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ROLL NUMBER:234102501
Date: 24/08/2024

EXPERIMENT 1

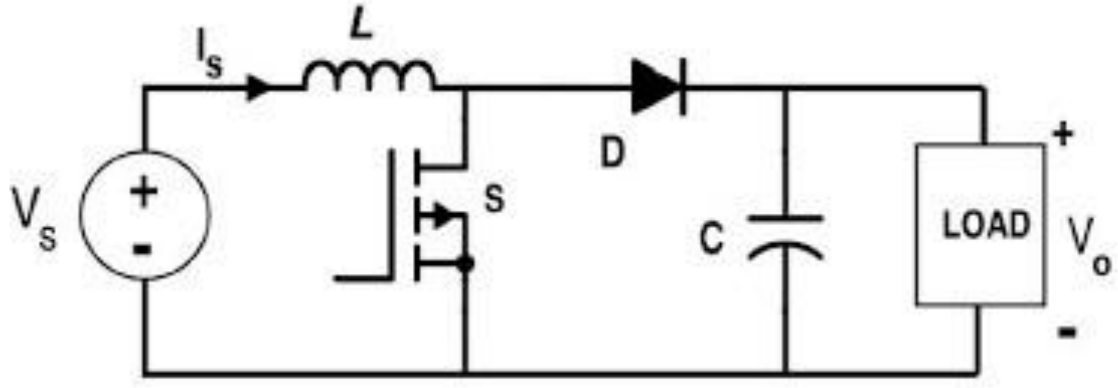
TITLE: STUDY BOOST AND BUCK BOOST CONVERTER CIRCUIT AND DESIGN USING CALCULATED DESIGN PARAMETERS.

OBJECTIVE: TO ANALYSE BOOST AND BUCK-BOOST CONVERTER USING THEORETICAL APPROACH AND PRACTICAL SIMULINK MODEL

THEORY :

BOOST CONVERTER

The operation of the boost converter is based on the principle of storing energy in an inductor. The voltage drop across an inductor is proportional to the change in the electric current flowing through the device. The circuit arrangement operates in such a way that it helps in maintaining a regulated and increased DC output at the load. The circuit diagram for a typical boost converter is shown in the figure below.



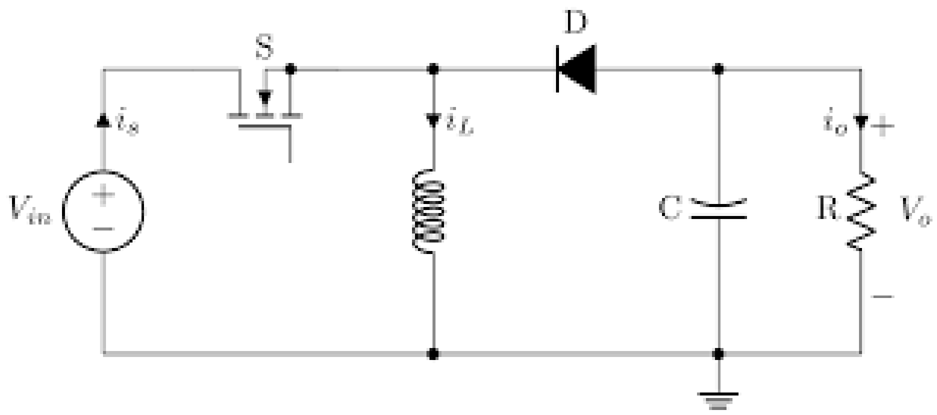
In this circuit, the solid-state device such as power MOSFET which operates as a switch is connected across the source. A diode is used as a second switch. The diode is connected to the capacitor and the load. The capacitor and load are connected in parallel as shown in the above circuit diagram. The inductor is connected in series with the supply voltage source which leads to a constant input current. So the boost converter acts as a constant current input source and loads act as a constant voltage source.

The controlled switch S is turned on and off by using PWM (Pulse Width Modulation). PWM can be time-based or frequency-based. Time-based Modulation is mostly used for Boost Converter because it is simple to construct and use. The frequency remains constant in this type of PWM modulation. Whereas Frequency-based modulation has a wide range of frequencies to achieve the desired control of the switch and has a complicated design for the low-pass LC filter.

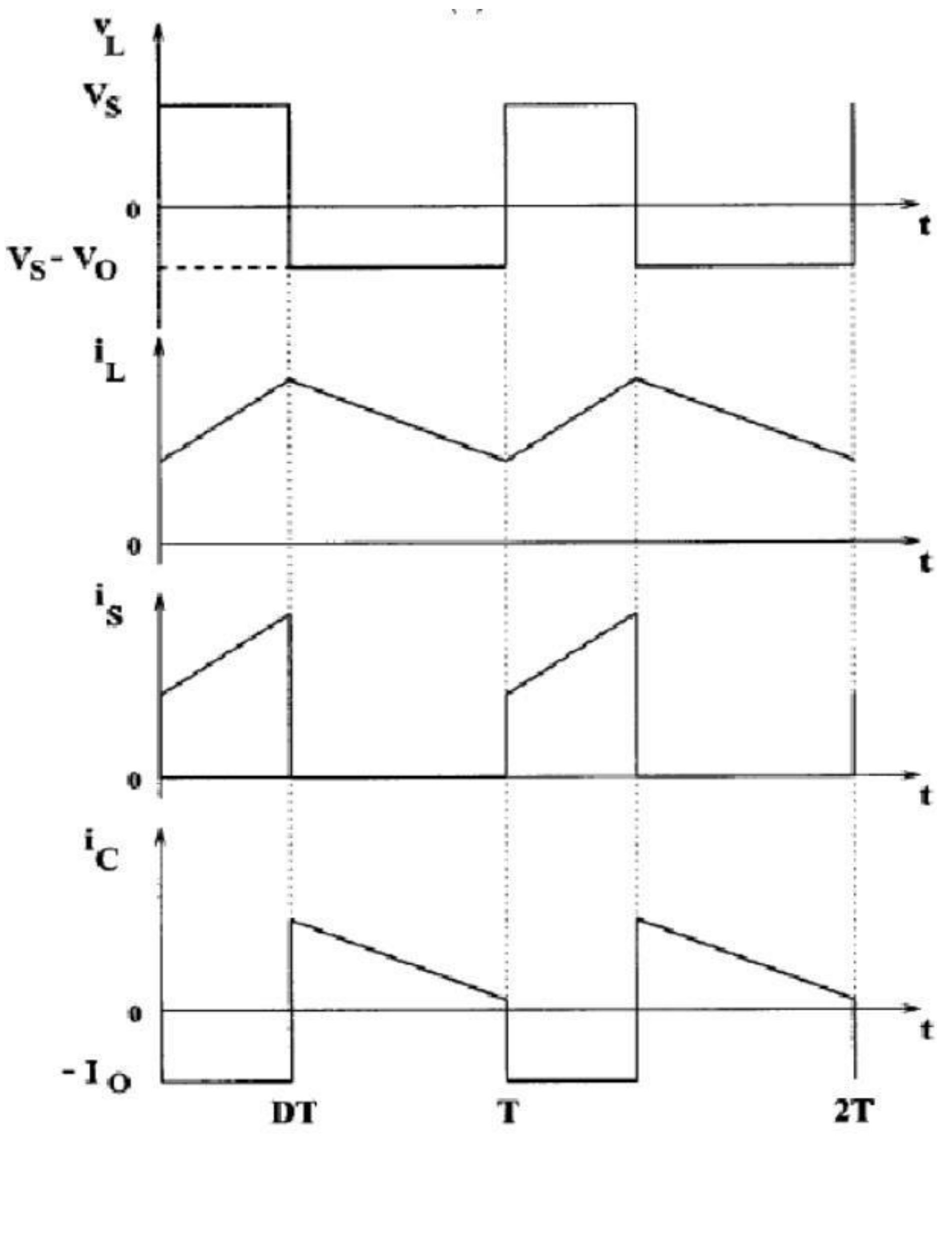
BUCK BOOST CONVERTER

The input voltage source is connected to a solid-state device. The second switch used is a diode. The diode is connected, in reverse to the direction of power flow from the source, to a capacitor, and the load and the two are connected in parallel as shown in the figure above. The controlled switch in the converter uses Pulse Width Modulation (PWM) to toggle on and off. PWM may operate based on time or frequency, with time-based being the more common approach. Frequency-based modulation, though versatile, has the disadvantage of requiring a wide range of frequencies to precisely control the

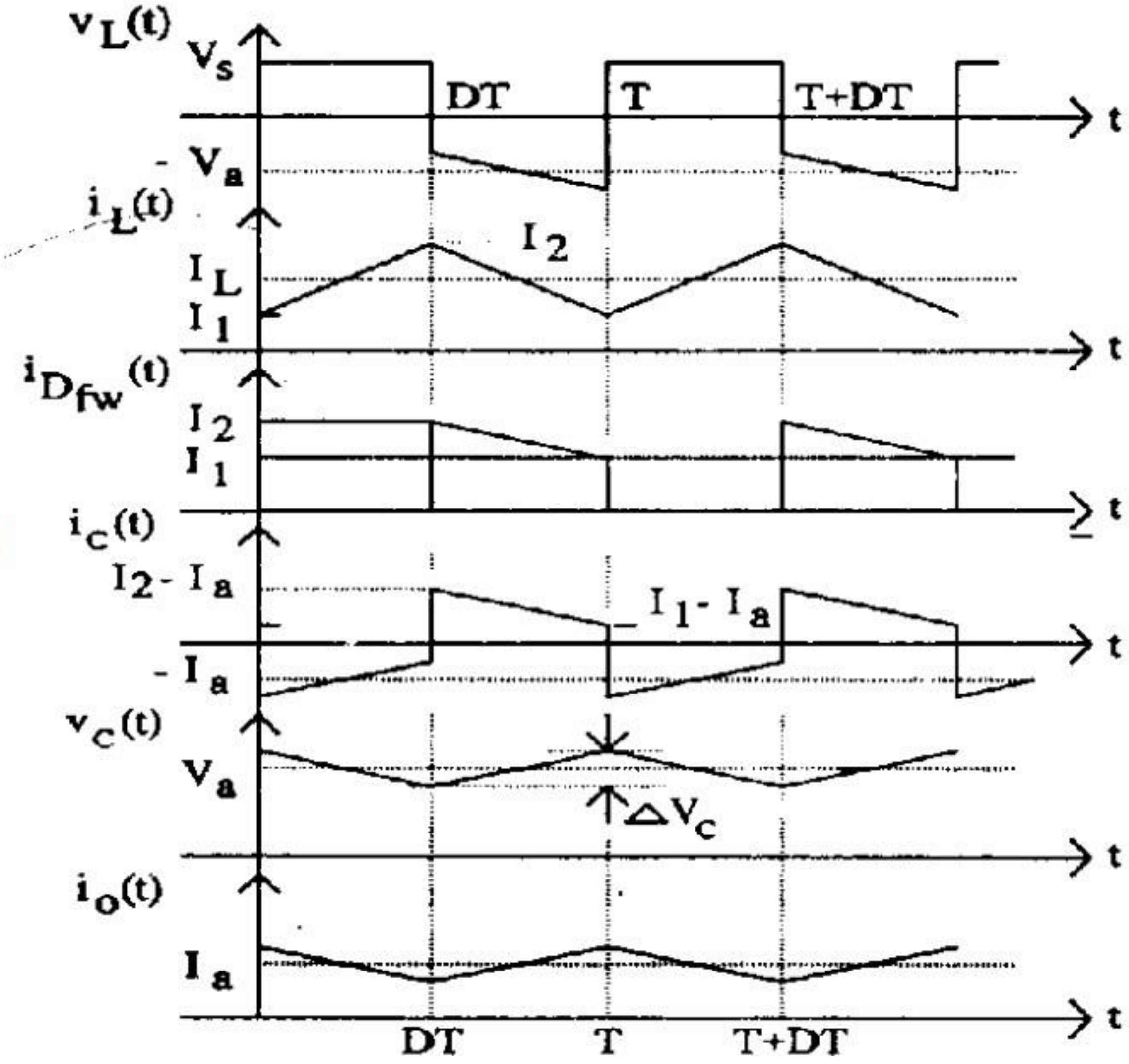
switch and thus achieve the desired output voltage. Time-based Modulation is mostly used for DC-DC converters. It is simple to construct and use. The frequency remains constant in this type of PWM modulation. The Buck-Boost converter has two modes of operation. The first mode is when the switch is on and conducting.



THEORETICAL WAVEFORMS OF BOOST CONVERTER



THEORETICAL WAVEFORM OF BUCK BOOST CONVERTER



CALCULATIONS :

BOOST CONVERTER WITH D =0.5

$$V_o = V_{in}\frac{1}{1-D}$$

$V_o = \frac{1}{1-0.5} V_{in}$ = 48V $\Delta I_L = 0.25 * I_L$ =2.08A

I_L = $\frac{Io}{1-D}$ = 8.33A (Inductor Current)

ΔI_L =$\frac{D*V_{in}}{f*L}$ or L= 57.6uH (Inductor Value)

Ripple in Capacitor Voltage = $\Delta V_o = 0.48V$

C= $\frac{D*IO}{f*\Delta V_O}$ = 434.062uF

Practically Ripple in Capacitor Voltage =

$\frac{47.31-47.26}{avg\ of\ peak\ and\ crest\ value} = 0.1\%$

Inductor Ripple Practically = $\frac{\Delta IL}{I_L} =$

$\frac{9.4-7.4}{avg\ of\ peak\ and\ crest\ value\ of\ inductor\ current}$ = 24.5%

BUCK BOOST CONVERTER WITH D=0.35 (BUCK MODE)

$V_o = \frac{0.35}{1-0.35} V_{in}$ =12.92V

I_L = $\frac{Io}{1-D}$ = 23.815A

ΔI_L =$\frac{D*V_{in}}{f*L}$ or L= 14.10uH (Inductor Value)

C= $\frac{D*IO}{f*\Delta V_O}$ = 4190.79uF

$$\frac{11.4-11.8}{avg\ of\ peak\ and\ crest\ value} = 0.1\%$$

Inductor Ripple Practically = $\frac{\Delta IL}{I_L} =$
$$\frac{23.4-20}{avg\ of\ peak\ and\ crest\ value\ of\ inductor\ current} = 24.25\%$$

BUCK BOOST CONVERTER WITH D=0.75 (BOOST MODE)

$V_o = \frac{0.75}{1-0.75} V_{in}$ =72V

$I_L = \frac{Io}{1-D}$ = 11.11A

$\Delta I_L = \frac{D*V_{in}}{f*L}$ or L= 64.74uH (Inductor Value)

C= $\frac{D*IO}{f*\Delta V_O}$ = 289.58uF

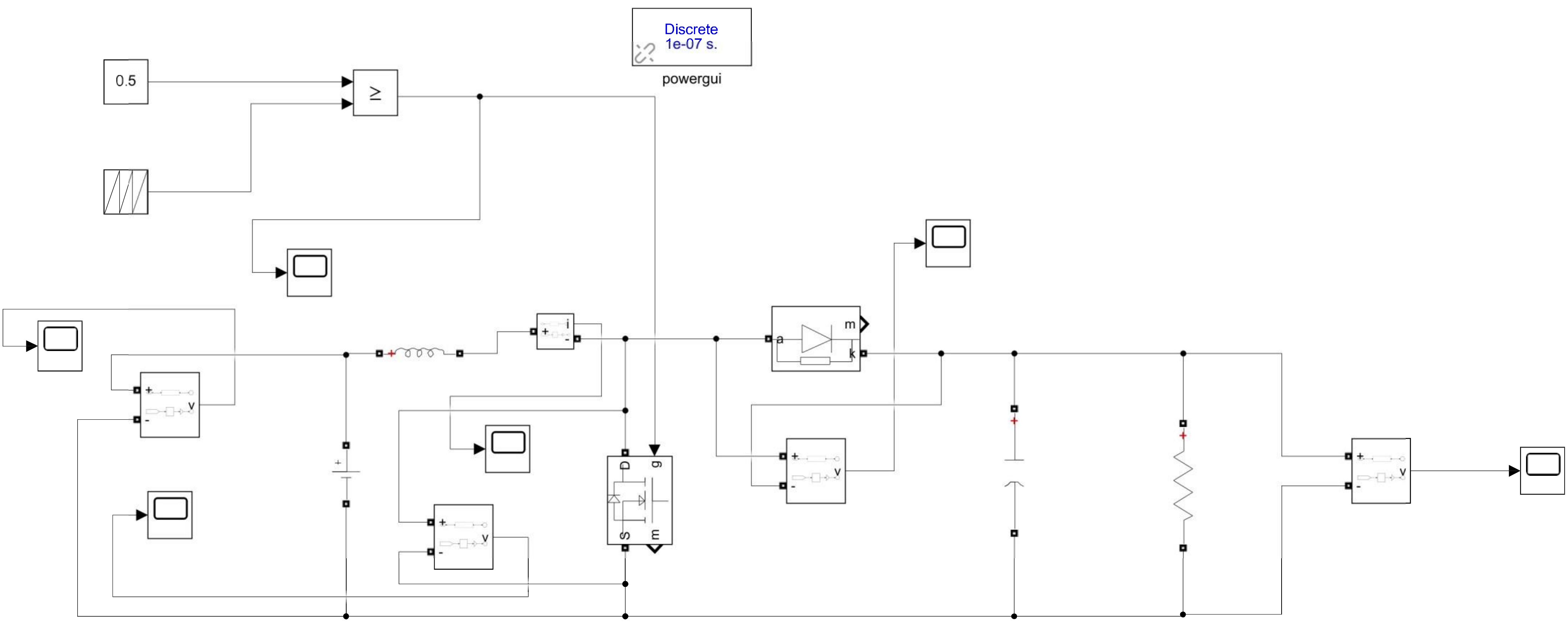
(Capacitor Value)

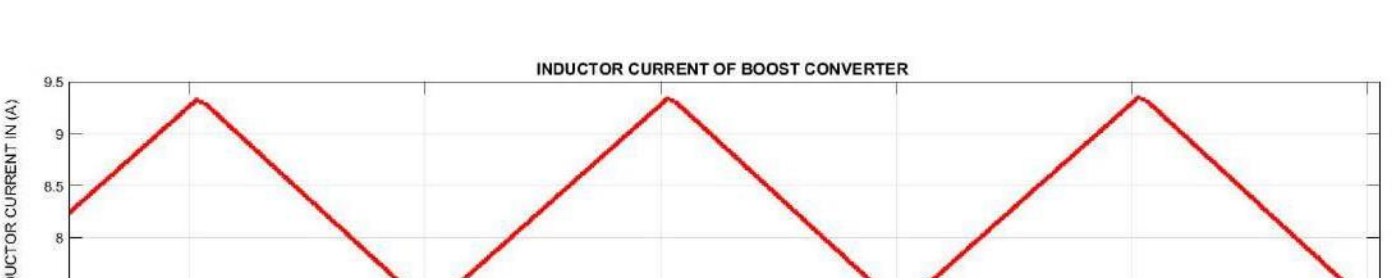
Practically Ripple in Capacitor Voltage =

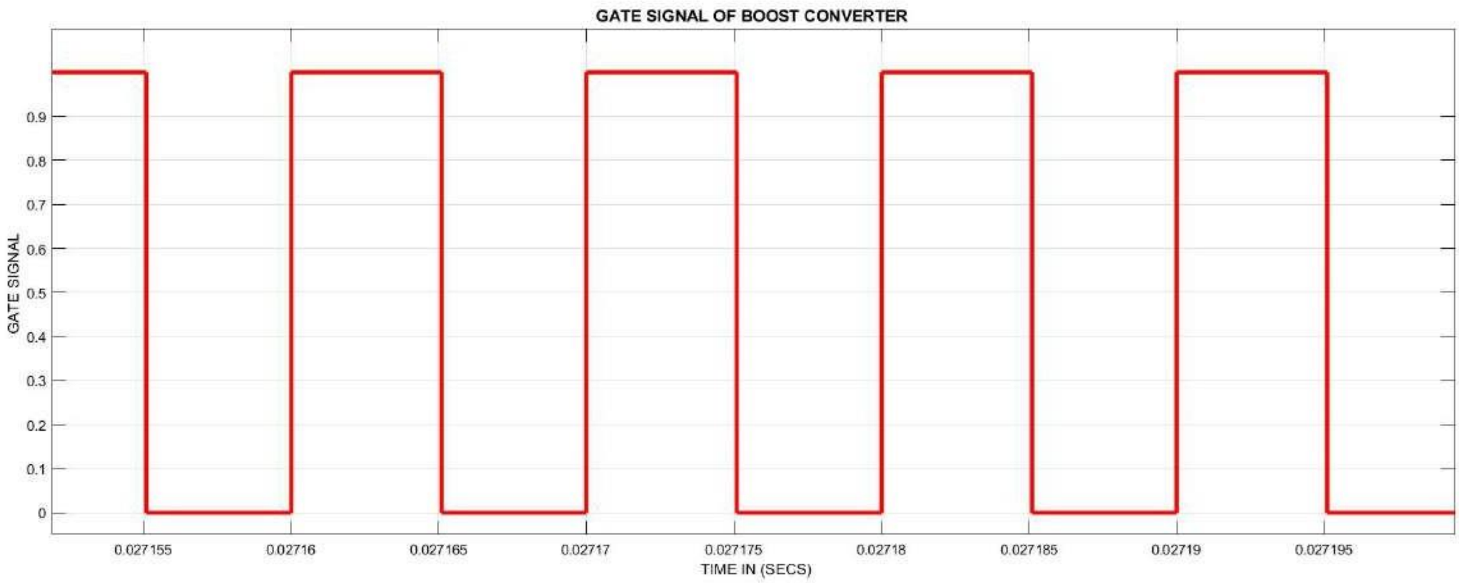
$$\frac{71.31-71.26}{avg\ of\ peak\ and\ crest\ value} = 0.1\%$$

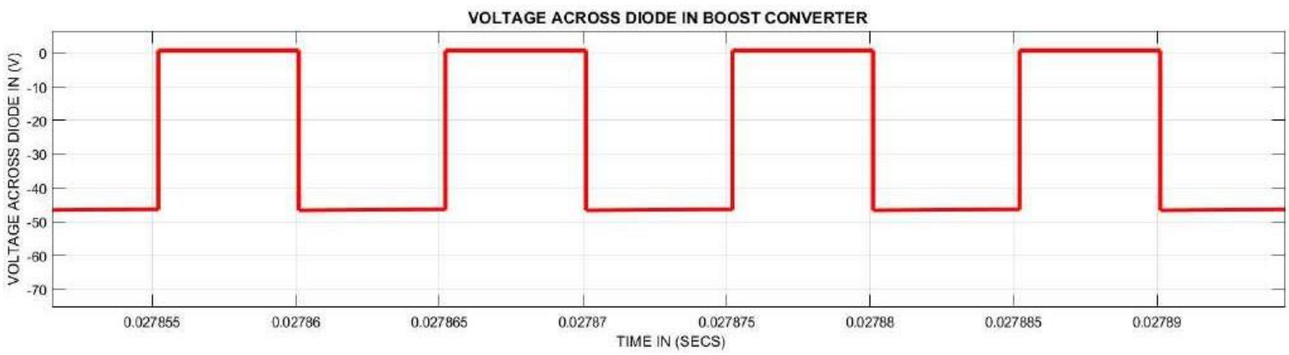
Inductor Ripple Practically = $\frac{\Delta IL}{I_L} =$
$$\frac{10.5-12}{avg\ of\ peak\ and\ crest\ value\ of\ inductor\ current} = 24.5\%$$

BOOST CONVERTER SIMULATED CIRCUIT IN MATLAB

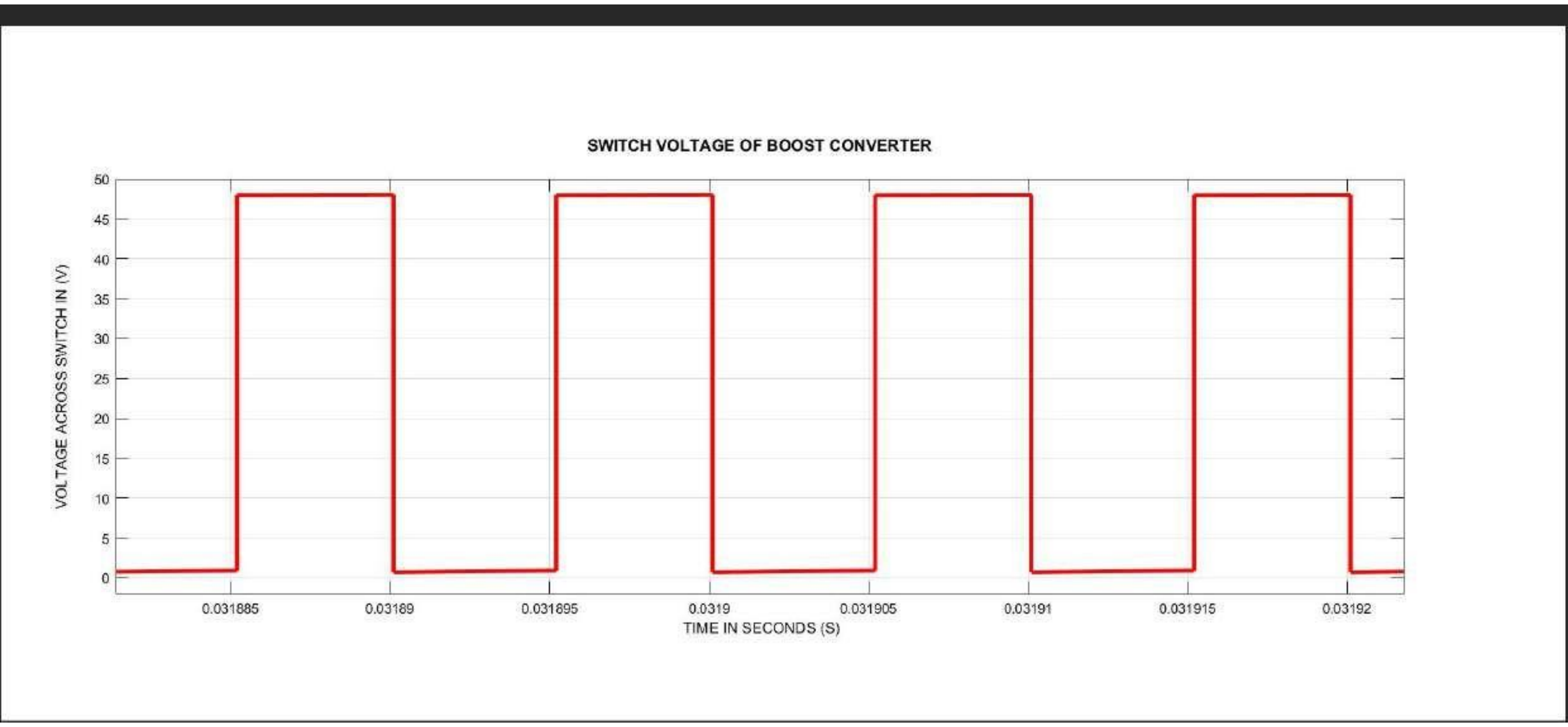


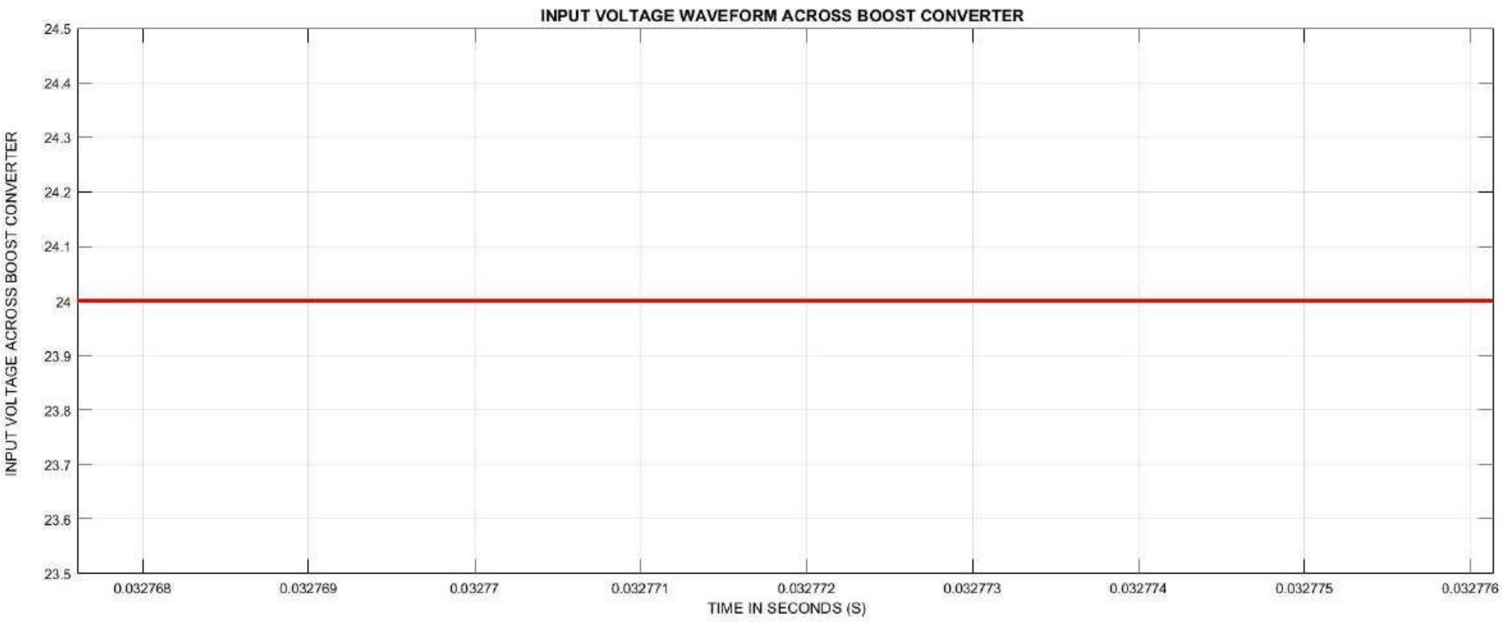

INDUCTOR CURRENT OF BOOST CONVERTER
INDUCTOR CURRENT IN (A)
9.5
9
8.5
8
7.5
0.069795
0.0698
0.069805
0.06981
0.069815
0.06982
TIME IN (SECONDS)

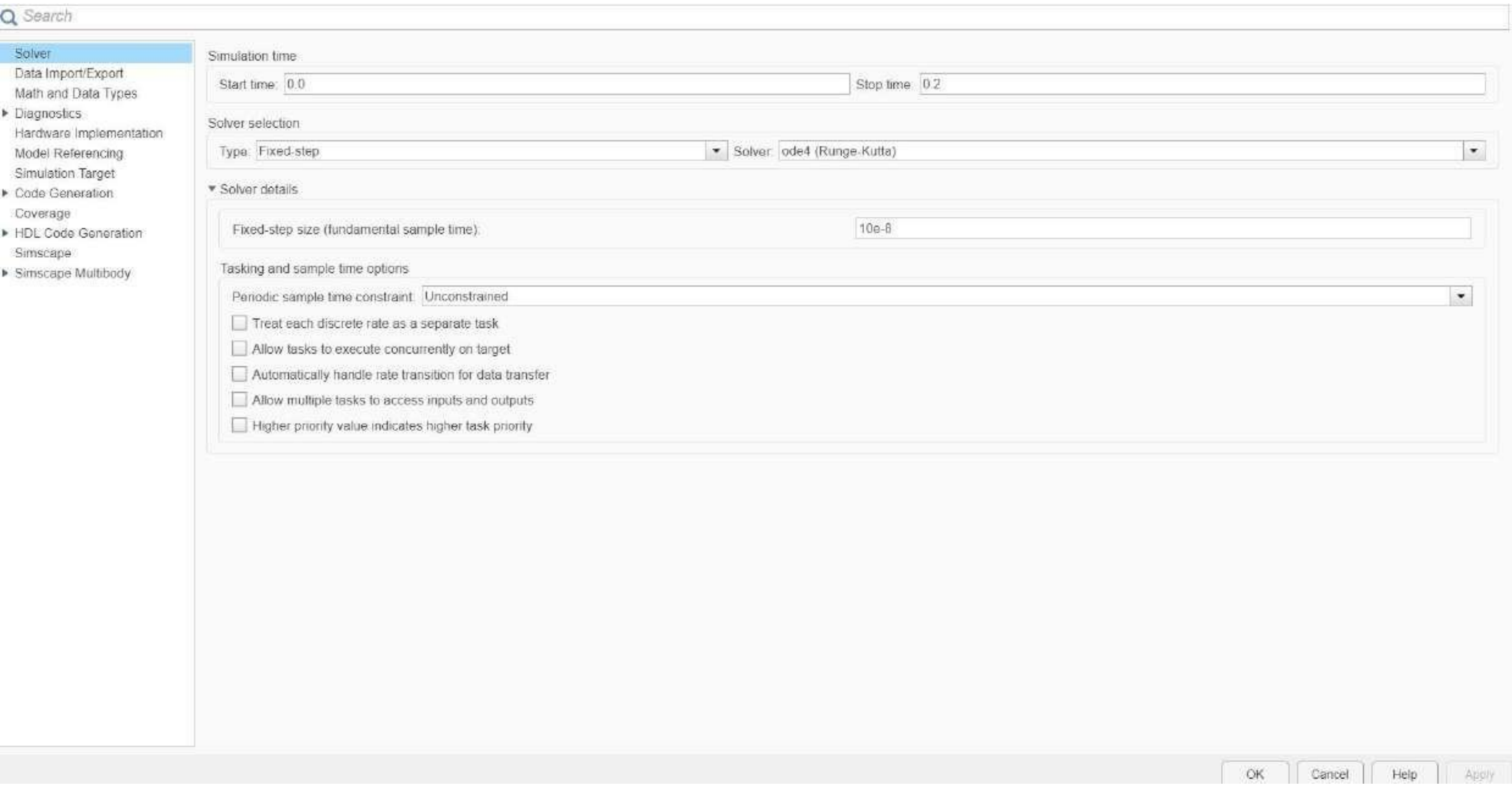

GATE SIGNAL OF BOOST CONVERTER
GATE SIGNAL
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0.027155
0.02716
0.027165
0.02717
0.027175
0.02718
0.027185
0.02719
0.027195
TIME IN (SECS)



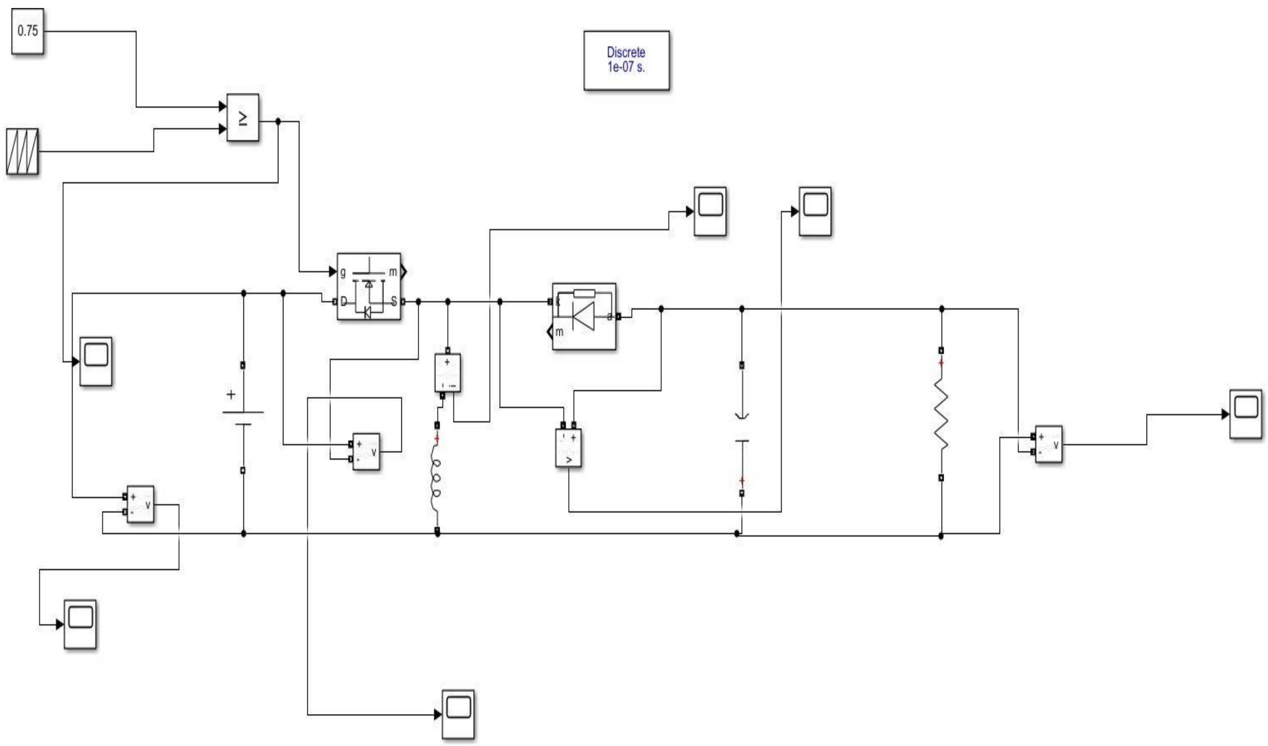
VOLTAGE ACROSS DIODE IN BOOST CONVERTER
VOLTAGE ACROSS DIODE IN (V)
0
-10
-20
-30
-40
-50
-60
-70
0.027855
0.02786
0.027865
0.02787
0.027875
0.02788
0.027885
0.02789
TIME IN (SECS)

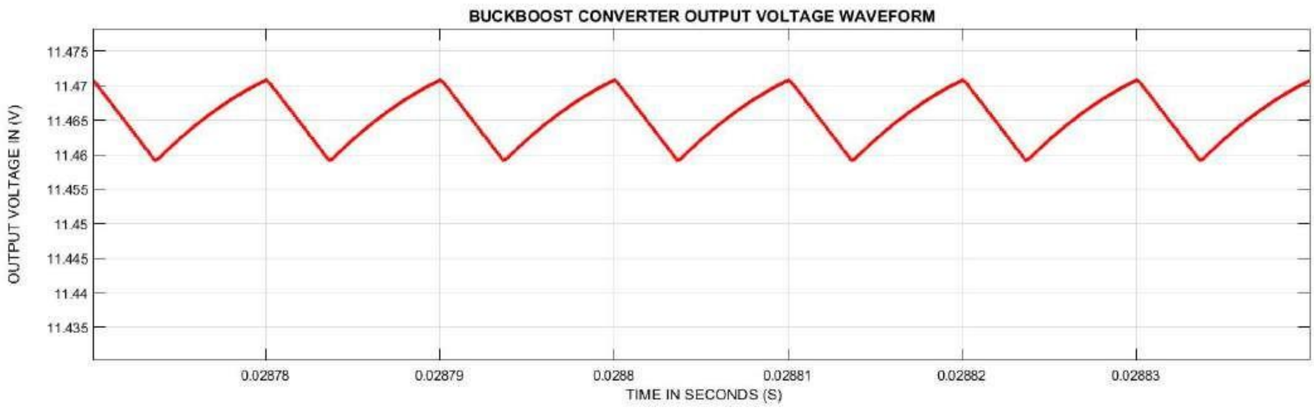

SWITCH VOLTAGE OF BOOST CONVERTER
VOLTAGE ACROSS SWITCH IN (V)
TIME IN SECONDS (S)
0
5
10
15
20
25
30
35
40
45
50
0.031885
0.03189
0.031895
0.0319
0.031905
0.03191
0.031915
0.03192

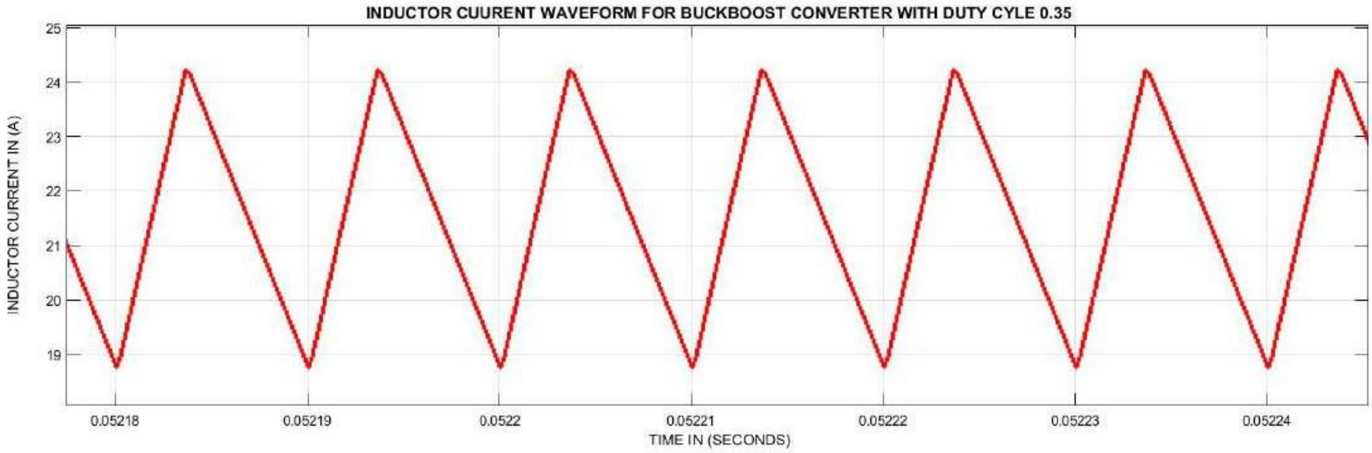

INPUT VOLTAGE WAVEFORM ACROSS BOOST CONVERTER
24.5
24.4
24.3
24.2
24.1
24
23.9
23.8
23.7
23.6
23.5
INPUT VOLTAGE ACROSS BOOST CONVERTER
0.032768
0.032769
0.03277
0.032771
0.032772
0.032773
0.032774
0.032775
0.032776
TIME IN SECONDS (S)

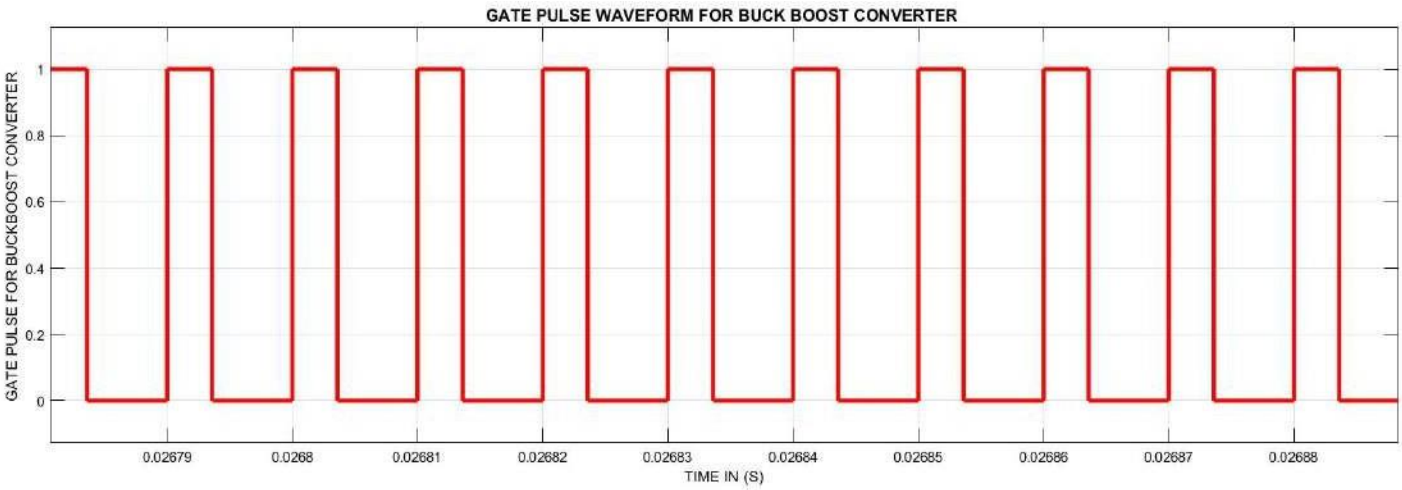

Search
Solver
Data Import/Export
Math and Data Types
Diagnostics
Hardware Implementation
Model Referencing
Simulation Target
Code Generation
Coverage
HDL Code Generation
Simscape
Simscape Multibody
Simulation time
Start time: 0.0
Stop time: 0.2
Solver selection
Type: Fixed-step
Solver: ode4 (Runge-Kutta)
Solver details
Fixed-step size (fundamental sample time): 10e-8
Tasking and sample time options
Periodic sample time constraint: Unconstrained
Treat each discrete rate as a separate task
Allow tasks to execute concurrently on target
Automatically handle rate transition for data transfer
Allow multiple tasks to access inputs and outputs
Higher priority value indicates higher task priority
OK
Cancel
Help
Apply

BUCK BOOST CONVERTER

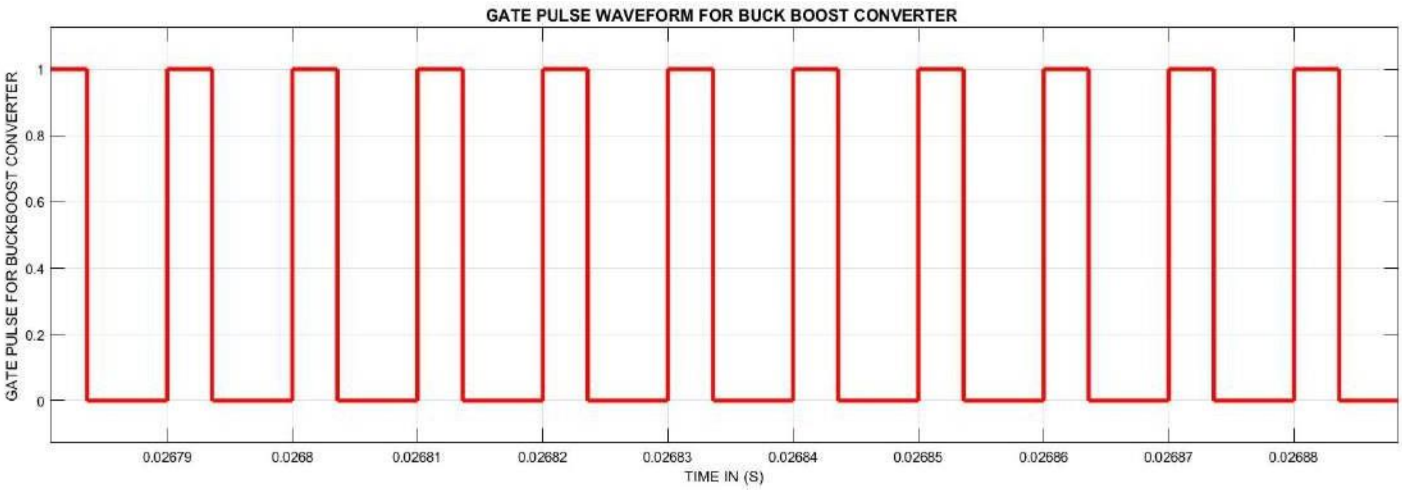


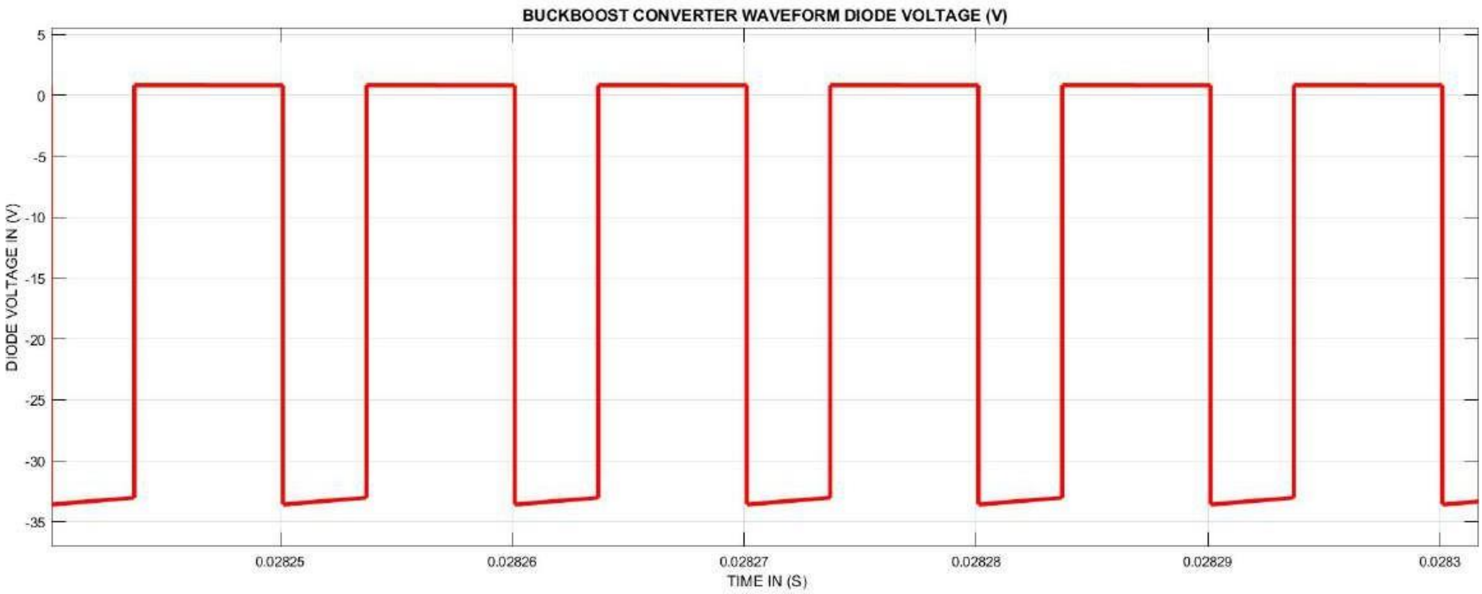

BUCKBOOST CONVERTER OUTPUT VOLTAGE WAVEFORM
OUTPUT VOLTAGE IN (V)
11.475
11.47
11.465
11.46
11.455
11.45
11.445
11.44
11.435
0.02878
0.02879
0.0288
0.02881
0.02882
0.02883
TIME IN SECONDS (S)

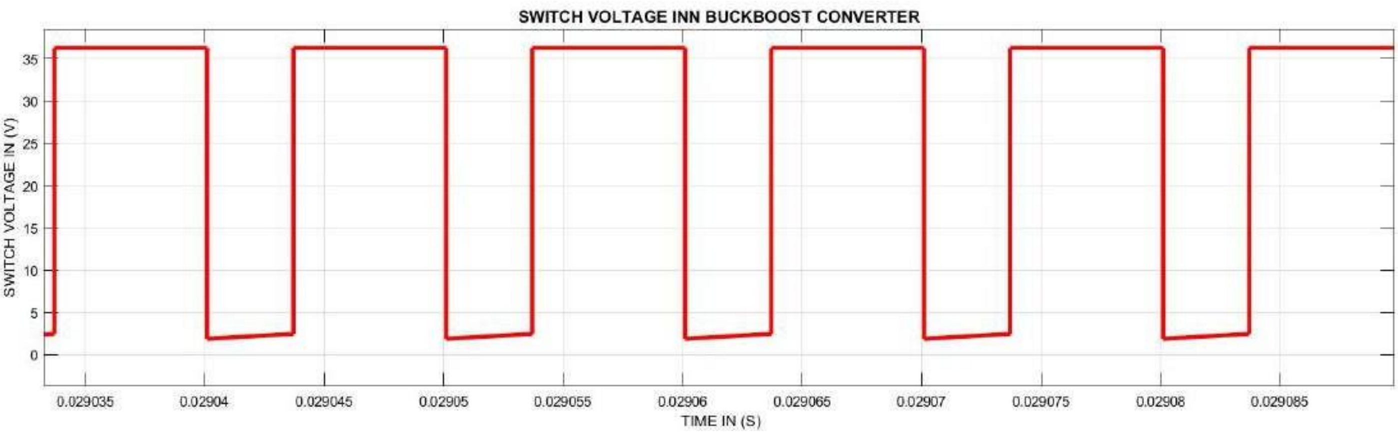

INDUCTOR CUURENT WAVEFORM FOR BUCKBOOST CONVERTER WITH DUTY CYLE 0.35
INDUCTOR CURRENT IN (A)
25
24
23
22
21
20
19
0.05218
0.05219
0.0522
0.05221
0.05222
0.05223
0.05224
TIME IN (SECONDS)

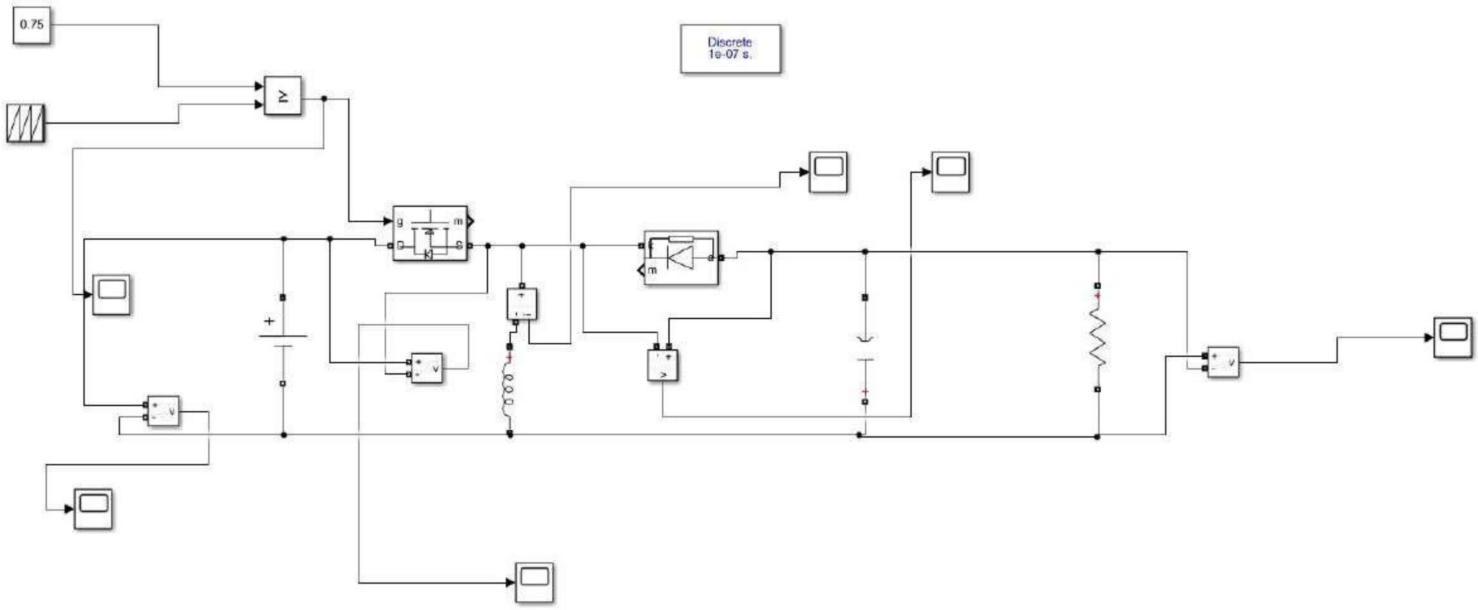


GATE PULSE WAVEFORM FOR BUCK BOOST CONVERTER
GATE PULSE FOR BUCKBOOST CONVERTER
1
0.8
0.6
0.4
0.2
0
0.02679
0.0268
0.02681
0.02682
0.02683
0.02684
0.02685
0.02686
0.02687
0.02688
TIME IN (S)

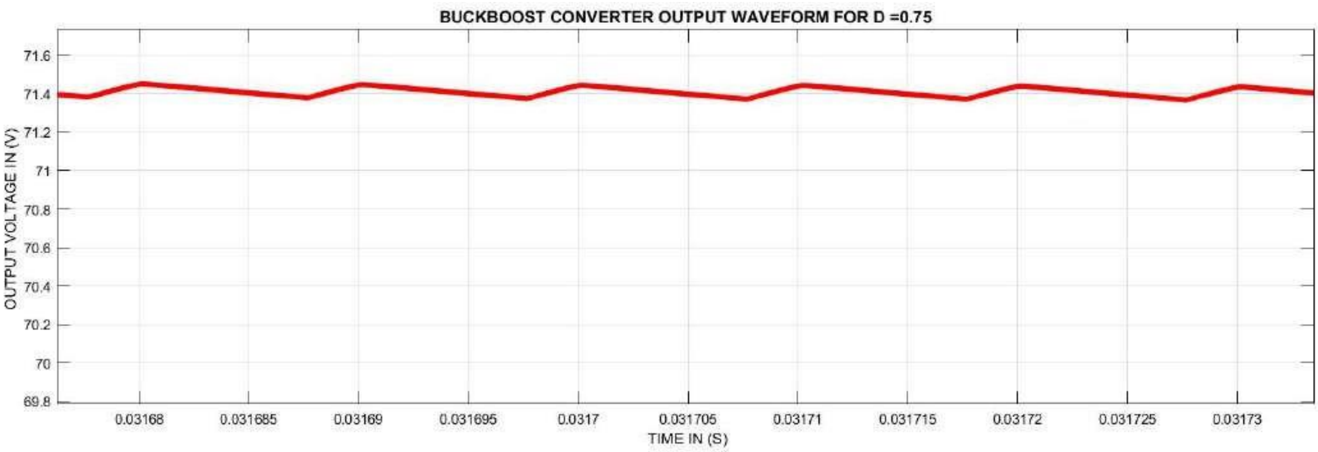

GATE PULSE WAVEFORM FOR BUCK BOOST CONVERTER
GATE PULSE FOR BUCKBOOST CONVERTER
1
0.8
0.6
0.4
0.2
0
0.02679
0.0268
0.02681
0.02682
0.02683
0.02684
0.02685
0.02686
0.02687
0.02688
TIME IN (S)


BUCKBOOST CONVERTER WAVEFORM DIODE VOLTAGE (V)
DIODE VOLTAGE IN (V)
TIME IN (S)
5
0
-5
-10
-15
-20
-25
-30
-35
0.02825
0.02826
0.02827
0.02828
0.02829
0.0283

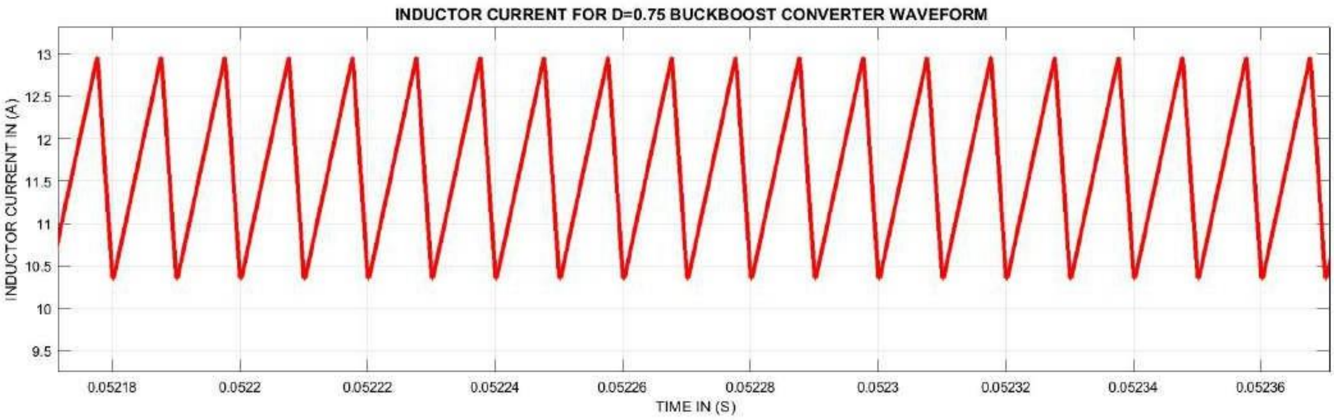

SWITCH VOLTAGE INN BUCKBOOST CONVERTER
SWITCH VOLTAGE IN (V)
TIME IN (S)
0
5
10
15
20
25
30
35
0.029035
0.02904
0.029045
0.02905
0.029055
0.02906
0.029065
0.02907
0.029075
0.02908
0.029085

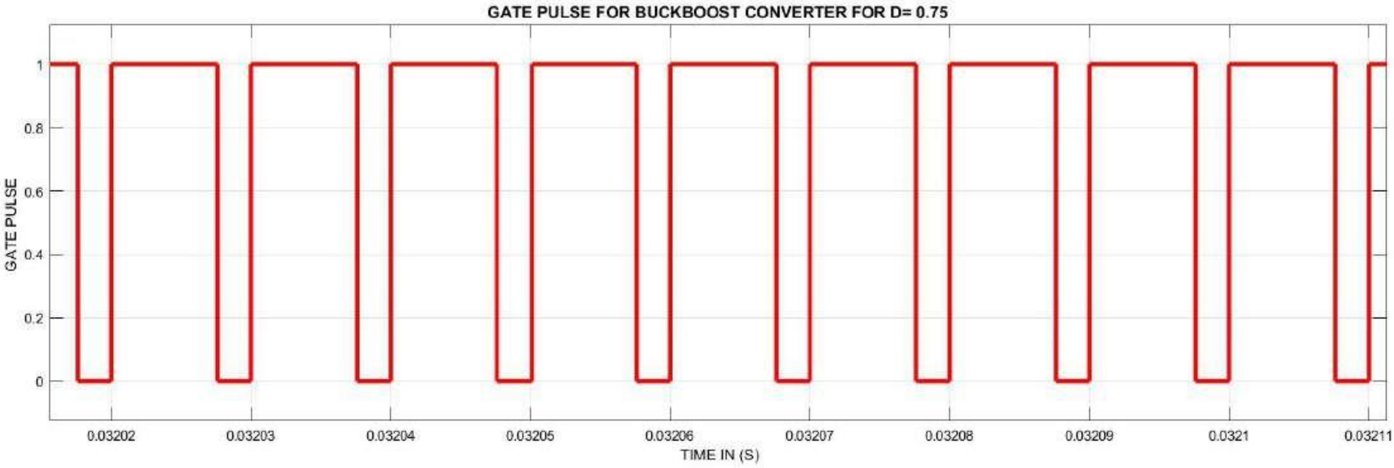


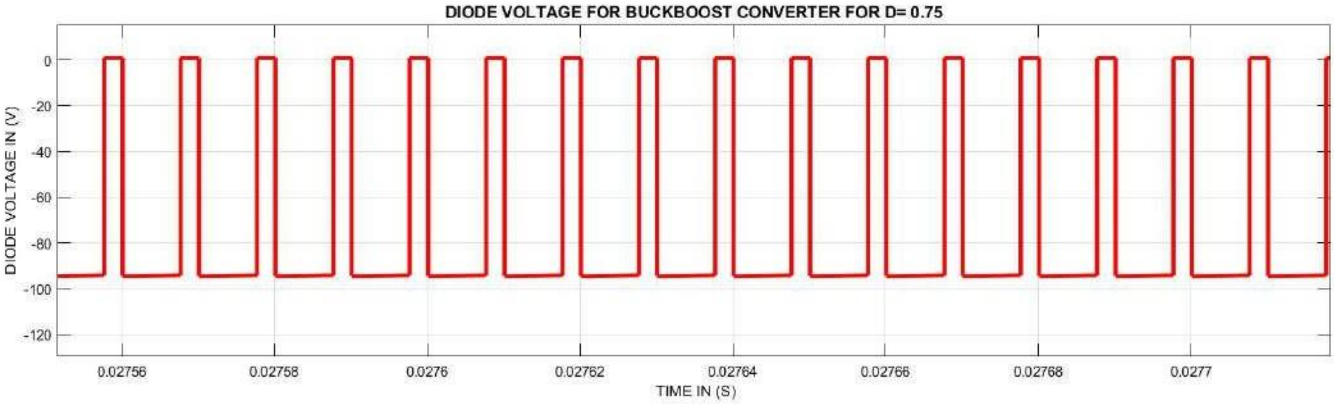
0.75
Discrete
1e-07 s.

