Q1)

# Average Output Voltage:

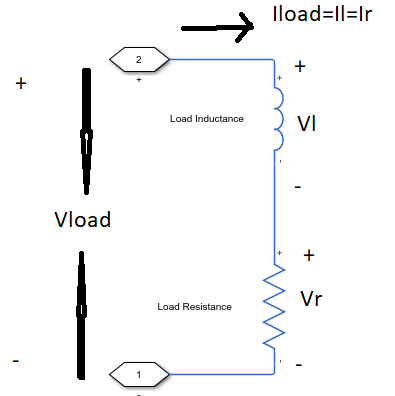


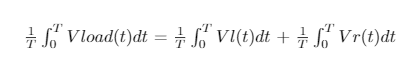
Figure 1 Load Voltage and Current Diagram

As can be seen at Figure X , Load voltage can be found with respect to Load current, inductance and resistance value. However, we can not know load current with respect to time. Only average value of current is given, ripple of load current is not known.So, Average voltage of load should be found by using only resistance value and average current of load. In addition, there is some assumption that voltage drop due to commutation is calculated average current, not minumum current.

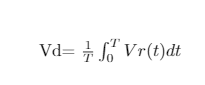
If required analytical explanation,



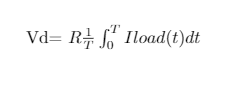
Equation 1



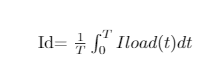
Equation 2



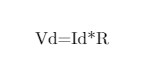
Equation 3



Equation 4



Equation 5



Equation 6

Equation 1 shows that KVL is valid for load. Series RL circuit has common current. For the time independent formulation, we take a mean value of each side of equation like Equation 2. For ındcutor, second voltage law says that mean value of inductor voltage must be zero. So, we can reduce the equation like Equation 3. Then, with property of integral, average value of voltage is written as kind of average current. Finally, Equation 6 is obtained and it indicates that average voltage of output is independent from inductance.

Average output voltage is 160 V for resistor with 4 ohm and this calculation is independent from source side.So, both of circuits, fully and half controlled, have same average voltage. Average current gives us the voltage drop from commutation and firing angle can be found by using output voltages and input voltages.

