BUCK-BOOST CURRENT MODE CONTROL CONVERTER

SHUBHAM RAJ 2023EEM1052
SATYAM SINGH 2023EEM1049

OBJECTIVES:

- 1. SIMULATE A CLOSED LOOP BUCK-BOOST CONVERTER WITH CURRENT MODE CONTROL.
- 2.OBTAIN THE BODE PLOT BEFORE AND AFTER THE CONTROLLER DESIGN AND SHOW THAT A PHASE MARGIN OF 40 DEGREE IS ACHIEVED.
- 3.DRAW THE NYQUIST PLOT OF OPEN LOOP GAIN AND CONFIRM THE SAME AS IN 2.
- 4. DRAW THE ROOT LOCUS OF THE INDUCTOR SERIES RESISTANCE VARIATION AND SHOW THE LINITS OF THE INDUCTOR SERIES RESISTANCE VARIATION FOR STABLE OPERATION.

PARAMETERS USED

- Vdc=24v
- Vo=30v(let)
- Duty cycle=0.55
- L=10mH
- C=480microF
- R=3.2ohm
- F=37khz
- Vo=(D/1-D)*Vdc
- Io=Vo/R=9.375Amp
- Ripple current<1%
- Ripple voltage=1%
- Inductor current =20.833A

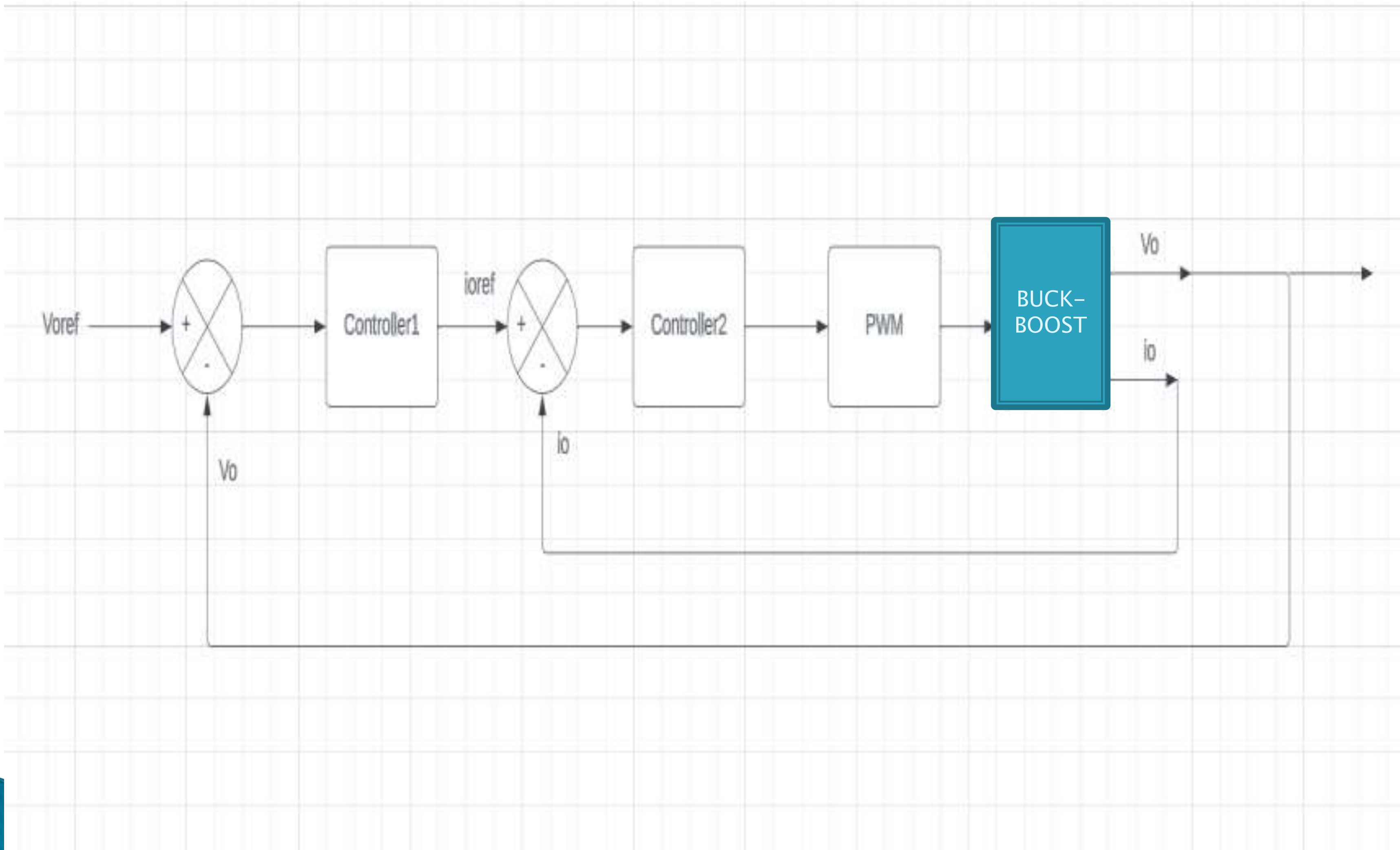
IEEE Reference:- Sliding mode control of PV powered DC/DC Buck-Boost converter with digital signal processor

By Mustafa Ergin ŞAHİN1 , Halil İbrahim OKUMUŞ2 , and Hakan KAHVECİ 2 1 Department of Electrical and Electronics Engineering, RTE University 53100, Rize, TURKEY.

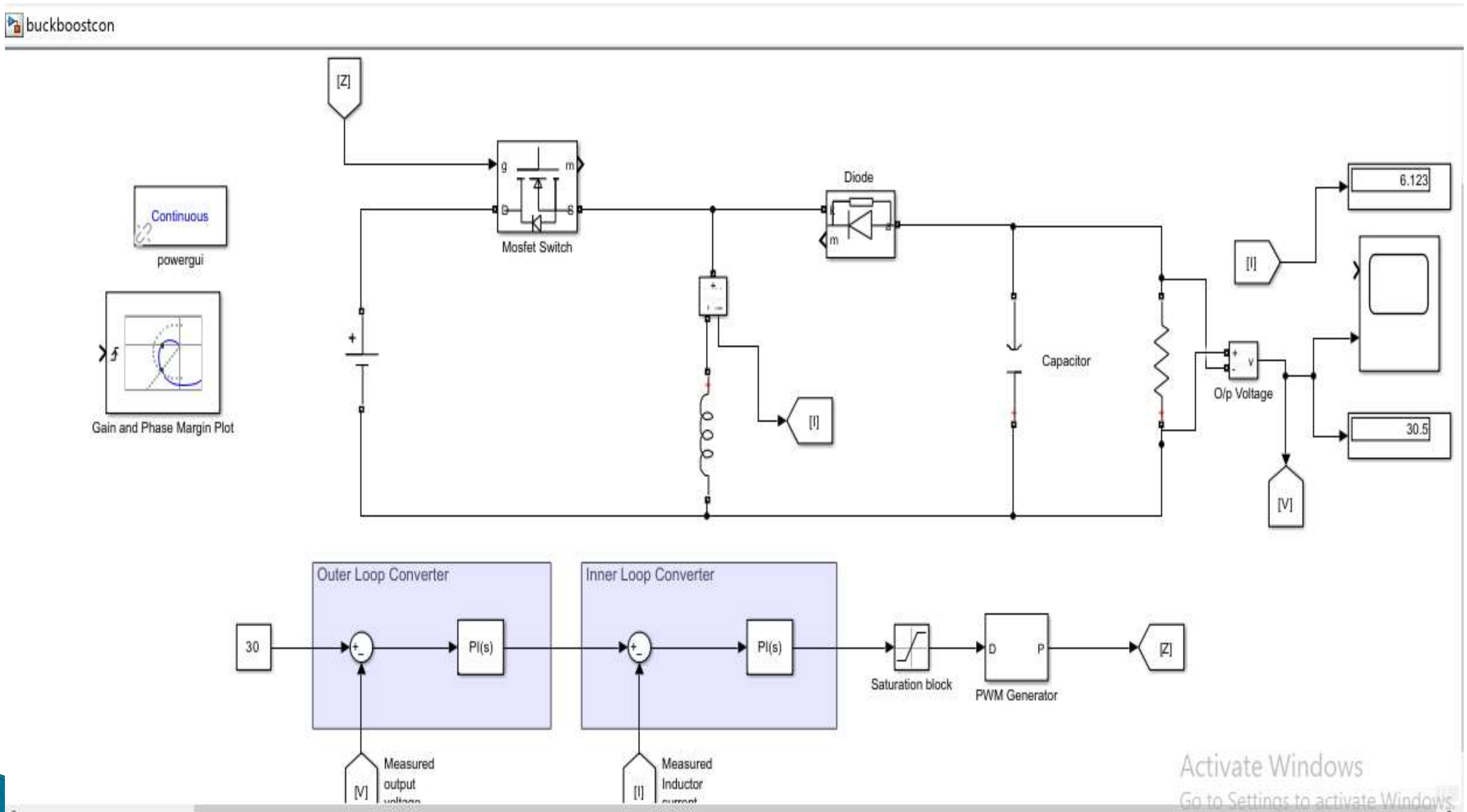
- # OBJECTIVE- 1

SIMULATE A CLOSED LOOP BUCK-BOOST CONVERTER WITH CURRENT MODE CONTROL.