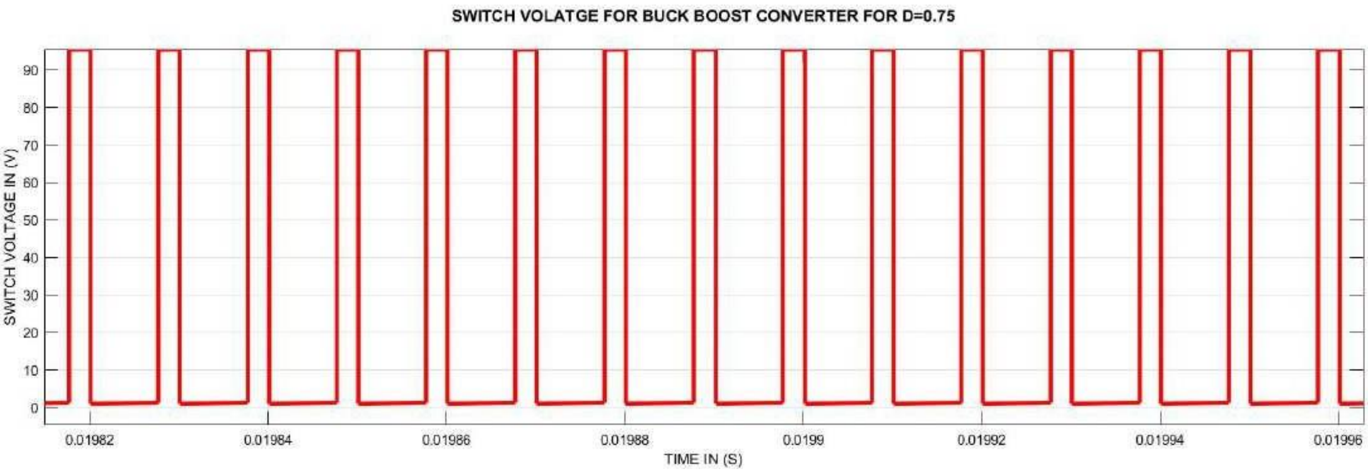


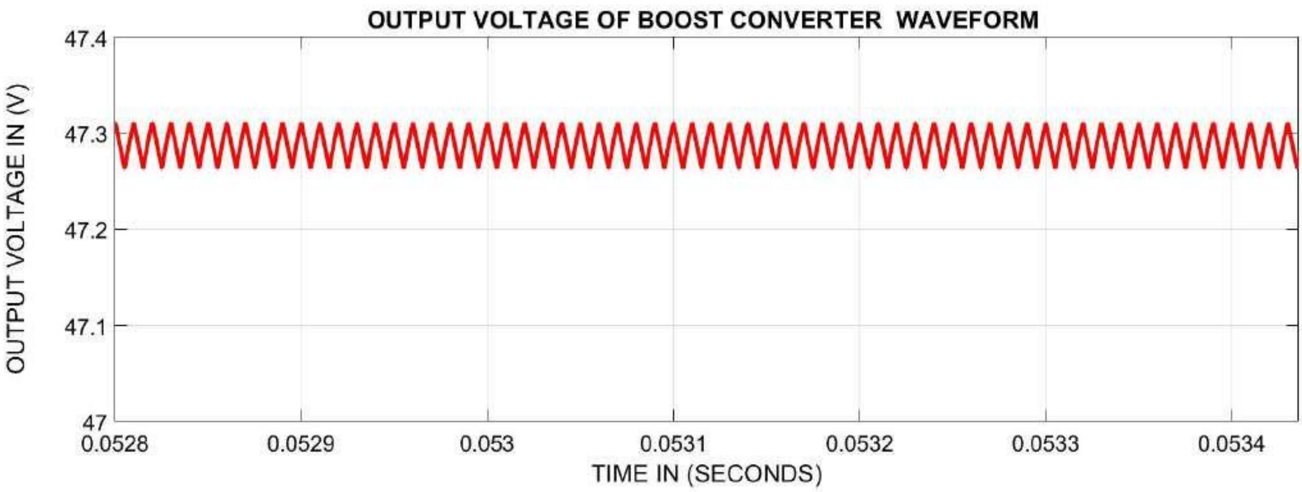
BUCKBOOST CONVERTER OUTPUT WAVEFORM FOR D =0.75
OUTPUT VOLTAGE IN (V)
TIME IN (S)
71.6
71.4
71.2
71
70.8
70.6
70.4
70.2
70
69.8
0.03168
0.031685
0.03169
0.031695
0.0317
0.031705
0.03171
0.031715
0.03172
0.031725
0.03173


INDUCTOR CURRENT FOR D=0.75 BUCKBOOST CONVERTER WAVEFORM
INDUCTOR CURRENT IN (A)
13
12.5
12
11.5
11
10.5
10
9.5
0.05218
0.0522
0.05222
0.05224
0.05226
0.05228
0.0523
0.05232
0.05234
0.05236
TIME IN (S)


GATE PULSE FOR BUCKBOOST CONVERTER FOR D= 0.75
GATE PULSE
1
0.8
0.6
0.4
0.2
0
0.03202
0.03203
0.03204
0.03205
0.03206
0.03207
0.03208
0.03209
0.0321
0.03211
TIME IN (S)


DIODE VOLTAGE FOR BUCKBOOST CONVERTER FOR D= 0.75
DIODE VOLTAGE IN (V)
0
-20
-40
-60
-80
-100
-120
0.02756
0.02758
0.0276
0.02762
0.02764
0.02766
0.02768
0.0277
TIME IN (S)


SWITCH VOLATGE FOR BUCK BOOST CONVERTER FOR D=0.75
SWITCH VOLTAGE IN (V)
TIME IN (S)
0.01982
0.01984
0.01986
0.01988
0.0199
0.01992
0.01994
0.01996



OUTPUT VOLTAGE OF BOOST CONVERTER WAVEFORM
47.4
47.3
47.2
47.1
47
OUTPUT VOLTAGE IN (V)
0.0528
0.0529
0.053
0.0531
0.0532
0.0533
0.0534
TIME IN (SECONDS)

CONCLUSIONS: Through the analysis of Boost and Buck Boost Converter we got deep insight about the circuit design techniques and the practicalities involved in it. The practical deviation of the output voltage is especially due to the ideality involved in the circuit. The difference between practical and theoretical value is mainly due to on-state resistances in the switch and diode.

ARYA MALLICK Roll No:234102501

EXPERIMENT: 2

Title: To Study Continuous and Discontinuous conduction modes of DC-DC Converters using MATLAB/SIMULINK.

Objective: Analysis of CCM, Boundary, and DCM Modes for Buck, Boost, and Buck-Boost Converter theoretically and practically.

Calculations:

CCM , BOUNDARY , DCM MODE FOR BUCK CONVERTER

$L_{cr} = \frac{R*(1-D)}{2*f}$=25uH $L_{con} = 10 * L_{cr} = 250uH$

$$L_{discon} = 0.1 * L_{cr} = 2.5uH$$

For CCM and Boundary : $V_0 = D * Vs = 0.5 * 48 = 24V$

For DCM Mode: $V_o = \frac{2}{1+\sqrt{1+\frac{4*K}{D^2}}} * V_S = 41\,Volts$

CCM , BOUNDARY , DCM MODE FOR BOOST CONVERTER

$L_{cr} = \frac{R*(1-D)*(1-D)*D}{2*f}$=12.5uH $L_{con} = 10 * L_{cr} = 125uH$

$$L_{discon} = 0.1 * L_{cr} = 1.25uH$$

For CCM and Boundary: $V_0 = \frac{1}{1-D} * Vs = 0.5 * 24 = 48V$

For DCM Mode : $V_o = \frac{1+\sqrt{1+\frac{4*D^2}{K}}}{2} * V_s$= 120 Volts

CCM , BOUNDARY, DCM MODE FOR BUCK-BOOST CONVERTER

$L_{cr} = \frac{R*(1-D)*(1-D)}{2*f}$=111.11uH $L_{con} = 10 * L_{cr} = 1111.11uH$

$$L_{discon} = 0.1 * L_{cr} = 11.11uH$$

For CCM and Boundary: $V_0 = \frac{D}{1-D} * Vs = \frac{\frac{1}{3}}{1-\frac{1}{3}} * 100 = 49.25\,V$

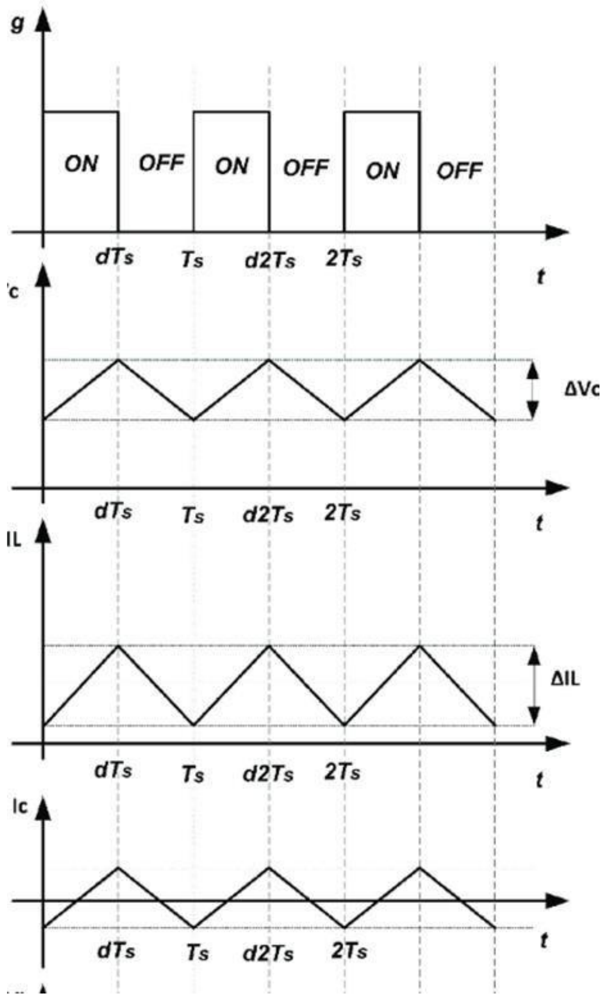
For DCM Mode: $V_o = V_s * \frac{D}{\sqrt{K}} = 156.5\,Volts$

Where , K=$(\frac{2*L}{R*T_s})$

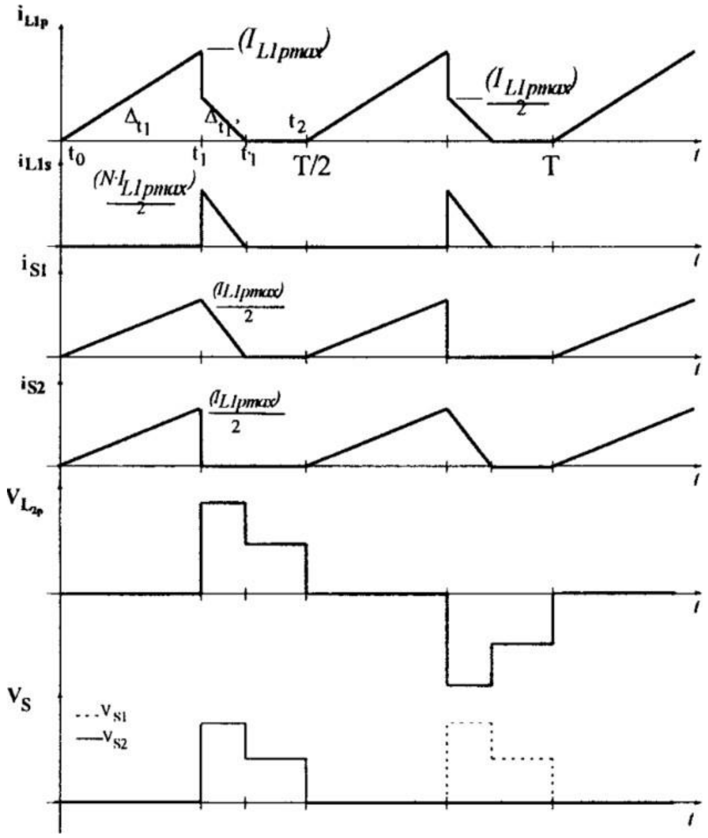
Design Procedure :

- The inductor value was changed from above critical to below critical to obtain the desired values.
- The same methodology was repeated for visualizing output voltages in CCM, Boundary, and DCM Mode.
- The results obtained are justified theoretically and practically.

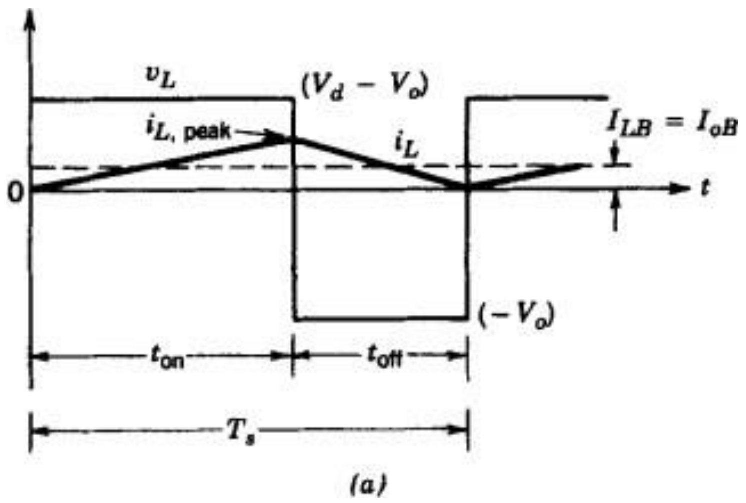
Theortical Waveforms:



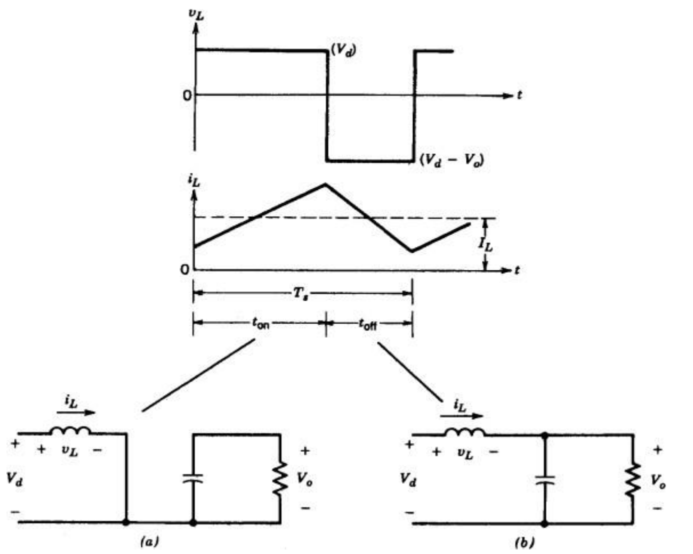
CCM MODE FOR BUCK CONVERTER



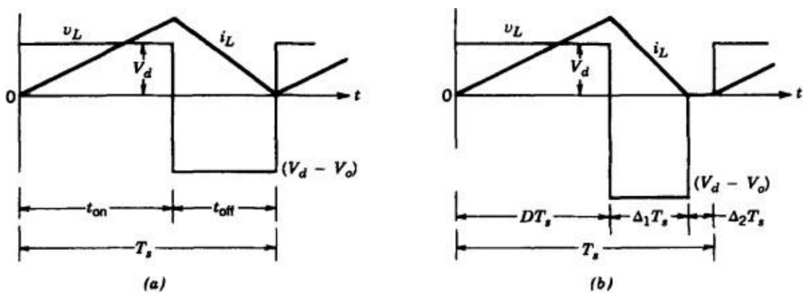
DCM MODE FOR BUCK CONVERTER



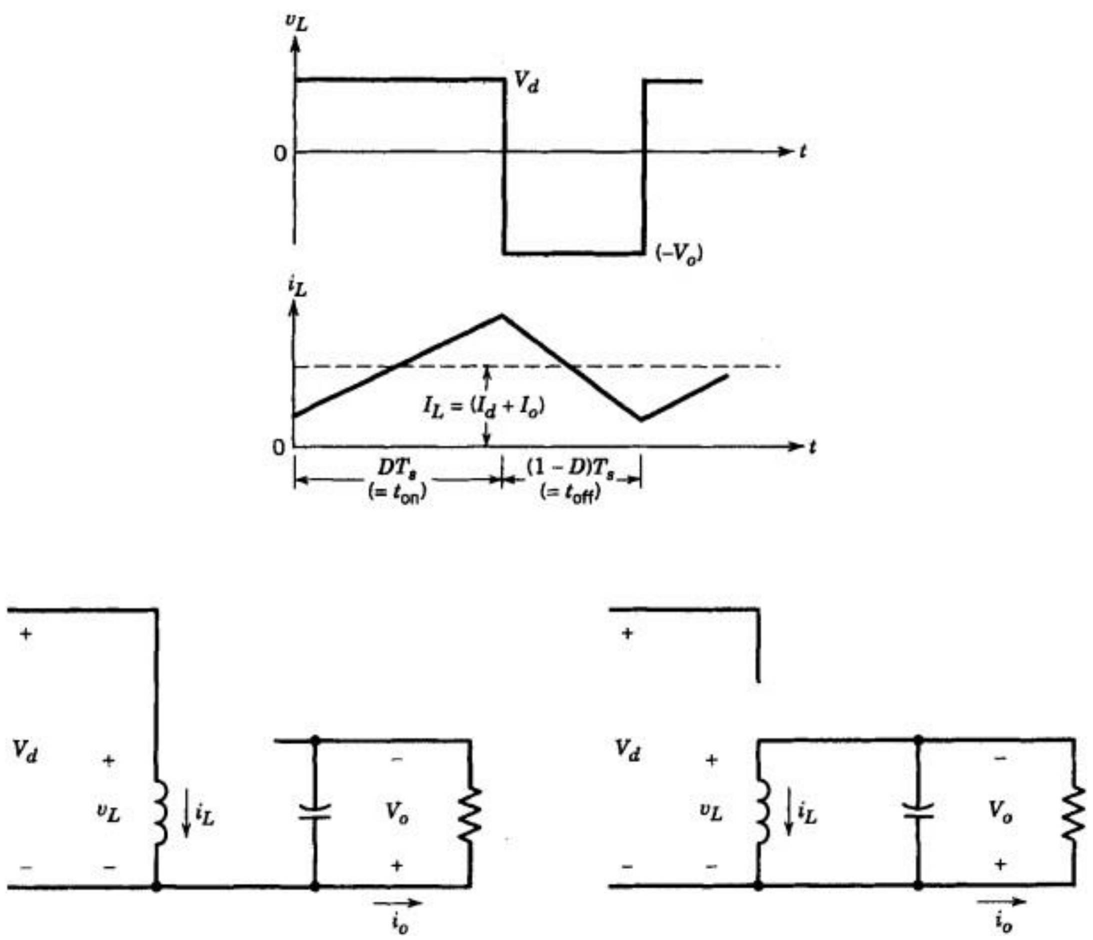
BOUNDARY CONDITION FOR BUCK



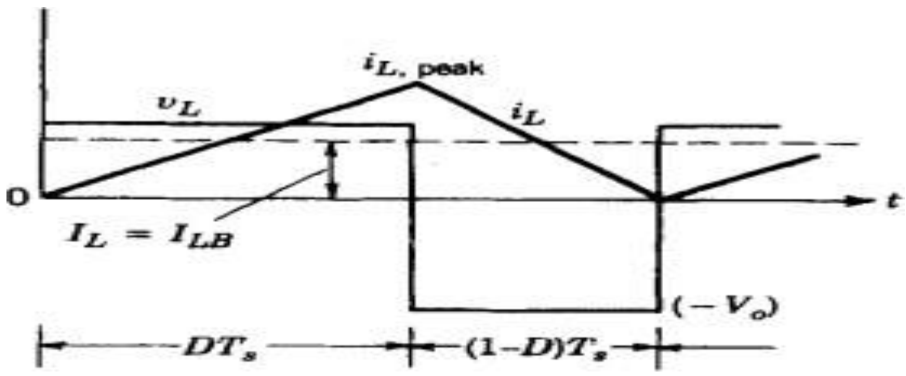
CCM MODE FOR BOOST CONVERTER



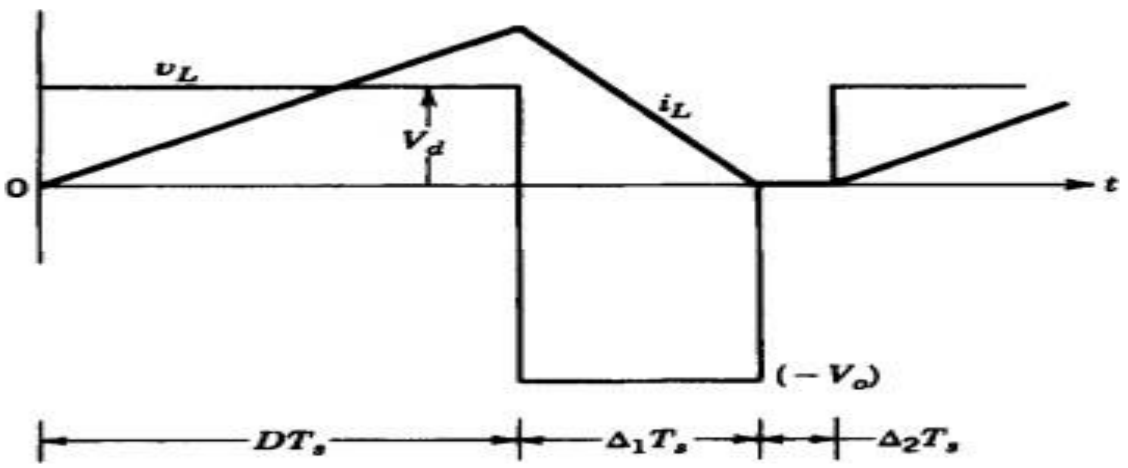
BOUNDARY AND DCM MODE FOR BOOST CONVERTER



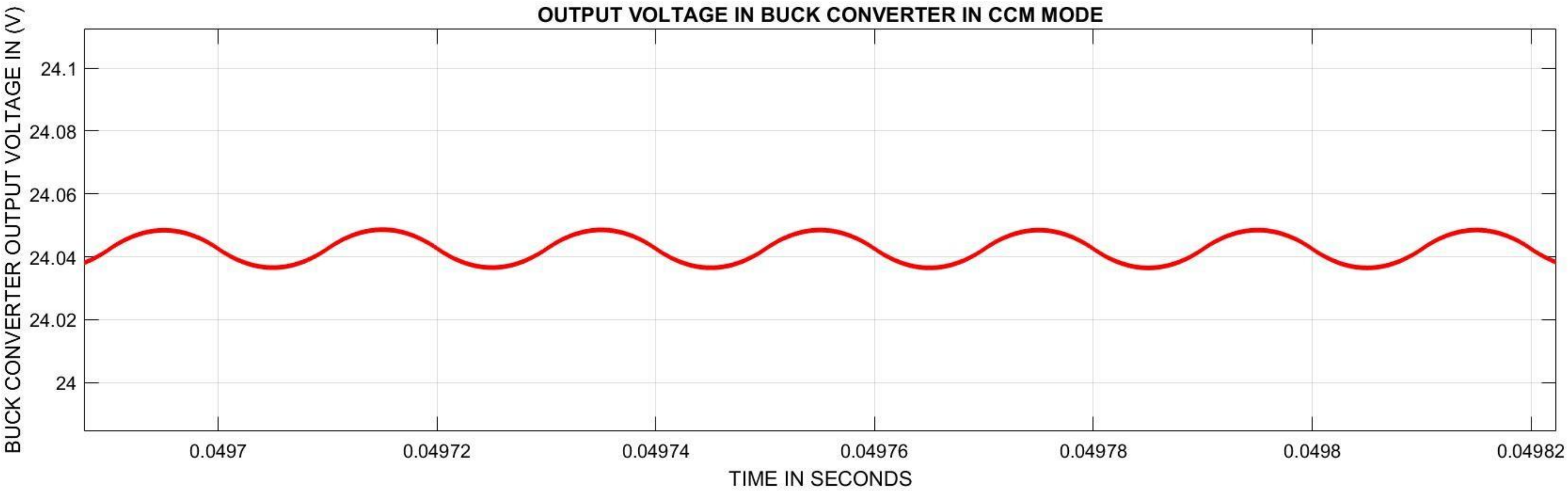
CCM MODE FOR BUCK BOOST CONVERTER

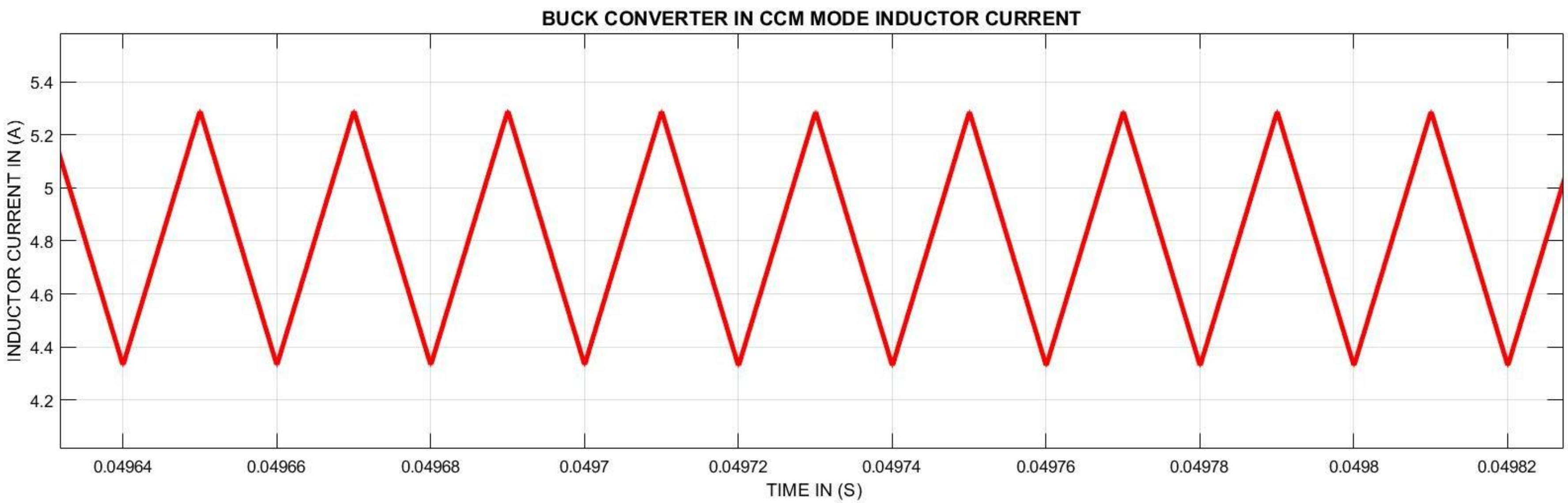


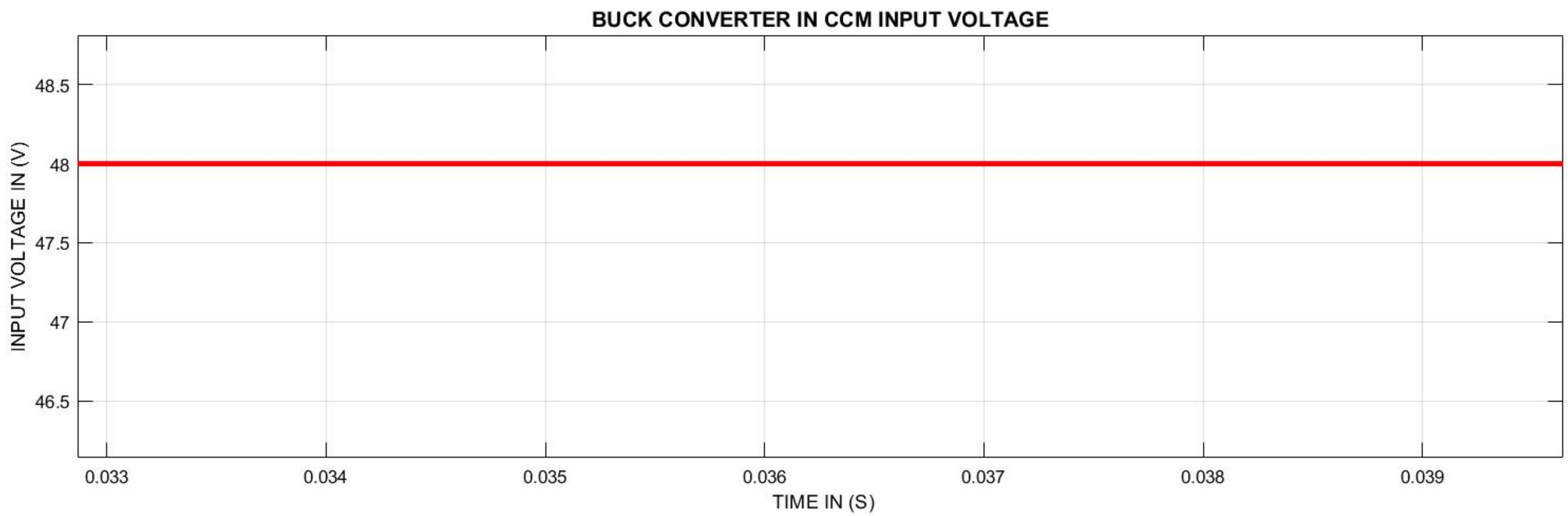
BOUNDARY FOR BUCK BOOST CONVERTER

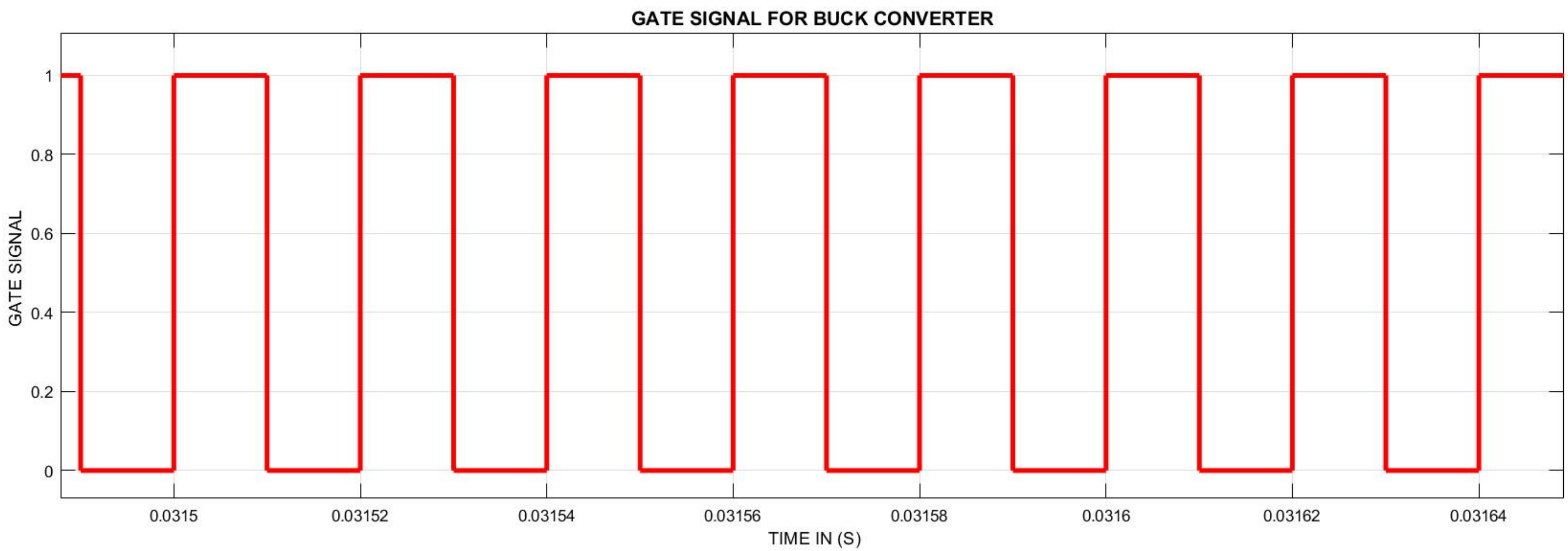


DCM MODE FOR DISCONTINUOUS MODE FOR BUCK BOOST CONVERTER

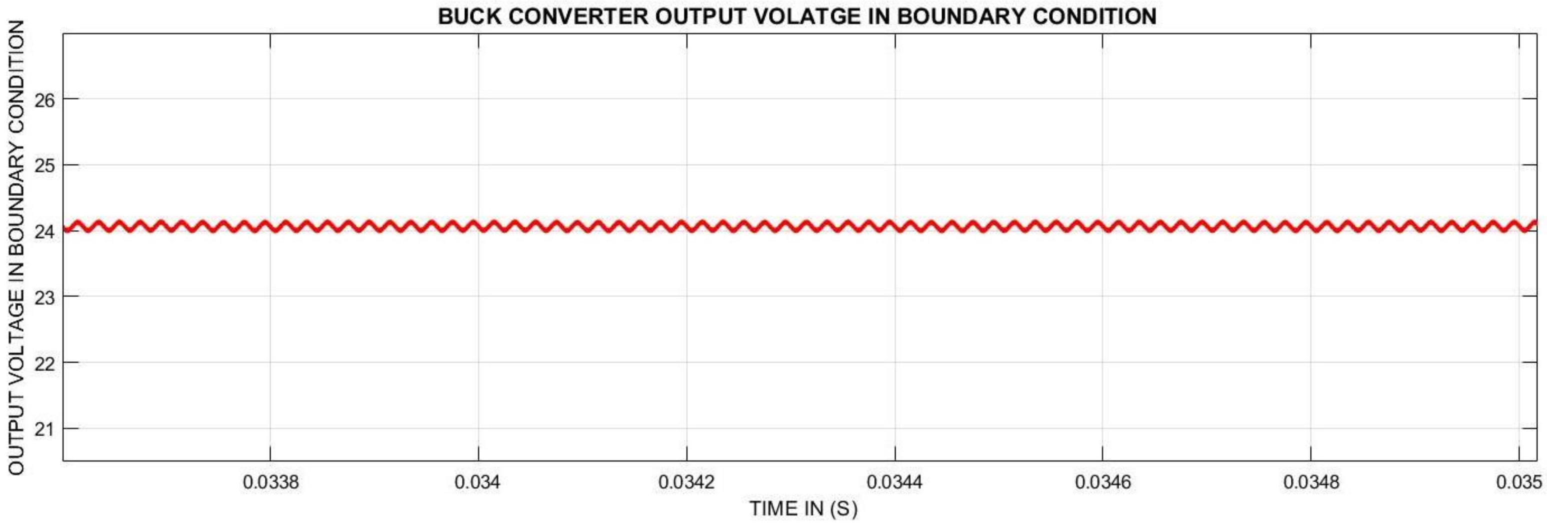

OUTPUT VOLTAGE IN BUCK CONVERTER IN CCM MODE
BUCK CONVERTER OUTPUT VOLTAGE IN (V)
24.1
24.08
24.06
24.04
24.02
24
0.0497
0.04972
0.04974
0.04976
0.04978
0.0498
0.04982
TIME IN SECONDS


BUCK CONVERTER IN CCM MODE INDUCTOR CURRENT
INDUCTOR CURRENT IN (A)
5.4
5.2
5
4.8
4.6
4.4
4.2
0.04964
0.04966
0.04968
0.0497
0.04972
0.04974
0.04976
0.04978
0.0498
0.04982
TIME IN (S)

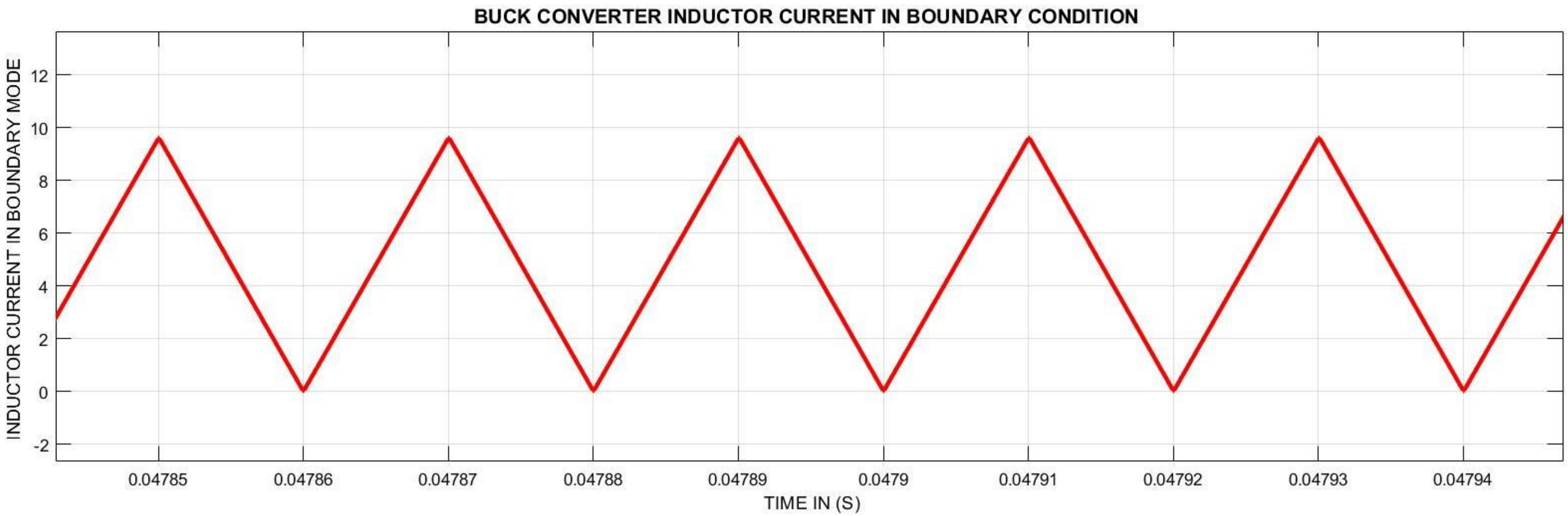

BUCK CONVERTER IN CCM INPUT VOLTAGE
INPUT VOLTAGE IN (V)
48.5
48
47.5
47
46.5
0.033
0.034
0.035
0.036
0.037
0.038
0.039
TIME IN (S)

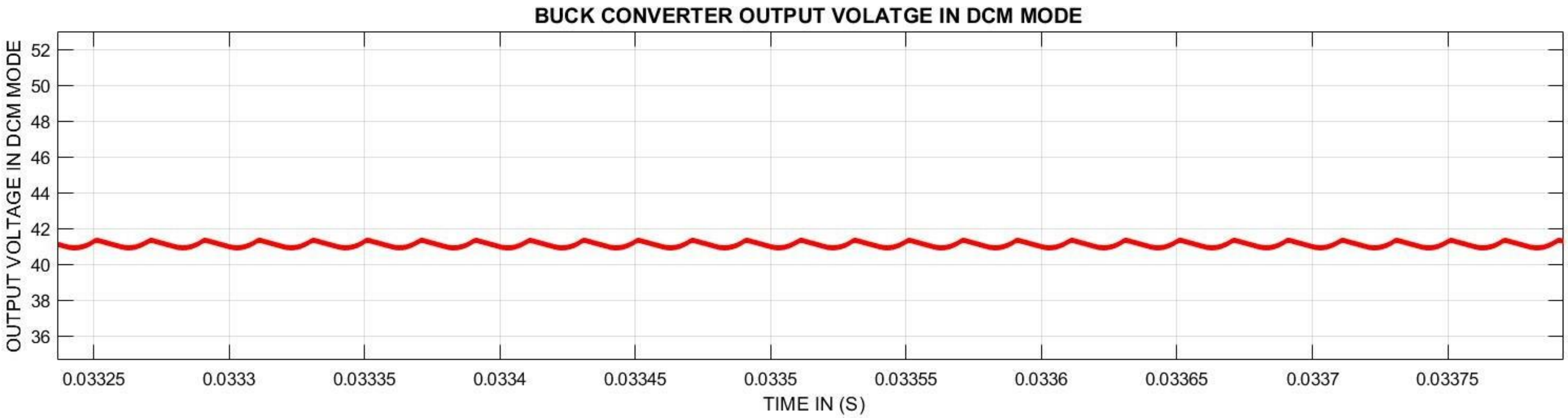


GATE SIGNAL FOR BUCK CONVERTER
GATE SIGNAL
1
0.8
0.6
0.4
0.2
0
0.0315
0.03152
0.03154
0.03156
0.03158
0.0316
0.03162
0.03164
TIME IN (S)

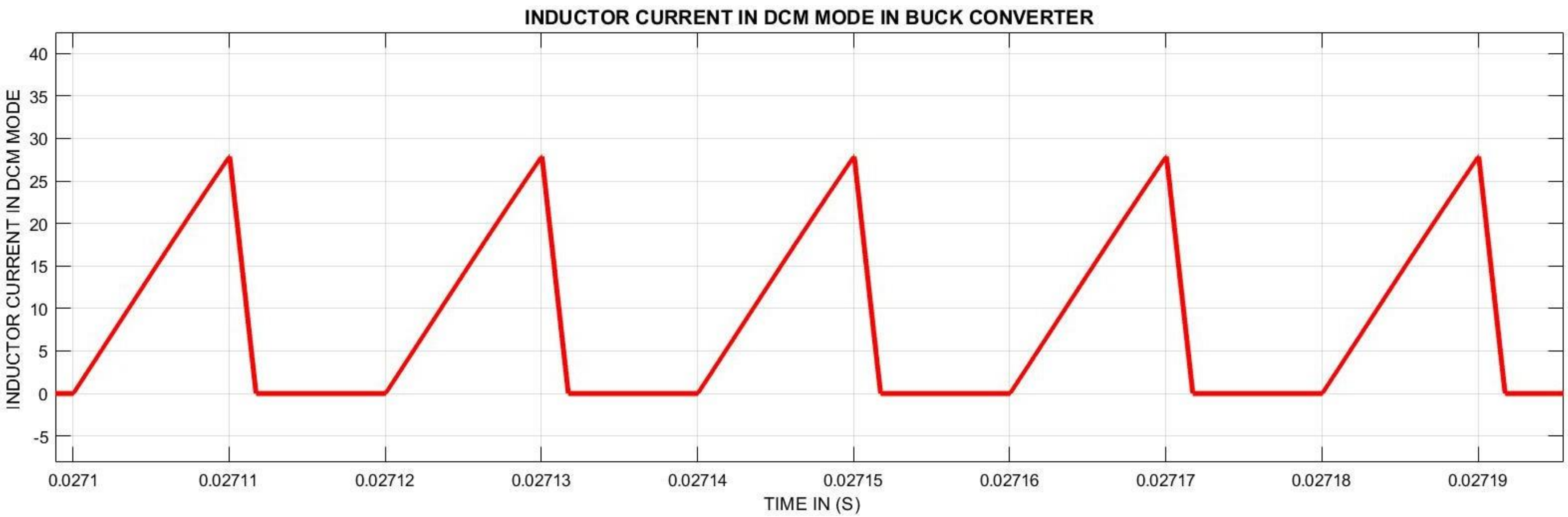


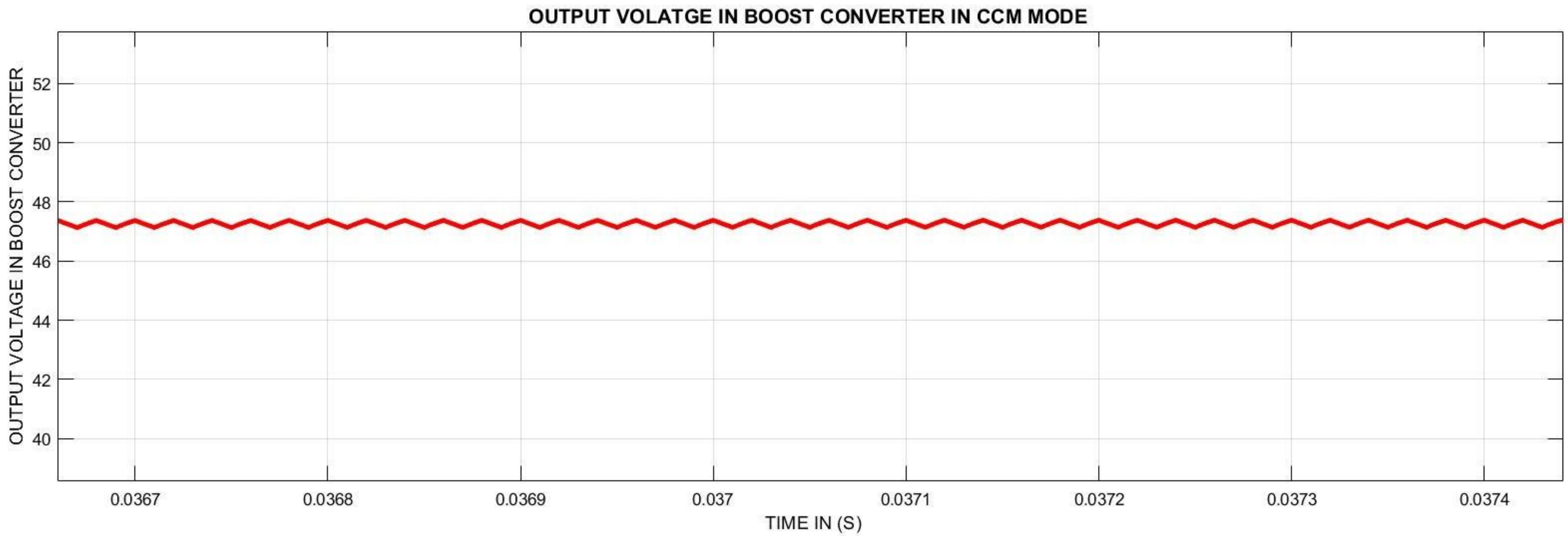
BUCK CONVERTER OUTPUT VOLATGE IN BOUNDARY CONDITION
OUTPUT VOLTAGE IN BOUNDARY CONDITION
26
25
24
23
22
21
0.0338
0.034
0.0342
0.0344
0.0346
0.0348
0.035
TIME IN (S)

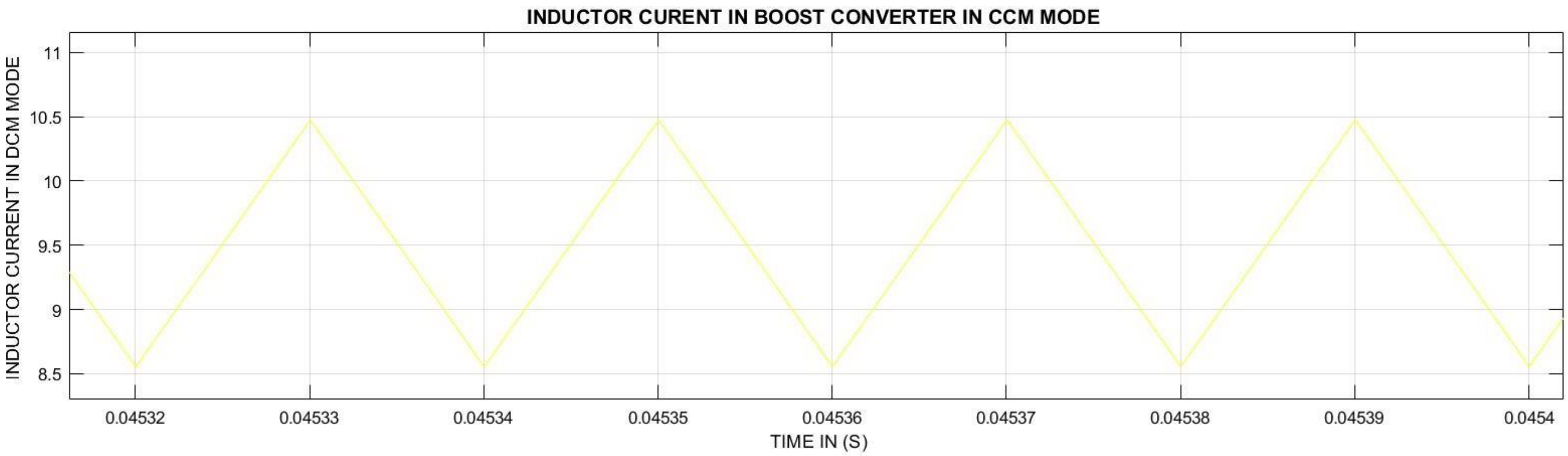

BUCK CONVERTER INDUCTOR CURRENT IN BOUNDARY CONDITION
INDUCTOR CURRENT IN BOUNDARY MODE
12
10
8
6
4
2
0
-2
0.04785
0.04786
0.04787
0.04788
0.04789
0.0479
0.04791
0.04792
0.04793
0.04794
TIME IN (S)



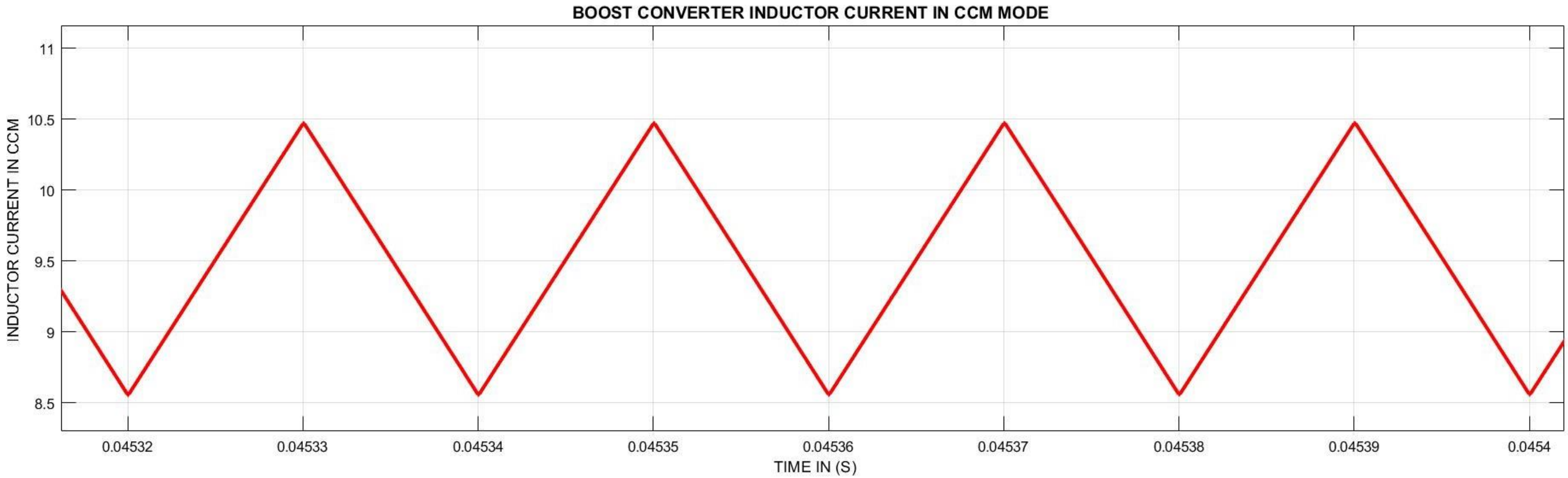
BUCK CONVERTER OUTPUT VOLATGE IN DCM MODE
OUTPUT VOLTAGE IN DCM MODE
52
50
48
46
44
42
40
38
36
0.03325
0.0333
0.03335
0.0334
0.03345
0.0335
0.03355
0.0336
0.03365
0.0337
0.03375
TIME IN (S)

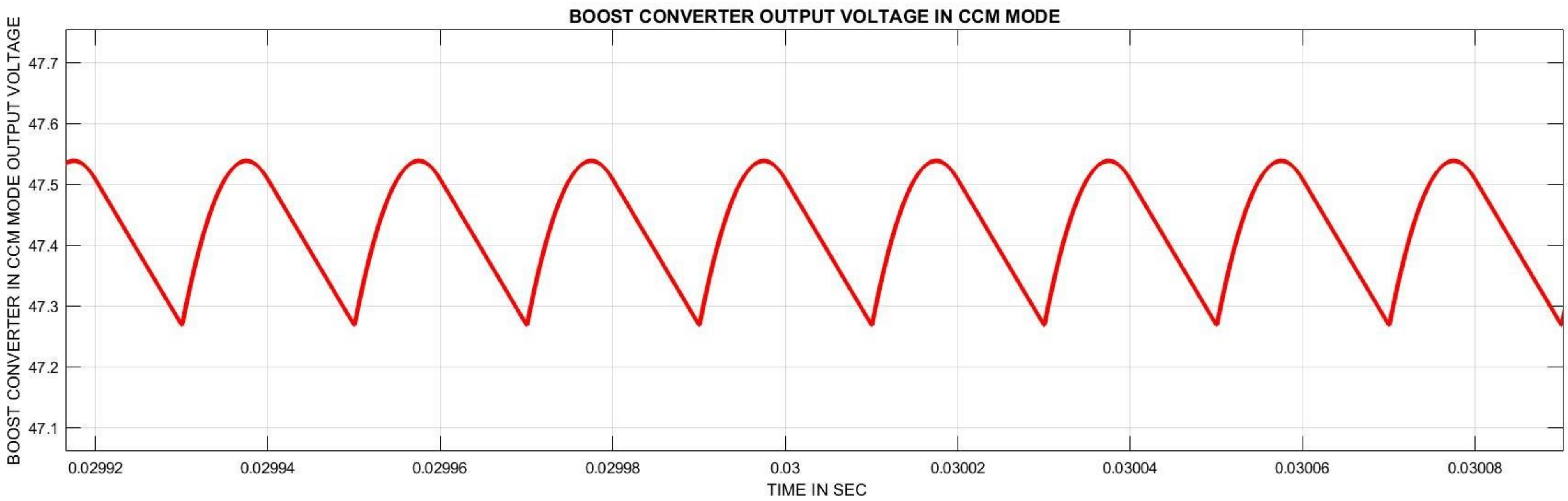

INDUCTOR CURRENT IN DCM MODE IN BUCK CONVERTER
INDUCTOR CURRENT IN DCM MODE
40
35
30
25
20
15
10
5
0
-5
0.0271
0.02711
0.02712
0.02713
0.02714
0.02715
0.02716
0.02717
0.02718
0.02719
TIME IN (S)


OUTPUT VOLATGE IN BOOST CONVERTER IN CCM MODE
OUTPUT VOLTAGE IN BOOST CONVERTER
52
50
48
46
44
42
40
0.0367
0.0368
0.0369
0.037
0.0371
0.0372
0.0373
0.0374
TIME IN (S)