# Firing Angle Calculation of Fully Controlled Rectifier

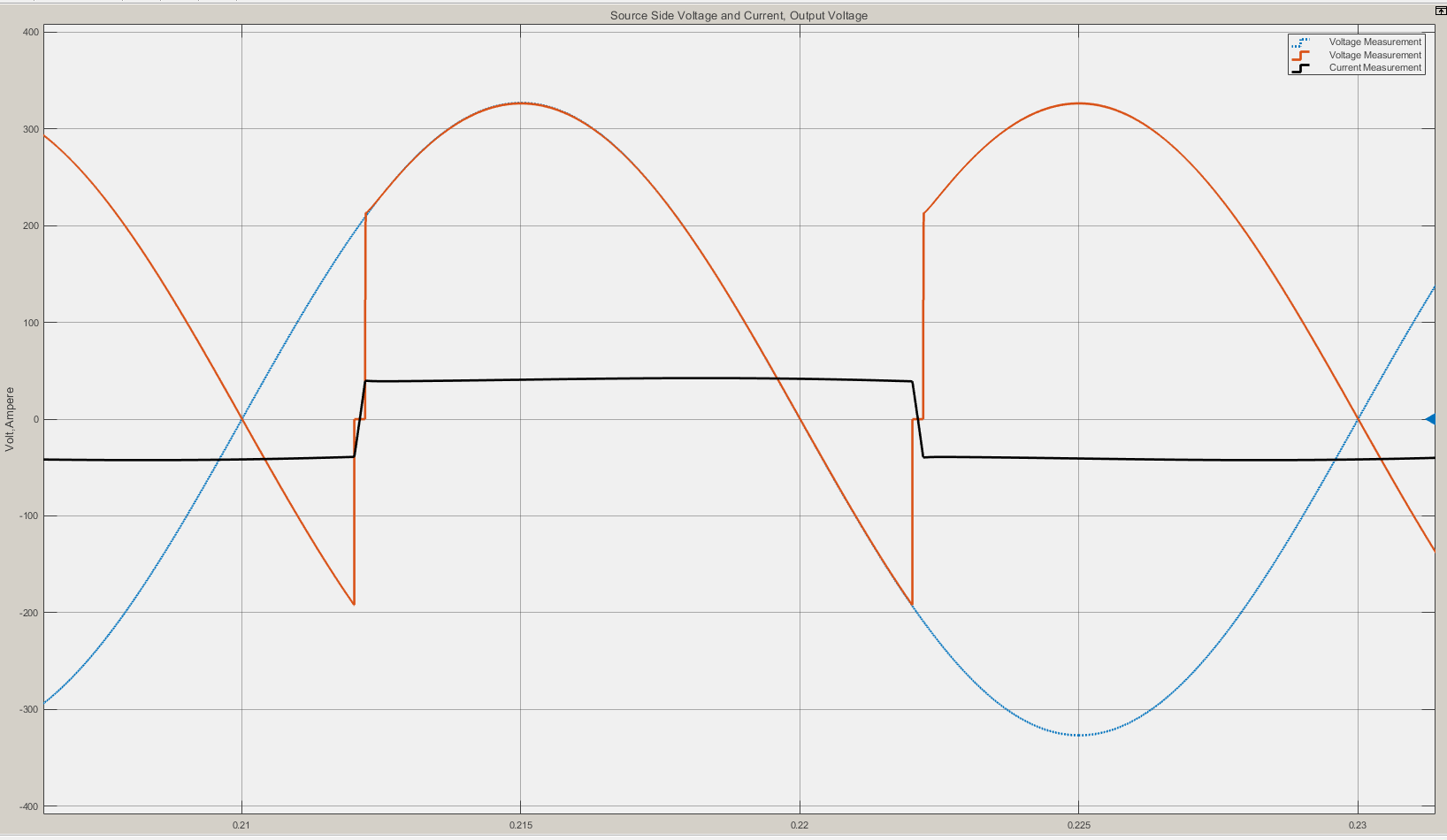
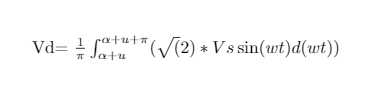


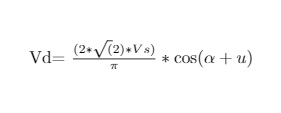
Figure 2

As can be seen Figure 2, there is a commutation at transition between thyristors. It reduces average voltage of rectifier. For the calculation of average voltage, it can not be ignored.



Equation 7

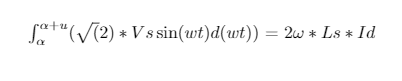
Equation 7 is used for calculate average output voltage of rectifier. The equation contains commutation time.



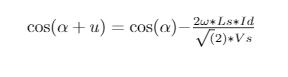
Equation 8

Equation 8 is deducted from equation 7. Average voltage depends on both firing angle and commutation time.

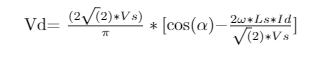
Commutation time depends on line inductance. It balances that current changes with respect to time. It is found by using voltage seconds law(Equation 9).



Equation 9



Equation 10



Then, average voltage is written with only firing angle dependency. It is not required commutation time to find firing angle

If numerical values are placed and firing angle that provides required average current is found 36.1 degree. Simulation are adjusted to 36.1 degree firing angle.

