EEE422

Power Electronics Laboratory

Project Report

Section: 1 **Group: 2**

Inspiring Excellence

Name of Project: Design a DC-DC converter that will provide a fixed DC output for an AC input.

Group Members:

Name	ID	Responsibility
Asif Mahmud	18321001	Alternative design
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K. M. Ekramul Haque	17221007	Objective,Problem statement
Sazzad Hossain	18321051	calculation
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Date of Submission: 30/08/2022

Table of Content

1. Objective:

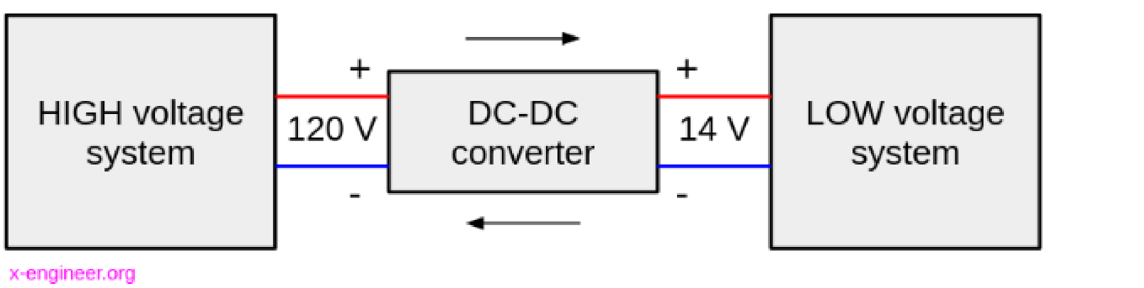
The objective of the experiment is to design a DC-DC converter circuit that will have to be able to change the duty cycle on its own, depending on the input voltage level and will provide a fixed DC output for an AC input.

2. Problem Specification:

For an AC supply of 100V Peak at 60Hz as input we need to have a DC output of 50V (+/- 3.5V) at the steady state region. To get the fixed DC output from an AC input, we have to design a converter and according to the requirements, it should be a DC-DC converter. We need to find out the value of components to design a circuit where the components value has to be at least 10 times the minimum requirement and depending on the input voltage level the circuit should have the ability to change the duty cycle on its own to deliver a fixed DC output.

3. Introduction:

A DC-DC converter is an electrical system (device) which converts direct current (DC) sources from one voltage level to another. In other words, a DC-DC converter takes input voltage and outputs a different DC voltage. The output DC voltage can be higher or lower than the DC input voltage. A DC-DC converter is also called a DC-DC power converter or voltage regulator.



A more efficient type of DC-DC converter is the switching DC-DC converter. There are several topologies of switching DC-DC converters, the most common being presented in the image below.

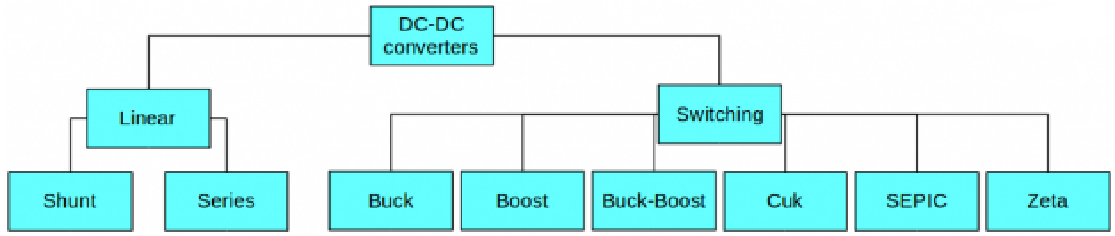


Image: Classification of DC-DC converters

For this project we will just discuss about 3 types of DC-DC converters and they are:

1.Buck DC-DC converter, also called step-down DC-DC converter, is a DC-DC power converter which lowers the output voltage, while increasing the output current. It consists of at least four components:

- a power transistor used as a switching element (Q1)
- a rectifying diode (D1)
- an inductor (L) as energy storage element
- a filter capacitor (C)

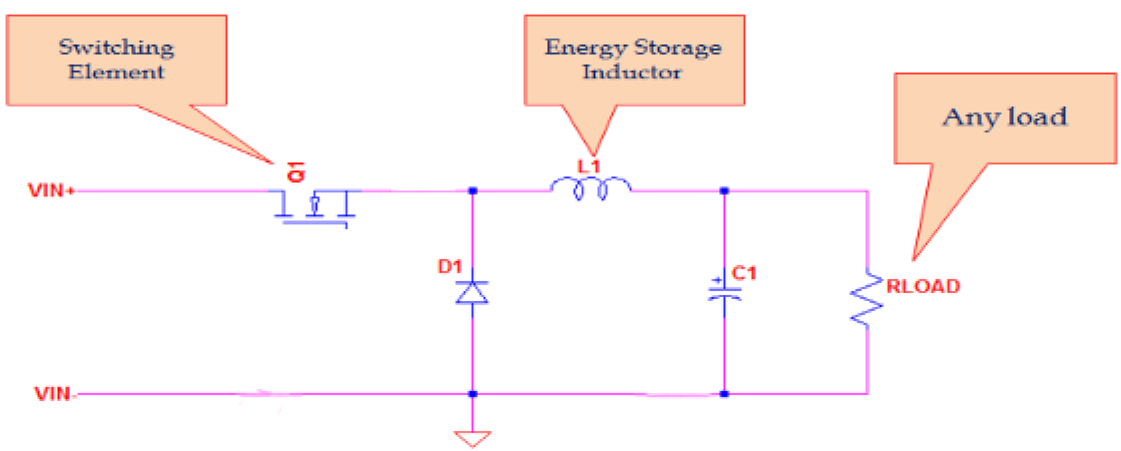


Figure: Buck Converter

the relationships between input and output voltage, current and power are as follows:

- $V_{out} < V_{in}$
- $I_{out} > I_{in}$
- $P_{out} = P_{in} – P_{loss}$

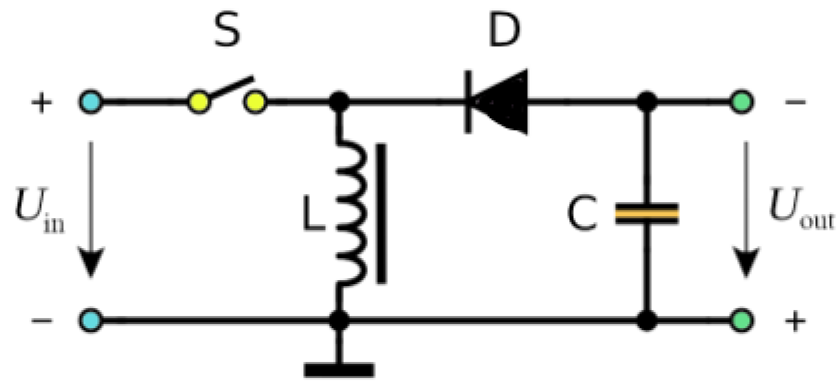
In electric vehicle applications, buck DC-DC converters are used to lower the high voltage of the main battery (e.g. 400 V) to lower values (12-14 V) required by the auxiliary systems of the vehicle (multimedia, navigation, radio, lightning, sensors, etc.).

2.Boost DC-DC converter, also called step-up DC-DC converter, is a DC-DC power converter which increases the output voltage, while decreasing the output current. It contains the same components as a buck DC-DC converter but arranged in a different topology.

The relationships between input and output voltage, current and power are as follows:

- $U_{out} > U_{in}$
- $I_{out} < I_{in}$
- $P_{out} = P_{in} – P_{loss}$

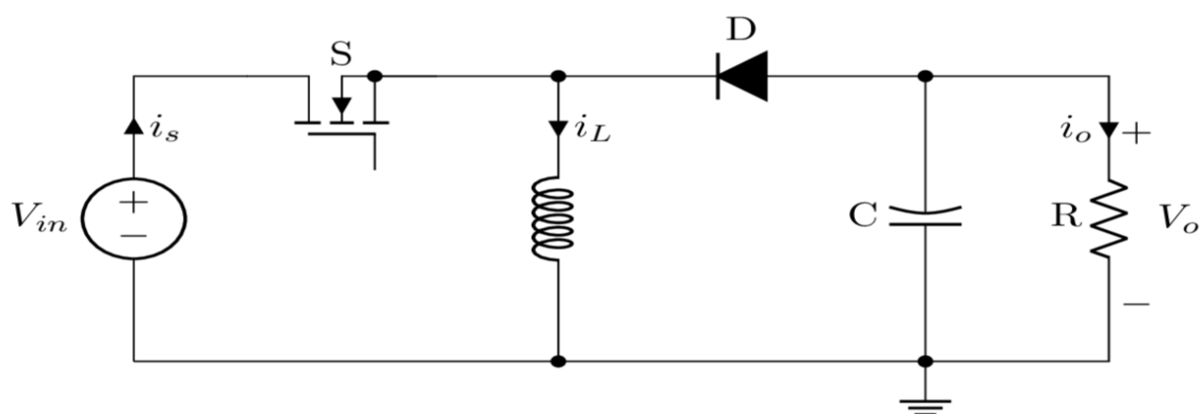
In some Hybrid Electric Vehicle (HEV) applications, boost DC-DC converters are used to step up the voltage from the battery from 202 V to 500 V. The voltage of the battery in a hybrid electric vehicle (HEV) application is limited by the number of battery cells in series. Due to limited space, the batteries are limited in number of cells in series therefore output voltage is limited as well. Using boost DC-DC converters, the battery voltage can be increased to the higher voltage required by the electric machine.



Buck-Boost DC-DC converter

3.**Buck-Boost DC-DC converter:**In Buck DC-DC converters the output voltage is always less than the input voltage. On the other hand, in DC-DC Boost converters, the output voltage is always greater than the input voltage. A Buck-Boost DC-DC converter combines the two and can have its output voltage both higher and lower compared to the input voltage, depending on the duty ratio applied to the switch.

The inverting topology buck-boost DC-DC converter outputs a voltage with opposite polarity compared to the input voltage. The output voltage is an adjusted function of the duty cycle of the switching element (transistor).



Buck-Boost converter

For this project as our input voltage is given which is 100V peak voltage and our output should be 50V so from our previous study we can clearly assume that to get the appropriate output we need to use a BUCK DC-DC converter which will help us to step-down our input voltage.

Buck Converter for step-down operation:

Switch On:

- Diode Reverse bias
- Vin causes a current flow through the Inductor
- C1 charges up.

Switch off:

- Magnetic field around the inductor
- D1 forward bias
- Stored energy in the L1 magnetic field forces the current to flow the load.

Derivation of expressions of all the design components:

Duty Cycle:D=Vo/Vin

D=ton/T, T=ton+toff

For Capacitor and Inductor derivation: The working operation of a buck converter can be explained in two modes. Mode 1, when the switch is turned ON while mode 2, when the switch is turned OFF. Both modes are explicitly discussed here.

Mode 1

By turning ON the switch, the diode will reverse bias to the applied input. Therefore, all the input current will flow through the inductor. Hence the DC input current Idc flowing in the circuit is equal to the inductor current.

$$IL = Idc$$

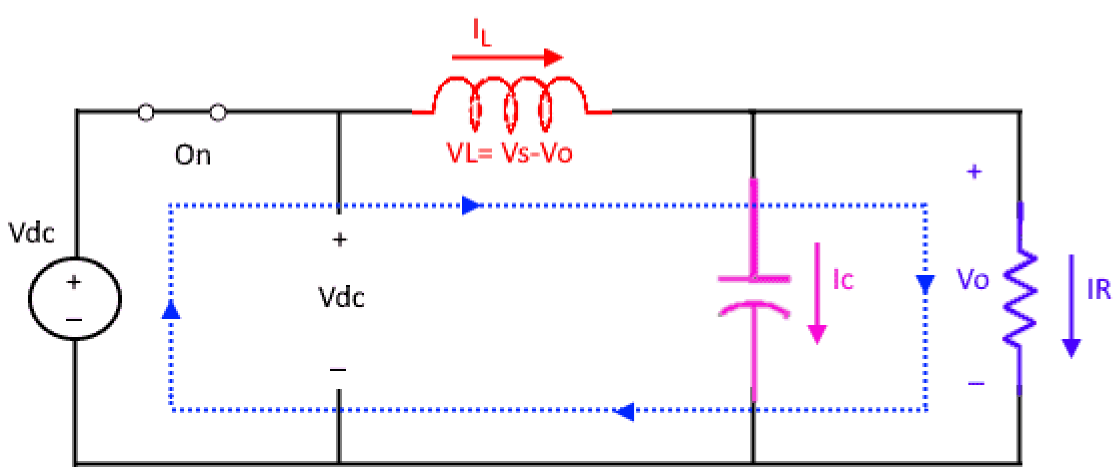
The inductor will charge during turn ON time. This current further divides into load current Io and capacitor current Ic.

$$IL = Ic + IR$$

The inductor voltage VLon during this period is the voltage difference between applied DC voltage Vdc and output voltage Vo.

$$VLon = Vdc - Vo$$

The average voltage across inductor VL is zero according to volt second balance. Recalling the duty cycle equation, the turn ON time ton is the product of duty cycle D and total time T.



the rippling current during turn-on mode can be find from inductor current voltage relationship

$$VL = Ldi/dt$$

$$di/dt = VL/L$$

By putting the value of VL we get

$$di/dt = (V_{dc}-V_o)/dt$$

$$\Delta IL_{on} = \Delta t_{on} (V_{dc}-V_o)/L$$

By putting the value of Δton, the final form of the equation is as given

$$\Delta IL_{on} = DT (V_{dc}-V_o)/L$$

The final result shows the current slope of inductor current during on time. The waveform shown below shows the rippling current that first increases in ON time and then reduces with negative slope.