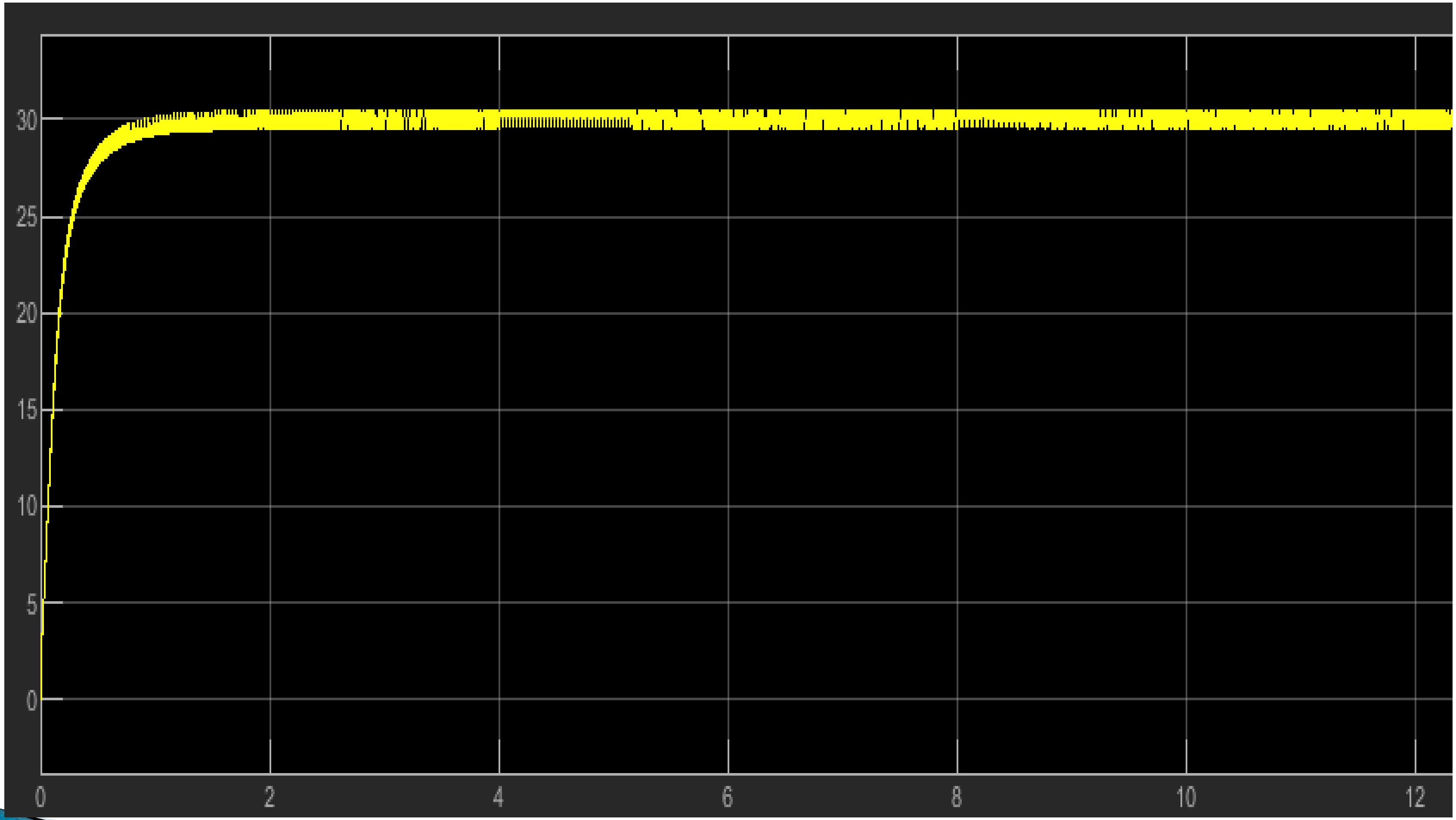
BLOCK DIAGRAM



BUCK-BOOST SIMULATION MODEL



Output voltage keeping Vref=30v



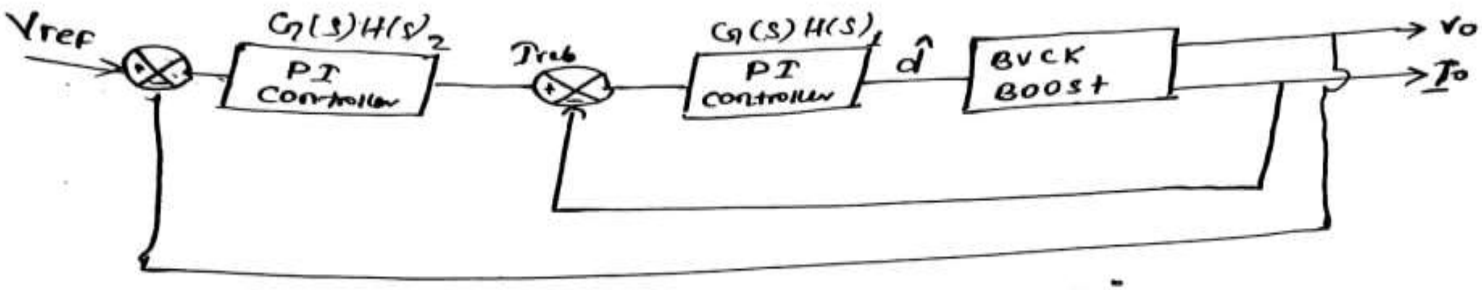
OBJECTIVE- 2

OBTAIN THE BODE PLOT BEFORE AND AFTER THE CONTROLLER DESIGN AND SHOW THAT A PHASE MARGIN OF 40 DEGREE IS ACHIEVED.

BEFORE THE CONTROLLER

g1 =

$$g1 = \frac{-1.356e04\ s + 1.582e06}{s^2 + 651\ s + 4.219e04}$$



$$\frac{\Delta I_o}{\Delta d} = \frac{\frac{1}{RLC}(1-D)(V_{dc}+V_c) - \frac{s\, i_L}{RC}}{s^2 + \frac{1}{RC}s + \frac{1}{LC}(1-D)^2}$$

