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EE463 Static Power Conversion 1

HOMEWORK-1 REPORT

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# Introduction

In this homework, the simple single-phase half wave and full-wave rectifier, and the three-phase full-wave rectifier will be analyzed. The output voltage waveform will be observed. The average voltage values and the total harmonic distortion values will be calculated and compared with the simulation results. In addition, the effect of the grid side inductance will be observed. The different type of rectifier concepts will be clear after the simulation and observations.

## PART 1 : The Single Phase Half-Bridge Rectifier

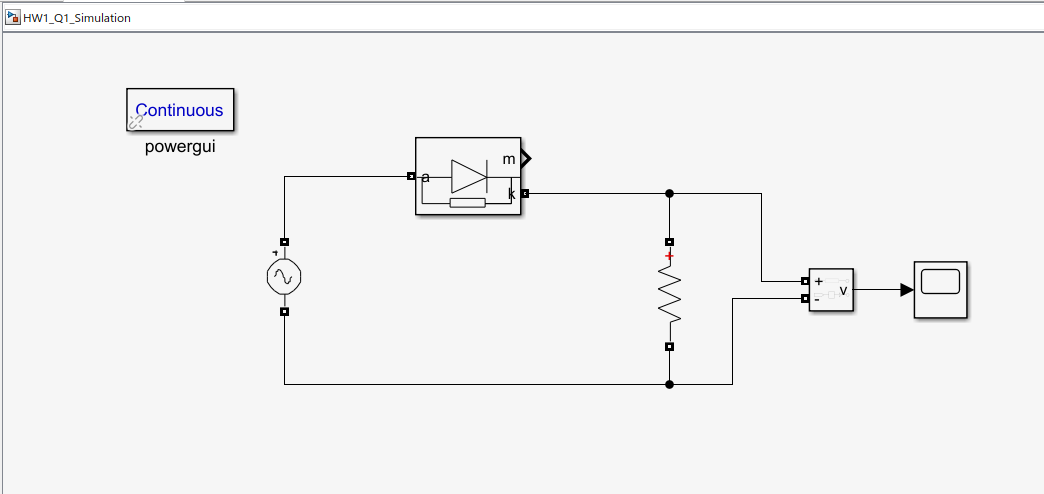


Figure 1: The Circuit Schematic for Single Phase Half-Wave Rectifier

1. For the part-a, the circuit schematic in above is simulated with different time steps such as 1 ns, 0.1 ms and 1 ms. Note that RL is 80 ohm and AC voltage source generates 230 Vrms at 50 Hz which is the Turkish electricity grid phase neutral voltage. However, the AC source in Simulink requires to giving peak value of voltage. Therefore, 230 Vrms is multiplied with square root of 2. The output voltage waveforms are given in below.