Mode 2

After turning OFF the switch, mode 1 changes to mode 2. In this mode the polarity of the inductor reverses and it starts acting as a source. The current in this mode flows due to the stored energy in the inductor. The DC source is disconnected during this period. Therefore, the current flows in the circuit till the inductor discharges. The voltage appearing across the inductor is equal to the load voltage with negative polarity.

$$VL_{off} = -V_o$$

After turning OFF the switch, the polarity of the inductor changes which make the diode forward bias. The anode voltage becomes more positive than cathode during this period and hence starts conducting.

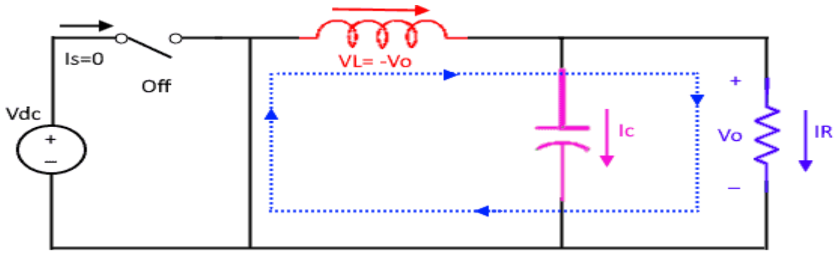
The turn off time toff can be derived from turn on time ton in duty cycle.

$$t_{off} = T - t_{on}$$

$$t_{off} = T - DT$$

The turn off time can be written in the final form as

$$t_{off} = (1- D) T$$



The slope of inductor current can be found once again by the voltage current equation of the inductor.

VL = Ldi/dt = -Vo

di/dt = -Vo/L

ΔILoff = Δtoff (-Vo)/L

By putting the value of Δtoff, the final form of negative slope of the inductor current is as given

ΔILoff = T (1-D) (-Vo)/L

Minimum and Maximum Peak of Inductor Current:

Minimum inductor current ILMIN and maximum inductor current IMAX are both most important terms in designing. Therefore, both minimum peak and maximum peak of the current need be found. Both ILMIN and IMAX can be found very easily according to previous discussion.

ILmin Calculation

ILmin= IL – |ΔIL|/2

By putting the values that we have been discussed in previous two modes of operation, the form of equation will become as given

$$I_{\mathrm{Lmin}} = \frac{V_o}{R} - \frac{1}{2}\left(\frac{V_o(1-\mathrm{D})\mathrm{T}}{L}\right)$$

Further simplifying the above equation, the final form of the minimum inductor current can be achieved as given below.

$$I_{\mathrm{Lmin}} = \boldsymbol{V}_{\mathbf{o}}[\frac{\mathbf{1}}{\boldsymbol{R}} - \frac{(\mathbf{1}-\mathbf{D})}{\mathbf{2}\boldsymbol{L}\boldsymbol{f}}]$$

ILmax Calculation

ILmax= IL + |ΔIL|/2

By putting the previously discussed values in the above equation, we will get

$$I_{\mathrm{Lmax}} = \frac{\boldsymbol{V}_{\mathbf{o}}}{R} + \frac{1}{2}(\frac{\boldsymbol{V}_{\mathbf{o}}(\mathbf{1}-\mathbf{D})\mathbf{T}}{L})$$

Further simplifying the above equation, we will get the final form as given below for maximum inductor current

$$I_{\mathrm{Lmax}} = \boldsymbol{V}_{\mathbf{o}}[\frac{\mathbf{1}}{\boldsymbol{R}} + \frac{(\mathbf{1}-\mathbf{D})}{\mathbf{2}\boldsymbol{L}\boldsymbol{f}}]$$

Inductor Designing for Buck Converter

This section will describe the important aspect of the inductor required for a buck converter. This includes two main ideas i.e. critical inductance and peak current rating of inductor.

Critical Inductance

Critical inductance Lc is the minimum value of inductance at which inductor current reaches zero. Therefore, it is the most important condition for operating a buck converter in discontinuous mode. In other words, the value of the inductor is chosen below critical inductance for operating the buck converter in discontinuous mode.

The requirement is set by means of minimum percentage load. The other way is to set a requirement by max ΔIL discussed previously. For operating buck converters in CCM mode, the inductor value is chosen more than critical inductance.

- L < Lc for operating buck converter in DCM
- L > 1.05Lc for operating buck converter in CCM

The critical inductance value can be easily found by using the previously derived ILmin equation where setting ILmin =0 in the equation.

ILmin = 0 = IL-|ΔIL|/2

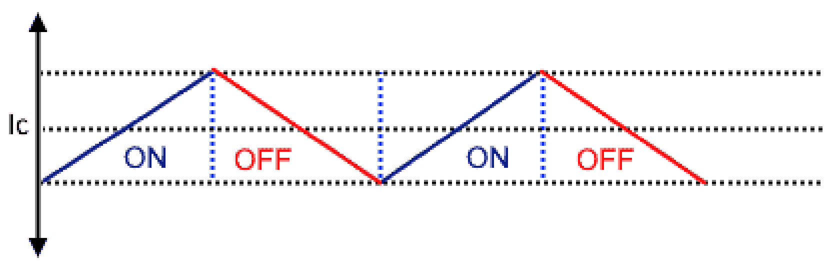
$$I_{\mathrm{Lmin}} = V_o\left[\frac{1}{R} - \frac{(1-D\quad)}{2Lf}\right] = 0$$

The value of critical inductance can be found directly by simplifying the equation. We get the following result after solving the above equation.

$$\boxed{L_c = \frac{(1-D\quad)R}{2f}}$$

Minimum Capacitance According to Voltage:

The designed capacitor will provide a path for AC ripples of inductor current while pure DC current will flow into the load. That is how the capacitor will act as a filter. The waveform of the capacitor current will look as shown below.



It can be seen from the below given waveform capacitor current w.r.t time that charge is the product of area of area and slope.

Q = area. Δ

$$q = \frac{1}{2}\left(\frac{T}{2}\right)\left(\frac{\Delta I_L}{2}\right)$$

By putting the values and simplifying the result will become

$$\frac{\Delta I_L}{8f} = \frac{\frac{V_o}{L}(1-D)T}{8f} = \left(\frac{(1-D)V_o}{8Lf^2}\right)$$

As we know that q=CV. Therefore, C=q/v

By putting values in equation C=q/v

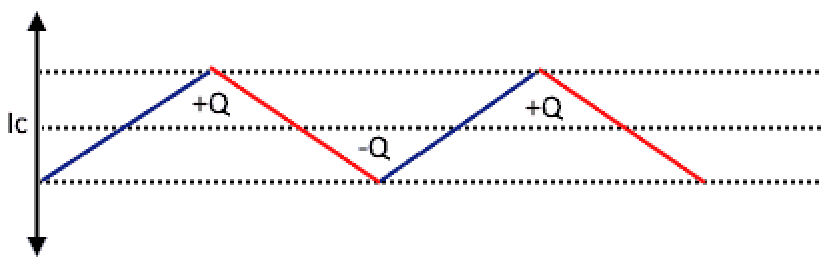
$$C = \frac{(1-D)V_o}{8Lf^2\Delta V_o}$$

$$C = \frac{(1-D)}{8Lf^2\Delta V_o/V_o}$$

The final result for minimum capacitance will be as shown below

$$\boxed{C = \frac{(1-D)}{8Lf^2\Delta V_o/V_o}}$$ here ΔVo/Vo=Ripple voltage

The value ΔVo is given in percent of peak to peak value of output voltage



4. Software Requirements:

***Matlab-Simulink:**To develop our Simulink model, we used MATLAB-Simulink. Simulink is a graphical editor with customizable block libraries and solvers for modeling and simulating dynamic systems.It is integrated with MATLAB so MATLAB algorithms can be incorporated into models and exports simulation results to MATLAB for further analysis. This graphical extension to MATLAB comes with a variety of toolboxes. The toolboxes are function libraries made with the MATLAB technical computing environment.We used various components from the simulink library to construct our circuit diagram and by which we can see input output results of current,voltage and graphical shape of them as well as we can compare them with our desired output.

5. Circuit Diagram (From Simulink)

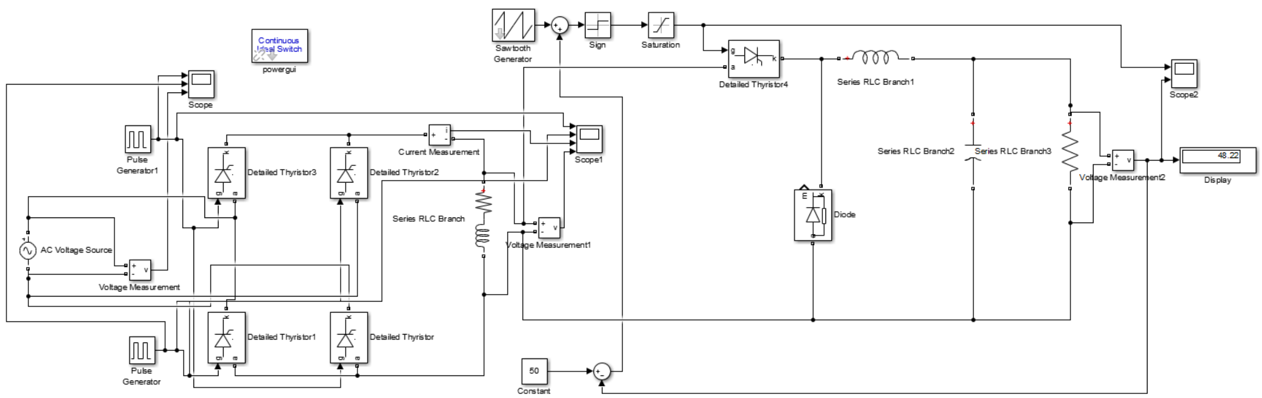


Figure1: Buck Converter(100v AC,AC-DC then DC-DC)