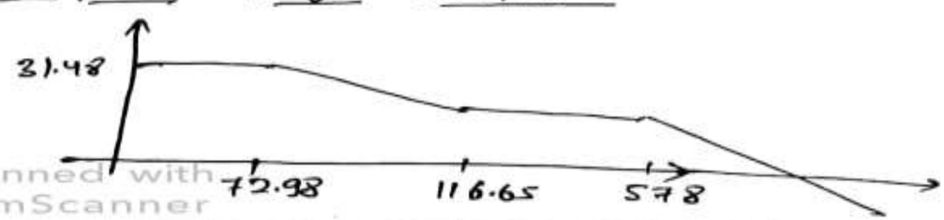
$$= \frac{1582031.250 - 13561.197\, s}{s^2 + 651 s + 42187.5}$$

$$= \frac{37.5\left(1 - \frac{s}{116.65}\right)}{\left(1 + \frac{s}{72.98}\right)\left(1 + \frac{s}{578}\right)}$$

zeros: 116.65

poles: −72.98, −578

Bode plot Before controller



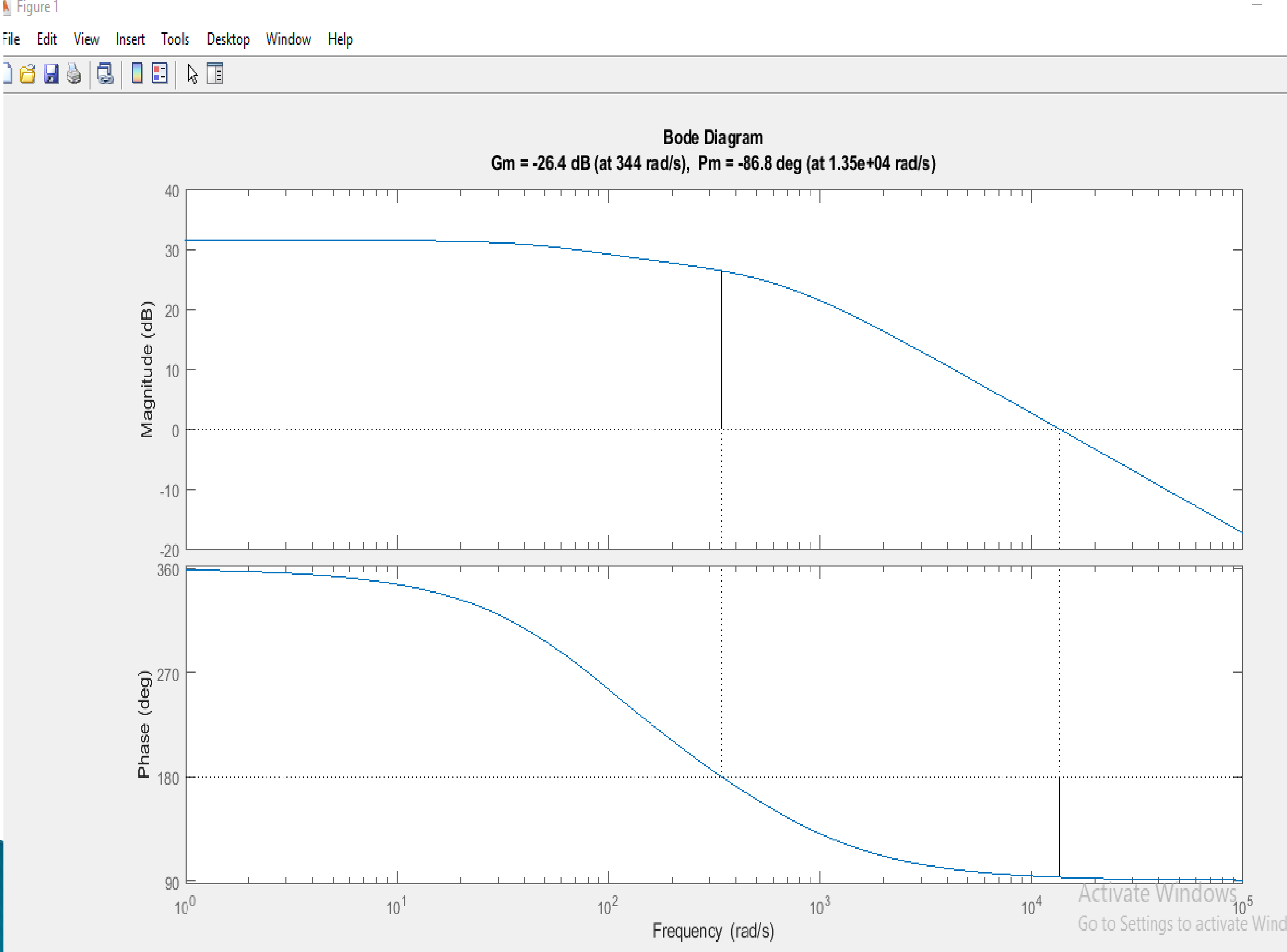


Figure 1
File Edit View Insert Tools Desktop Window Help
Bode Diagram
Gm = -26.4 dB (at 344 rad/s), Pm = -86.8 deg (at 1.35e+04 rad/s)
Magnitude (dB)
Phase (deg)
Frequency (rad/s)
40
30
20
10
0
-10
-20
360
270
180
90
10^0
10^1
10^2
10^3
10^4
10^5
Activate Windows
Go to Settings to activate Windo

INNER/ CURRENT LOOP CONTROLLER

GH1 =

$$\frac{-67.8\,s + 7909}{s^2 + 578\,s}$$

Kp=0.005

Ki=0.3649

With inner loop controller:

$$G(s)H(s)_1 = \frac{\left(K_{P1} + \frac{K_{I1}}{s}\right) 37.5 \left(1 - \frac{s}{116.65}\right)}{\left(1 + \frac{s}{72.98}\right)\left(1 + \frac{s}{578}\right)}$$

$$= \frac{13560.57\, K_P\, (116.65 - s)\left(s + \frac{K_I}{K_P}\right)}{s\,(s + 72.98)(s + 578)}$$

