**MIDDLE EAST TECHNICAL UNIVERSITY**

**ELECTRICAL AND ELECTRONICS ENGINEERING DEPARTMENT**



**EE463 STATIC POWER CONVERSION-I**

**PROJECT #1 REPORT**

**Due Date: 25.11.2018**

**Team Members**

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**Introduction**

In this project we have made simulations, observations and inferences about single phase diode rectifiers. In the beginning, we learnt that choosing right step size is very important when one is performing discrete time simulation. After that, we observe output voltage waveform of a single phase diode rectifier with different loads. We made comments using the background information gained in lectures. Moreover, we select a single diode and diode rectifier module for our single phase diode rectifier. In this step, we examine different diodes from datasheets and indicate the parameters we looked at while selecting a diode. Lastly, we observe output voltages of rectifiers when there is capacitor at load and line inductance at source side and made comments about differences between parts. In the last section, we made some calculations of a circuit includes 3 single phase diode rectifiers.

Aims of this report are to show certain simulation results and comments related to them and making interferences using theoretical background learnt about rectifier in the class.

**Question 1-)** In this part, we try different step sizes for single phase rectifier and we observed that they different from each other. We performed our simulations with discrete time and constant step duration. Performing the simulation might be longer or shorter than the duration of time step since computer is also working discrete domain. Due to that, computer takes data with respect to step size. When step size is small like 1.5 msec in figure 1, we did not observe waveform clearly since computer take less data and some point is missed. In other words, computer needed more time to perform the simulation than time step. When we increase step size, computer take more data at unit time and missed point decrease. Because of that, we observe waveform clearly in figure 2 and 3. For computer, step duration is very important to interpret waveforms correctly. On the other in some cases decreasing the time step increases the simulation time. Hence it is important to perform the simulation in correct time step.