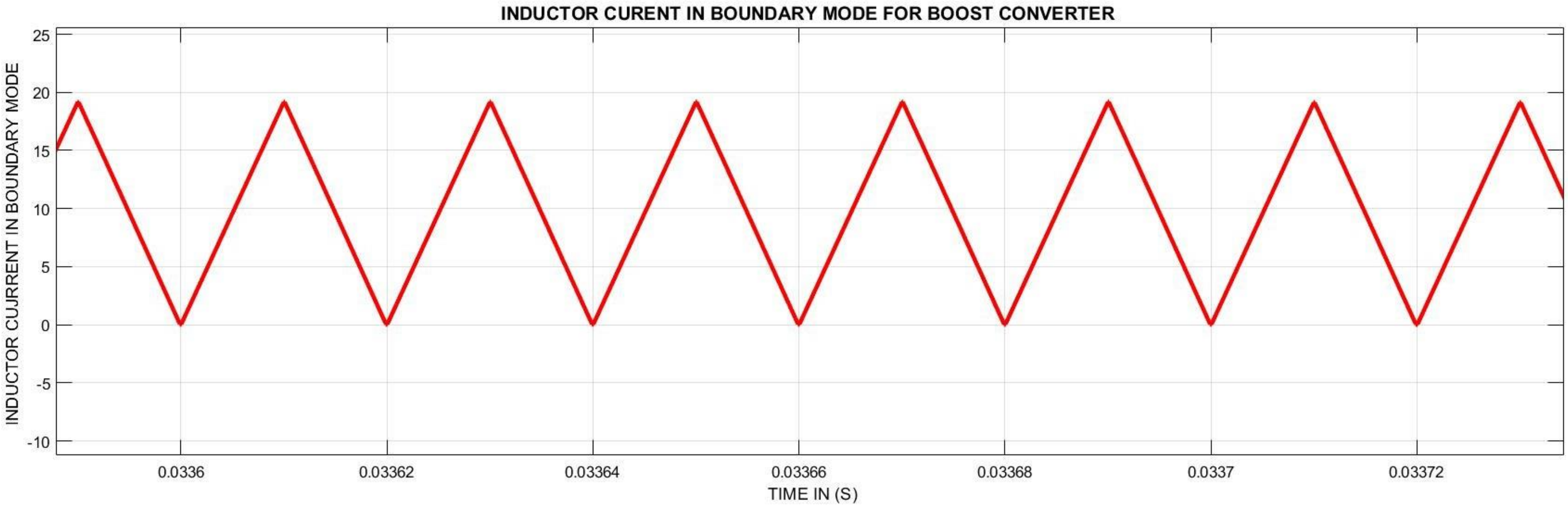


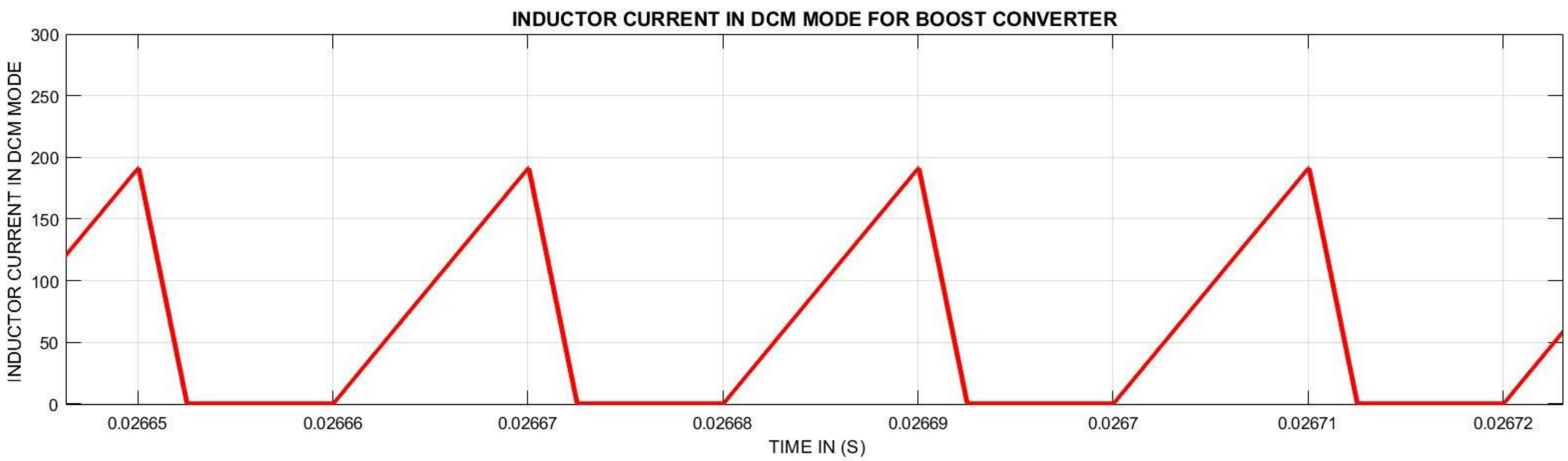
INDUCTOR CURENT IN BOOST CONVERTER IN CCM MODE
INDUCTOR CURRENT IN DCM MODE
11
10.5
10
9.5
9
8.5
0.04532
0.04533
0.04534
0.04535
0.04536
0.04537
0.04538
0.04539
0.0454
TIME IN (S)


BOOST CONVERTER INDUCTOR CURRENT IN CCM MODE
INDUCTOR CURRENT IN CCM
11
10.5
10
9.5
9
8.5
0.04532
0.04533
0.04534
0.04535
0.04536
0.04537
0.04538
0.04539
0.0454
TIME IN (S)

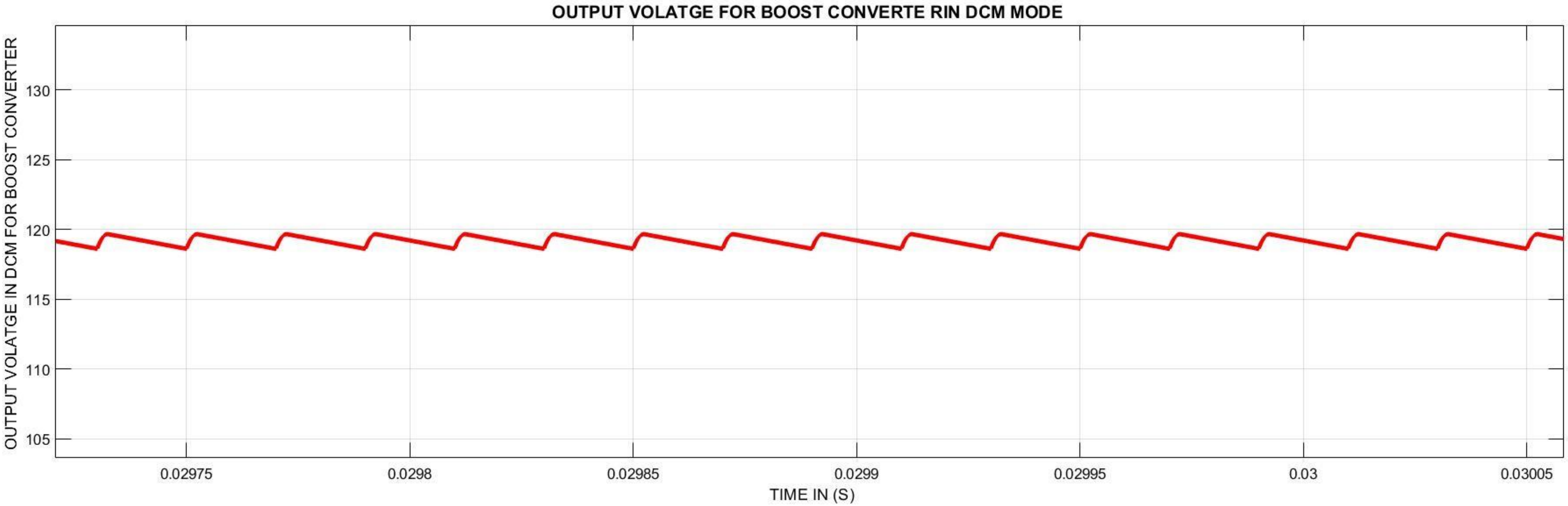


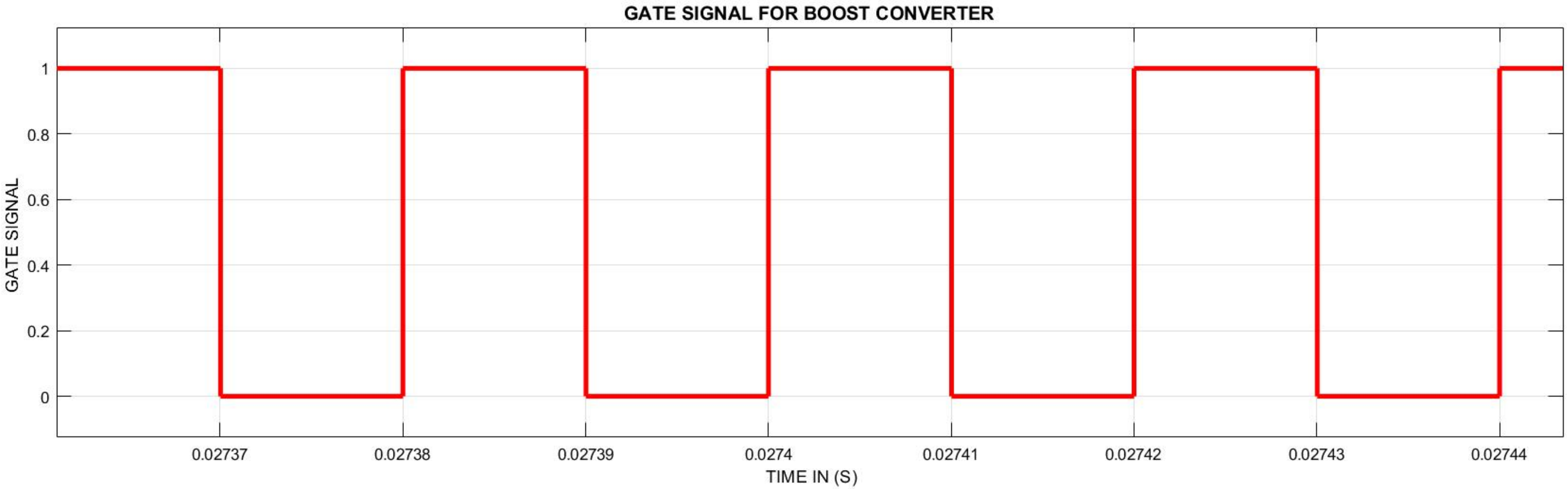
BOOST CONVERTER OUTPUT VOLTAGE IN CCM MODE
BOOST CONVERTER IN CCM MODE OUTPUT VOLTAGE
47.7
47.6
47.5
47.4
47.3
47.2
47.1
0.02992
0.02994
0.02996
0.02998
0.03
0.03002
0.03004
0.03006
0.03008
TIME IN SEC

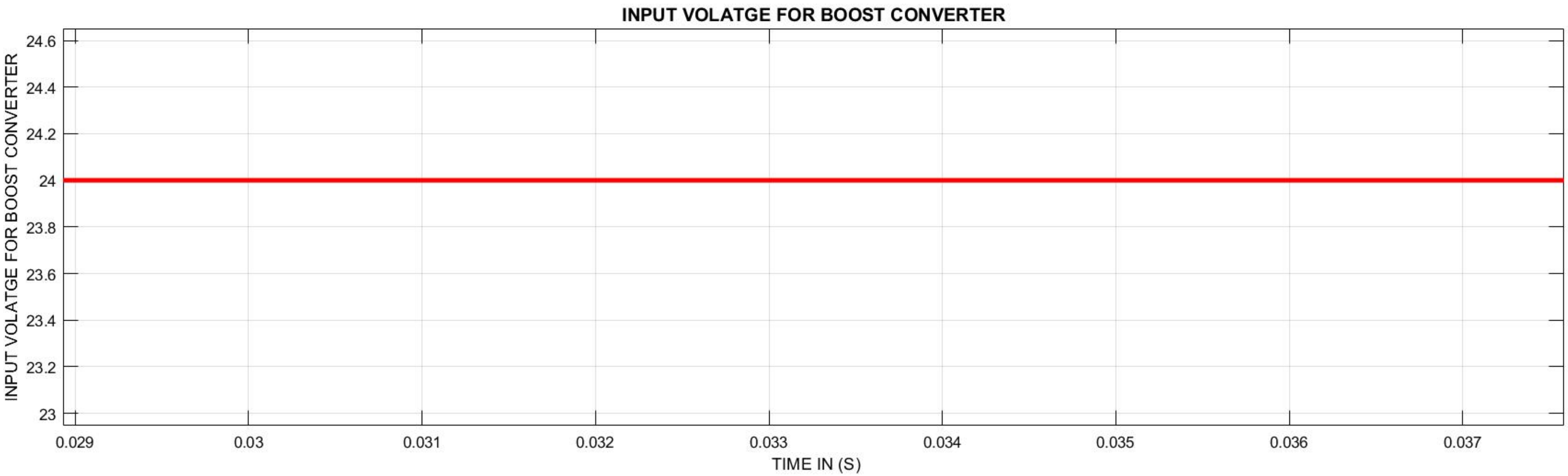

INDUCTOR CURENT IN BOUNDARY MODE FOR BOOST CONVERTER
INDUCTOR CUJRRENT IN BOUNDARY MODE
25
20
15
10
5
0
-5
-10
0.0336
0.03362
0.03364
0.03366
0.03368
0.0337
0.03372
TIME IN (S)



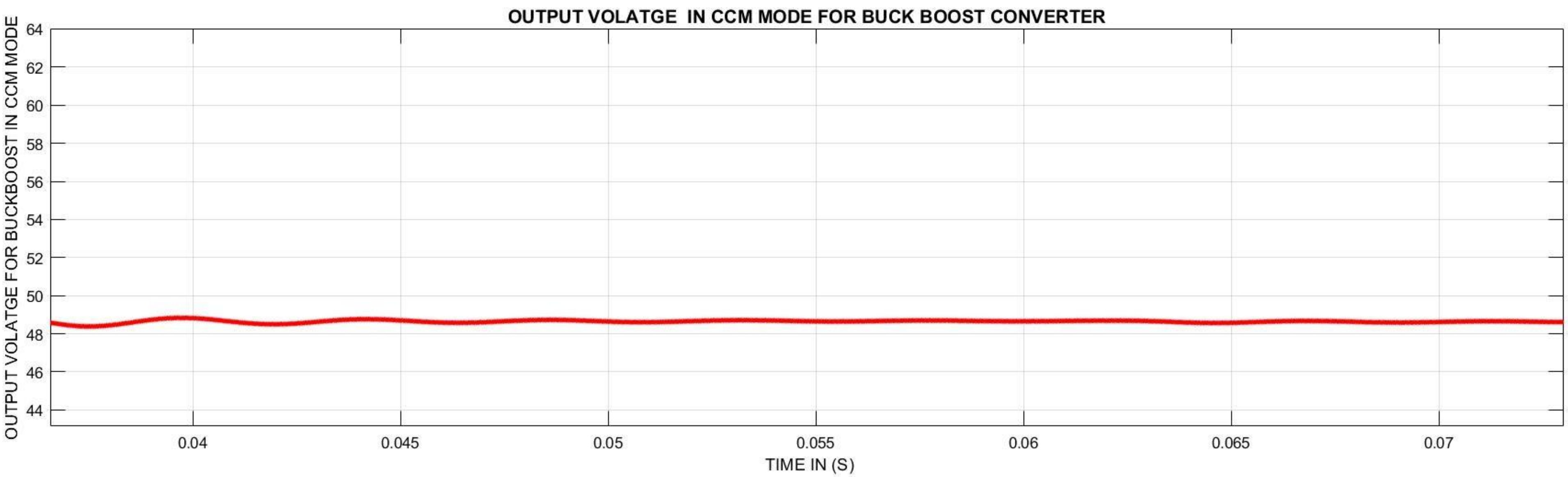
INDUCTOR CURRENT IN DCM MODE FOR BOOST CONVERTER
INDUCTOR CURRENT IN DCM MODE
300
250
200
150
100
50
0
0.02665
0.02666
0.02667
0.02668
0.02669
0.0267
0.02671
0.02672
TIME IN (S)


OUTPUT VOLATGE FOR BOOST CONVERTE RIN DCM MODE
OUTPUT VOLATGE IN DCM FOR BOOST CONVERTER
130
125
120
115
110
105
0.02975
0.0298
0.02985
0.0299
0.02995
0.03
0.03005
TIME IN (S)

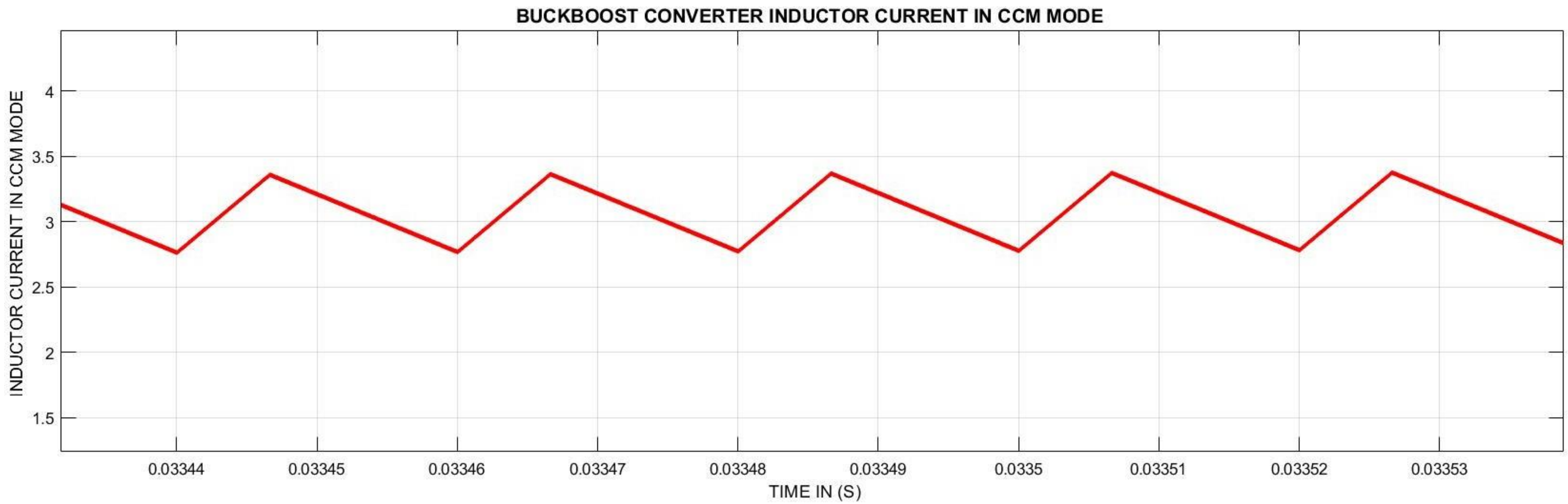

GATE SIGNAL FOR BOOST CONVERTER
GATE SIGNAL
1
0.8
0.6
0.4
0.2
0
0.02737
0.02738
0.02739
0.0274
0.02741
0.02742
0.02743
0.02744
TIME IN (S)

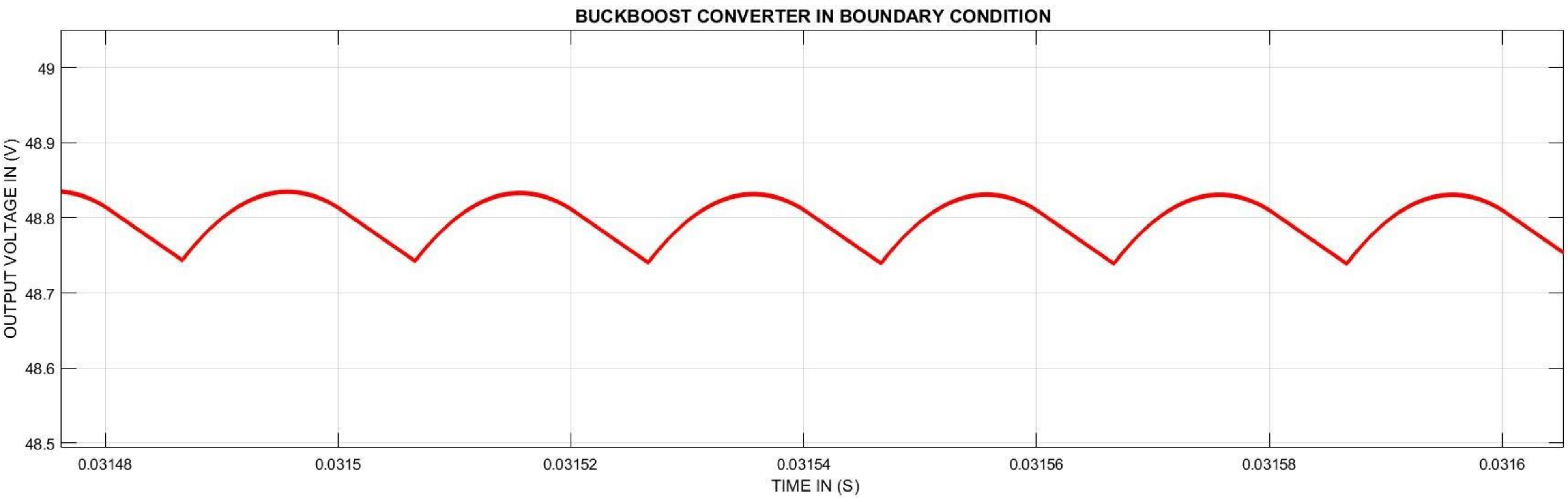


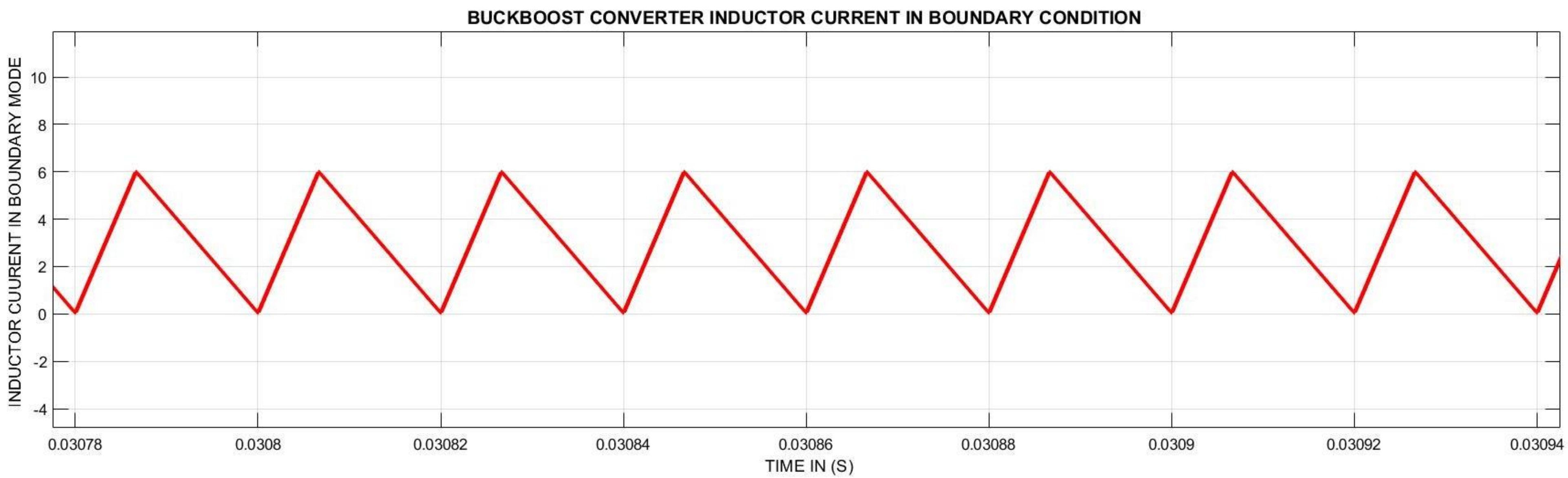
INPUT VOLATGE FOR BOOST CONVERTER
INPUT VOLATGE FOR BOOST CONVERTER
24.6
24.4
24.2
24
23.8
23.6
23.4
23.2
23
0.029
0.03
0.031
0.032
0.033
0.034
0.035
0.036
0.037
TIME IN (S)

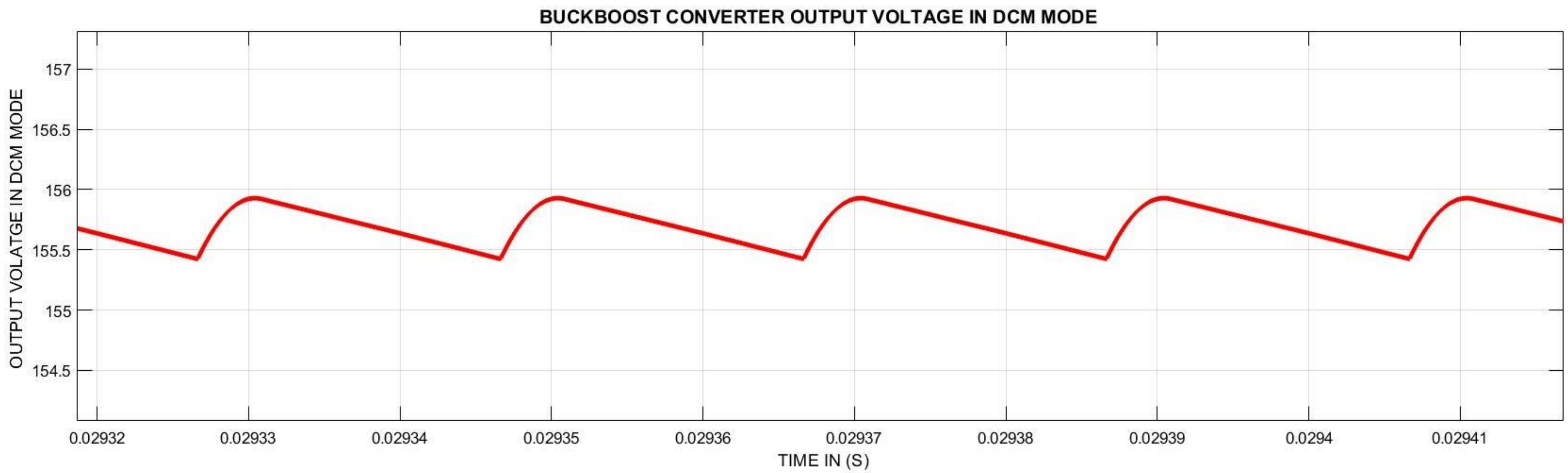


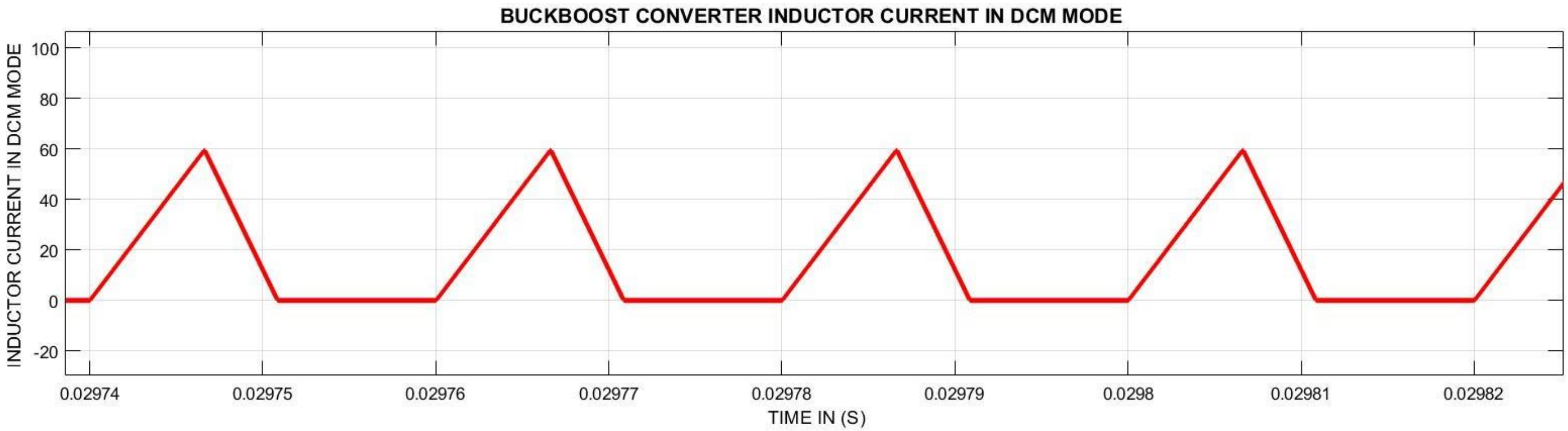
OUTPUT VOLATGE IN CCM MODE FOR BUCK BOOST CONVERTER
OUTPUT VOLATGE FOR BUCKBOOST IN CCM MODE
TIME IN (S)
64
62
60
58
56
54
52
50
48
46
44
0.04
0.045
0.05
0.055
0.06
0.065
0.07

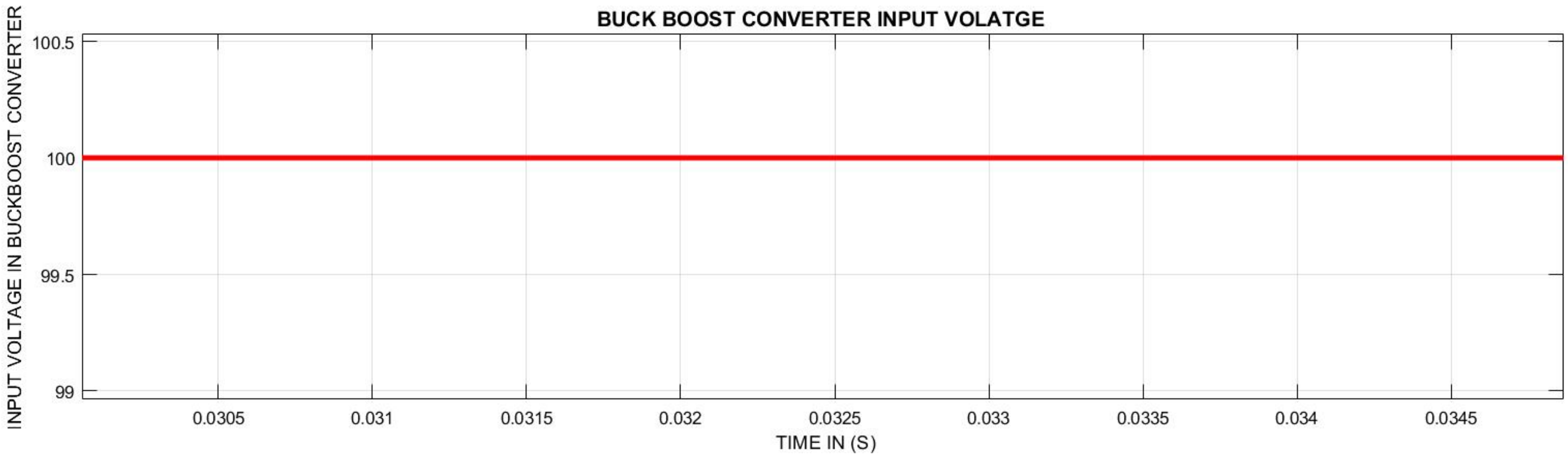

BUCKBOOST CONVERTER INDUCTOR CURRENT IN CCM MODE
INDUCTOR CURRENT IN CCM MODE
4
3.5
3
2.5
2
1.5
0.03344
0.03345
0.03346
0.03347
0.03348
0.03349
0.0335
0.03351
0.03352
0.03353
TIME IN (S)

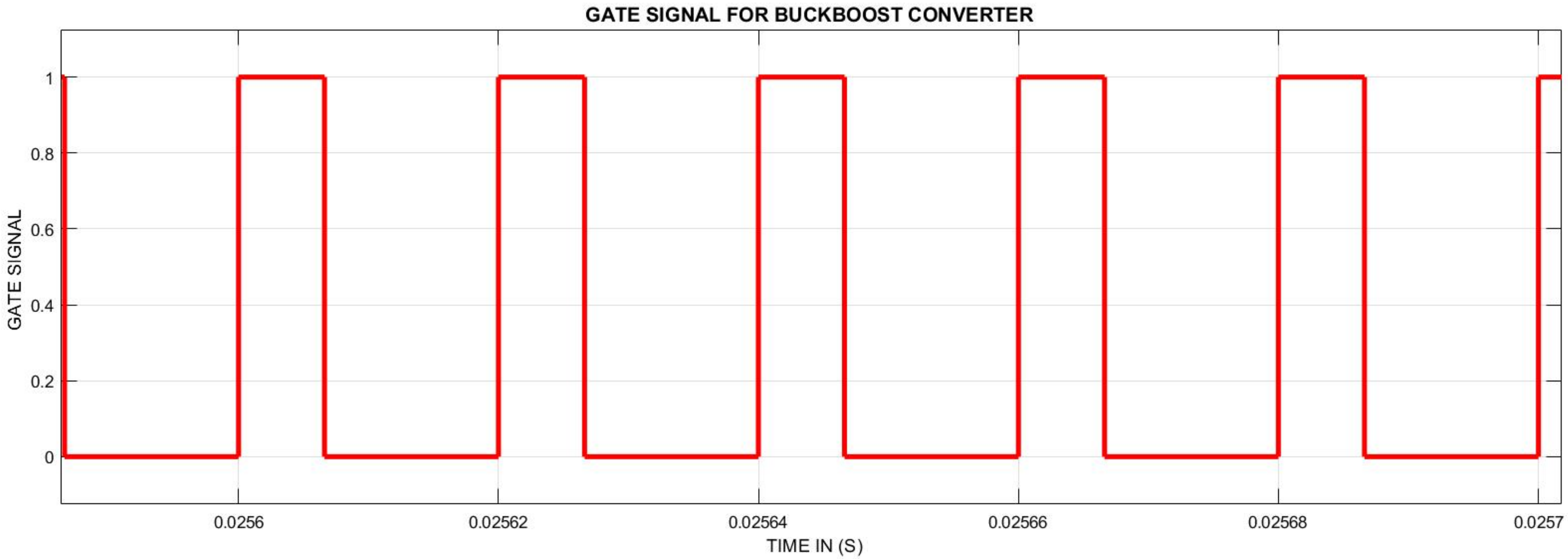

BUCKBOOST CONVERTER IN BOUNDARY CONDITION
OUTPUT VOLTAGE IN (V)
49
48.9
48.8
48.7
48.6
48.5
0.03148
0.0315
0.03152
0.03154
0.03156
0.03158
0.0316
TIME IN (S)


BUCKBOOST CONVERTER INDUCTOR CURRENT IN BOUNDARY CONDITION
INDUCTOR CUURENT IN BOUNDARY MODE
10
8
6
4
2
0
-2
-4
0.03078
0.0308
0.03082
0.03084
0.03086
0.03088
0.0309
0.03092
0.03094
TIME IN (S)


BUCKBOOST CONVERTER OUTPUT VOLTAGE IN DCM MODE
OUTPUT VOLATGE IN DCM MODE
157
156.5
156
155.5
155
154.5
0.02932
0.02933
0.02934
0.02935
0.02936
0.02937
0.02938
0.02939
0.0294
0.02941
TIME IN (S)

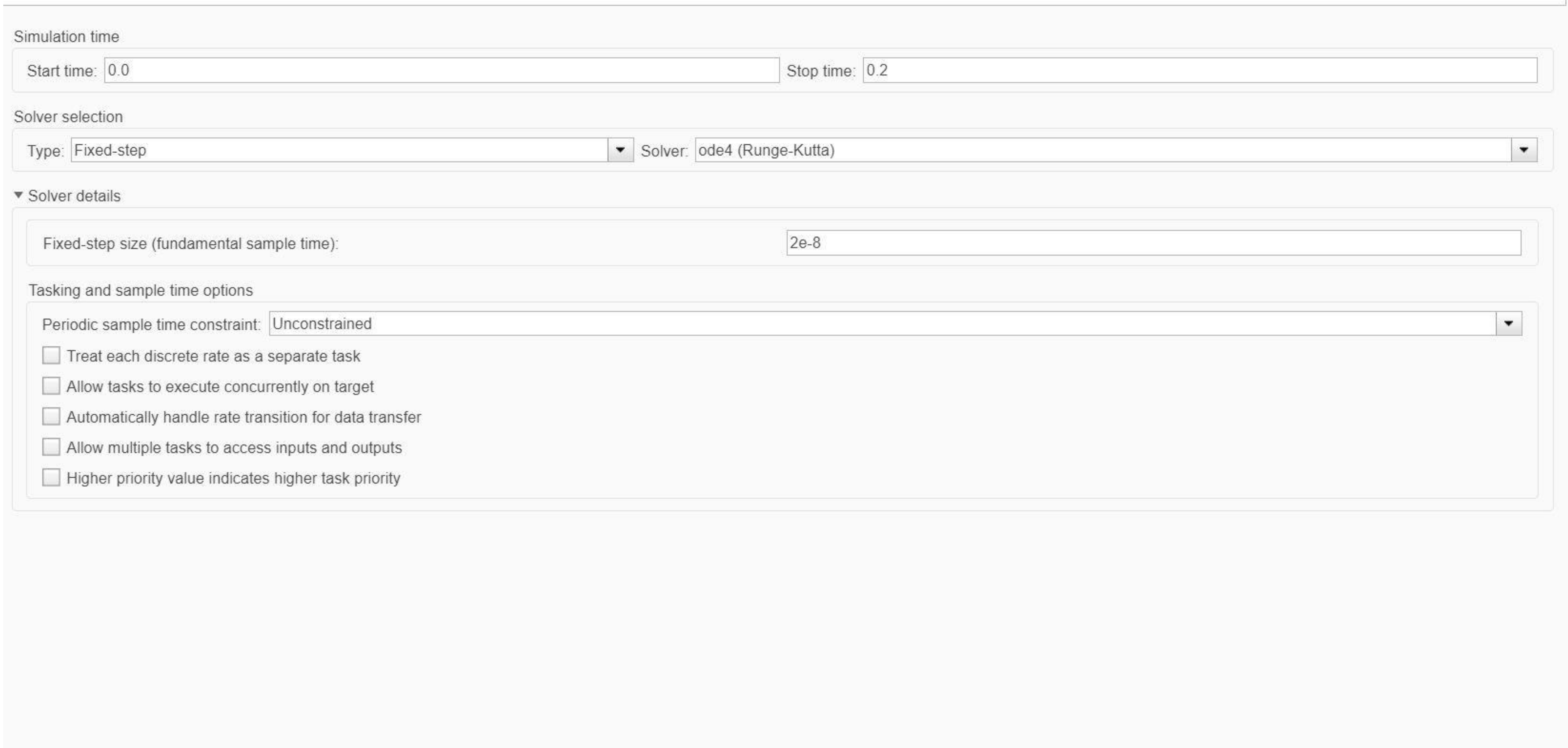

BUCKBOOST CONVERTER INDUCTOR CURRENT IN DCM MODE
INDUCTOR CURRENT IN DCM MODE
TIME IN (S)
100
80
60
40
20
0
-20
0.02974
0.02975
0.02976
0.02977
0.02978
0.02979
0.0298
0.02981
0.02982


BUCK BOOST CONVERTER INPUT VOLATGE
INPUT VOLTAGE IN BUCKBOOST CONVERTER
100.5
100
99.5
99
0.0305
0.031
0.0315
0.032
0.0325
0.033
0.0335
0.034
0.0345
TIME IN (S)

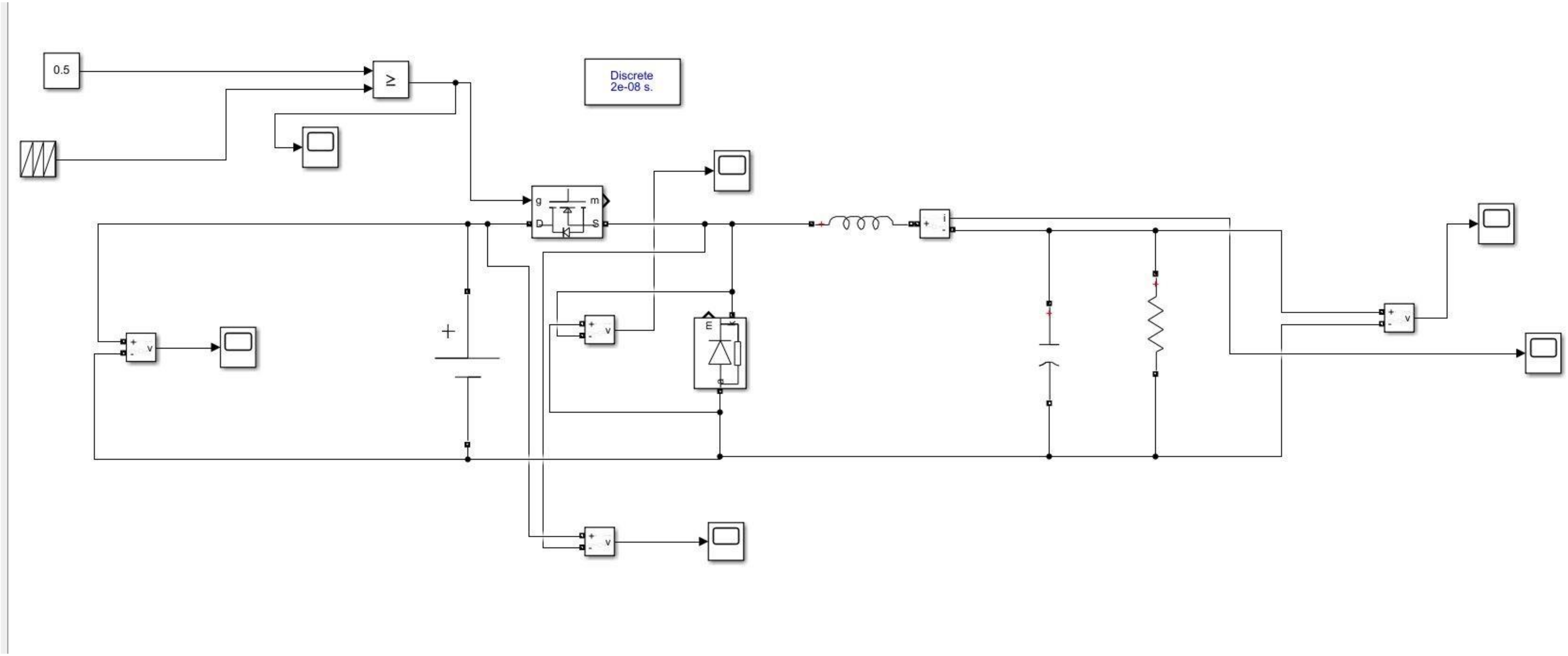


GATE SIGNAL FOR BUCKBOOST CONVERTER
GATE SIGNAL
1
0.8
0.6
0.4
0.2
0
0.0256
0.02562
0.02564
0.02566
0.02568
0.0257
TIME IN (S)

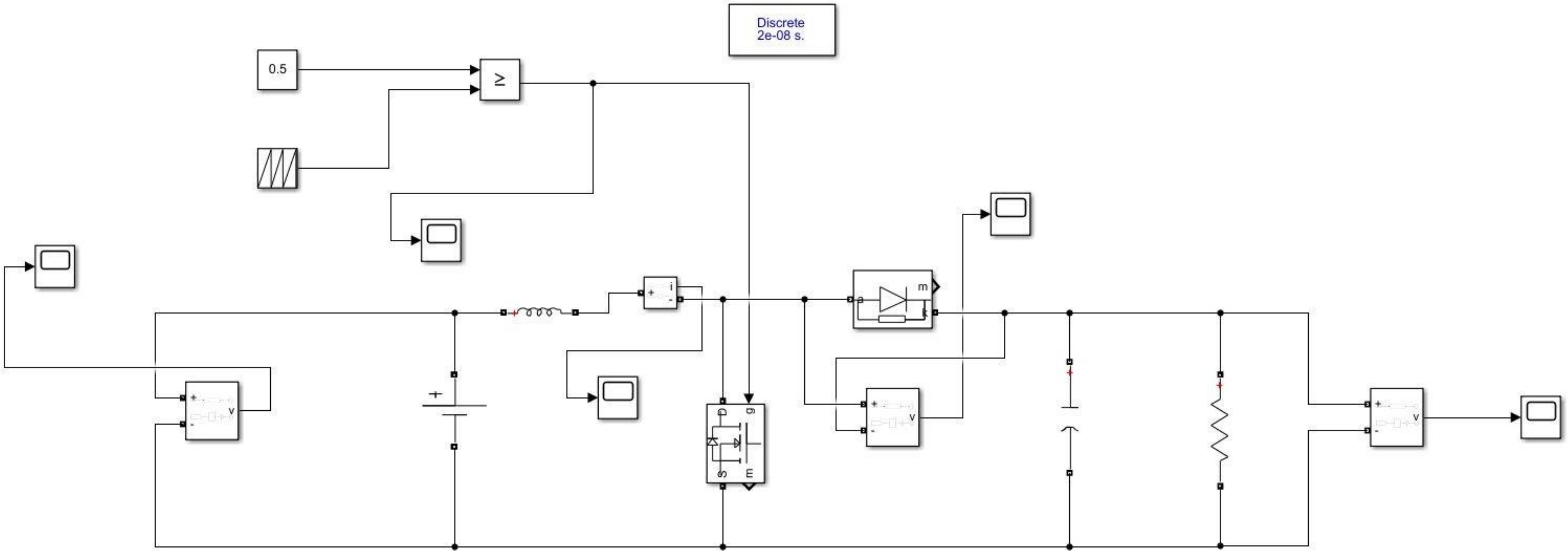
Conclusions: The analysis of buck, boost, and buck-boost converter in continuous mode, boundary mode, and discontinuous mode gave us a deep insight into the nature of inductor current in all three modes and also the variation in output voltages. The experiment in necessary for our understanding strong for the analysis of buck, boost, and buck- boost converters in different modes of operation.


Simulation time
Start time: 0.0
Stop time: 0.2
Solver selection
Type: Fixed-step
Solver: ode4 (Runge-Kutta)
Solver details
Fixed-step size (fundamental sample time):
2e-8
Tasking and sample time options
Periodic sample time constraint: Unconstrained
Treat each discrete rate as a separate task
Allow tasks to execute concurrently on target
Automatically handle rate transition for data transfer
Allow multiple tasks to access inputs and outputs
Higher priority value indicates higher task priority

BUCK CONVERTER SIMULINK MODEL



BOOST CONVERTER MODEL IN SIMULINK



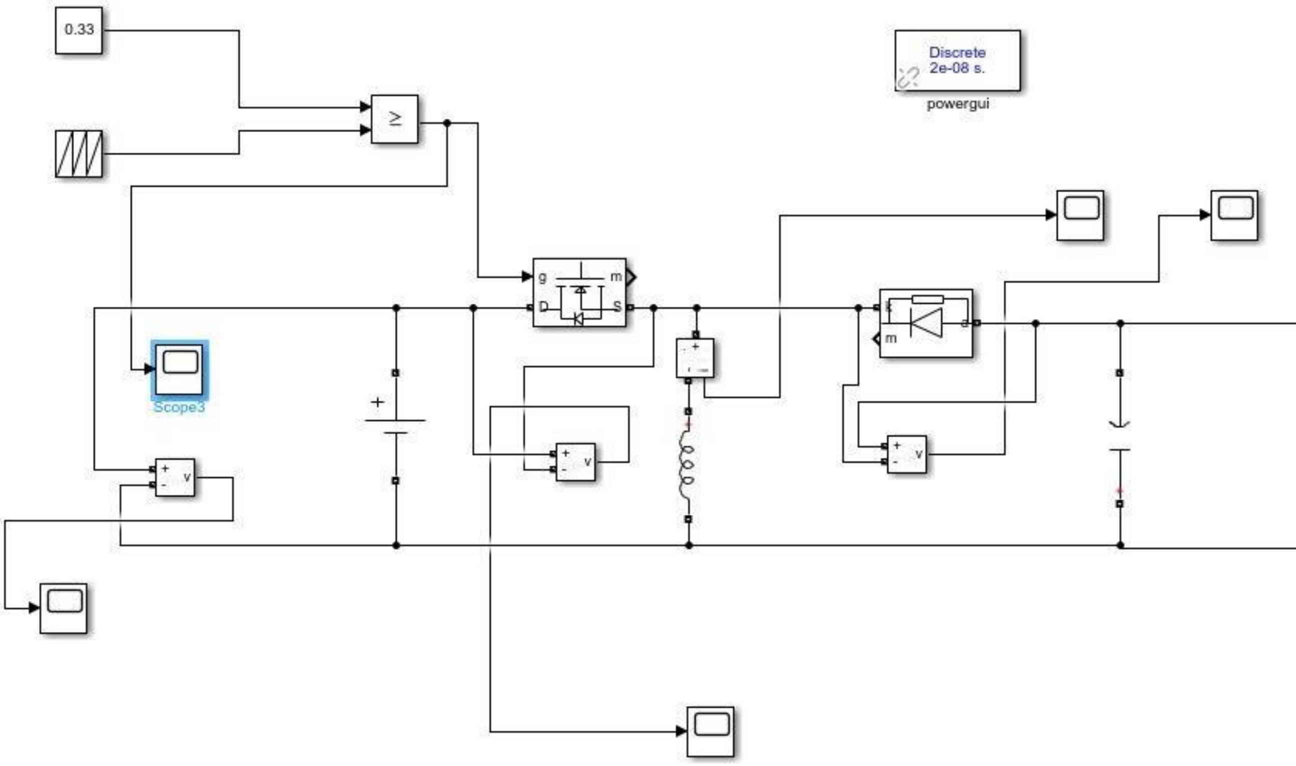
EXPERIMENT 4

BUCKBOOST CONVERTER MODEL IN SIMULINK

Date:06/09/2024

ARYA MALLICK

Roll No:234102501



EXPERIMENT 4

Date:06/09/2024
ARYA MALLICK
Roll No:234102501

TITLE: To study Flyback and SEPIC Converter and analyze them theoretically and practically in SIMULINK.

OBJECTIVE: To compare Flyback and SEPIC Converter and find out output voltage, inductor current. ripple in inductor current, etc,

THEORY:

Working of the fly back converter

Case 1:

In the fly back converter the winding of the transformer will act as inductor. When the MOSFET is turned on at that time this primary side of the transformer will act like an inductor and this will start storing energy coming from the input. We will triggering the gate pulses. Hence at this time, there will not be any voltage at the output side, this is known as an energy storing phase in the flyback converter. When the current will start flowing in the primary winding it will induce voltage in the secondary winding. Assuming the dot convention when the current is entering the dot convention the voltage induced at the secondary will have opposite polarities. In primary side we have positive sign upward and negative side downward while at the secondary side the negative sign will be upward and positive sign will be downward. Now as the diode will get negative voltage so it will be in reverse bias and it will act as open circuit and there will be no current flowing to the load.

EXPERIMENT 4

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Roll No:234102501

Case 2:

Now the transistor is turned off. This time the polarity of the inductor i.e. primary side of the transformer will get reversed and voltage will get induced in the secondary side of the transformer due to electromagnetic induction and diode will get forward biased and magnitude of this induced voltage is given by turns ratio

i.e. $V_{in}/V_o = N_p/N_s$

The switch will be as open circuit. This is known as the flyback phase of the converter, here primary side is fully off and voltage will be delivered to the output capacitor and it will get charged. It is used for mostly in lower power applications when the power required is less.

In next energy storing phase output capacitor delivers the voltage to the load. These cycles get repeated over a period of time and we get regulated DC output voltage. This is how the flyback converter works.

EXPERIMENT 4

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Roll No:234102501

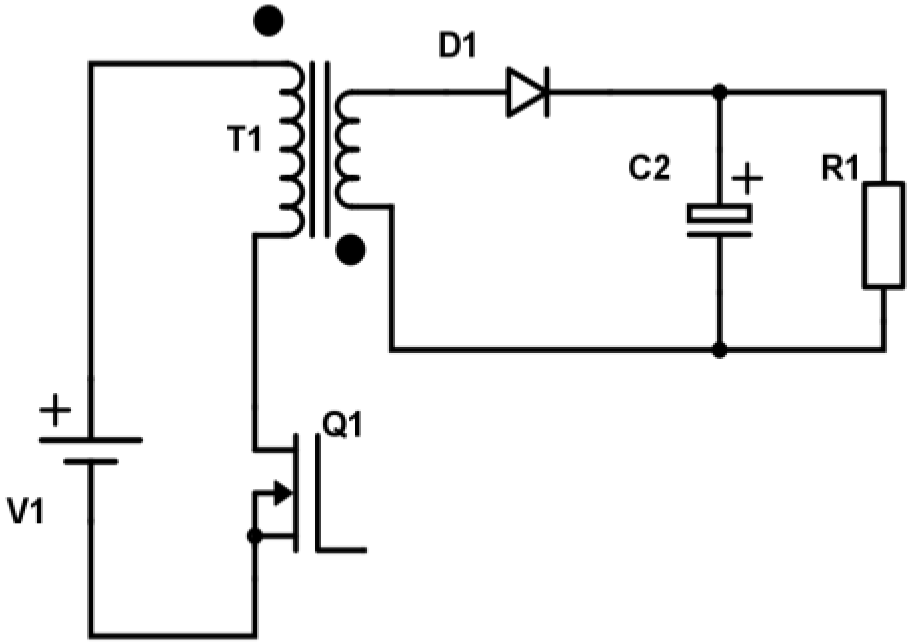
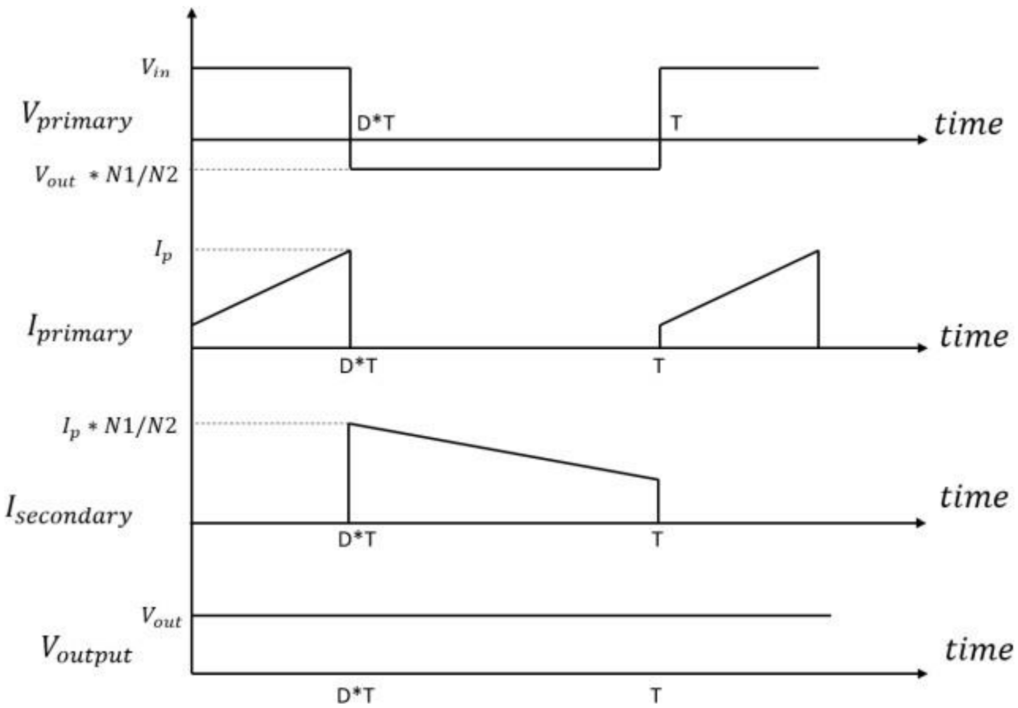


Figure 1: Flyback converter



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ARYA MALLICK
Roll No:234102501

SEPIC CONVERTER:

The Single-Ended Primary Inductor Converter (SEPIC), a flexible and effective DC-DC converter topology, can step-up and step-down the input voltage, making it the perfect option for applications with different input voltage needs. The SEPIC converter's distinctive qualities, such as its capacity to deliver a non-inverted output voltage and uphold minimal input and output ripple, make it ideal for various uses, including battery-powered and renewable energy systems and automotive electronics.

The SEPIC converter's fundamental working theory depends on the energy transfer between two inductors and a capacitor. Two inductors (L1 and L2) and a capacitor (C1) are connected to provide an intermediate energy storage stage in a SEPIC converter. The coupled inductors and capacitors in this configuration enable the converter to transfer energy from the input to the output. In contrast, the output voltage is controlled by the switching component (often a MOSFET) and output capacitor.

During the on-state of the switch, the energy is stored in both inductors, and the capacitor is charged. The inductors' stored energy is transmitted to the output capacitor and the load when the switch is in the off position. The output voltage is regulated as a result of this continual energy transfer process, and depending on the duty cycle of the switch, it may be either greater or lower than the input voltage.

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The SEPIC converter is a useful addition to the spectrum of existing DC-DC converter topologies because it can step-up and step-down the input voltage while maintaining a non-inverted output voltage.