# Simulation Results of Fully Controlled Rectifier

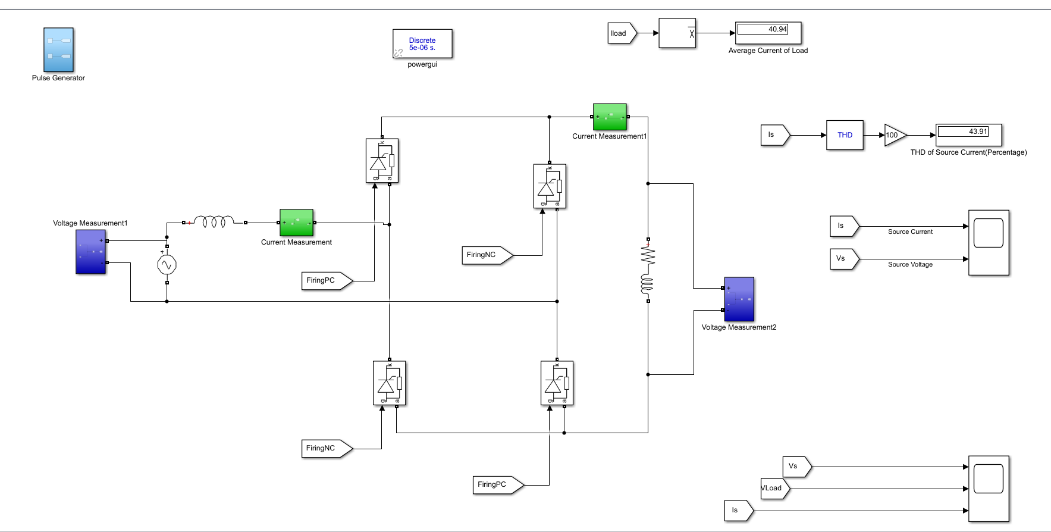


Figure 3

All circuit diagram shown Figure 3. The circuit has some subsystem that provides firing angles, measurement of currents,voltages and calculation of mean value and THD.

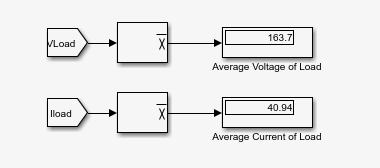


Figure 4

Average voltage and current at figure 4 is almost the same as analytical solution. In simulation, thyrisyors have snubber circuits and it can changes result in small size. In addition, we can solve analytically with assumption that commutation occurs ar average current.

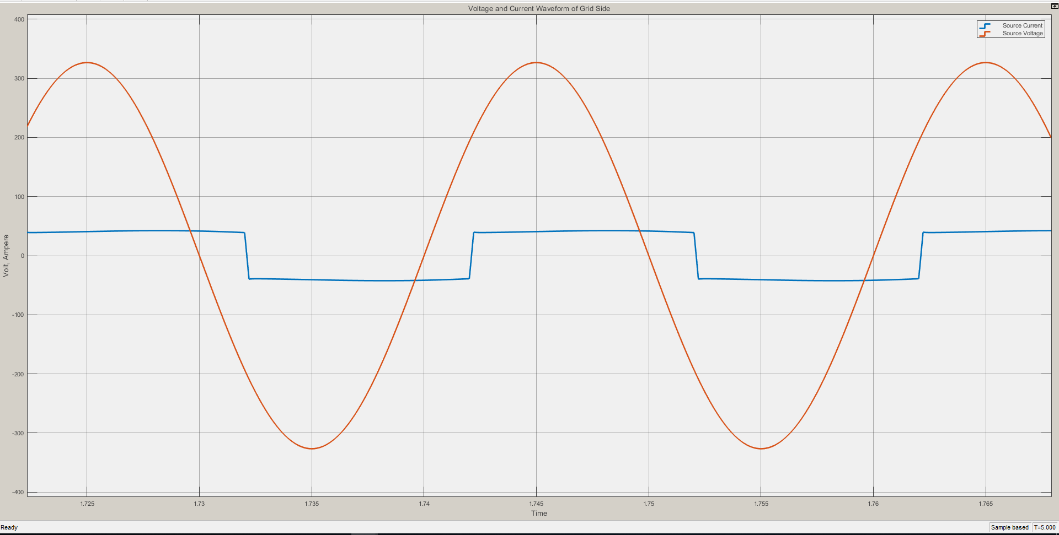


Figure 5

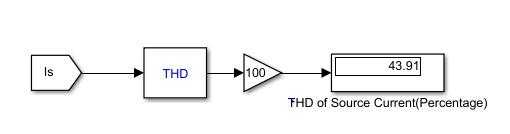


Figure 6

As expected, there is a phase difference at line current and line voltages. The circuit works on rectifier mode because of firing angle is smaller than 90 degree. The phase difference depends on firing angle and commutation time.



Equation 11

THD is smaller than 48% because commutation makes the current more smoother than square wave.