using dominant pole

$$\frac{K_I}{K_P} = 72.98$$

let $K_P = 0.005$

$K_I = 0.3649$

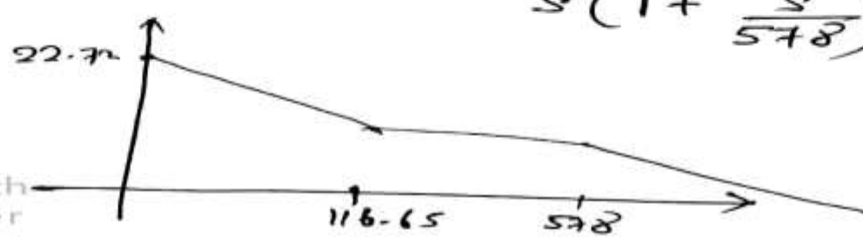
$$\tau = \frac{K_P}{K_I} = 0.0137$$

Now, $$G(s)H(s) = \frac{-67.8s + 7909.2}{s^2 + 578s + 0}$$

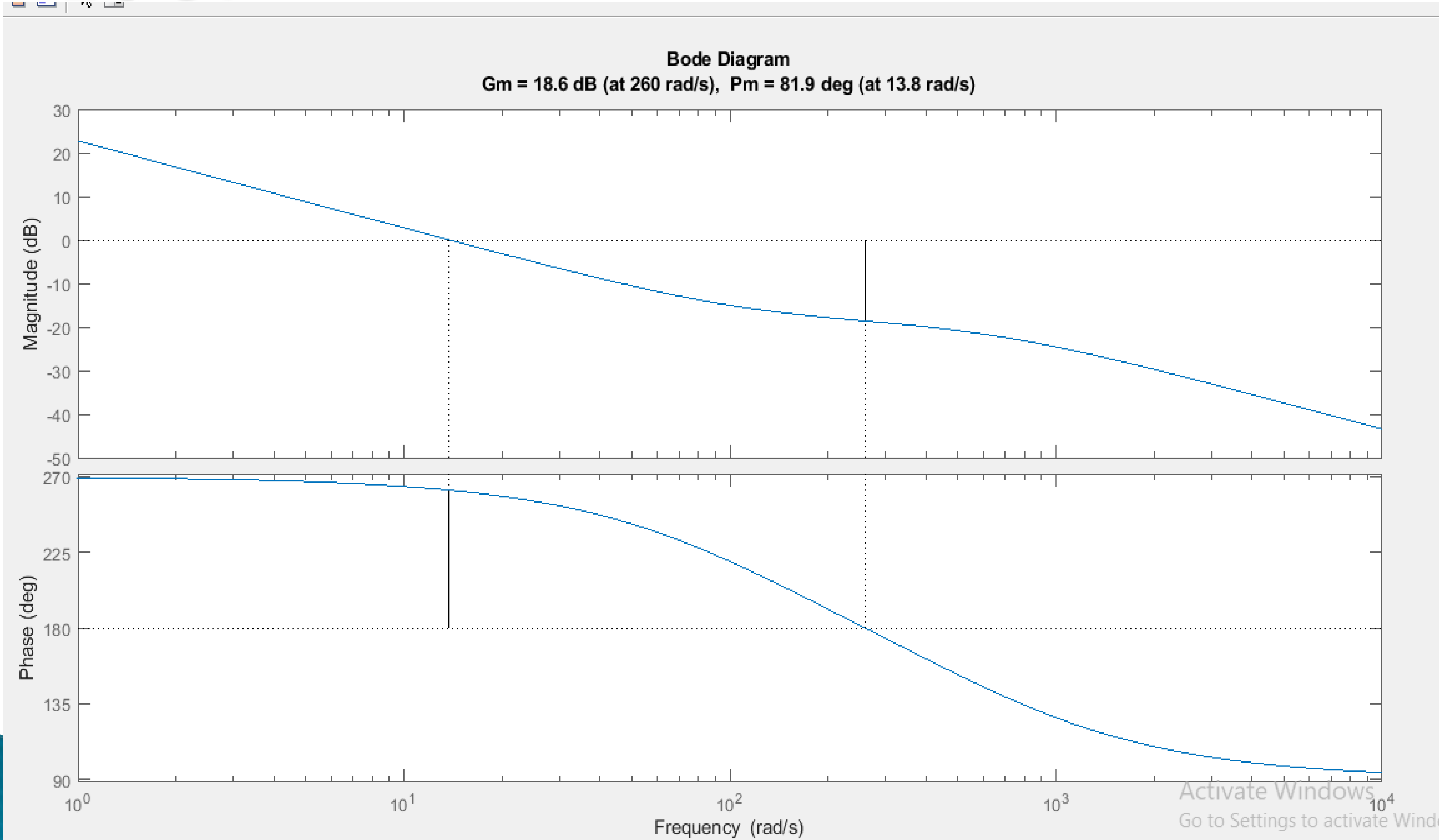
zero: 116.65

pole: 0, 578

$$G(s)H(s)_1 = \frac{13.683\left(1 - \frac{s}{116.65}\right)}{s\left(1 + \frac{s}{578}\right)}$$



BODE PLOT OF INNER/CURRENT LOOP



OUTER LOOP CONTROLLER

- gh2 =
-
- -0.3389 s + 39.53
- ------------------
- s^2 + 494.2 s

Overall Transfer function of inner loop

$$\frac{I_o}{I_{ref}} = \frac{G(s)}{1+G(s)H(s)} = \frac{\frac{67.8(116.65-s)}{s(s+578)}}{1+\frac{67.8(116.65-s)}{s(s+578)}}$$

$$= \frac{7908.87 - 67.8s}{s^2+510.2s+7908.87}$$

pole : $-16, -494.2$

zero : 116.65

2nd controller : $K_{p2} + \frac{K_{I2}}{s}$

outer loop controller

$$GH_2(s) = \left(K_{p2} + \frac{K_{I2}}{s}\right)\left(\frac{7908.87 - 67.8s}{s^2+510.2s+7908.87}\right)$$