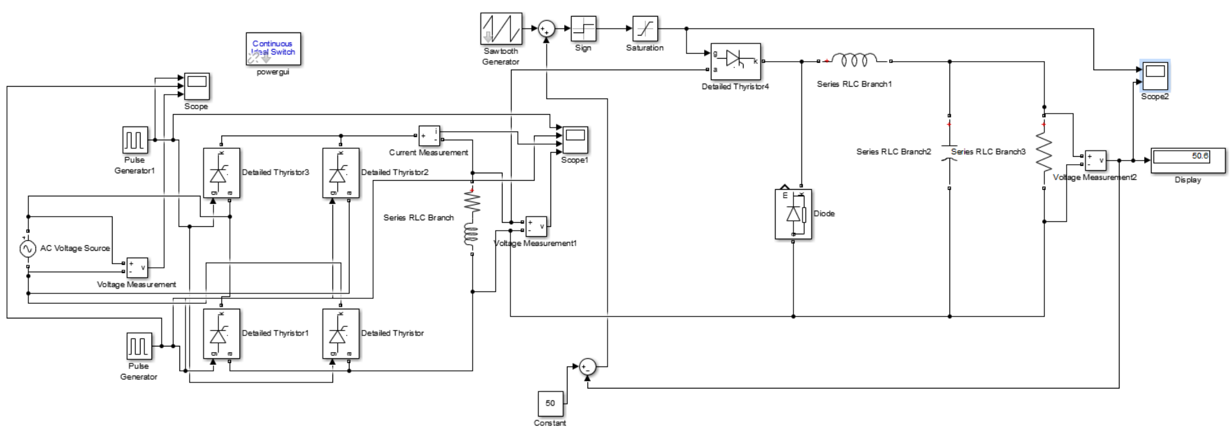
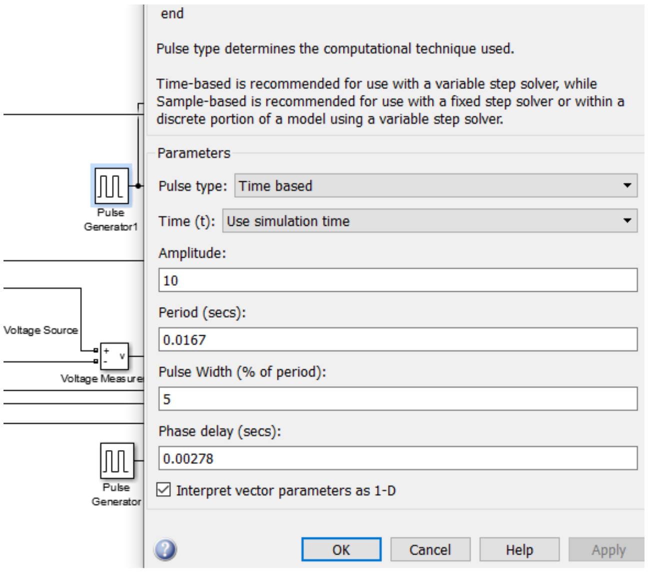


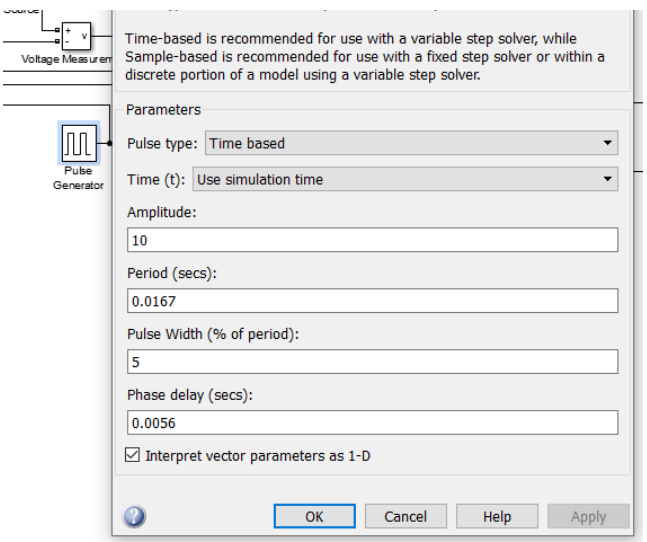
Figure2: Buck Converter(120v AC,AC-DC then DC-DC)

6. Design :

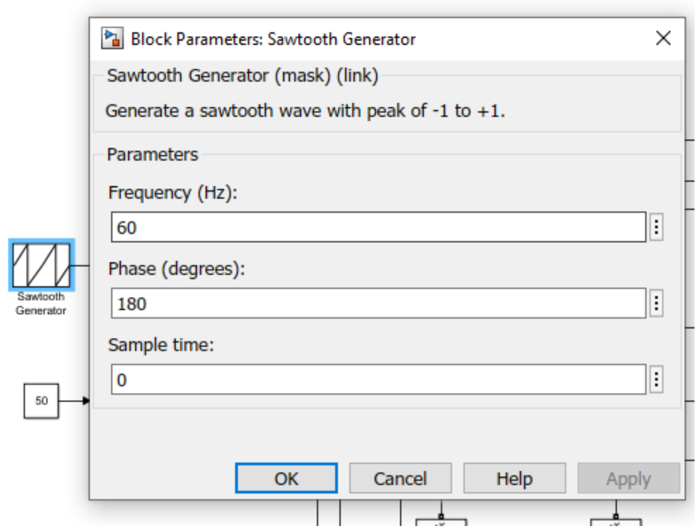
Components value:

Pulse generator:

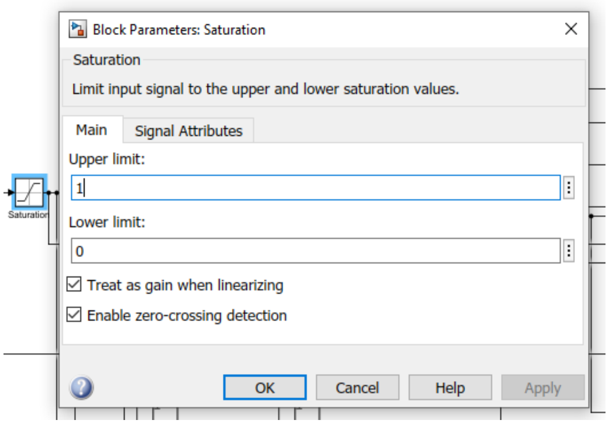




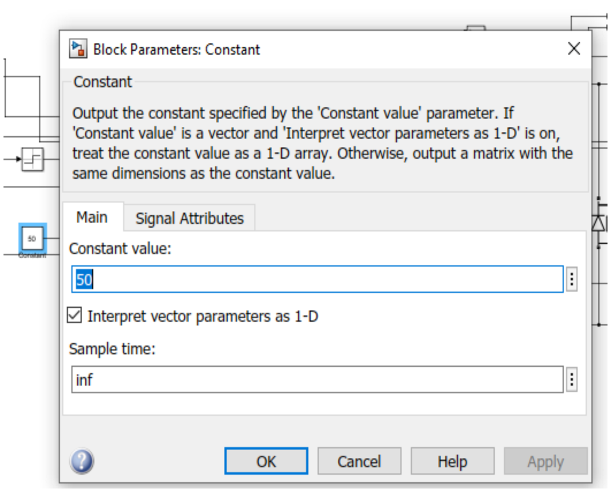
Sawtooth:



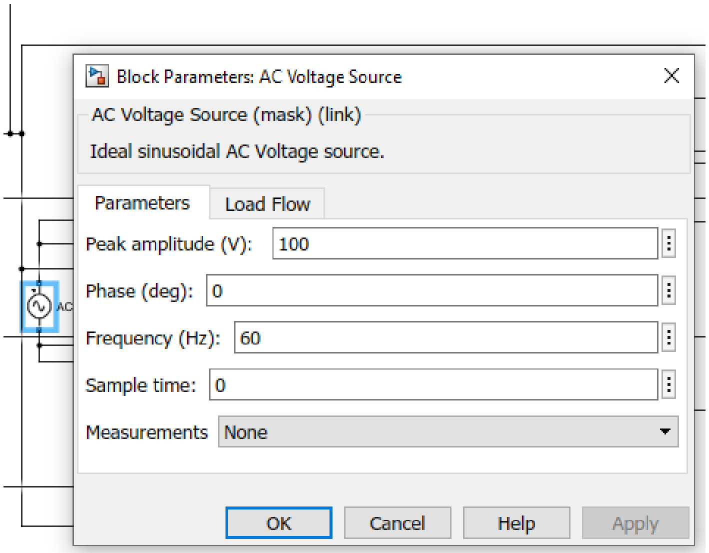
Saturation:



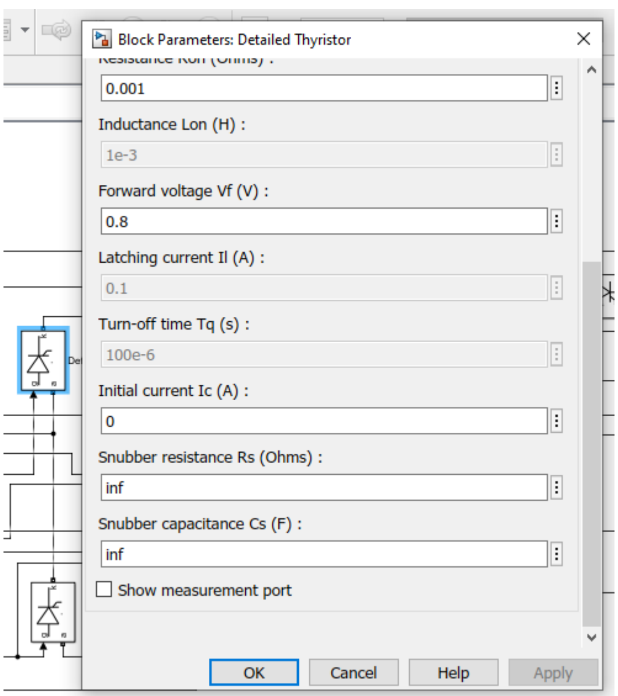
Constant:



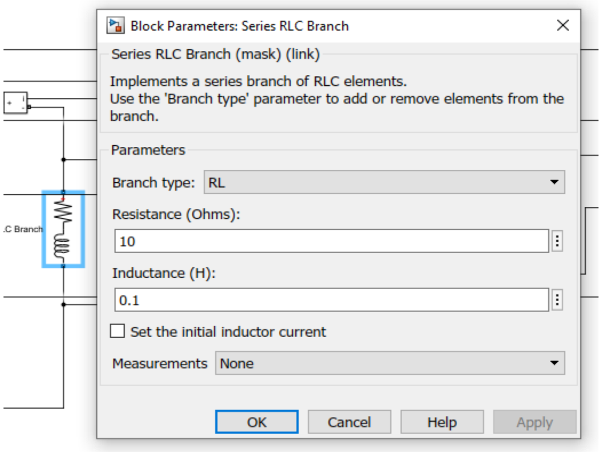
AC voltage source:



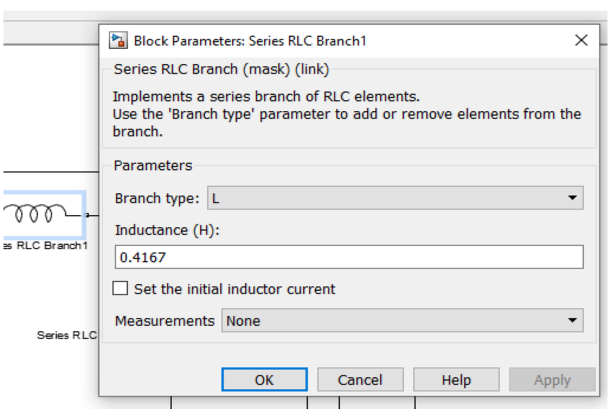
Thyristor: (For all):



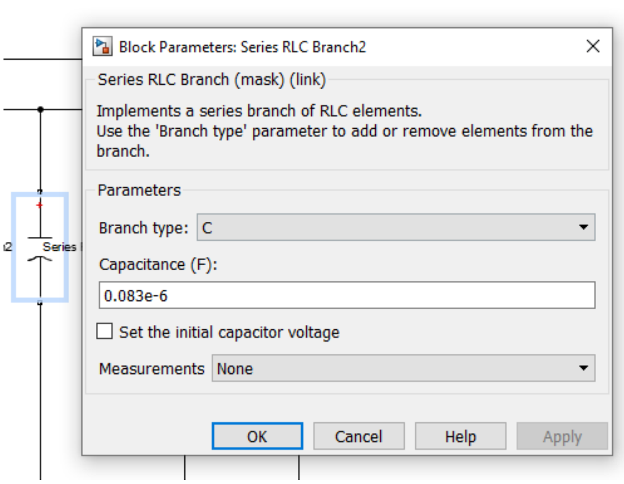
RLC branch:



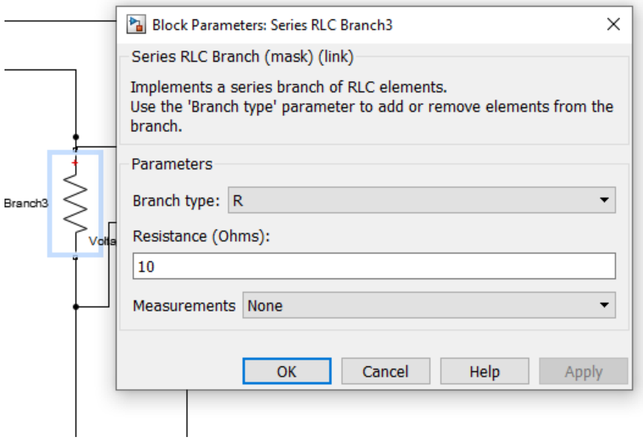
Inductance:



Capacitance:



Resistance:



<u>Calculation:</u>

<u>MAIN DESIGN:</u>

Alpha=60 degree

T=1/60=0.0167

Firing angle for 1st pulse=(0.0167*60)/360=0.00278

Now, (180+60)=240

Firing angle for 2nd pulse=(0.0167*240)/360=0.00278

Here, R = 10

ΔVo/Vo= 0.5%=0.005

V_O = 50V

V_i =100V

F = 60Hz

D = $\frac{V_O}{V_i}$

$=\frac{50}{100}$

= 0.5

L= $\frac{(1-D)R}{2f}$

$= \frac{(1-0.5)\times 10}{2\times 60}$

$= 4.16\times 10^{-3}$

= 0.4167 [10 times bigger value]

$\mathbf{C} = \frac{(1-D)}{8\left(\Delta V_{\underline{O}} [\![Vo)f]\!]^2 L\right.}$

$= \frac{50\times(1-0.5)}{8\times 0.005\times 60^2\times 0.4167}$

$= 8.33\times 10^{-3}$

$= 0.083\ e^{-6}$F

As given, f=60Hz , Vin=100v, Vout=50v so we wanted to keep a small ripple voltage so we took **Δ**Vo/V0=0.005v. Also we took R=10ohm and L=0.1 H so that we can see a kick back dc voltage in AC-DC converter. In DC-DC converter side we took R=10ohm and calculated L and C . We took a small value of R to avoid any problem and see if we r getting propre output or not .