Figure 2: The Output Voltage Waveform for Time-Step 1 ns

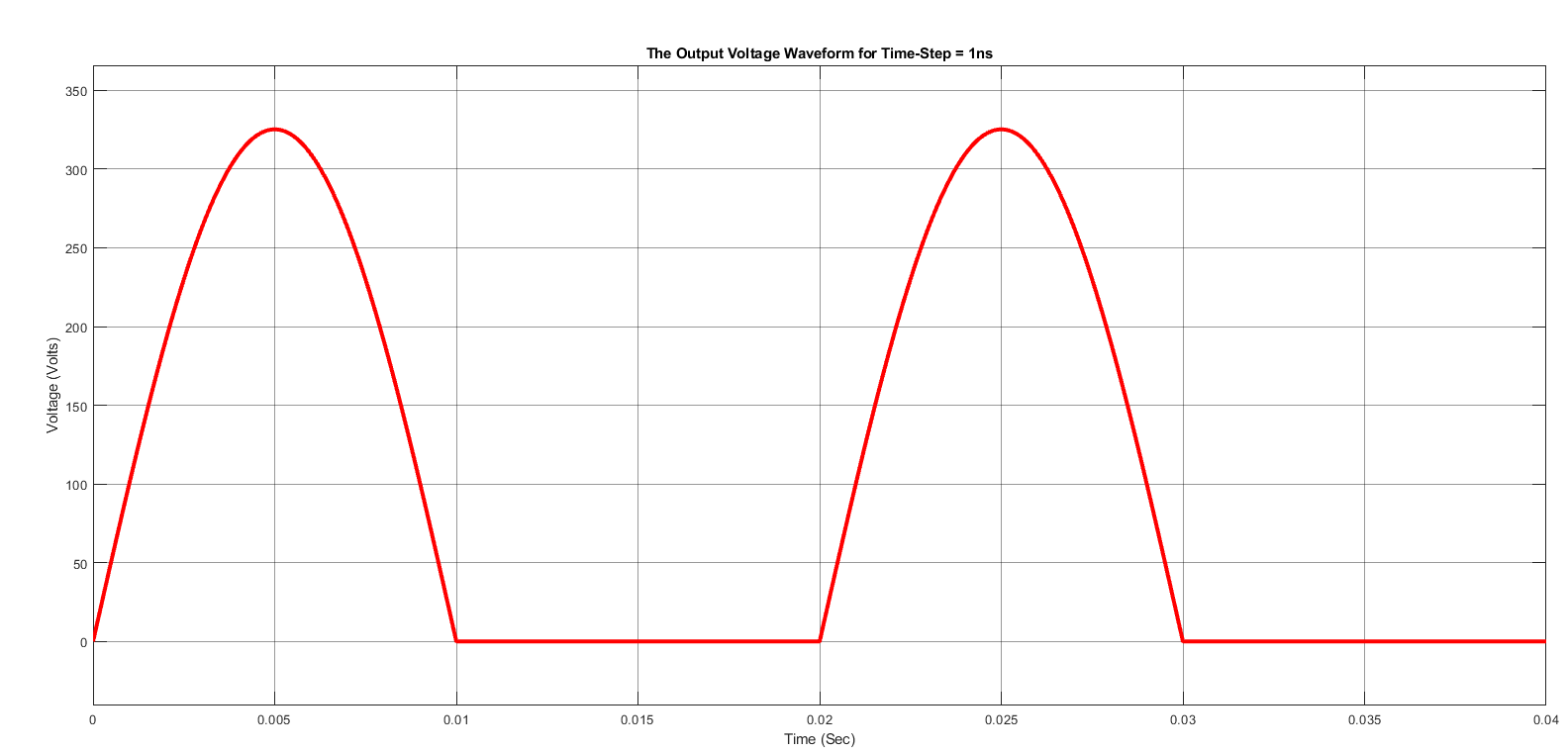


Figure 3: The Output Voltage Waveform for Time Step 0.1 ms

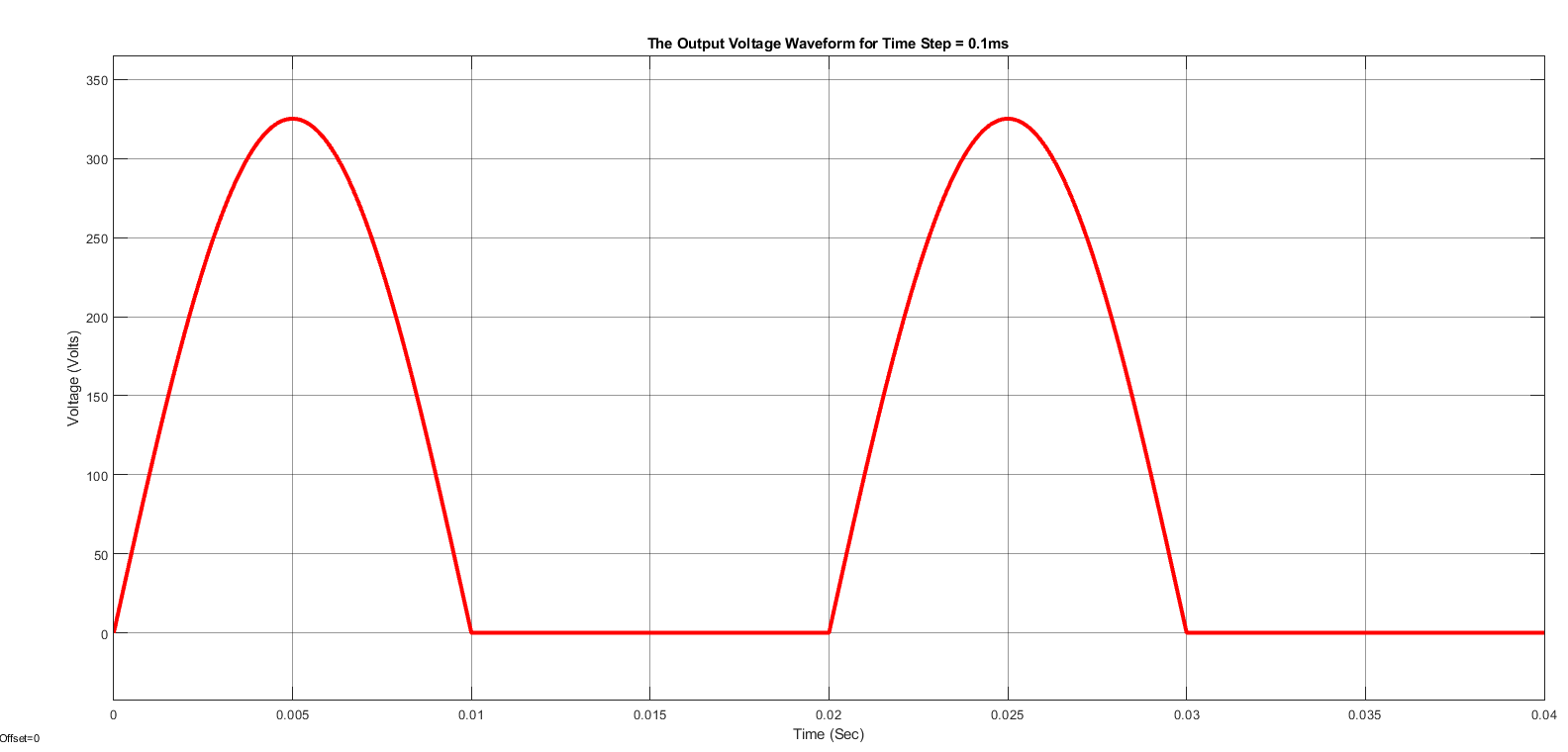
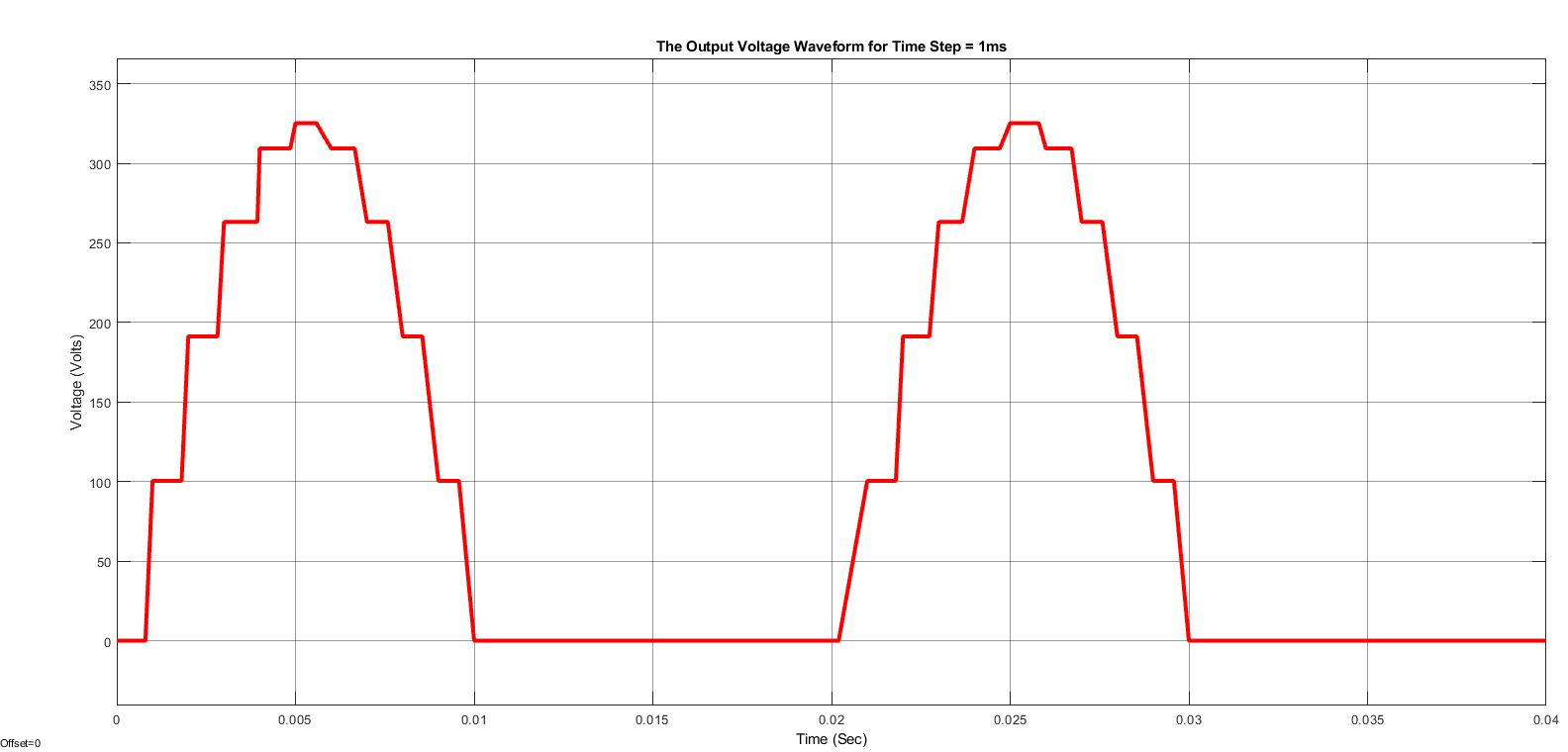
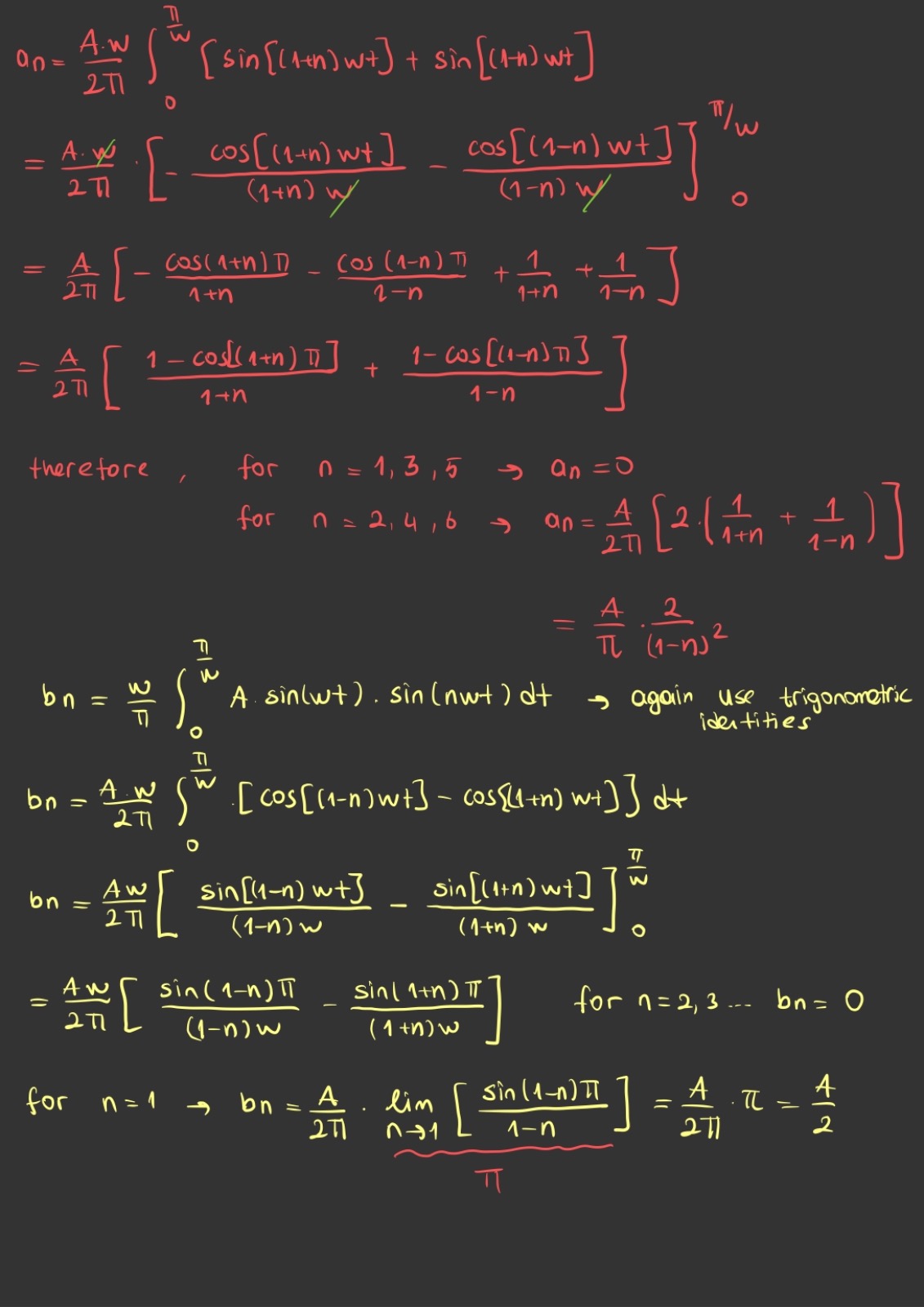


