EE 463 Term Project 1

Fall 2018

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Contents

1) INTRODUCTION

Input voltage from the grid is 50 - 60 ac signal and it is converted to dc signal in many power electronics applications. Controlled or uncontrolled rectifiers can be used to provide this dc voltage. Uncontrolled rectifiers provide cheap solutions and are used for switching dc power supplies, ac motor drives, dc servo drives, etc.

This report is written for the first project of EE463 Fall2018 class in order to understand single phase diode rectifier operation and characteristics. First question examines how Simulink's Solver's step size affects simulation results. For the second question, circuit in Figure 1 is used with slight modifications which are explained in the questions.

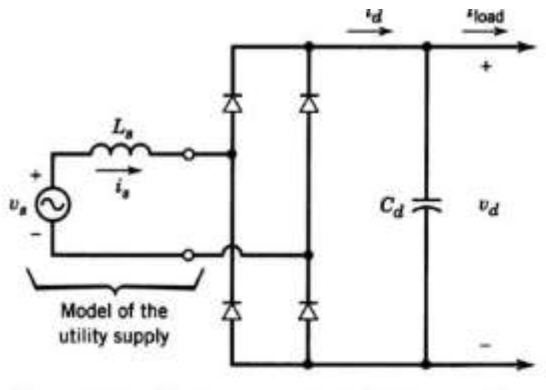

Figure 1 :Single phase diode rectifier

Question 2.1 asks FFT analysis of the output voltage and line current for different RL loads in the absence of line inductance. Question 2.2, aims to teach choosing discrete diodes and module rectifier for a particular circuit. In question 2.3, ripple voltage and choosing a capacitance value is explained. Question 2.4, examines the effect of the line inductance and commutation, whereas question 2.5 investigates distortions in the line voltage due to distorted currents drawn by rectifier circuits.

In the last question single-phase diode rectifiers operated from a three-phase grid with neutral connection are investigated. In 3.1, PF and THD of input current are asked. In question 3.2, RMS values of line currents and neutral current are found and finally in question 3.3, the same procedure is carried out without line inductance.

2) RESULTS

Q1.

The simulation of a Simulink model involves solving the dynamic system that is changing in time represented by the block diagram. Simulink engine takes care of all the computation to solve the block diagram. Simulink solver determines the time steps for which the simulation results are computed according to the changing behavior of the simulation. In Figure 2, if the dynamics of the system changes abruptly the Variable Step Solver (Set to work in Auto) chooses smaller time steps. However, if we choose to use the Discrete Step Solver and use a step size that is comparable with the period of the dynamic system, the solver might miss some of the changes in the dynamic behavior of the system.

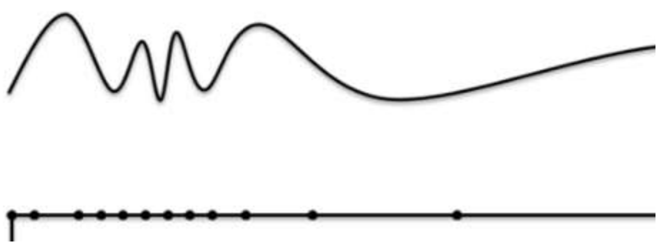

Figure 2:Chosen step sizes of an example signal by the Solver

In this question discrete time step calculations in the simulation of a single-phase uncontrolled rectifier that is feeding a resistive load (R=100Ω) is performed. Simulation results with step size 1.5 msec, 10 μsec and 1 μsec can be observed in Figure 3, 4, and 5, respectively. Since 1.5 msec is comparable with 10msec we see a distorted signal.