$$= \frac{67.785K_p(116.65-s)\left(s+\frac{K_I}{K_p}\right)}{s(s+16)(s+494.2)}$$

using dominant pole

$$\frac{K_I}{K_p} = 16$$

let $K_p = 0.005$

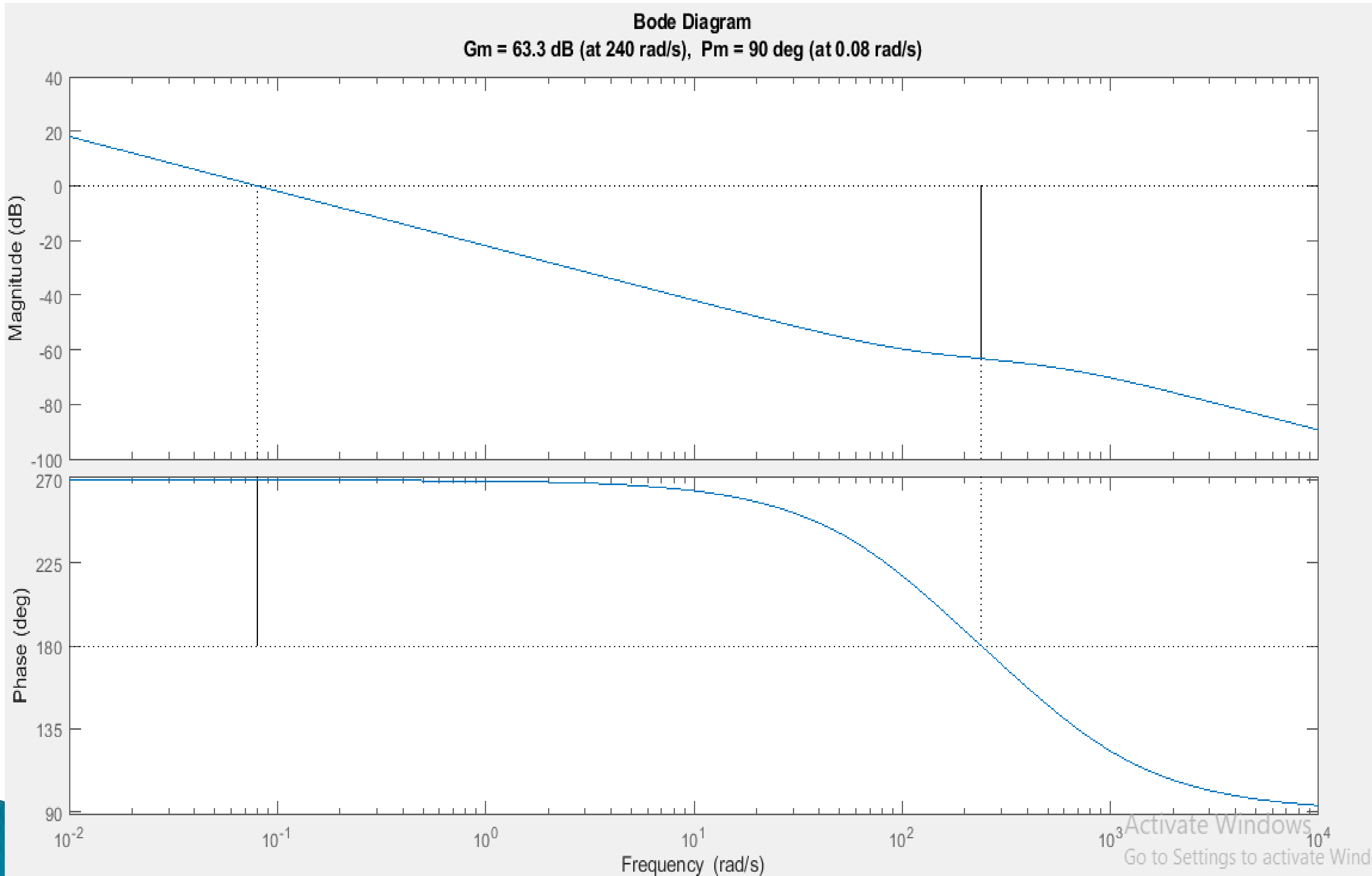
$K_I = 0.08$

$\tau_2 = 0.0625 > \tau_1 = 0.0137$

$G(s)H(s)_2$

$$= \frac{39.532 - 0.3389s}{s^2+494.2s+0}$$

BODE PLOT after both controller

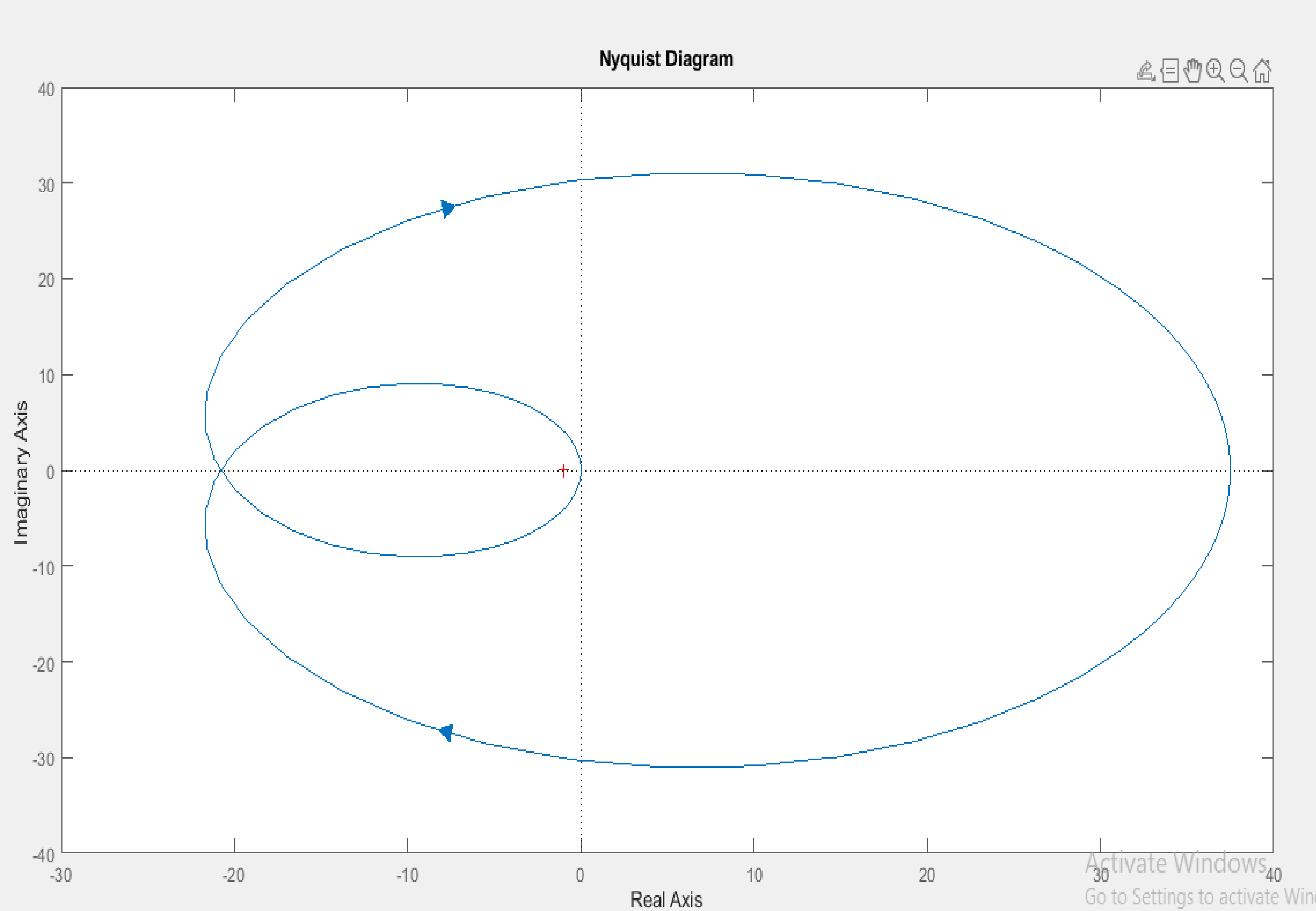


- 3.DRAW THE NYQUIST PLOT OF OPEN LOOP GAIN AND CONFIRM THE SAME AS IN 2.

Nyquist plot without controller

- g1 =

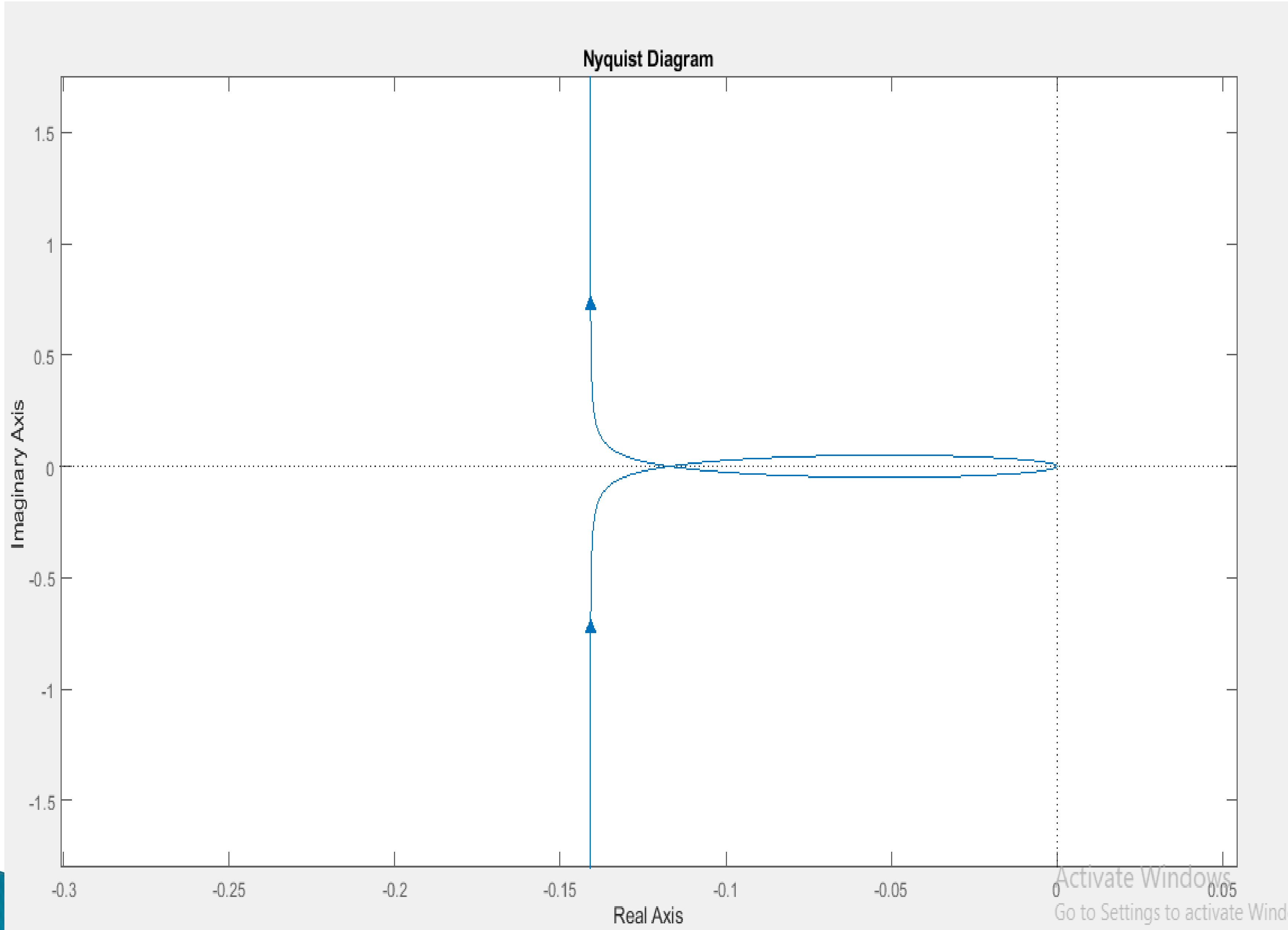
$$\frac{-1.356e04\, s + 1.582e06}{s^2 + 651\, s + 4.219e04}$$


Nyquist Diagram
Imaginary Axis
Real Axis
40
30
20
10
0
-10
-20
-30
-40
-30
-20
-10
0
10
20
30
40

Nyquist plot with controller(inner loop)