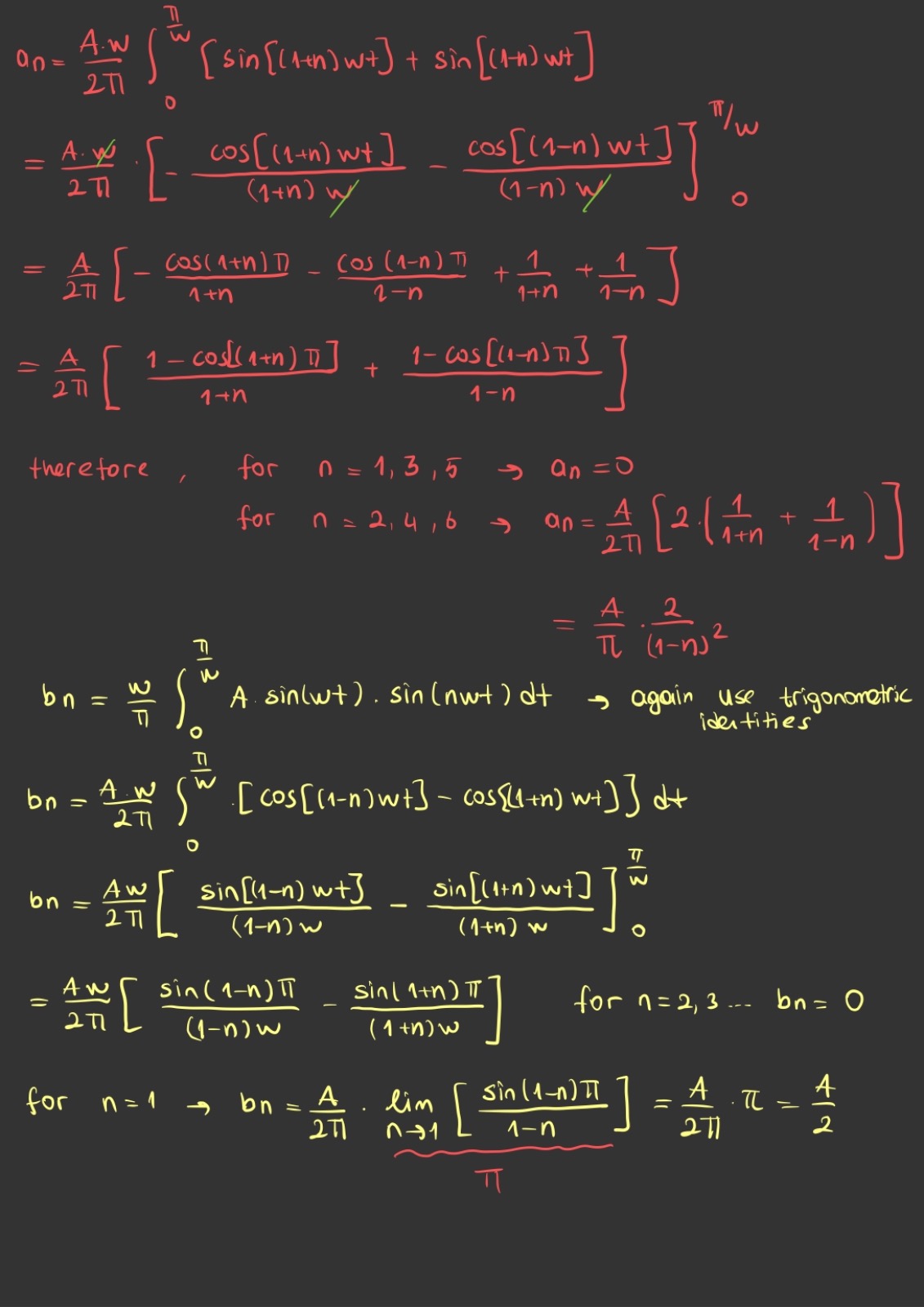
Figure 4: The Output Voltage Waveform for Time Step 1 ms



1. As can be seen from the figures in part-a, the waveform for time-step 1 ms is distorted. It is because the time step is too large to create a smooth waveform. Since, the output voltage has many harmonics inside, the proper step time is necessary to see the waveform clearly. Other way around, if the step time is too small, the simulation takes too much time and it creates not a good observation for the user. The proper value can be determined by looking the frequency of the voltage. In this case, the best option to simulate is 0.1 ms.
2. Text

   Description automatically generatedCalculation of the average output voltage waveform and THD:

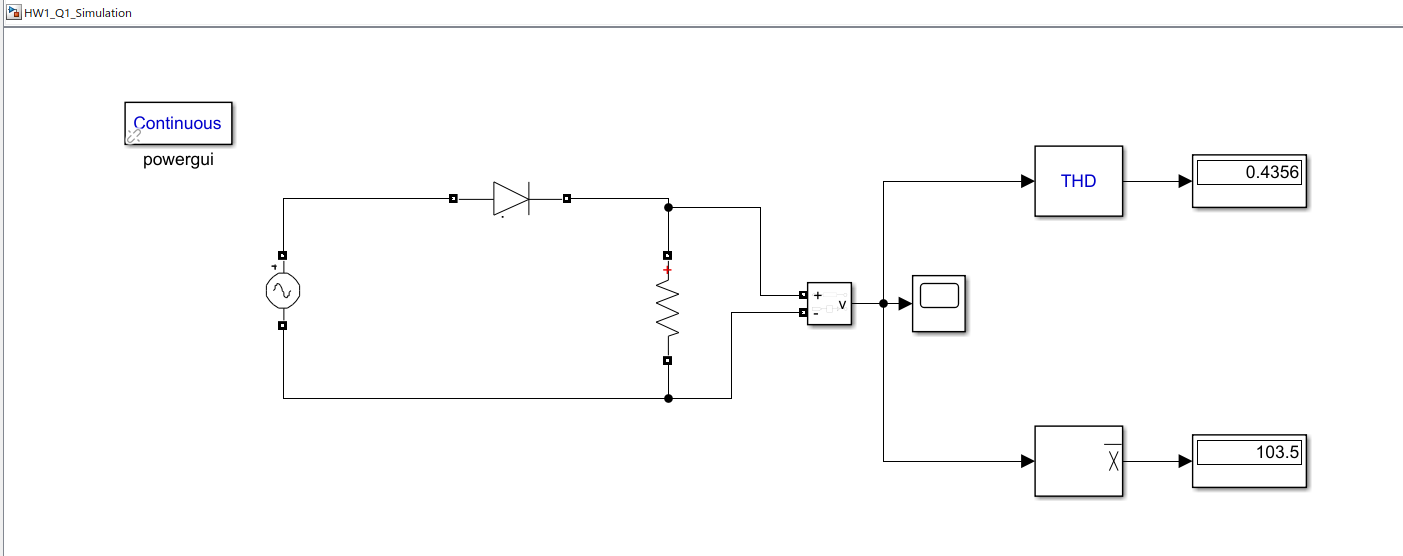




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Figure 5: The Circuit Schematic to obtain THD and Mean Voltage



1. As can be seen from the Figure 5, the average voltage is equal to 103.5 Volts which is consistent with the analitically calculation. In a single phase half bridge rectifier, the mean voltage of the output is roughly equal to 0.45Vrms. In this case Vrms value for the AC voltage source is 230 Volts. Then:

## PART 2 : The Single Phase Full-Bridge Rectifier

1. In practical applications Ls and Rs on the given circuit refers to internal inductance and resistance value of the AC Voltage source
2. In part b we are asked to obtain 3% output voltage peak-to-peak ripple voltage to mean ratio by adjusting the capacitor accordingly. In this circuit capacitor carries out filtering operation. When a source is connected to the circuit first capacitor draws current and becomes charged. When AC voltage is lower than the capacitor voltage, then capacitor feeds the load so that we obtain more DC like output voltage. Therefore, capacitance value should be chosen wisely. For example if capacitance value is choosen too large, then in the beginning it draws large amount of current that might harm the diodes. Moreover, if capacitance value is too small, then capacitor will not be enough the feed the circuit, this leads to obtain worse DC like output voltage.