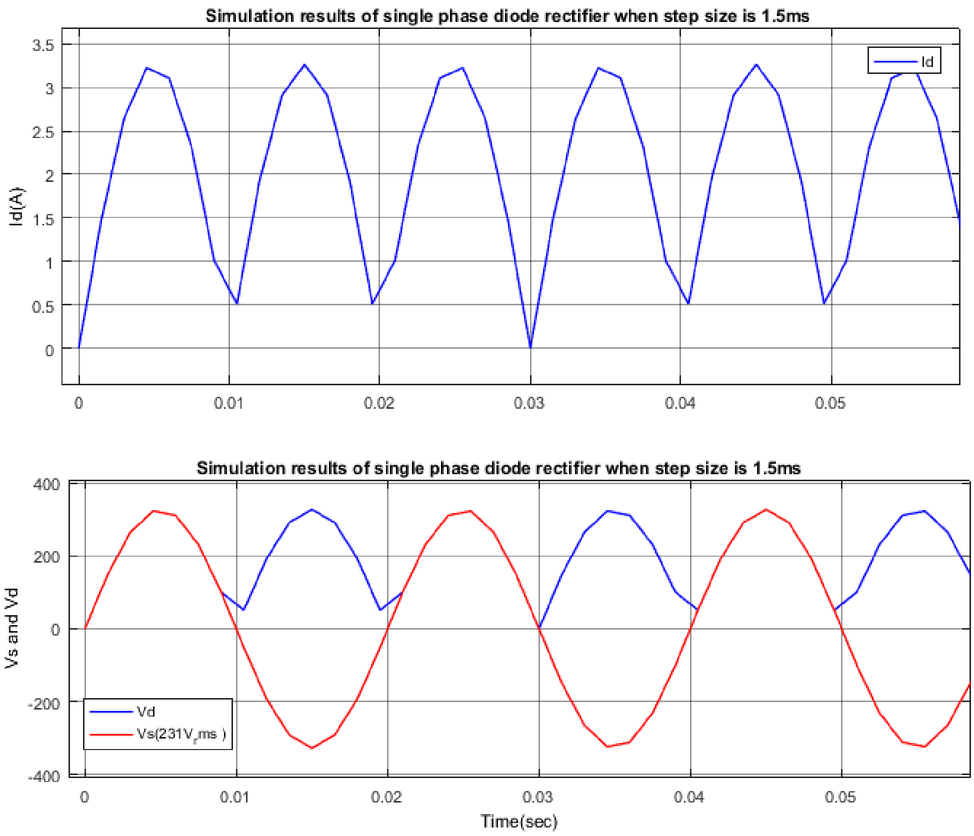

Figure 3:Simulation Results of Id, Vd and Vs when step size is 1.5e-3

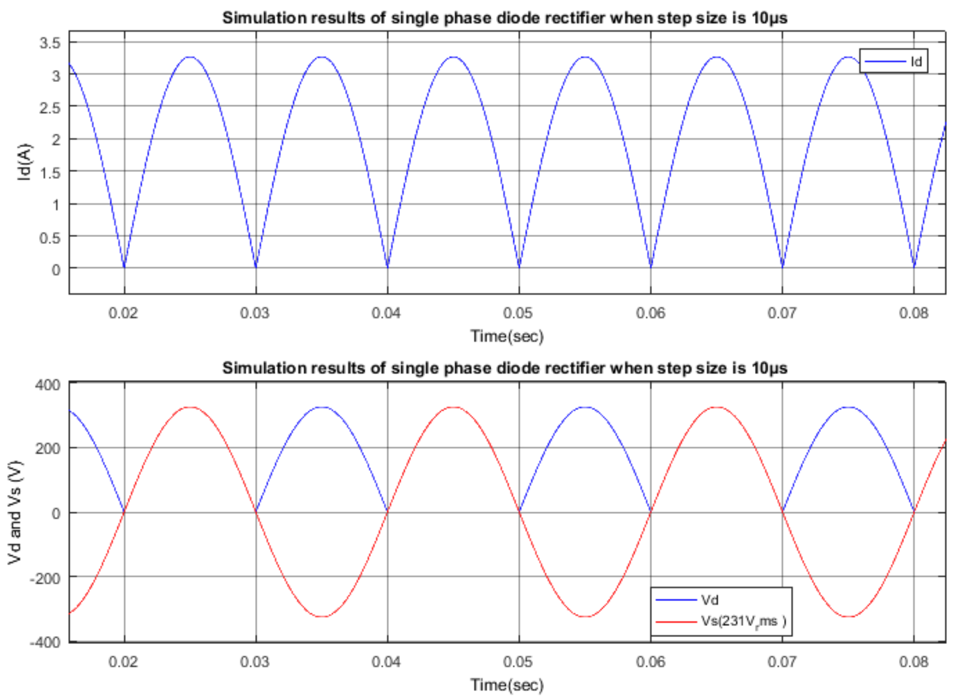

Figure 4:Simulation Results of Id, Vd and Vs when step size is 1e-5

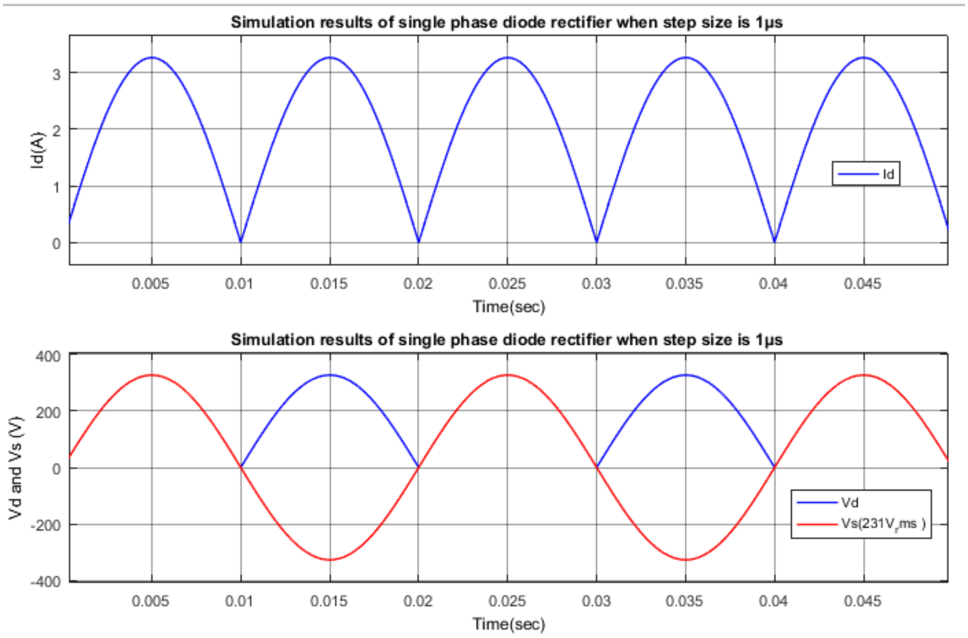

Figure 5:Simulation Results of Id, Vd and Vs when step size is 1e-6

Q2.1.

Line current and the output voltage waveforms of R=25Ω load can be observed in Figure 6. FFT Analysis of the signals yields that Dc component (V_{mean}) of V_{out} is 207.9V whereas THD of the line current is 0. It is expected since the waveform of the line current is a pure sine wave.

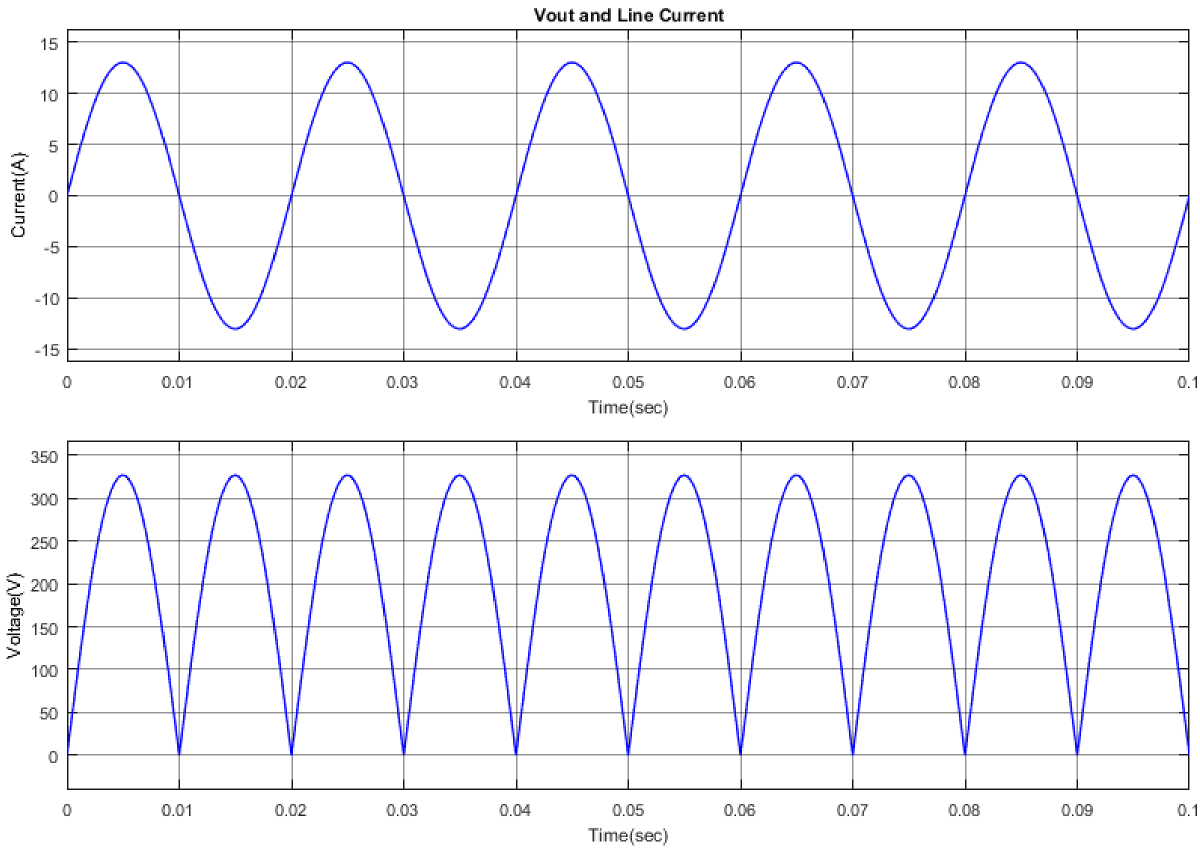

Figure 6:Line current and Output Voltage of R=25Ω load

Line current and the output voltage waveforms of R=25Ω and L=10mH load can be observed in Figure 7. As it can be seen that V_{out} is the same (V_{mean} =207.9V) but now there are distortions in the line current waveform. Higher harmonics of the current signal scaled by the first harmonic can be seen in Figure 8. THD of the waveform is 4.57%.