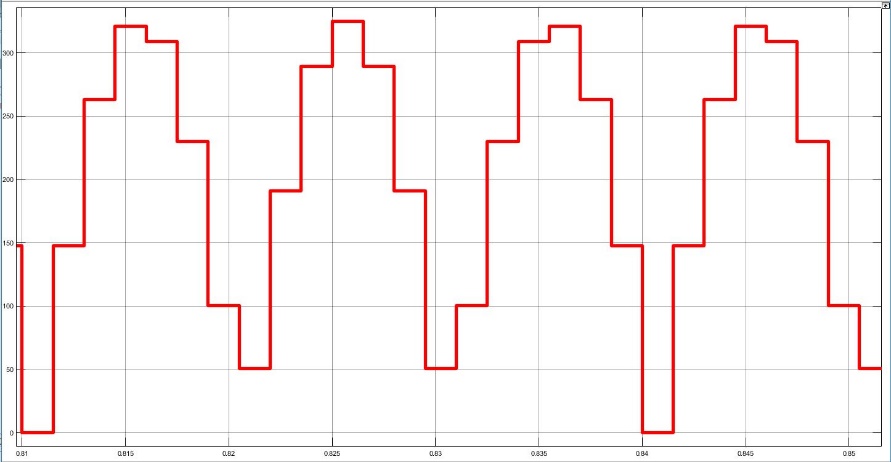


Figure 1: Output waveform at 1.5 msec

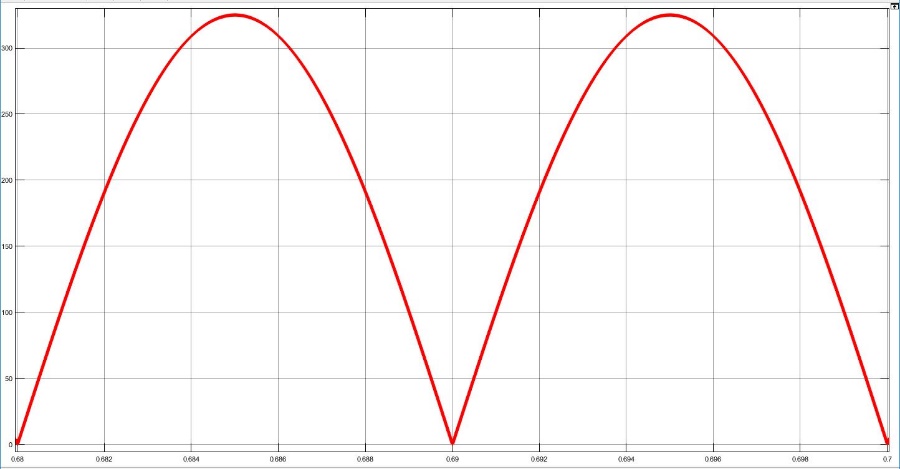


Figure 2: Output waveform at 10 usec

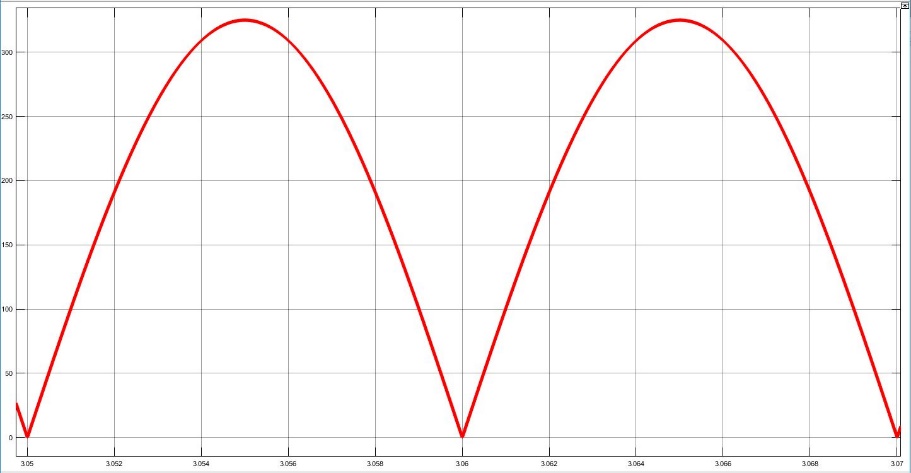


Figure 3: Output waveform at 1 usec

**Question2-)**

**Part 1-)**

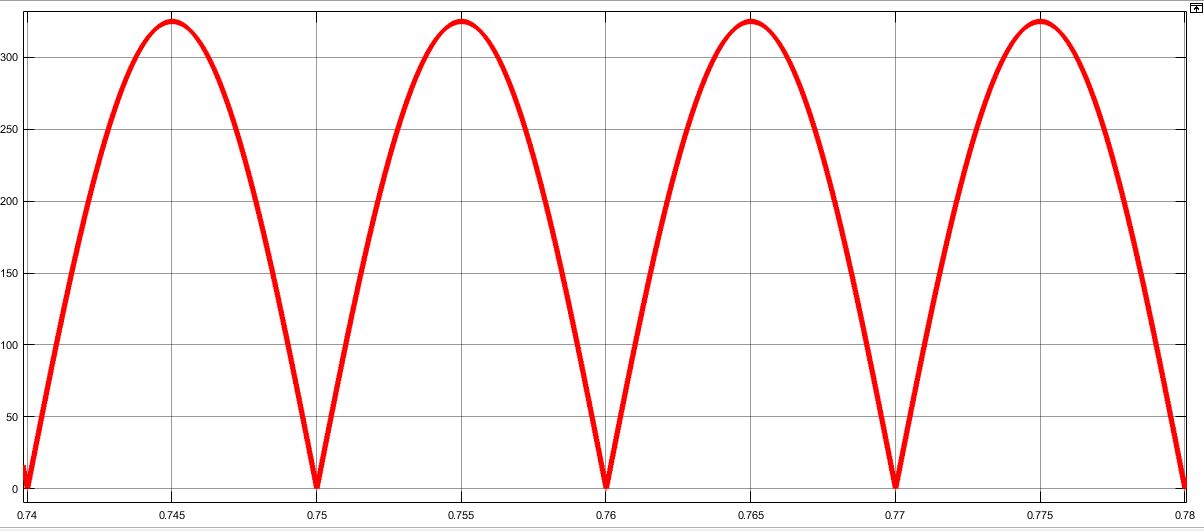


Figure 4: Output voltage waveform with resistive load of R = 25 ohm

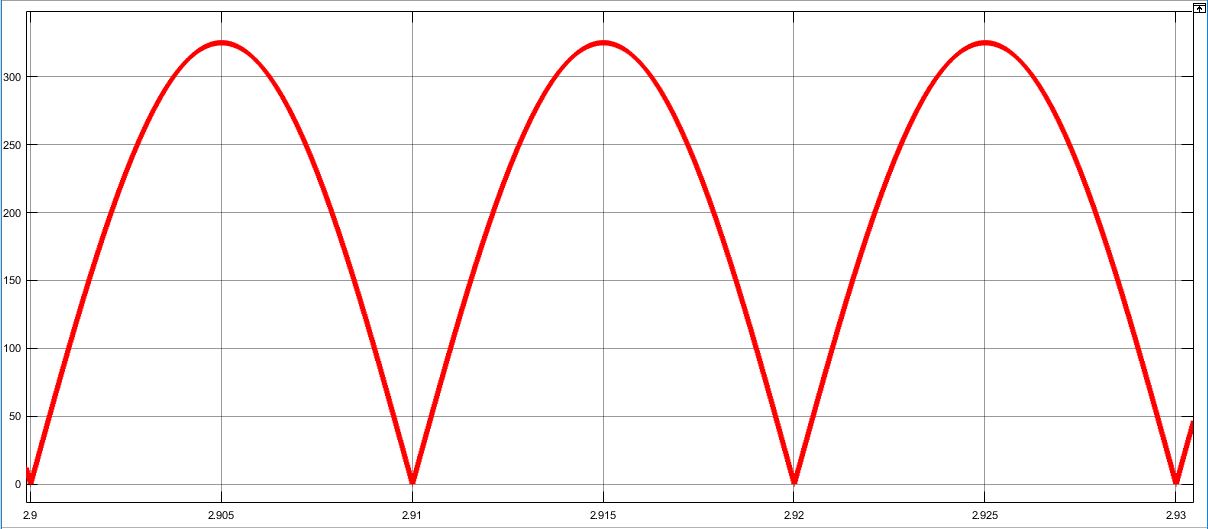


Figure 5: Output voltage waveform of RL load of R = 25 ohm, L = 10 mH

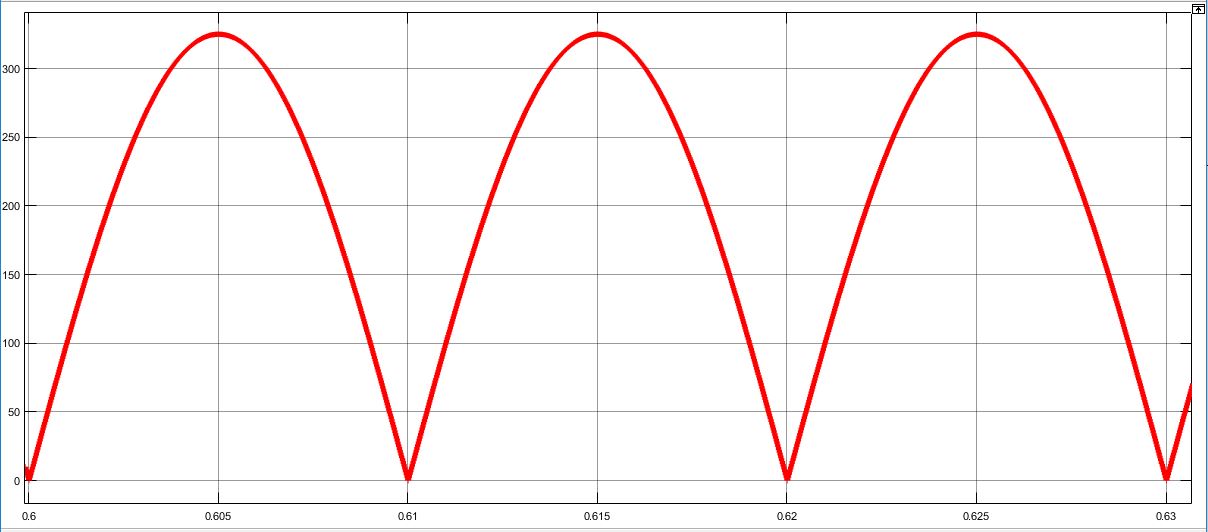


Figure 6: Output voltage waveform of RL load of R = 25 ohm, L = 1 H

Output waveforms of three simulation results are in the figure 4, 5 and 6. In those pictures, we see that output waveform does not change with adding inductor. Because of that, average voltage also does not change and average value is almost 207 