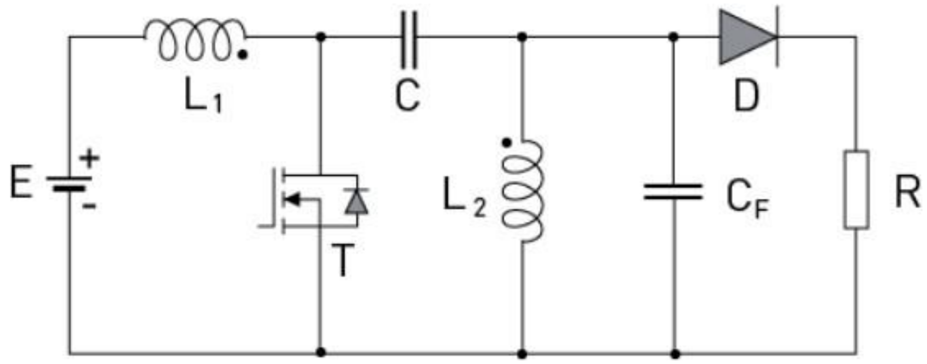

Fig 2: SEPIC Converter

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Date:06/09/2024
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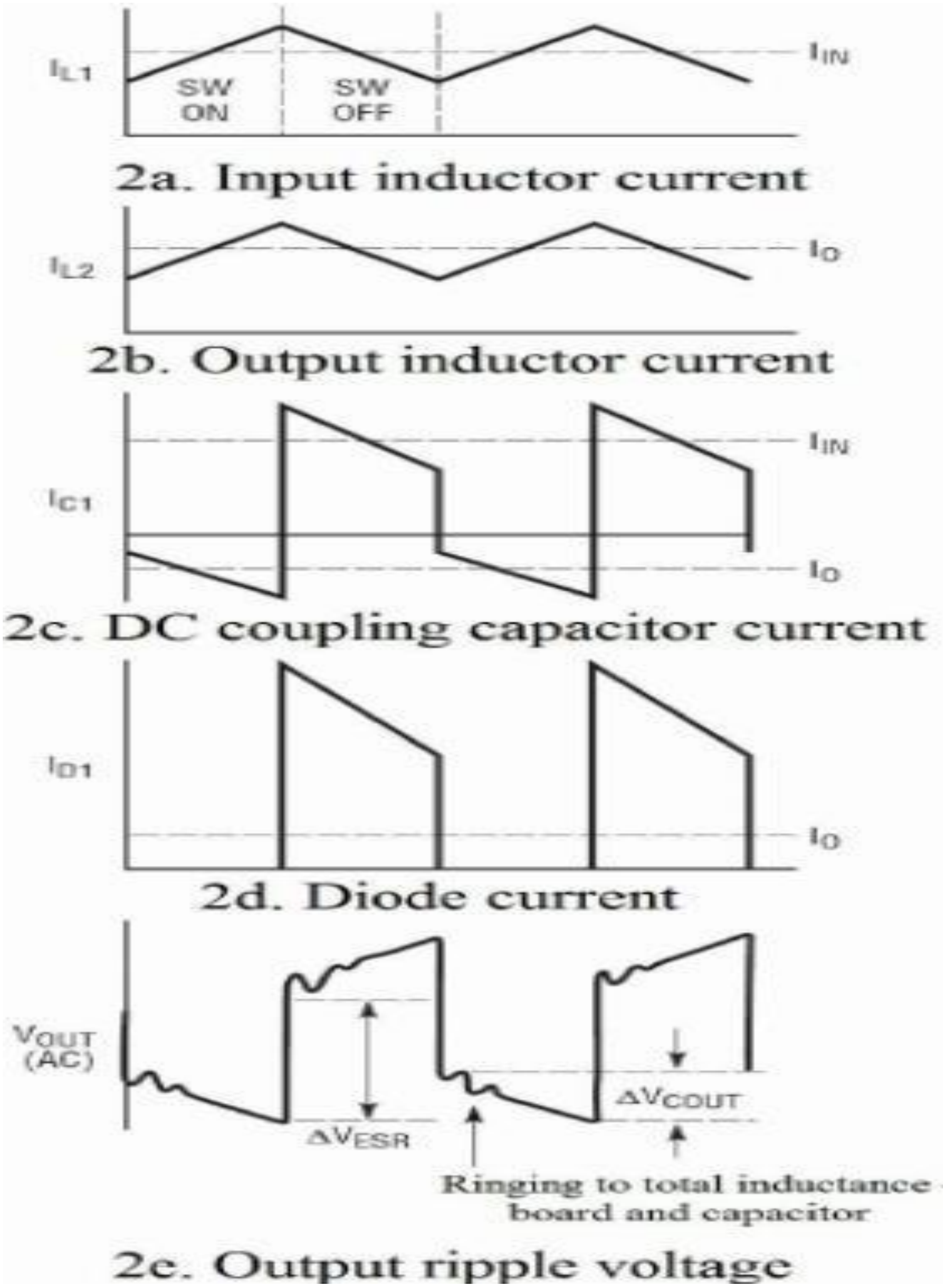
Roll No:234102501



2a. Input inductor current

2b. Output inductor current

2c. DC coupling capacitor current

2d. Diode current

2e. Output ripple voltage

CALCULATIONS:

EXPERIMENT 4

Date:06/09/2024

ARYA MALLICK

Roll No:234102501

FLYBACK CONVERTER:

Given: Vs=24 V ; D=1/3; R=5 ohms ; f_S= 20kHz;C=200uF

$$V_0 = \frac{D}{1-D} * V_s * \frac{N_2}{N_1} = 60\,Volts$$

$$V_s = L\frac{\Delta I_l}{DT}\ OR\ L = 22.11uH$$

$$I_m = \frac{V_0}{R*(1-D)} * \frac{N_2}{N_1} = 89.55\,A \qquad \Delta I_L = 20\,\%\ of\ I_m = 22.38\,A$$

SEPIC CONVERTER:

Given: Vs=48 V ; D=2/3; R=10 ohms ; f_S= 50kHz;C=200uF

$$V_0 = \frac{D}{1-D} * V_s = 97.4\,Volts$$

$$I_0 = \frac{V_0}{R} = 9.7\,A$$

$$I_{L2} = I_0 = 9.7\,A$$

$$I_{L1} = \frac{D}{1-D} * I_0 = 19.2\,A$$

$$L_1 = \frac{D * V_s}{f * \Delta I_{L1}} = 167.5\,uH$$

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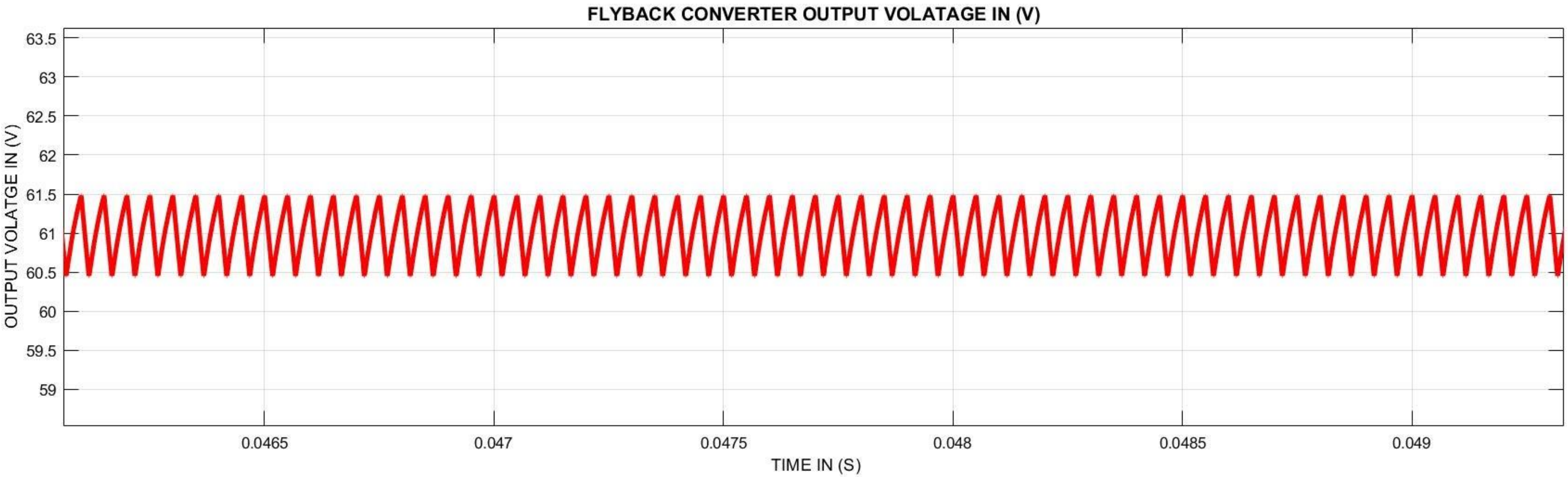
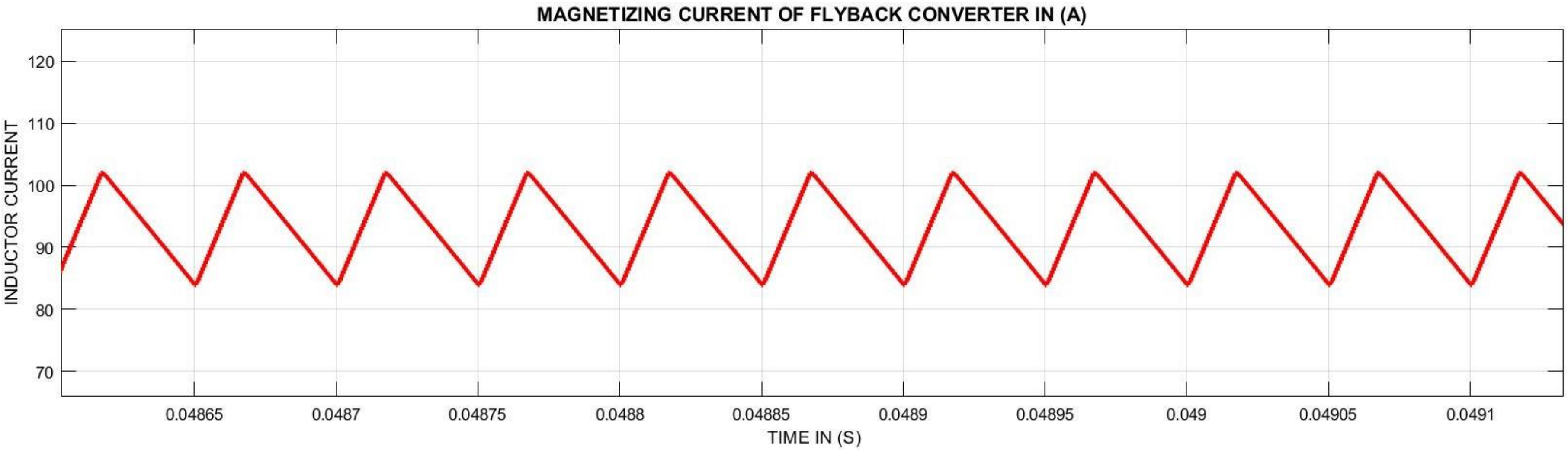
$$L_2 = \frac{D * V_s}{f * \Delta I_{L2}} = 333.33\ uH$$

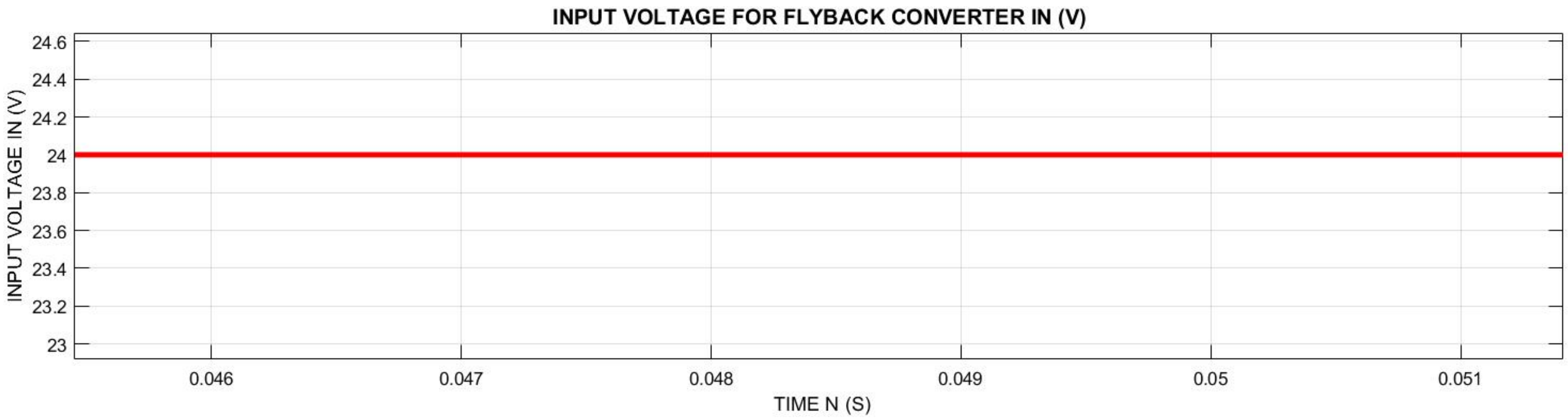
Thus theoretically and practically we got almost same values and error is almost negligible.



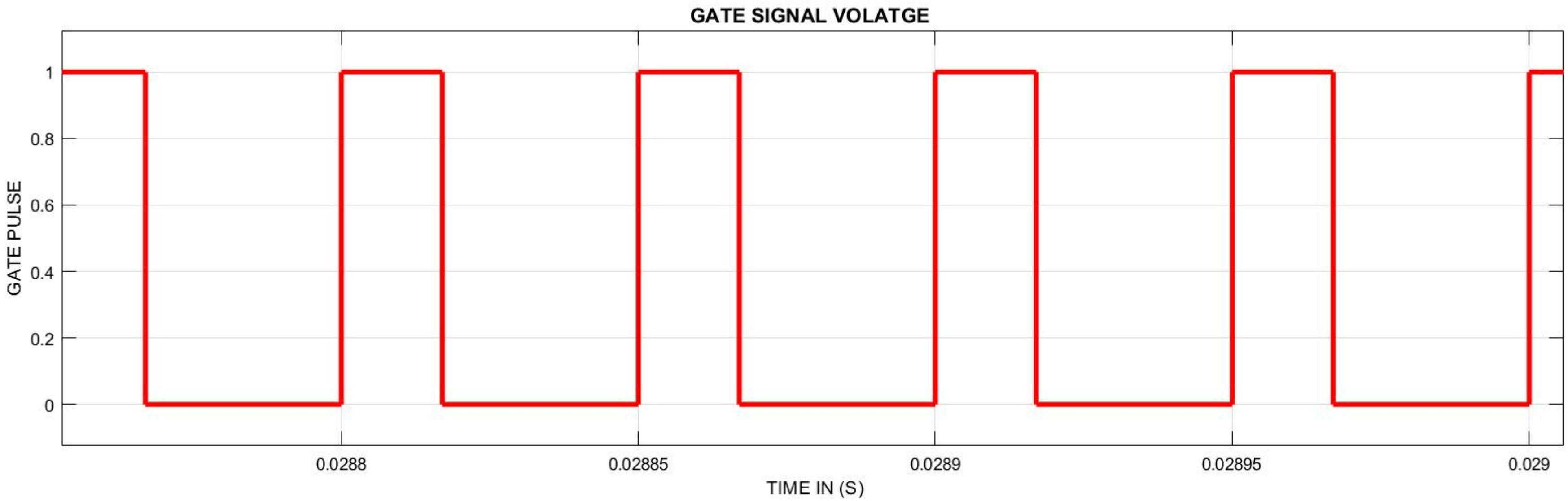
FLYBACK CONVERTER OUTPUT VOLATAGE IN (V)
63.5
63
62.5
62
61.5
61
60.5
60
59.5
59
OUTPUT VOLATGE IN (V)
0.0465
0.047
0.0475
0.048
0.0485
0.049
TIME IN (S)

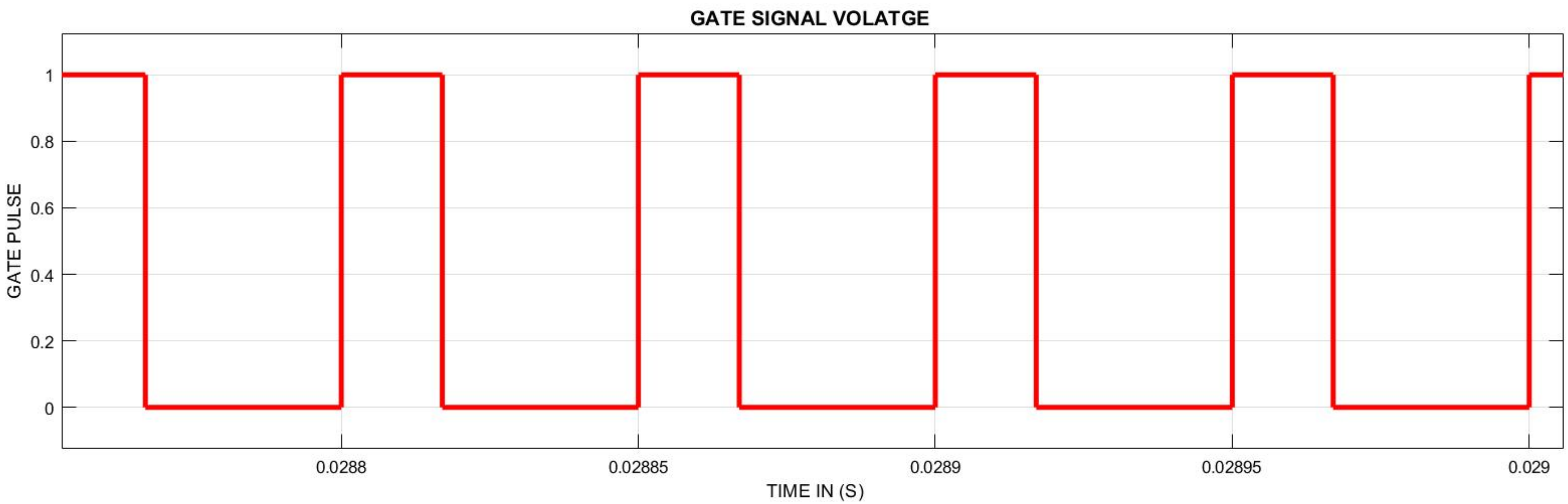


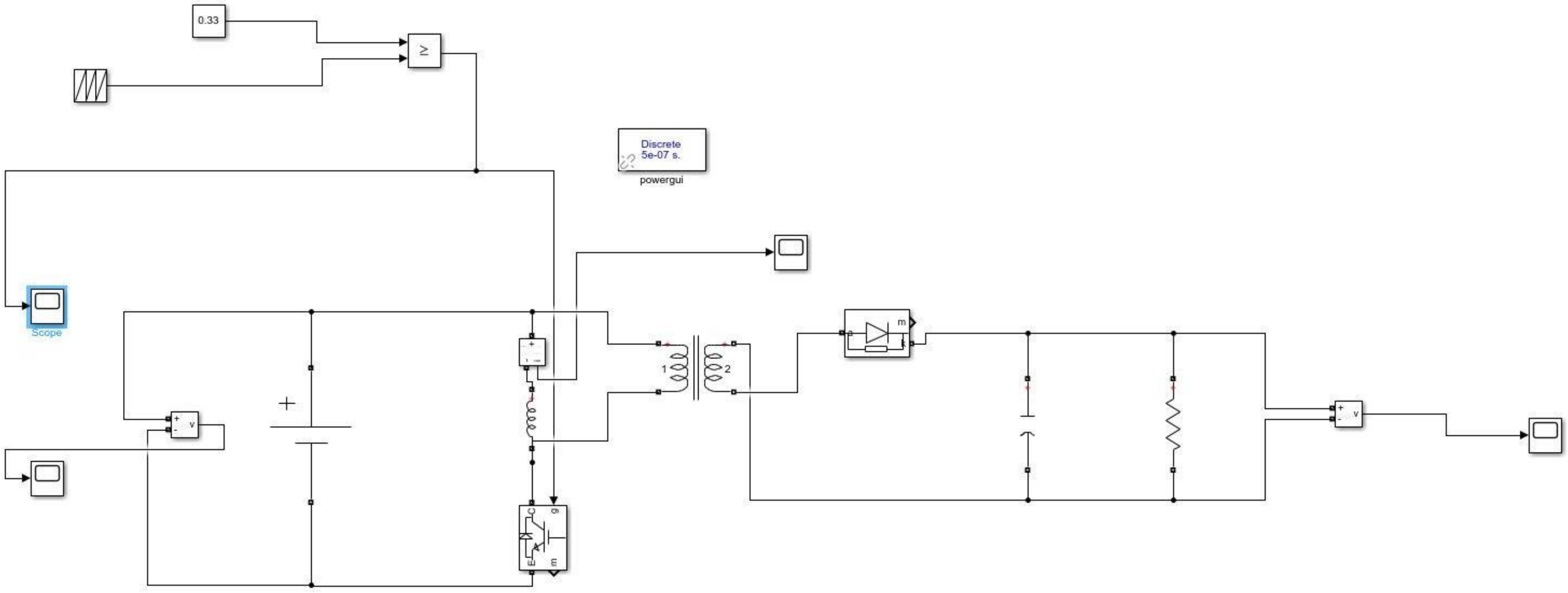
MAGNETIZING CURRENT OF FLYBACK CONVERTER IN (A)
INDUCTOR CURRENT
120
110
100
90
80
70
0.04865
0.0487
0.04875
0.0488
0.04885
0.0489
0.04895
0.049
0.04905
0.0491
TIME IN (S)

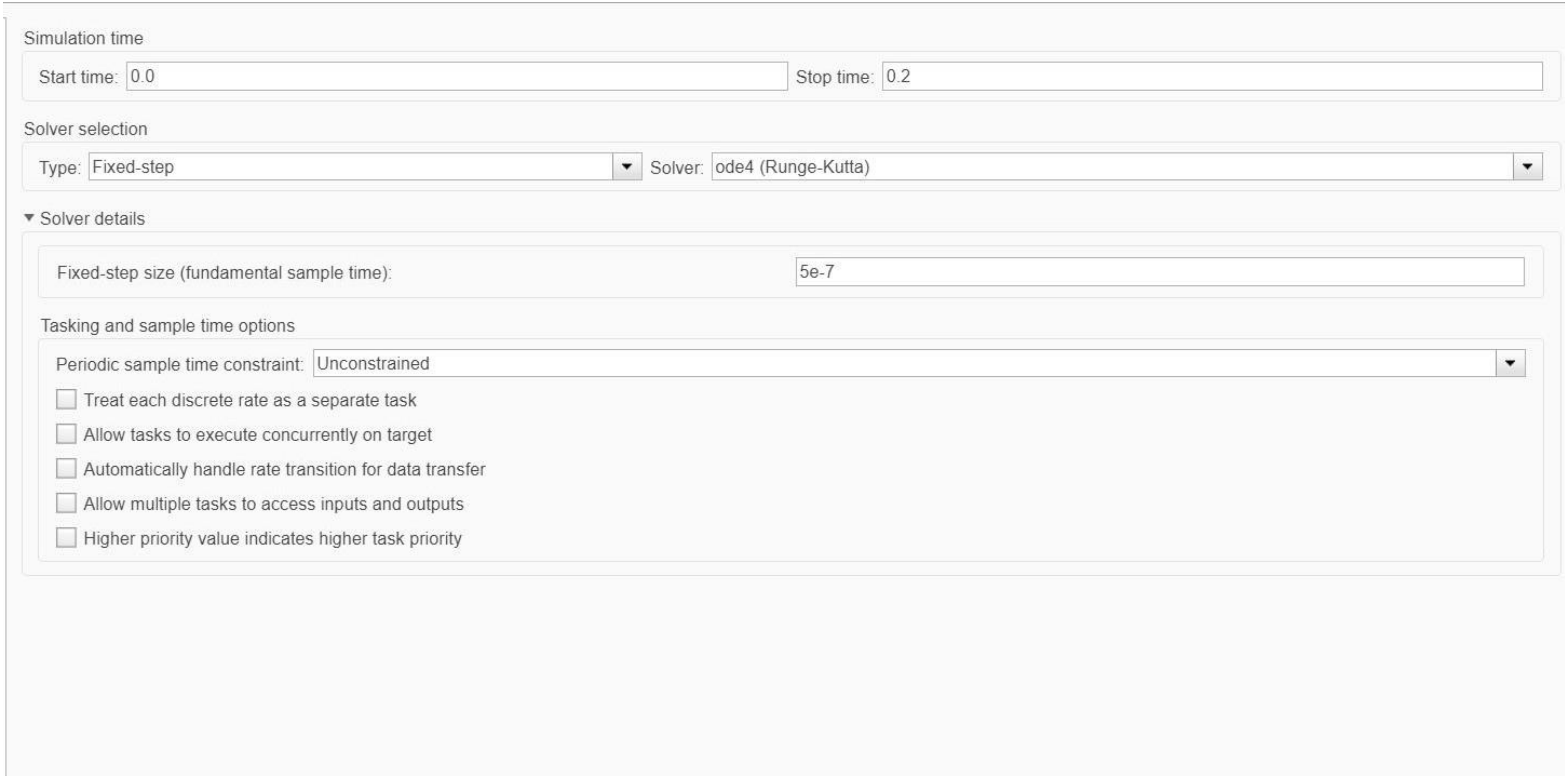


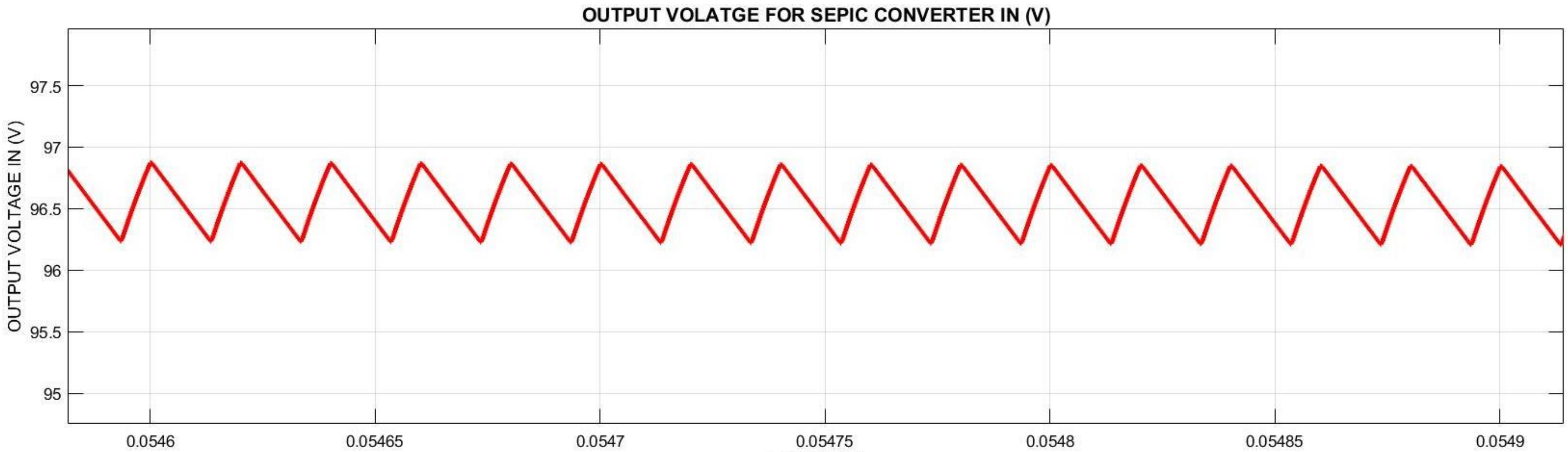
INPUT VOLTAGE FOR FLYBACK CONVERTER IN (V)
INPUT VOLTAGE IN (V)
24.6
24.4
24.2
24
23.8
23.6
23.4
23.2
23
0.046
0.047
0.048
0.049
0.05
0.051
TIME N (S)


GATE SIGNAL VOLATGE
GATE PULSE
1
0.8
0.6
0.4
0.2
0
0.0288
0.02885
0.0289
0.02895
0.029
TIME IN (S)

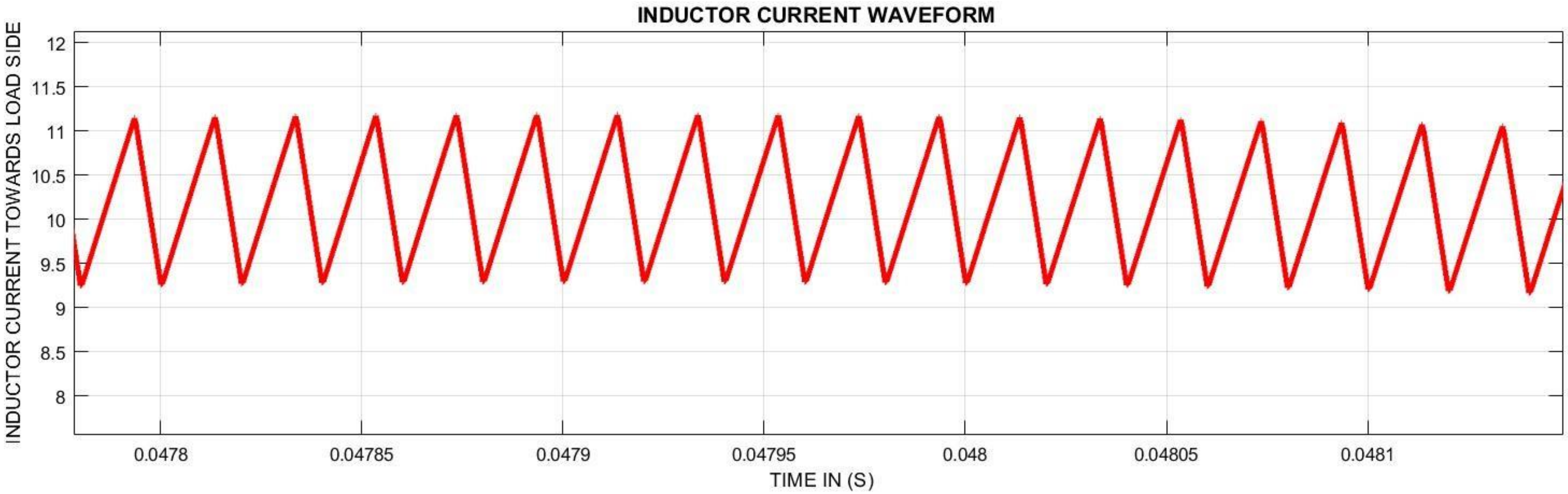

GATE SIGNAL VOLATGE
GATE PULSE
1
0.8
0.6
0.4
0.2
0
0.0288
0.02885
0.0289
0.02895
0.029
TIME IN (S)

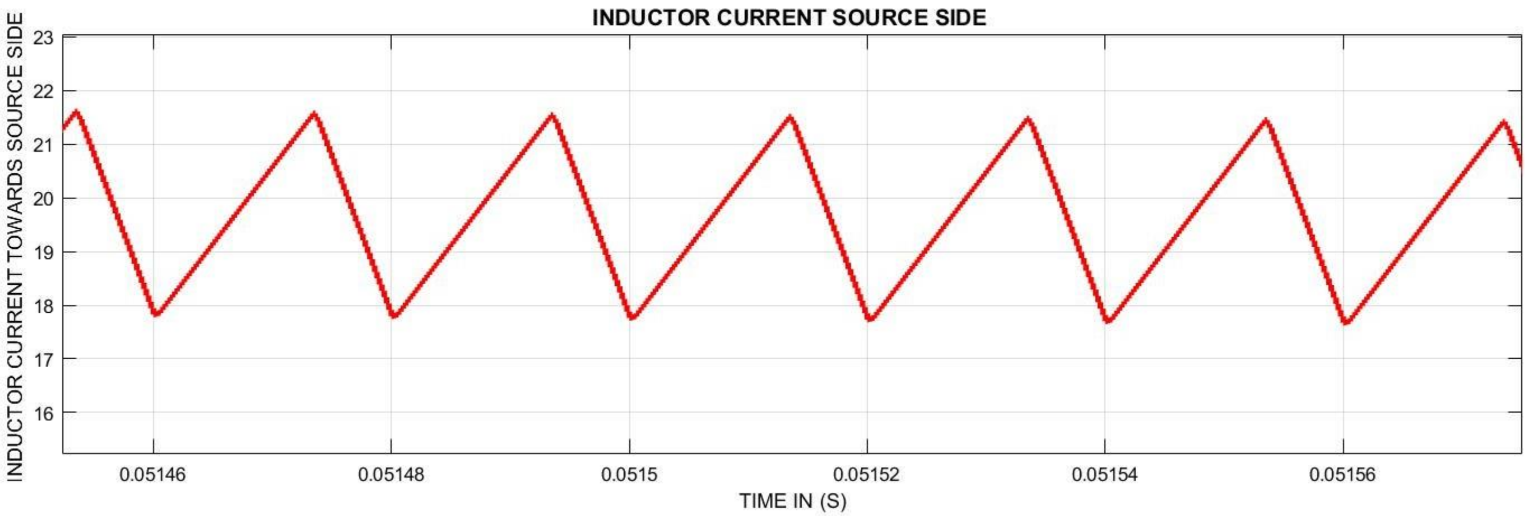

0.33
≥
Discrete
5e-07 s.
powergui
Scope
1
2

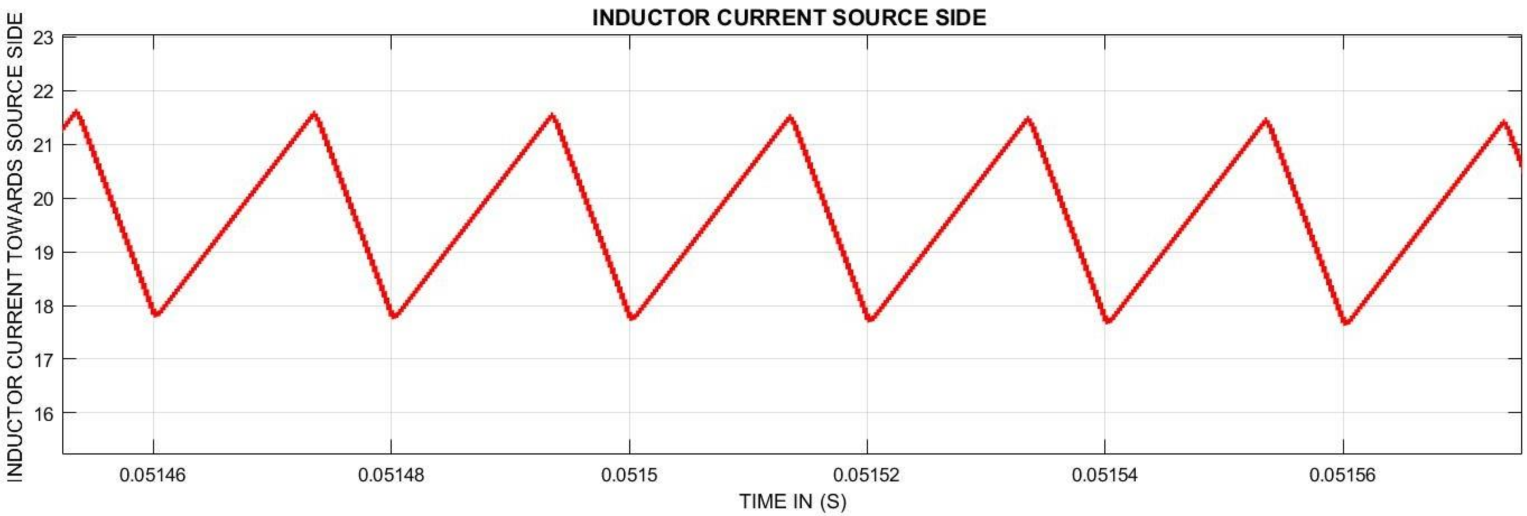

Simulation time
Start time: 0.0
Stop time: 0.2
Solver selection
Type: Fixed-step
Solver: ode4 (Runge-Kutta)
Solver details
Fixed-step size (fundamental sample time):
5e-7
Tasking and sample time options
Periodic sample time constraint: Unconstrained
Treat each discrete rate as a separate task
Allow tasks to execute concurrently on target
Automatically handle rate transition for data transfer
Allow multiple tasks to access inputs and outputs
Higher priority value indicates higher task priority



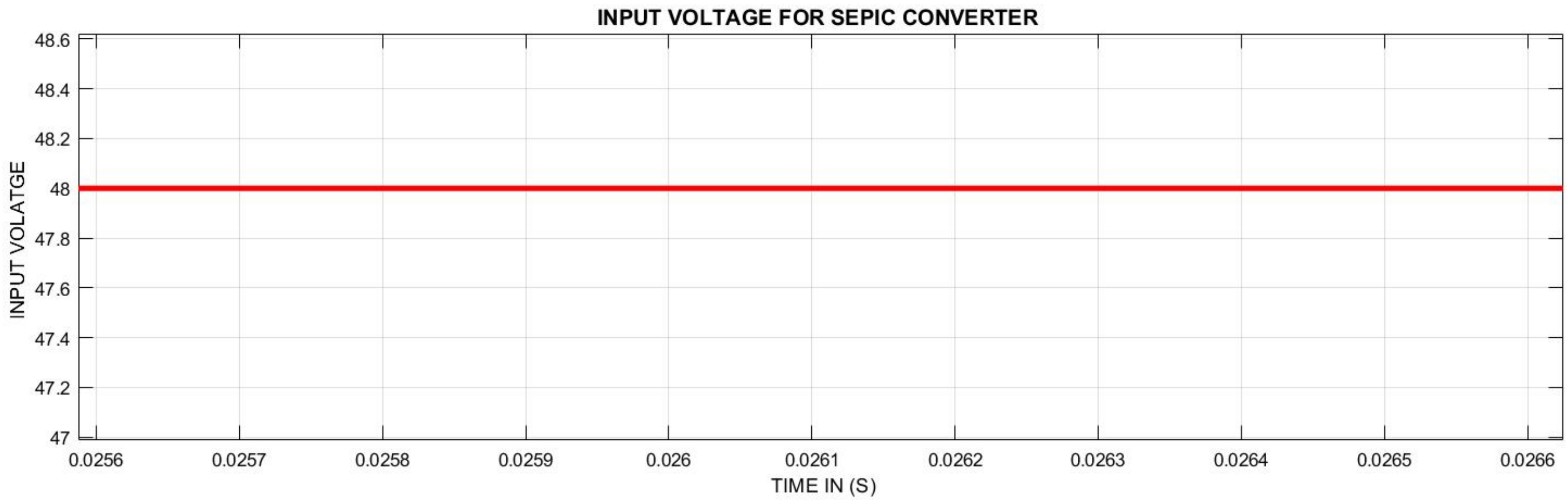
OUTPUT VOLATGE FOR SEPIC CONVERTER IN (V)
OUTPUT VOLTAGE IN (V)
97.5
97
96.5
96
95.5
95
0.0546
0.05465
0.0547
0.05475
0.0548
0.05485
0.0549
TIME IN (S)


INDUCTOR CURRENT WAVEFORM
INDUCTOR CURRENT TOWARDS LOAD SIDE
12
11.5
11
10.5
10
9.5
9
8.5
8
0.0478
0.04785
0.0479
0.04795
0.048
0.04805
0.0481
TIME IN (S)

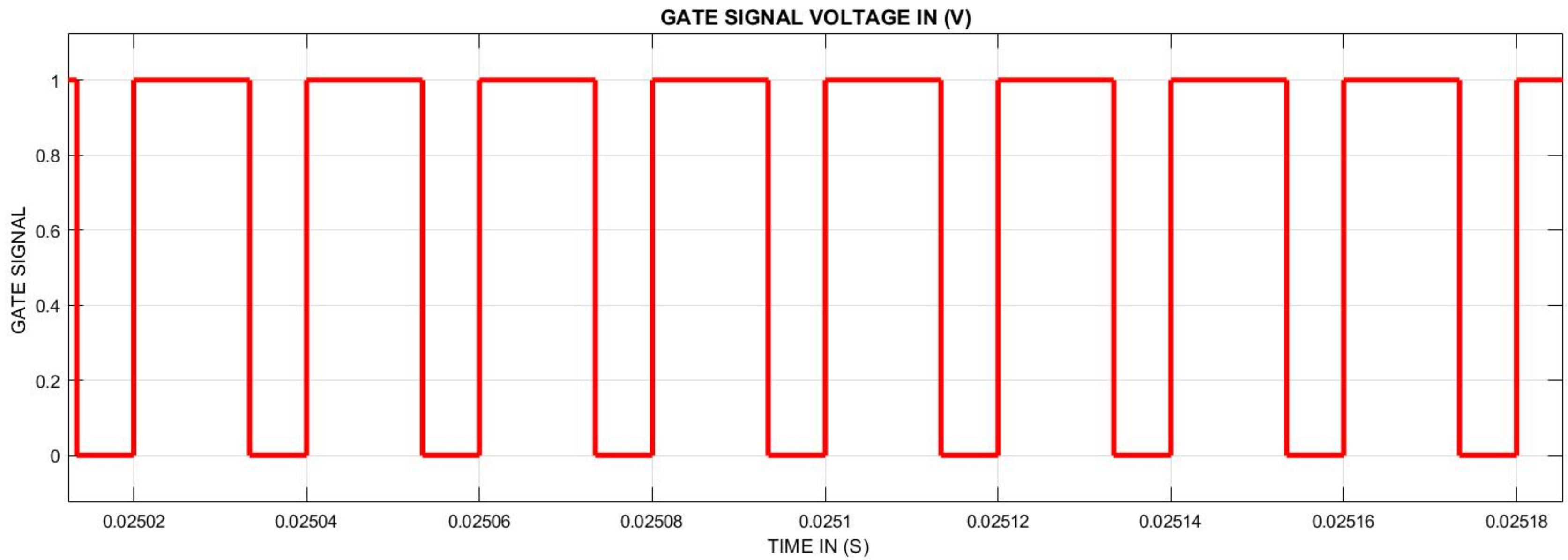

INDUCTOR CURRENT SOURCE SIDE
INDUCTOR CURRENT TOWARDS SOURCE SIDE
23
22
21
20
19
18
17
16
0.05146
0.05148
0.0515
0.05152
0.05154
0.05156
TIME IN (S)

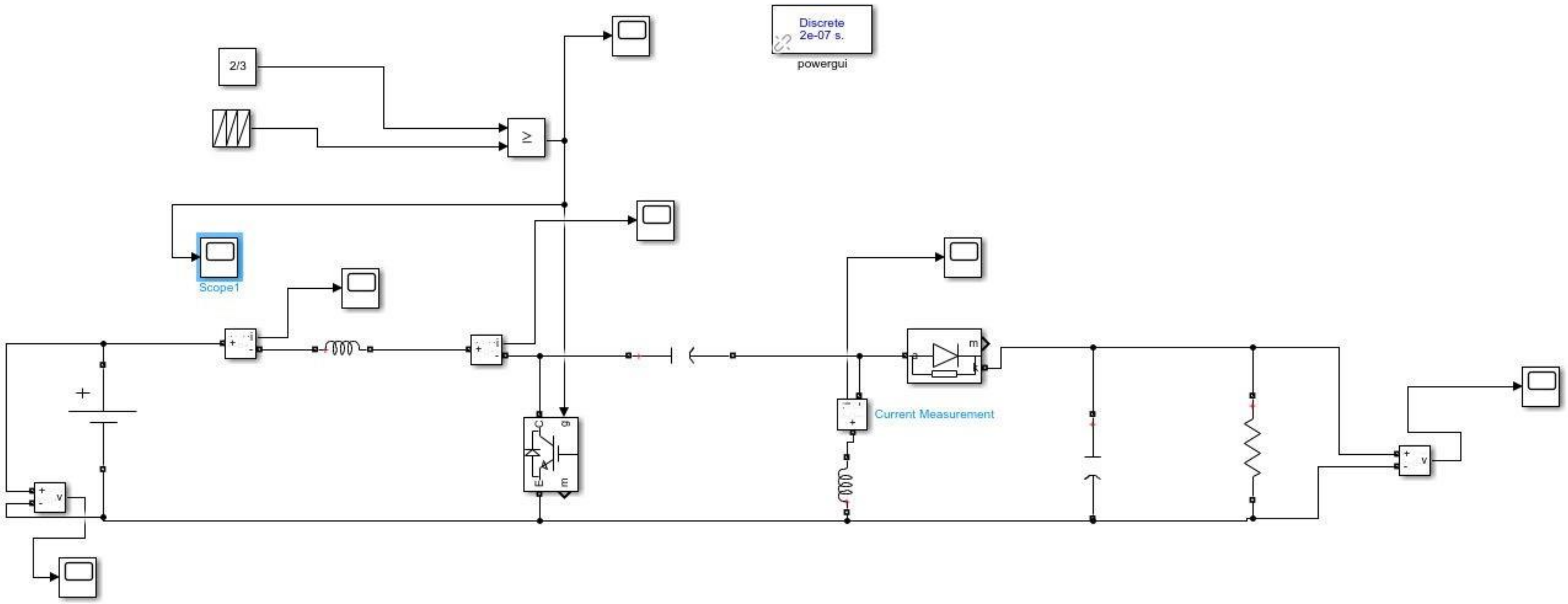


INDUCTOR CURRENT SOURCE SIDE
INDUCTOR CURRENT TOWARDS SOURCE SIDE
23
22
21
20
19
18
17
16
0.05146
0.05148
0.0515
0.05152
0.05154
0.05156
TIME IN (S)

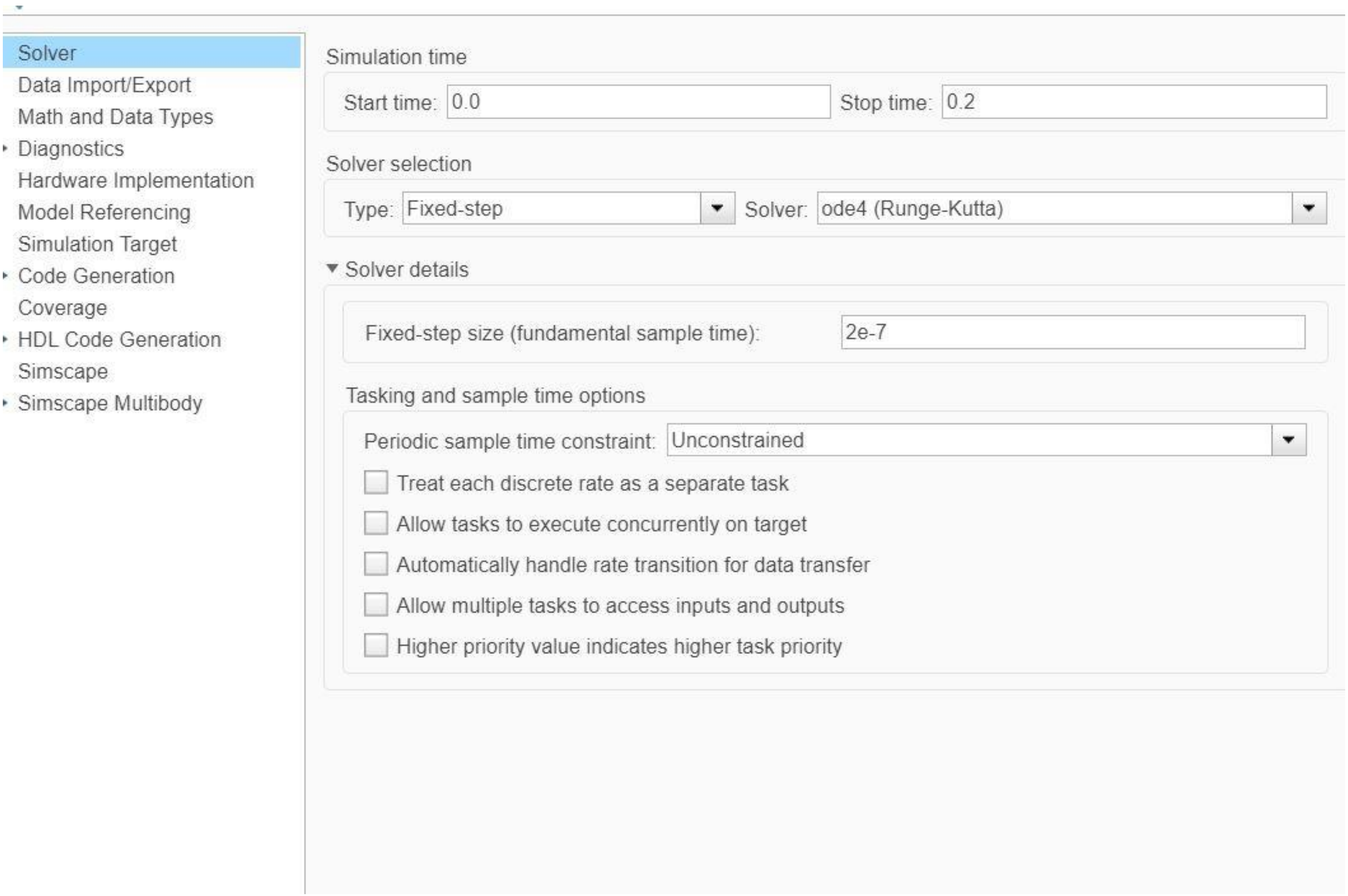


INPUT VOLTAGE FOR SEPIC CONVERTER
48.6
48.4
48.2
48
47.8
47.6
47.4
47.2
47
INPUT VOLATGE
0.0256
0.0257
0.0258
0.0259
0.026
0.0261
0.0262
0.0263
0.0264
0.0265
0.0266
TIME IN (S)


GATE SIGNAL VOLTAGE IN (V)
GATE SIGNAL
1
0.8
0.6
0.4
0.2
0
0.02502
0.02504
0.02506
0.02508
0.0251
0.02512
0.02514
0.02516
0.02518
TIME IN (S)



Discrete
2e-07 s.
powergui
2/3
Scope1
Current Measurement


Solver
Data Import/Export
Math and Data Types
Diagnostics
Hardware Implementation
Model Referencing
Simulation Target
Code Generation
Coverage
HDL Code Generation
Simscape
Simscape Multibody
Simulation time
Start time: 0.0
Stop time: 0.2
Solver selection
Type: Fixed-step
Solver: ode4 (Runge-Kutta)
Solver details
Fixed-step size (fundamental sample time): 2e-7
Tasking and sample time options
Periodic sample time constraint: Unconstrained
Treat each discrete rate as a separate task
Allow tasks to execute concurrently on target
Automatically handle rate transition for data transfer
Allow multiple tasks to access inputs and outputs
Higher priority value indicates higher task priority

CONCLUSIONS: The experiment was extremely insightful for learning the Operation and design of the Flyback Converter and SEPIC Converter in Simulink and verifying the parameters theoretically and practically.

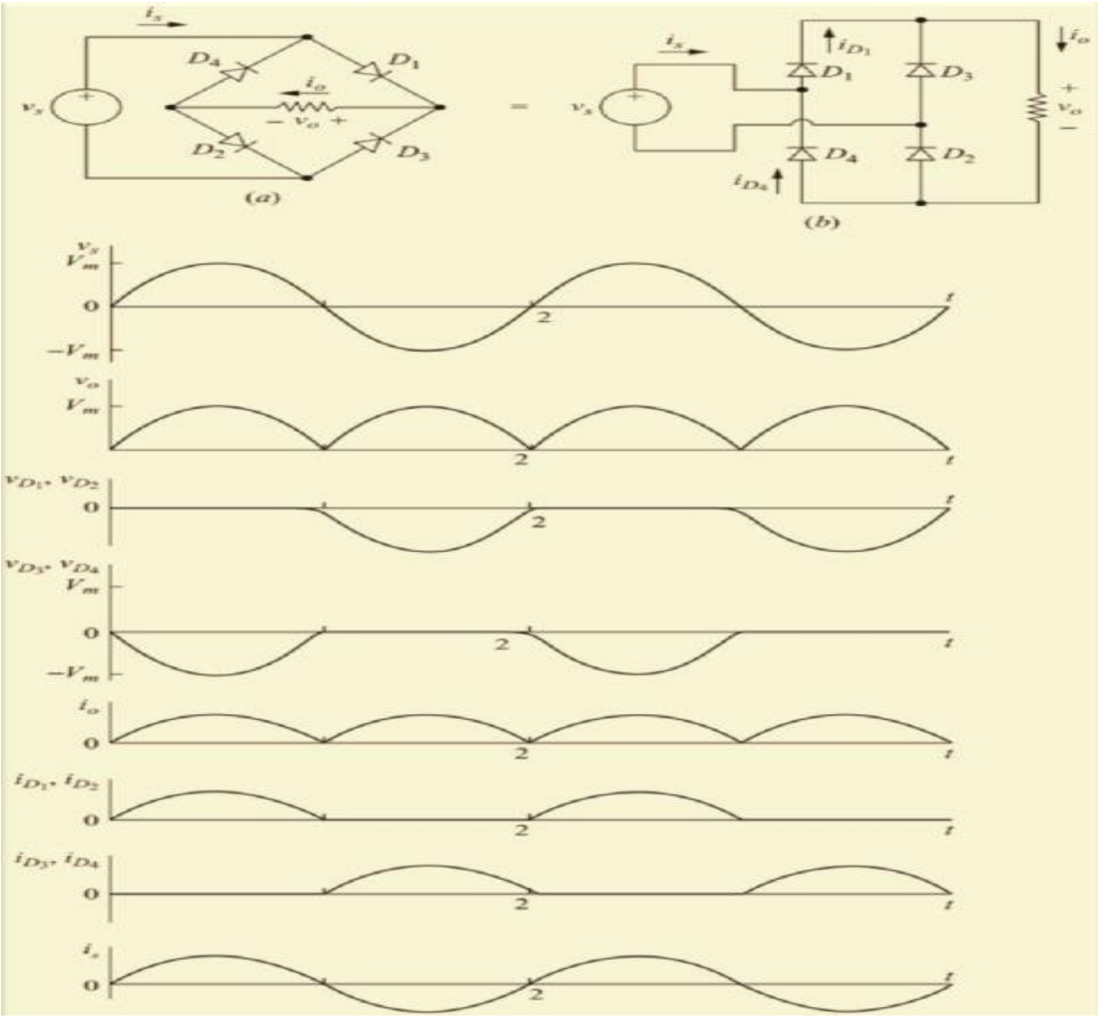
LAB REPORT 5
ARYA MALLICK Roll No: 234102501

TITLE: To study the uncontrolled and controlled single phase rectifiers.

OBJECTIVE:To analyse the single phase uncontrolled and controlled rectifiers and analyse them with source inductance in MATLAB and SIMULINK.

THEORY:

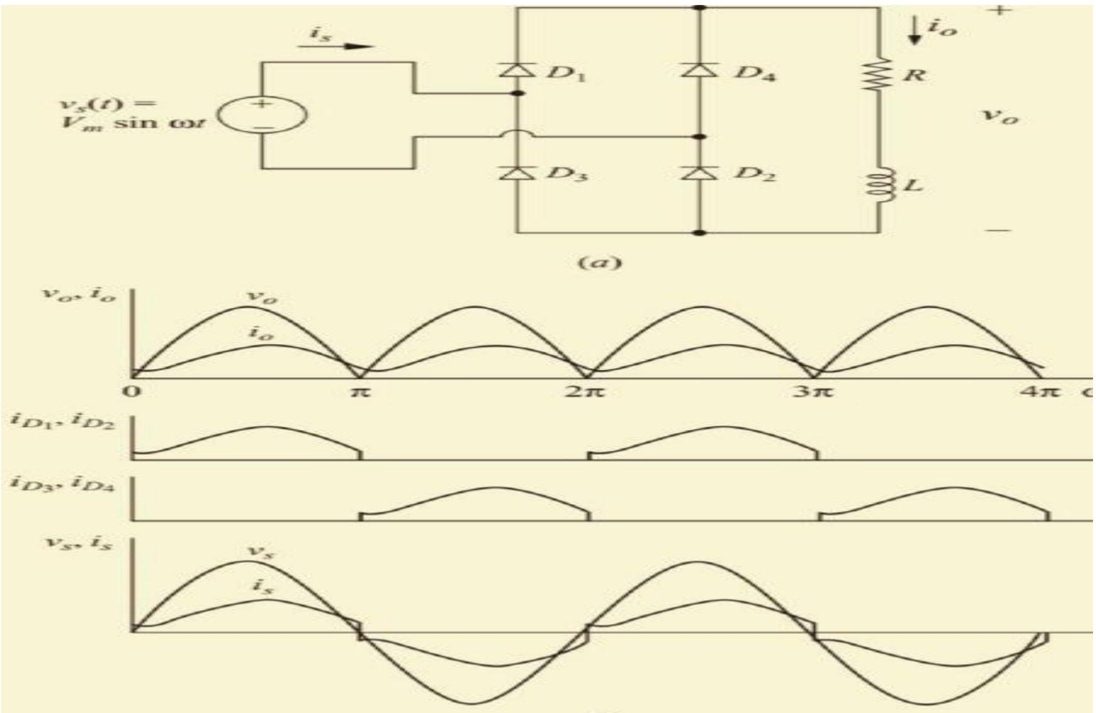
UNCONTROLLED FULL BRIGE RECTIFIER



LAB REPORT 5

ARYA MALLICK Roll No: 234102501

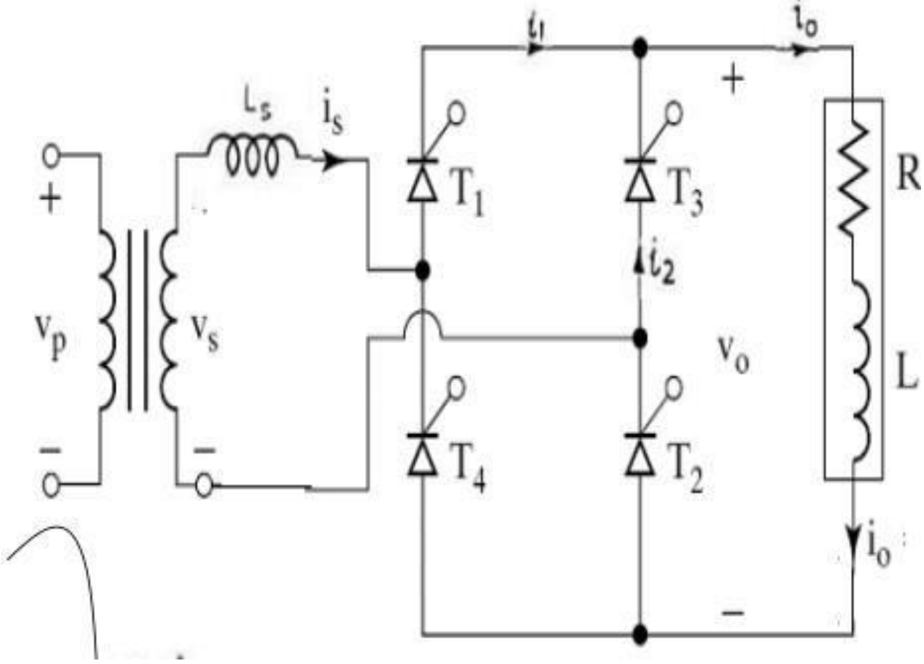
- Diodes D1 and D2 conduct together, and D3 and D4 conduct together. D1 and D3 cannot be ON at the same time. Similarly, D2 and D4 cannot conduct simultaneously. The load current can be positive or zero but can never be negative.
- The voltage across the load is +vs when D1 and D2 are ON. The voltage across the load is -vs when D3 and D4 are ON. • The maximum voltage across a reverse-biased diode is the peak value of the source. This can be shown by Kirchhoff’s voltage law around the loop containing the source, D1 , and D3 . With D1 ON, the voltage across D3 is -vs
- .The current entering the bridge from the source is iD1 -iD4 , which is symmetric about zero. Therefore, the average source current is zero.
- The rms source current is the same as the rms load current. The source current is the same as the load current for one-half of the source period and is the negative of the load current for the other half. The squares of the load and source currents are the same, so the rms currents are equal.
- The fundamental frequency of the output voltage is 2 ω, where ω is the frequency of the ac input since two periods of the output occur for every period of the input.



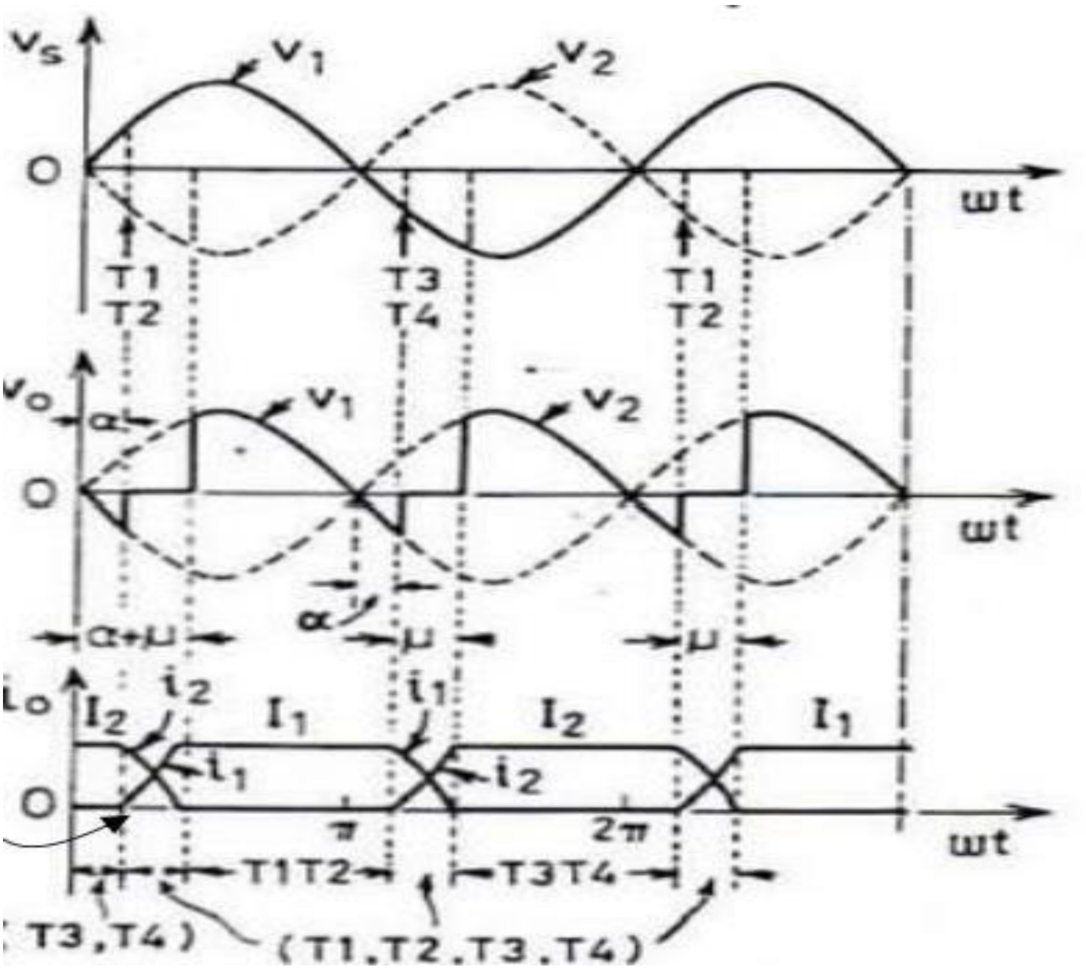
- For an RL series-connected load in fig. a, the method of analysis is similar to that for the half-wave rectifier with the freewheeling diode.
- After a transient that occurs during startup, the load current io reaches a periodic steady-state condition similar to that in fig. b. For the bridge circuit, current is transferred from one pair of diodes to the other pair when the source changes polarity.