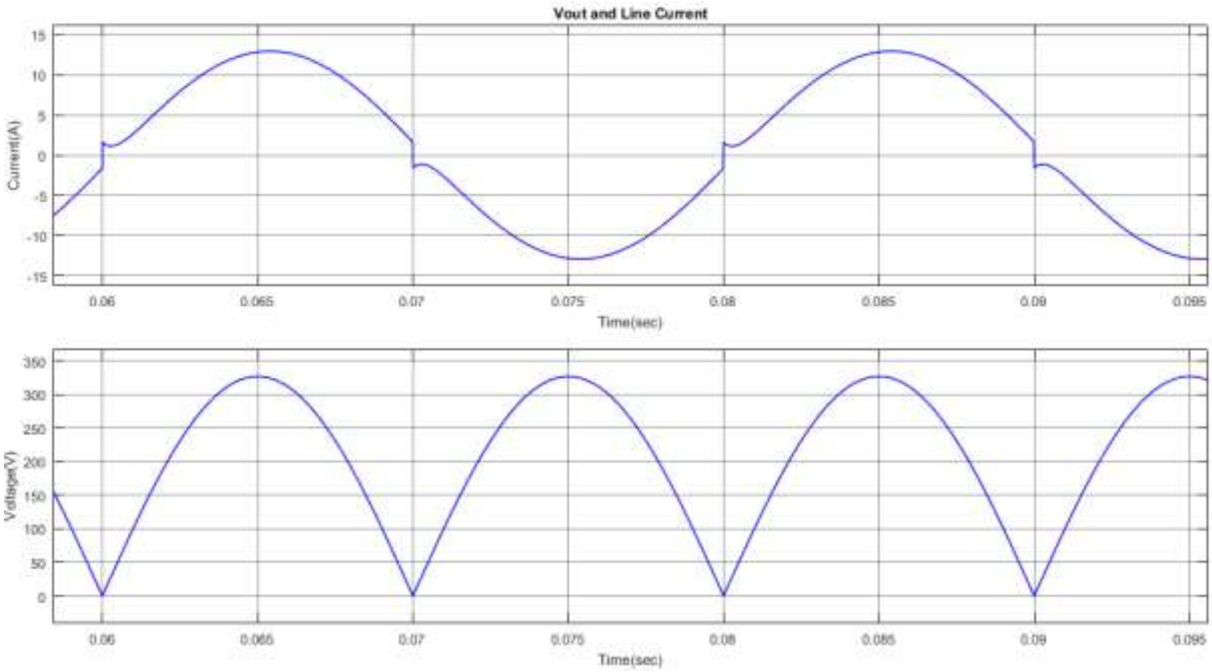

Figure 7:Line current and Output Voltage of R=25Ω L =10mH load

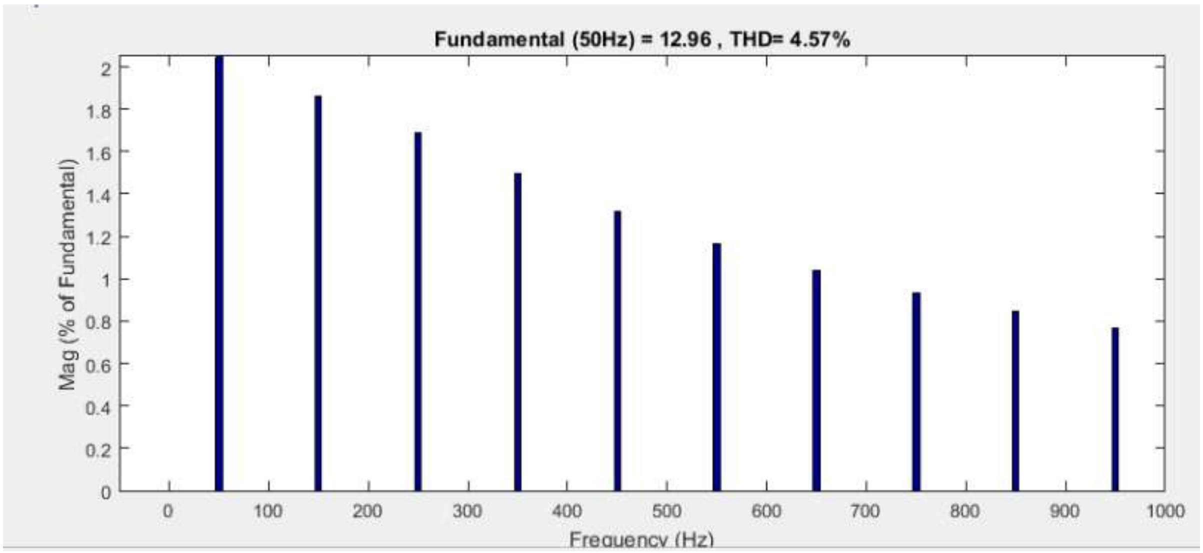

Figure 8:Bar graph of the higher harmonics (Relative to the fundamental) of the line current when the load is R=25Ω L =10mH

Line current and the output voltage waveforms in steady state when the load is R=25Ω and L=1H can be observed in Figure 9. V_{out} is still the same (V_{mean} =207.9V) and distortions in the line current waveform increased. Higher harmonics of the current signal scaled by the first harmonic can be seen in Figure 10. THD of the waveform is 48.25%.

Another thing to note in here is that as load inductance increases, Id approaches to ideal source characteristics.

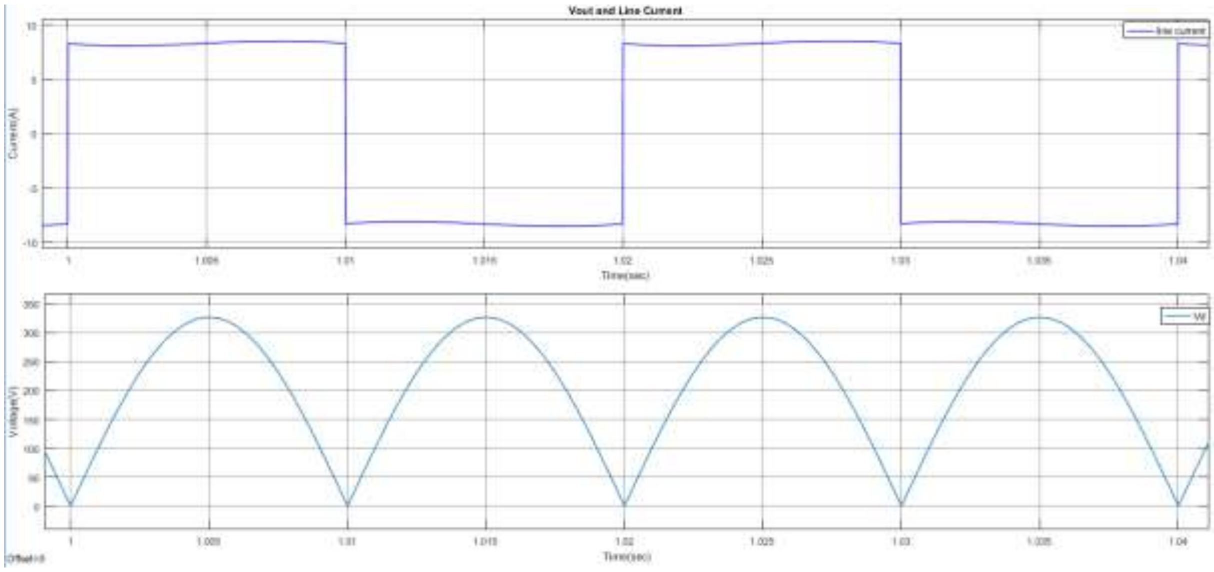

Figure 9:Line current and Output Voltage of R=25Ω L =1H load

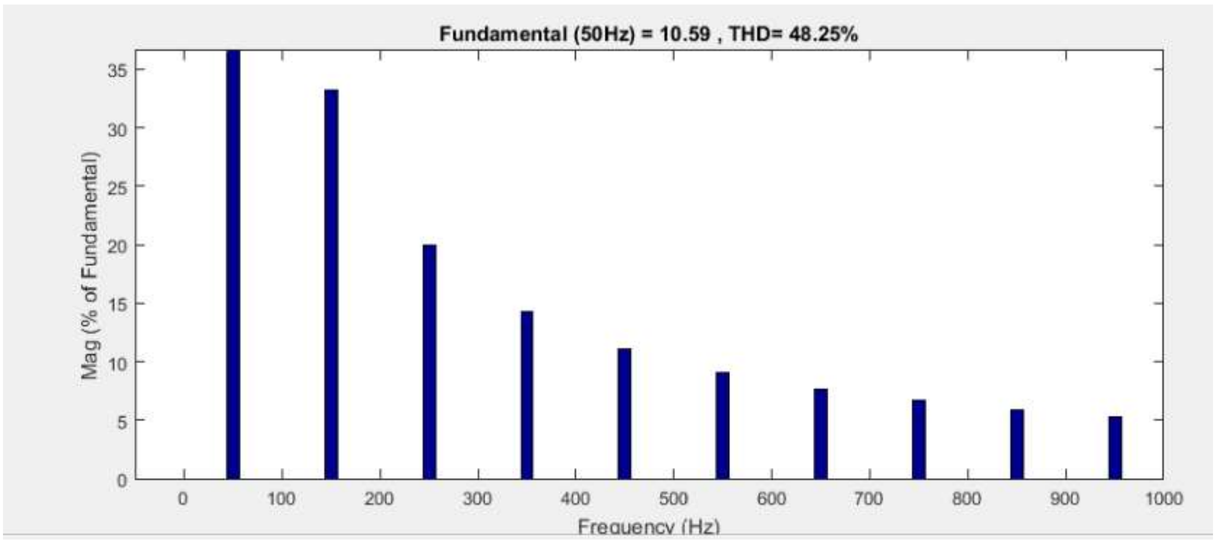

Figure 10:Bar graph of the higher harmonics (Relative to the fundamental) of the line current when the load is R=25Ω L =1H

Q2.2.