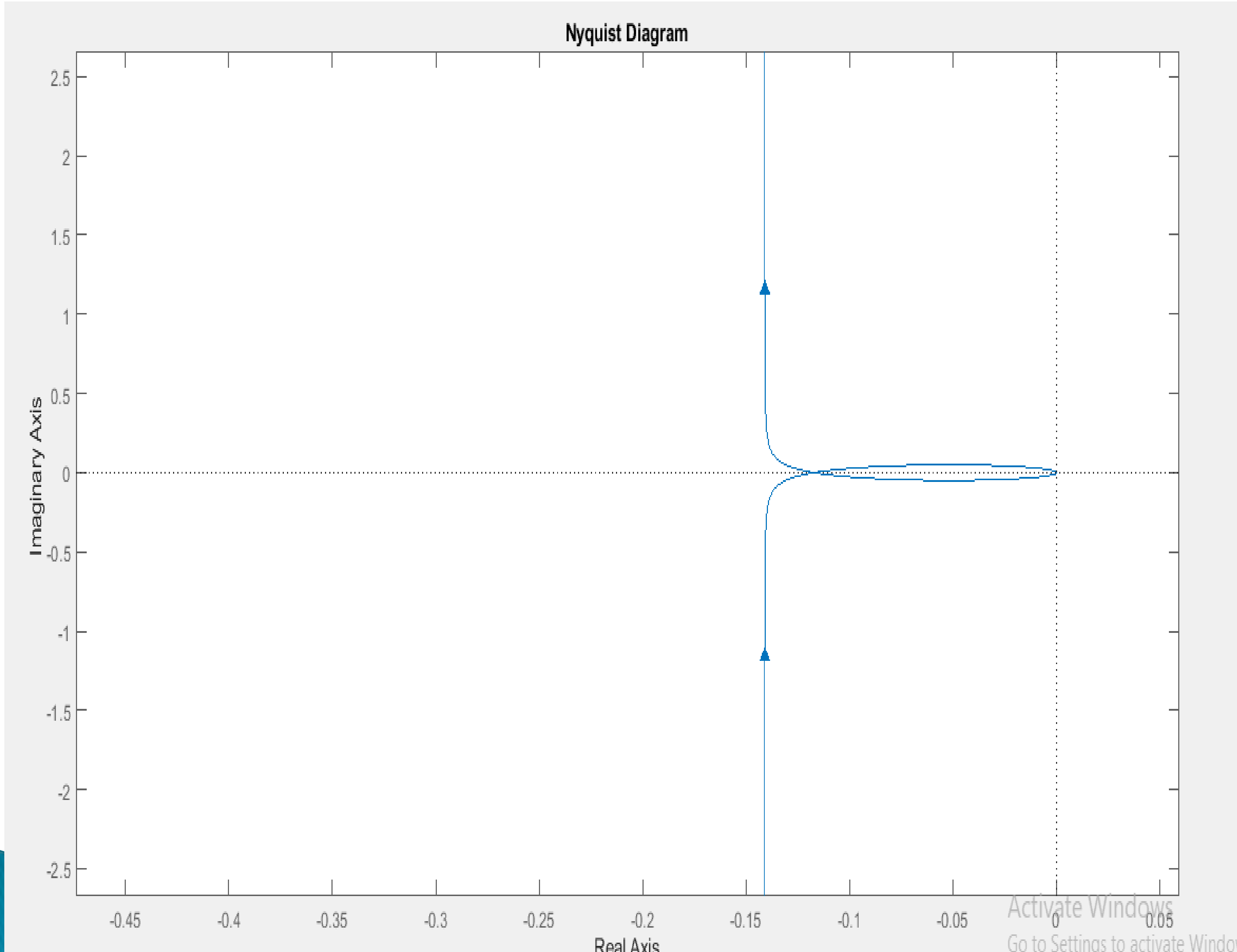
GH1 =

-67.8 s + 7909
----
s^2 + 578 s


Nyquist Diagram
Imaginary Axis
Real Axis
1.5
1
0.5
0
-0.5
-1
-1.5
-0.3
-0.25
-0.2
-0.15
-0.1
-0.05
0
0.05

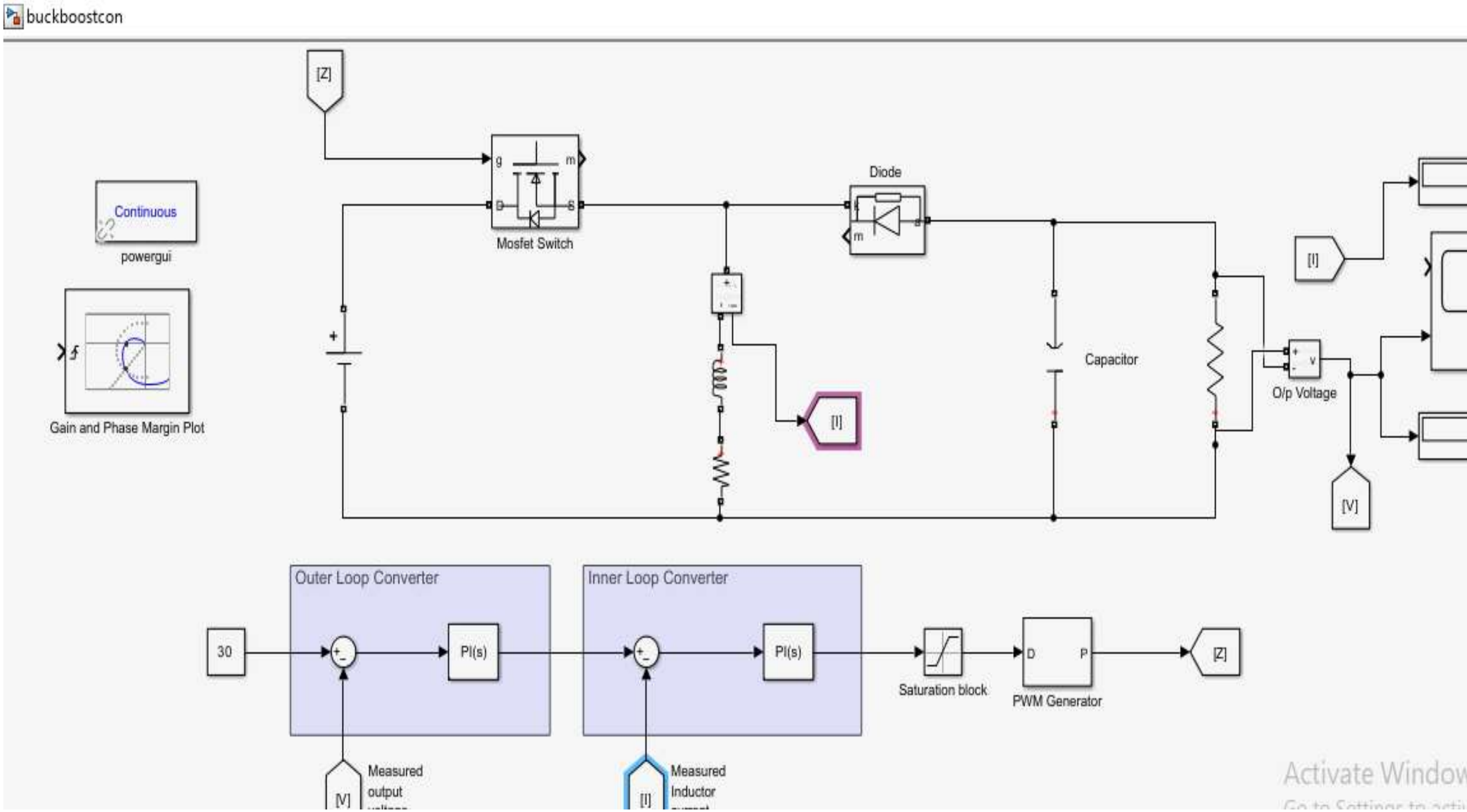
Nyquist plot with controller(outer loop)

- gh2 =
-
-   -0.3389 s + 39.53
-   ----------------
-     s^2 + 494.2 s

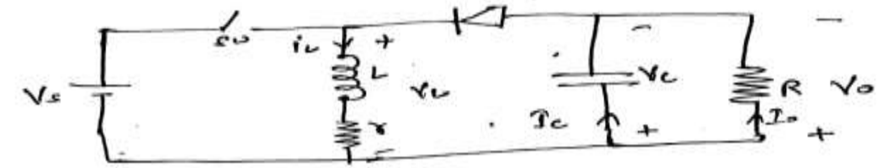

Nyquist Diagram
Imaginary Axis
Real Axis
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-0.45
-0.4
-0.35
-0.3
-0.25
-0.2
-0.15
-0.1
-0.05
0
0.05

- 4. DRAW THE ROOT LOCUS OF THE INDUCTOR SERIES RESISTANCE VARIATION AND SHOW THE LIMITS OF THE INDUCTOR SERIES RESISTANCE VARIATION FOR STABLE OPERATION.