LAB REPORT 5
ARYA MALLICK Roll No: 234102501

- The voltage across the RL load is a full-wave rectified sinusoid, as it was for the resistive load.

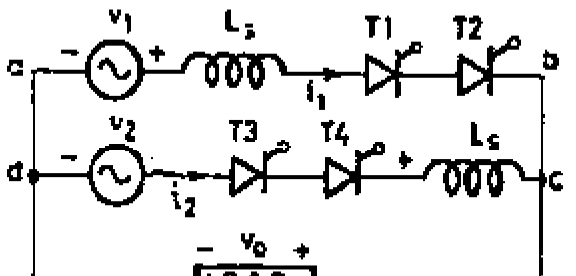


LAB REPORT 5
ARYA MALLICK   Roll No: 234102501



When T_1 , T_2 are triggered at a firing angle α , the commutation of already conducting T_3, T_4 begins. Because of the presence of source inductance L_s" the current via outgoing devices T_3, T_4 decreases gradually to zero from its initial value of i_o ; whereas in incoming SCRs T_1, T_2 ; the current builds up gradually from zero to full value of i_o,

Hence, the full-bridge equivalent circuit during this period is look like the following circuit:



During overlap period μ:

- ➢ The current flow via L_s, T_1, Load, and T_2
- ➢ The current flow via T_3, load, T_4, and L_s At beginning of μ , L_s stored energy by i_2, while then realise energy by i_1.

By applying KVL for abcda loop:

$$v_1 - L_s \cdot \frac{di_1}{dt} = v_2 - L_s \frac{di_2}{dt} \qquad v_1 - v_2 = L_s\left(\frac{di_1}{dt} - \frac{di_2}{dt}\right)$$

if $v_1 = V_m \sin \omega t$, then $v_2 = -V_m \sin \omega t$. $\quad L_s\left(\frac{di_1}{dt} - \frac{di_2}{dt}\right) = 2\,V_m \sin \omega t$

$i_1 + i_2 = I_0$ Differentiating this $\frac{di_1}{dt} + \frac{di_2}{dt} = 0$

$$\frac{di_1}{dt} - \frac{di_2}{dt} = \frac{2V_m}{L_s} \sin \omega t \;\Rightarrow\; \frac{di_1}{dt} = \frac{V_m}{L_s} \sin \omega t$$

at $\omega t = \alpha$, $i_1 = 0$ and at $\omega t = (\alpha + \mu)$, $i_1 = I_0$ $\Rightarrow \int_0^{I_0} di_1 = \frac{V_m}{L_s} \int_{\alpha/\omega}^{(\alpha+\mu)/\omega} \sin \omega t \cdot dt$

$$\boxed{I_0 = \frac{V_m}{\omega L_s}[\cos \alpha - \cos(\alpha + \mu)]}$$

$$V_\alpha = \frac{V_m}{\pi} \int_{(\alpha+\mu)}^{(\alpha+\pi)} \sin \omega t \cdot d(\omega t) = \frac{V_m}{\pi}[\cos(\alpha+\mu) - \cos(\alpha+\pi)] \boxed{= \frac{V_m}{\pi}[\cos \alpha + \cos(\alpha+\mu)]}$$

It can be re-expressed Dc output voltage to make a relation between V_o and load current and value of source inductance:

V_o without overlap is equal to: $\quad V_o = \frac{2V_m}{\pi} \cos \alpha$

The maximum DC voltage occur at $\alpha = 0^0$. Thus, $\quad V_{om} = \frac{2V_m}{\pi}$

Hence, output voltage with overlap period is can be found as:

$$V_\alpha = \frac{V_{om}}{2}[\cos \alpha + \cos(\alpha + \mu)]$$

From load current equation it can be obtained that:

$$\boxed{\cos(\alpha+\mu) = \cos \alpha - \frac{\omega L_s}{V_m} I_0}$$

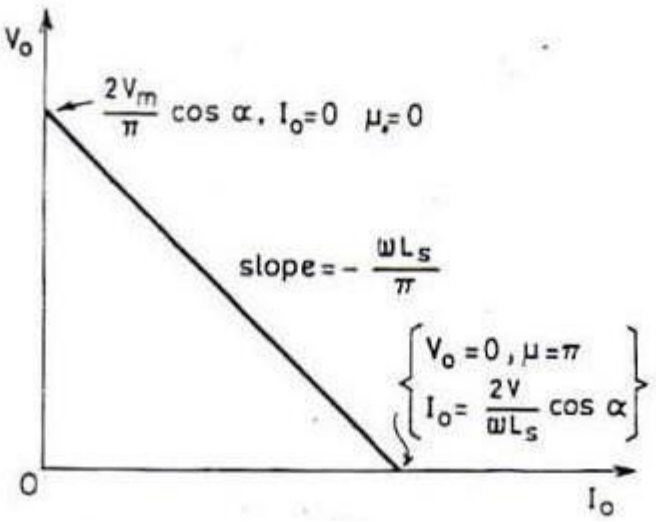
then

It can be seen from equation above that the voltage drop due to L_s, is proportional to I_o and L_s.

NOTE: for $\mu<\pi$, V_o is reduces due to L_s, for $\mu=\pi$, V_o=0V since all SCRs are conducting.

NOTE: if $\alpha=0^0$, then V_o can be controlled between $\mu\le\alpha\le\pi$

NOTE: The maximum value of firing angle can be $(180^0- \mu)$.



CALCULATIONS:

$V_{oavg} = 2 * \frac{V_m}{\pi} = 206\,V$ (For R Load, R L load)

$I_{oavg} = \frac{V_{oavg}}{R} = 10.34\,A$ (For R Load, R L load)

$V_{oavg} = \frac{V_m}{\pi} * (1 + \cos(\alpha))$ (For R load)

$V_{oavg} = (\frac{V_m}{\pi} * (\cos(\alpha) - \cos(\beta))$ (For RL load) where $(\beta = 180 + \alpha)$

$V_{oavg} = 192\,V\ For\ \alpha = 30\ degree$ (For R load)

$V_{oavg} = 178\,V\ For\ \alpha = 30\ degree$ (For R Lload)

LAB REPORT 5

ARYA MALLICK Roll No: 234102501

$V_{oavg} = 103\, V\ For\ \alpha = 90\ degree$ (For R load)

$V_{oavg} = 0\, V\ For\ \alpha = 90\ degree$ (For R L load)

With Source Inductance commutation angle:

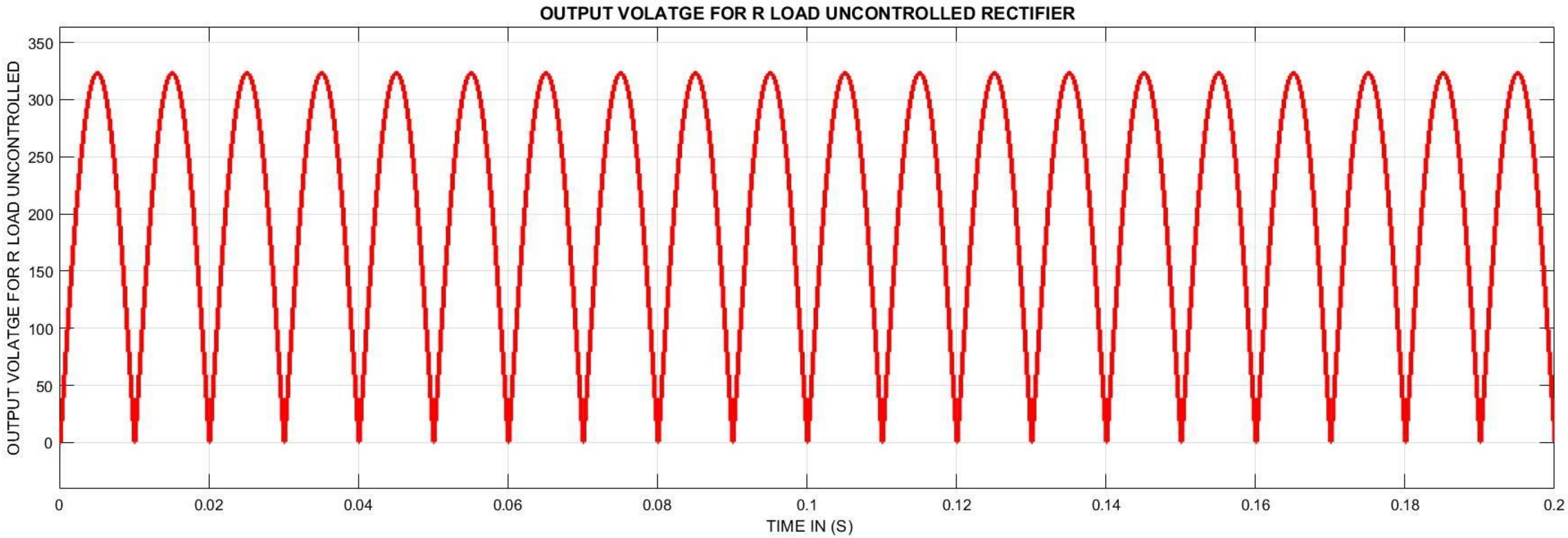
$$\boldsymbol{\mu = 36\ degree\ for\ diode\ rectifiers.and\ practically\ \mu = 33\ degree}$$

We get value of μ this from the formula($\frac{Vm}{\pi}(1 - \cos(\mu)) = (4 * f * L_s * I_0)$ (theoretically) for diode rectifiers .($\alpha = 0\ degree$)

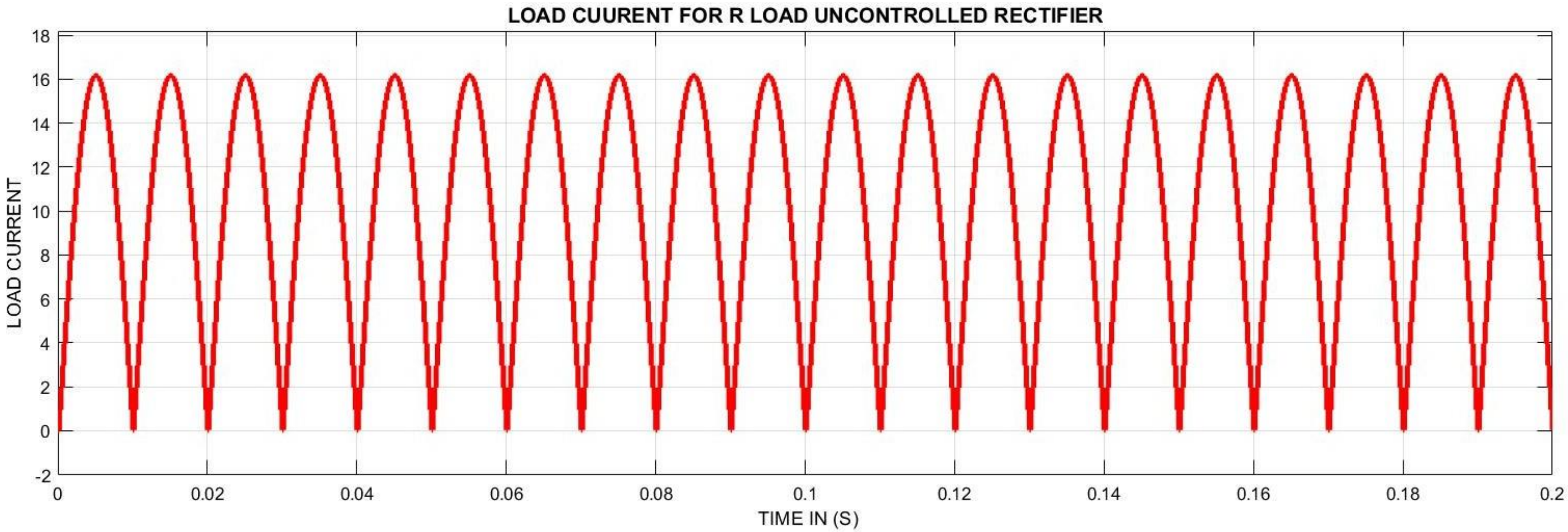
For controlled rectifiers for $\alpha = 30\ degree\ , \mu\ is\ calculated\ from\ formula$:

$(\frac{Vm}{\pi}(\cos(\alpha) - \cos(\alpha + \mu)) = (4 * f * L_s * I_0)$

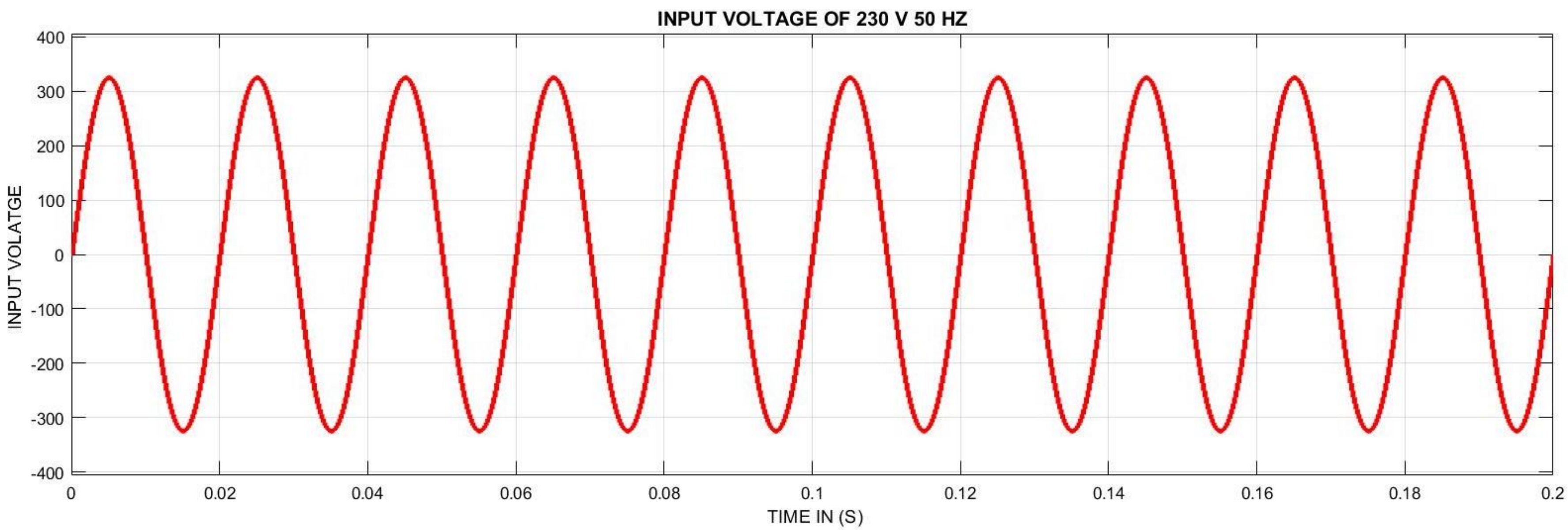
For controlled rectifier with $\alpha = 30\ degree$ we get value of **μ =14.7 degree ttheoretically and practically we get 13.5 degree as the value of μ by close observations.**



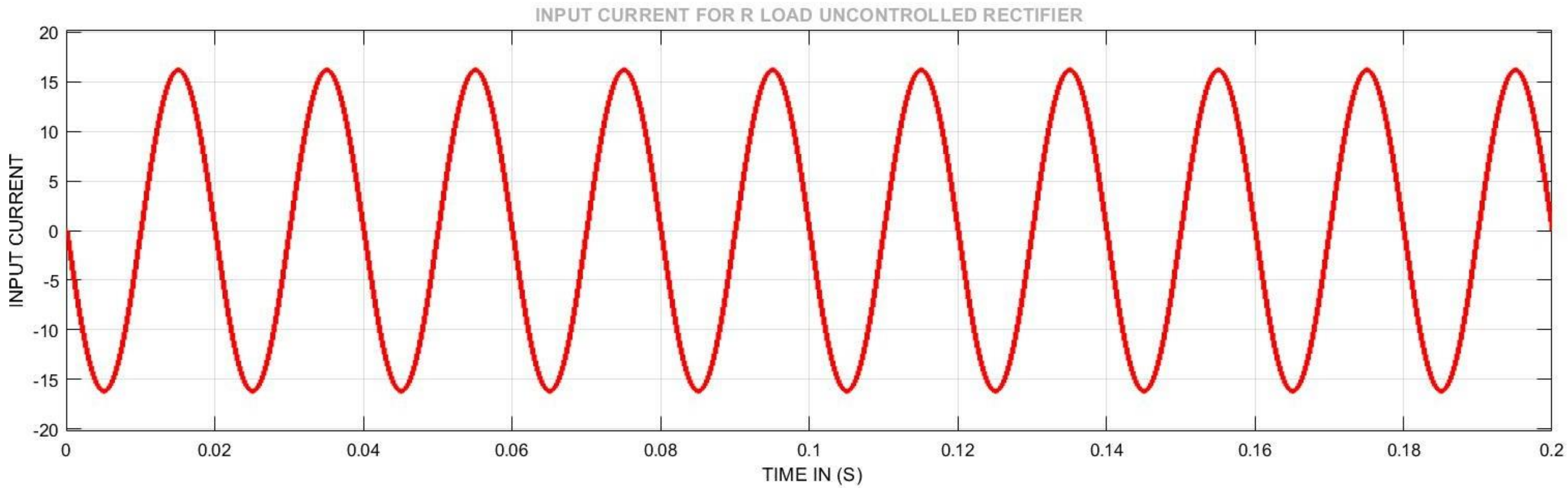
OUTPUT VOLATGE FOR R LOAD UNCONTROLLED RECTIFIER
OUTPUT VOLATGE FOR R LOAD UNCONTROLLED
TIME IN (S)
0
50
100
150
200
250
300
350
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2



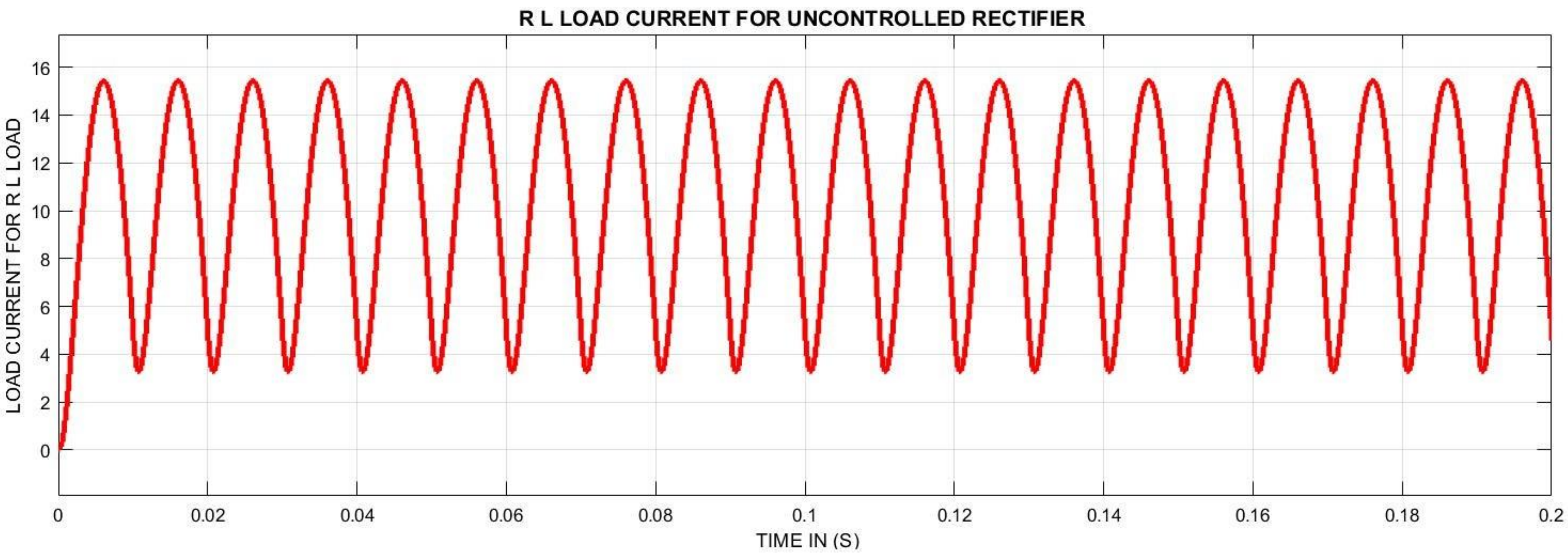
LOAD CUURENT FOR R LOAD UNCONTROLLED RECTIFIER
LOAD CURRENT
18
16
14
12
10
8
6
4
2
0
-2
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
TIME IN (S)

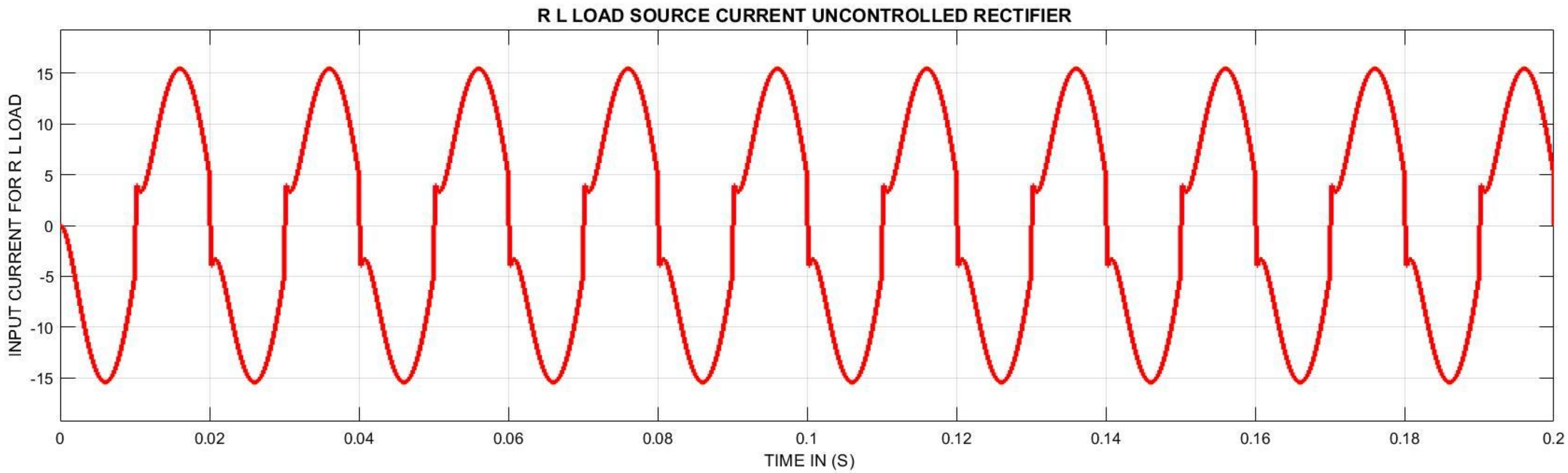


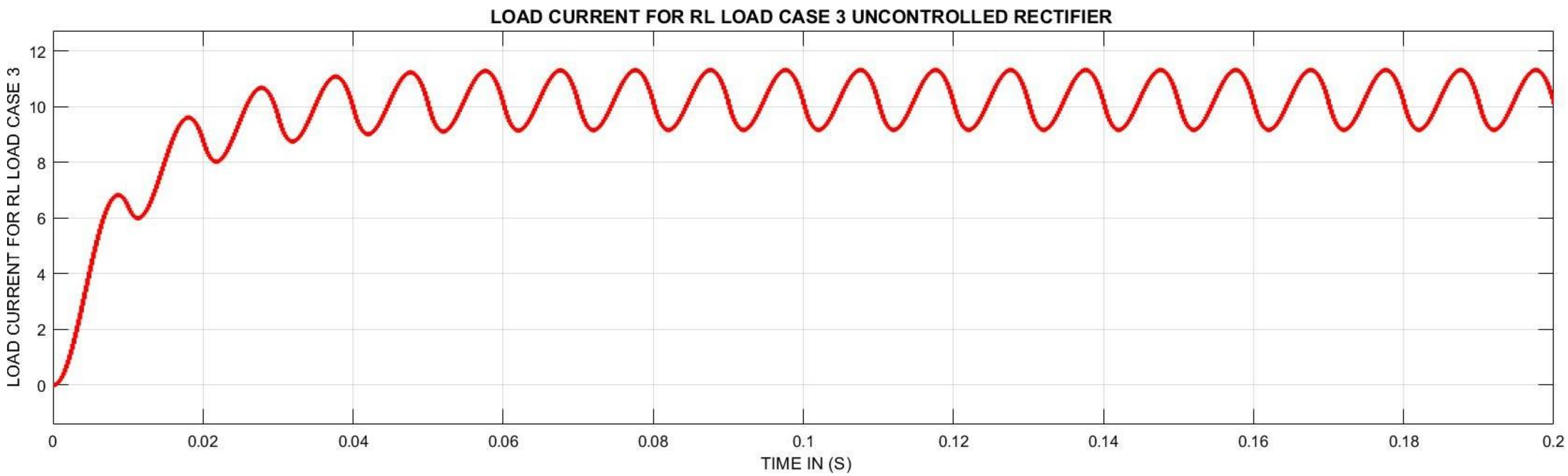
INPUT VOLTAGE OF 230 V 50 HZ
400
300
200
100
0
-100
-200
-300
-400
INPUT VOLATGE
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
TIME IN (S)

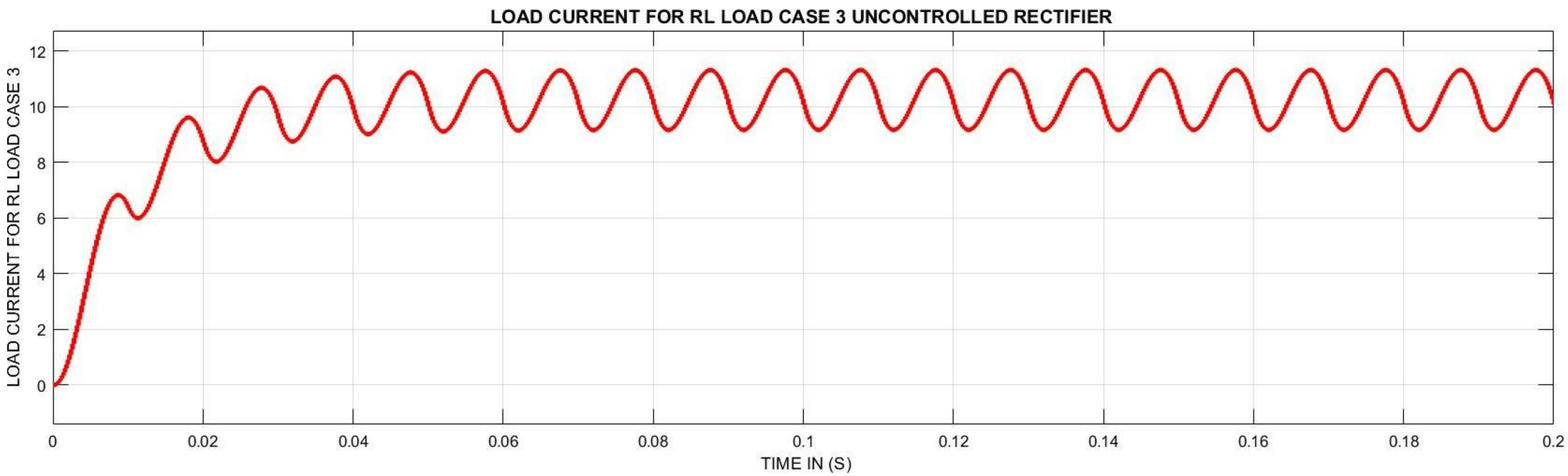


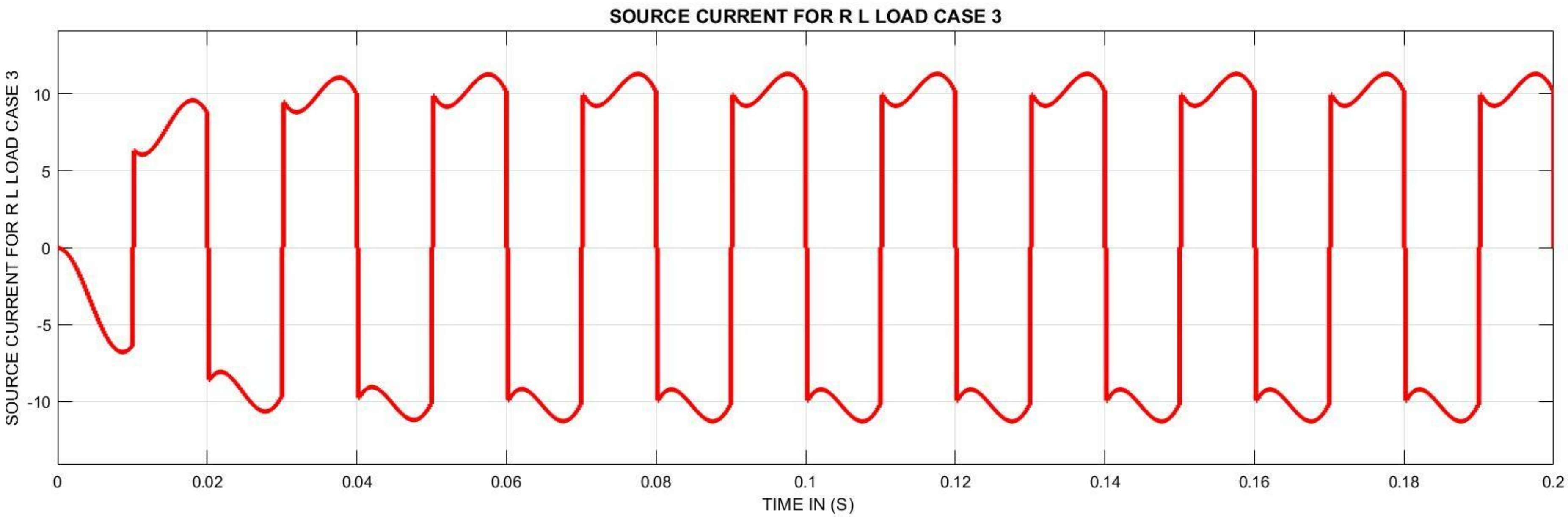
INPUT CURRENT FOR R LOAD UNCONTROLLED RECTIFIER
INPUT CURRENT
TIME IN (S)
20
15
10
5
0
-5
-10
-15
-20
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2

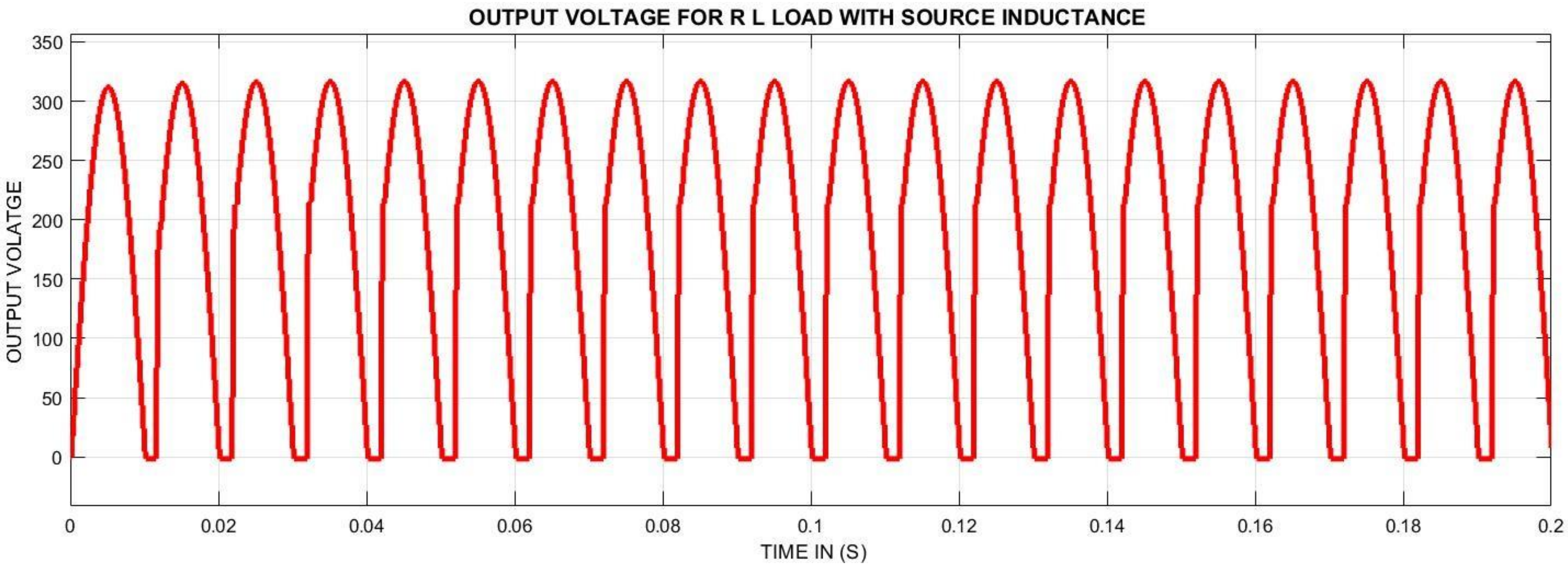

R L LOAD CURRENT FOR UNCONTROLLED RECTIFIER
LOAD CURRENT FOR R L LOAD
TIME IN (S)
0
2
4
6
8
10
12
14
16
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2

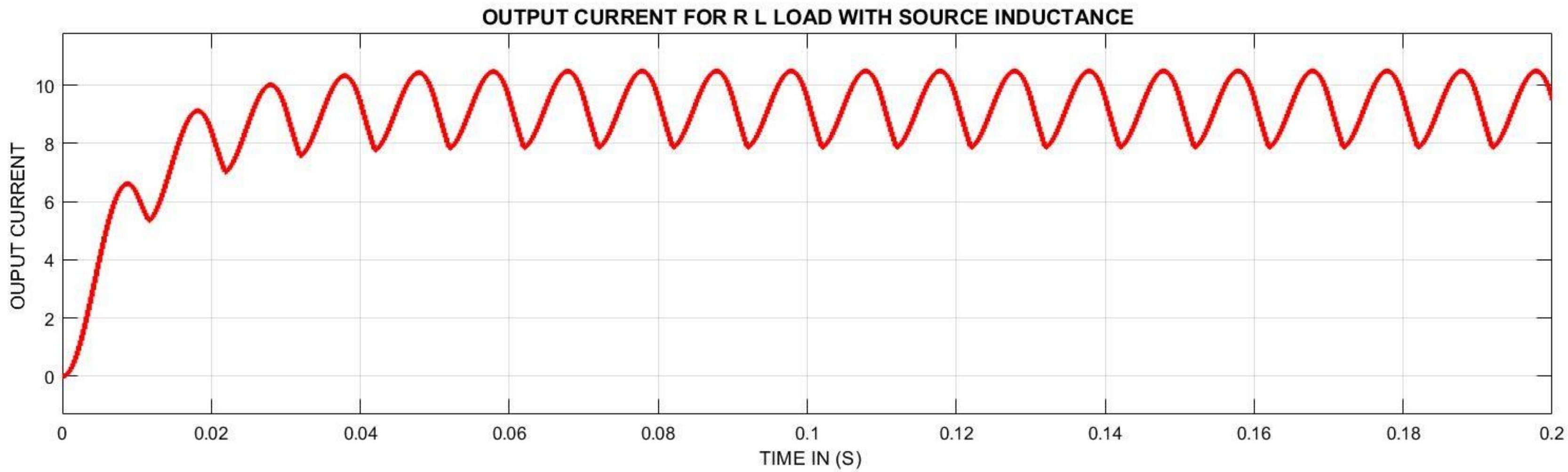

R L LOAD SOURCE CURRENT UNCONTROLLED RECTIFIER
INPUT CURRENT FOR R L LOAD
15
10
5
0
-5
-10
-15
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
TIME IN (S)


LOAD CURRENT FOR RL LOAD CASE 3 UNCONTROLLED RECTIFIER
LOAD CURRENT FOR RL LOAD CASE 3
TIME IN (S)
0
2
4
6
8
10
12
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2

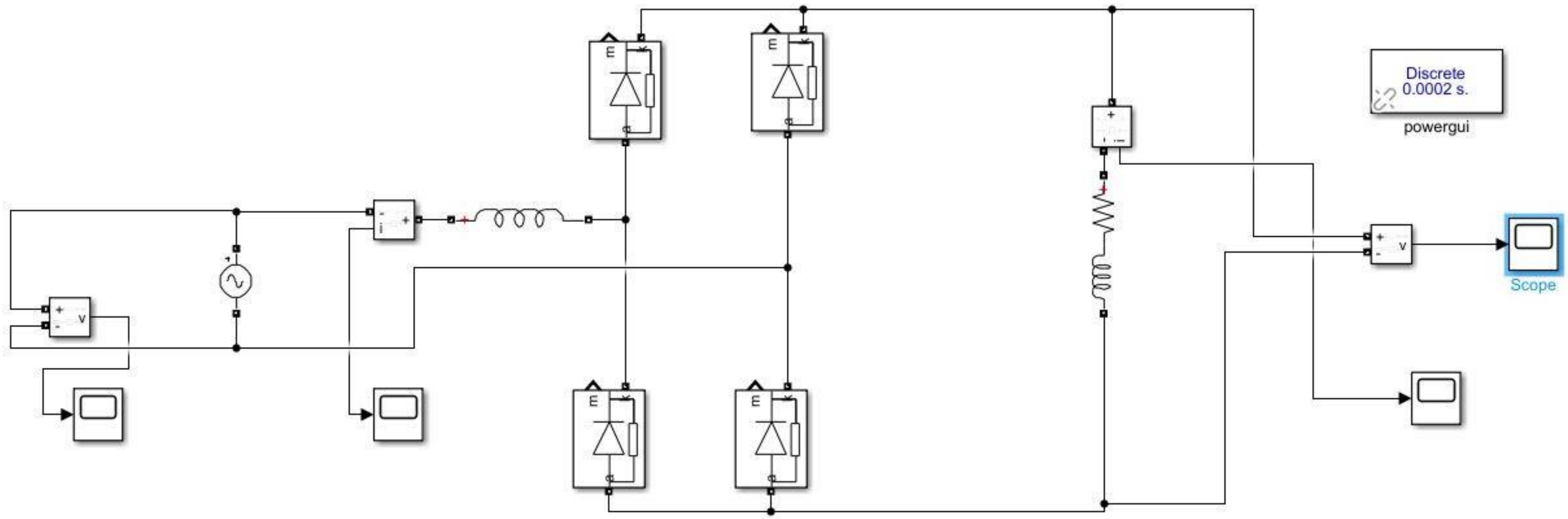

LOAD CURRENT FOR RL LOAD CASE 3 UNCONTROLLED RECTIFIER
LOAD CURRENT FOR RL LOAD CASE 3
TIME IN (S)
12
10
8
6
4
2
0
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2

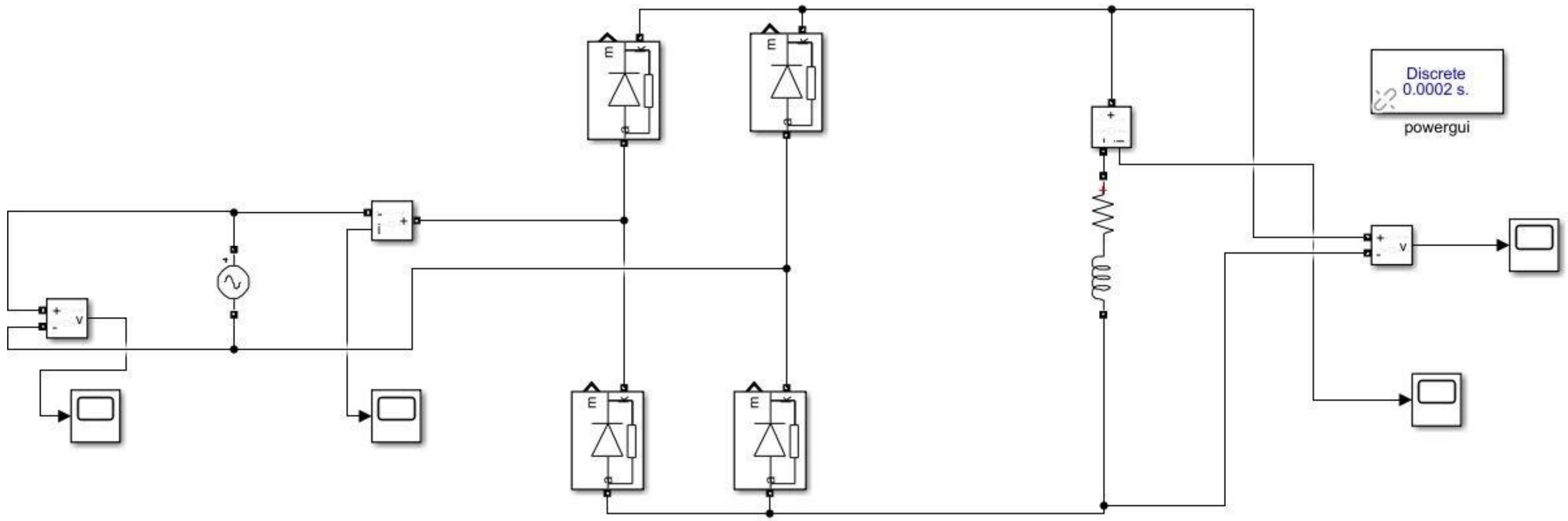

SOURCE CURRENT FOR R L LOAD CASE 3
SOURCE CURRENT FOR R L LOAD CASE 3
10
5
0
-5
-10
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
TIME IN (S)


OUTPUT VOLTAGE FOR R L LOAD WITH SOURCE INDUCTANCE
OUTPUT VOLATGE
TIME IN (S)
350
300
250
200
150
100
50
0
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2

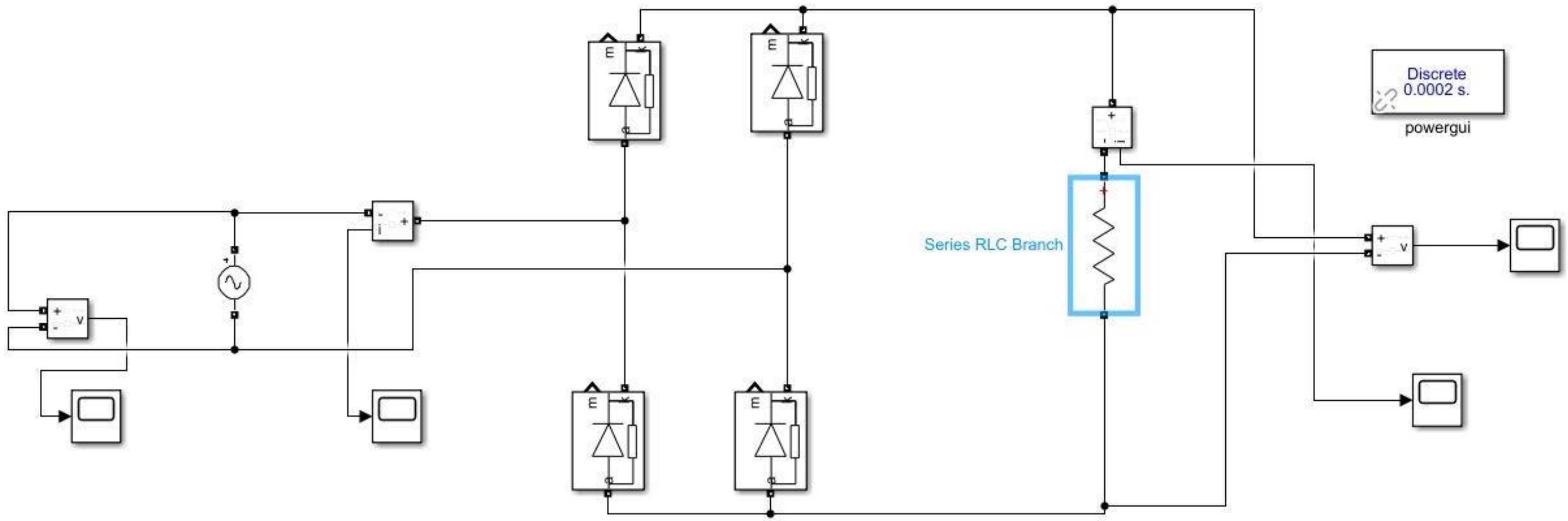


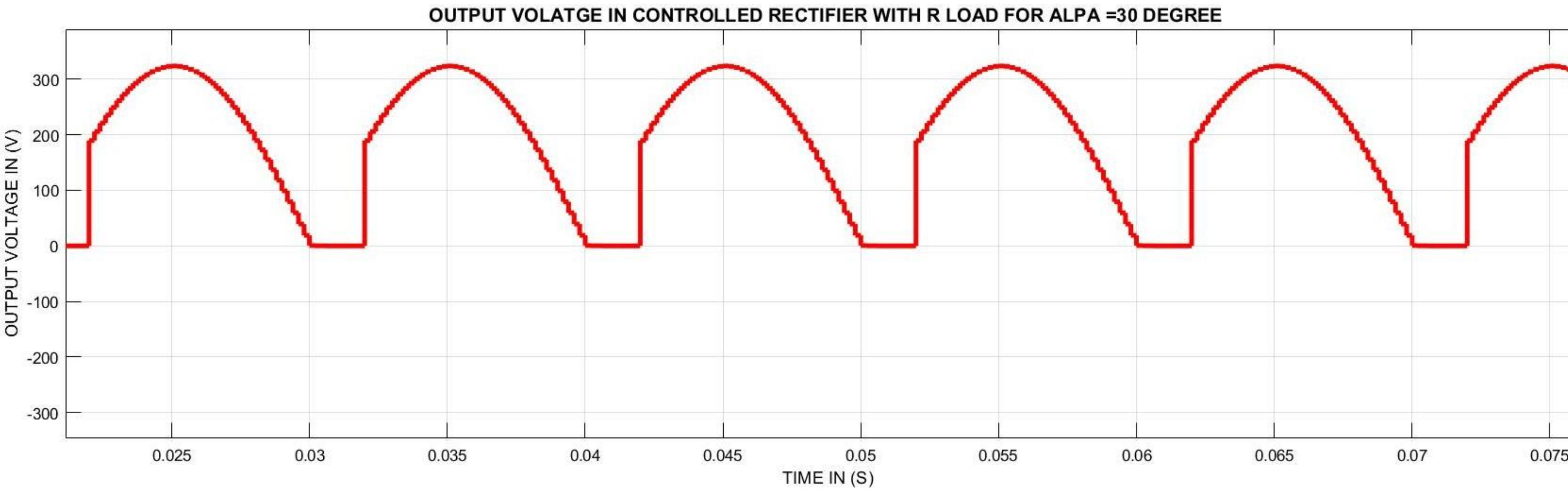
OUTPUT CURRENT FOR R L LOAD WITH SOURCE INDUCTANCE
OUPUT CURRENT
TIME IN (S)
0
2
4
6
8
10
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2

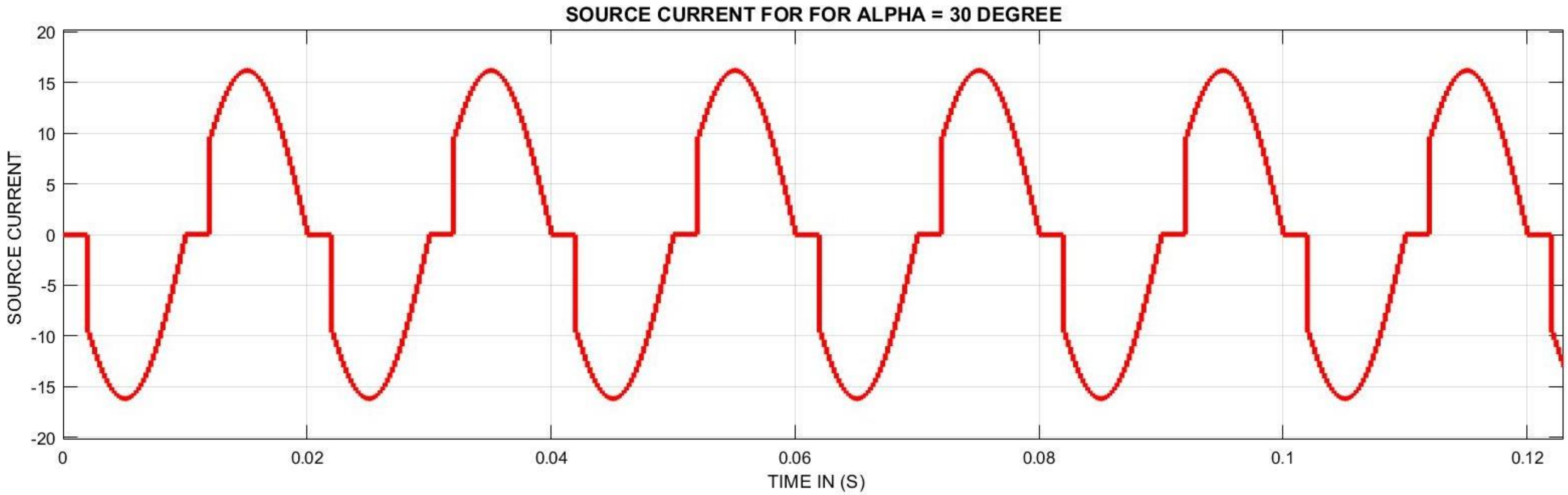

Discrete
0.0002 s.
powergui
Scope

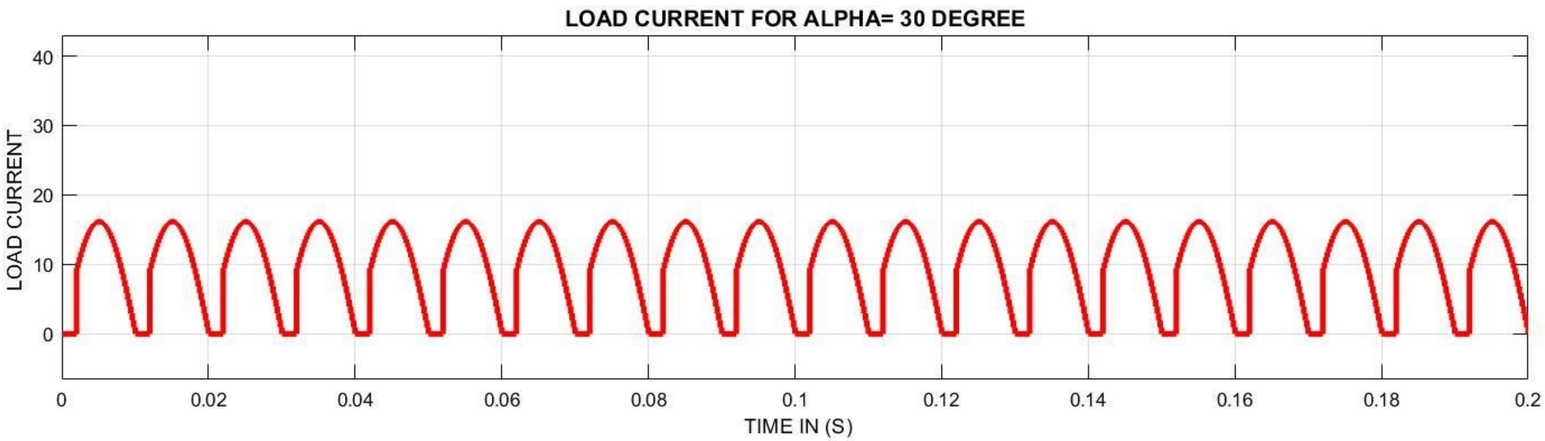


Discrete
0.0002 s.
powergui

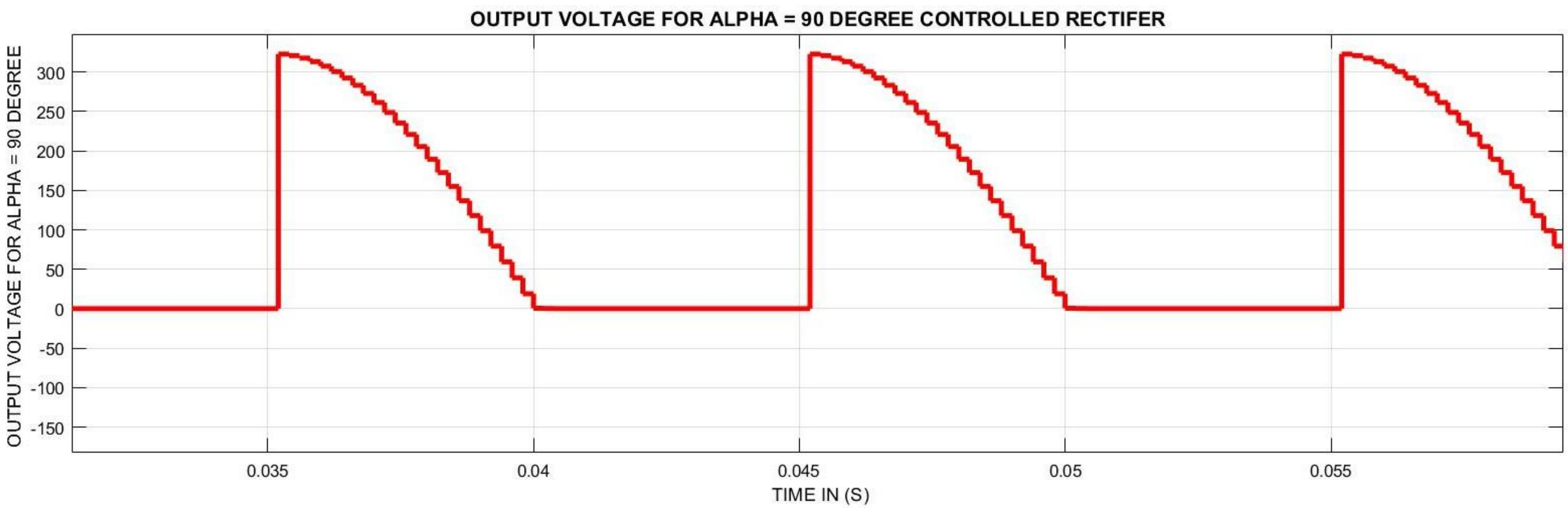

Discrete
0.0002 s.
powergui
Series RLC Branch

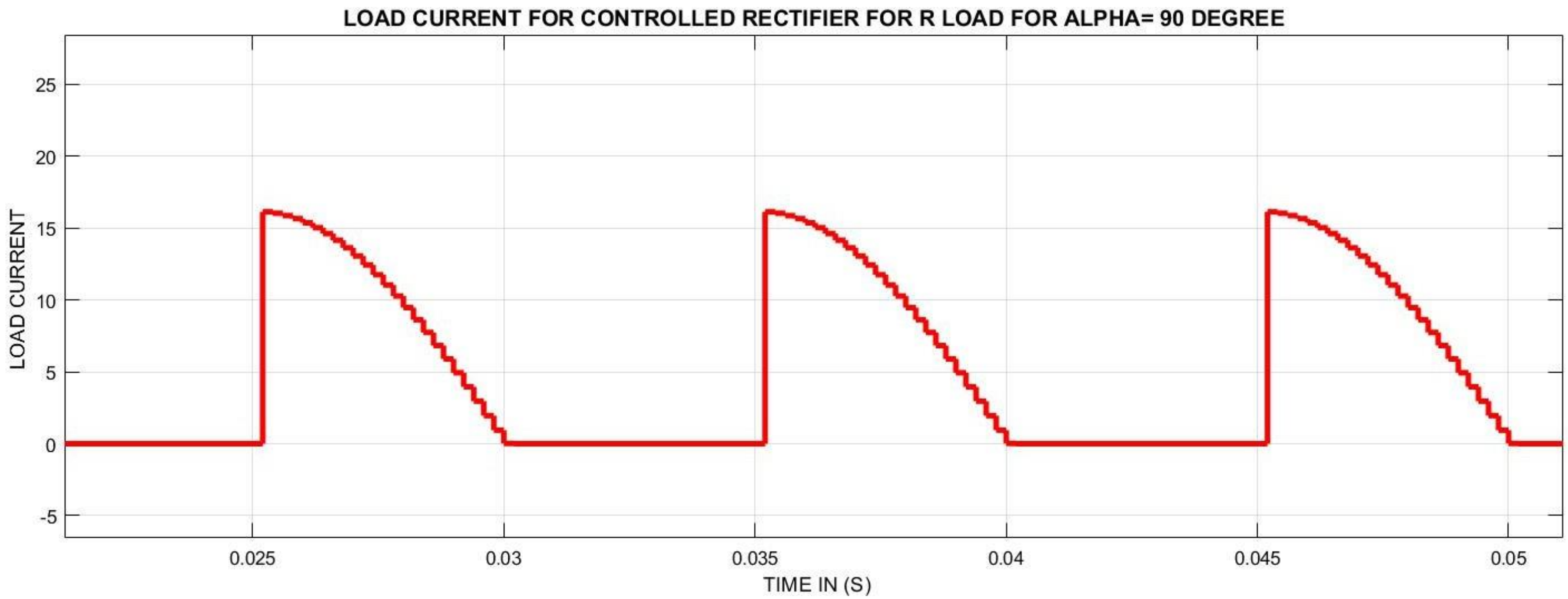

OUTPUT VOLATGE IN CONTROLLED RECTIFIER WITH R LOAD FOR ALPA =30 DEGREE
OUTPUT VOLTAGE IN (V)
300
200
100
0
-100
-200
-300
0.025
0.03
0.035
0.04
0.045
0.05
0.055
0.06
0.065
0.07
0.075
TIME IN (S)