In Figure 10 when Vs in its positive cycle D1 and D2 is on so the current passing them is equal to I_{line} and voltage drop of them is equal to zero since the diodes are ideal; whereas the voltage drops on D3 and D4 are equal to V_s

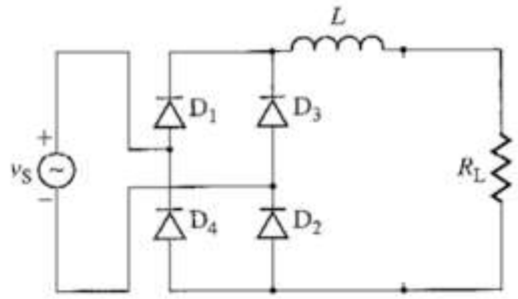

Figure 11: Single phase diode rectifier

In figure 12, the plots showing voltage drop and the current passing through on a single diode in steady state is shown. For simulation we used the third load in part 2.1.

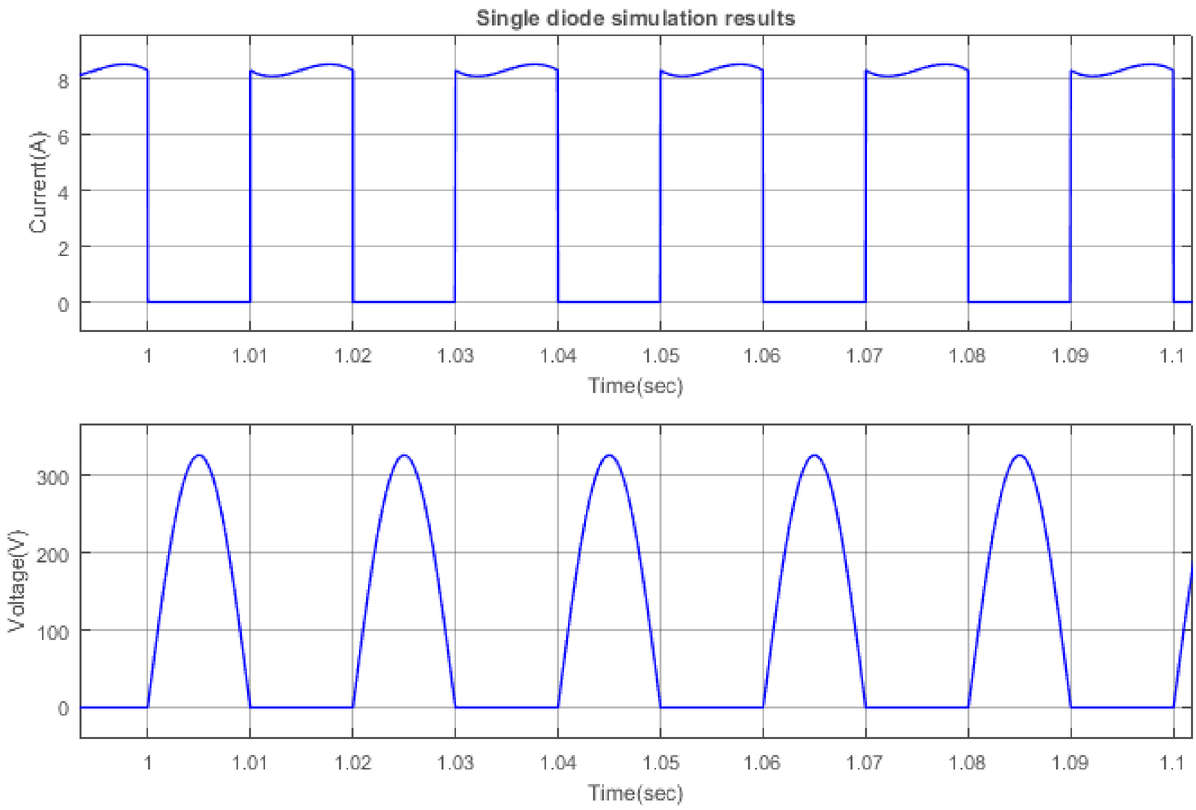

Figure 12:Voltage drop and the current passing through on a single diode in steady state

To select a practical diode for an application several parameters should be considered such as absolute ratings and how they change with temperature rise, thermal parameter, static electrical parameters to evaluate conduction loss, and dynamic parameters to evaluate switching losses. However, for this particular circuit frequency of the grid is 50 Hz which makes some dynamic parameters such as forward & reverse recovery time and switching losses insignificant. A general-purpose diode with standard recovery time should be sufficient.

From Figure 12, the peak voltage drop on diodes is 326.6V whereas V_{av} is 104V whereas, the maximum repetitive current passing is 8.5A and I_{av} is 4.158A.

To choose a discrete diode limiting factors will be maximum repetitive peak voltage (Let's look for a diode with 400V) and $I_{f(av)}$ (Let's look for a diode with 5-6 Amps). We can use 6A4 diode for $0.176 from Micro Commercial Components (http://www.mccsemi.com/up_pdf/6A05-6A10(R-6).pdf) or S5GC diode for $0.15 from Diodes Incorporated (https://www.diodes.com/assets/Datasheets/ds16007.pdf).

To choose a single-phase diode rectifier module we should look for 9-9.5 Amp output rectified output current and again similar maximum repetitive peak voltage values under standard purpose single phase bridges section. Note that I searched for 10Amps because there were less options in 9Amps. We can use MP10 04G-G for $1.61 or GBU 1004-G for $1.33 (http://www.comchiptech.com/admin/files/product/GBU10005-G%20Thru402044.%20GBU1010-G%20RevC.pdf)from Comchip Technology (http://www.comchiptech.com/admin/files/product/MP10005G-G%20Thru242784.%20MP1010G-G%20RevC.pdf)

Obviously, buying four discrete diodes is a cheaper solution. From maximum ratings points of view using discrete diodes is a better selection as well. Also, by using discrete devices we can increase the surface area, this could be useful to decrease thermal rise. However, the power modules are normally assembled in relatively small area to save space and this is the main advantage of the modules.

Q2.3

From Figure 13, we can see that V_{RRM} of the 100Ω load is 327V according to this I_{load} is in phase with Figure 13 and peaks at 3.27A; therefore, we need to find the required capacitance for output voltage ripple smaller than 65V.