# Firing Angle Calculation of Half Controlled Rectifier

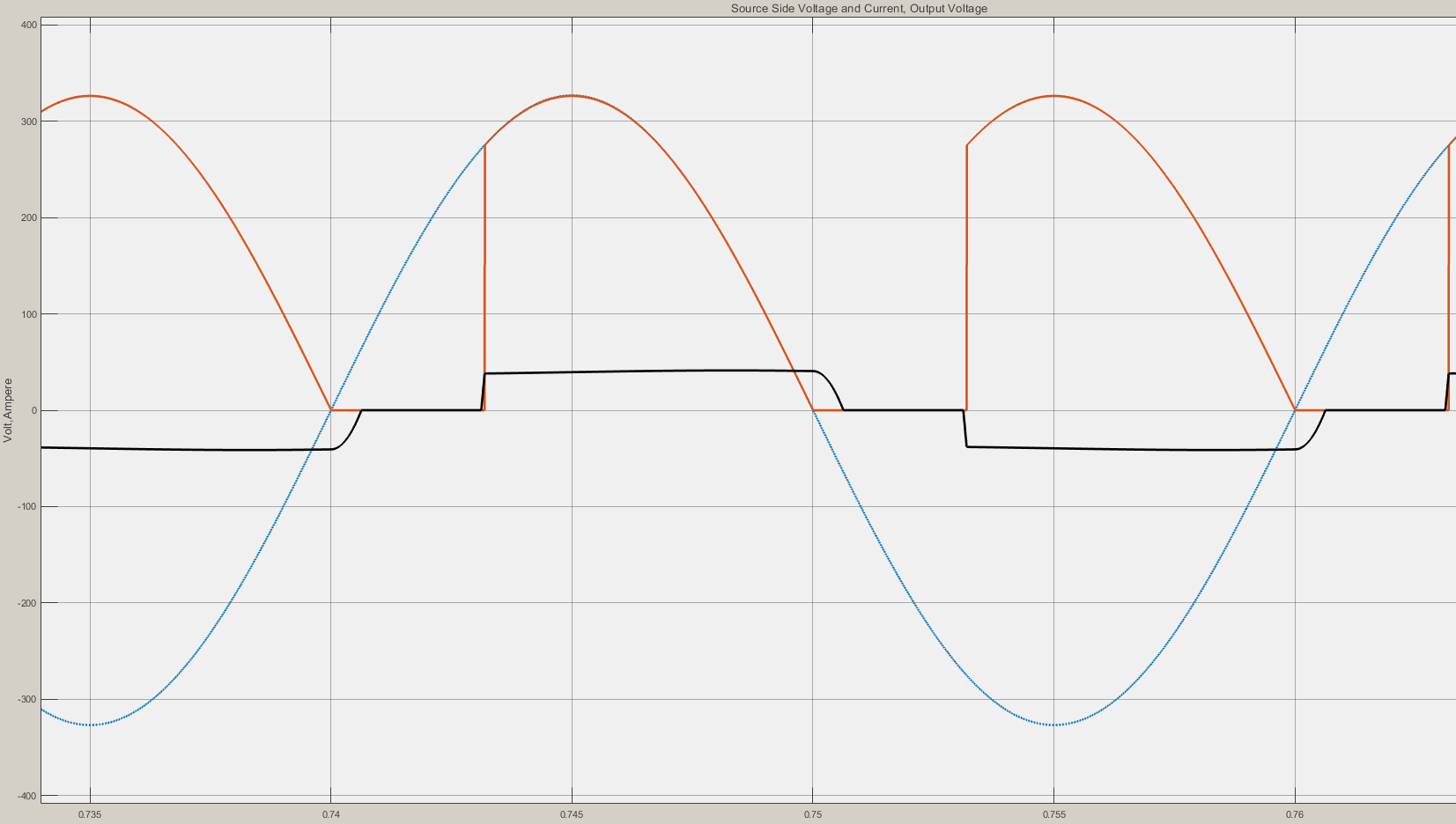
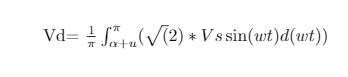


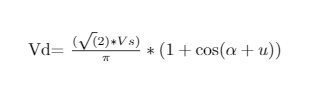
Figure 7

As can be seen Figure X output voltage can not passing negative cycle because of diodes. So, commutation occurs for transition between -Id and zero or zero and Id.



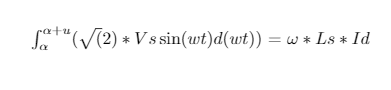
Equation 12

Equation11 shows that average output with respect to firing angle and commutation time. The equation is reduced to Equation 12.