V. However, THD of line current changes with inductor values. When there is only resistor and no inductive element, THD is zero since resistor does not any harmonic effect to circuit. When there is an inductive, THD increases with its value.

In this part, we understood that output voltage of single phase rectifier does not depend on load of bridge.

**Part 2-)** In this part we are asked to choose both a single diode and rectifier module for the converter we simulate in part 1. For choosing single diode, we looked at the average current first. You can see the result in figure 7.

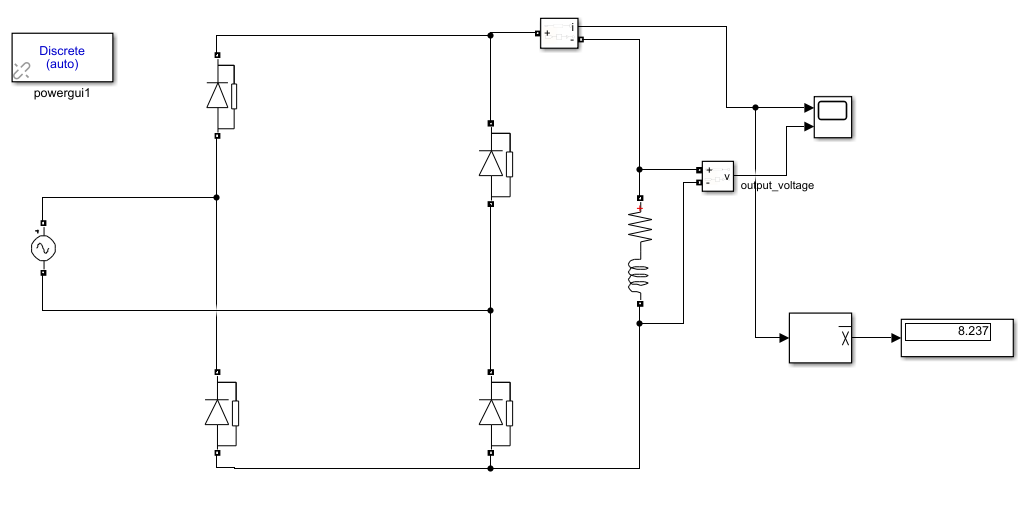


Figure 7: Average current of rectifier

Since we have an average current 8.2 A, after putting a margin, we have looked at diode has average forward current 10 A. The code and related link of the selected diode provided below.