Model:


buckboostcon
[Z]
Continuous
powergui
Mosfet Switch
Diode
Gain and Phase Margin Plot
[I]
Capacitor
O/p Voltage
[V]
Outer Loop Converter
Inner Loop Converter
30
PI(s)
PI(s)
Saturation block
D
P
PWM Generator
[Z]
[V]
Measured
output
[I]
Measured
Inductor
Activate Windows

Calculations:



$$\begin{bmatrix} \dot{i}_L \\ \dot{V}_c \end{bmatrix} = \begin{bmatrix} -\frac{r}{L} & -\frac{1}{L}(1-D) \\ \frac{(1-D)}{C} & -\frac{1}{RC} \end{bmatrix} \begin{bmatrix} i_L \\ V_c \end{bmatrix} + \begin{bmatrix} \frac{D}{L} \\ 0 \end{bmatrix} V_{dc}$$

$$I_o = \begin{bmatrix} 0 & \frac{1}{R} \end{bmatrix} \begin{bmatrix} i_L \\ V_c \end{bmatrix}$$

$$\begin{bmatrix} \Delta \dot{i}_L \\ \Delta \dot{V}_c \end{bmatrix} = \begin{bmatrix} -\frac{r}{L} & -\frac{1}{L}(1-D) \\ \frac{1}{C}(1-D) & -\frac{1}{RC} \end{bmatrix} \begin{bmatrix} \Delta i_L \\ \Delta V_c \end{bmatrix} + \begin{bmatrix} \frac{V_c}{L} \\ -\frac{i_L}{C} \end{bmatrix} \Delta d$$

$$T.F = C[SI-A]^{-1}B \; : \qquad \Delta I_o = \begin{bmatrix} 0 & \frac{1}{R} \end{bmatrix} \begin{bmatrix} \Delta i_L \\ \Delta V_c \end{bmatrix}$$

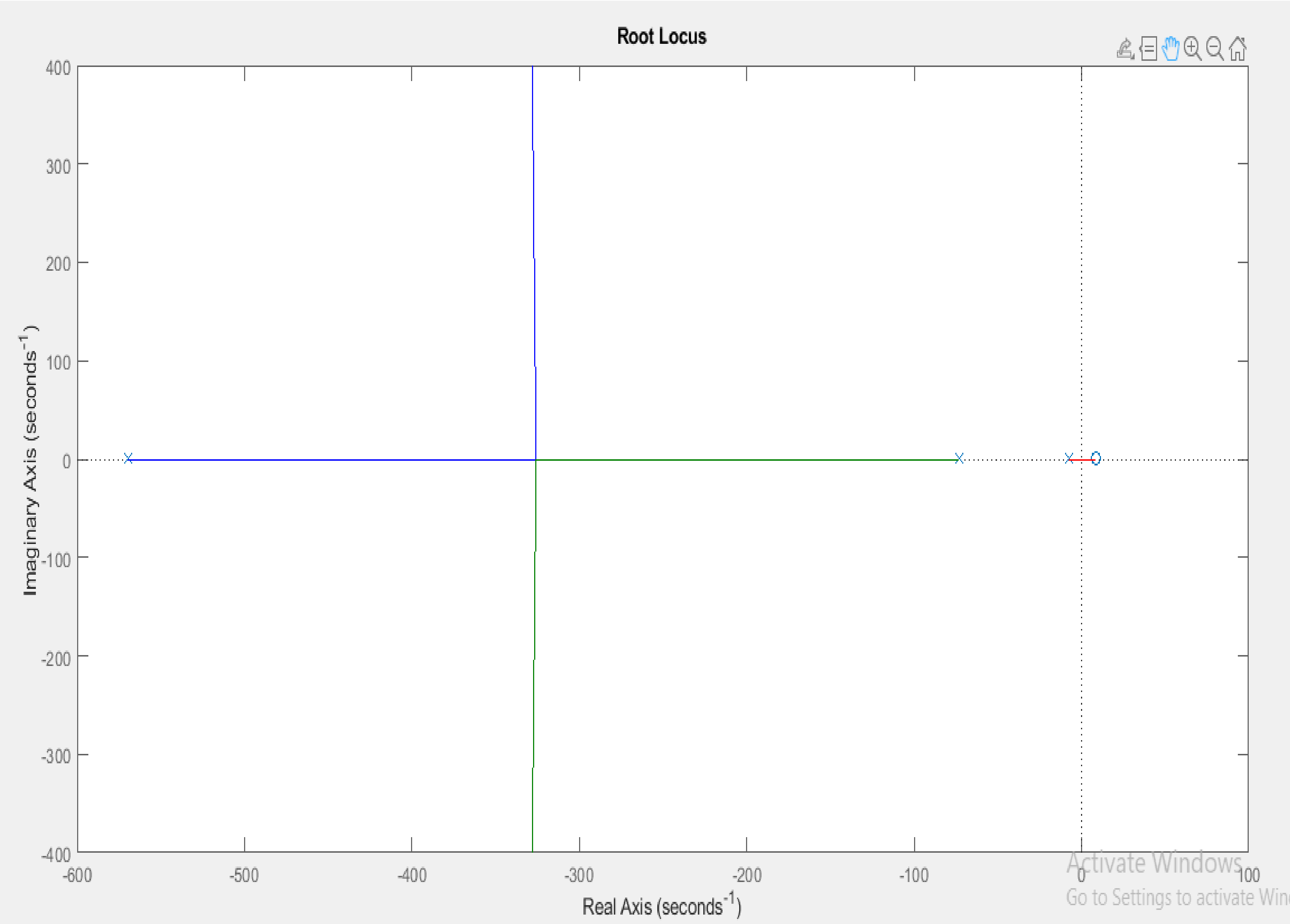
$$\frac{\Delta i_o}{\Delta d} = \frac{\frac{V_c(1-D)}{RLC} - \frac{i_L}{RC}\left(s+\frac{r}{L}\right)}{s^2 + \left(\frac{r}{L}+\frac{1}{RC}\right)s + \left(\frac{r}{RLC}+\frac{1}{LC}(1-D)^2\right)}$$

putting values

$$1 + K\,G(s)H(s) = 0$$

$$1 + r\,G(s)\,H(s) = 0$$

$$1 + r\,\frac{(0.8959 s^2 - 7.5994 s + 0)}{15.36\times10^{-6} s^4 + 0.00999 s^3 + 0.7154 s^2 + 4.927 s + 0}$$


Root Locus
400
300
200
100
0
-100
-200
-300
-400
Imaginary Axis (seconds^{-1})
-600
-500
-400
-300
-200
-100
0
100
Real Axis (seconds^{-1})
Activate Windows
Go to Settings to activate Windo

The value of 'r' for which the system is unstable.

The value of 'γ' for which the system becomes unstable

$$\frac{G(s)H(s)}{1+\gamma\, G(s)H(s)}$$

Denominator: i.e pole:

$$1+\gamma\, G(s)H(s)=0$$

$$1+\frac{\gamma\,(0.8959\, s^2-7.5994 s)}{15.36\times10^{-6} s^4+0.00999 s^3+0.7154 s^2+4.927 s}=0$$

$$\Rightarrow 15.36\times10^{-6} s^4+0.00999 s^3+0.7154 s^2+4.927 s + \gamma(0.8959)s^2-(7.5994\gamma)s=0$$

$$\Rightarrow 15.36\times10^{-6} s^4+0.00999 s^3+(0.7154+0.8959\gamma)s^2 + (4.927-7.5994\gamma)s=0$$

The characteristic equation are:

$$15.36\times10^{-6} s^4+0.0099 s^3+(0.7154+0.8959\gamma)s^2 + (4.927-7.5994\gamma)s=0$$