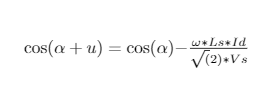


Equation 13

Commutation time is depends on line inductance, current and grid frequency. Then, Equation 13 is written to calculate commutation and it is written as Equaition 14.

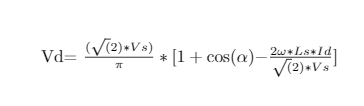


Equation 14



Equation 15

Then, average output voltage can be calculated as only firing agle varible if the circuit parameters and average current are known.



Equation 16

From equation 15, only unknown is firing angle. By placing other parameters numerical, firing angle is drawn as 56.06 degree.Simulation are adjusted to give 56.06 degree firing angle.

# Simulation Results of Half Controlled Rectifier

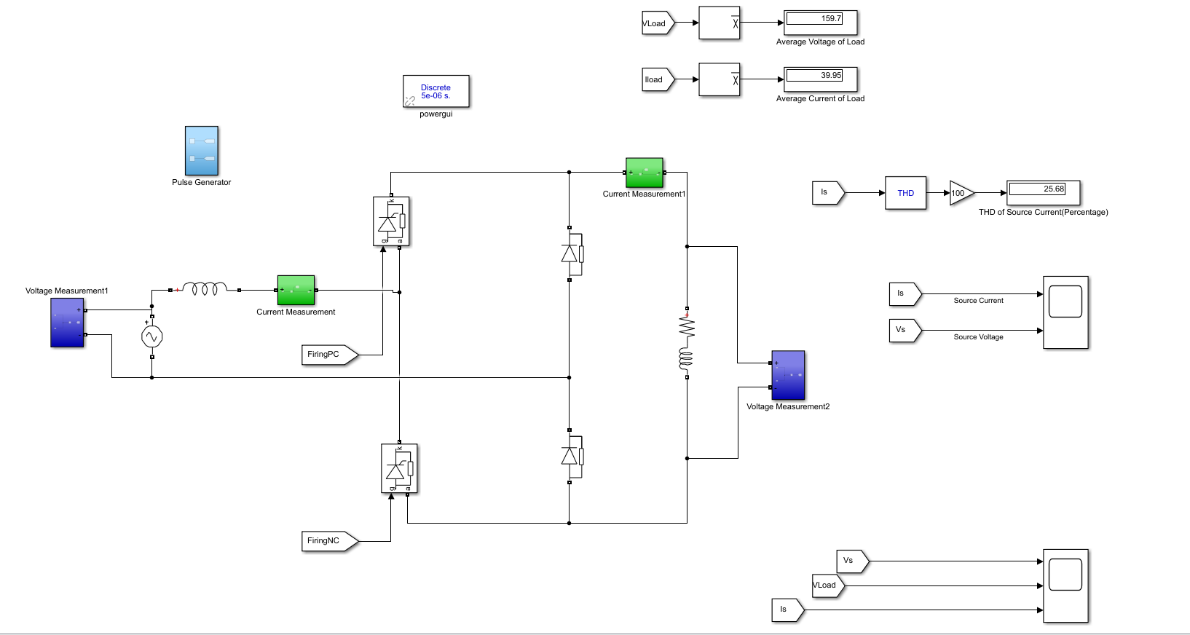


Figure 8

There is a half controlled rectifier at Figure 8. It is two ways to create these circuit. One of them is using one diodes and 4 thyristor. Other one is established by 2 diodes and 2 thyristors. Second one is used for this setup.

There is a sum subsytem to measure the reqiure voltage and current and calculation about them.

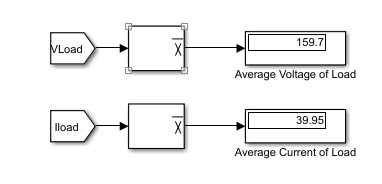


Figure 9

Figure 9 represents that our analytical calculation is true because as expected, the average current is like 40 ampers. Small changes are related to snubber circuit among diodes and thyristors. For the commutation, average current is taken to calculate analytically by assumption.