* Product code: SFF1006GC0G-ND
* Product link: <https://www.digikey.com/products/en?keywords=SFF1006GC0G-ND>
* Datasheet link: <https://www.taiwansemi.com/products/datasheet/SFF1001G%20SERIES_L14.pdf>

We know that diodes has large forward voltage drop when rated maximum voltage is high i.e. forward voltage drop of a diode is proportional with the rated maximum voltage. Thus, in order to keep forward voltage drop low, we select a diode that has enough rated maximum voltage. The numerical values of these two critical parameters indicated in table 1.

Table 1: Maximum RMS voltage and forward voltage drop ratings of different type of diodes

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Parameter | 1001G | 1002G | 1003G | 1004G | 1005G | 1006G | 1007G | 1008G |
| VRMS(MAX) | 35V | 70V | 105V | 140V | 210V | 280V | 350V | 420V |
| VF\* | 0.975V | | | | 1.3V | | 1.7 V | |

\*For IF = 5 A

The highlighted values are our diode type and its ratings. Moreover notice that after 280 VRMS forward voltage drop increases.

Maximum repetitive peak reverse voltage of our diode is 400V which is enough for our application. In addition to these parameters our diode has 35 ns recovery time in certain operating conditions, lastly it has a maximum reverse current (at rated VR) 10 µA. Since money is not our primary concern we try to choose a diode has good performance.

We also need to find single phase diode rectifier module for this part. We have same average forward rectified current 8.2 A which means that we need to look for 10 A average forward current.

Selected component code and link added in below.

* Product code: GBU1004DI-ND
* Product link: <https://www.digikey.com/product-detail/en/diodes-incorporated/GBU1004/GBU1004DI-ND/1935027>
* Datasheet link: <https://www.diodes.com/assets/Datasheets/ds30052.pdf>

In this rectifier module, we had the same voltage ratings as in the single diode:

* VRRM = 400V (Peak repetitive reverse voltage)
* VR = 280 V

However, when we compare single diode and rectifier bridge, there are some differences shown in table 2.

Table 2: Comparison of single diode and rectifier bridge:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Parameter | | Single Diode | Rectifier Bridge | Comparison |
| Forward Voltage (VF) | | 1.3V | 1.0 V (per element) | When we compare these values for same voltage ratings rectifier bridge has smaller forward voltage which is desired |
| Maximum reverse current (IR) | T=25o C | 10 µA | 5 µA | Rectifier bridge has smaller reverse current in the our operating conditions which implies that we will have smaller conduction losses in rectifier bridge |
| T=125o C | 400 µA | 500 µA |

Note: Both components measured at 1.0MHz and applied reverse voltage of 4.0V DC

Although both components have same operating and storage temperature range (-55o C to +150o C), bridge rectifier gets heated up more easily with the current flows thru itself due to its smaller surface area.

Lastly, bridge rectifier is cheaper than 4 discrete diode.

**Part 3-)** We find capacitor value as 0.47 uF. In this situation, average voltage is 300.5 and 20% of it is 60.1 V. Our ripple voltage is around 50 V. We can see output voltage waveform in the figure 8.

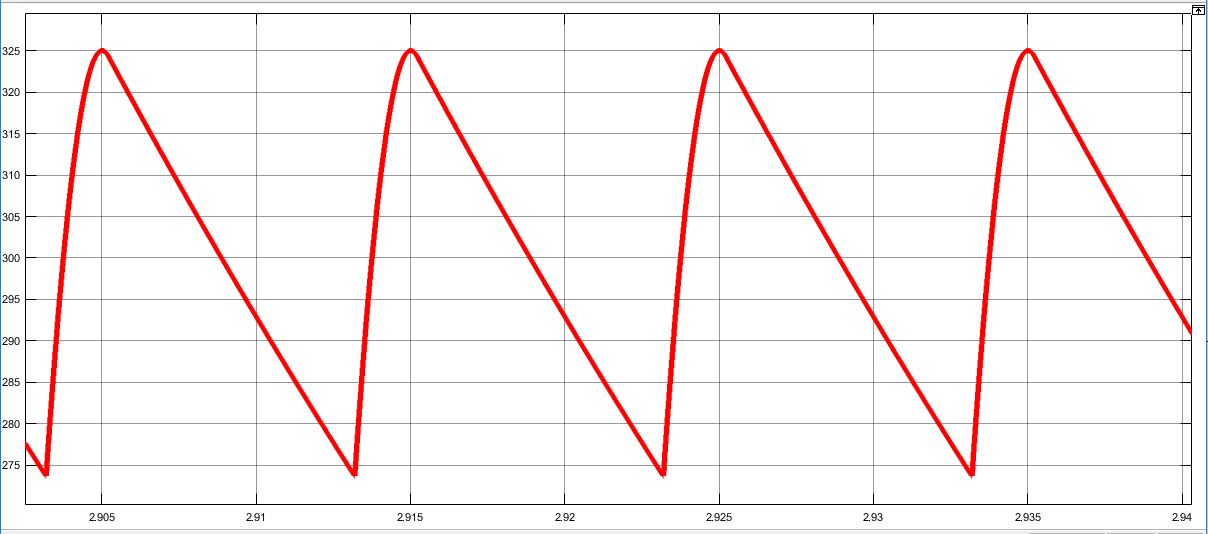


Figure 8: Output waveform of single-phase rectifier with RC load

You can see the product code and link related to selected capacitor below.