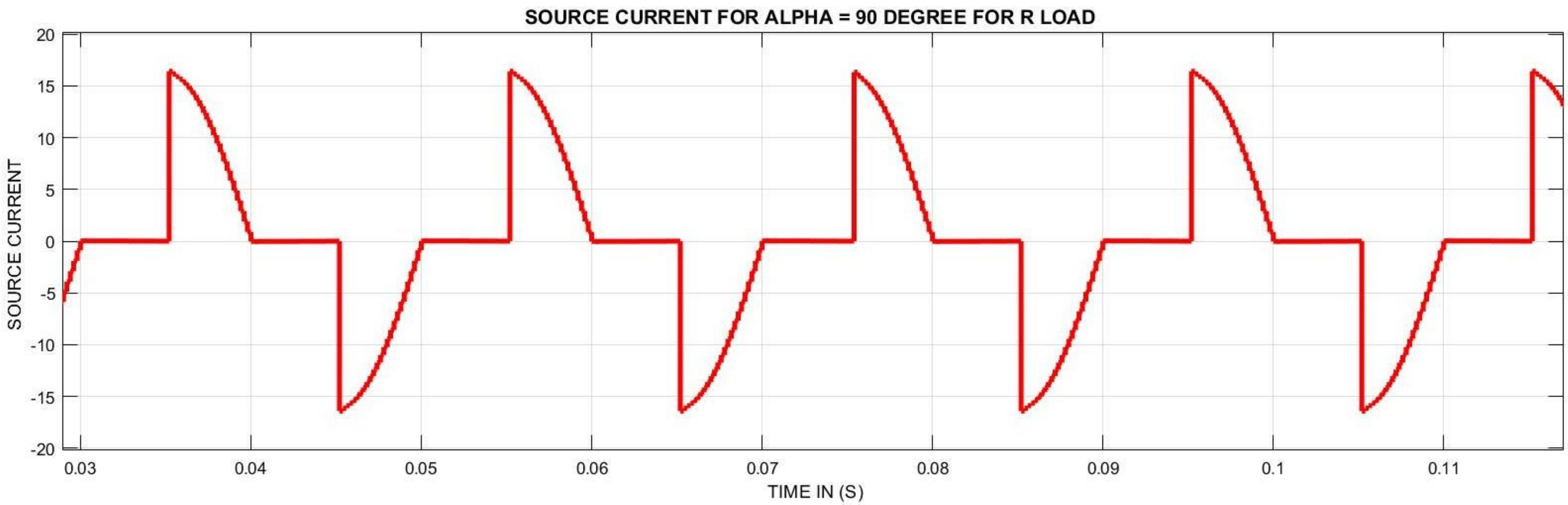

SOURCE CURRENT FOR FOR ALPHA = 30 DEGREE
SOURCE CURRENT
TIME IN (S)
20
15
10
5
0
-5
-10
-15
-20
0
0.02
0.04
0.06
0.08
0.1
0.12

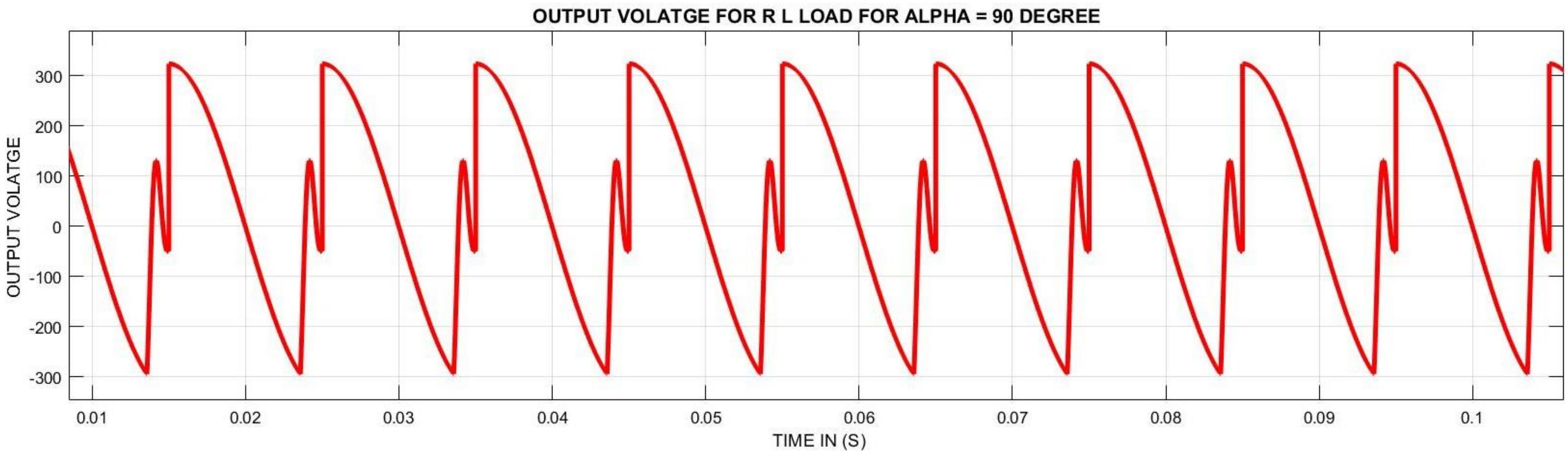


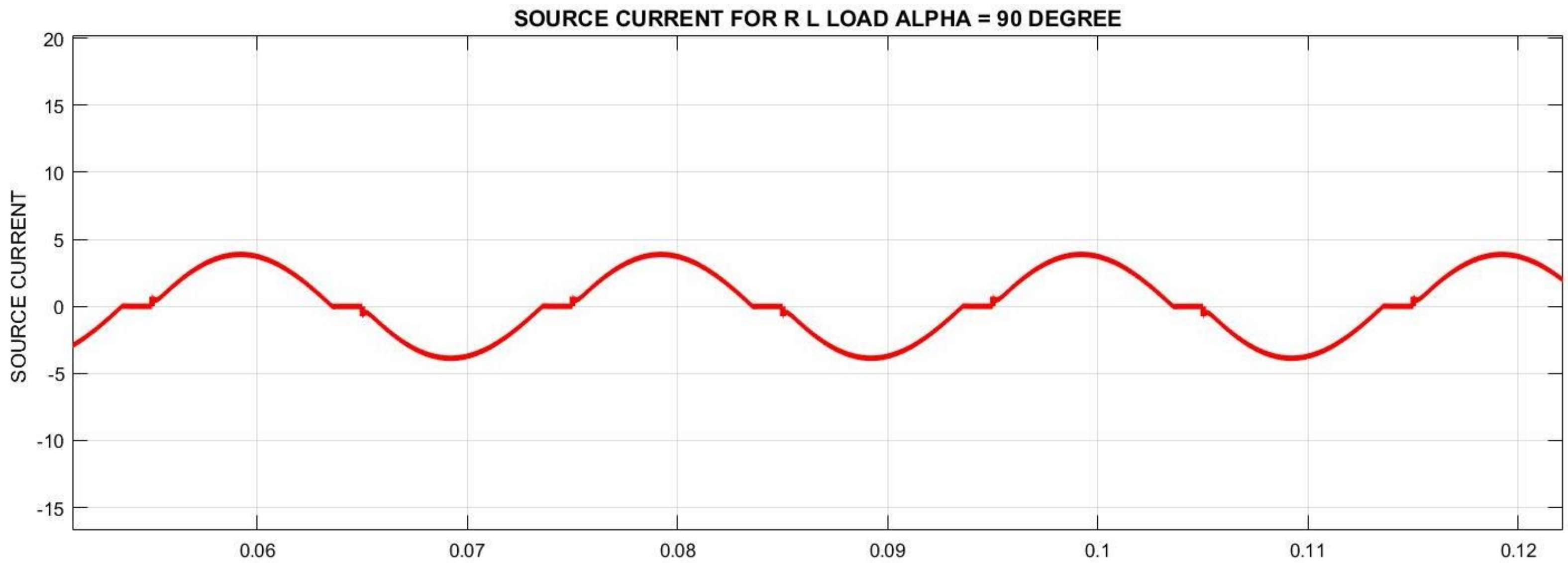
LOAD CURRENT FOR ALPHA= 30 DEGREE
LOAD CURRENT
TIME IN (S)
40
30
20
10
0
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2

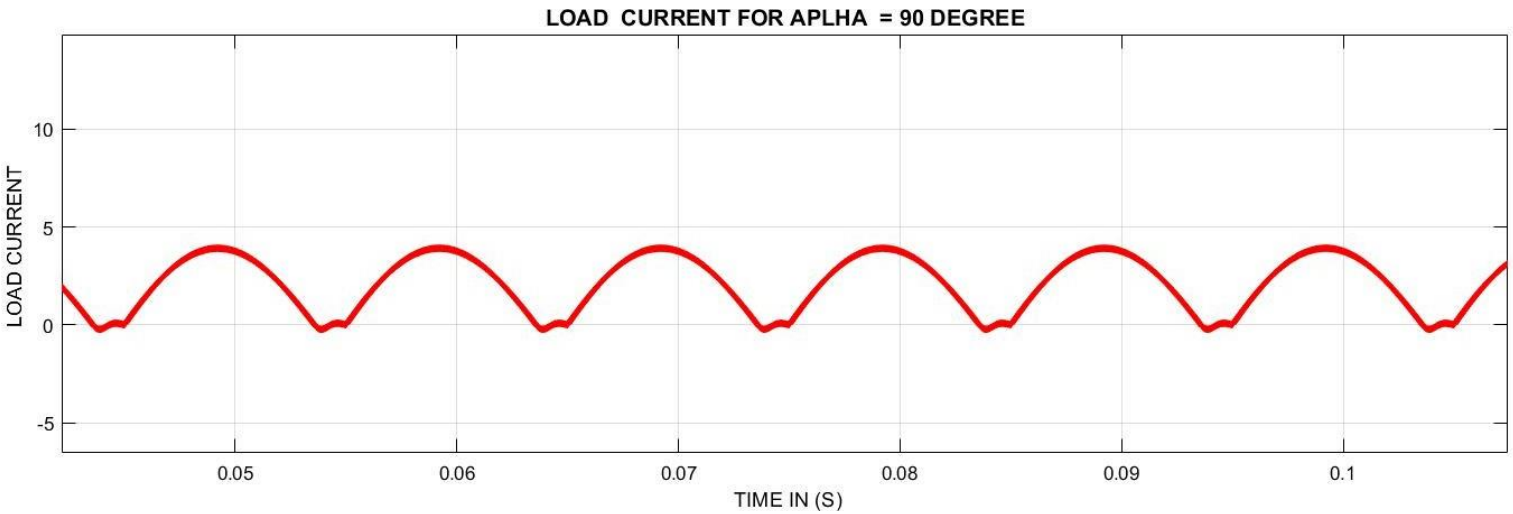

OUTPUT VOLTAGE FOR ALPHA = 90 DEGREE CONTROLLED RECTIFER
OUTPUT VOLTAGE FOR ALPHA = 90 DEGREE
300
250
200
150
100
50
0
-50
-100
-150
0.035
0.04
0.045
0.05
0.055
TIME IN (S)

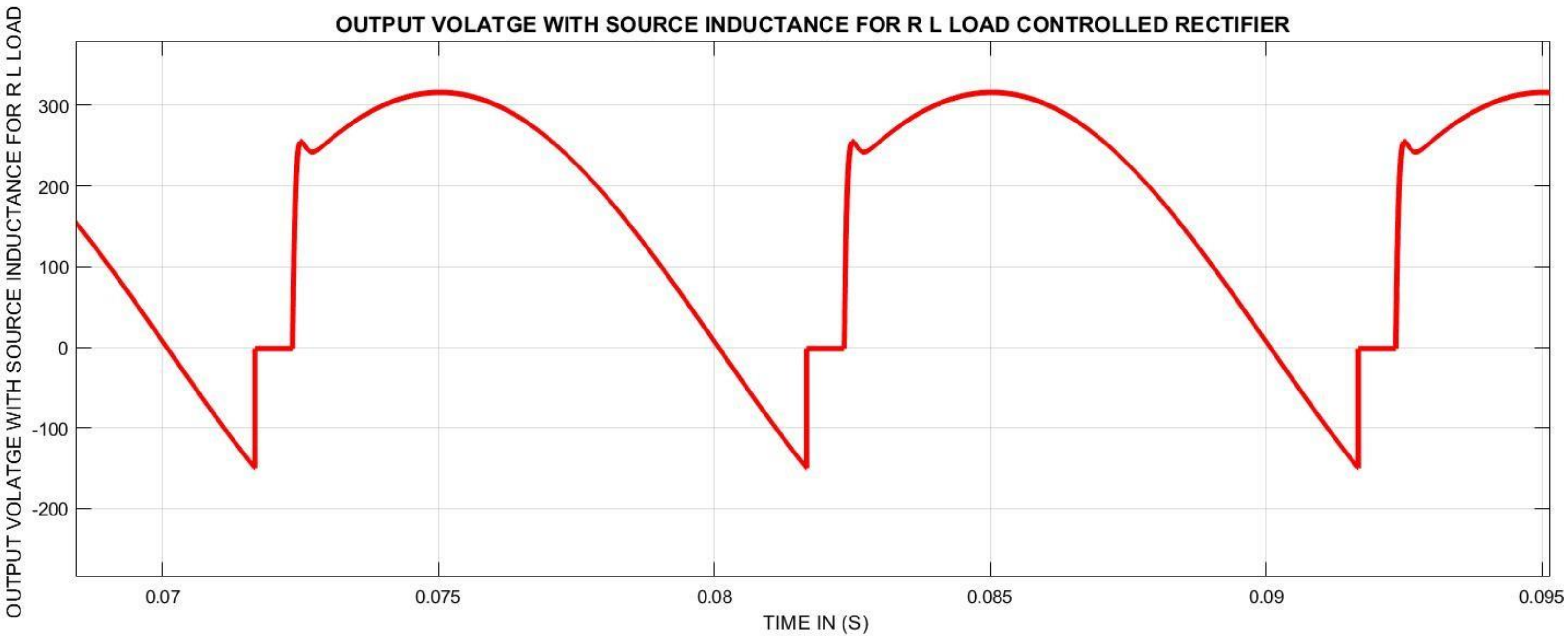

LOAD CURRENT FOR CONTROLLED RECTIFIER FOR R LOAD FOR ALPHA= 90 DEGREE
LOAD CURRENT
TIME IN (S)
25
20
15
10
5
0
-5
0.025
0.03
0.035
0.04
0.045
0.05


SOURCE CURRENT FOR ALPHA = 90 DEGREE FOR R LOAD
20
15
10
5
0
-5
-10
-15
-20
SOURCE CURRENT
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
0.11
TIME IN (S)

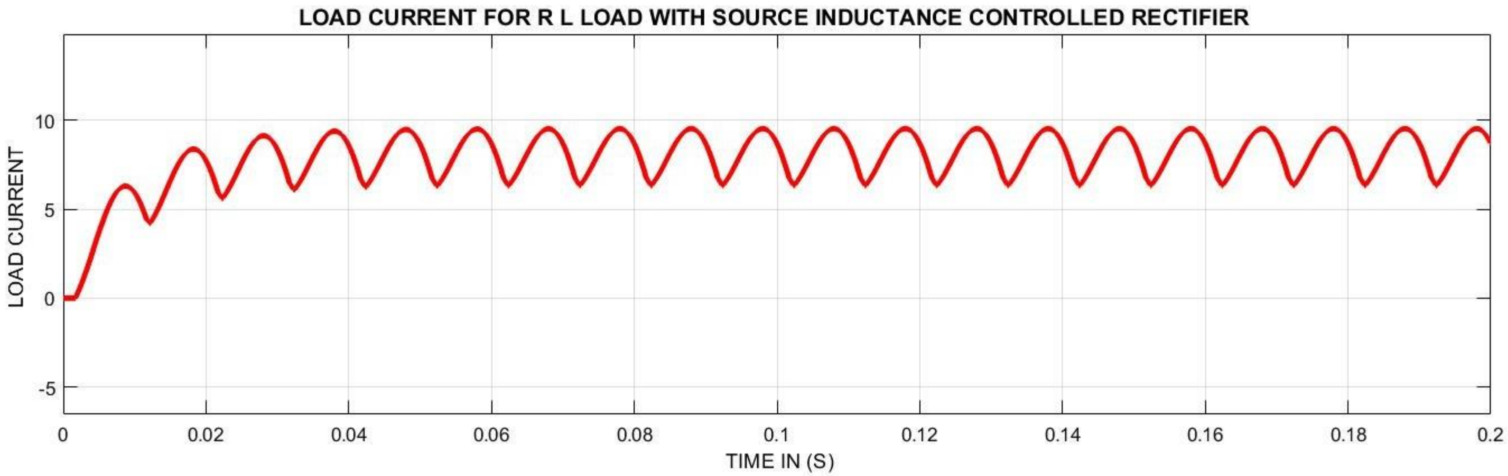

OUTPUT VOLATGE FOR R L LOAD FOR ALPHA = 90 DEGREE
OUTPUT VOLATGE
TIME IN (S)
300
200
100
0
-100
-200
-300
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1

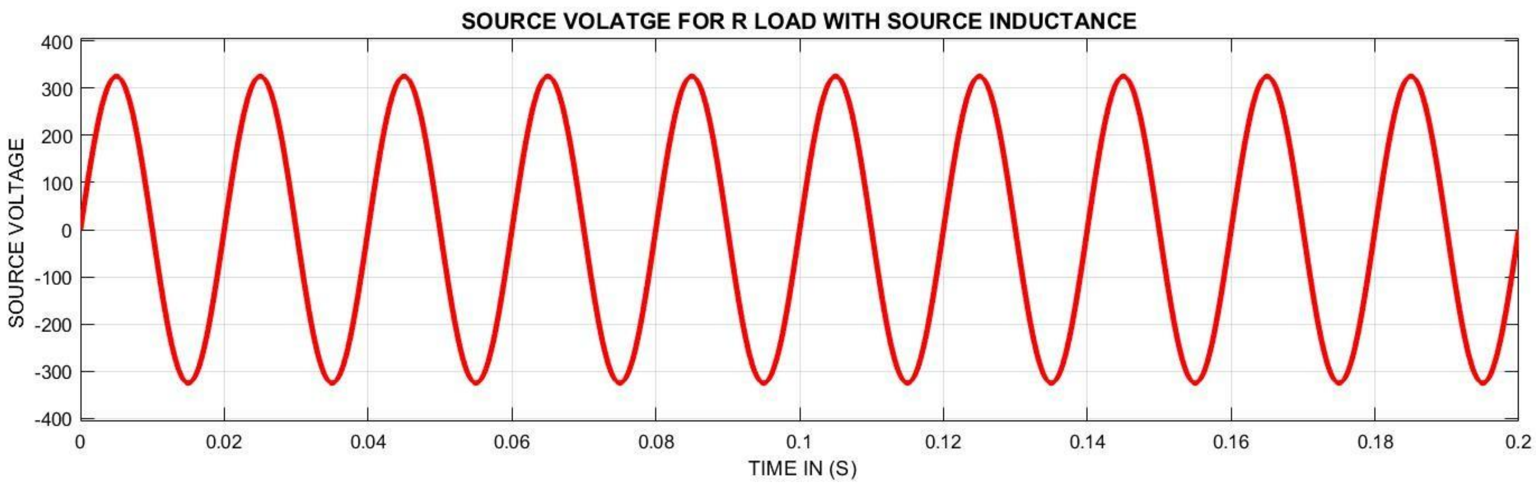

SOURCE CURRENT FOR R L LOAD ALPHA = 90 DEGREE
SOURCE CURRENT
20
15
10
5
0
-5
-10
-15
0.06
0.07
0.08
0.09
0.1
0.11
0.12


LOAD CURRENT FOR APLHA = 90 DEGREE
LOAD CURRENT
10
5
0
-5
0.05
0.06
0.07
0.08
0.09
0.1
TIME IN (S)

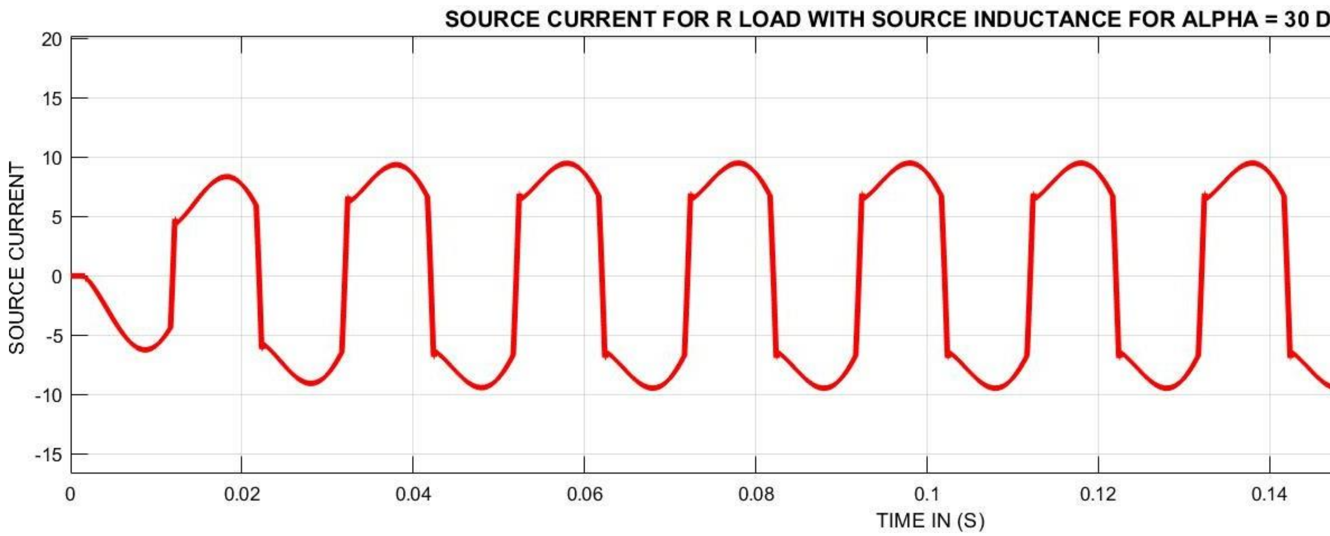


OUTPUT VOLATGE WITH SOURCE INDUCTANCE FOR R L LOAD CONTROLLED RECTIFIER
OUTPUT VOLATGE WITH SOURCE INDUCTANCE FOR R L LOAD
300
200
100
0
-100
-200
0.07
0.075
0.08
0.085
0.09
0.095
TIME IN (S)


LOAD CURRENT FOR R L LOAD WITH SOURCE INDUCTANCE CONTROLLED RECTIFIER
LOAD CURRENT
10
5
0
-5
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
TIME IN (S)



SOURCE VOLATGE FOR R LOAD WITH SOURCE INDUCTANCE
SOURCE VOLTAGE
400
300
200
100
0
-100
-200
-300
-400
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
TIME IN (S)


SOURCE CURRENT FOR R LOAD WITH SOURCE INDUCTANCE FOR ALPHA = 30 D
SOURCE CURRENT
TIME IN (S)
20
15
10
5
0
-5
-10
-15
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14

EXPERIMENT 6

ARYA MALLICK

Roll Number: 234102501

- **Objective**

  The objective of his experiment is to study the operation of 3-phase uncontrolled and controlled rectifiers using MATLAB/SIMULINK.

- **Theory**

  A 3-phase full bridge diode rectifier has six diodes, two in each phase. At a time only two diodes will be conducted, one from upper three and one from lower three. Diodes in the same leg won't conduct simultaneously. From the upper three diodes, that one will conduct whose anode voltage will be highest in positive value and from the lower three that one will conduct which has the lowest negative voltage at its cathode. The following re volation gives the output average voltage.

$$V_{dc} = \frac{3\sqrt{3}V_m}{\pi}$$

where V_m is the maximum phase voltage. Here,

$$V_{dc} = \frac{3 \times \sqrt{2} \times 400}{\pi}$$

$$V_{dc} = 540.189\ V$$

Now, in this case as current through inductor is periodic, average inductor voltage will be

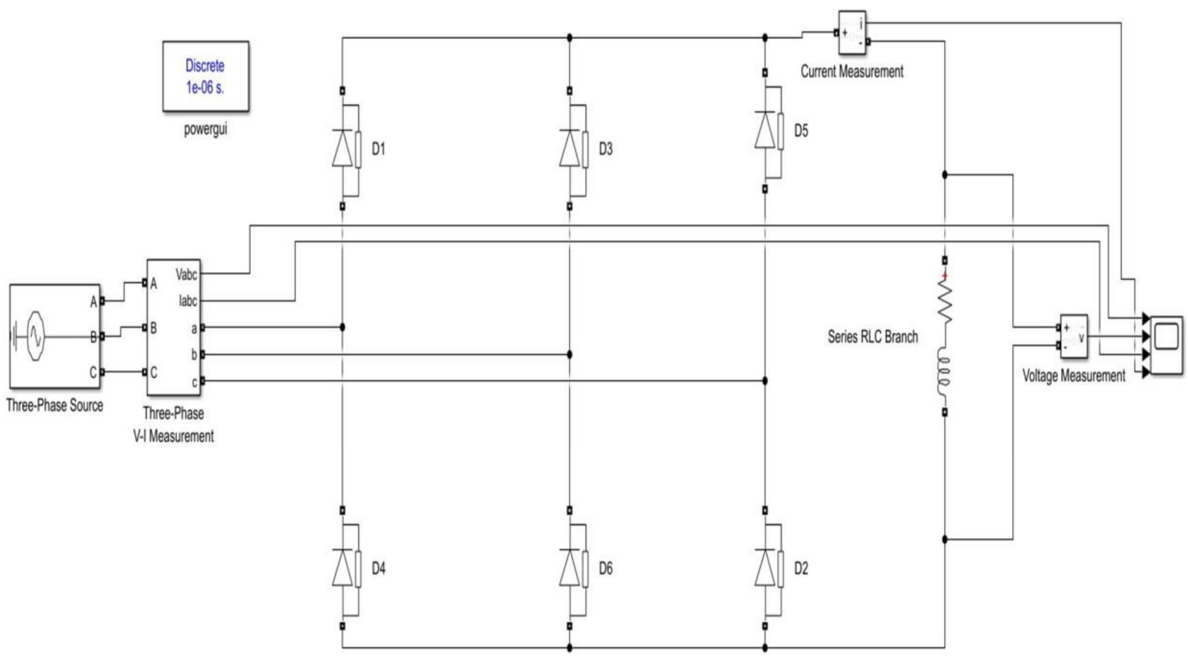
0. Hence,

$$I_{dc} = \frac{V_{dc}}{R}$$

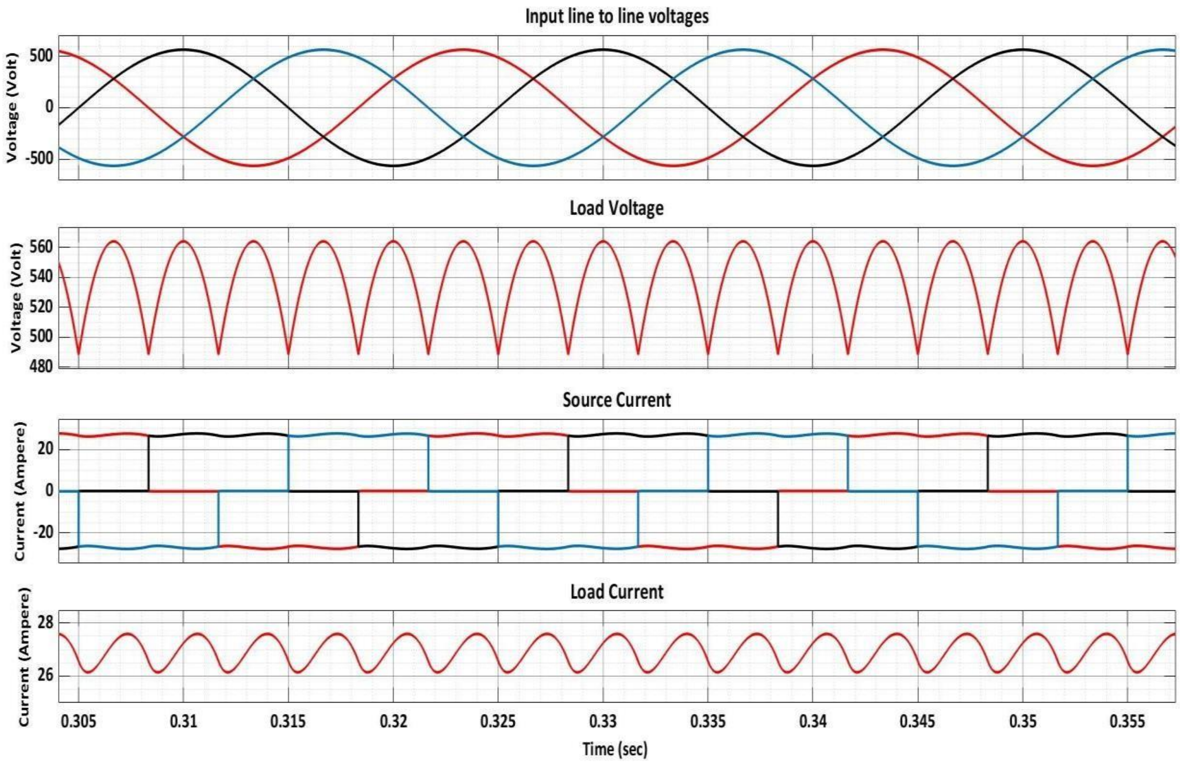
$$I_{dc} = \frac{540.189}{20}$$

$$I_{dc} = 27\ A$$

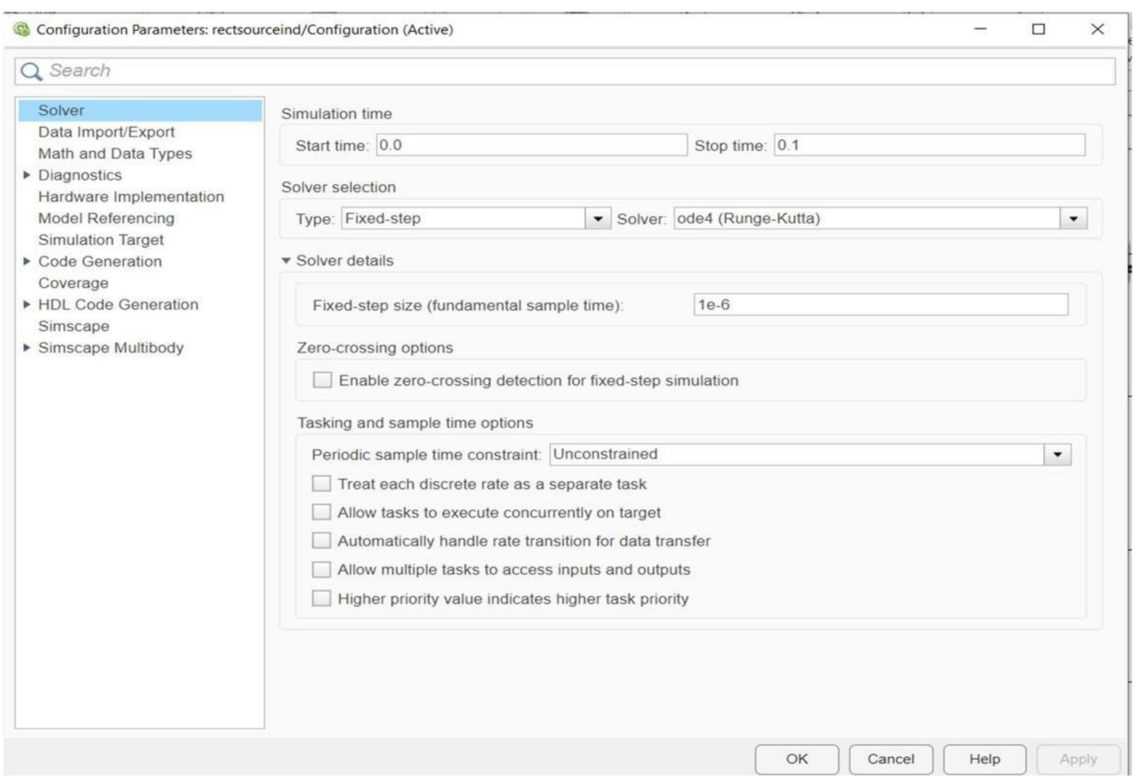
- **MATLAB/SIMULINK Simulation**



- **Simulation Waveforms**



- **Simulation Configuration Parameters**



- **Simulation Results**

On analyzing the above waveforms, we got I_{dc} = 26.93 A. Also, from the above output voltage waveform, we got V_{dc} = 537.9 V. Moreover, the ripple in load current came out to be 1.459 A.

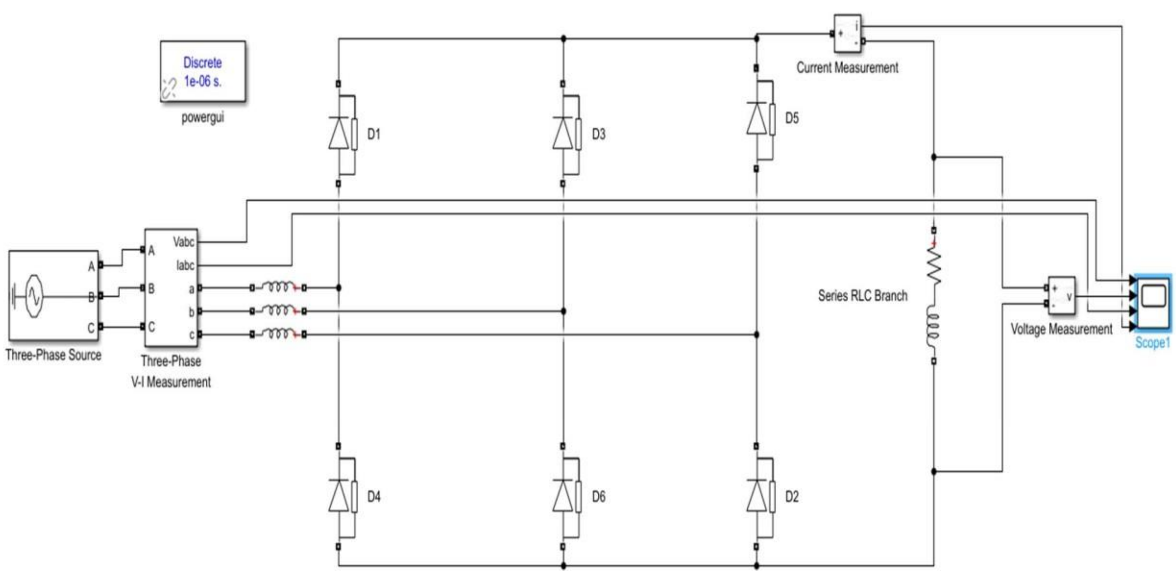
3-Phase Diode Rectifier with source inductance L_s = 10 mH

- **Design Procedure**

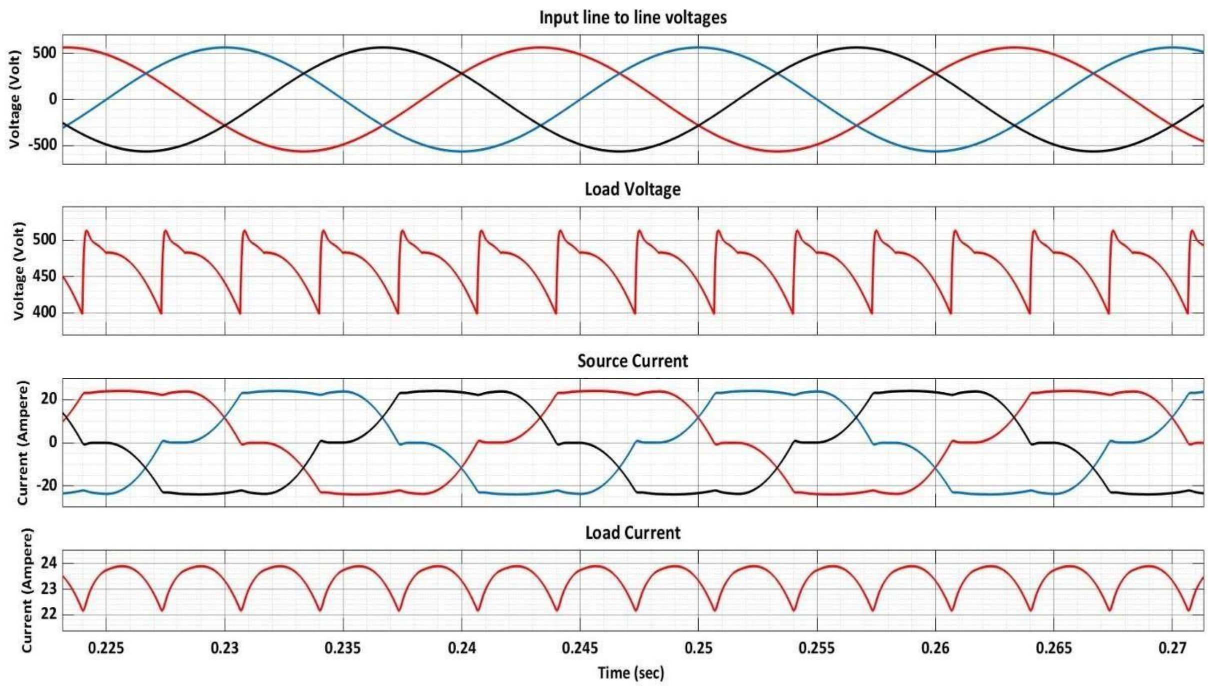
A 3-phase ac source of line to line voltage V_{rms} = 400 V and frequency f = 50 Hz was connected. The diodes were connected in the arrangement shown in the figure above and connected an RL load with R = 20 Ω and L = 20 mH. A source inductance in this case with L_s = 10 mH was also connected in each phase on the source side.

The circuit diagram shown above was simulated using MATLAB/SIMULINK software. Diodes were used as our switches. One pair of diodes conducted during the positive half cycle and another pair conducted during the negative half cycle. The output we got was a rectified DC voltage and current across the load.

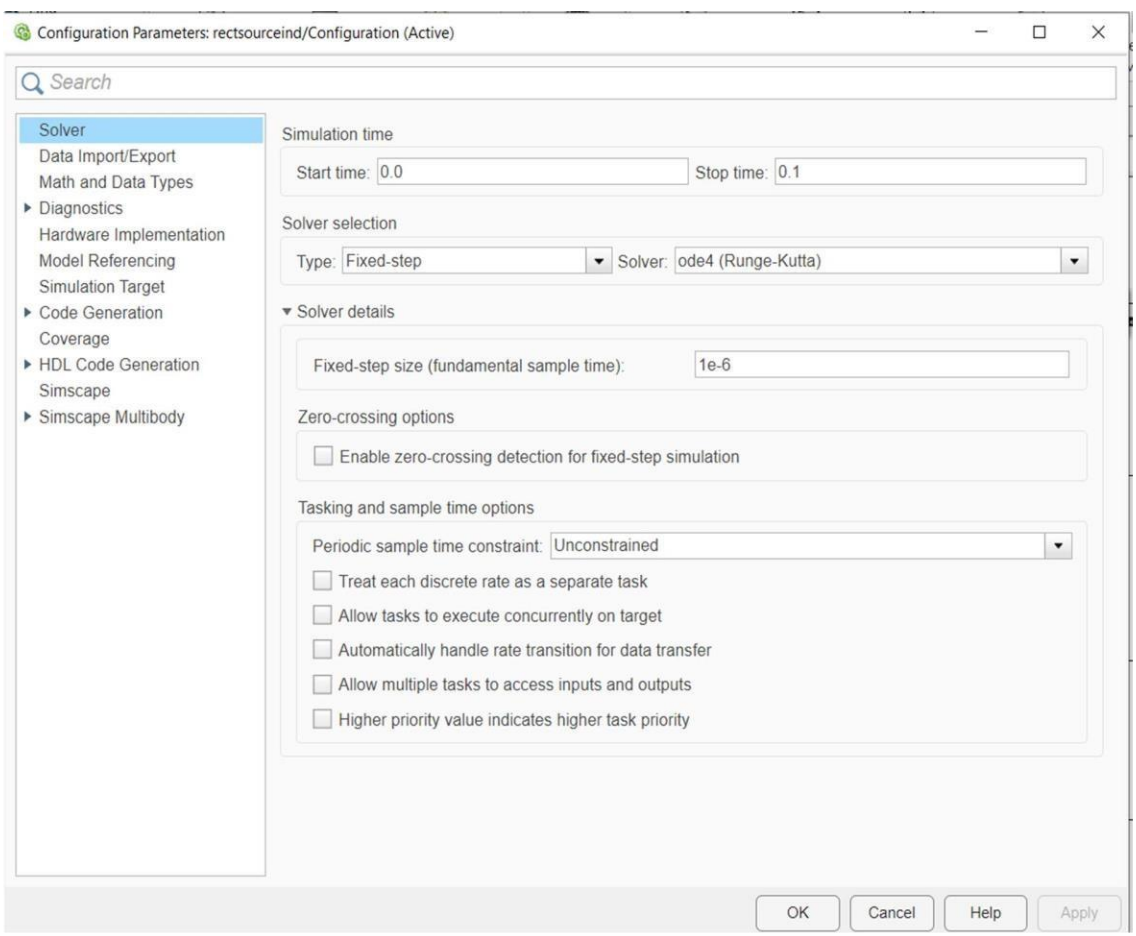
- **MATLAB/SIMULINK Simulation**



- **Simulation Waveforms**



- **Simulation Configuration Parameters**



- **Simulation Results**

  On analyzing the above waveforms, we got I_{dc} = 23.29 A. Also, from the above output voltage waveform, we got V_{dc} = 468.7 V. Moreover, the ripple in load current came out to be 1.748 A.

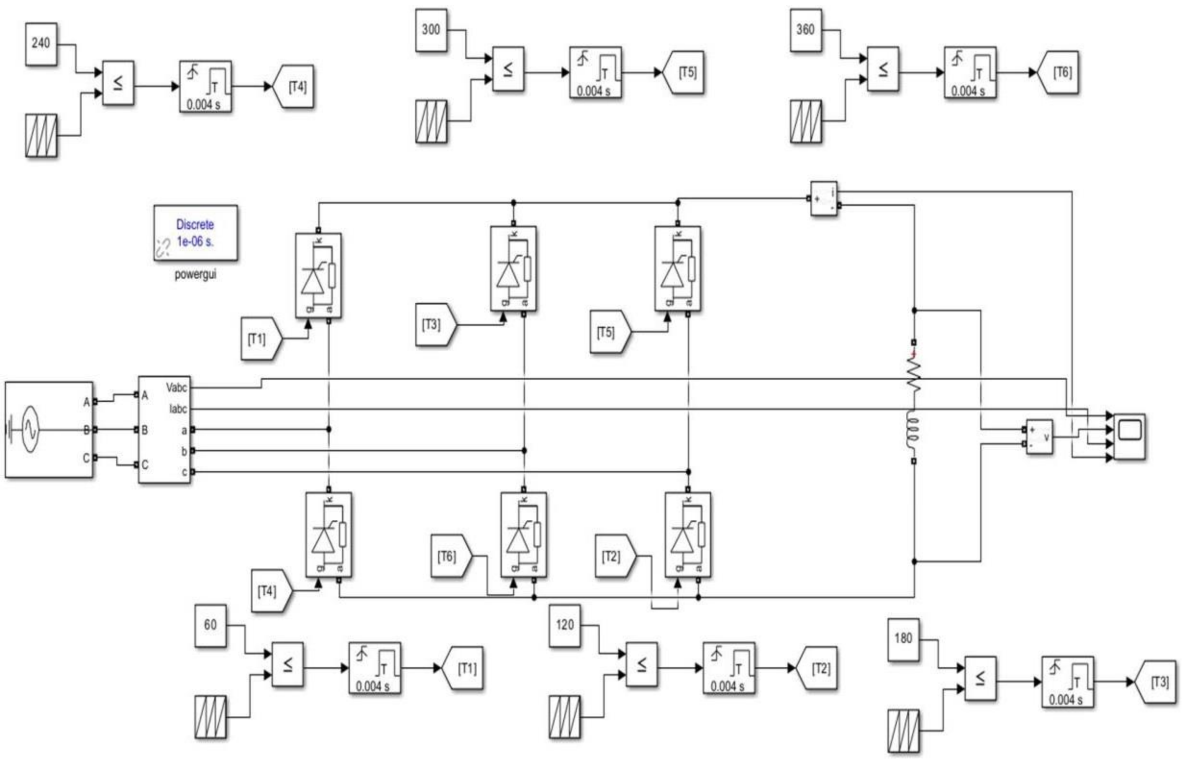
  μ = 42.1566°.

Phase Controlled 3-phase AC-DC Converter with R = $20\ \Omega$ and L = $20\ mH$ load and without Source Inductance

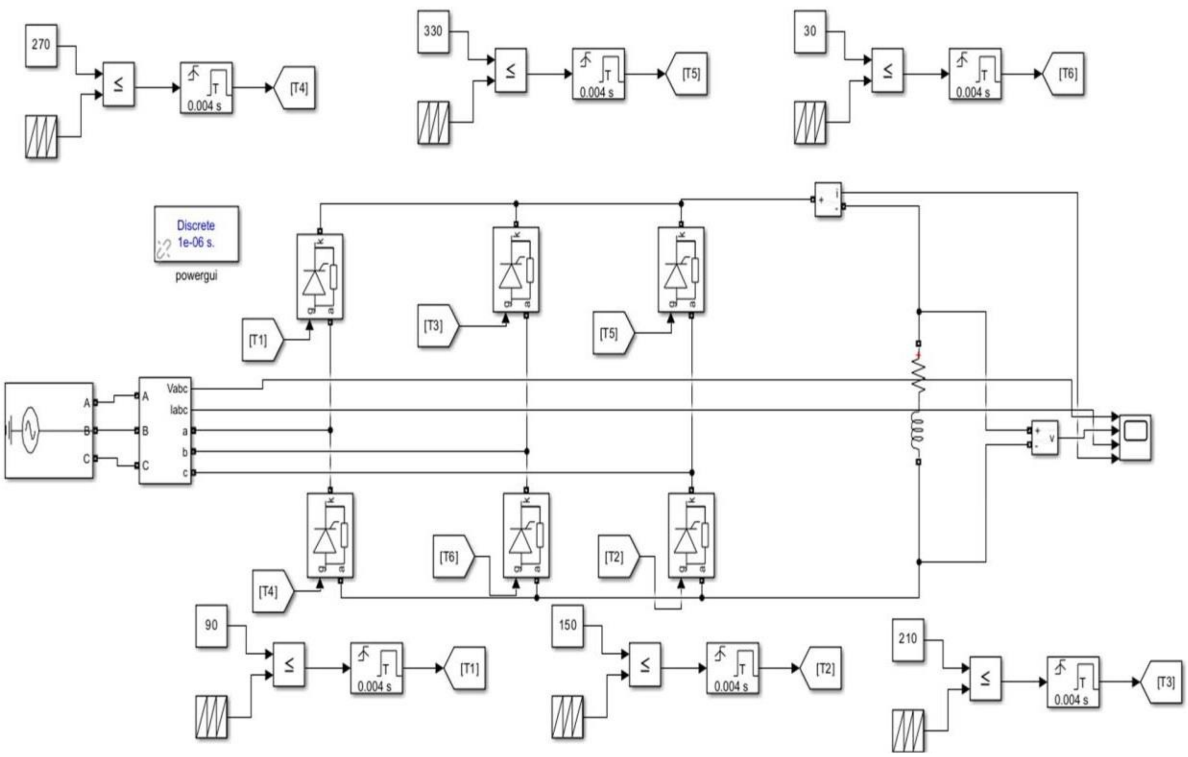
- **Design Procedure**

  An AC source of V_{ll} = 400 V and frequency f = 50 Hz was connected. The thyristors were connected in the arrangement shown in the figure above and connected the RL load with
  R = 20 Ω and L = 20 mH.
  The circuit diagram shown above was simulated using MATLAB/SIMULINK software with four different firing angles for thyristors viz α = 30°, α = 60°, α = 120° and α = 150°,. Thyristors were used as our switches. The firing pulse to T_1 was given at α + 30° as in case of 3-phase controlled AC-DC converters, α is measured not from ωt = 0° but 30° ahead. Hence the actual firing pulse is given at α + 30°. All the subsequent thyristors are triggered after 60° from the previous one. So, two thyristors will be conducting together and each thyristor will conduct for 120° in one period.

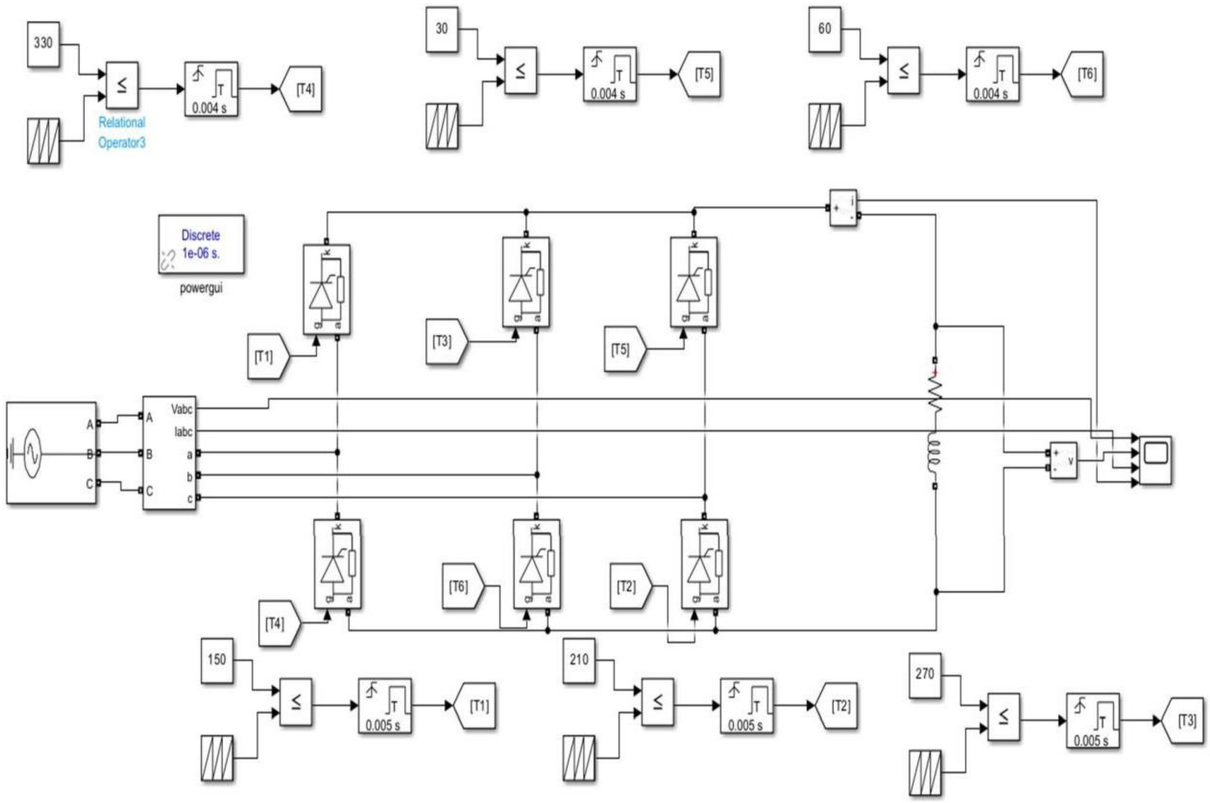
- **MATLAB/SIMULINK Simulation**
  - α = 30°