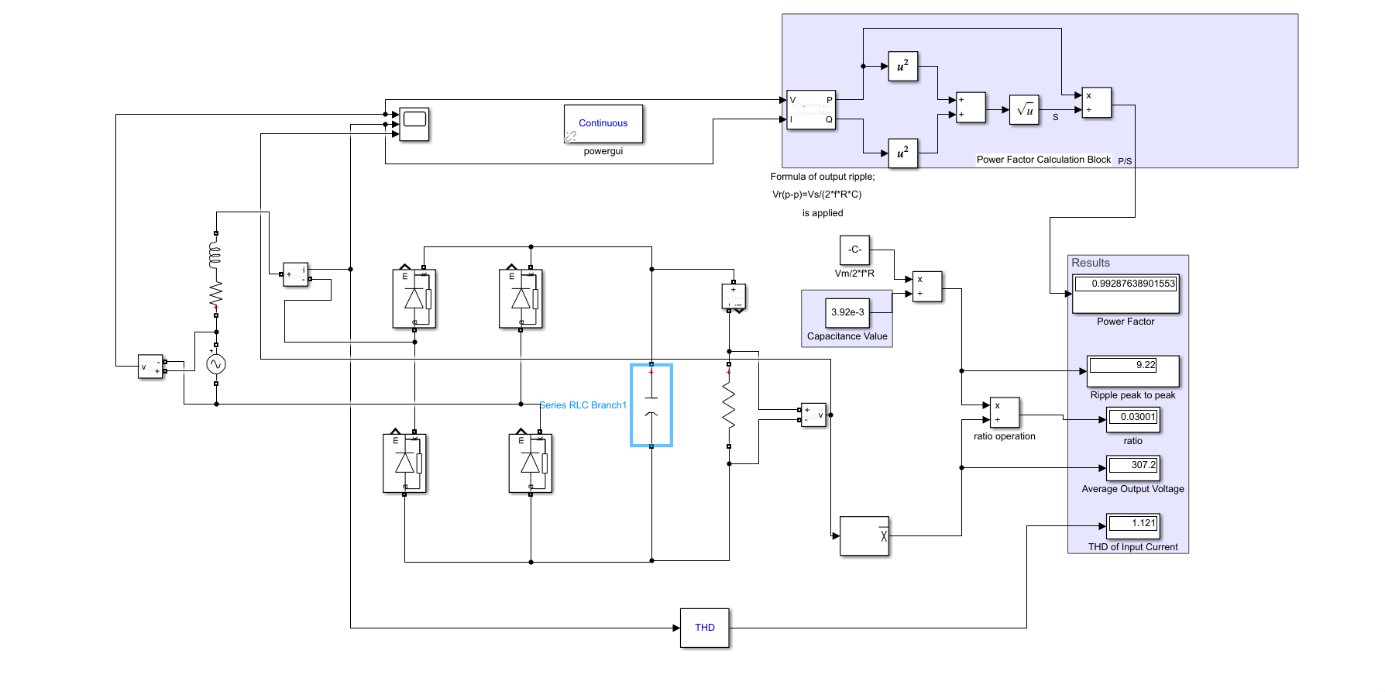


Figure 6: The Circuit Diagram of Single Phase Full Bridge Rectifier

In this diagram all the calculations are shown, and 3% ratio is obtained with C= 3.92 mF.

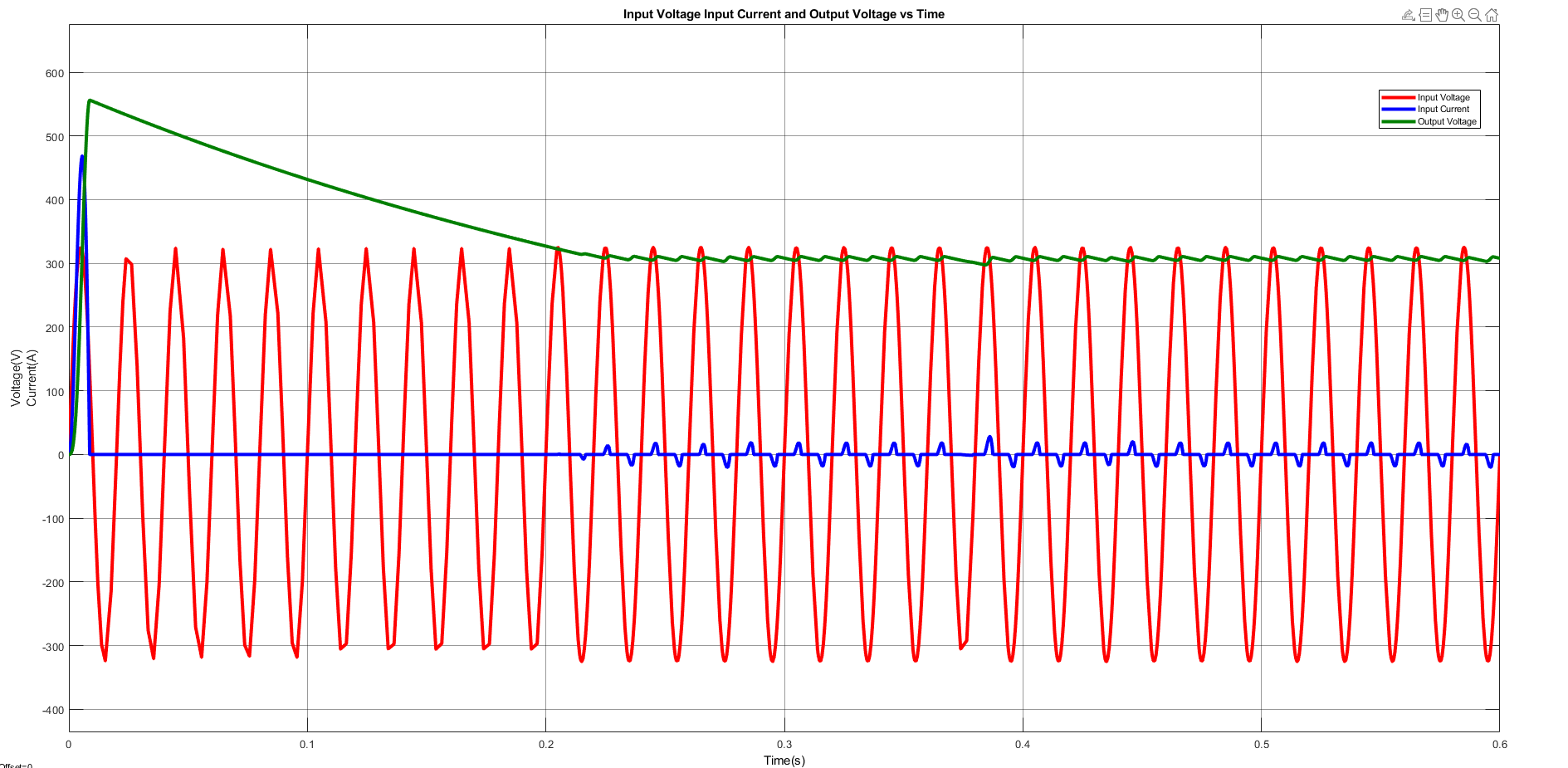


Figure 7: The Output,Input Voltage and Current of the Single Phase Full Bridge Rectifier with Rs and Ls

As mentioned, in the beginning there is a jump on currents graph due to capacitor. Also we can say that the capacitance value affect the time required for circuit to become stable.

1. In part (b), necessary measurements are shown.
2. In part (e), Ls and Rs are removed, that is we assumed that the AC voltage source is ideal.