* Product code: 493-12648-1-ND
* Product link: <https://www.digikey.com/product-detail/en/nichicon/UVK2GR47MED1TD/493-12648-1-ND/4328729>
* Datasheet link: <http://nichicon-us.com/english/products/pdfs/e-uvk.pdf>

We have selected an aluminum electrolytic capacitor that has 400 V rated voltage

**Part 4-)**

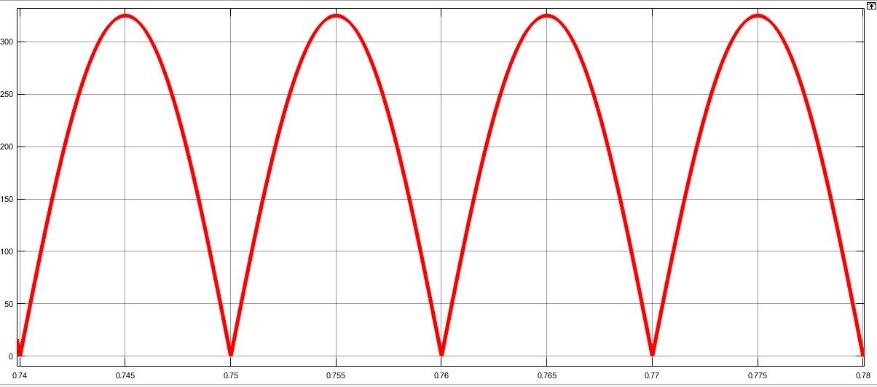


Figure 9: Output voltage waveform without line inductance

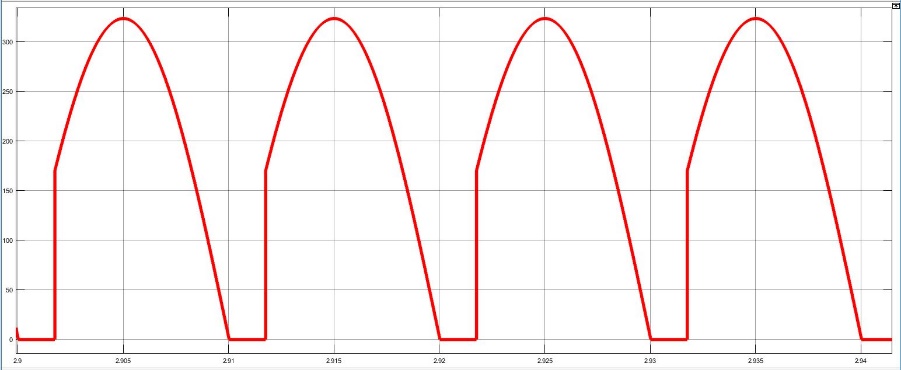


Figure 10: Output voltage waveform with line inductance

Without Ls in the figure 9, we do not observe any changing the output voltage waveform. However, with source inductance Ls in the figure 10, as we expected, we observed commutation effect. When source has inductive effect, there is lost of voltage. This situation is observed when all diodes in bridge are on since inductor has some current and this current do not allow to turn off the diodes.

**Part 5-)** In this part we consider a case taken from our text book. Waveform of source voltage is indicated in Figure 11.