7. Timing Diagram (Input and output)

when Vin=100v

Input:

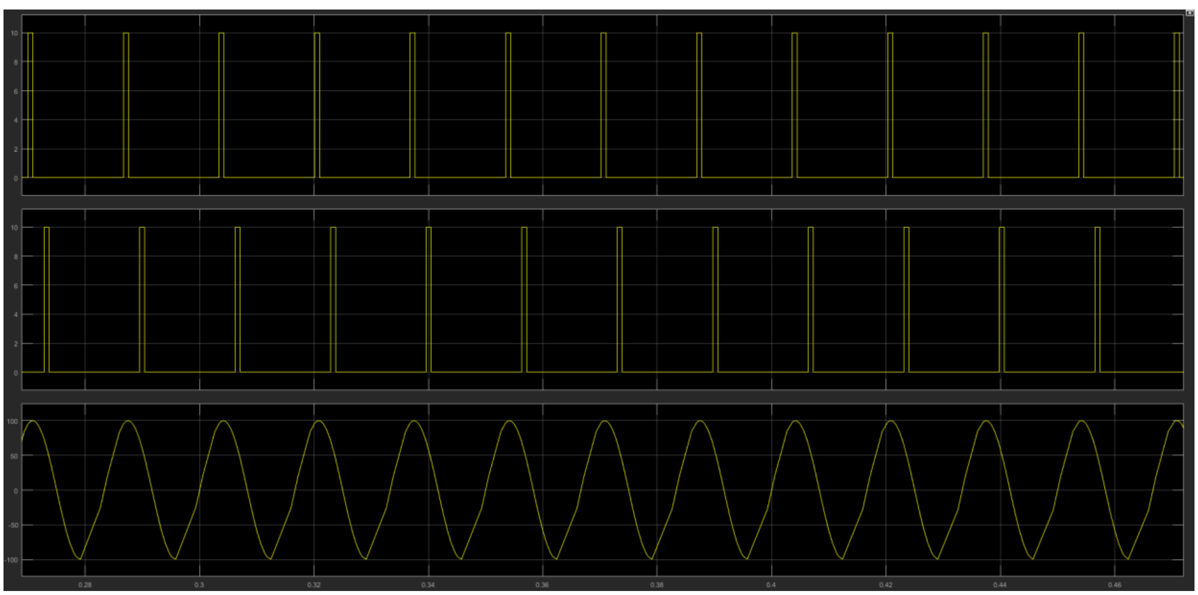


Figure3:Input 100v AC voltage

Output:

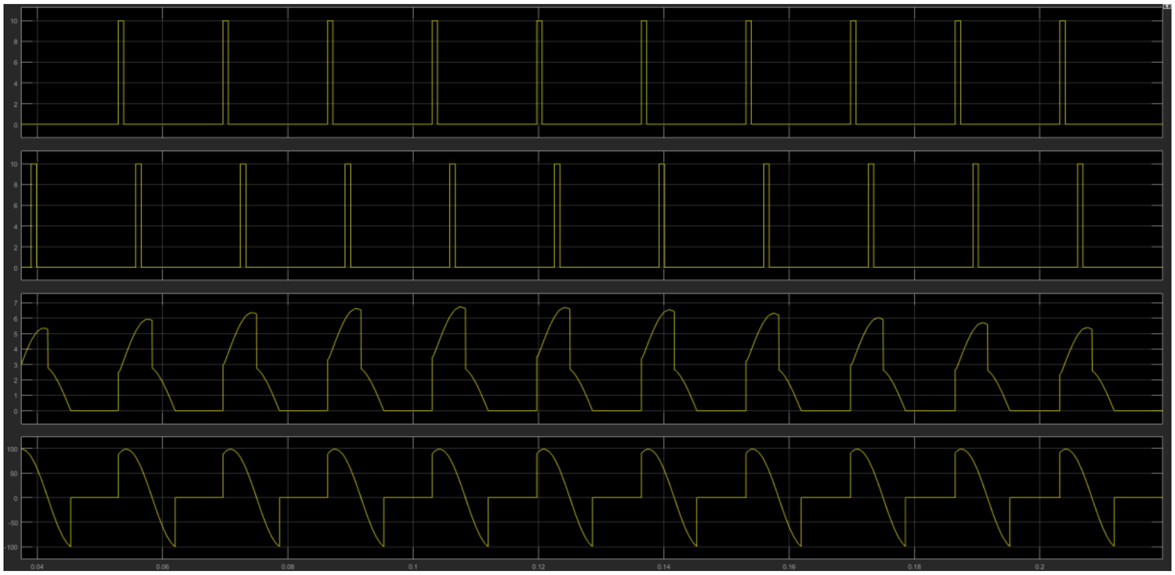


Figure4: Output of AC-DC converter

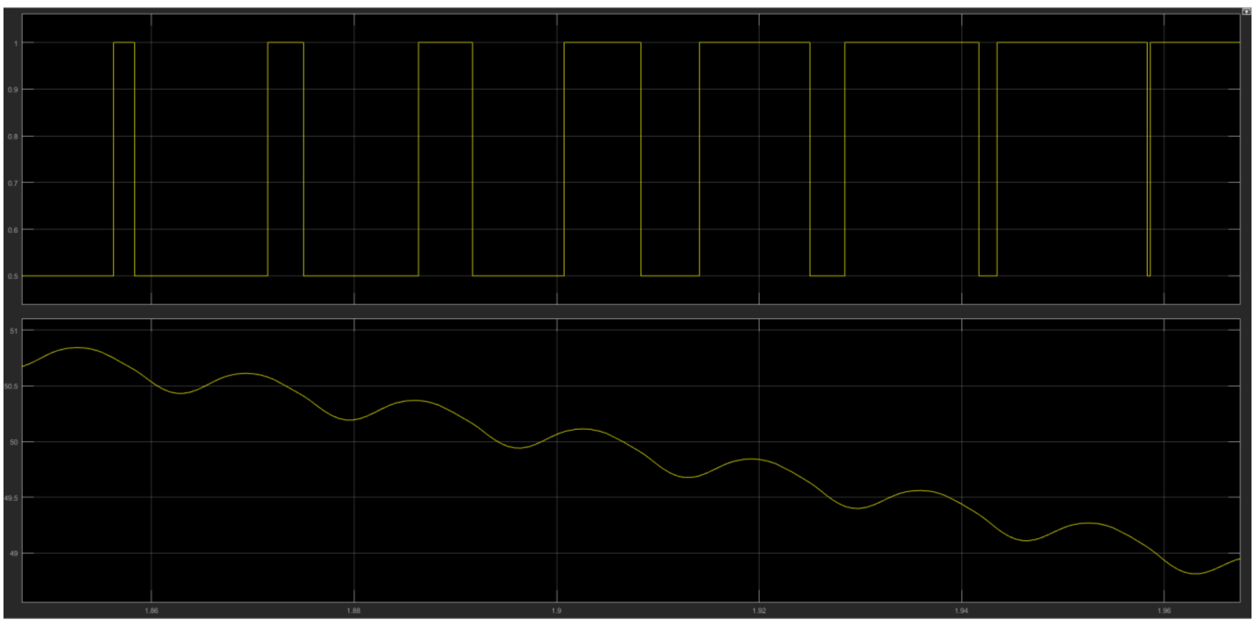


Figure5: Output of DC-DC converter

when Vin=120v

Input:

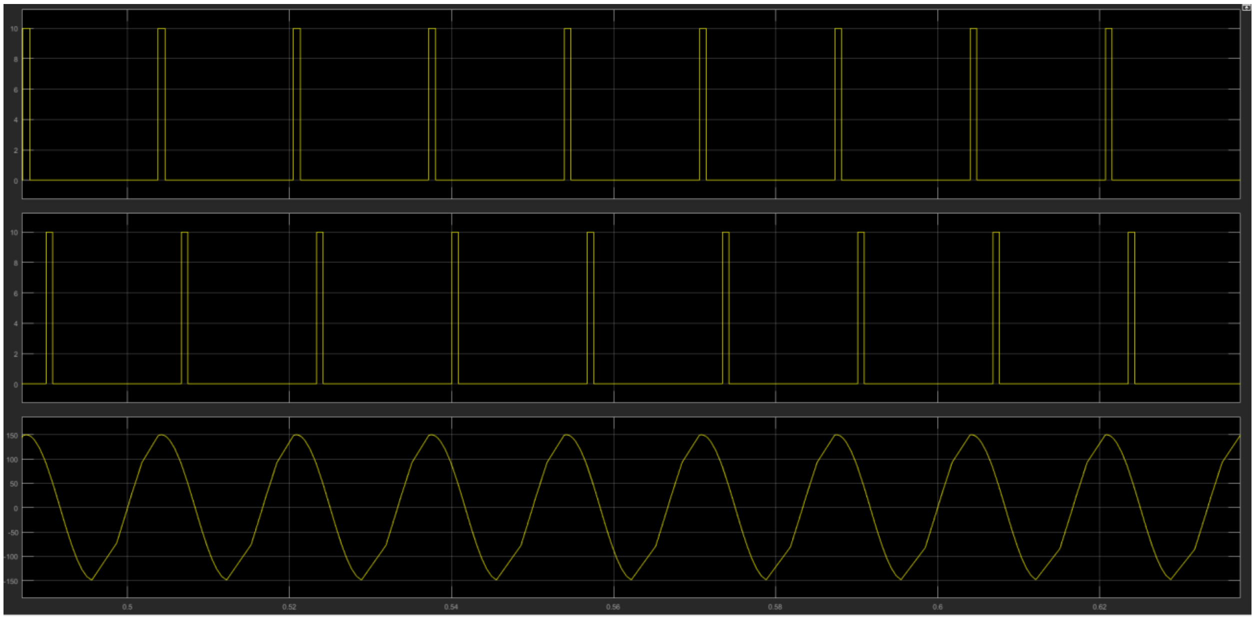


Figure6:Input 100v AC voltage

Output:

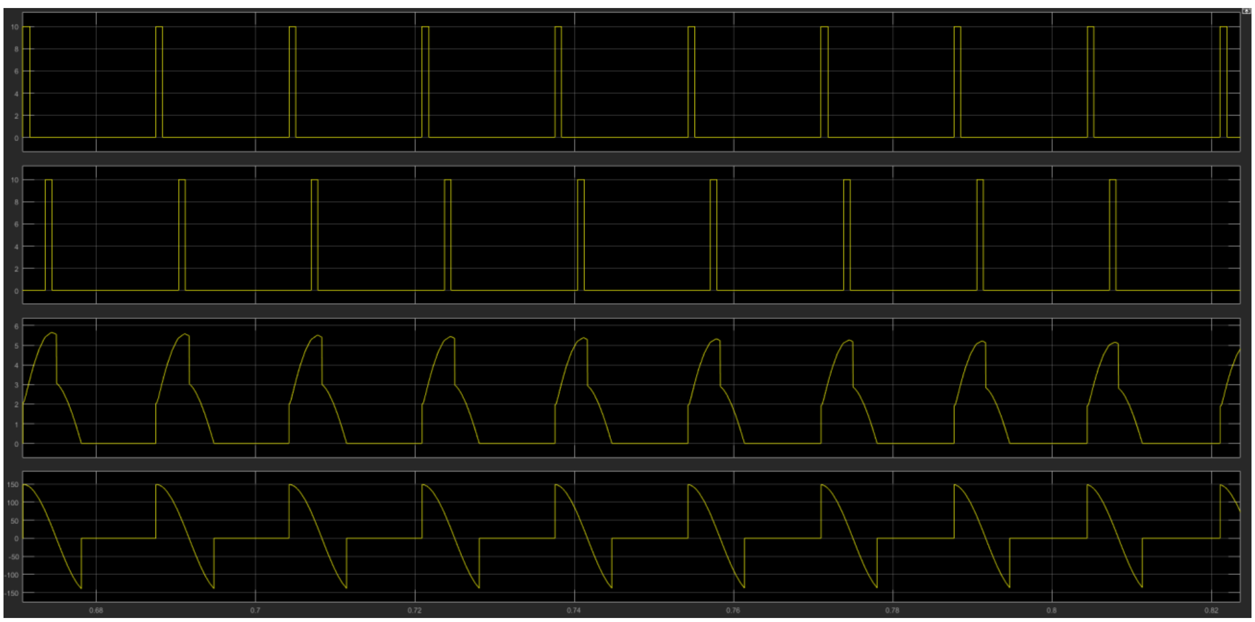


Figure7: Output of AC-DC converter

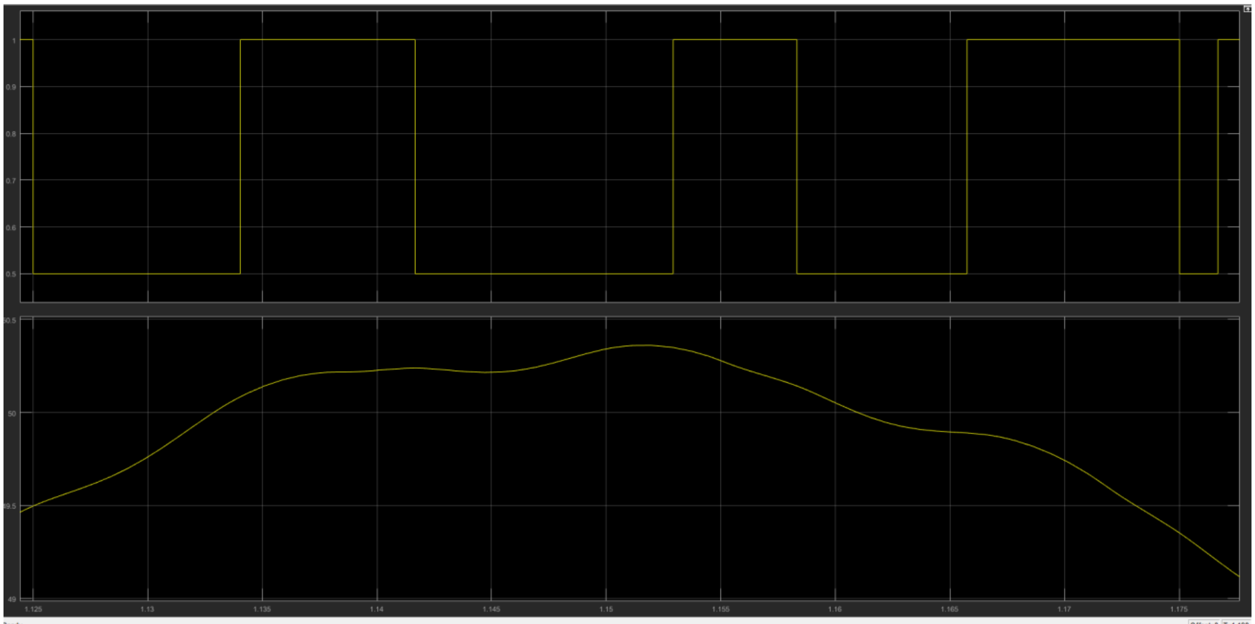


Figure8: Output of DC-DC converter

8. Working procedure:

AC to DC converter: This component plays the role of a rectifier because 100V 60Hz AC input voltage is converted to 100V DC by using this AC-DC converter. Here we are generating pulse using pulse generator with alpha=60degree and 180 degree phase shift. We are giving connection thyristor 1 and 4 with one pulse and 2 and 3 number thyristor with another pulse to get the pulse .We are using thyristor to make a rectifier.We use a rectifier for rectifying alternative current to direct current. This device periodically reverses the direction of alternating current (AC) to direct current (DC), which usually flows in just one direction. Mainly the bridge rectifier which has four diodes converts the AC voltage to DC voltage. But the V_{avg} was low. Because there was some ripple while converting the DC wave shape. So after rectification we are getting 100v DC voltage .

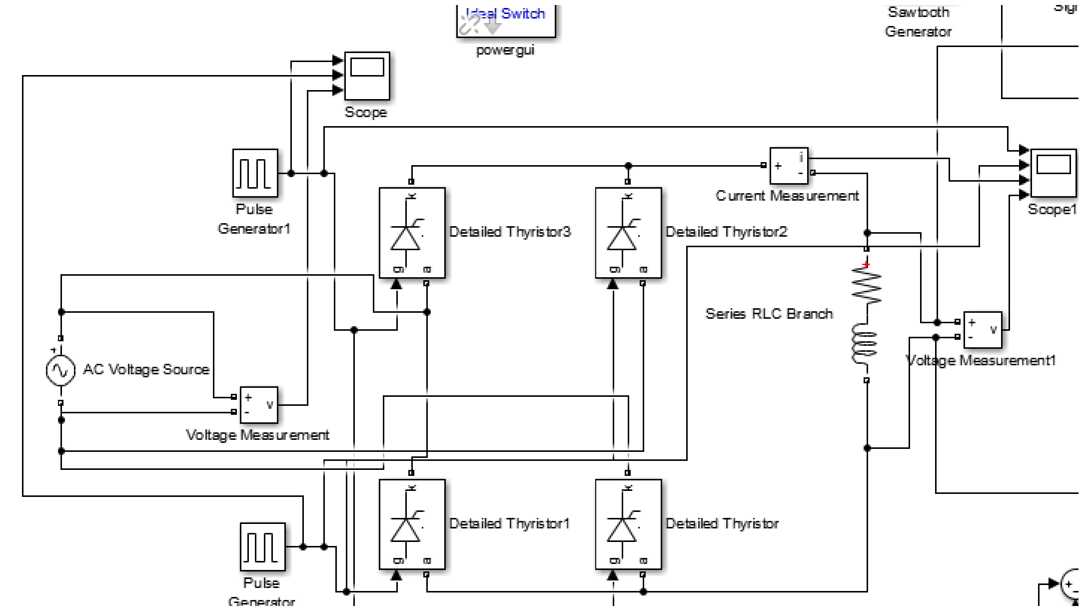


Figure9:AC to DC converter

DC-DC converter: DC-DC converters are widely used to produce a regulated voltage that may or may not be well controlled to a load that may or may not be constant. Buck converter or simply the DC to DC converter was used to increase the DC voltage. Here we are using the same DC voltage that we got after AC-DC conversion and giving the sawtooth generator connecting with saturation and sign connection through the thyristor to get a pulse. After designing buck converter we are getting output voltage 48.22v

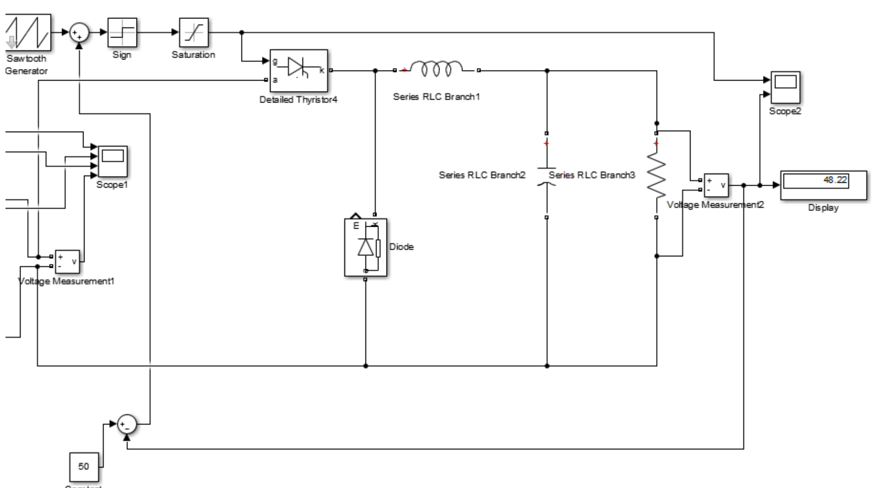


Figure10:DC-DC converter

Role of Components:

Sawtooth generator: Sawtooth generator is used for generating sawtooth waves which are a non-sinusoidal waveform or simply dc pulses. It can be easily generated using a simple oscillator. In our circuit we wanted to create a pulse, that's why we used it.

Saturation: The Saturation block produces an output signal that is the value of the input signal bounded to the upper and lower saturation values. The upper and lower limits are specified by the parameters upper limit and lower limit. We wanted to limit the input signal for a clear output.

Constant: The Constant block generates a real or complex value signal. We used this block to provide a constant signal output.

Thyristors: Thyristors , widely used for power control DC systems. The circuits use a variety of different methods to control the load current flow, but all require the gate to be fired and the anode cathode voltage to be removed to stop the current flow. As we know, thyristors can only conduct in one direction so it is mostly called a DC switch; and our goal is converting dc to dc signal, that's why we used thyristors.

Diode:A diode is a two-terminal electronic component that conducts current primarily in one direction (asymmetric conductance); it has low (ideally zero) resistance in one direction, and high (ideally infinite) resistance in the other.

Result and Observation :

From the while input is 100v AC, output graph we can see that in AC-DC conversion we are getting proper 100v dc voltage and at DC-DC output we are getting a dc voltage at 48.22 v and it has some ripple till 49.6v. So we can see that we are getting a small amount of ripple in dc voltage. When input is 120 v AC, then the width of the pulse changes and we are getting output voltage around 50.6 v along with some ripple voltage till 50 v.So from the observation we can see that even if we change the input voltage but the output voltage will be limited within 50v.Also when the input is changing then width of the pulse is also changing along with input. So we were able to design the circuit in such a way that it does not exceed the limit and fulfill the requirement.

9. Alternative Design

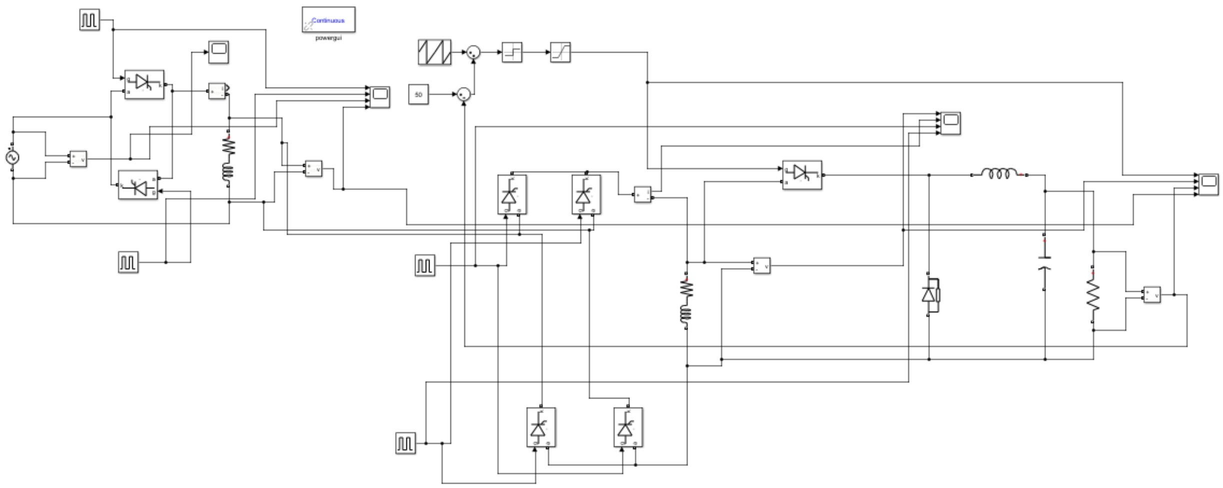


Figure11: Buck Converter(AC,AC-AC voltage controller then AC-DC then DC-DC)

AC-AC voltage controller: Here we are giving 100v ac input and by using AC-AC voltage controller circuit we want to control the AC voltage so that while conversion we don't get much voltage loss.