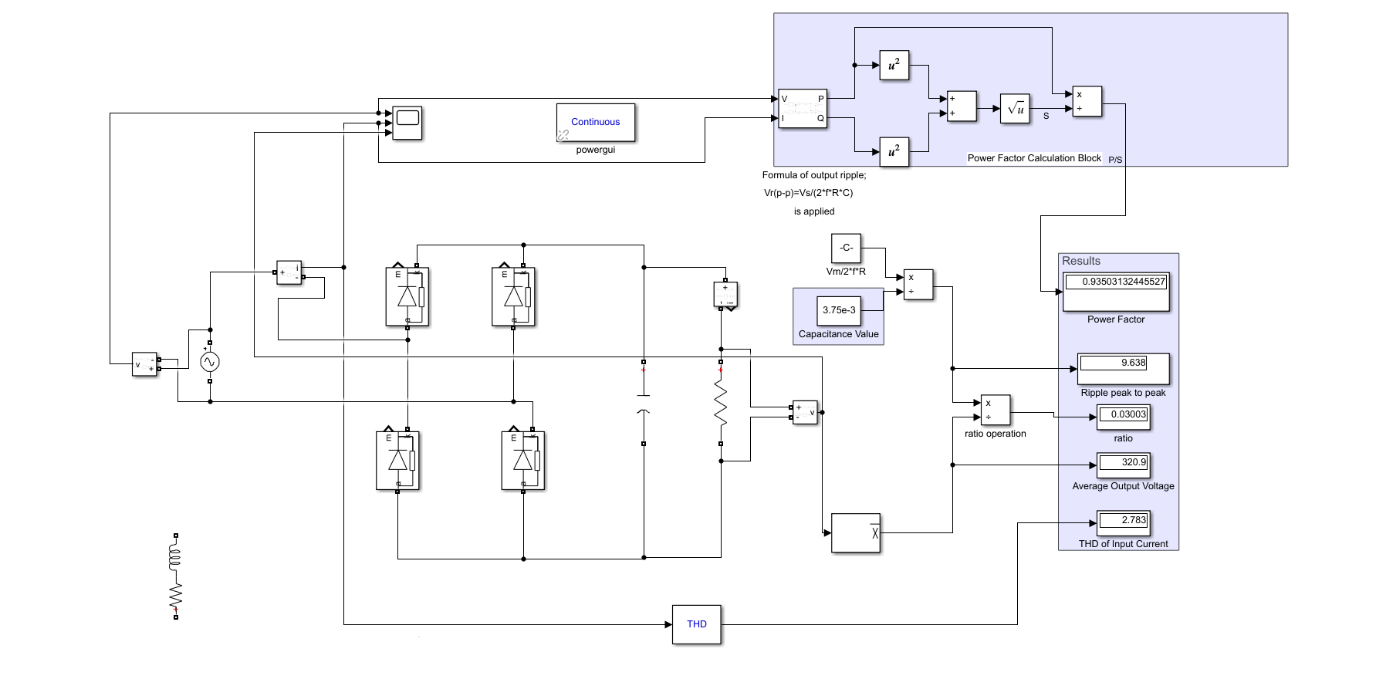


Figure 8: The Circuit Diagram of Single Phase Full Bridge Rectifier without Rs and Ls

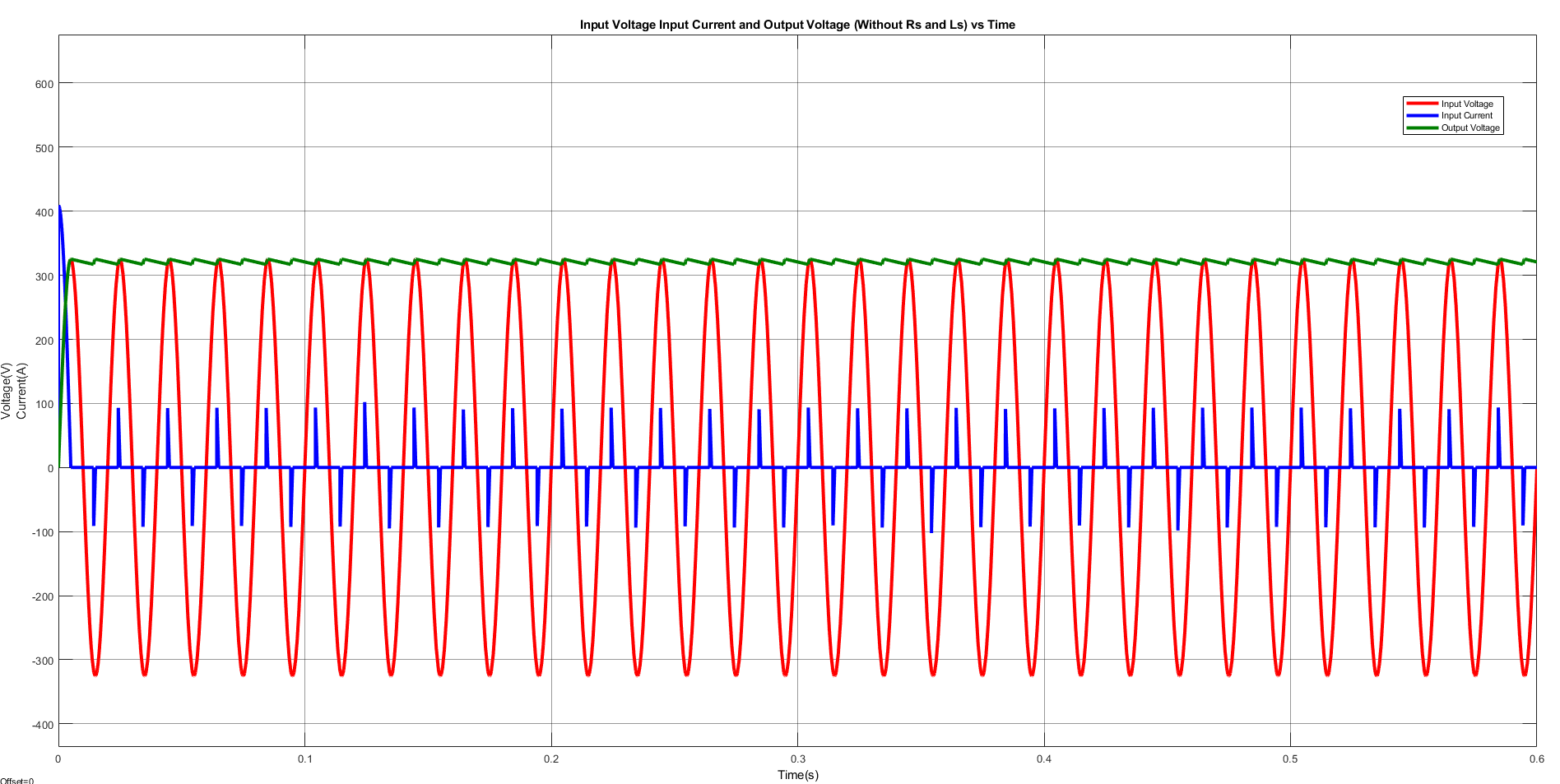


Figure 9: The Output,Input Voltage and Current of the Single Phase Full Bridge Rectifier without Rs and Ls

When Ls and Rs are removed, we observed that now current have sharp transitions. This is because when there is an inductor in the circuit, it prevent the sharp current transitions because it results in infinite voltage on the inductor. This leads input current to increase suddenly so we can say that charging time of the capacitor (time required for stabilization of the circuit) is decreased. In addition to these, following differences are obtained.

* Average output voltage increased.
* Capacitance value required to have 3% ratio decrased.
* Input current increased and has sharp edges.
* Power factor decreased.
* THD increased.

## PART 3 : The Three Phase Full-Bridge Rectifier

1. In the Part-a, the circuit schematic simulated in below figure. The three-phase voltage source is arranged to 400 Vrms and 50 Hz as in Turkey electricity grid. Also, the DC current source is equal to 60 Amps.

The output voltage waveform and input current waveform are given in Figure 11. As can be seen, the peak value of the output voltage is equal to which is roughly equal to 565 Volts. Also, the input current waveform is square waveform as expected. The peak value is 60 Amps like DC current sources.