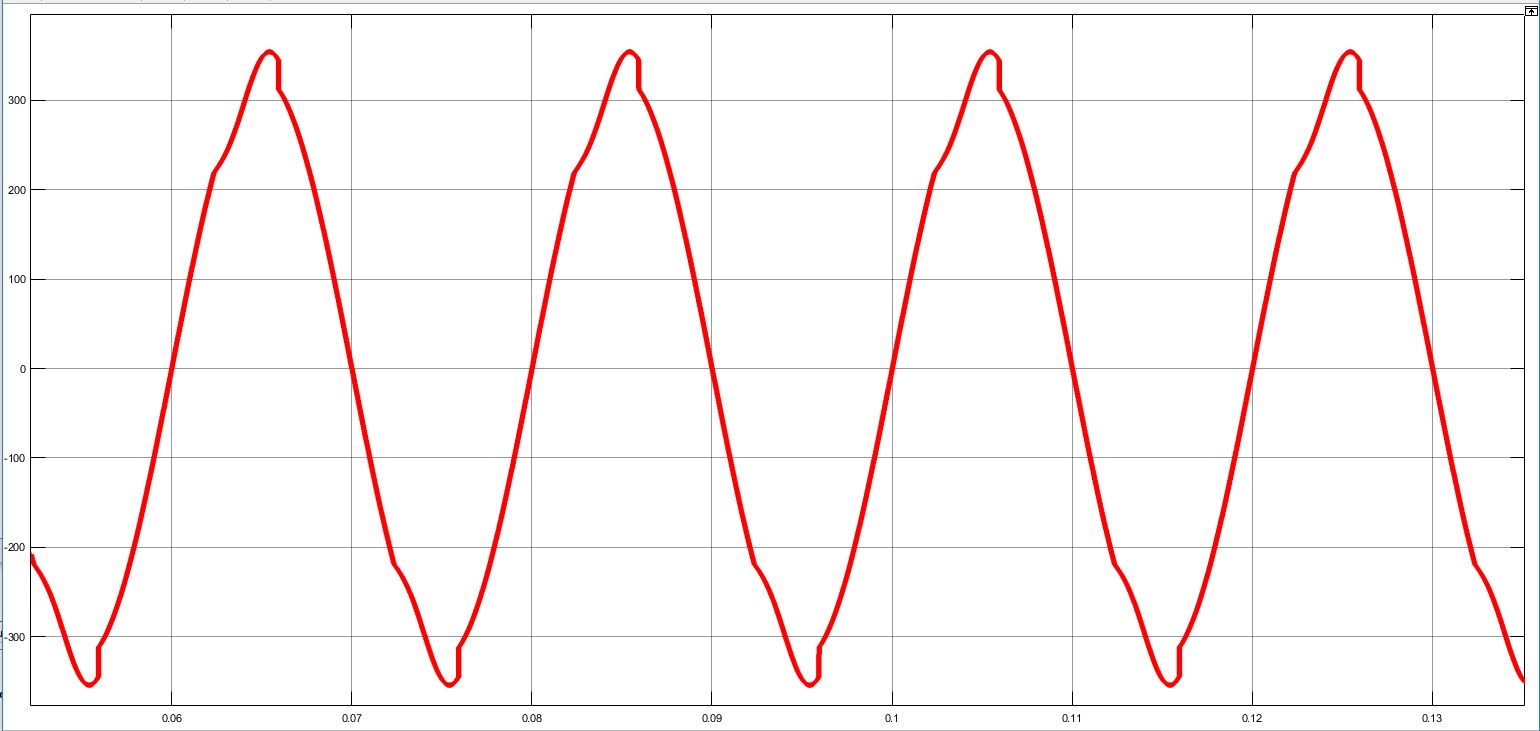


Figure 11: Voltage waveform from point of common coupling

As seen in figure 11, voltage waveform is distorted considerably. The reason is current harmonics of the source current. Since we have harmonic components in the current from Eq. 1 below there are distortions.

vPCC=vs-Ls1dis/dt (1)

vpcc is voltage taken from source inductance end to neutral and is is source current with the high harmonic components.

**Question 3-)**

**Part 1-)**

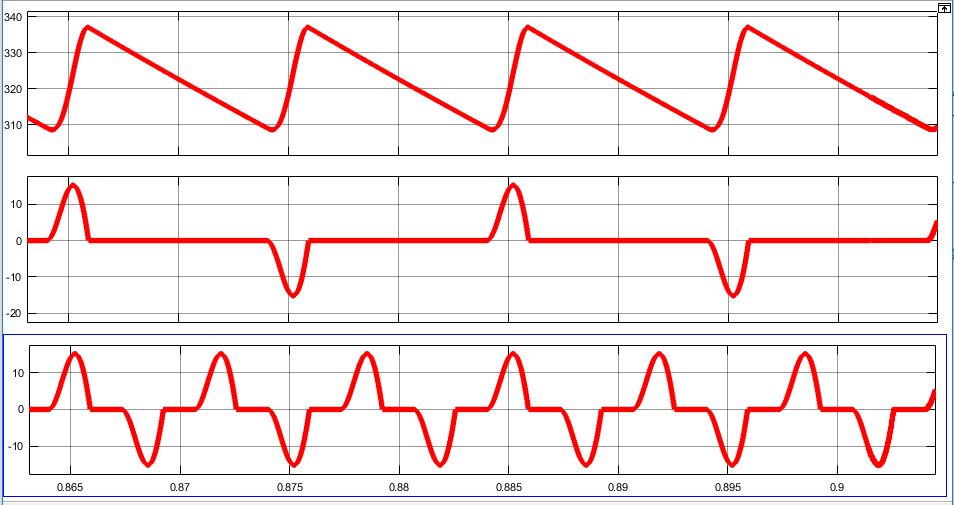


Figure 12: waveforms for output voltage, Phase A current and neutral wire current, respectively

As we can see figure 12, output voltage has ripple because of capacitor. THD value of line current is %163,30. There is huge amount harmonics in it.