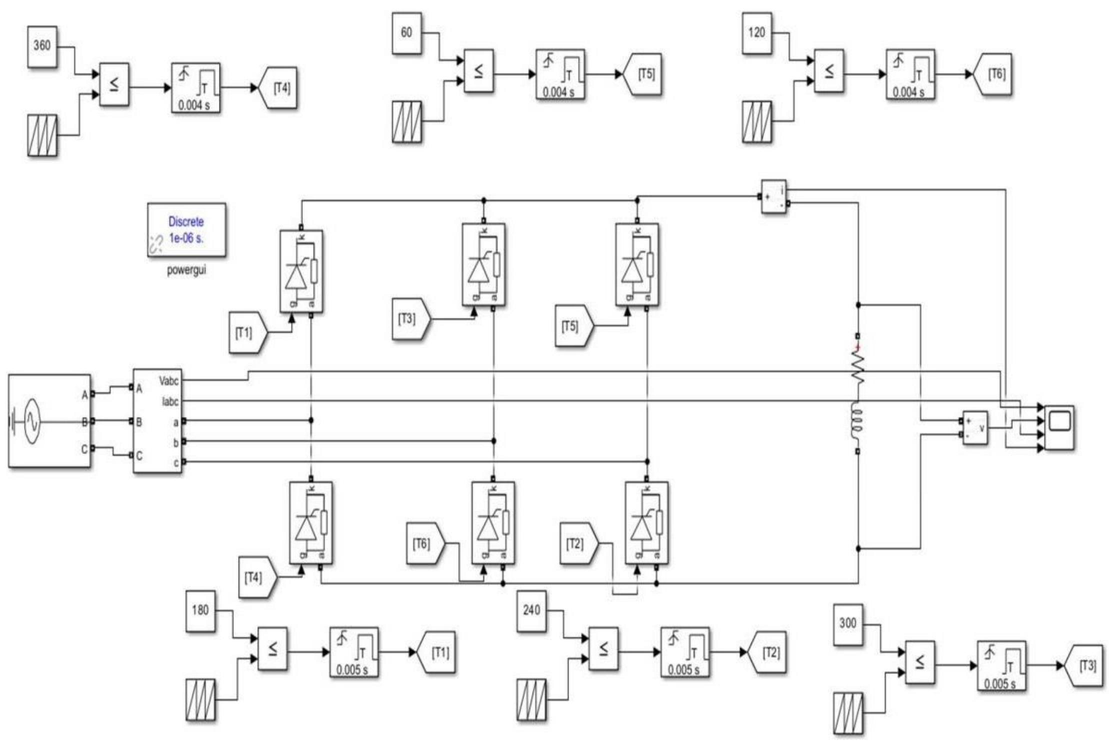
- $\alpha = 60°$



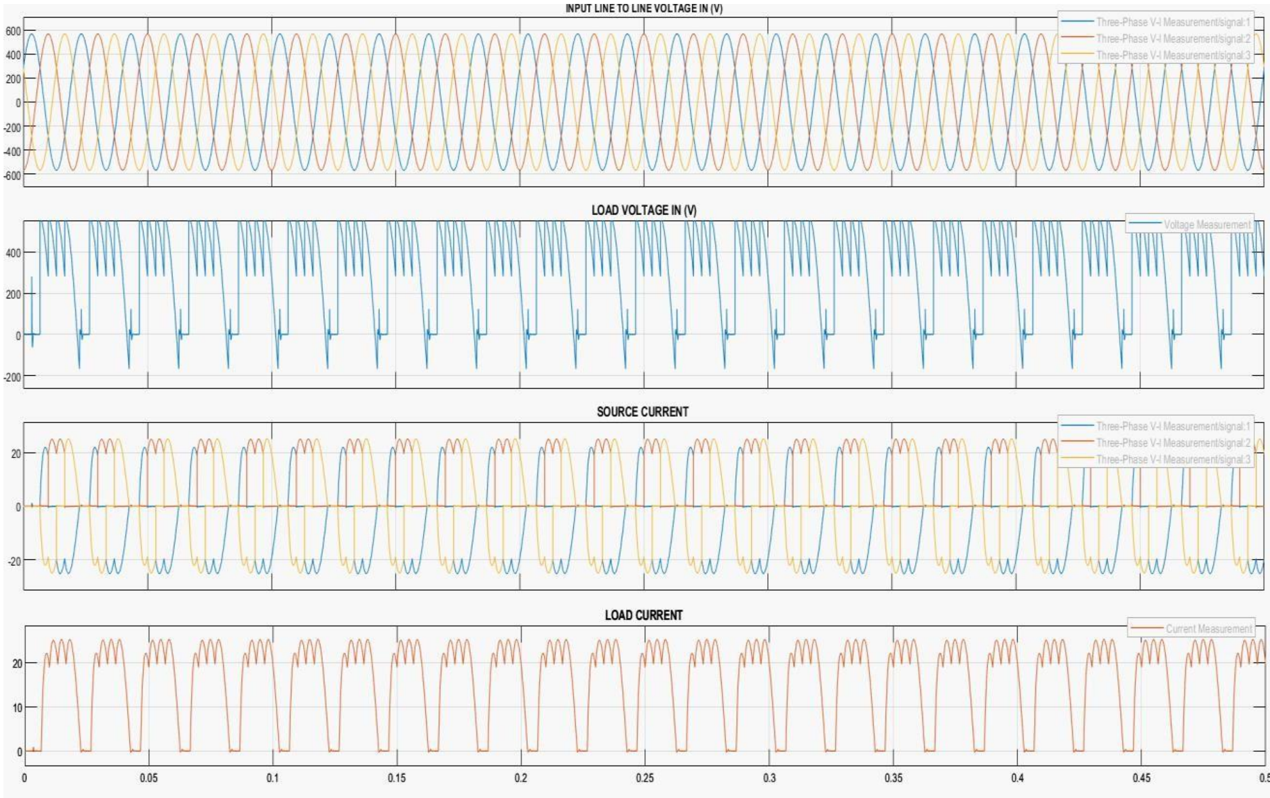
- $\alpha = 120°$



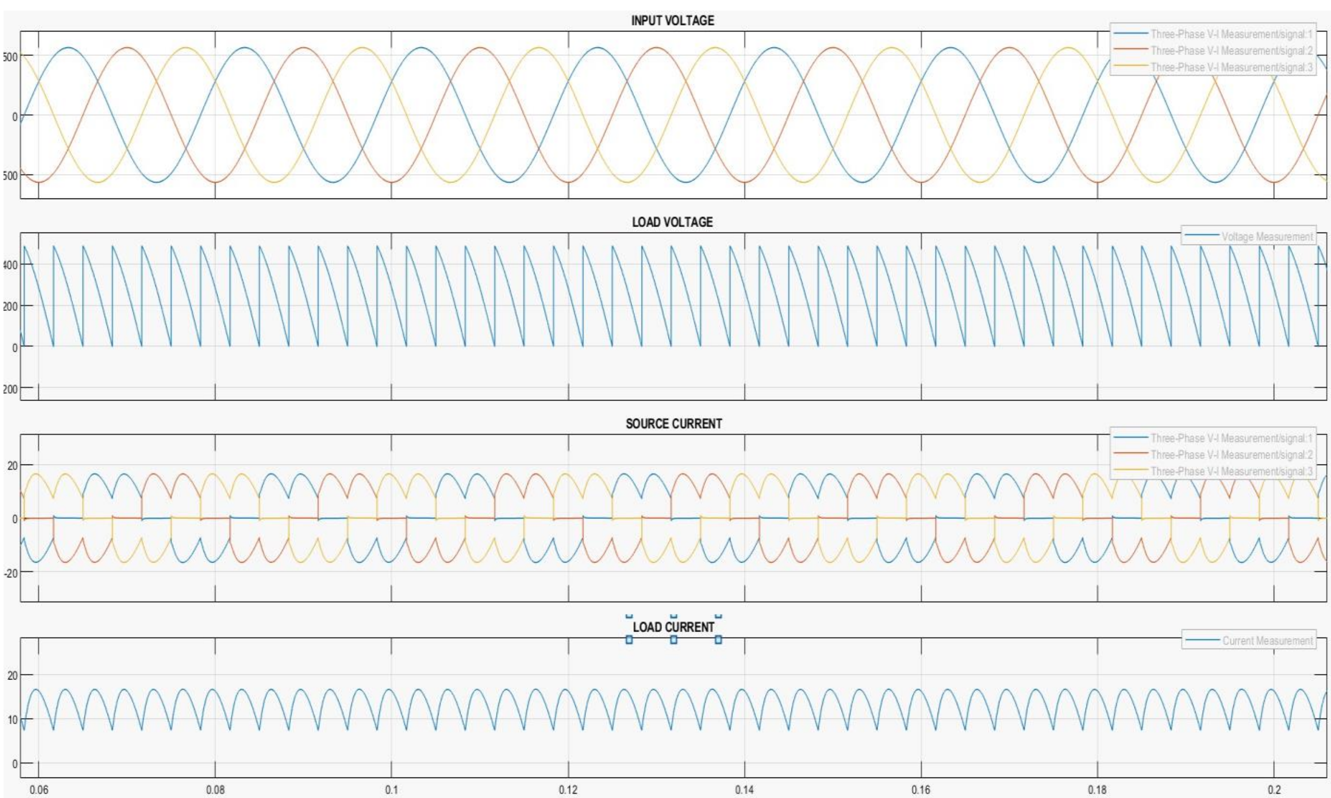
- α = 150°



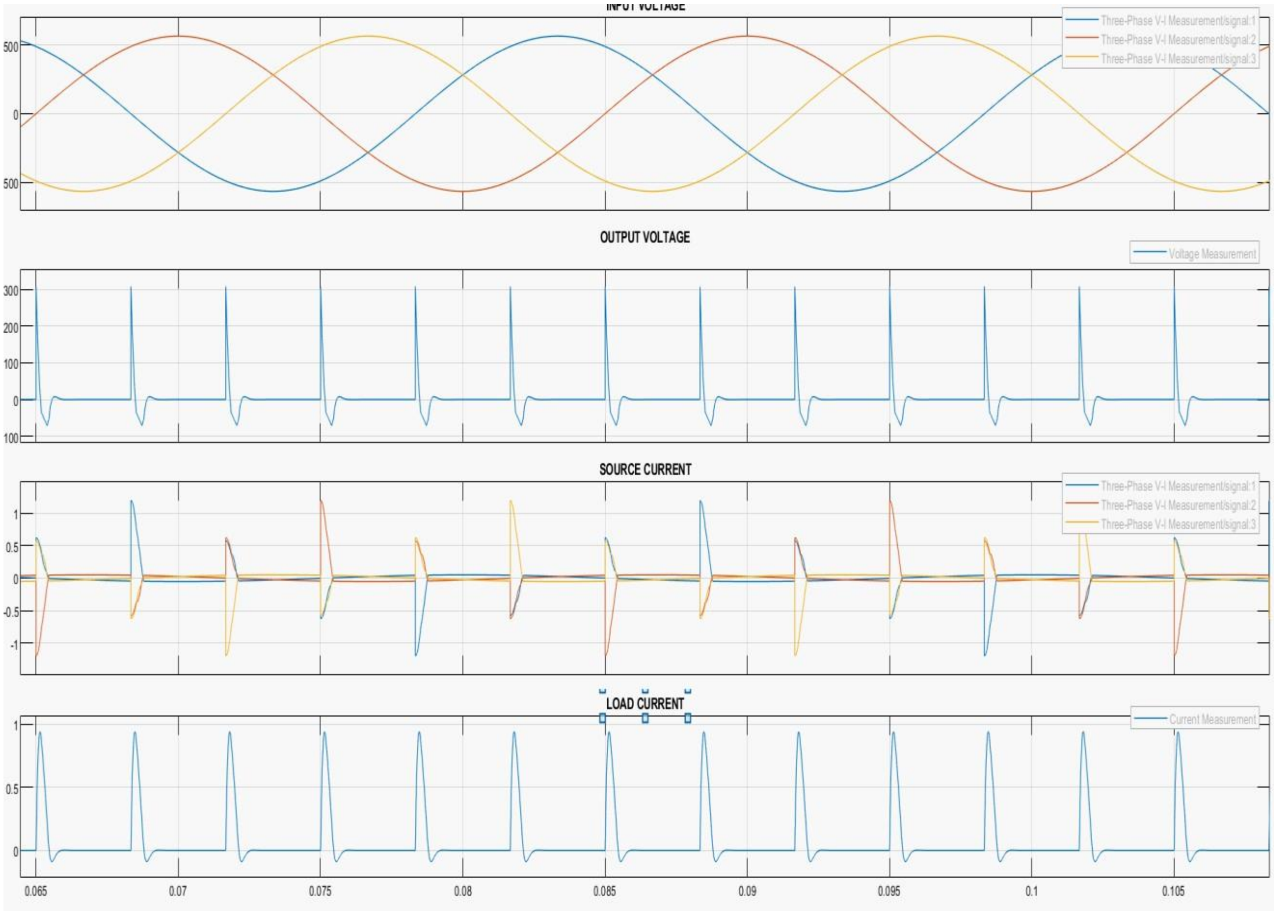
- α = 30°



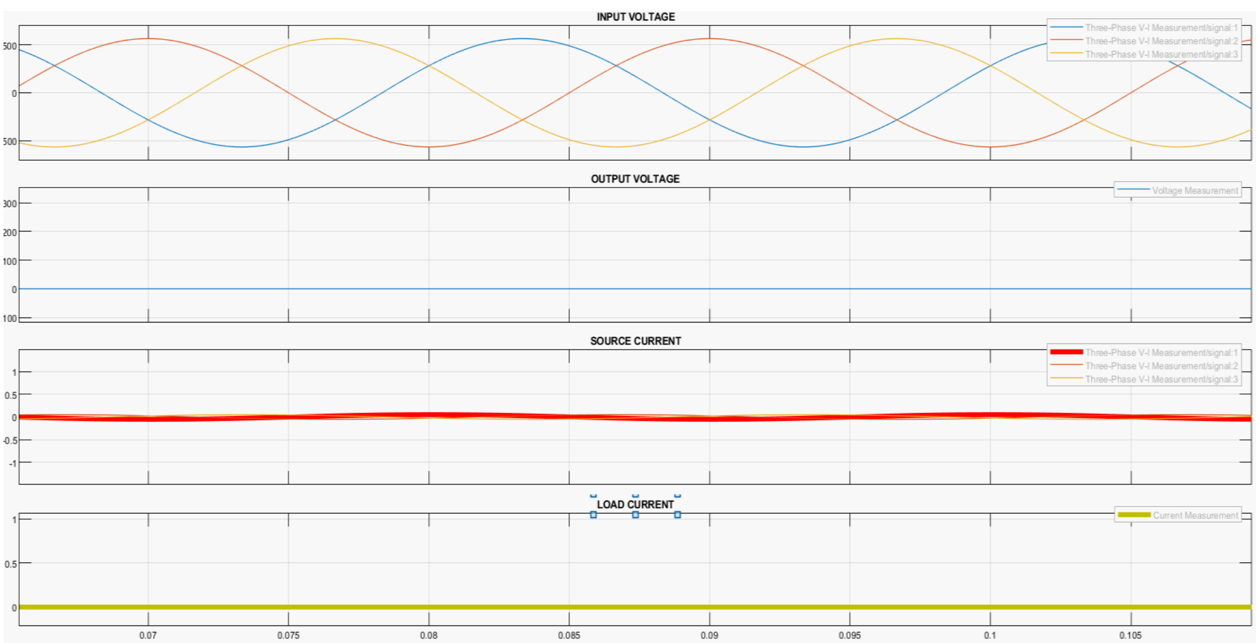
- $\alpha = 60°$



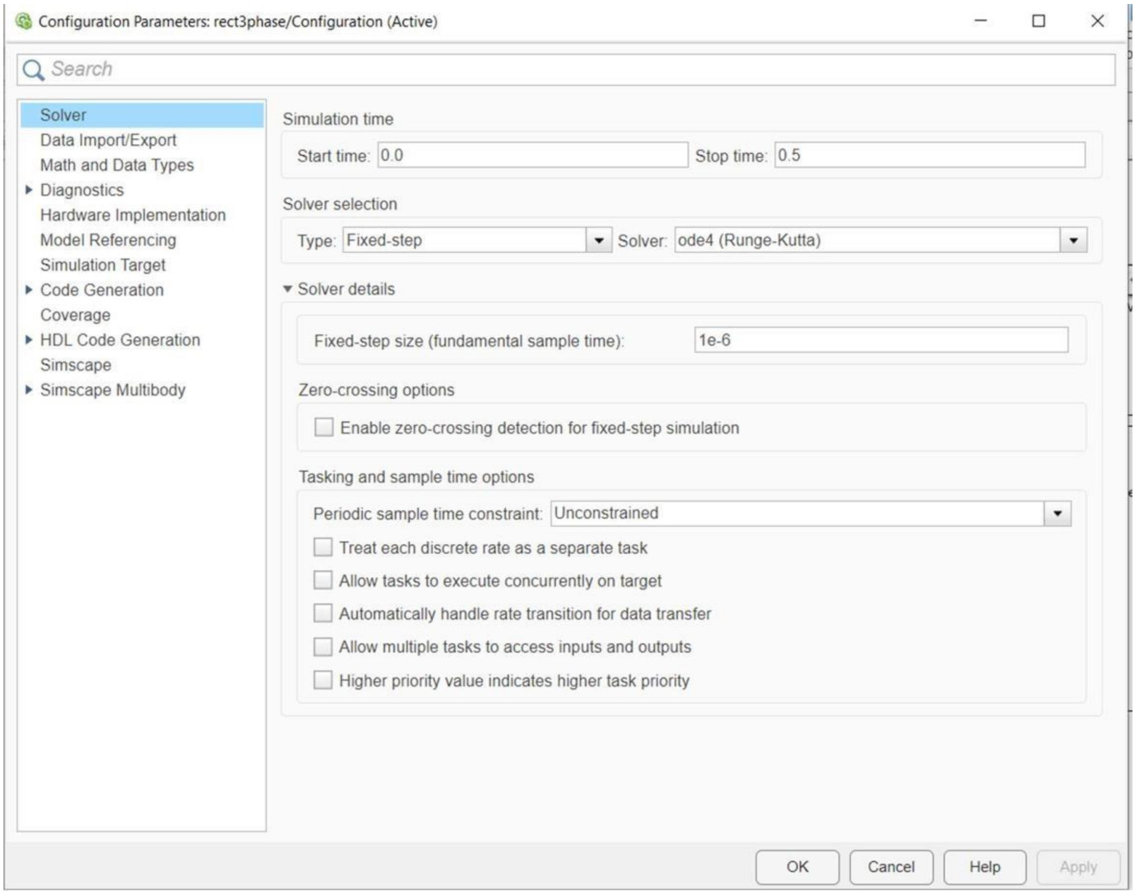
- $\alpha = 120°$



- $\alpha = 150°$



- **Simulation Configuration Parameters**



- **Simulation Results**
  - $\alpha = 30°$

On analyzing the above waveforms, we got $I_{dc} = 23.32\ A$. Also, from the above output voltage waveform, we got $V_{dc} = 466.8\ V$. Moreover, the ripple in load current came out to be $5.61\ A$.

  - $\alpha = 60°$

On analyzing the above waveforms, we got $I_{dc} = 13.45\ A$. Also, from the above output voltage waveform, we got $V_{dc} = 266\ V$. Moreover, the ripple in load current came out to be $9.304\ A$.

  - $\alpha = 120°$

On analyzing the above waveforms, we got $I_{dc} = 0.0803\ A$. Also, from the above output voltage waveform, we got $V_{dc} = 1.593\ V$. Moreover, the ripple in load current came out to be $1.029\ A$.

  - $\alpha = 150°$

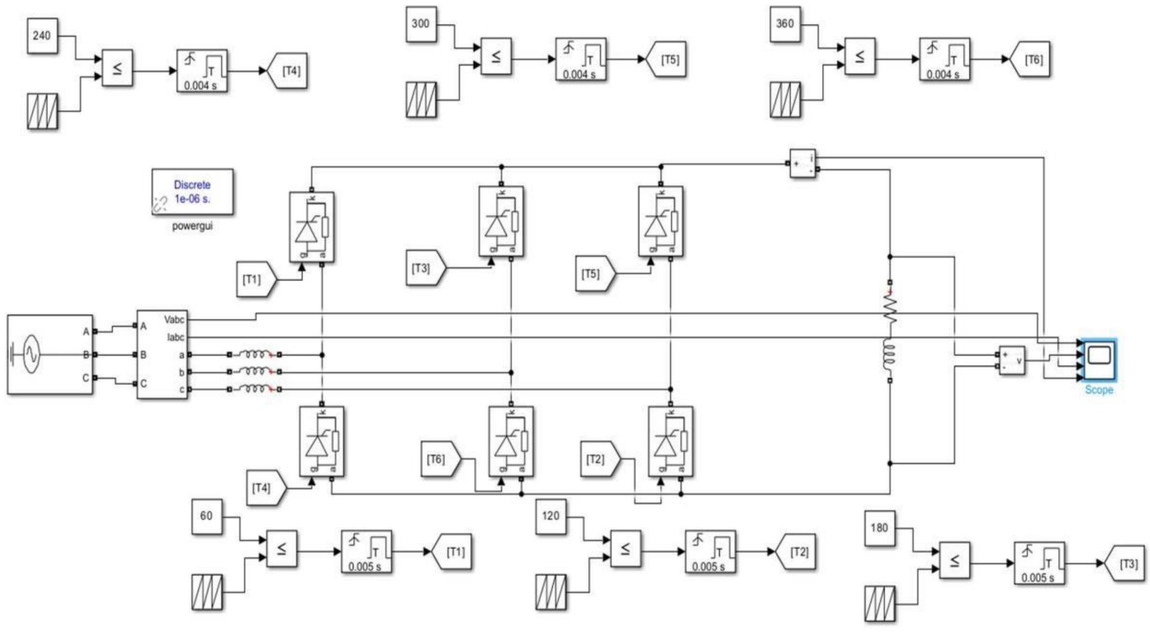
On analyzing the above waveforms, we got I_{dc} = 0 A. Also, from the above output voltage waveform, we got V_{dc} = 0 V. Moreover, the ripple in load current came out to be 0 A.

Phase Controlled 3-phase AC-DC Converter with R = $20\ \Omega$ and L = $20\ mH$ load and with Source Inductance L_s = $10\ mH$

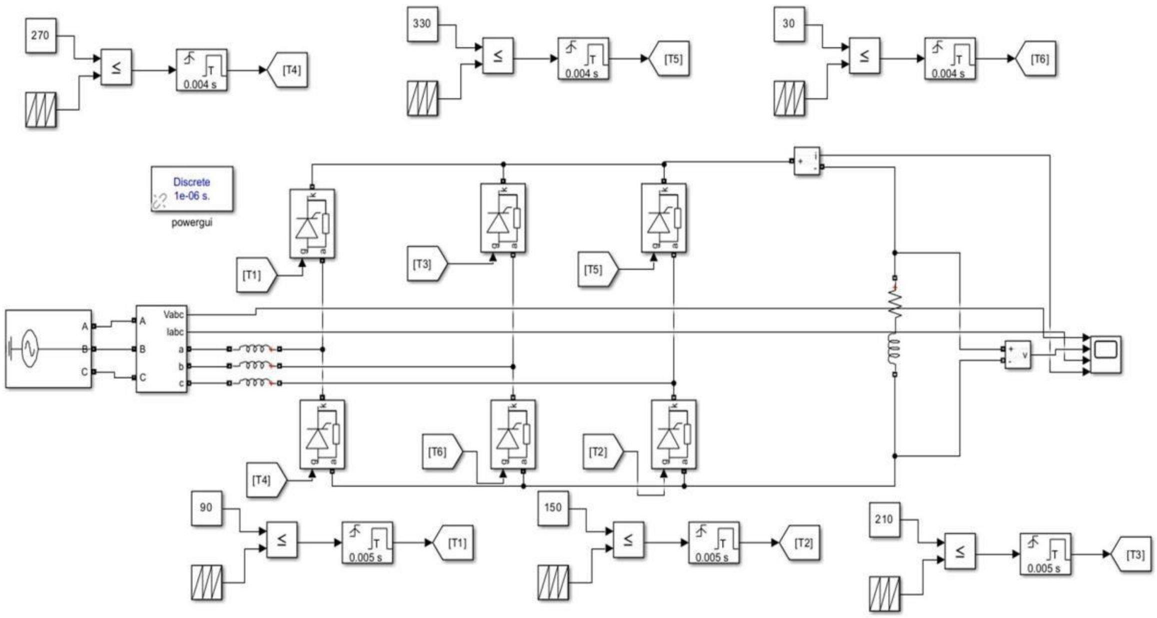
- **Design Procedure**

An AC source of V_{ll} = 400 V and frequency f = 50 Hz was connected. The thyristors were connected in the arrangement shown in the figure above and connected the RL load with R = 20 Ω and L = 20 mH. A source inductance of L_s = 10 mH was also present in each phase. The circuit shown above was simulated using MATLAB/SIMULINK software with four different firing angles for thyristors viz α = 30°, α = 60°, α = 120° and α = 150°. Thyristors were used as our switches. The firing pulse to T_1 was given at α + 30° as in case of 3-phase controlled AC-DC converters, α is measured not from ωt = 0° but 30° ahead. Hence the actual firing pulse is given at α + 30°. All the subsequent thyristors are triggered after 60° from the previous one. There was an overlapping angle of μ when a thristor was triggered as the current through source inductor cannot change instantaneously.

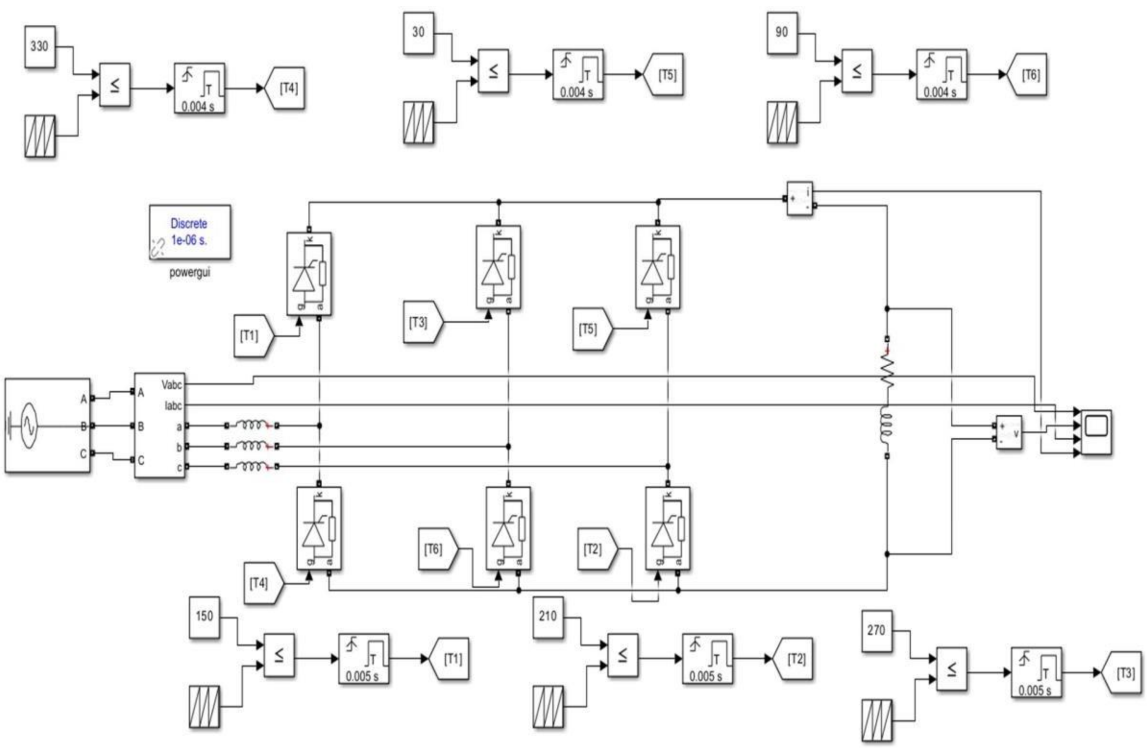
- **MATLAB/SIMULINK Simulation**
  - α = 30°


240
0.004 s
[T4]
300
0.004 s
[T5]
360
0.004 s
[T6]
Discrete
1e-06 s.
powergui
[T1]
[T3]
[T5]
Vabc
Iabc
A
B
C
a
b
c
Scope
[T4]
[T6]
[T2]
60
0.005 s
[T1]
120
0.005 s
[T2]
180
0.005 s
[T3]

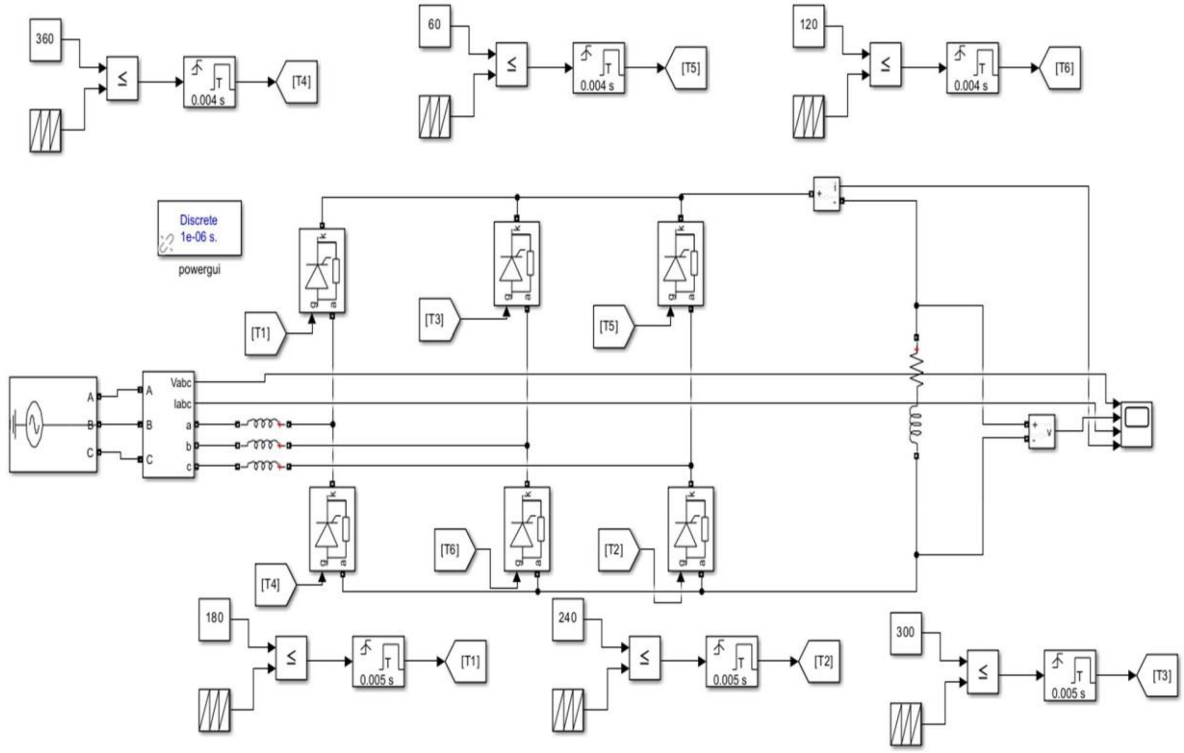
- $\alpha = 60°$



- $\alpha = 120°$

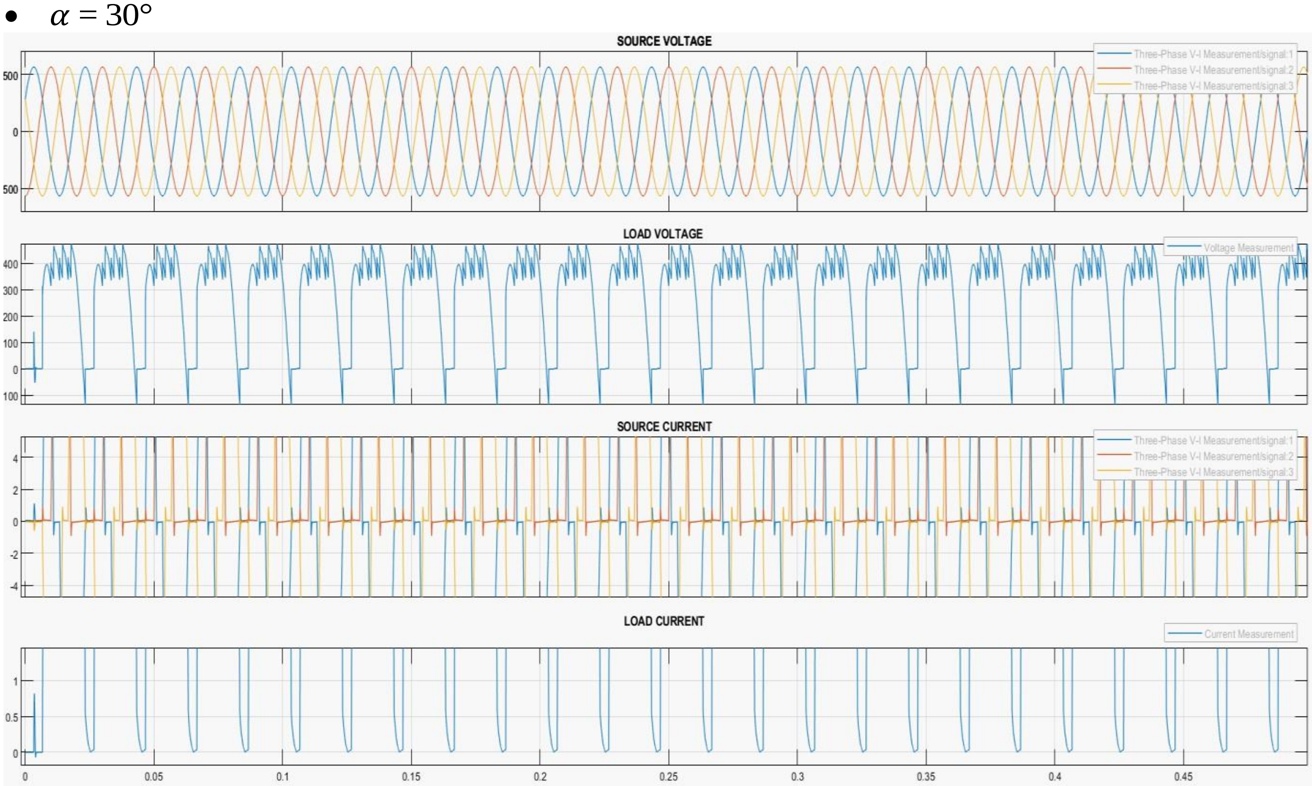


- $\alpha = 150°$

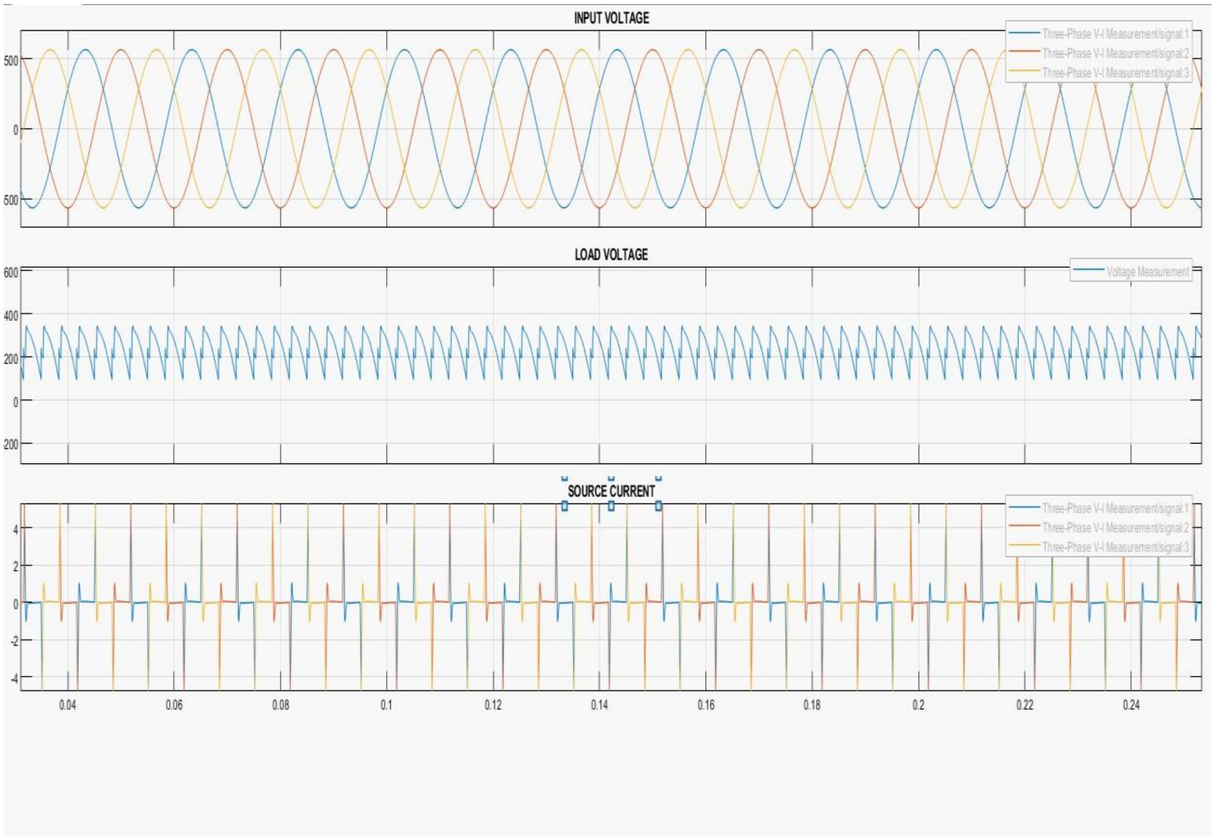


- **Simulation Waveforms**

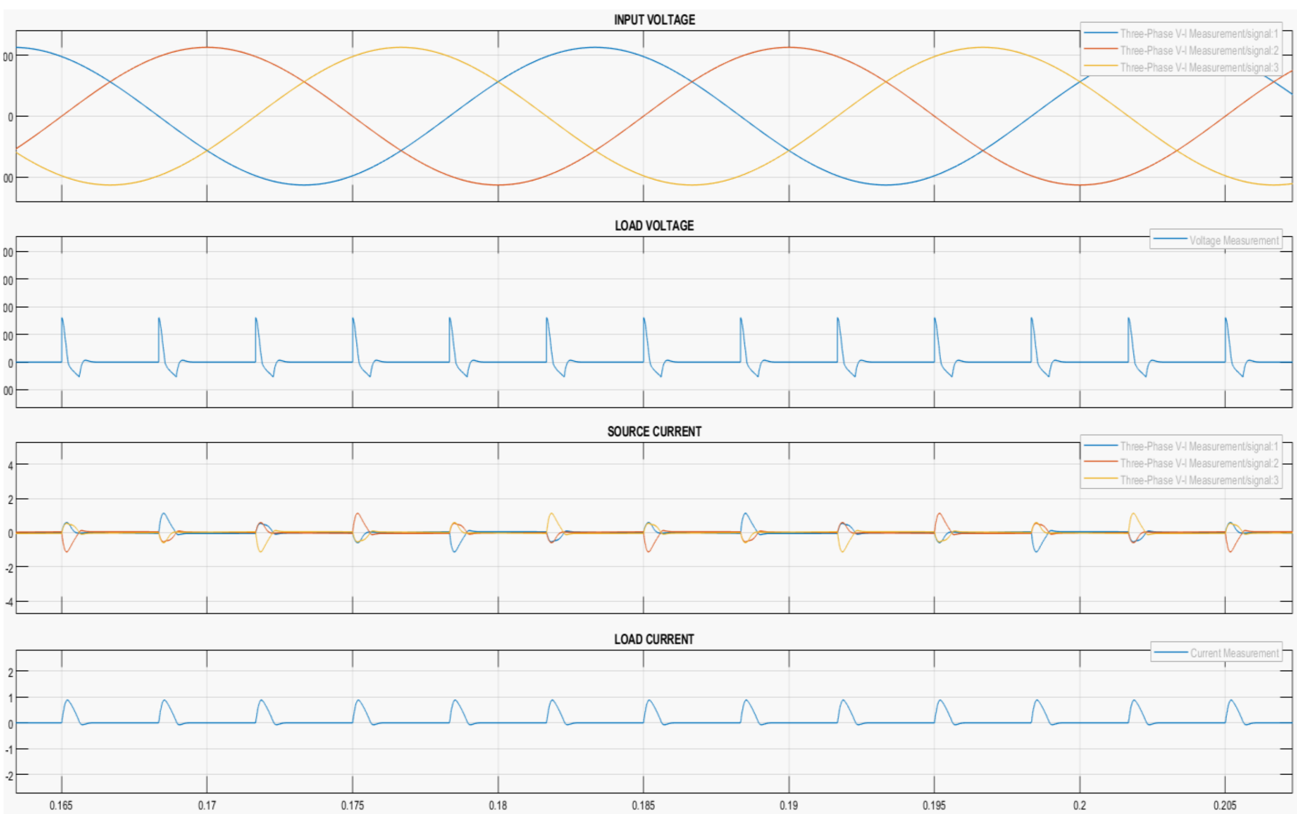
- $\alpha = 30°$



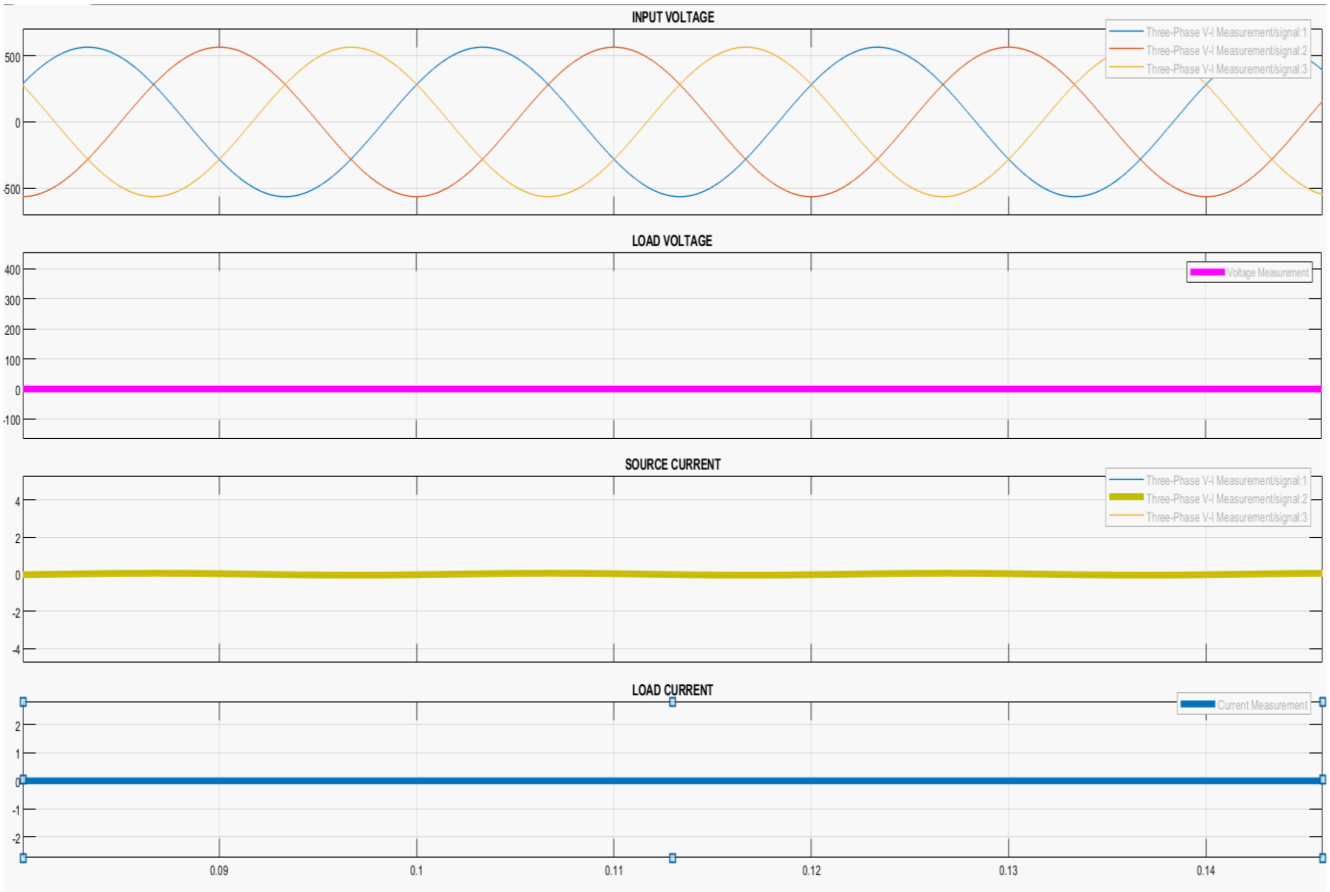
- $\alpha = 60°$



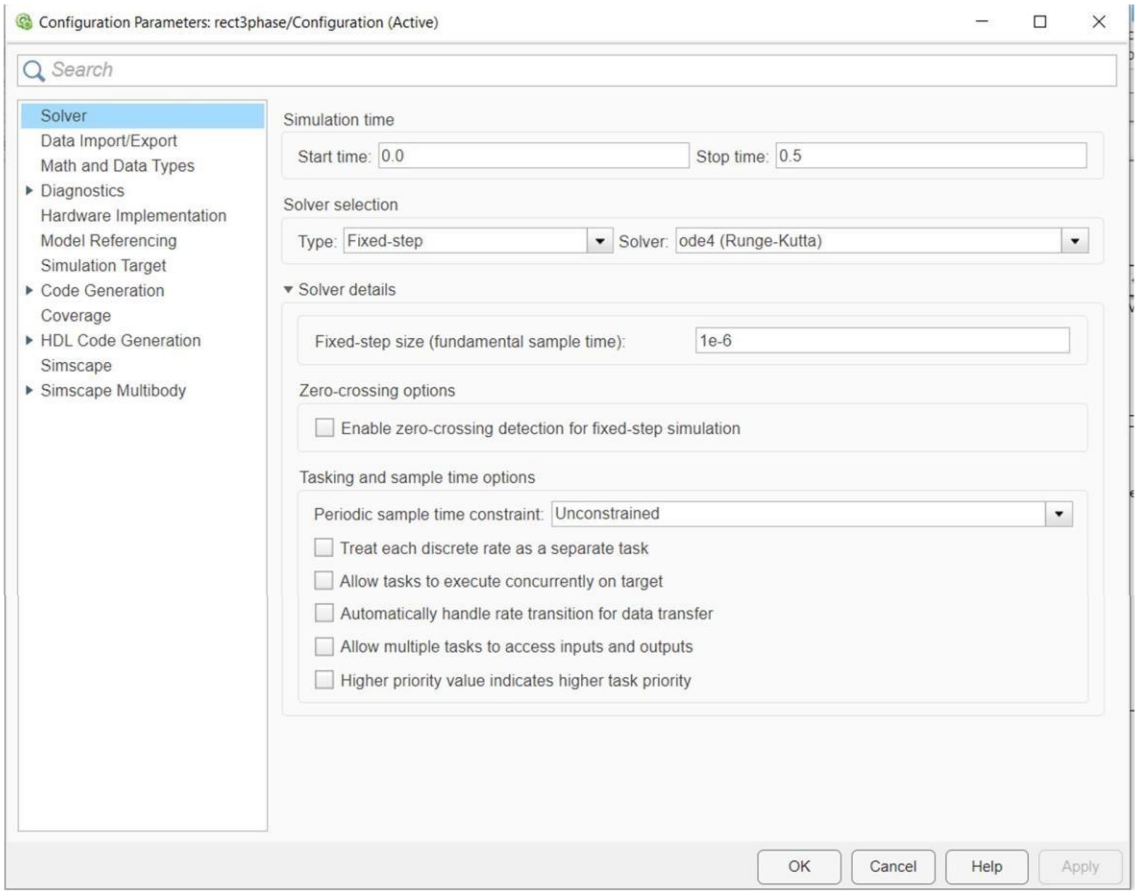
- $\alpha = 120°$



- $\alpha = 150°$



- **Simulation Configuration Parameters**



- **Simulation Results**
  - $\alpha = 30°$

On analyzing the above waveforms, we got $I_{dc} = 20.33\ A$. Also, from the above output voltage waveform, we got $V_{dc} = 407.5\ V$. Moreover, the ripple in load current came out to be $2.21\ A$. Also, the overlapping angle was computed as

$$\cos(\mu + \alpha) = \cos\alpha - \frac{2\omega L_s I_{dc}}{V_{llp}}$$

$$\cos(\mu + 30°) = \cos 30° - \frac{2 \times 100\pi \times 10 \times 10^{-3} \times 20.33}{400 \times \sqrt{2}}$$

$$\mu = 20.192°$$

- $\alpha = 60°$

On analyzing the above waveforms, we got $I_{dc} = 12\ A$. Also, from the above output voltage waveform, we got $V_{dc} = 244.3\ V$. Moreover, the ripple in load current came out to be $4.28\ A$. Also, the overlapping angle was computed as

$$\cos(\mu + \alpha) = \cos\alpha - \frac{2\omega L_s I_{dc}}{V_m}$$

$$\cos(\mu + 60°) = \cos 60° - \frac{2 \times 100\pi \times 10 \times 10^{-3} \times 12}{400 \times \sqrt{2}}$$

$$\mu = 8.48°$$

- $\alpha = 120°$

On analyzing the above waveforms, we got $I_{dc} = 0.0984\ A$. Also, from the above output voltage waveform, we got $V_{dc} = 1.968\ V$. Moreover, the ripple in load current came out to be $0.9545\ A$. Also, the overlapping angle was computed as

$$\cos(\mu + \alpha) = \cos\alpha - \frac{2\omega L_s I_{dc}}{V_{llp}}$$

$$\cos(\mu + 120°) = \cos 120° - \frac{2 \times 100\pi \times 10 \times 10^{-3} \times 0.0984}{400 \times \sqrt{2}}$$

$$\mu = 0.0723°$$

- $\alpha = 150°$

On analyzing the above waveforms, we got $I_{dc} = 0\ A$. Also, from the above output voltage waveform, we got $V_{dc} = 0\ V$. Moreover, the ripple in load current came out to be $0\ A$. Also, the overlapping angle was computed as

$$\cos(\mu + \alpha) = \cos\alpha - \frac{2\omega L_s I_{dc}}{V_{llp}}$$

$$\cos(\mu + 150°) = \cos 150° - \frac{2 \times 100\pi \times 10 \times 10^{-3} \times 0}{400 \times \sqrt{2}}$$

$$\mu = 0°$$

- **Conclusion**

The operation of a three-phase regulated ac-dc converter with RL load and source inductance was demonstrated in this experiment. By adjusting the firing angle, we were able to regulate the average DC voltage in this type of converter. Since the output voltage during the overlapping time is zero when the source is shorted, the average DC voltage in this instance dropped because the switches overlapped and the current through the source inductance cannot be altered instantly.

Name: Arya Mallick
Roll number: 234102501
Experiment 7

Objective

The objective of this experiment is to study the operation of single-phase and three phase voltage source inverters (VSI) using MATLAB/SIMULINK Parameters

Parameters	**Single Phase-VSI**
Output Voltage	230V 50 Hz
Output Power	1 kW
Switching Frequency	10 kHz
Load Type	Resistive
Modulation Index	0.4 and 0.8

Single Phase Inverter

Theory

Inverter in Power-Electronics refers to a class of power conversion circuits that operate from a DC voltage source or a DC current source and convert it into a symmetric AC voltage or current. It does the reverse of what ac-to-dc ‘converter’ does. The input to the inverter is a direct dc or dc source derived from an AC source. For example, the primary input power source may be a utility ac voltage supply converted to DC by an AC - dc rectifier with a filter capacitor and then ‘inverted’ back to AC using an inverter. Here, the final AC output may be of a different frequency and magnitude than the input AC of the utility supply. If the input DC is a voltage source, the inverter is called a Voltage Source Inverter (VSI). The simplest DC voltage source for a VSI may be a battery bank or a solar photovoltaic cell stack. An AC voltage supply, after rectification into DC, can also serve as a DC voltage source.

Circuit Diagram:

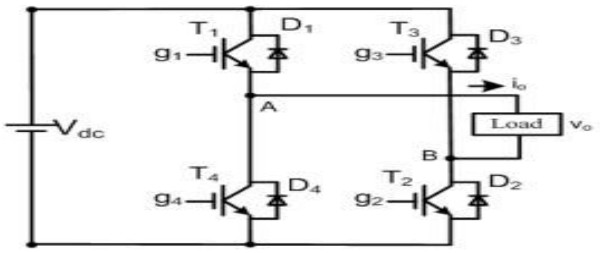


Fig. 1 Single phase voltage source inverter.

Calculations:

To design a single phase invetter we need to calculate some parameters.We need to design a filter that will remove the higher order harmonics.For this the cutoff frequency is taken to be less than or equal to the switching frequency.

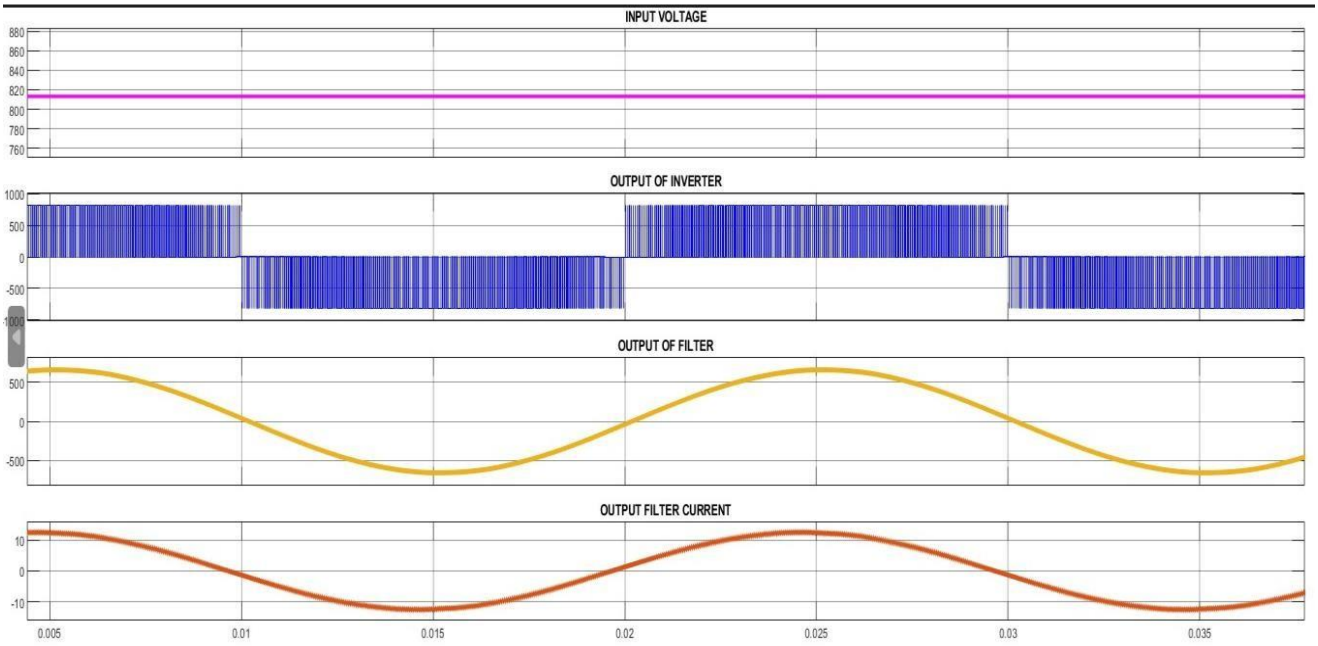
Filter Capacitance C_f. We consider here $L_f = 10\ mH$.
Now we need to calculate $f_{cutoff} = \frac{1}{2\pi\sqrt{LC}}$ OR C_f = 10.13 uF

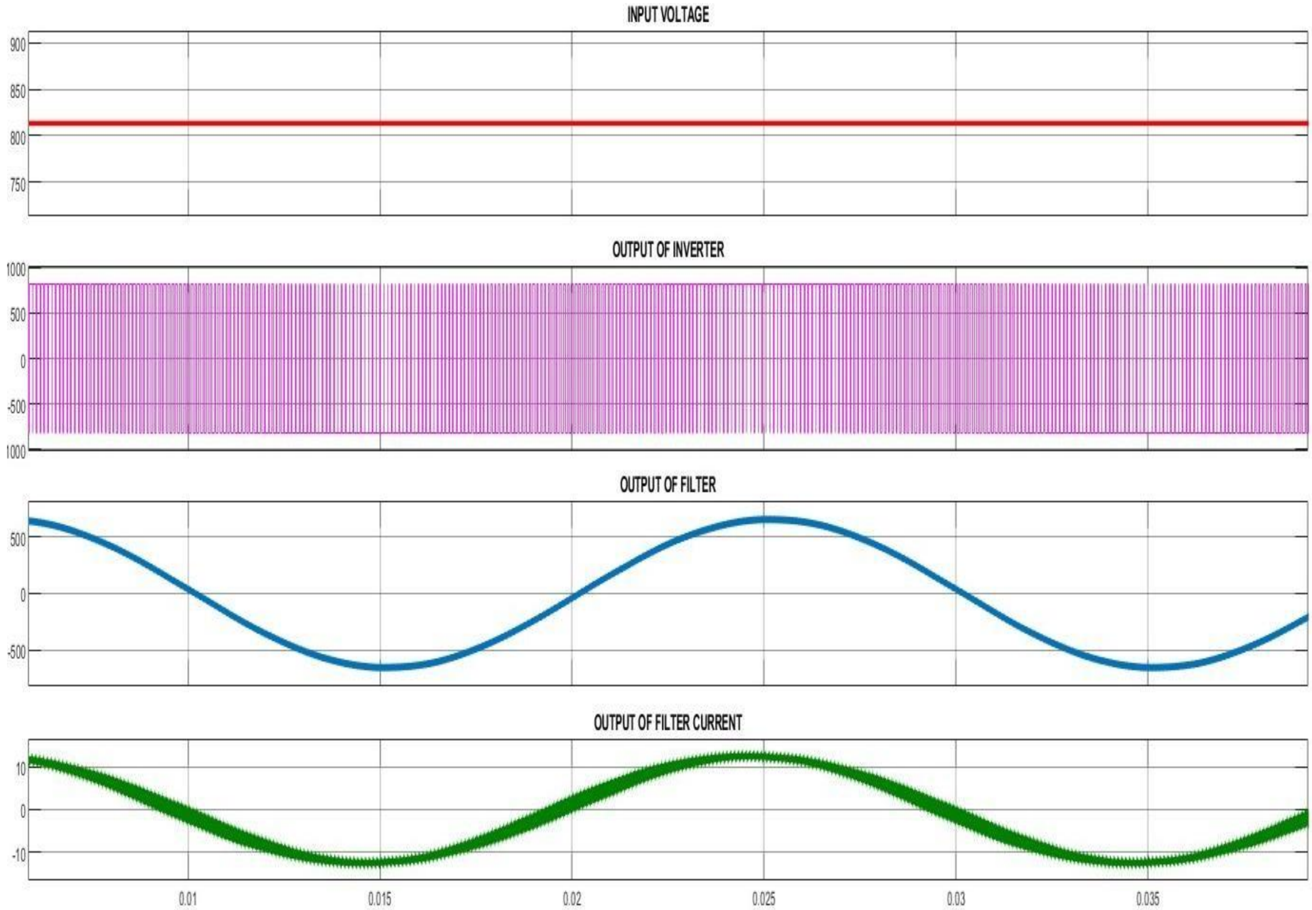
Input DC Voltage :

$V_{dc} = \frac{Vpeak}{m_a}$ or $V_{dc} = 813.172\ Volt$ (for $m_a = 0.4$)
$V_{dc} = \frac{Vpeak}{m_a}$ or $V_{dc} = 406.586\ Volt$ (for $m_a = 0.8$)

These are the parameters computed to design the VSI is both bipolar and unipolar modes of switching.The only difference is switching techniques and the voltage levels in unipolar and bipolar modes of operation.

Simulation Waveforms





Three Phase VSI

Parameter	Three-phase VSI
Output voltage	400 V, 50 Hz
Output Power	10 kW
Switching Frequency	10 kHz
Load type	Resistive, Y-connected
Modulation index	0.4 and 0.8

The main function of this kind of inverter is to change the input of DC to the output of three-phase AC. A basic 3-phase inverter includes 3 single-phase inverter switches where each switch can be connected to one of the 3 load terminals. Generally, the three arms of this inverter will be delayed with 120-degree angle to generate a 3-phase AC supply.
The switches used in the inverter have a 50% ratio and switching can occur after every 60 degrees angle. The switches like S1, S2, S3, S4, S5, and S6 will complement each other. In this, three inverters with single-phase are placed across a similar DC source. The pole voltages within the three-phase inverter are equivalent to the pole voltages within the half-bridge inverter with a single phase.'

The two types of inverters like the single-phase and three-phase include two conduction modes like 180 degrees conduction mode and 120 degrees conduction mode.

180° Conduction Mode

In this conduction mode, each device will be in conduction with 180° where they are activated at intervals with 60°. The output terminals like A, B, and C are connected to the star or 3 phase delta connection of the load.

Balanced Load
Balanced Load
The balanced load for three phases is explained in the following diagram. For 0 to 60 degrees, the switches like S1, S5 & S6 are in conduction mode. The load terminals like A & C are linked to the source on its positive point, whereas the

B terminal is associated with the source on its negative point. Furthermore, the R/2 resistance is available among the two ends of neutral & the positive whereas R resistance is available among the neutral & the negative terminal.

In this mode, the voltages of load are given in the following.

VAN = V/3,

VBN = −2V/3,

VCN = V/3

The line voltages are given in the following.

VAB = VAN − VBN = V,

VBC = VBN − VCN = −V,

VCA = VCN − VAN = 0

120° Conduction Mode

In this type of conduction mode, every electronic device will be in a conduction state with 120°. It is apt for a delta connection within a load as it results within a six-step kind of waveform across one of its phases. So, at any instant, only these devices will conduct every device that will conduct at 120° only.

The connection of ‘A’ terminal on the load can be done through the positive end whereas the B terminal can be connected toward the negative terminal of the source. The ‘C’ terminal on the load will be in conduction is known as the floating state. Also, the phase voltages are equivalent to the voltages of load which is given below.

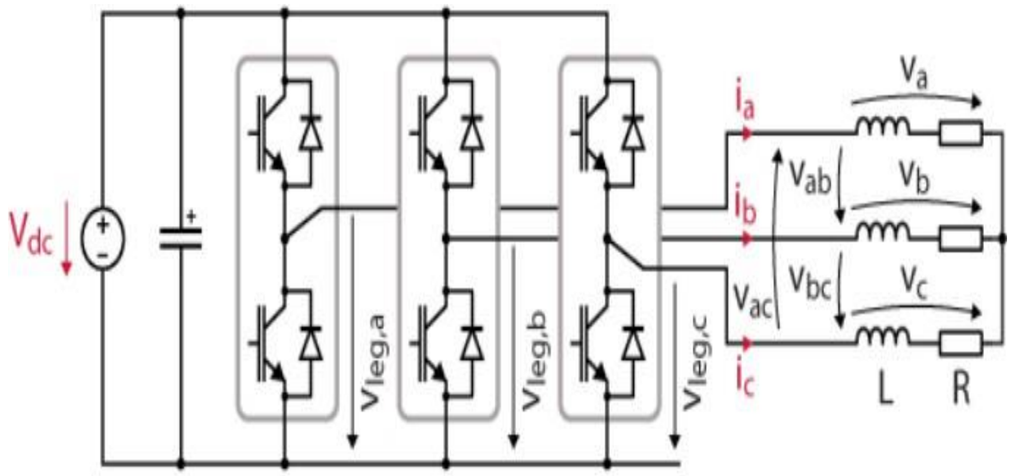
Phase voltages are equal to line voltages, so

VAB = V

VBC = −V/2

VCA = −V/2

Circuit Diagram



Topology overview of a three-phase voltage source inverter (VSI).

Calculations:

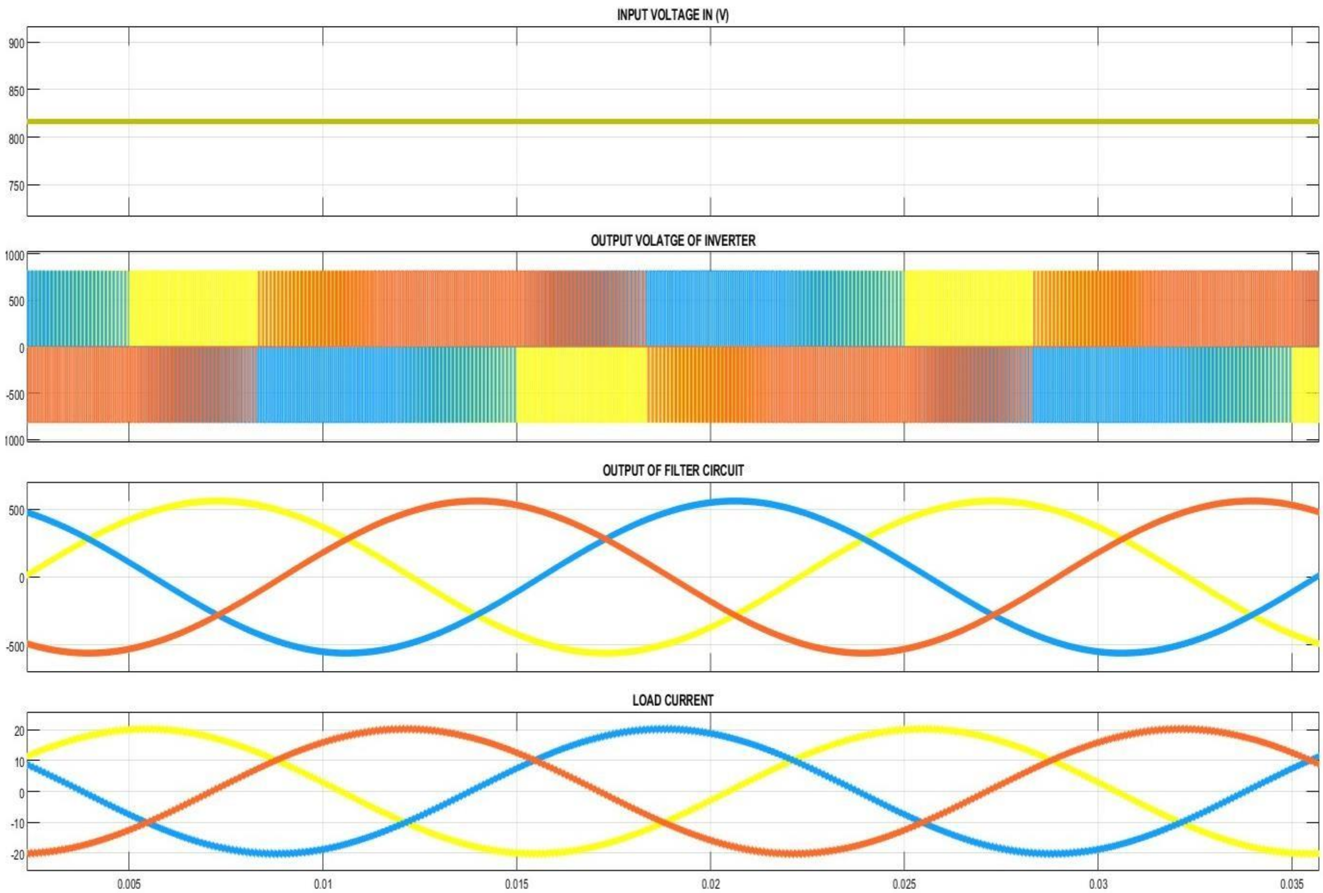
We are using same L_f and C_f values for three phase calculation.