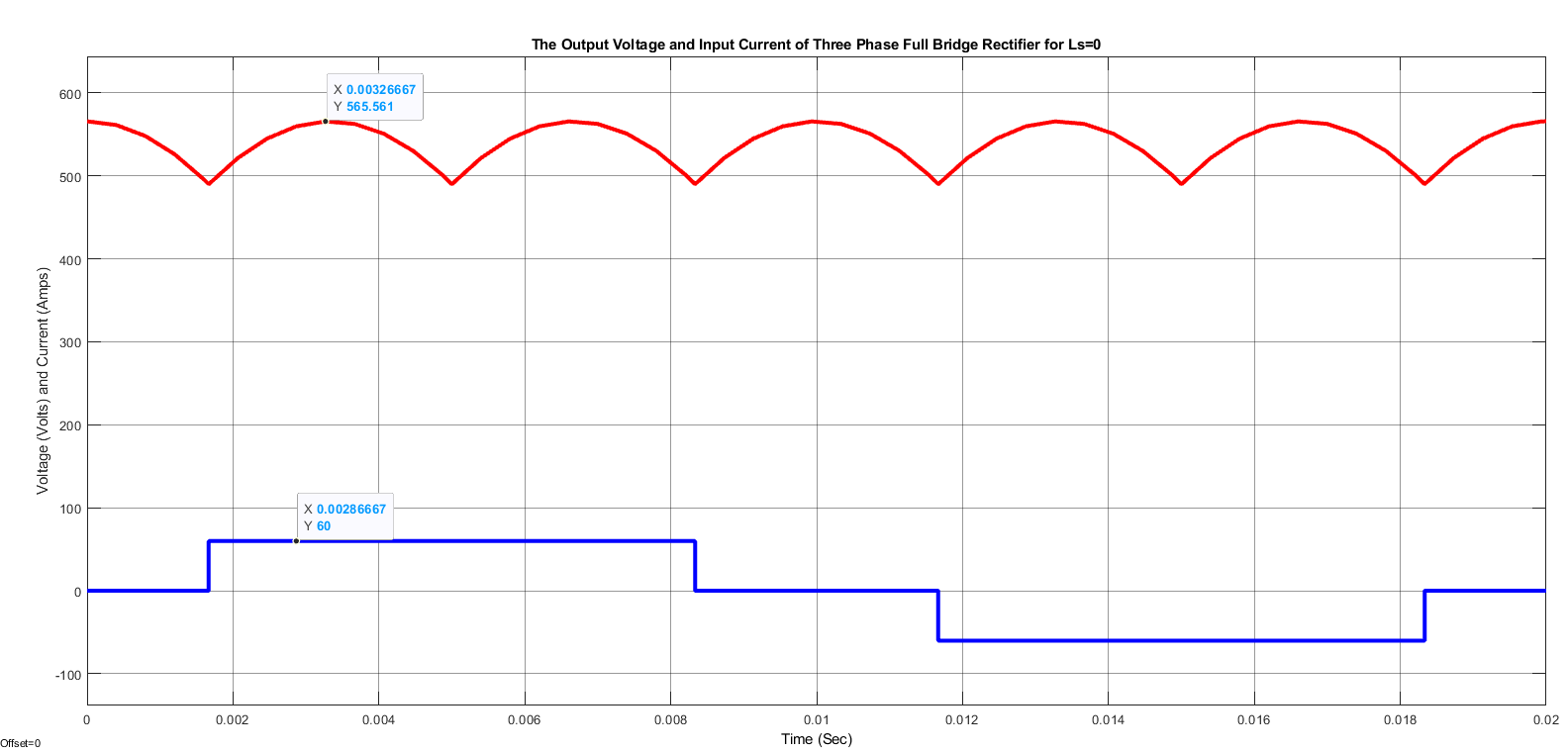


Figure 10: The Output Voltage and Input Current Waveforms for Three-Phase Full Bridge Rectifier without Ls

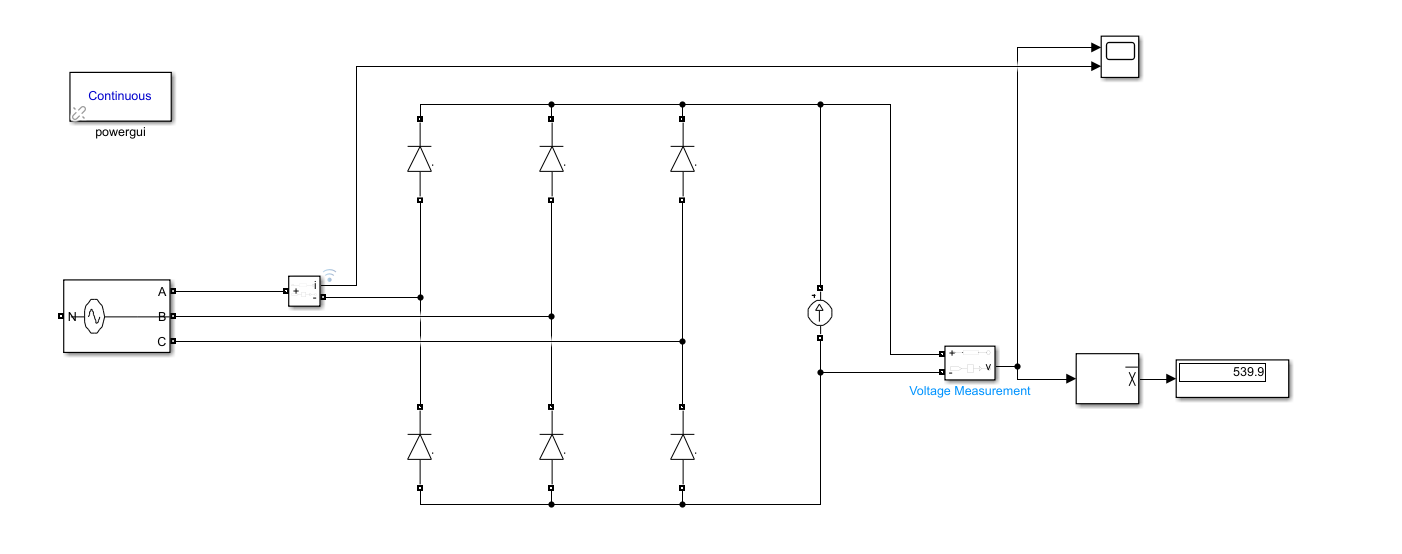


Figure 11: The Circuit Diagram for Three Phase Full Bridge Rectifier without Ls

Unlike single phase rectifier we do not observe a square input current waveform but there are some interval that no input current is supplied.

1. In order to find the mean voltage of three-phase full bridge rectifier:

As can be seen from the simulation figure, the mean of output voltage is observed 539.9 Volts which is nearly same the theoretical value.

1. By using the FFT analyzer in *powergui,* the harmonic analysis is made as follows.

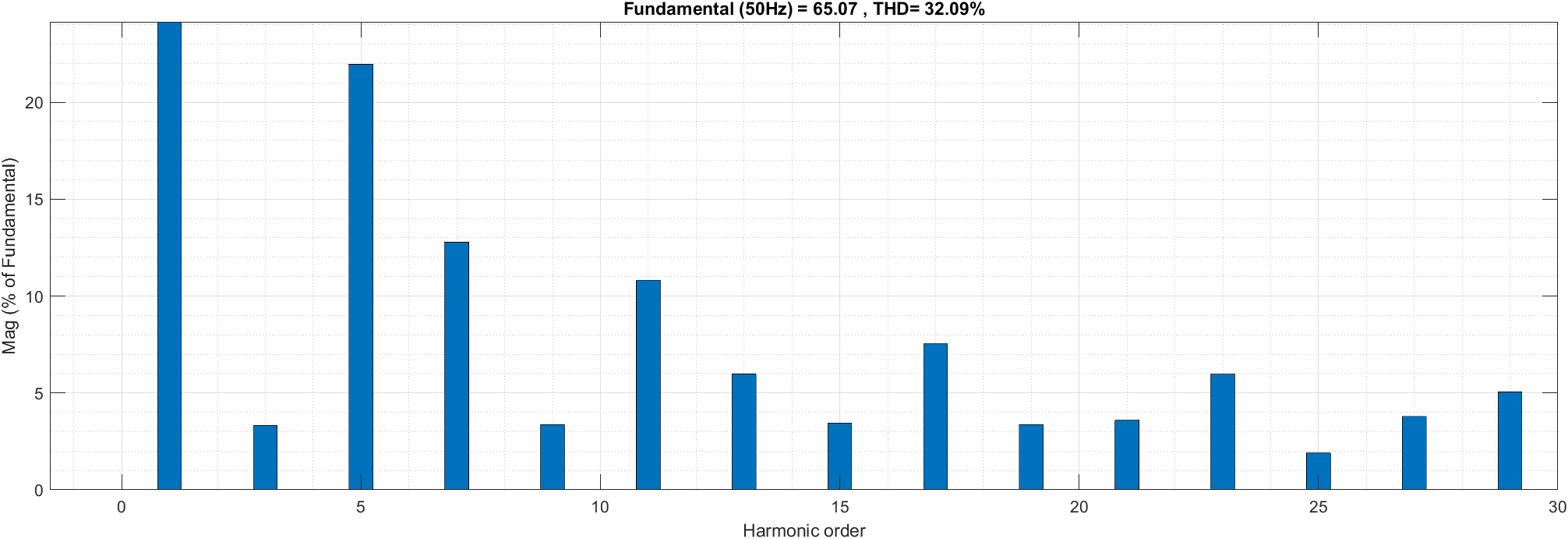


Figure 12: The Harmonic Analysis of the Input Current (without Ls)

As can be seen from the Figure 12, the majority of harmonic content for the input current waveform is the 5th harmonic. The 7th harmonic follows it. Notice that, the third harmonic has very little effect on the input current which is expected.

For the output voltage, the harmonic analysis is also performed in Figure 13.