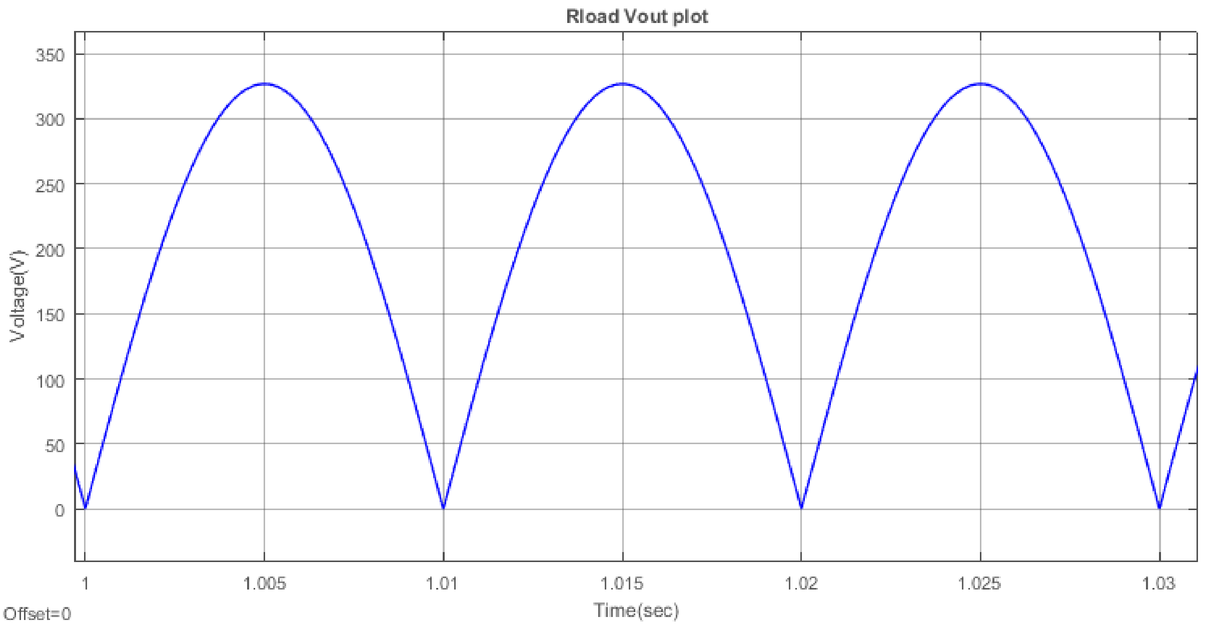

Figure 13:Vout of 100Ω load

To choose the required capacitance time constant should be significantly longer than the time interval between the successive peaks of the rectified waveform (1). When the ripple is small compared to the output peak voltage it behaves (2) where I_{load} is the maximum load current.

$$\tau = R_{load} * C \gg \frac{1}{2f_{line}} \quad (1)$$

$$V_{ripple} = \frac{I_{load}}{2f_{line}C} \quad (2)$$

According to (2), for approximately 50V ripple C should be 654µF which makes τ 6.5 times the time interval between successive peaks of the rectified waveform. In Figure 14, you can observe the output waveforms, note that ripple is approximately 40V. Then, an aluminum electrolytic capacitor whose working voltage is above 305V should be looked for. I chose 620µF capacitor from Cornell Dubilier Electronics with call number CGS621T300R2L. (https://media.digikey.com/pdf/Data%20Sheets/United%20Chemi-Con%20PDFs/U36D%20Series.pdf)

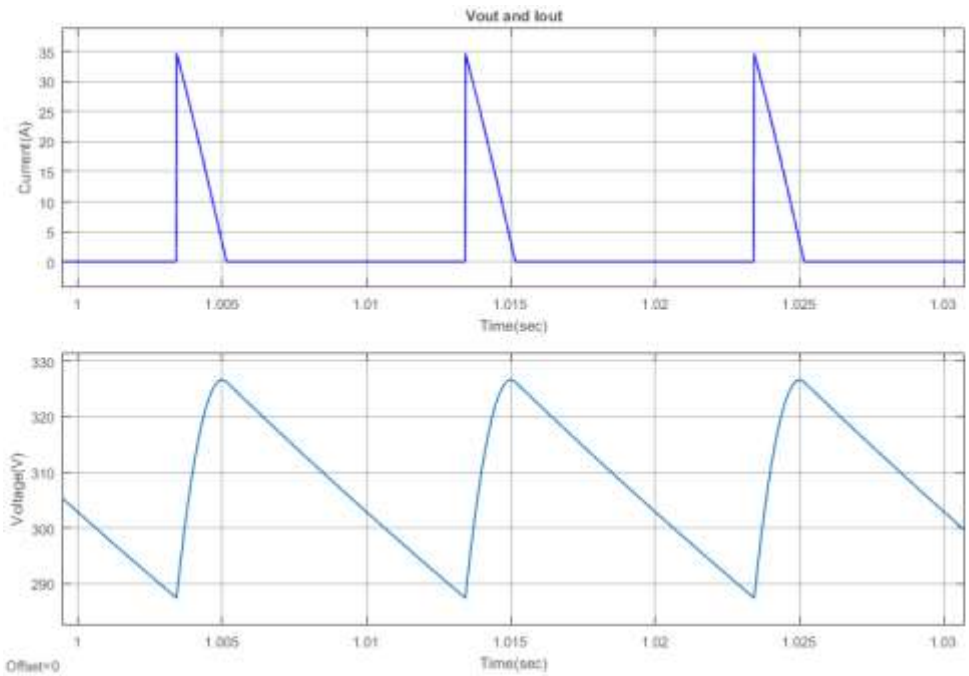

Figure 14:: Voltage drop and the current passing through the load in steady state

Q2.4.

When there is line inductance, L_s =10mH, the transition of the line current from I_d to $-I_d$ or vice versa takes some time which is called the commutation time. Figure 15 shows during commutation V_{out} is zero and transition of the line current is not instantaneous which is not the case in Figure 9 when the line inductance is zero.

From (3) where Ls=10mH, I_d is approximately 8A, w=2π50 rad/s, and finally V_{peak} is 327V u is 22.6°. which 1.78 msec where period is 20msec.Indeed, In Figure 14, commutation time is 2msec.

$$u = \cos^{-1}\left(1 - \frac{wL_s 2I_d}{V_{peak}}\right) \quad (3)$$

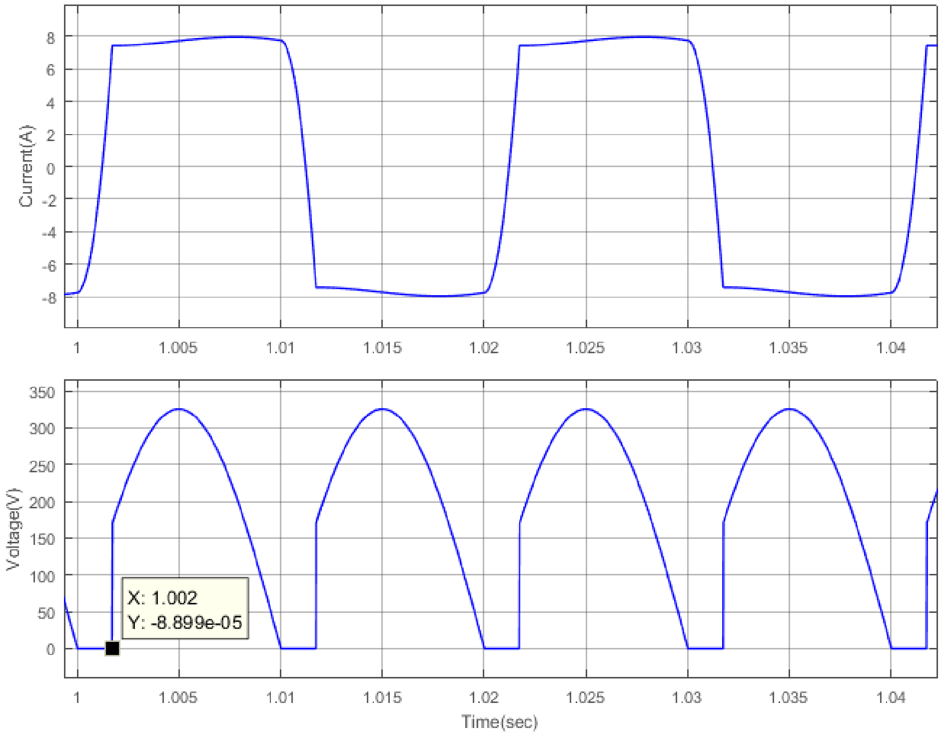

Figure 15:: Line current and Output Voltage of R=25Ω L =1H load when line inductance exists

Q2.5)

In Figure 16, adding a capacitor to the load causes drawn of distorted currents in the source side. These distorted currents can result in distortion in the utility waveform. Voltage at the point of the coupling is expressed by (4) and it can be expressed in terms of current's fundamental and higher harmonics by (5). Then, the distorted component of Vpcc due to higher harmonics is stated by (6). Effect of (6) can be observed in Figure 17.

