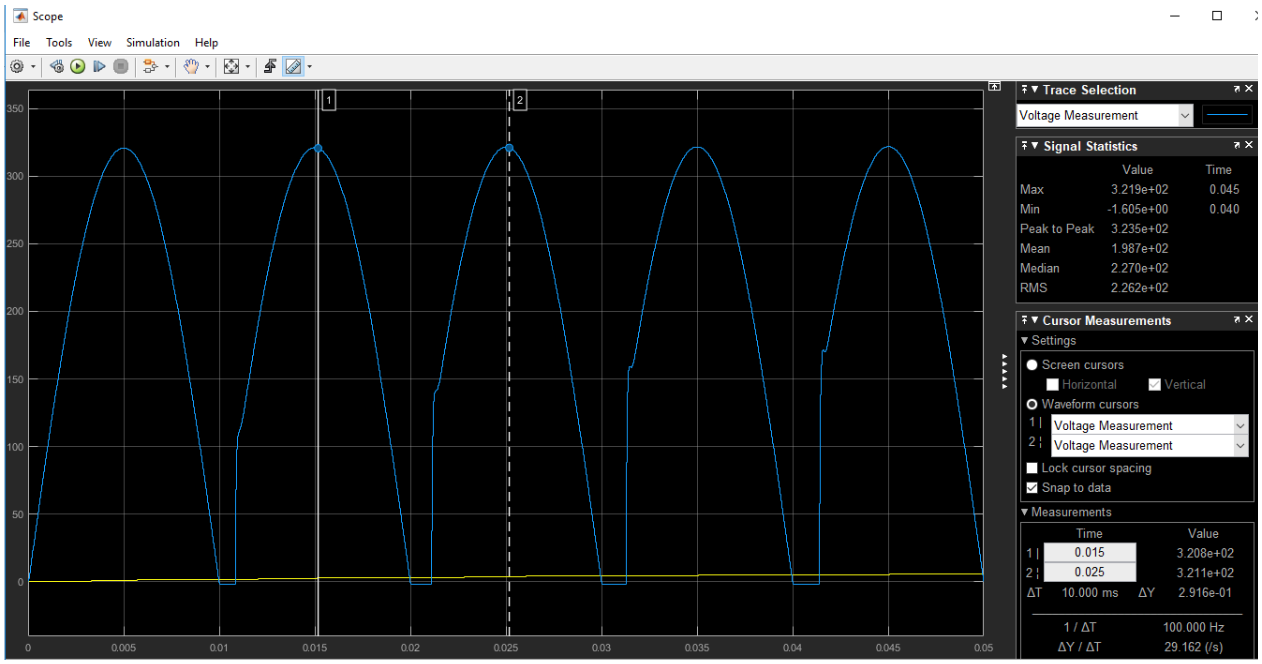

Figure 12: Output voltage waveform when line inductance is added

During commutation time, output power is zero due to zero voltage, so mean value of the voltage is decreased. The waveform is not so clear because of highly inductive load. We may consider that there is a constant current source in the load side, so the current is almost DC.

2.5

RC loaded diode bridge rectifier draws distorted current. Because of the converter inductance (L_{s2}) and current harmonics, voltage is distorted at the common point. We can eliminate this distorted waveform by reducing the load capacitance and increasing the line inductance.

3.1

Total Harmonic Distortion (THD) of the input current is equal to 168.32%. THD is Calculated with using FFT in "powergui".

Power Factor (PF) is equal to 0.9994. It is calculated with obtaining all active power (P) and all reactive power (Q). Then divide each other which gives the tangent of the angle of PF. Then using "arctan" function, angle of PF is obtained. Then using cosine function we obtain PF. You can see the circuit diagram of the three single phase diodes with RC load in Figure-13. Also, THD of input current, Phase-A current, neutral wire current and output voltage of Diode Bridge-1 are given in the Figure 14-15-16-17.