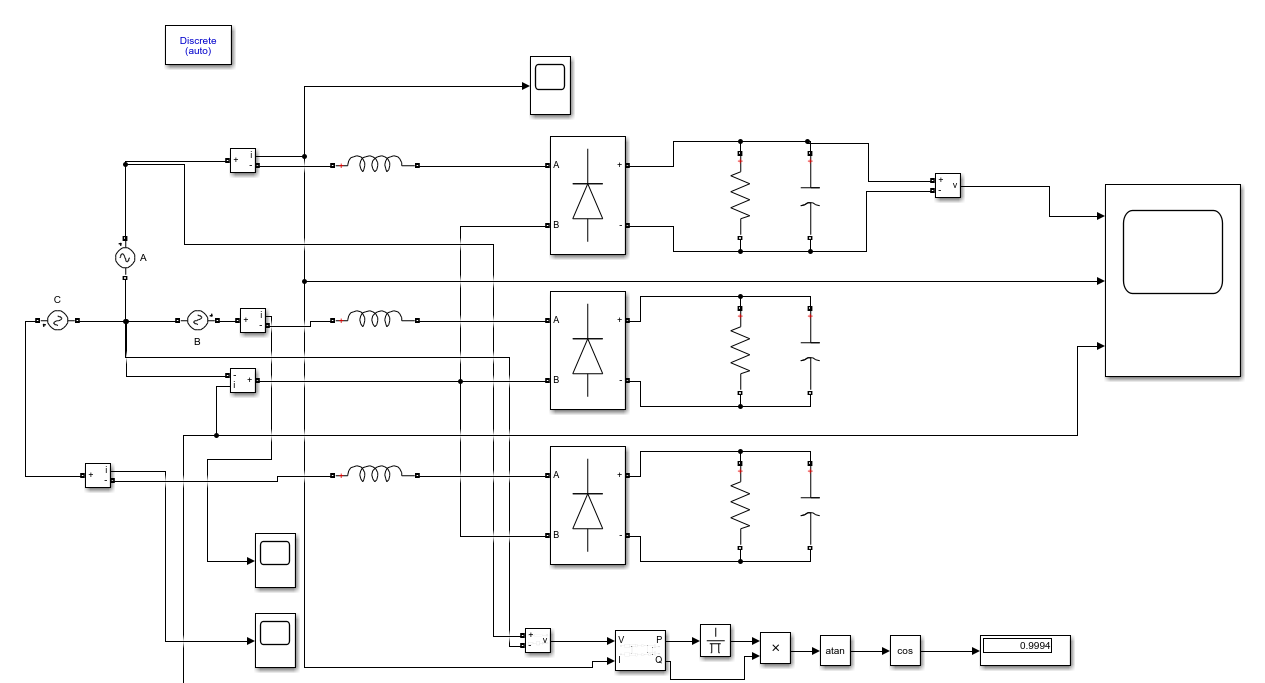


Figure : Power factor calculation of input current

In power factor calculation in the figure 13, we did not find any block in the Simulink. Due to this, we calculated the factor its definition. We found 0.9994.

**Part 2-)**

RMS values of phase A, phase B, phase C and neutral current are 4.346, 4.343, 4.343 and 7.523 Arms, respectively. RMS value of line current is the same. We were expecting this solution since they provide the current to system. Also, Neutral current is greater since this current vectoral sum of line currents. This is basically one of the phase current multiply with √3. As we can see in the figure 12, frequency of this current and peak value is greater.