$$V_{pcc} = V_s - \frac{L_{s1}\, d_{is}}{d_t} \quad (4)$$

$$V_{pcc} = \left(v_s - L_s\left(\frac{d_{is}}{dt}\right)\right) + L_{s1} \sum_{h \neq 1} \frac{di_{sh}}{dt} \quad (5)$$

$$v_{pcc} = L_{s1} \sum_{h \neq 1} \frac{di_{sh}}{dt} \quad (6)$$

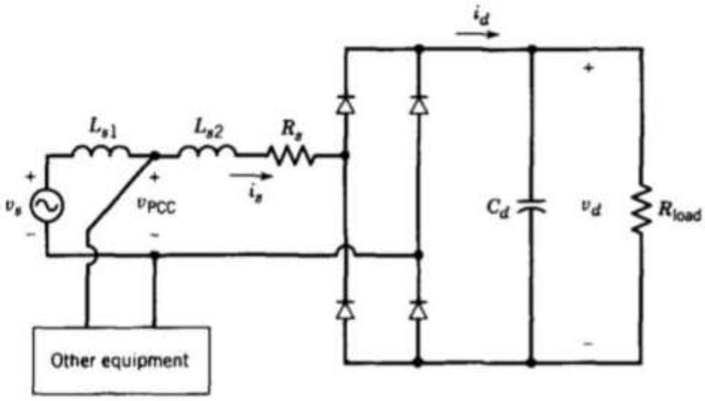

Figure 16:: Line voltage notching and distortion

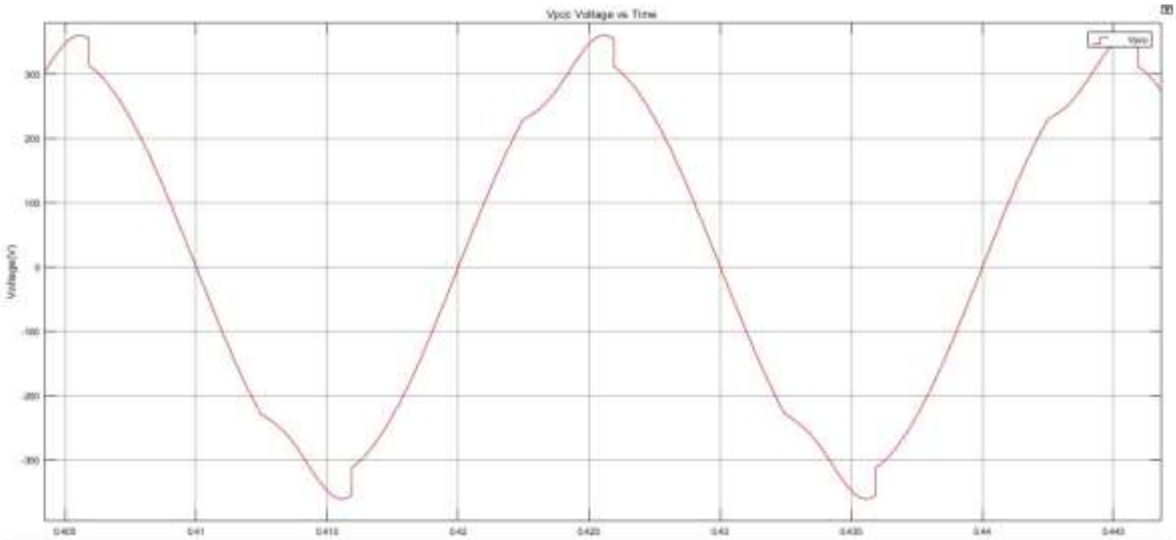

Figure 17:Line voltage at the point of common coupling point

Q3

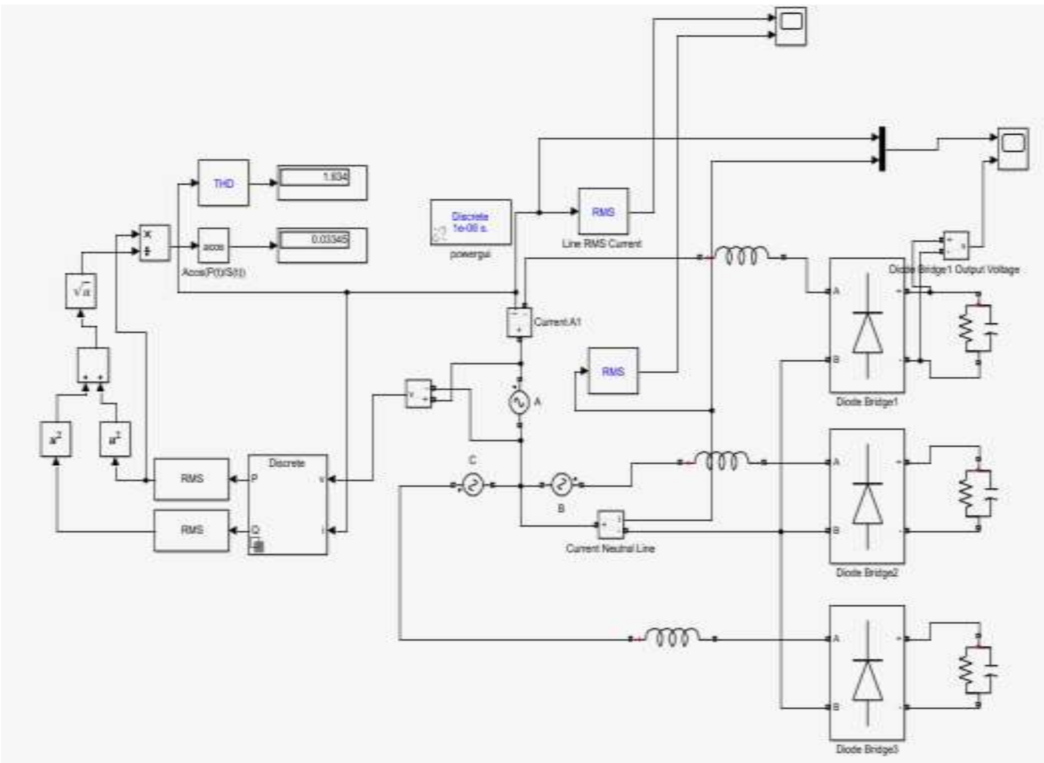

Figure 18: Schematic of the Circuit in Q3 part

Q3.1

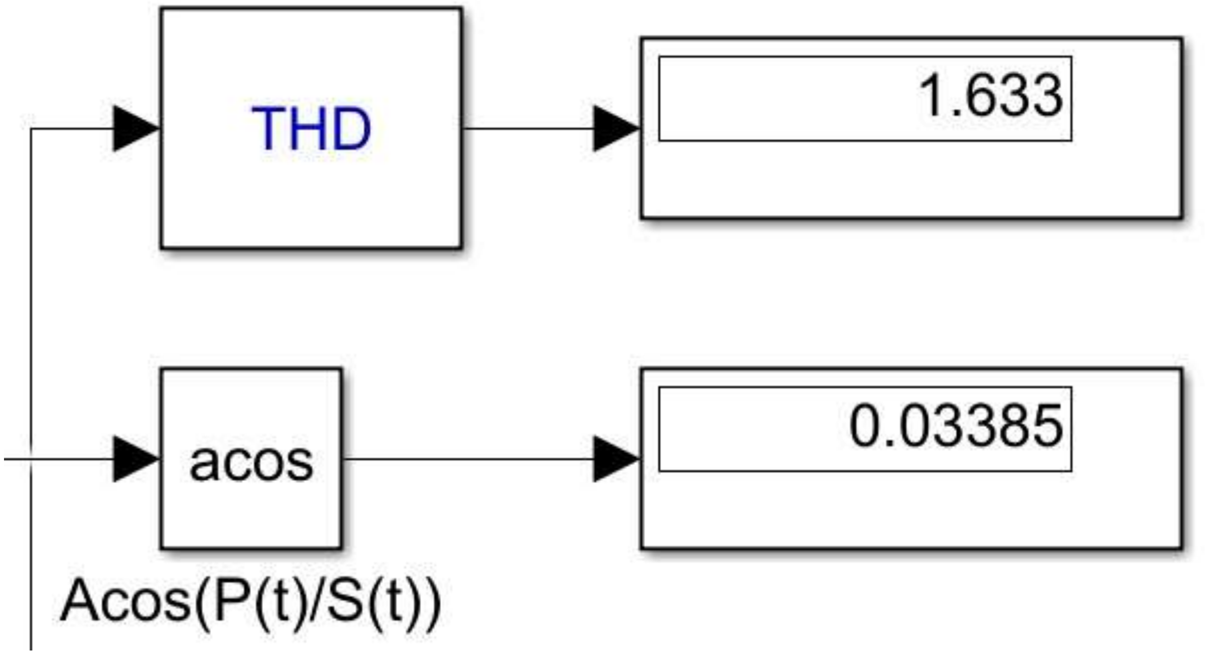

Figure 19: Power Factor and THD of İnput Current

Corresponding to pf=0.03385 and THD=163.3%

The power factor of a load supplied with alternating current is defined as PF = Average Power / Vrms * Irms. If the current is sinusoidal, the power factor is equal to the cosine of the phase difference between current and voltage . Moreover, the R.M.S value is greater than the R.M.S value of the base component because the current also includes harmonics. Therefore, the value calculated with cosinden is lower than the actual power factor value.