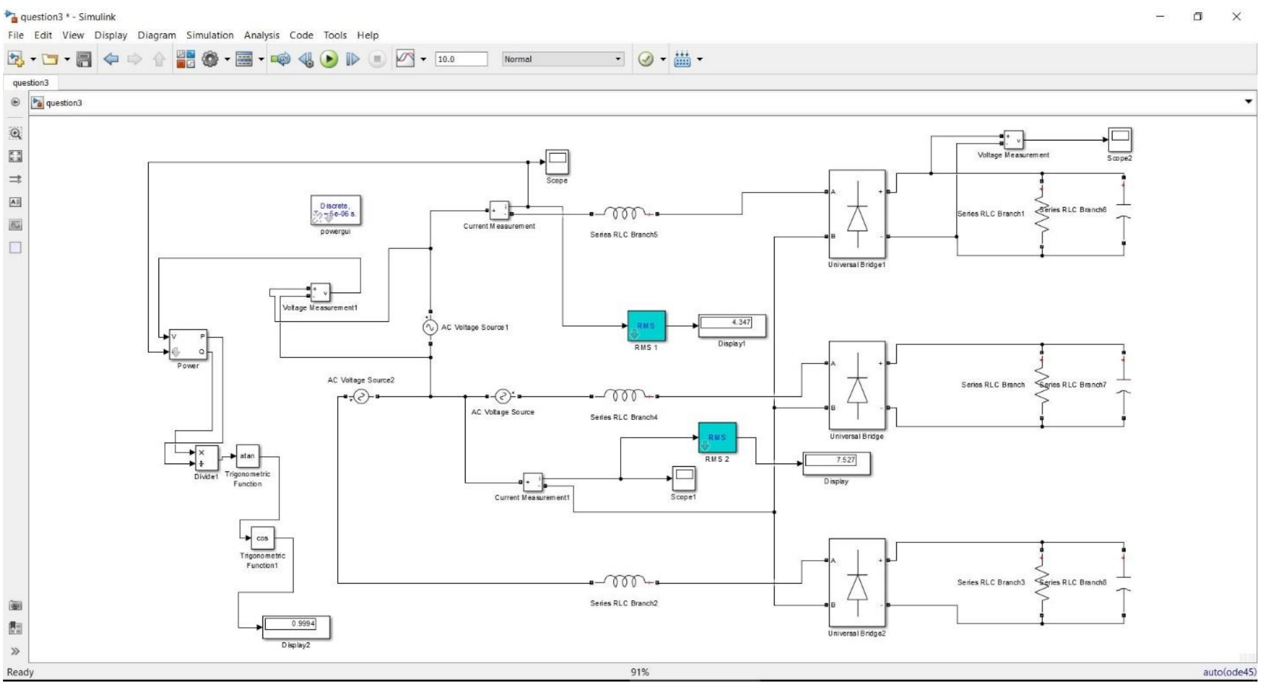

Figure 13: Circuit diagram of the three single phase diodes with RC load

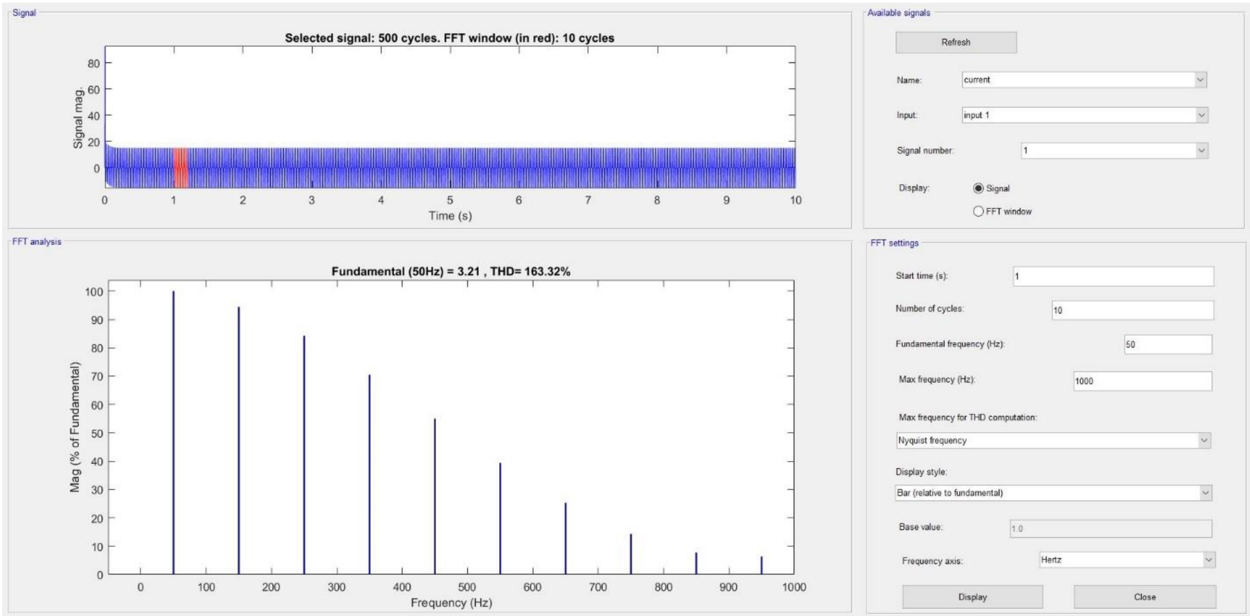

Figure 14: THD of the input current

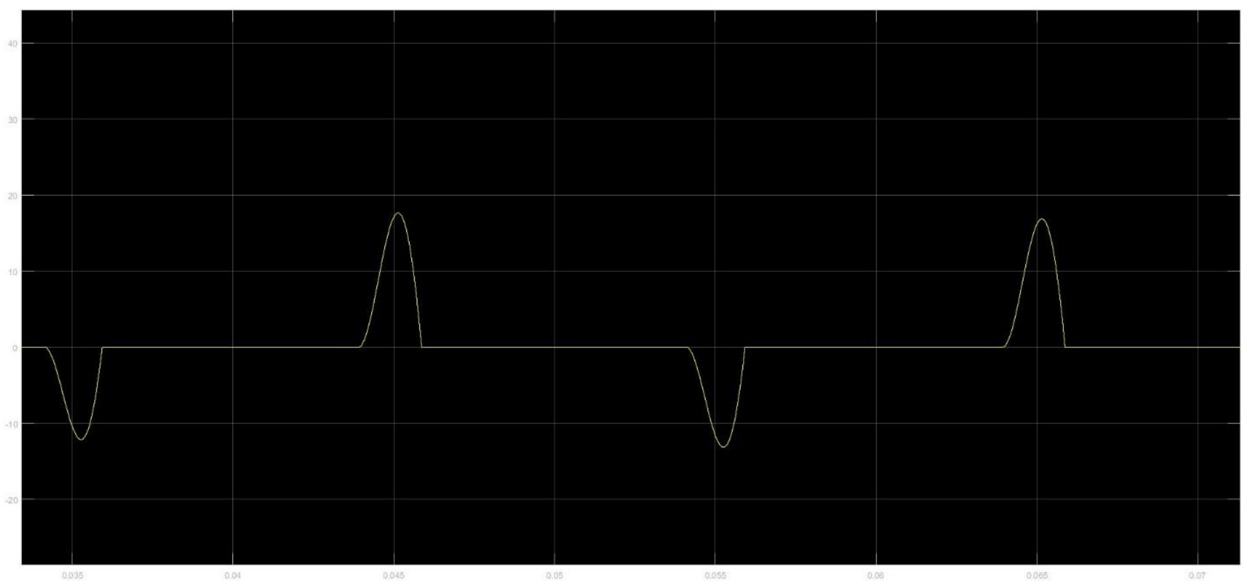

Figure 15: Phase-A current waveform

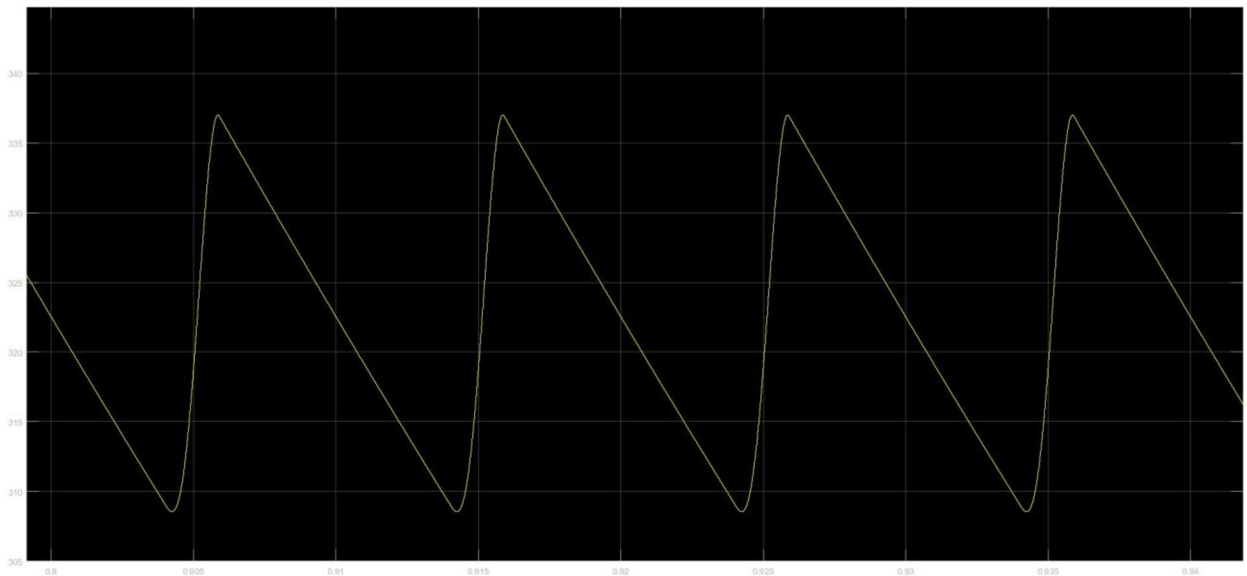

Figure 16: Neutral wire current waveform

Figure 17: Output voltage of Diode Bridge-1

3.2

RMS of the line current is equal to 4.347 and RMS of the neutral line is equal to 7.527 which is equal to square root 3 times 4.347. This difference is coming from “line to line” and “line to neutral” difference. This will be explained with example

For example, when phase A current is positive, other phase currents are negative because of Kirchhoff Current Law. However, half of this time (phase A current is positive) phase B current is negative and phase C current is zero. Other half of this time period, phase C current is negative and phase B current is zero. Therefore, always one phase is positive, and another phase is negative as seen in Figure-18. Because of this, neutral current is equal to line to line current of the phases.