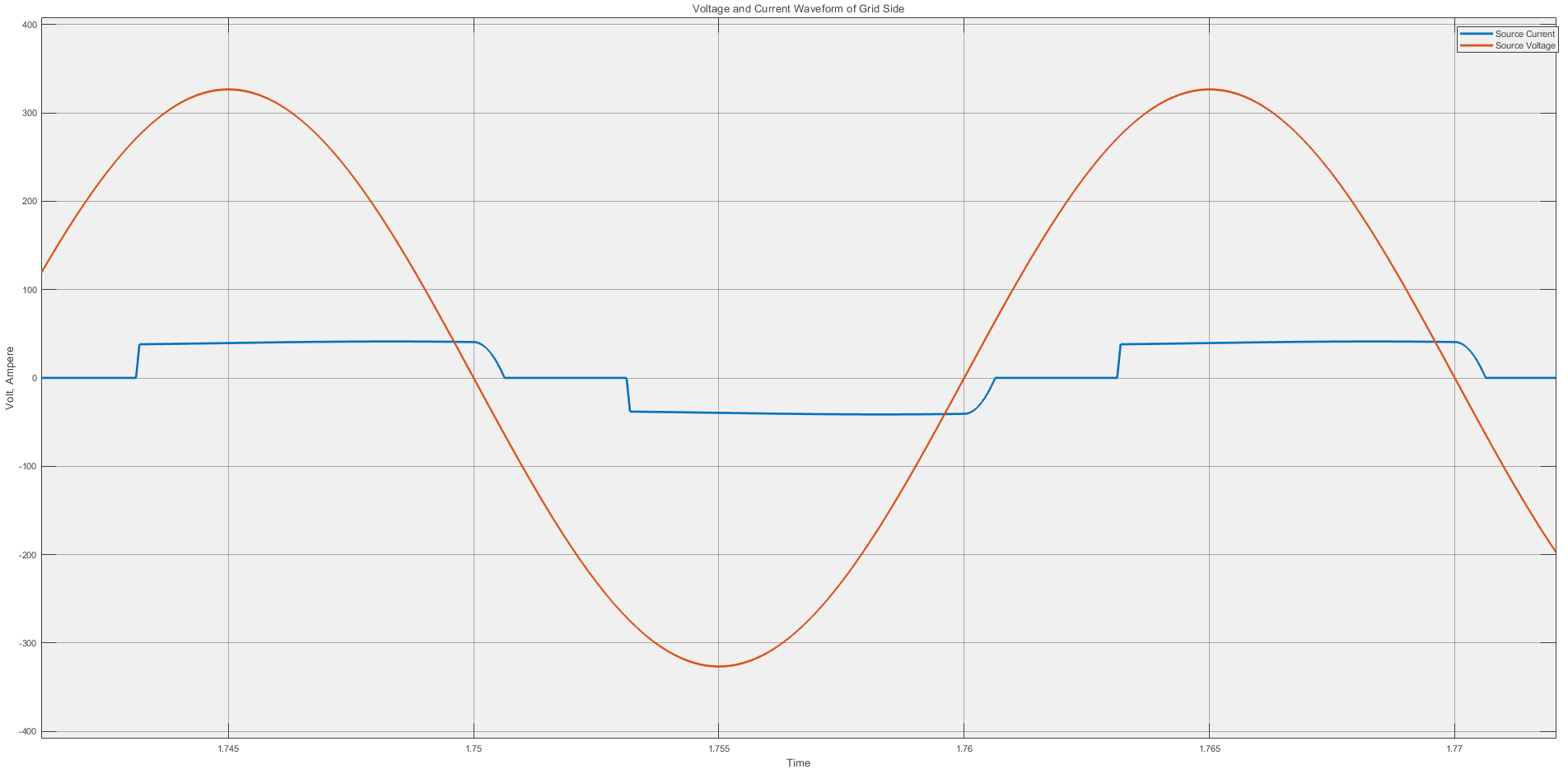


Figure 10

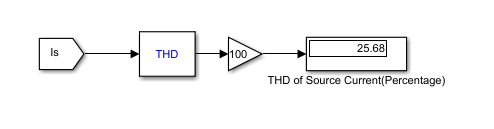


Figure 11

Current waveform is related to diodes. There is no negative current at output voltage and diodes provides that current is circulated. This behaviours reduces the THD of line current because the waveform is much smoother.

The phase difference between line current and line voltage depens on firing angle.( Equation 16)



Equation 17