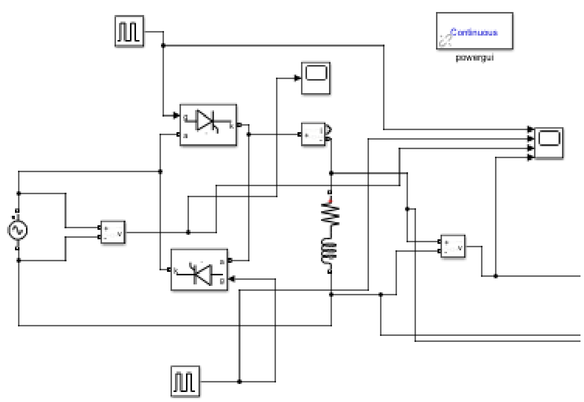


Figure13:AC-AC voltage controller

AC-DC converter : This component plays the role of a rectifier because 100V 60Hz AC input voltage is converted to 100V DC by using this AC-DC converter.

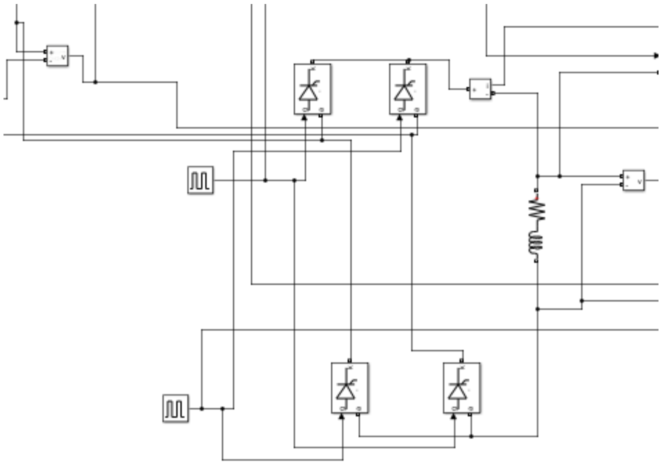


Figure14:AC-DC converter

DC-DC converter:DC-DC converters are widely used to produce a regulated voltage that may or may not be well controlled to a load that may or may not be constant.

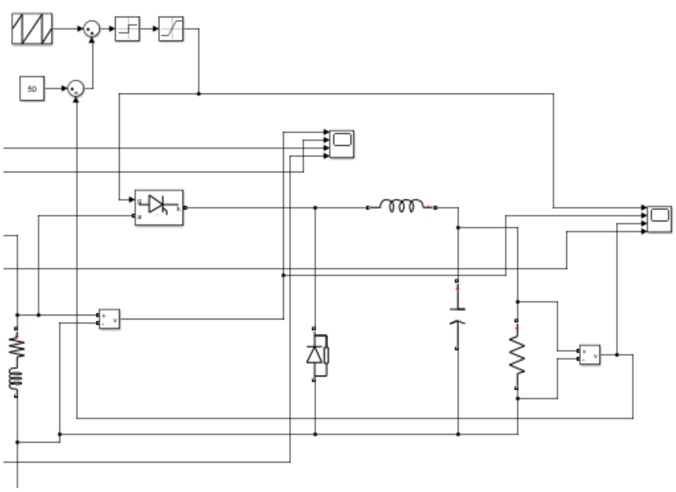
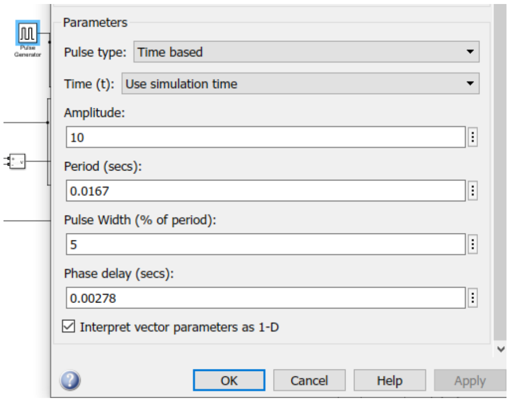
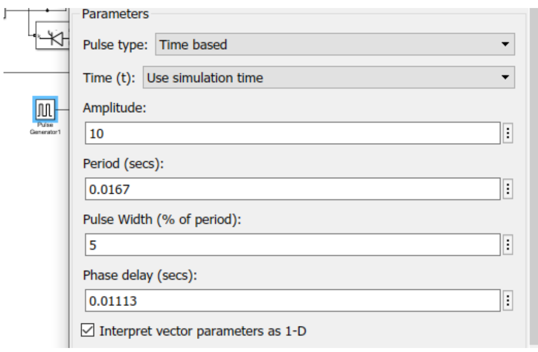
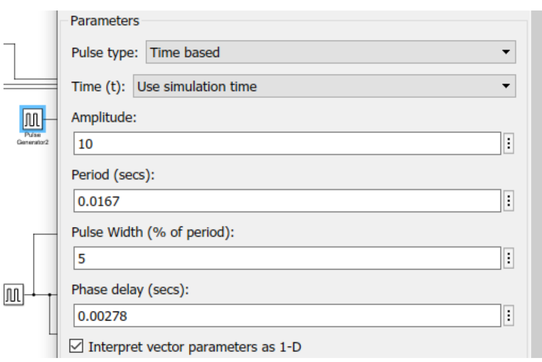


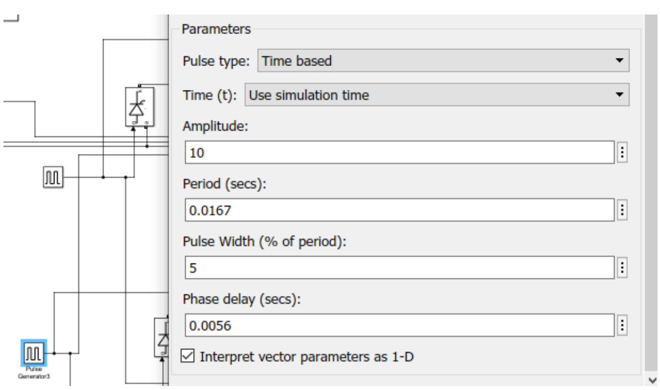
Figure15:DC-DC converter

Pulse Generator:

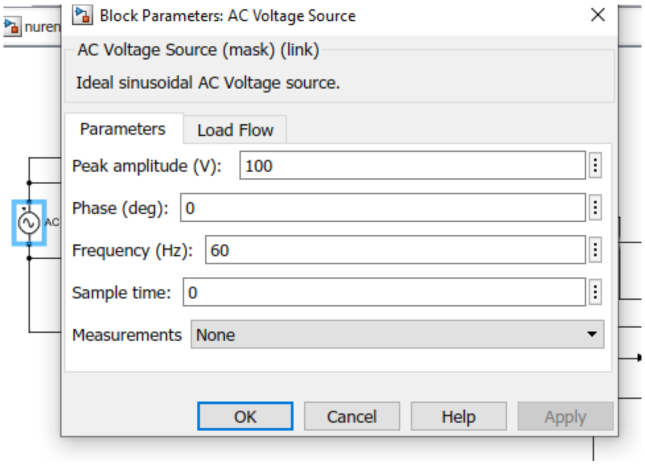




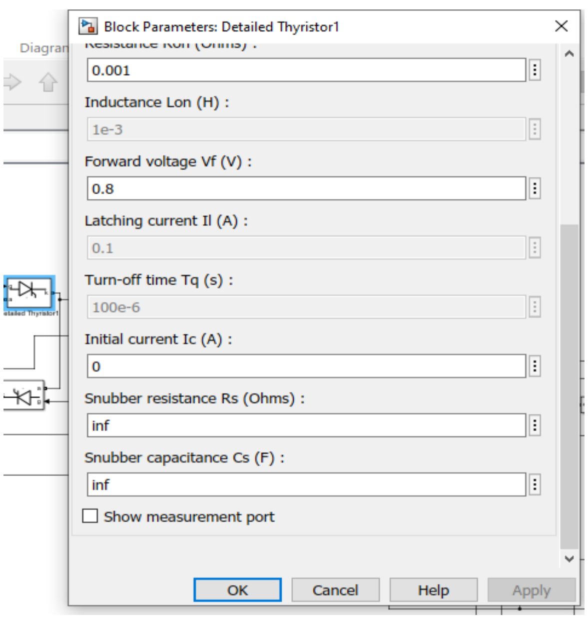




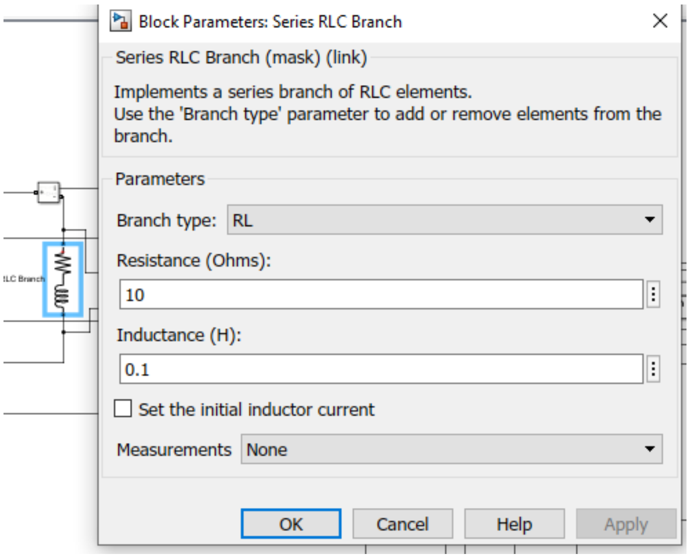
AC voltage source:



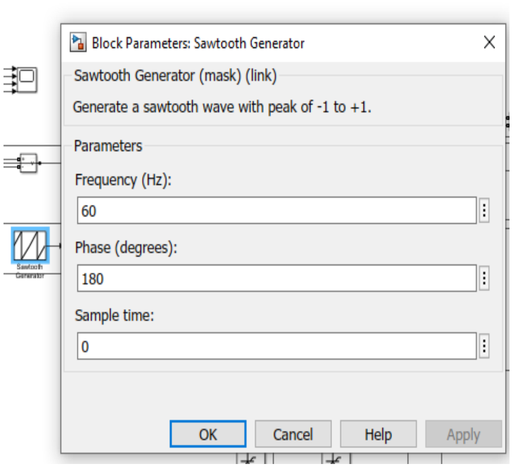
Thyristor(for all):



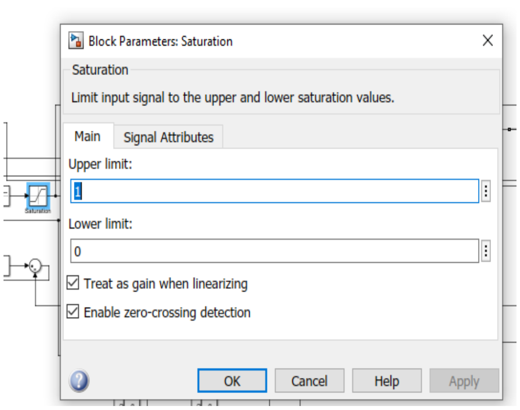
Series RLC branch:



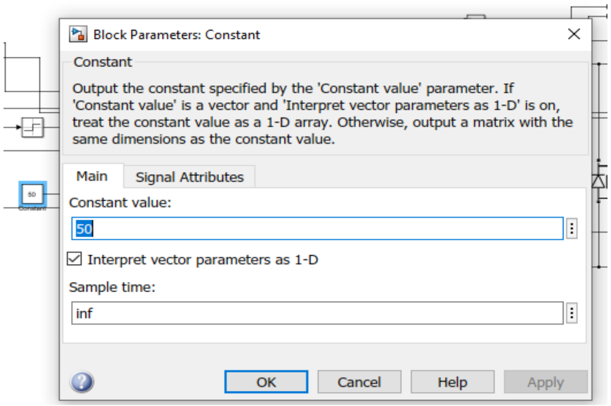
Sawtooth:



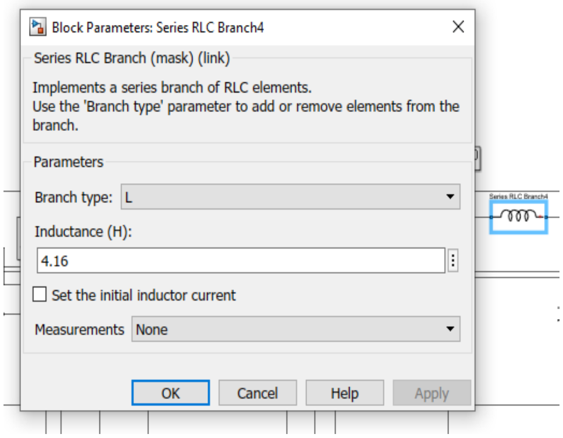
Saturation:



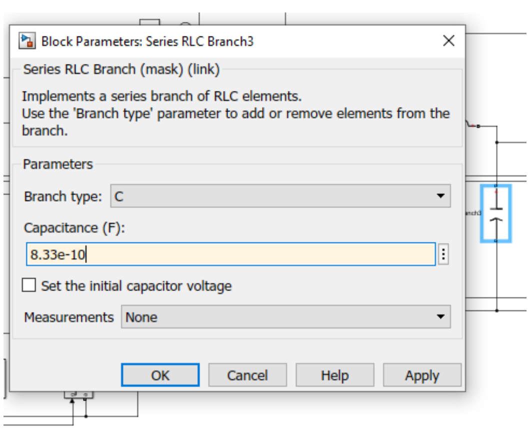
Constant:



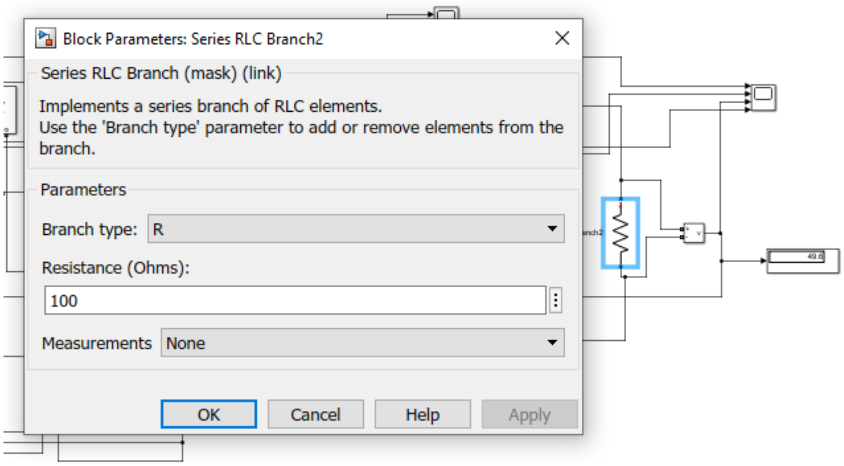
Inductance:



Capacitance:



Resistance:



<u>Calculation</u>

Alpha=60 degree

T=1/60=0.0167

For AC-AC

Firing angle for 1^{st} pulse=(0.0167*60)/360=0.00278

Now,

Firing angle for 2^{nd} pulse=(0.00835+0.00278)=0.0111

And for AC-DC

Firing angle for 1^{st} pulse=(0.0167*60)/360=0.00278

Now, (180+60)=240

Firing angle for 2^{nd} pulse=(0.0167*240)/360=0.00278

Here, R = 100

$\Delta Vo/Vo$ = 0.005V

V_i = 100V

V_O = 50V

F = 60Hz

$$L = \frac{(1-D)R}{2f}$$

$= \frac{(1-0.5)\times 100}{2\times 60}$

= 0.4167

= 4.167 [10 times bigger value]

C = $\frac{V_O(1-D)}{8\left(\frac{\Delta V_O}{Vo}\right)f^2L}$

$= \frac{(1-0.5)}{8\times 0.005\times 60^2\times 4.16}$

= 833.267e-6

= 833.267e^{-5} [10 times bigger value]

= 8.33e-10F

Input:

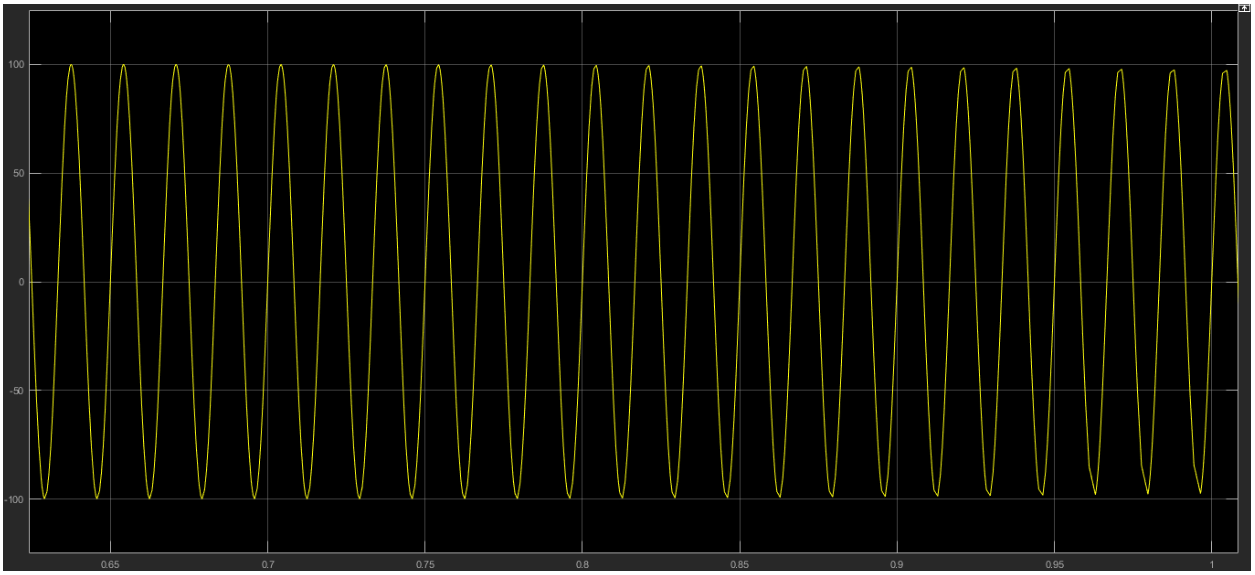


Figure16:Input 100v AC voltage

Output:

(AC-AC)

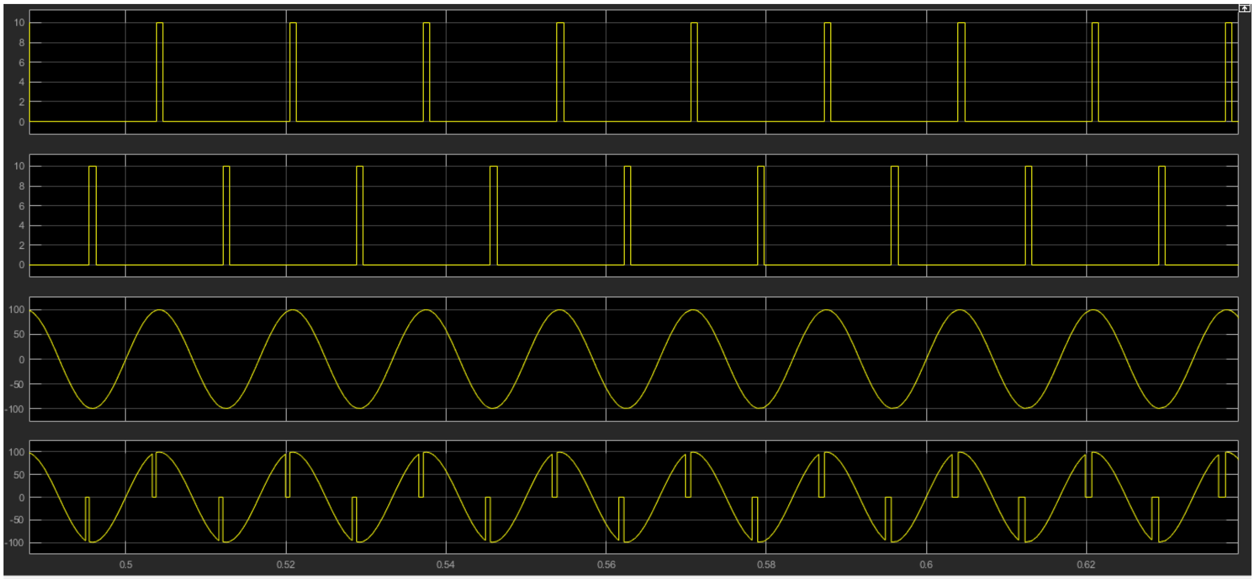


Figure17: Output of AC-AC converter

(AC-DC) Voltage/current:

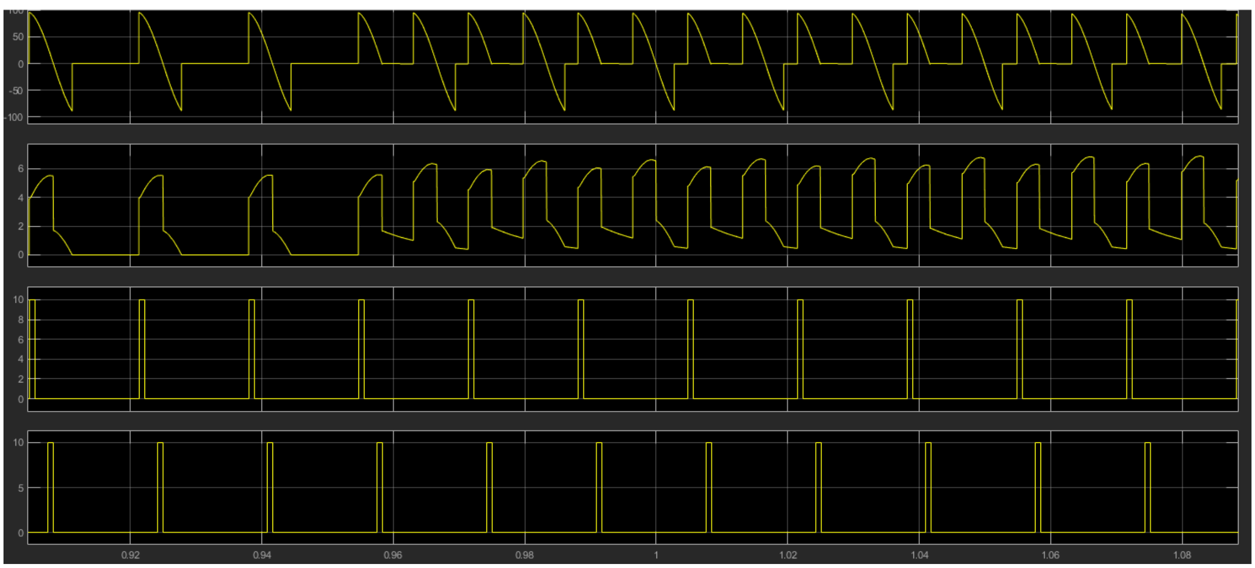


Figure18: Output of AC-DC converter

DC-DC:

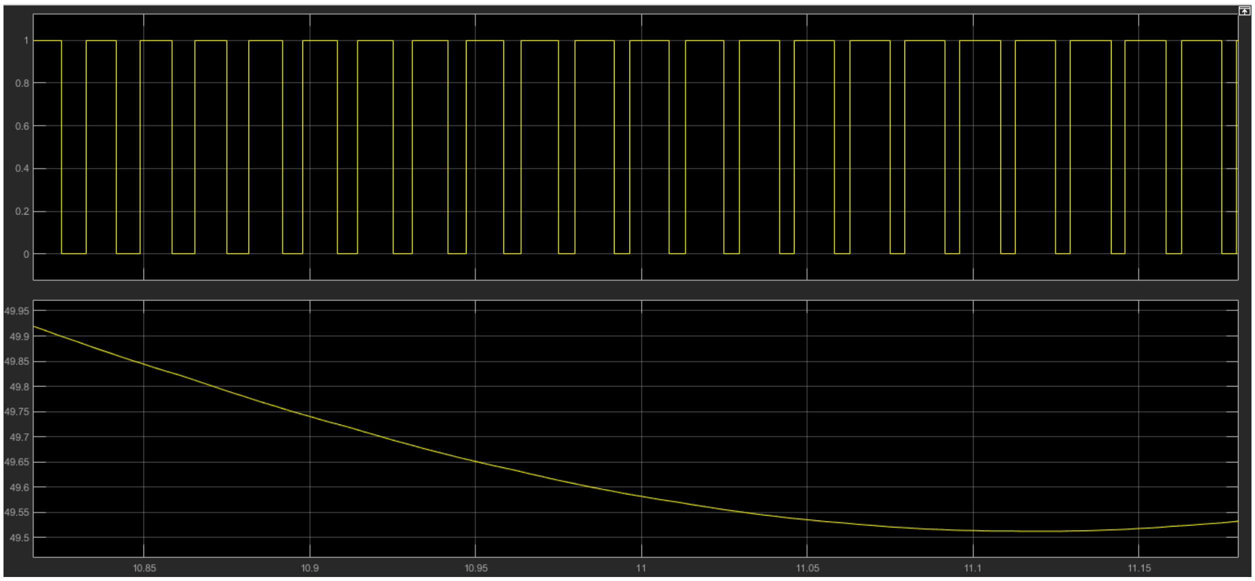


Figure19: Output of DC-DC converter

When Vin=120v

Input:

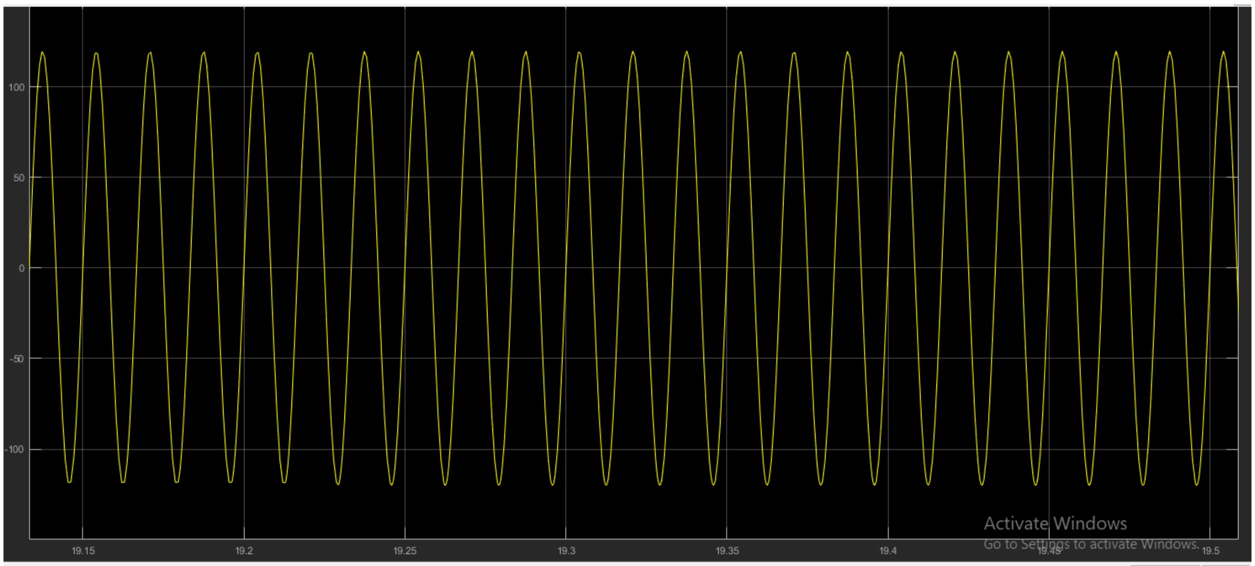


Figure20:Input 120v AC voltage

Output:

(AC-AC)

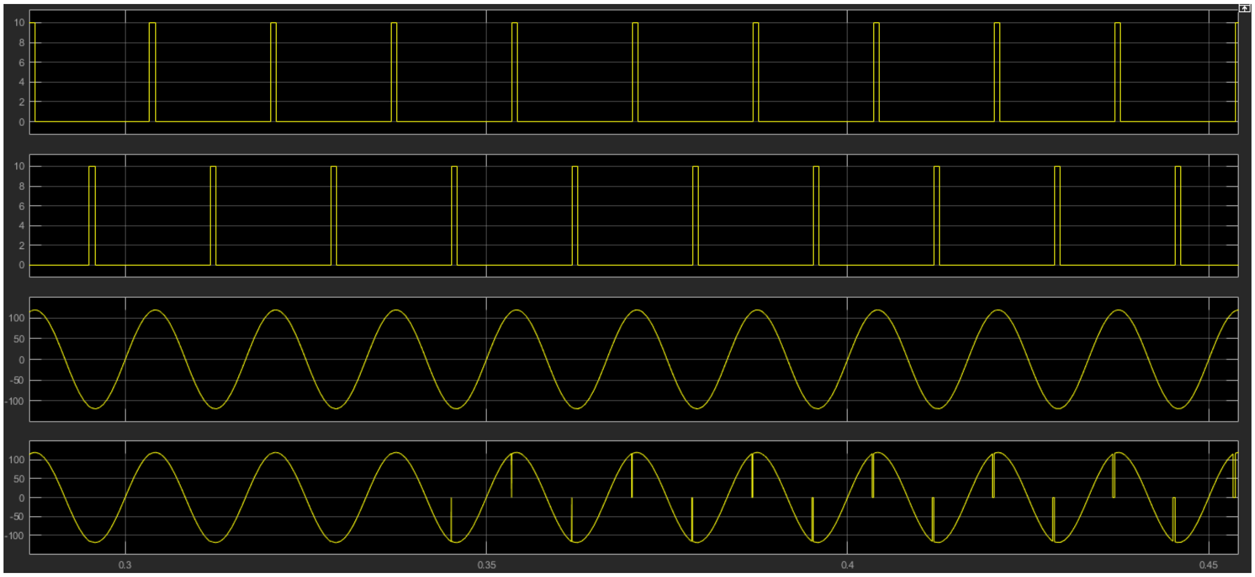


Figure21: Output of AC-AC converter

AC-DC:

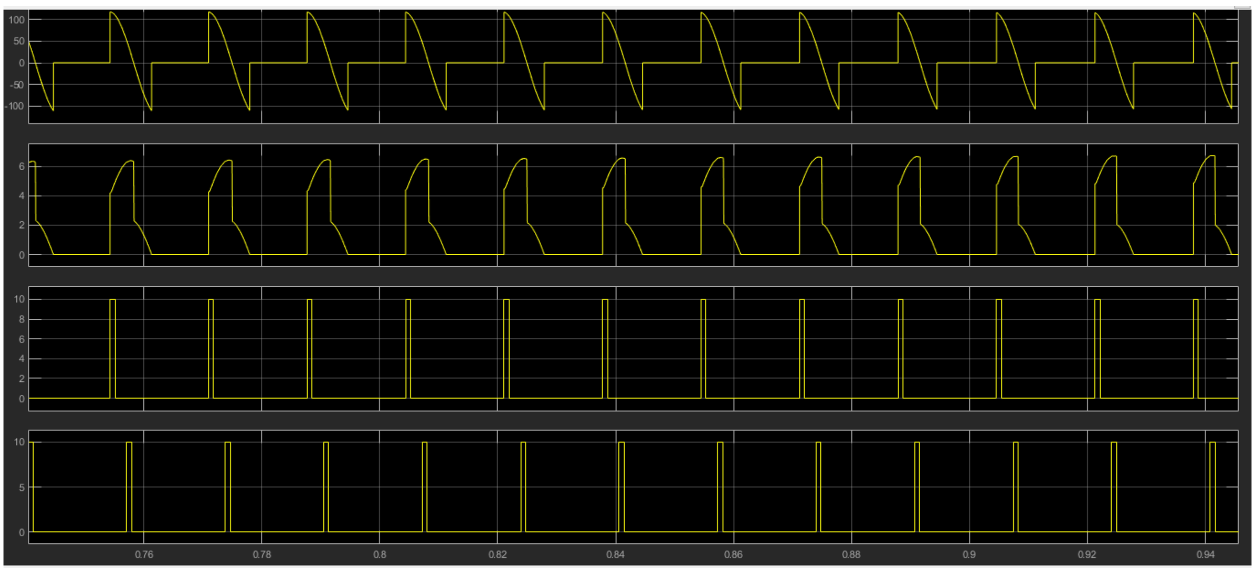


Figure22: Output of AC-DC converter

DC-DC:

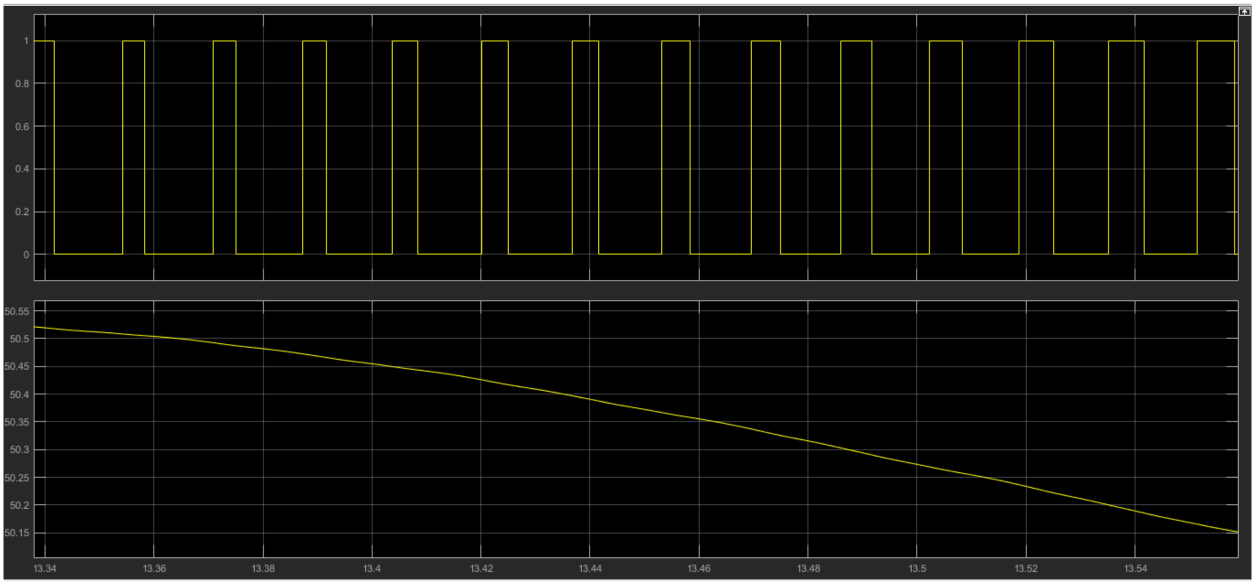


Figure23: Output of DC-DC converter

From the graph we can see that we are getting DC output at the end . When Vin=100v then the output is 49.85 v and when Vin=120 then output=50v and the width of the pulse is changing automatically with input .

10. Comparison with Alternative Design.

	Core Design	**Alternative Design**
Conversions	1st AC-DC conversion then DC-DC buck converter design	1st AC-AC conversion then AC-DC finally DC-DC buck converter design
Resistance value	Small resistance	Comparatively large resistance
Complexity	Less complex design	Complex design
Phase	AC-DC phase difference is 0.00278 and 0.0056	AC-AC phase difference is 0.0027 and 0.01113; AC-DC phase difference is 0.00278 and 0.0056

11. Discussion :

While doing this project our main issue was to design such a circuit which fulfills all the requirements keeping the output voltage within the range. So we have used an AC-AC voltage controller , AC-DC converter and DC-DC BUCK converter to build our circuit.Also for generating continuous pulse we used sawtooth to and connected with the thyristor to get the continuous pulse. We had to check through the calculation if the output value is in range or exceeding the range. If not then we had to fix it by doing the calculation again. Also we have to check if we have given propre connection or not.We had to check if the pulse width is changing or not along with input .Thus we finished our project after fulfilling the requirements .

Reference:

1.Technology, E. (2020, September 16). Buck converter - circuit, design, operation and examples. ELECTRICAL TECHNOLOGY. Retrieved August 26, 2022, from https://www.electricaltechnology.org/2020/09/buck-converter.html

2.*Thyristor*. (20 C.E.). Wikipedia. Retrieved 2022, from https://en.wikipedia.org/wiki/Thyristor

3. X-Engineer.org. (n.d.). Home. x. Retrieved August 26, 2022, from https://x-engineer.org/dc-dc-converter

File link:

https://drive.google.com/file/d/1LUhl56F4YEYarN7ASI5kojJbbVNL-CIL/view?usp=sharing