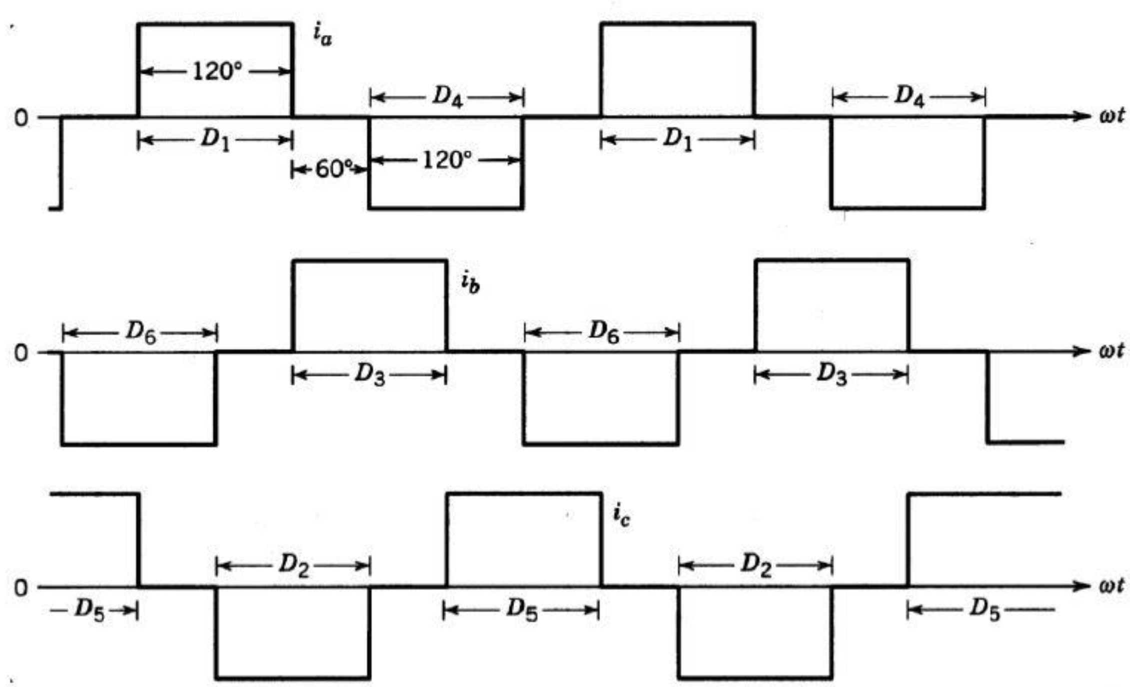

Figure 18: Output voltage waveform when line inductance is added

3.3

Total Harmonic Distortion (THD) of the input current is equal to 190.45

Power Factor (PF) is equal to 96.42 %

PF and THD is calculated like in part-3.1

If Ls is ignored, this means that there is no commutation of the input current. As shown in the figures which are in the below, input and neutral current can be increase very sharply from zero to maximum value. In question-3 part-i, currents are not like that. This difference comes from existing commutation. Moreover, voltage increase or decrease very sharply due to the same thing. You can see the circuit diagram of the three single phase diodes with RC load in Figure-19. Also, THD of input current, Phase-A current, neutral wire current and output voltage of Diode Bridge-1 are given in the Figure 20-21-22-23