**Part 3-)**

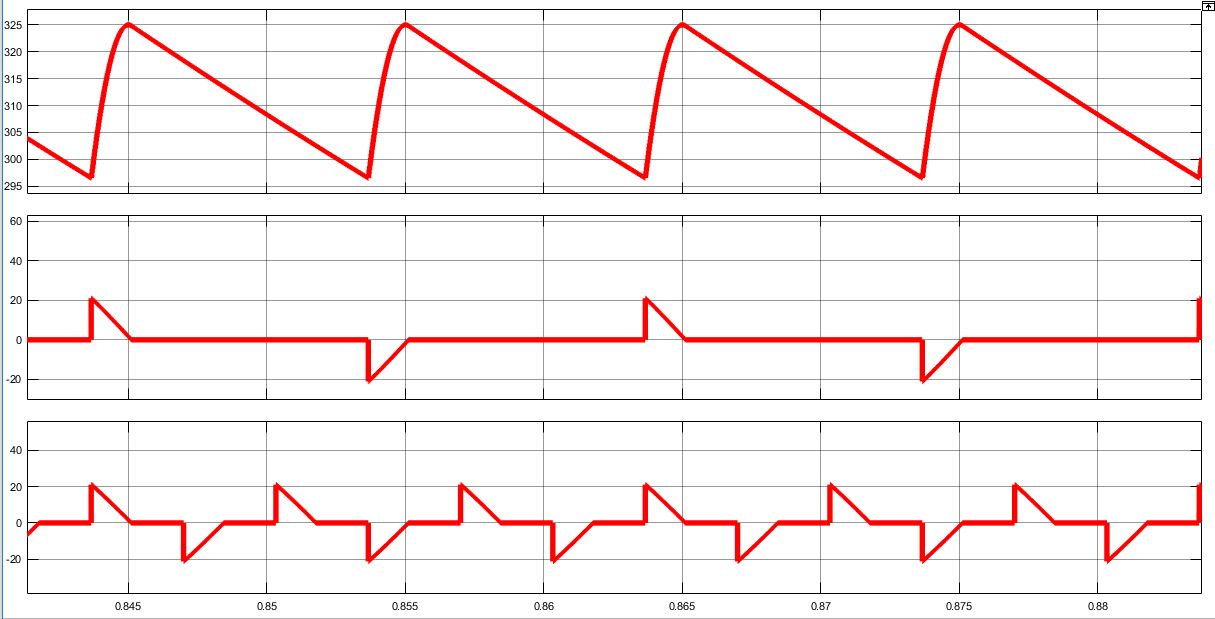


Figure 14: waveforms for output voltage, Phase A current and neutral wire current, respectively

THD value of line current is %189.91 and RMS values of phase A, phase B, phase and neutral current are 5.811, 5.854, 5.812 and 10.1 Arms, respectively.

As we expected, RMS value of line currents is the same and neutral current greater as explained in part 1. Also, without Ls in the figure 14, RMS values increased since we did not loss voltage due to commutation unlike part 1. This is also observed in Figure 8. When we do not have any line inductances our phase current waveform become sharp edged unlike part 1 with line inductance. Although, with or without line inductance, we had large THD values we observed smoother in the first part as indicated in figure 14.

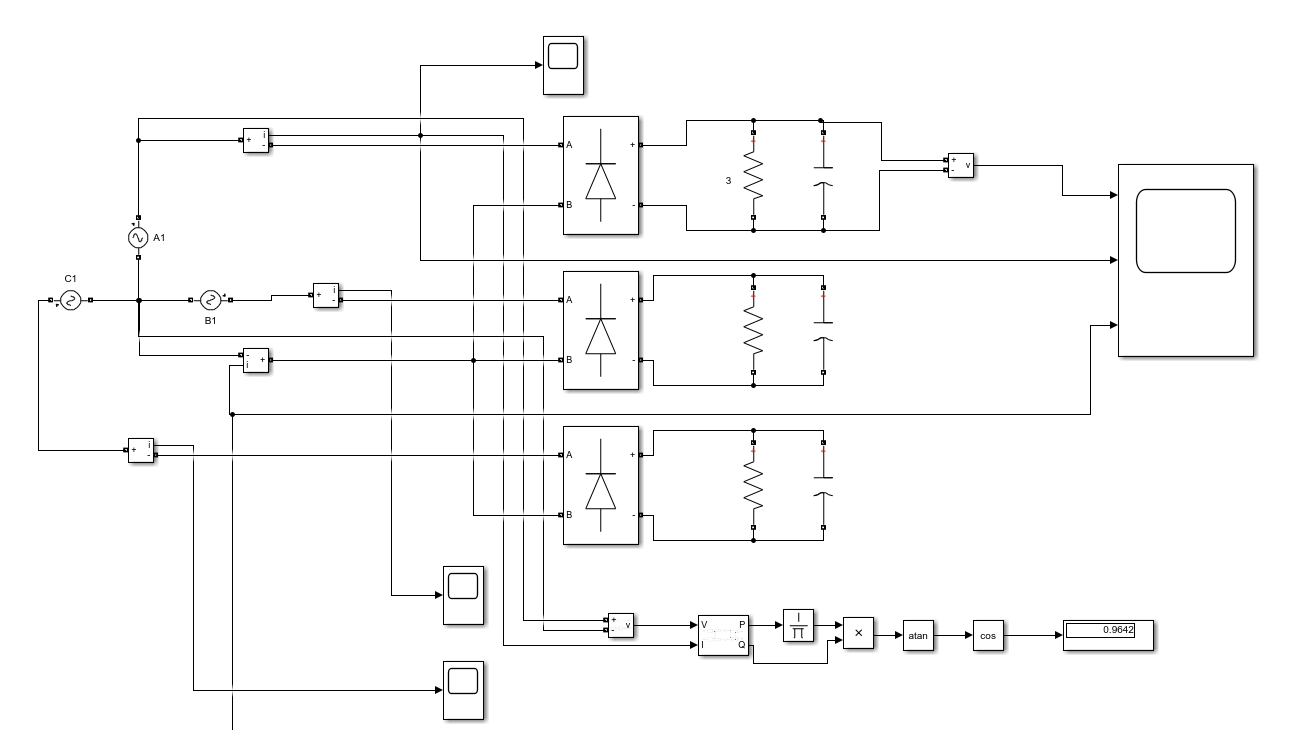


Figure : Power factor calculation of input current without line inductance

Without Ls in the figure 15, we calculated power factor as 0.9642. Current is leading since there is a capacitive effect on load side. However, in part 1, there is a little leading on current since inductor has lagging effect and capacitor and inductor compensate each other.