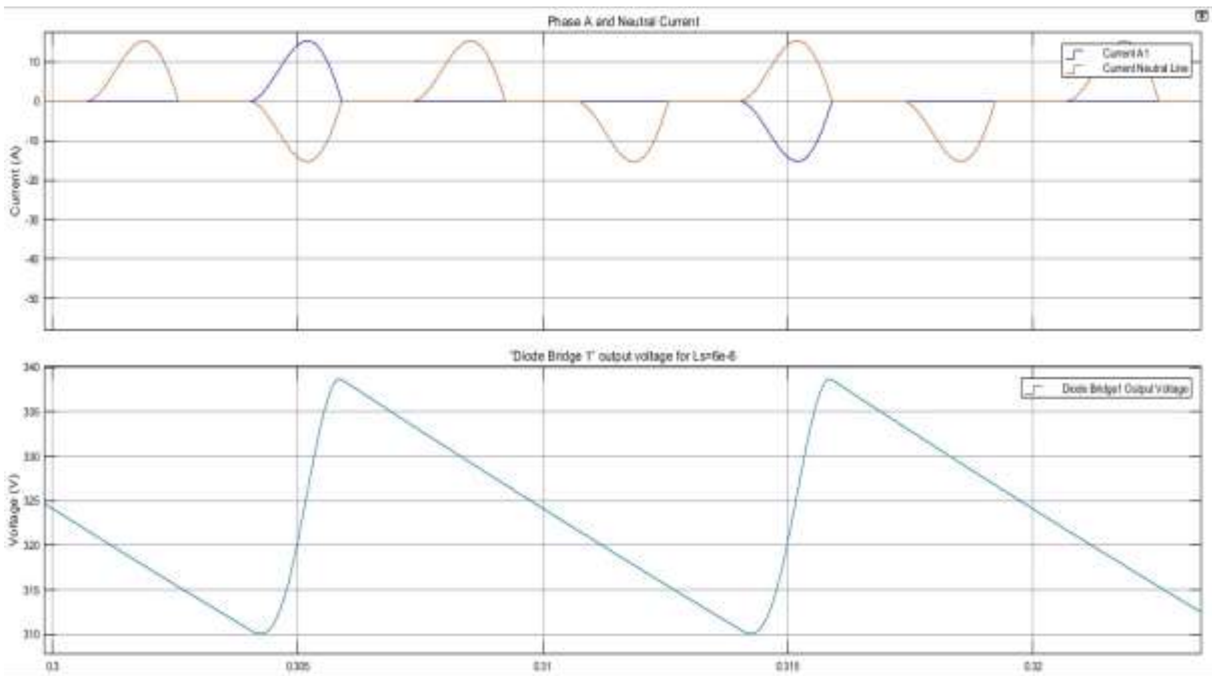

Figure 20: Waveforms for Phase A Current and Neutral Wire Current – DiodeBridge1 vs Time(s)

We observe higher peak current value. The reason is that , current decreases and increases harmonicly related to time and, inductance resists this current change. Therefore in figure 20, we observed small peak and smooth current curve.

Q3.2

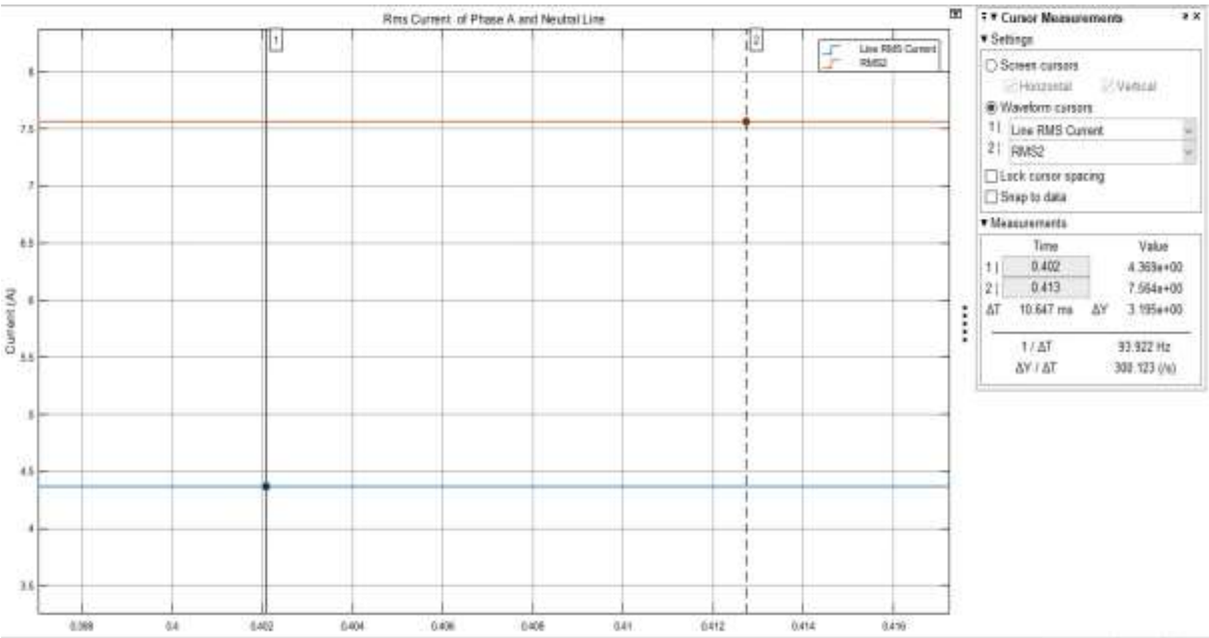

Figure 21: RMS Current of PhaseA and Neutral Line vs Time (s)

As seen figure21, RMS value of current of phase A corresponding to 4.369 A .Therefore we expect that neutral line is equal to 4.369*√3 and it is equal to expected value which is that 7.564 A. Because, neutral line is equal to summation of IphaseA+IphaseB+IphaseC in Figure 20 we observed there is 120degree phase difffrence between IphA,IphB and IphC .

Q3.3

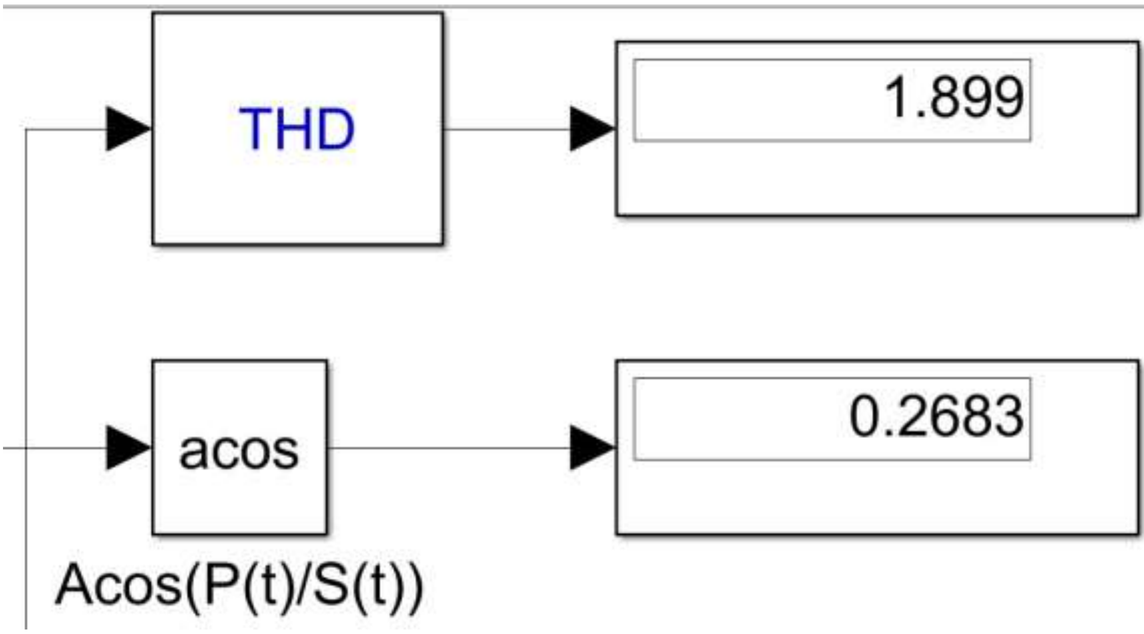

Figure 22: Power Factor and THD of İnput Current (Ls=0)