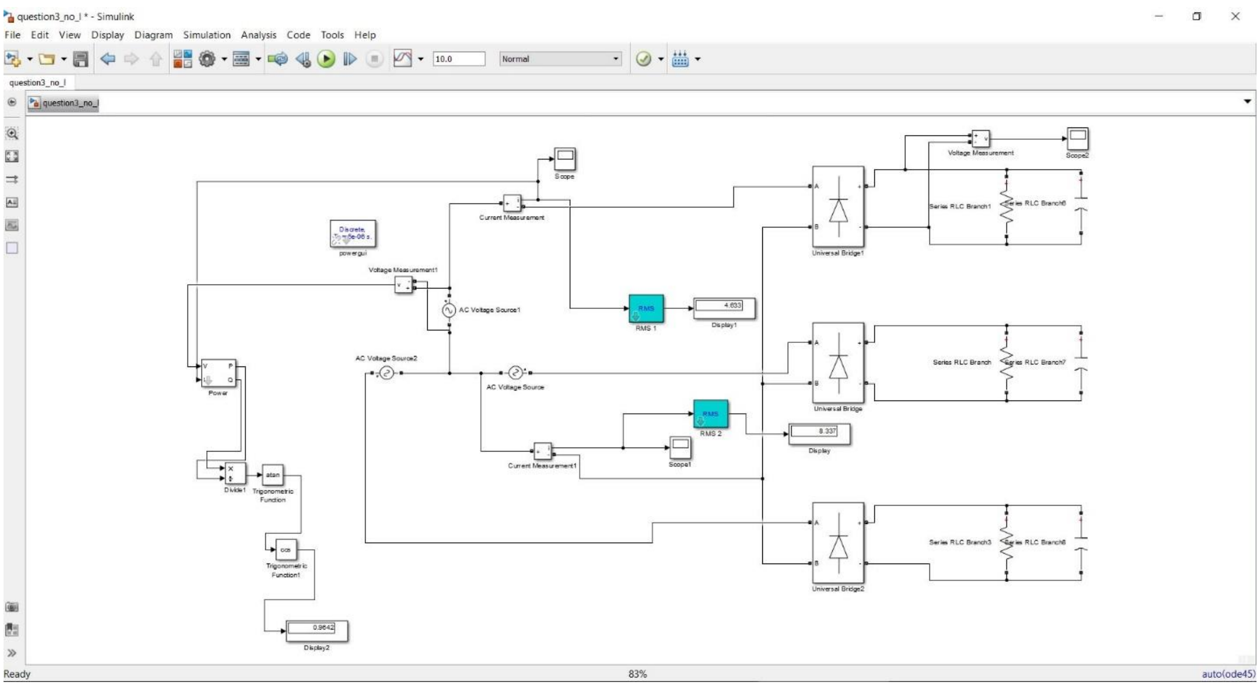

Figure 19: Circuit diagram of the three single phase diodes with RC load

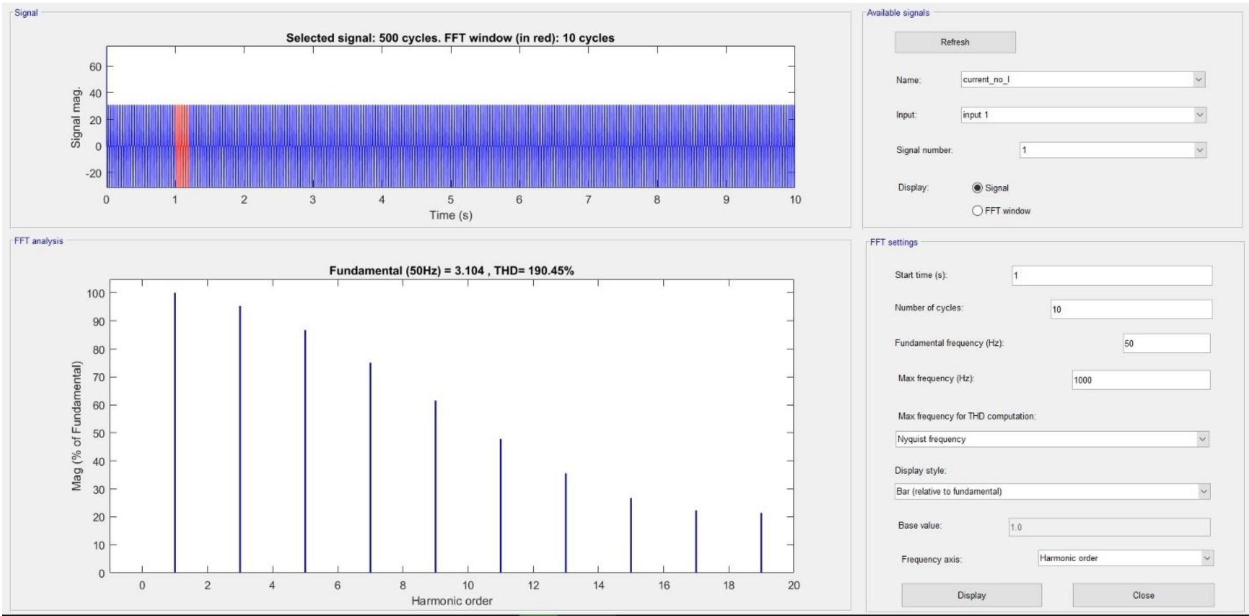

Figure 20: THD of the input current

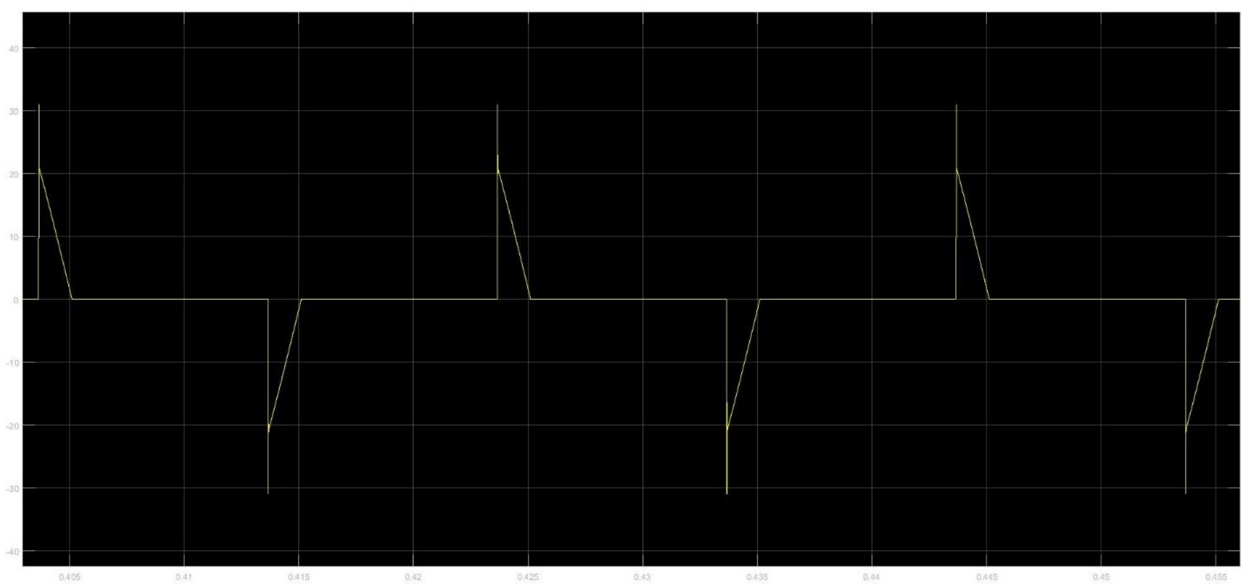

Figure 21: Phase-A current waveform

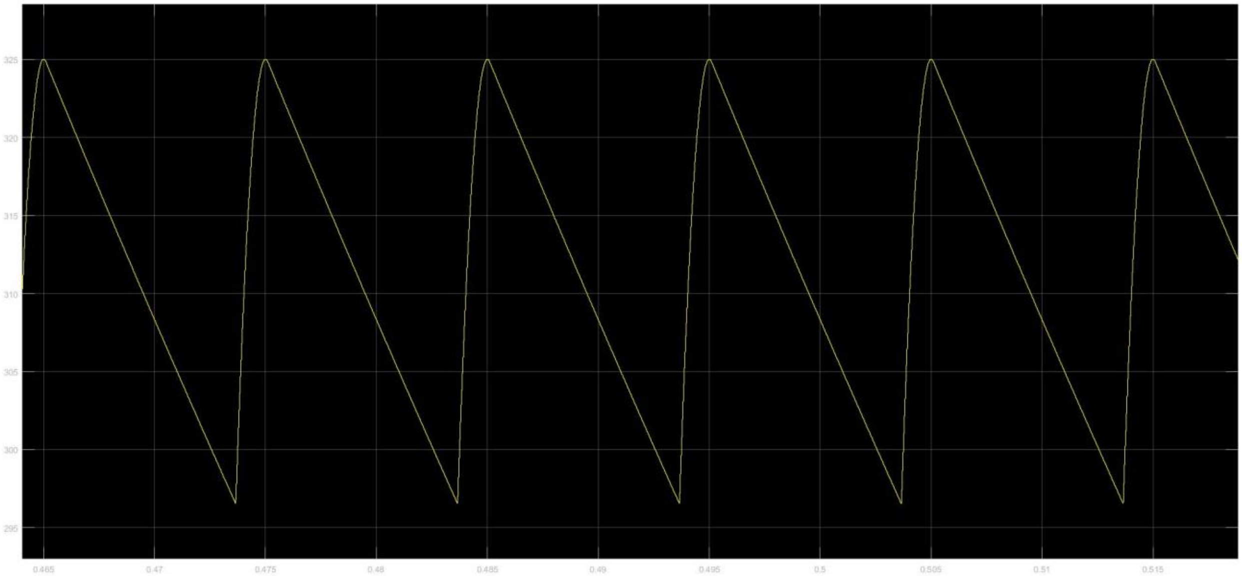

Figure 22: Neutral wire current waveform

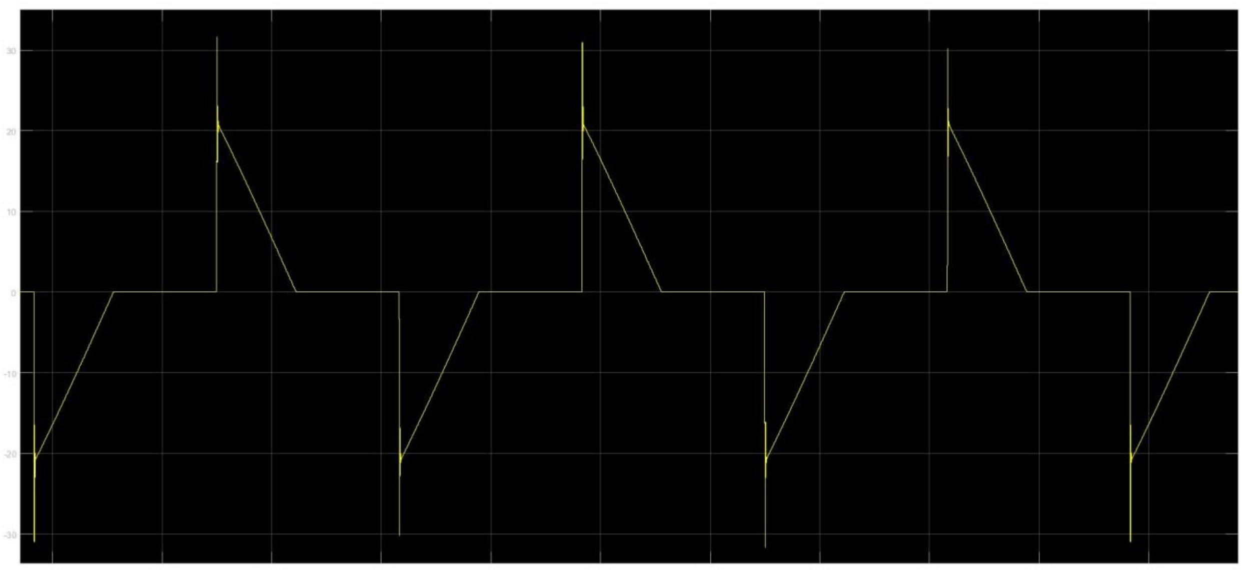

Figure 23: Output voltage of Diode Bridge-1

RMS of the line current is equal to 4.633 and RMS of the neutral line is equal to 8.337 which is equal to square root 3 times 4.633 like in part-ii. Reason of this is same.

Difference between RMS currents of the part-ii and part-iii is coming from decreasing load impedance. Because in first case passive elements are load resistance – load capacitance and source impedance. When source inductance is equal to 0, total impedance decreases. Because of this RMS of phase-A current and RMS of neutral line current increase.

THD of the phase A current increase. This means that current has more harmonics in this case. Because if there is no source inductance, the load is RC. That is, some harmonics come from capacitor. However, if there is source inductance, the system is compensated that is load is like resistive. Therefore, there is no inductance and capacitor in circuit, and there is less harmonic from capacitor and inductor.

PF of the phase A current decrease because PF has strong relationship with THD.

$$Power\ Factor = Displacemet\ Power\ Factor\ x\ \sqrt{\frac{1}{1 + THD^2}}$$

Reason of this real power is proportional with first harmonics of the voltage and current. If other harmonics come, these increase total power however do not affect real power. Therefore, If THD is high (which means that other harmonics exist), power factor is low.