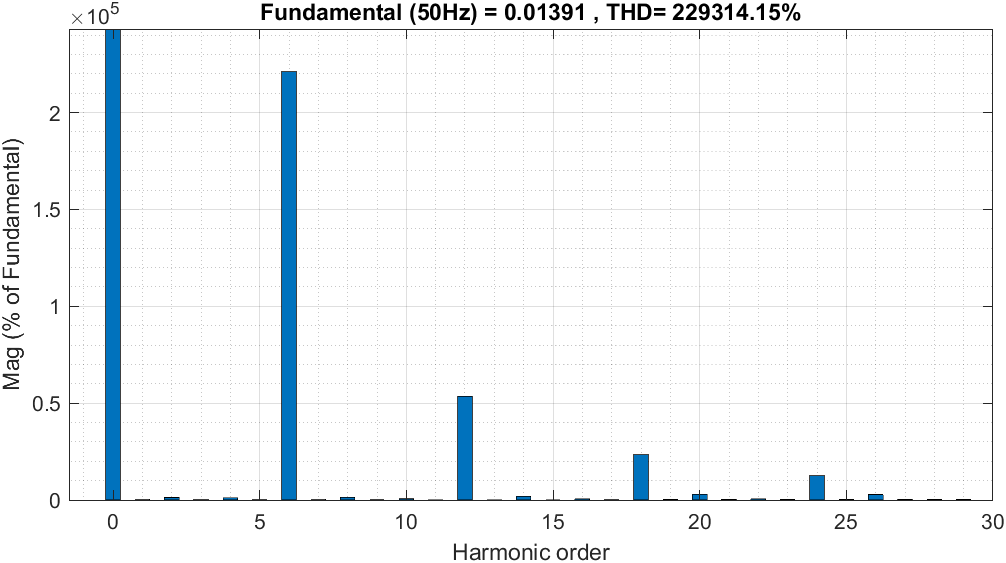


Figure 13: The Harmonic Analysis of the Output Voltage (without Ls)

1. The circuit diagram of three-phase full bridge rectifier with Ls=1.mH is given in Figure 14.

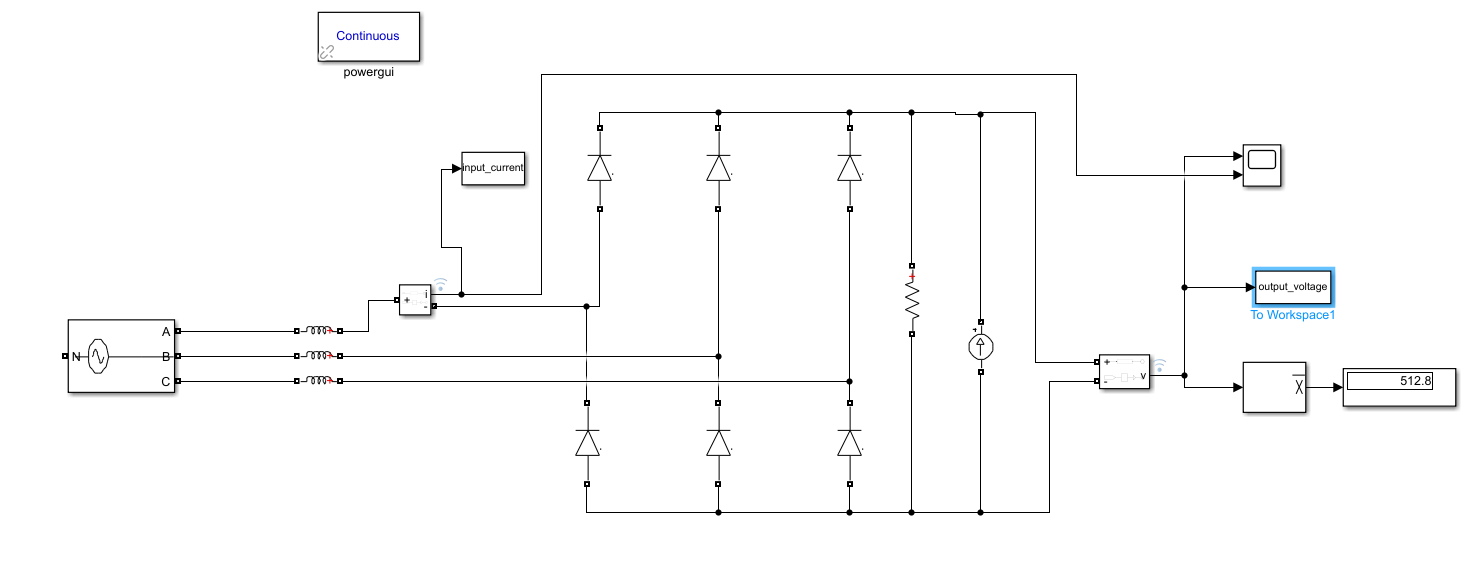


Figure 14: The Circuit Diagram for Three Phase Full Bridge Rectifier with Ls=1.5mH

As can be seen from the figure, the resistance is connected parallel to DC current source because the Simulink creates error when the inductances are connected the current source directly. Therefore, 1 Mohm resistance is connected parallel to diodes.

The output voltage and inpur current waveforms of the three phase full bridge rectifier with Ls=1.5 mH are shown in Figure 15 below.

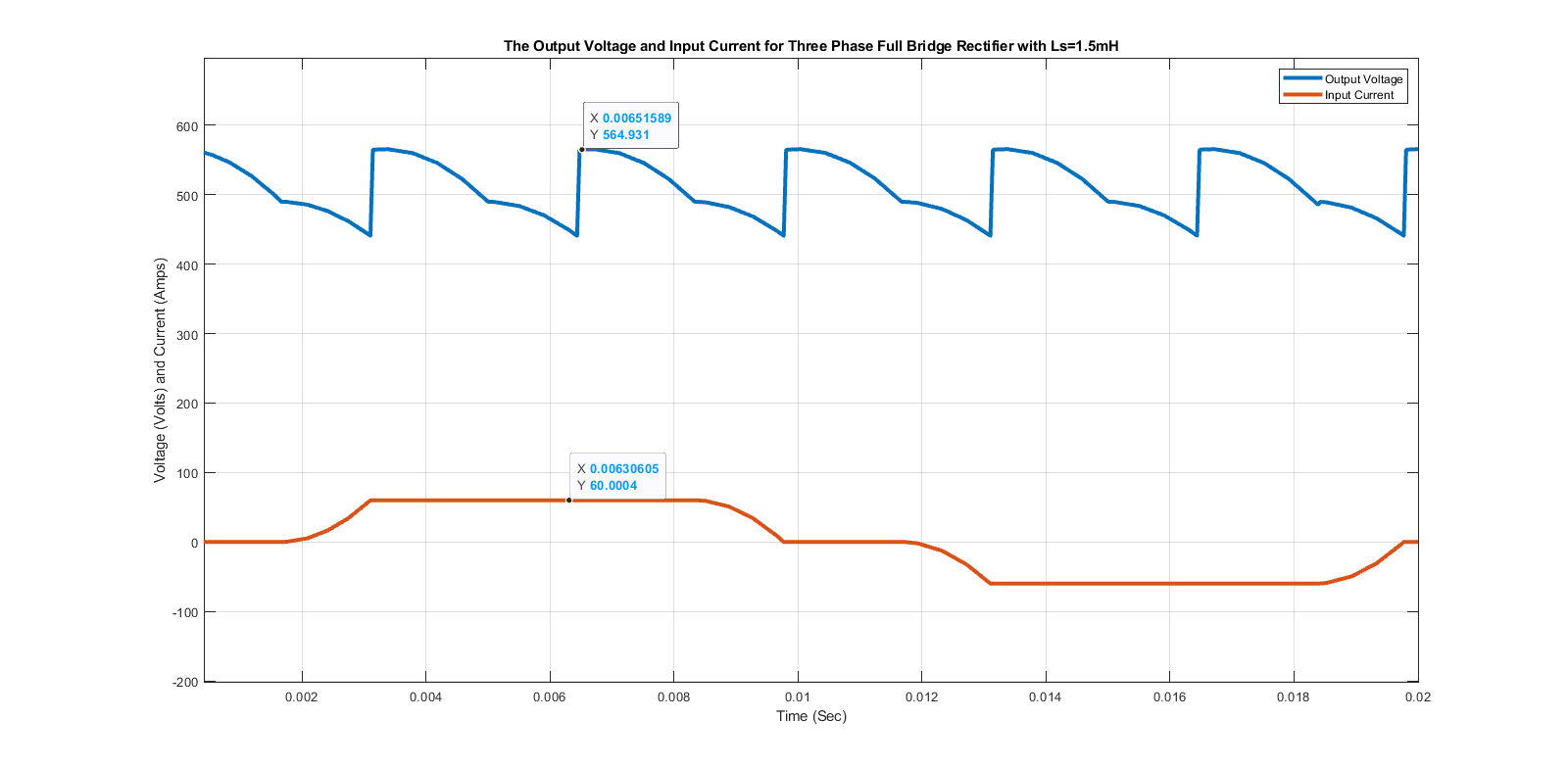


Figure 15:The Output Voltage and Input Current Waveforms for Three-Phase Full Bridge Rectifier with Ls=1.5mH

When the source inductances are added to three phase full bridge rectifier, the commutaion or overlap happens. Because of the inductances diodes cannot close immeditely, therefore, in a small period two phases are conducting at the same time.

Because of the commutation, the average voltage decreases with a small amount which is :

This equation implies the area lost in output voltage waveform. Another important change in the input current waveform. Because of the differential relation between inductance voltage and current, the current cannot change immeditatly. Therefore, it follows the way in Figure 15.