Corresponding to pf=0.2683 and THD=189.3% . Power factor is greater than Q3.1 . Because in part Q3.1 , there is a line inductive effect. It compensate power factor. Therefore we get higher pf value.

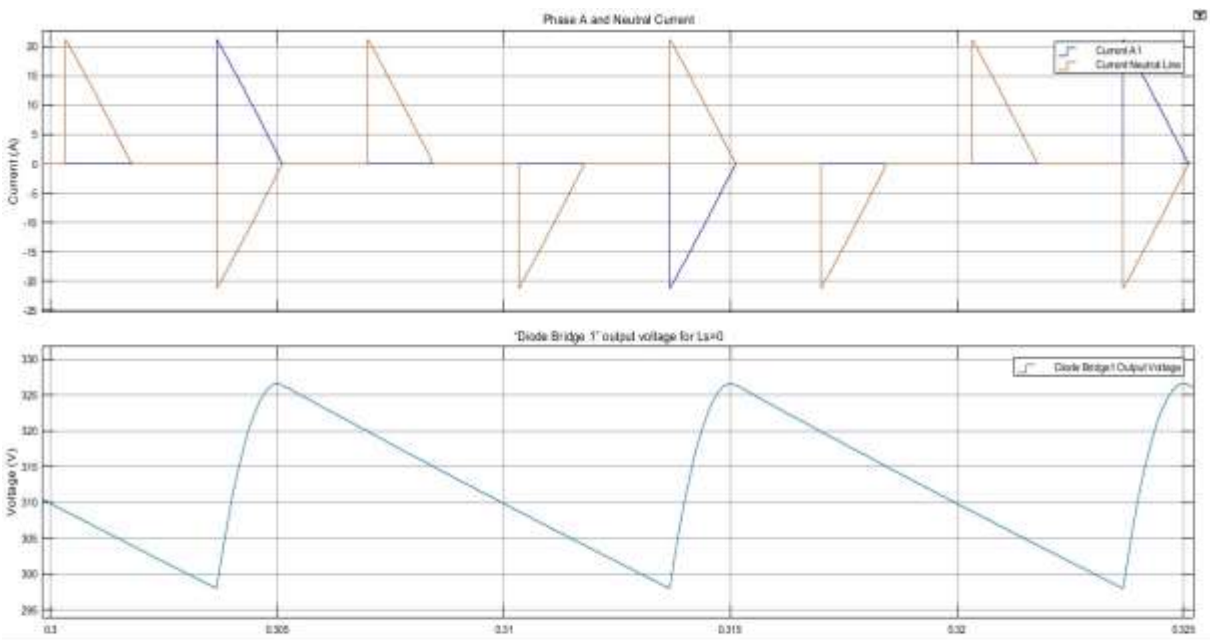

Figure 23:Waveforms for Phase A Current and Neutral Wire Current – DiodeBridge1 (Ls=0)

We observe higher peak current value. The reason is that , current decreases and increases harmonicly related to time and, inductance resists this current change. Therefore in figure 20, we observed small peak and smooth current curve. On the otherhand, figure 23, we get sharp current curve because of absence inductance line.

According to the previous situation from figure 21 , when the inductor began to transmit current, the deviation in the sinusiodial form of the input voltage was realized. In addition, the capacitor started to discharge the electric charge at a higher voltage and, as seen in the figure23 , about 11 volts differences were observed in the old (Q3.1) and new cases(Q3.3).

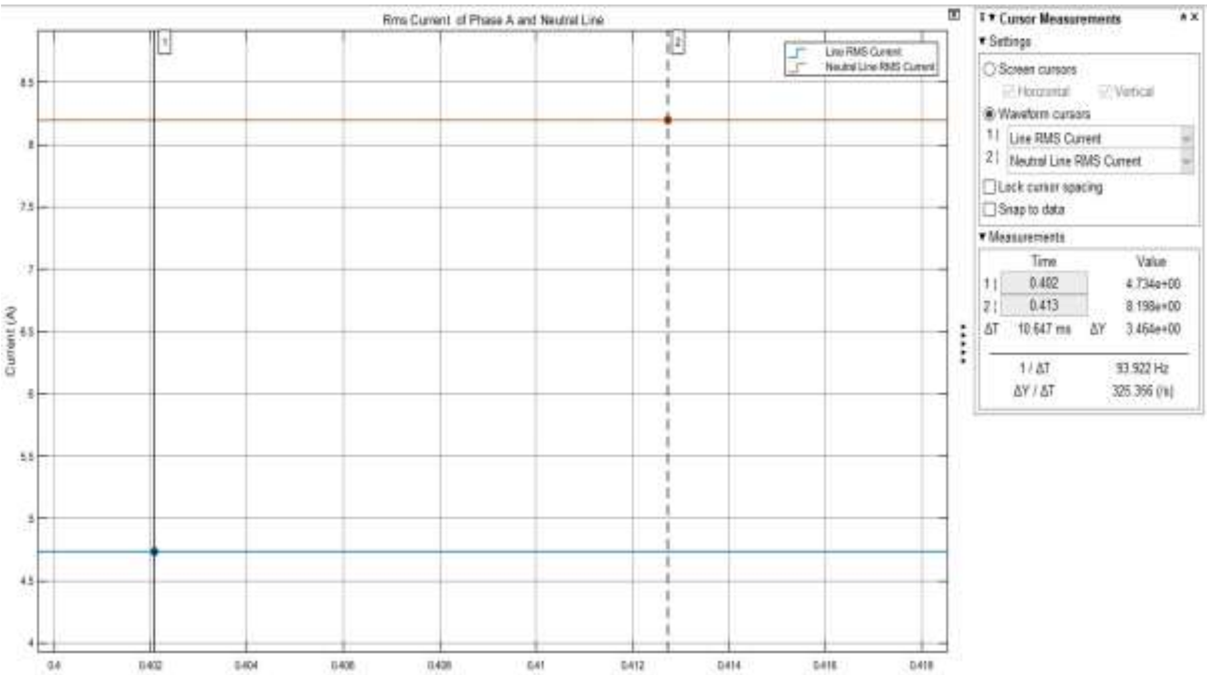

Figure 24:Figure 11: RMS Current of PhaseA and Neutral Line

As seen figure24, RMS value of current of phase A corresponding to 4.734 A .Therefore we expect that neutral line is equal to 4.734*√3 and it is equal to expected value which is that 8.198 A.

3) Conclusion

In part 1 , we observe effect discrete time step size of single-phase diode rectifier. We compared the results and comment on the differences step size and we learn what is the importance of step size in a digital simulation environment.

In part 2, we analyzed behavior of single phase diode rectifiers under different types loads.

In part 3 , We observed rectifier's behavior on conditions whether there is a line İnductance effect.

Obviously, the project achieves that we gain how to analyze the single phase rectifiers. Also we comprehended effects of Pf , THD ,RMS factors on analysis.

4) Reference

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- http://keysan.me/presentations/ee463_diode_rectifiers.html#1