Input DC Voltage :

$V_{dc} = \frac{2*Vpeak}{\sqrt{3}*m_a}$ or $V_{dc} = 1633\, Volt$ (for $m_a = 0.4$)

$V_{dc} = \frac{2*Vpeak}{\sqrt{3}*m_a}$ or $V_{dc} = 816.49\, Volt$ (for $m_a = 0.8$)

Simulation Waveforms



Conclusions :

From this experiment, we got to understand the modulation techniques in single-phase and three-phase inverters. We got to understand how the filter circuits help to remove higher-order harmonics and help us to get a smooth balanced Sinusoidal output.

Name: Arya Mallick
Roll number: 234102501
Experiment 8

- **Objective**

The objective of this experiment is to find the open-loop transfer functions of basic dcdc converters and to analyze the same using bode plots.

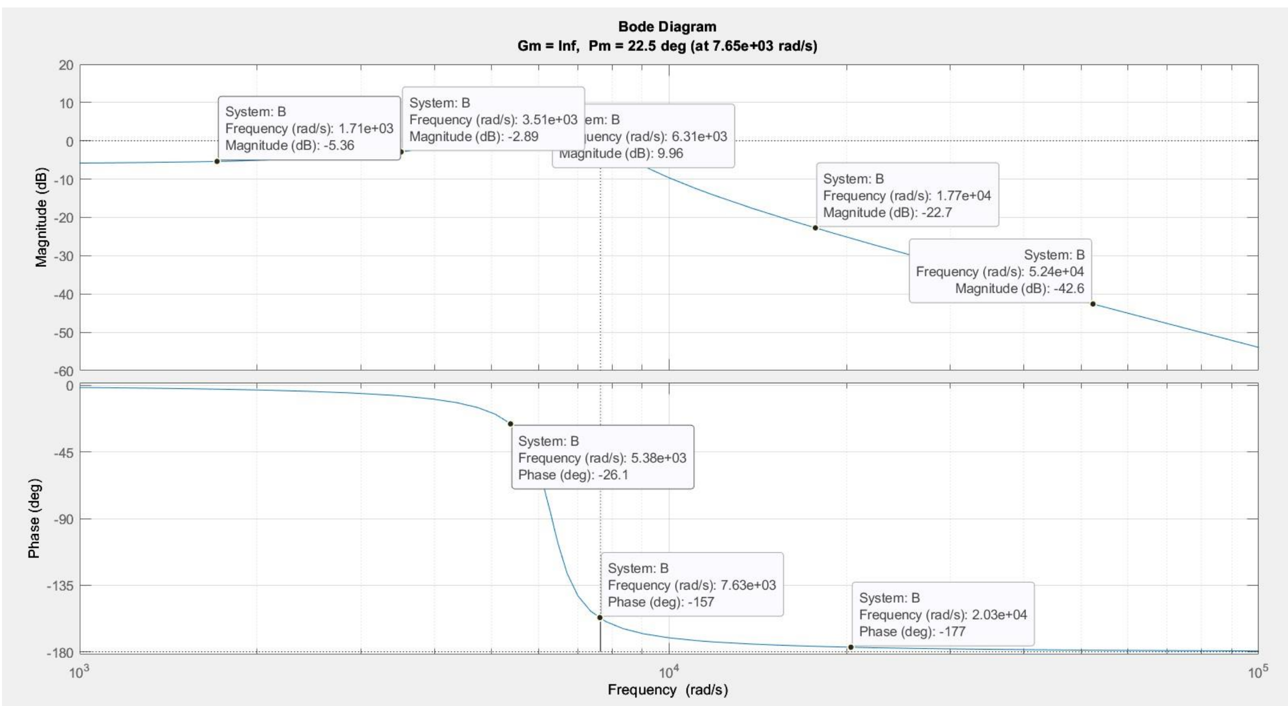
Parameter	**Buck Converter**	**Boost Converter**	**Buck-Boost Converter**
Input voltage	48 V	24 V	100 V
Duty Ratio	0.5	0.5	1/3
Load Resistance	5 Ω	5 Ω	25 Ω
Switching frequency	50 kHz	50 kHz	50 kHz
Capacitor	200 µF	200 µF	200 µF
Inductor	L = 5*Lcritical	L = 5*Lcritical	L = 5*Lcritical

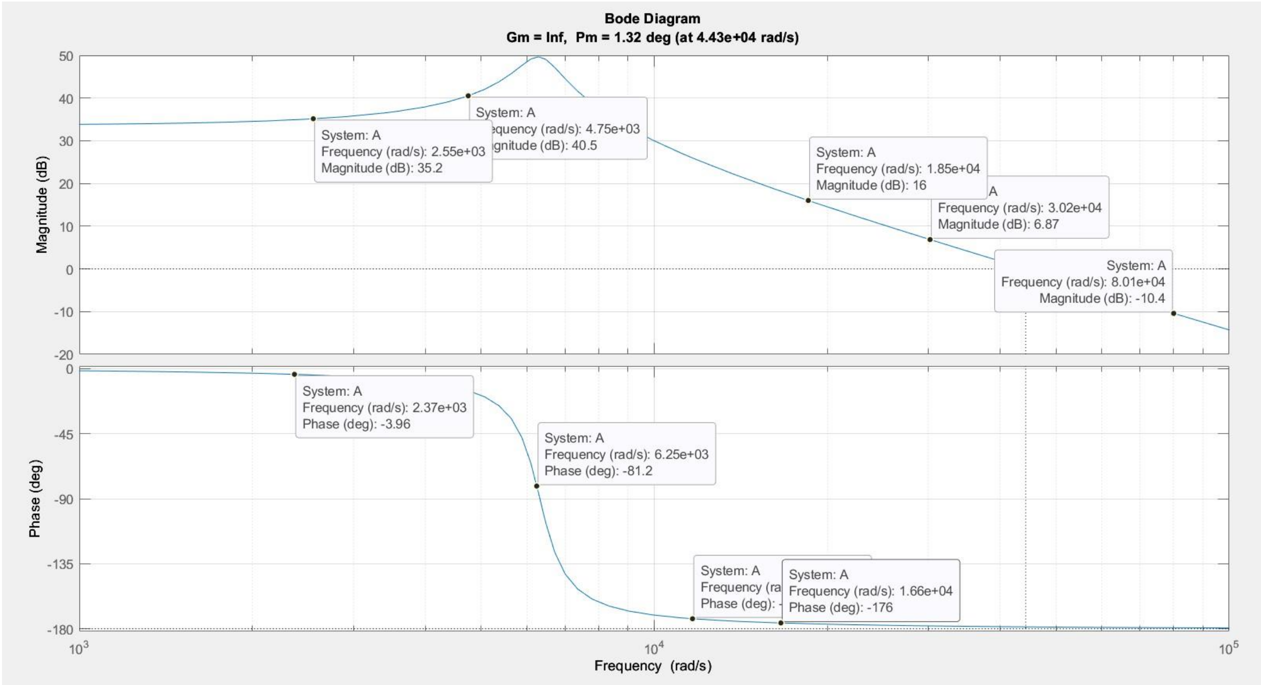
- **Code for Buck Converter:**

```
Vin=48;
D=0.5;
R=5;
fs=50*10^3;
C=200*10^-6;
Lcrit=(1-D)*R/(2*fs);
L=5*Lcrit
%now the transfer function is given by%
A=tf(Vin,[L*C L/R 1])
gainA=dcgain(A)
B=tf(D,[L*C L/R 1])
```

```
gainB=dcgain(B)
figure(1)
bode(A)
margin(A)
figure(2)
bode(B)
margin(B)
figure(3)
pzplot(A)
figure(4)
pzplot(B)
```

- **SIMULATION PLOTS** :





FREQUENCY DOMAIN PARAMETERS

GainMargin: Inf
GMFrequency: Inf
PhaseMargin: [161.0539 32.2379]
PMFrequency: [3.2468e+03 5.3347e+03]
DelayMargin: [8.6575e-04 1.0547e-04]
DMFrequency: [3.2468e+03 5.3347e+03]
Stable: 1

- **Code for Boost Converter:**

```
Vin=24;
D=0.5;
Doff=1-D;
Vo=Vin/Doff;
R=10;
fs=50*10^3;
C=200*10^-6;
Lcrit=(1-D)^2*D*R/(2*fs);
L=5*Lcrit;
IL=Vo/(R*Doff);
%now the transfer function is given by%
A=tf([-L*IL Doff*Vo],[L*C L/R Doff^2])
gainA=dcgain(A)
B=tf(Doff,[L*C L/R Doff^2])
```

```
gainB=dcgain(B)
```

```
figure(1)
bode(A)
margin(A)
figure(2)
bode(B)
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figure(3)
pzplot(A)
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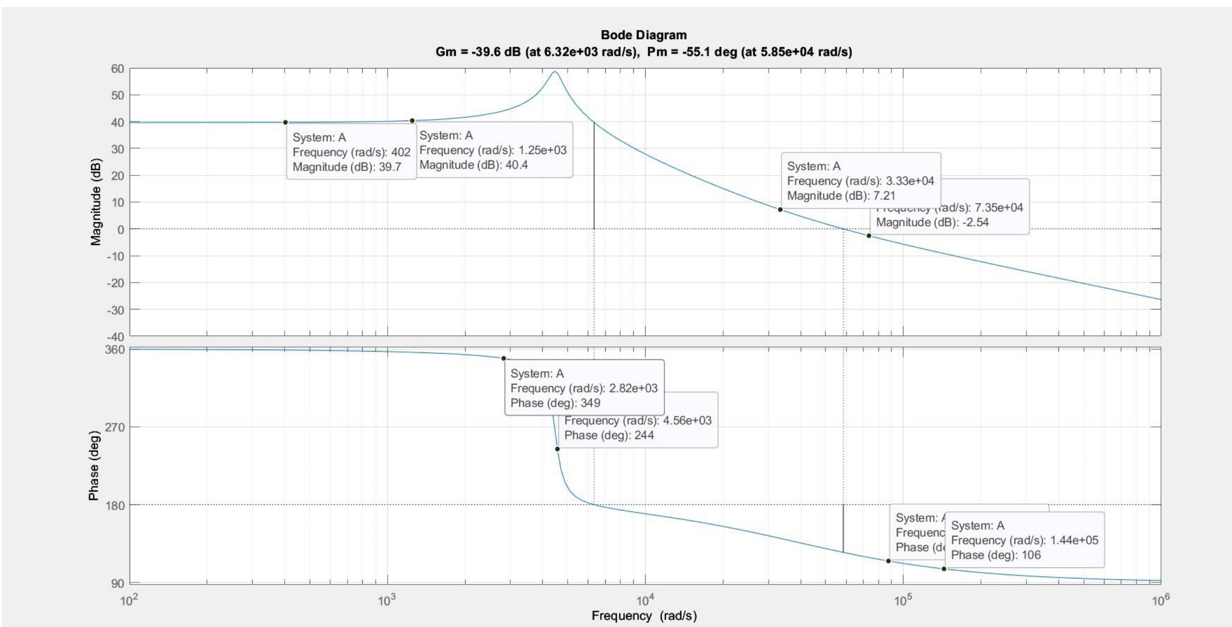
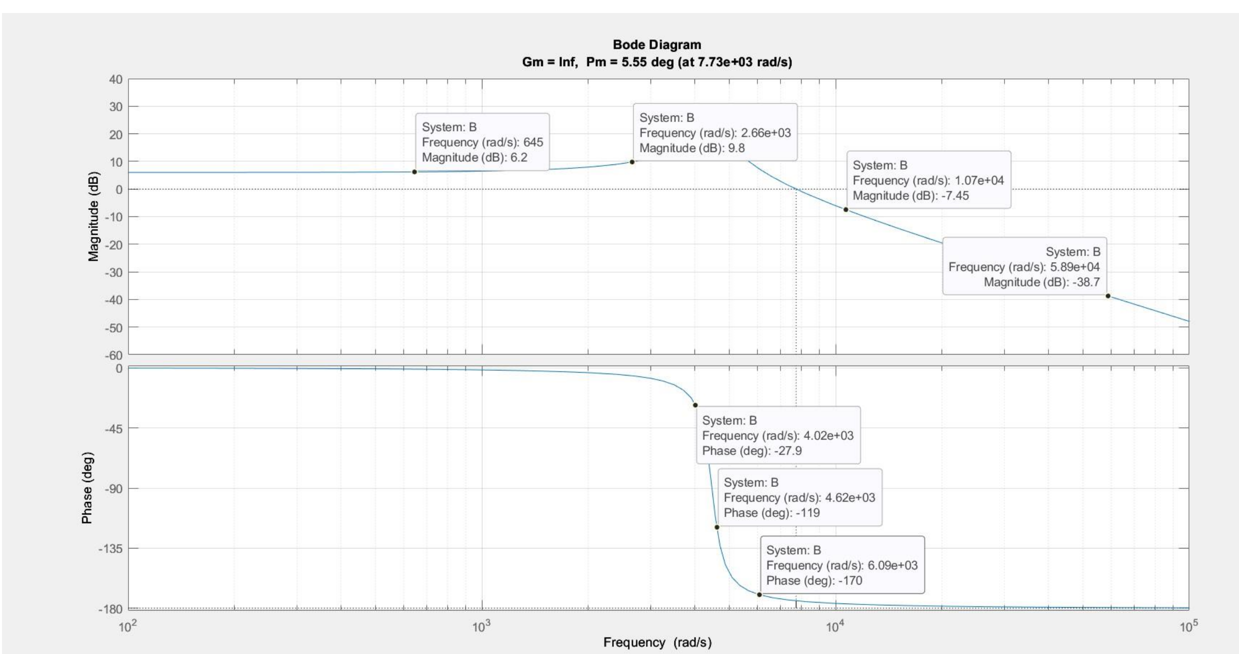
```

- **SIMULATION PLOTS:**





FREQUENCY DOMAIN PARAMETERS

GainMargin: Inf
GMFrequency: Inf
PhaseMargin: 5.5476
PMFrequency: 7.7339e+03
DelayMargin: 1.2519e-05
DMFrequency: 7.7339e+03
Stable: 1

- **Code for Buck-Boost Converter:**

```
Vin=100;
D=1/3;
Doff=1-D;
Vo=Vin*D/Doff
R=25;
fs=50*10^3;
C=200*10^-6;
Lcrit=(1-D)^2*R/(2*fs);
L=5*Lcrit;
%now the transfer function is given by%
A=(-D/Doff)*tf(1,[L*C/Doff^2 L/(R*Doff^2) 1])
gainA=dcgain(A)
B=(Vo*D/Doff)*tf([-L*D/(R*Doff^2) 1],[L*C/Doff^2 L/(R*Doff^2) 1])
gainB=dcgain(B)
figure(1)
bode(A)
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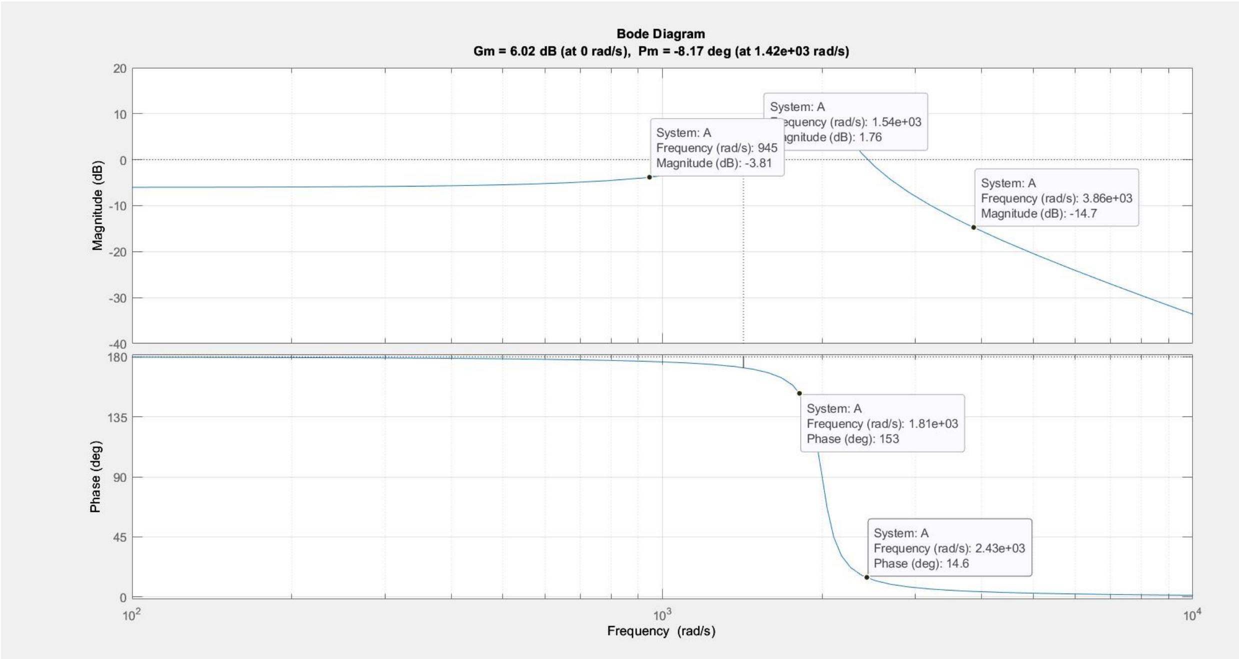
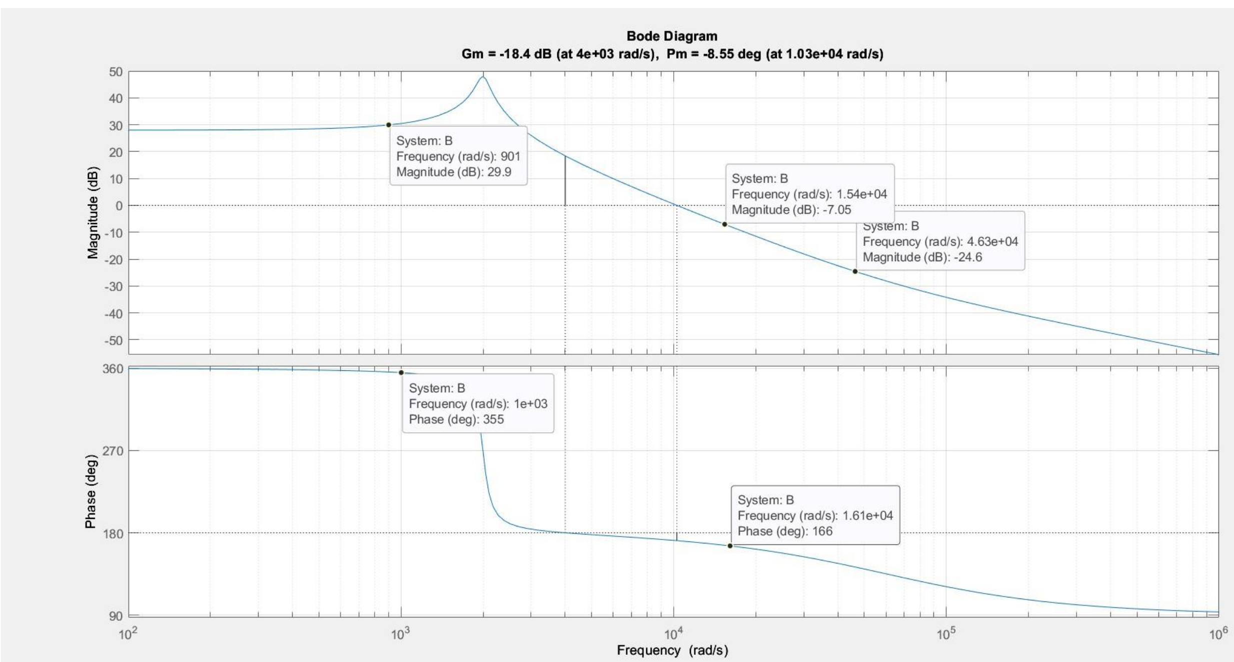
- **SIMULATION PLOTS:**





FREQUENCY DOMAIN PARAMETERS

GainMargin: 0.1200
GMFrequency: 4.0002e+03
PhaseMargin: -8.5513
PMFrequency: 1.0268e+04
DelayMargin: 5.9738e-04
DMFrequency: 1.0268e+04
Stable: 0

Conclusions:

From this experiment we got a brief idea about the nature of bode plots and frequency domain parameters for buck, boost and buck boost converters. The experiments proved a great insight to our practical knowledge in understating the stability of each of the converters and the poles and zeros which reflect the stability of the system.

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Experiment 8

- **Objective**

The objective of this experiment is to find the open-loop transfer functions of basic dcdc converters and to analyze the same using bode plots.

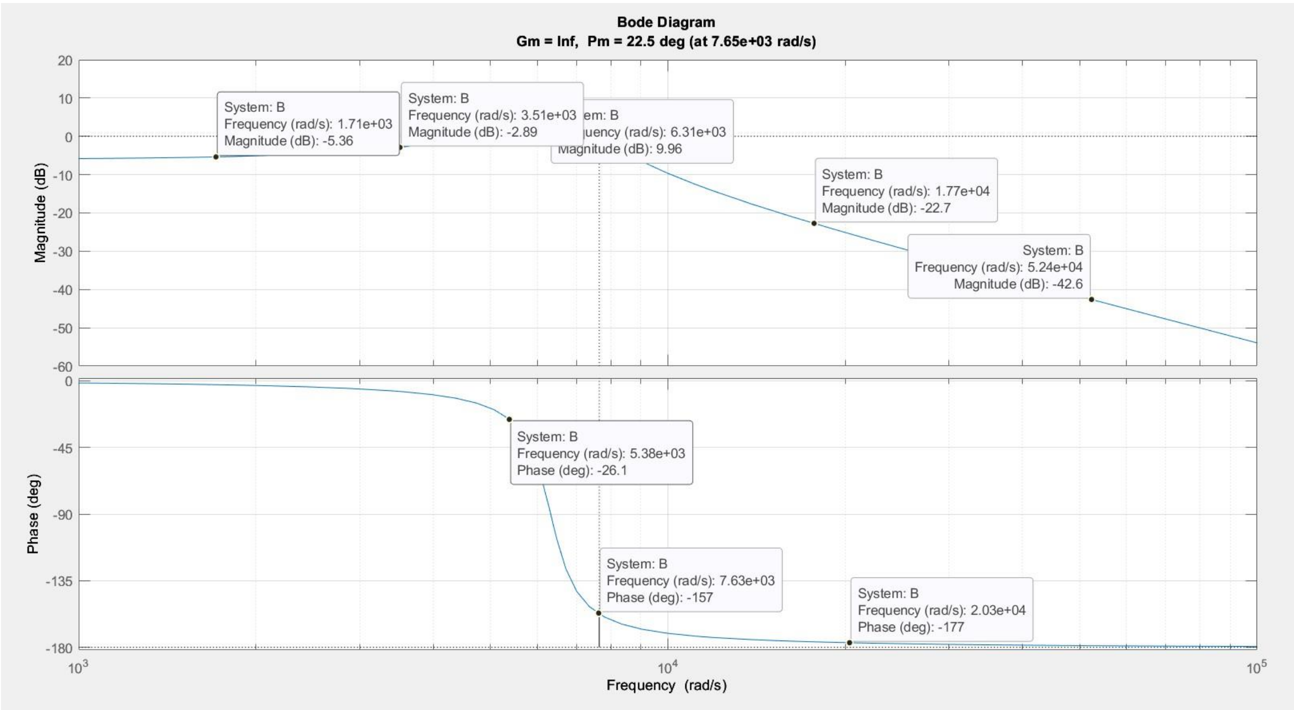
Parameter	Buck Converter	Boost Converter	Buck-Boost Converter
Input voltage	48 V	24 V	100 V
Duty Ratio	0.5	0.5	1/3
Load Resistance	5 Ω	5 Ω	25 Ω
Switching frequency	50 kHz	50 kHz	50 kHz
Capacitor	200 Mf	200 μF	200 μF
Inductor	L = 5*Lcritical	L = 5*Lcritical	L = 5*Lcritical

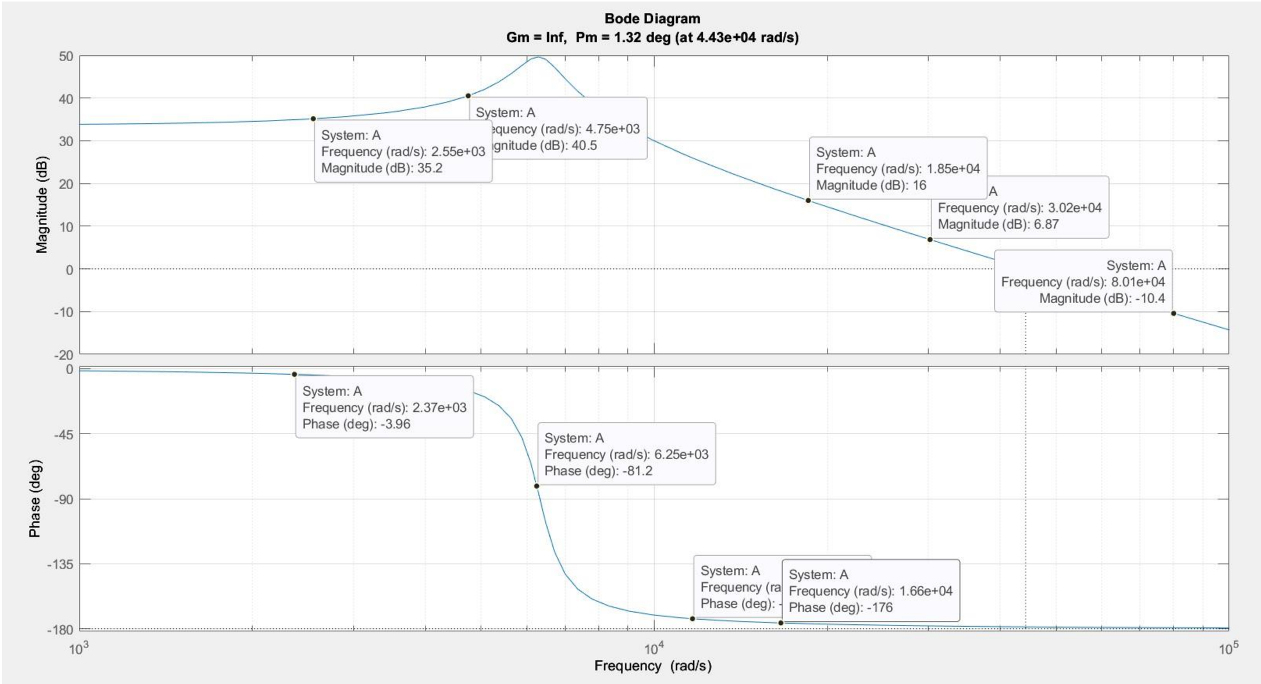
- **Code for Buck Converter:**

```
Vin=48;
D=0.5;
R=5;
fs=50*10^3;
C=200*10^-6;
Lcrit=(1-D)*R/(2*fs);
L=5*Lcrit
%now the transfer function is given by%
A=tf(Vin,[L*C L/R 1])
gainA=dcgain(A)
B=tf(D,[L*C L/R 1])
```

```
gainB=dcgain(B)
figure(1)
bode(A)
margin(A)
figure(2)
bode(B)
margin(B)
figure(3)
pzplot(A)
figure(4)
pzplot(B)
```

- **SIMULATION PLOTS** :





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GMFrequency: Inf
PhaseMargin: [161.0539 32.2379]
PMFrequency: [3.2468e+03 5.3347e+03]
DelayMargin: [8.6575e-04 1.0547e-04]
DMFrequency: [3.2468e+03 5.3347e+03]
Stable: 1

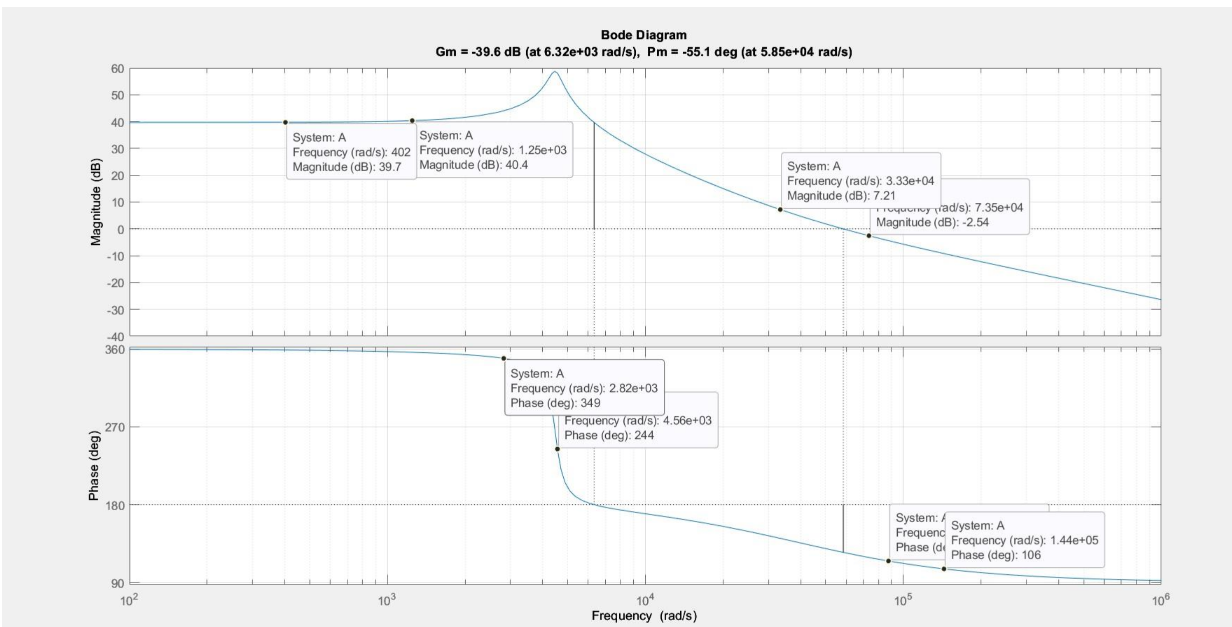
- **Code for Boost Converter:**

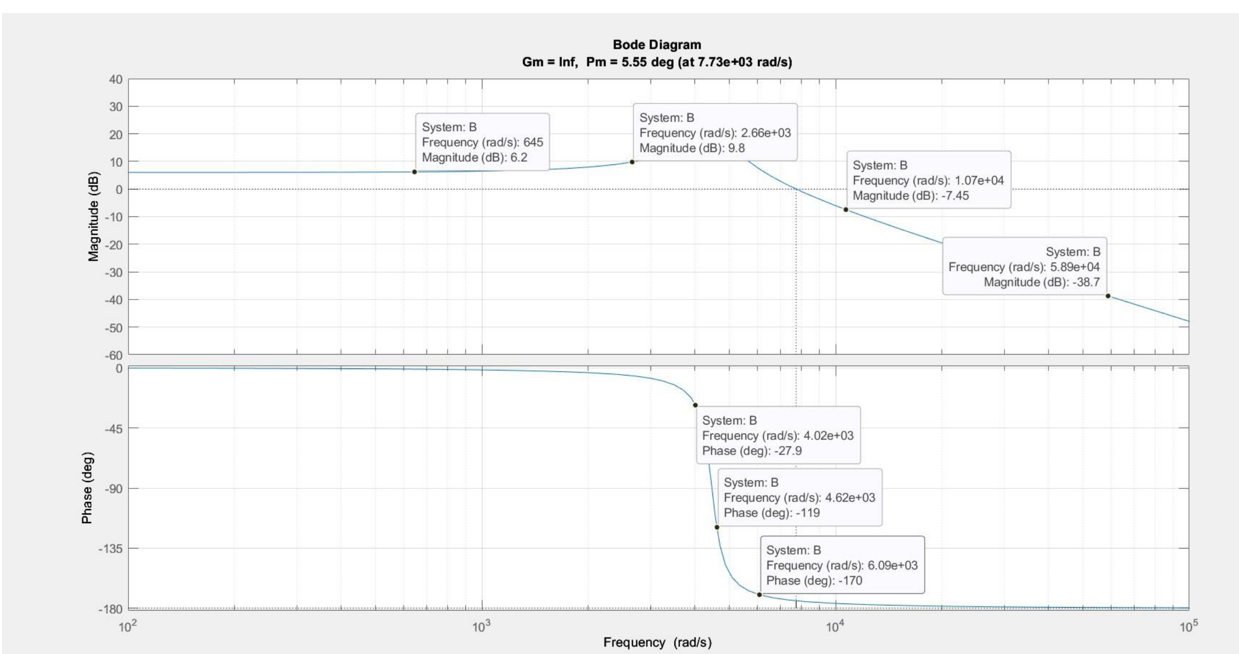
```
Vin=24;
D=0.5;
Doff=1-D;
Vo=Vin/Doff;
R=10;
fs=50*10^3;
C=200*10^-6;
Lcrit=(1-D)^2*D*R/(2*fs);
L=5*Lcrit;
IL=Vo/(R*Doff);
%now the transfer function is given by%
A=tf([-L*IL Doff*Vo],[L*C L/R Doff^2])
gainA=dcgain(A)
B=tf(Doff,[L*C L/R Doff^2])
```

```
gainB=dcgain(B)
```

```
figure(1)
bode(A)
margin(A)
figure(2)
bode(B)
margin(B)
figure(3)
pzplot(A)
figure(4)
pzplot(B)
```

- **SIMULATION PLOTS:**





FREQUENCY DOMAIN PARAMETERS

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PhaseMargin: 5.5476
PMFrequency: 7.7339e+03
DelayMargin: 1.2519e-05
DMFrequency: 7.7339e+03
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- **Code for Buck-Boost Converter:**

```
Vin=100;
D=1/3;
Doff=1-D;
Vo=Vin*D/Doff
R=25;
fs=50*10^3;
C=200*10^-6;
Lcrit=(1-D)^2*R/(2*fs);
L=5*Lcrit;
%now the transfer function is given by%
A=(-D/Doff)*tf(1,[L*C/Doff^2 L/(R*Doff^2) 1])
gainA=dcgain(A)
B=(Vo*D/Doff)*tf([-L*D/(R*Doff^2) 1],[L*C/Doff^2 L/(R*Doff^2) 1])
gainB=dcgain(B)
figure(1)
bode(A)
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margin(B)
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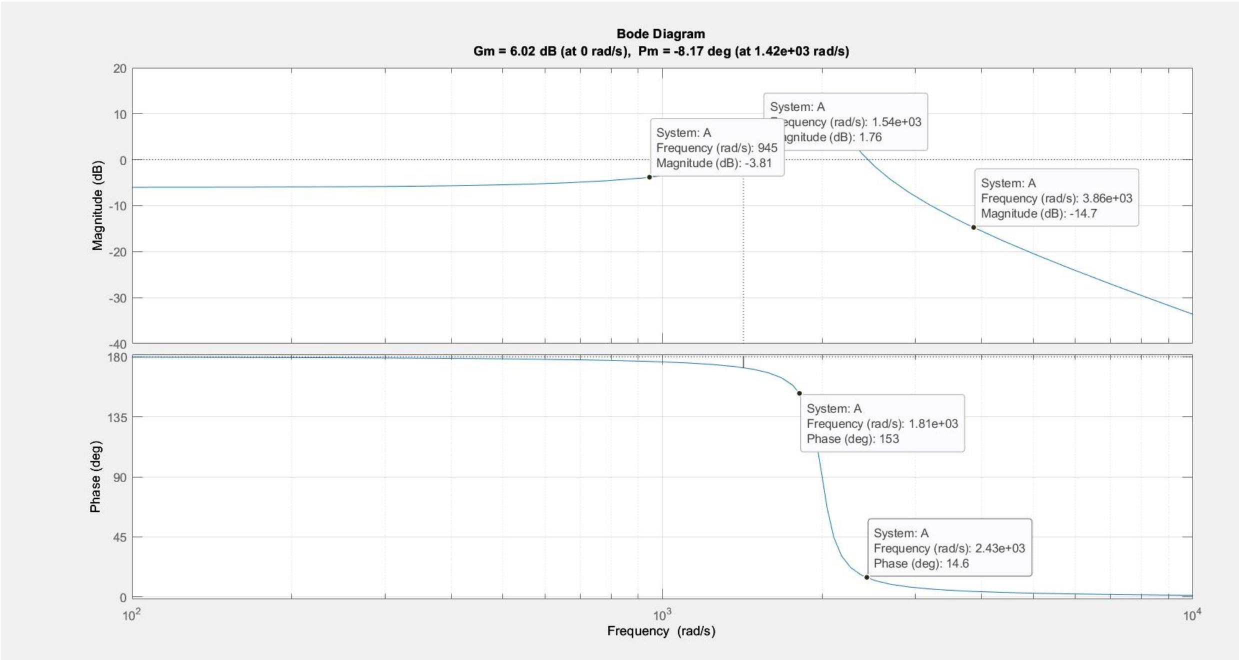
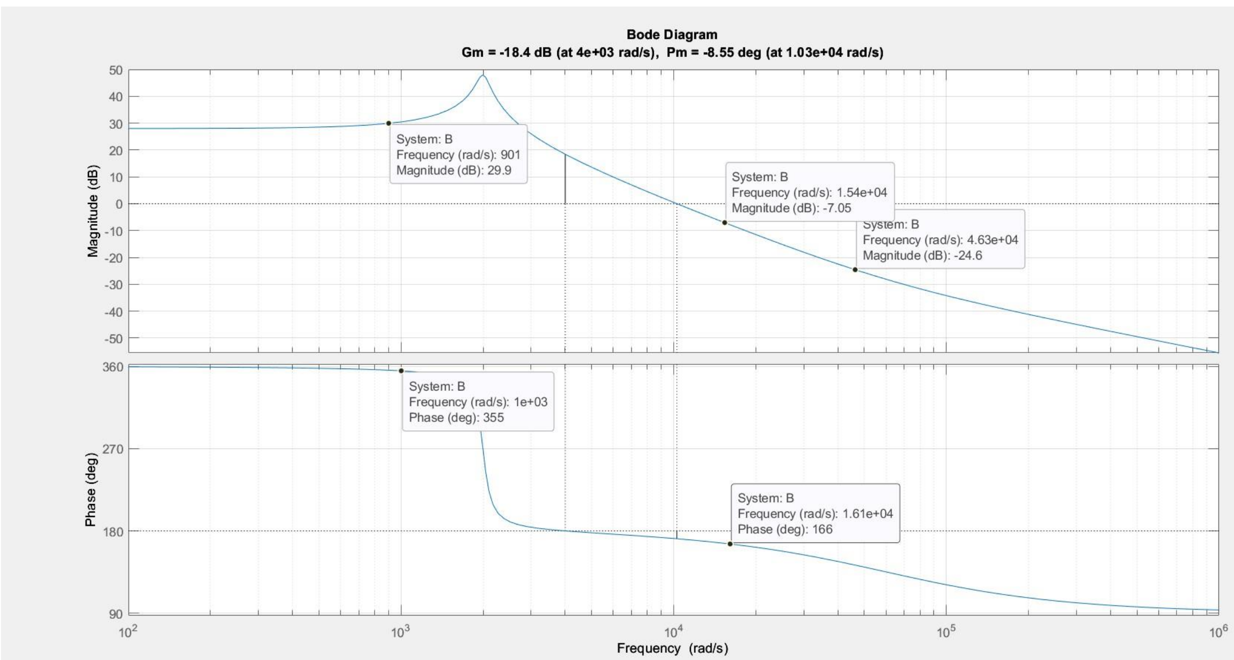
```

- **SIMULATION PLOTS:**





FREQUENCY DOMAIN PARAMETERS

GainMargin: 0.1200
GMFrequency: 4.0002e+03
PhaseMargin: -8.5513
PMFrequency: 1.0268e+04
DelayMargin: 5.9738e-04
DMFrequency: 1.0268e+04
Stable: 0

Conclusions:

From this experiment we got a brief idea about the nature of bode plots and frequency domain parameters for buck, boost and buck boost converters. The experiments proved a great insight to our practical knowledge in understating the stability of each of the converters and the poles and zeros which reflect the stability of the system.

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Experiment 9: Output voltage Regulation of Buck Converter using Type-II Compensator

- Objective

The objective of this experiment is to design a Type-II compensator for a buck converter to regulate its output voltage.

- Parameters

Parameter	Value
Input voltage V_{in}	24 V
Capacitor C	100 µF
Switching frequency f_{sw}	100 kHz
Capacitor C	200 µF
Load Resistance R	2 Ω
Desired Gain cross-over frequency of compensated system	100 Hz
Desired Phase Margin	90 to 120 degrees

Buck Converter

- Circuit Diagram

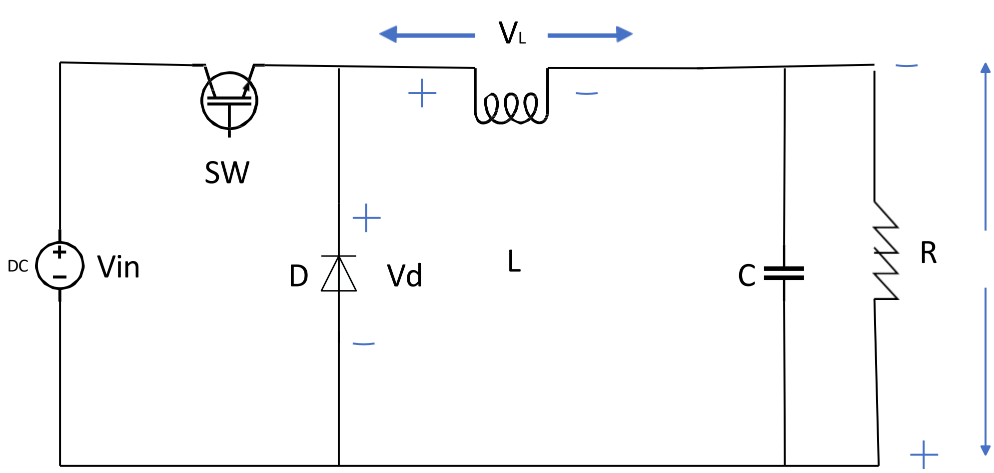


Fig. Buck convertor

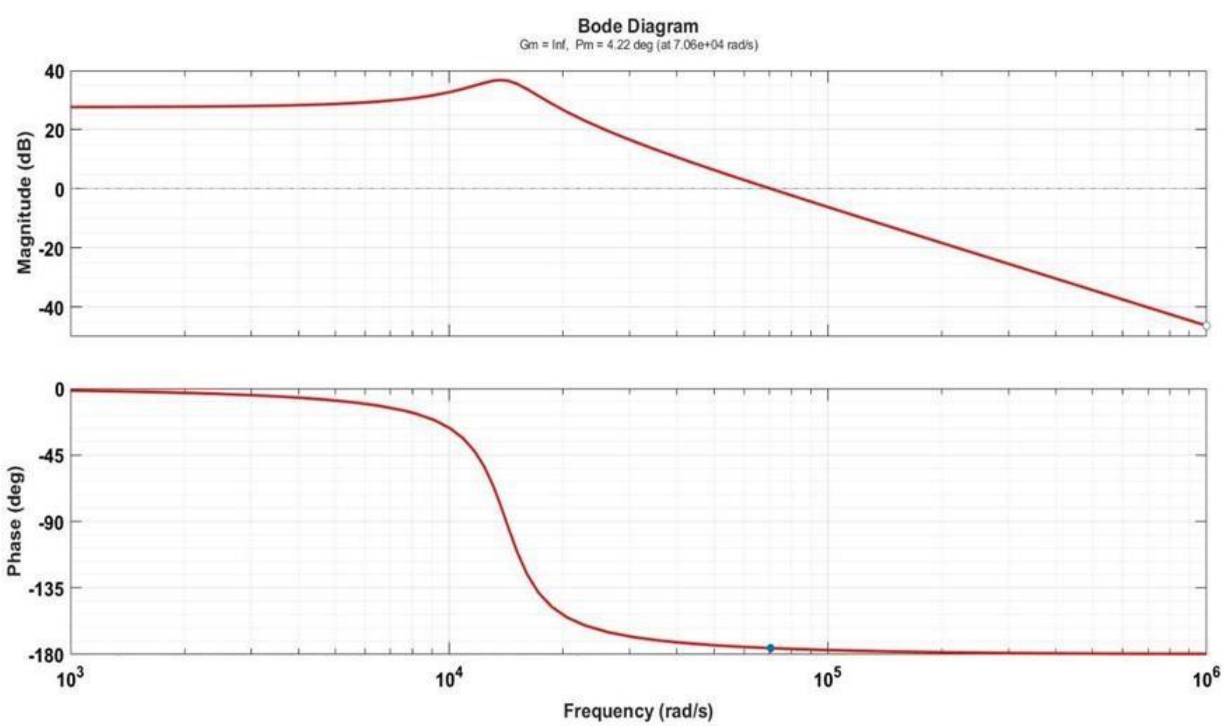
➢ Theory

To control the different parameters in a buck converter, the dynamic model of the converteris required. Through dynamic modelling, we derive the transfer function of the converter. The buck converter small signal output voltage v_o depends on input voltage v_{in} and dutycycle d. The transfer functions with respect to duty cycle is given as:

Designing of Compensator by K factor Method :

1. Get the plant transfer function. From MATLAB script results,
2. Get the bode plot of the plant.

1. Choose the desired gain cross-over frequency. In this case the desired gain-crossover frequency is $f_c = 100\ Hz$.
2. Choose the desired phase margin. In this case the desired phase margin is $PM = 100°$.
3. Calculate the required mid-band gain.



$$G_{MB} = \frac{1}{gain\ of\ G_p\ at\ f_c}$$

where G_p is the plant transfer function. From the bode plot, $|G_p|_{w_c} = 24.$

$$G_{MB} = \frac{1}{24}$$

$$G_{MB} = 0.0146$$

4. Calculate the phase boost.

$$Phase\ boost = PM - \emptyset|_{f_c} - 90°$$

where $\emptyset$ is the angle of G_p at f_c. From the bode plot, $\emptyset|_{f_c} = -0.92$.

$$Phase\ boost = 100° + 0.92 - 90$$

$$Phase\ boost = 50.92°$$

5. Find the value of k.

$$k = \tan\left[45° + \frac{phase\ boost}{2}\right]$$

$$k = \tan\left[45° + \frac{50.92°}{2}\right]$$

$$k = 1.211$$

6. Now,

$$w_z = \frac{2\pi f_c}{k}$$

$$w_z = \frac{2\pi \times 100}{1.211}$$

$$w_z = 518.842$$

And,

$$w_p = 2\pi f_c k$$

$$w_p = 2\pi \times 100 \times 1.211$$

$$w_p = 760.893$$

7. The transfer function of the compensator is given by the equation

$$G_{cs}(s) = \frac{G_{MB}\left(1+\frac{w_z}{s}\right)}{\left(1+\frac{s}{w_p}\right)}$$

$$G_{cs}(s) = \frac{0.04168s + 21.63}{0.001314s^2 + s}$$

This is the transfer function of the compensator for the plant designed according to the given parameters.

- MATLAB commands

```
11/5/24 11:42 PM  D:\MTech\Semester 1\Power El...\sc2_1.m   1 of 1

Vin=24;
R=2;
fs=100*10^3;
C=100*10^-6;
L=50*10^-6;
%now the transfer function is given by%
Gp=tf(Vin,[L*C L/R 1])
Gcs=tf([0.04168 0.04168*518.8427],[1/760.8937 1 0])
Cm=Gp*Gcs
figure(1)
bode(Gp)
margin(Gp)
figure(2)
bode(Gcs)
margin(Gcs)
figure(3)
bode(Cm)
margin(Cm)
```

- **MATLAB Command Results**

```
MATLAB Command Window                                          Page 1

>> sc2_1

Gp =

            24
  -------------------------
  5e-09 s^2 + 2.5e-05 s + 1

Continuous-time transfer function.
Model Properties

Gcs =

  0.04168 s + 21.63
  -----------------
  0.001314 s^2 + s

Continuous-time transfer function.
Model Properties

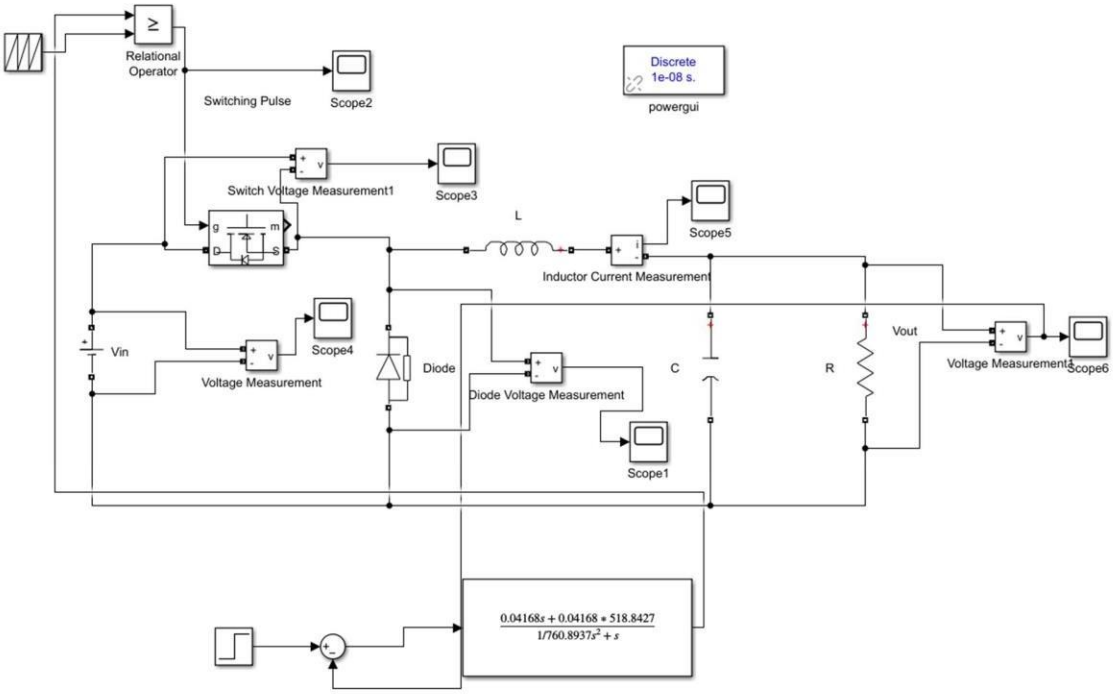
Cm =

                     s + 519
  ------------------------------------------------
  6.571e-12 s^4 + 3.786e-08 s^3 + 0.001339 s^2 + s

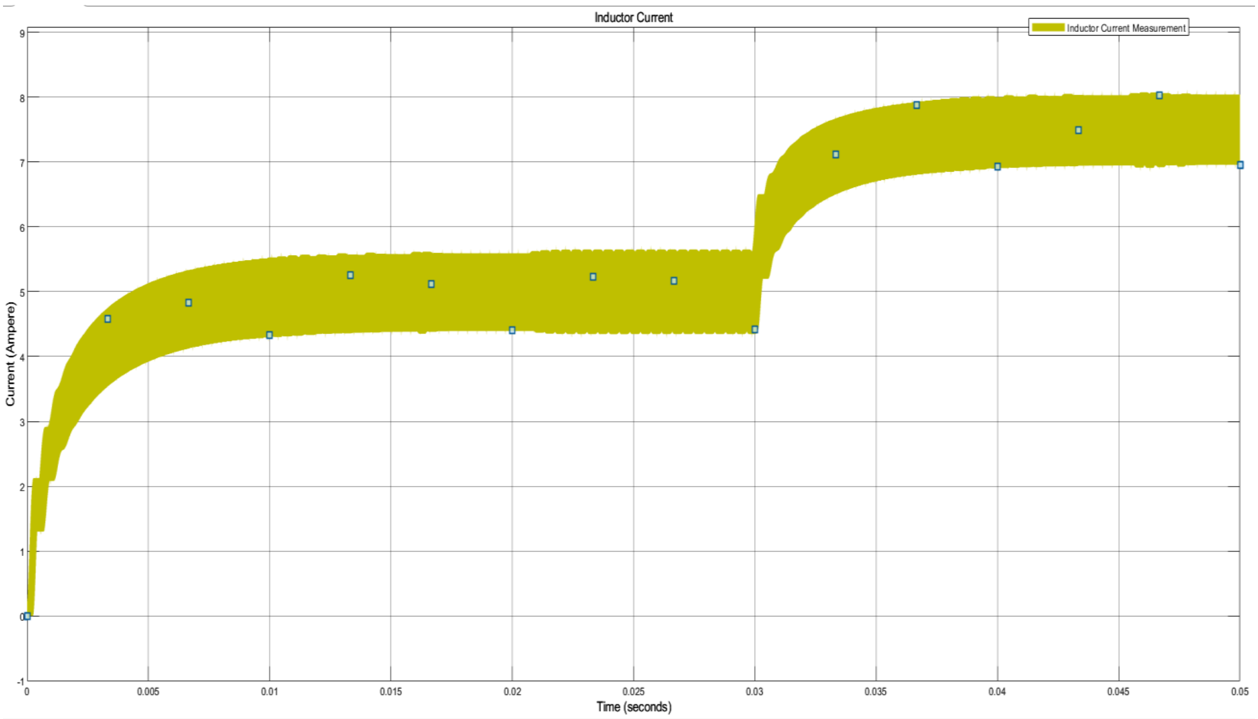
Continuous-time transfer function.
Model Properties
```

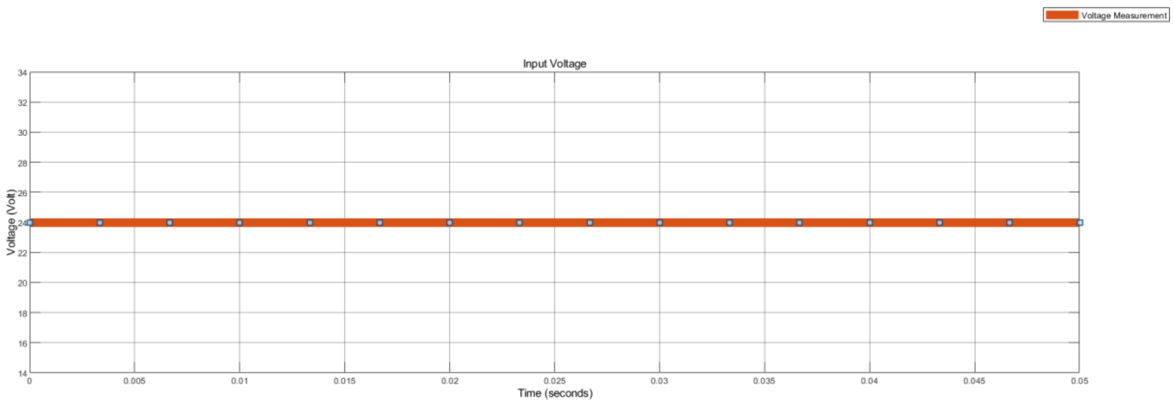
In the results shown above, $Cm(s) = G_{\mathrm{p}}(s)G_{\mathrm{cs}}(s)$.

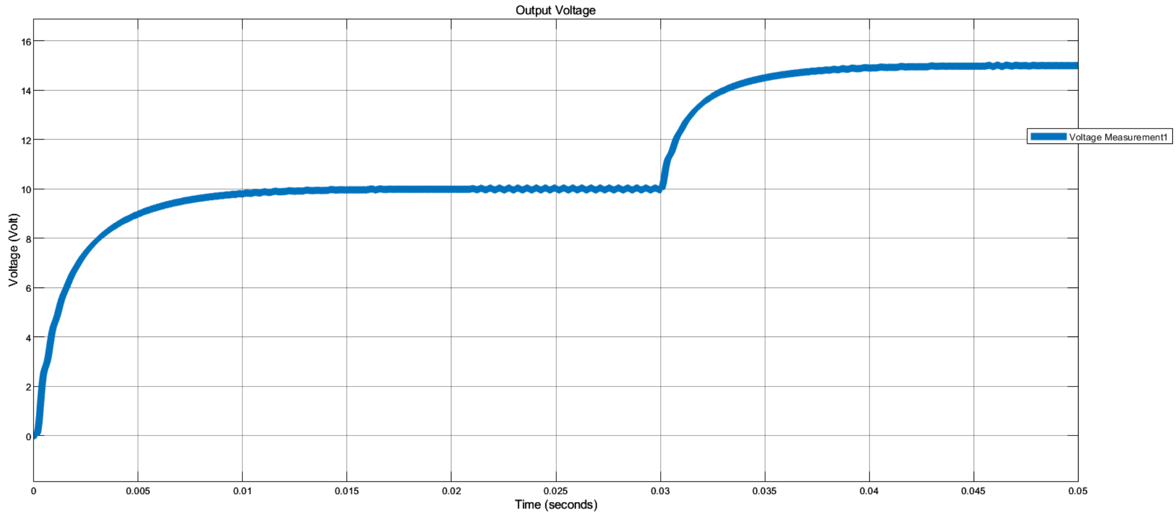
- MATLAB/SIMULINK simulation



We checked the step response of the above converter by employing the compensator derived above. The buck converter given above has the transfer function $G_{\mathrm{p}}(s)$.

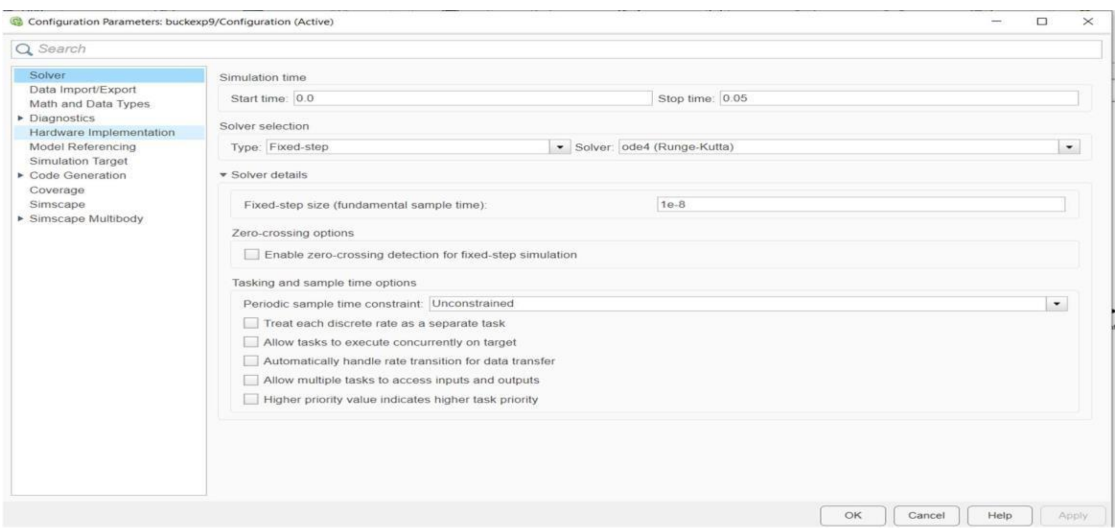






The reference voltage to the control system was changed from 12 V to 15 V at $t = 0.03\ sec$.

- Simulation Parameters



- **Conclusions :** We have learnt in depth how to design a type 2 Compensator and get the desired output for a buck converter.