1. The average output voltage with commutation can be calculated as follows :

The frequency of the frequency of three phase voltage source is 50 Hz which means . Also, the inductance value is 1.5 mH and the DC current is 60 Amps. Hence :

Also, the average output voltage is measured from the simulation program as can be seen from Figure 14. The measured value is 512.8 Volts which is very near to theoritical value.

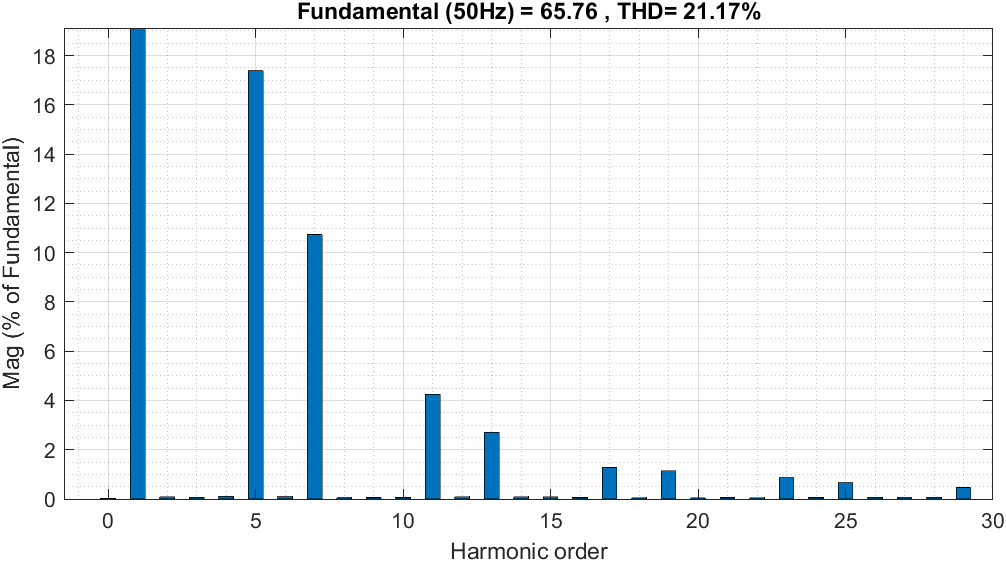


Figure 17: The Harmonic Analysis of the Input Current with Ls=1.5mH

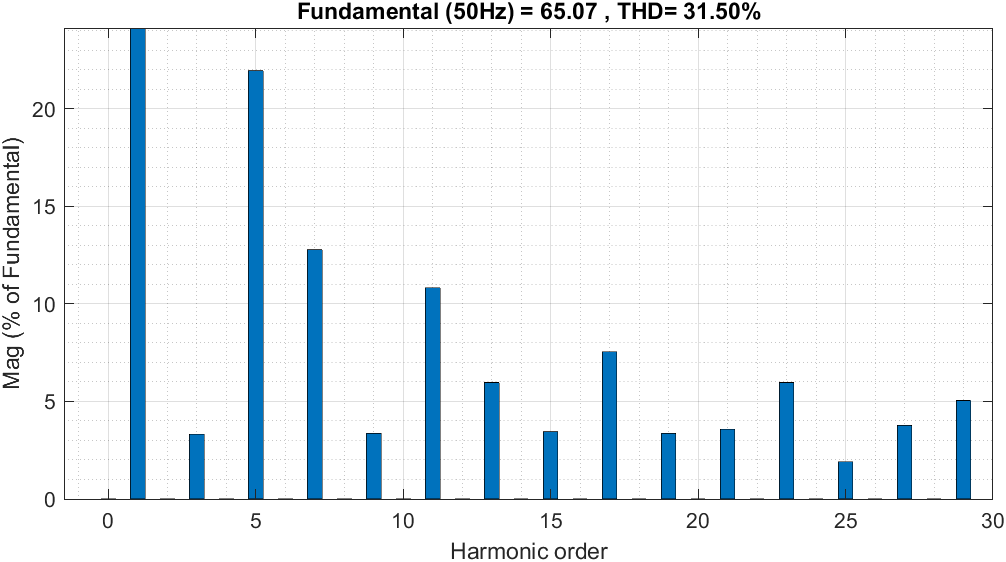


Figure 16: The Harmonic Analysis of the Input Current with Ls=0

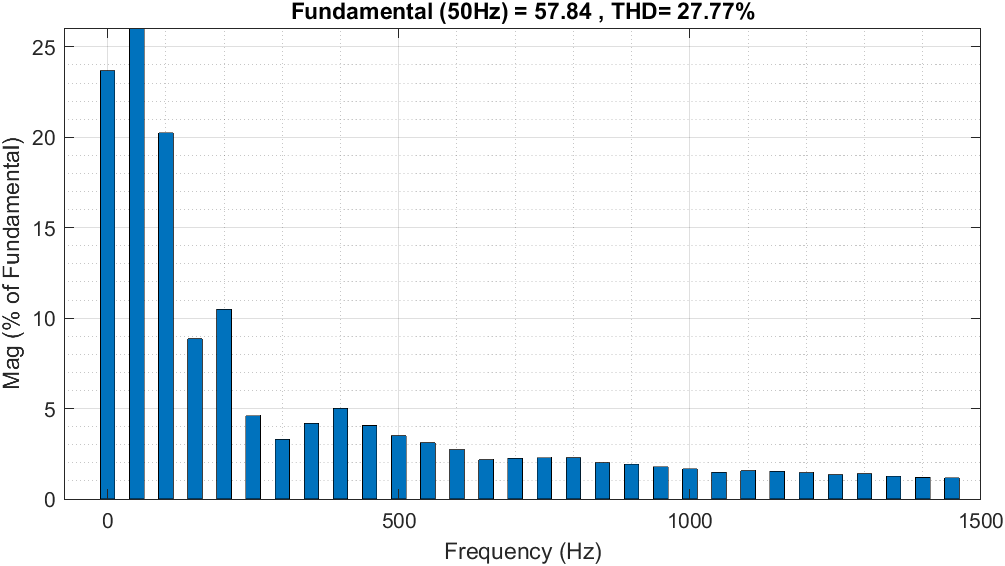
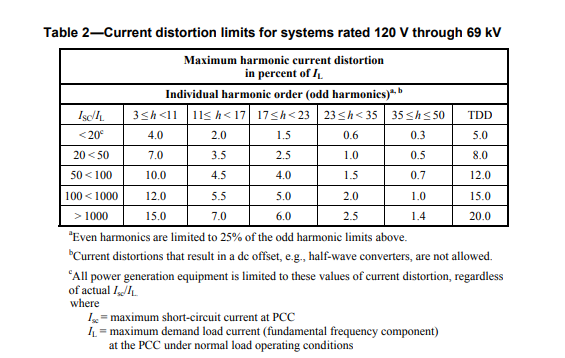


Figure 18: The Harmonic Analysis of the Input Current with Ls=15mH

The harmonic analysis for three different line inductances are given in Figure 16-17 and 18. According to IEEE 519-2014 Standart, the current distortion values are given in the Table-2.

When the harmonics analyses are examined, the rectifier which has the line inductance has 1.5 mH comforts IEEE standard most. Since, it has largest harmonic at 5th and after that it has almost no harmonics. Also, the THD value for this 1.5 mH is lower than other options.

Notice that when the line inductance is getting larger, the most effective harmonics is getting smaller such as in 15 mH case. Since, the most effective harmonics is near the fundamental frequency, it is harder to filter it.

The simulations are performed and THD values are measured from THD box in Simulink. Hence, the THD values for 0,1.5 and 15 mH are given in Table 1 below, respectively:

Table 1: THD Values according to the Line Inductance.

|  |  |
| --- | --- |
| The Line Inductance | Total Harmonic Distortion (THD) |
| 0 mH | 0.3604 |
| 1.5 mH | 0.3427 |
| 15 mH | 0.4235 |

As can be shown in Table 1, the lowest THD value is belong to the circuit with 1.5 mH line inductance. According to IEEE 519-2014 Standard, the THD value should be lower than 8%. Hence, all off them satisfy this condition but the second one is most applicable one. Since, lower THD values in power systems implies less peak currents,less heating and high efficiency. Because of these reasons, low THD is desirable property for power systems. The high THD values may cause big or small malfunctions of the equipment [1]. The high THD value in the input current can result higher current peaks as well as higher core losses. These core losses creates heating therefore, increasing temperature may damaged the operating grid and equipment.

## REFERENCES

[1] “IEEE Std 519™-2014, IEEE Recommended Practice and ...” [Online]. Available: https://edisciplinas.usp.br/pluginfile.php/1589263/mod\_resource/content/1/IEE%20Std%20519-2014.pdf. [Accessed: 14-Nov-2021].