⇒ We apply Routh Hurwitz criterion to find the value of 'γ' for which the system is stable

$$15.36\times10^{-6} s^4 + 0.00999 s^3 + (0.7154 + 0.8959\gamma) s^2 + (4.927 - 7.5994\gamma) s = 0$$

s^4	15.36×10^{-6}	$0.7154 + 0.8959\gamma$
s^3	0.00999	$4.927 - 7.5994\gamma$
s^2	$\dfrac{0.00999\times(0.7154+0.8959\gamma) - 15.36\times10^{-6}(4.927-7.5994\gamma)}{0.00999}$	
s^1		
s^0		

for stable: γ

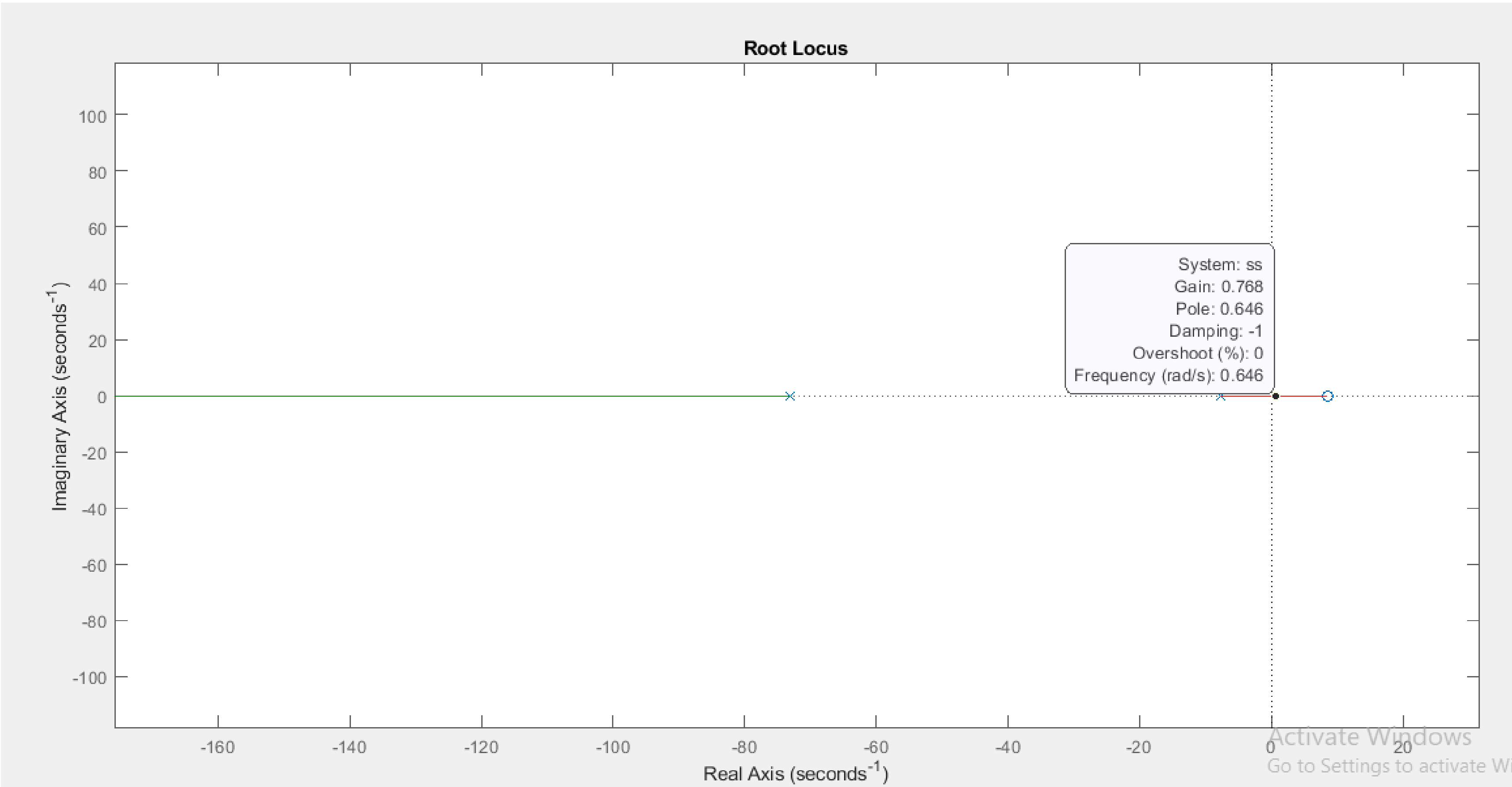
$$\rightarrow \frac{0.00999(0.7154 + 0.8959\gamma) - 15.36\times10^{-6}(4.927 - 7.5994\gamma)}{0.00999} > 0$$

$$\rightarrow 0.007146 + 0.00895\gamma - \frac{0.007567}{100} + \frac{0.001167}{10}\gamma > 0$$

$$\rightarrow 0.0090667\gamma - 0.00707 > 0$$

$$\gamma > \frac{0.00707}{0.0090667} = 0.7798$$

$$\boxed{\begin{array}{ll} \text{for stable} & \gamma > 0.7798 \\ \text{for unstable} & \gamma < 0.7798 \\ \text{for marginally stable} & \gamma = 0.7798 \end{array}}$$

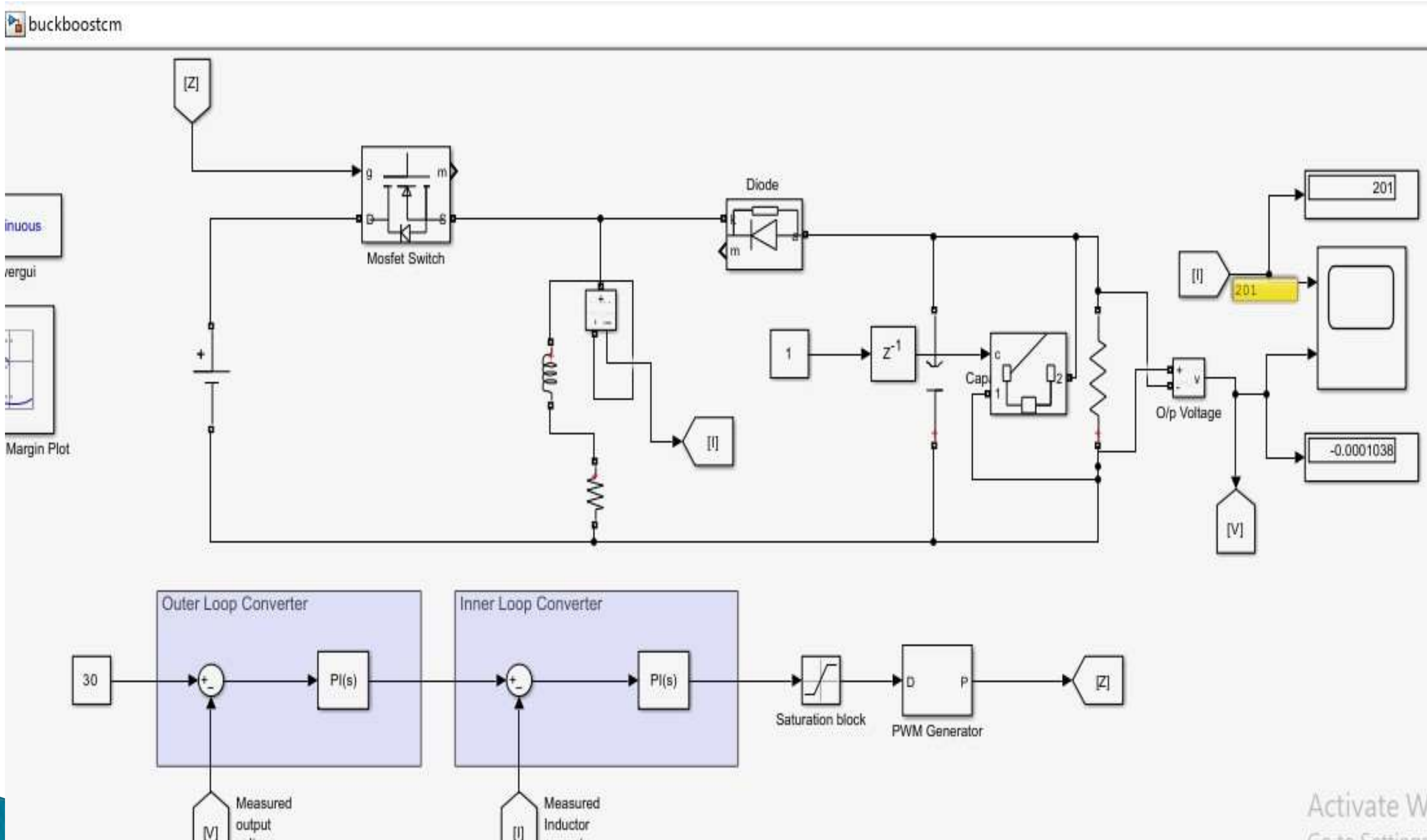


Root Locus
System: ss
Gain: 0.768
Pole: 0.646
Damping: -1
Overshoot (%): 0
Frequency (rad/s): 0.646
100
80
60
40
20
0
-20
-40
-60
-80
-100
Imaginary Axis (seconds-1)
-160
-140
-120
-100
-80
-60
-40
-20
0
20
Real Axis (seconds-1)

EXTRA OBSERVATIONS:

SHORT CIRCUITED THE LOAD AT T=10 SECONDS

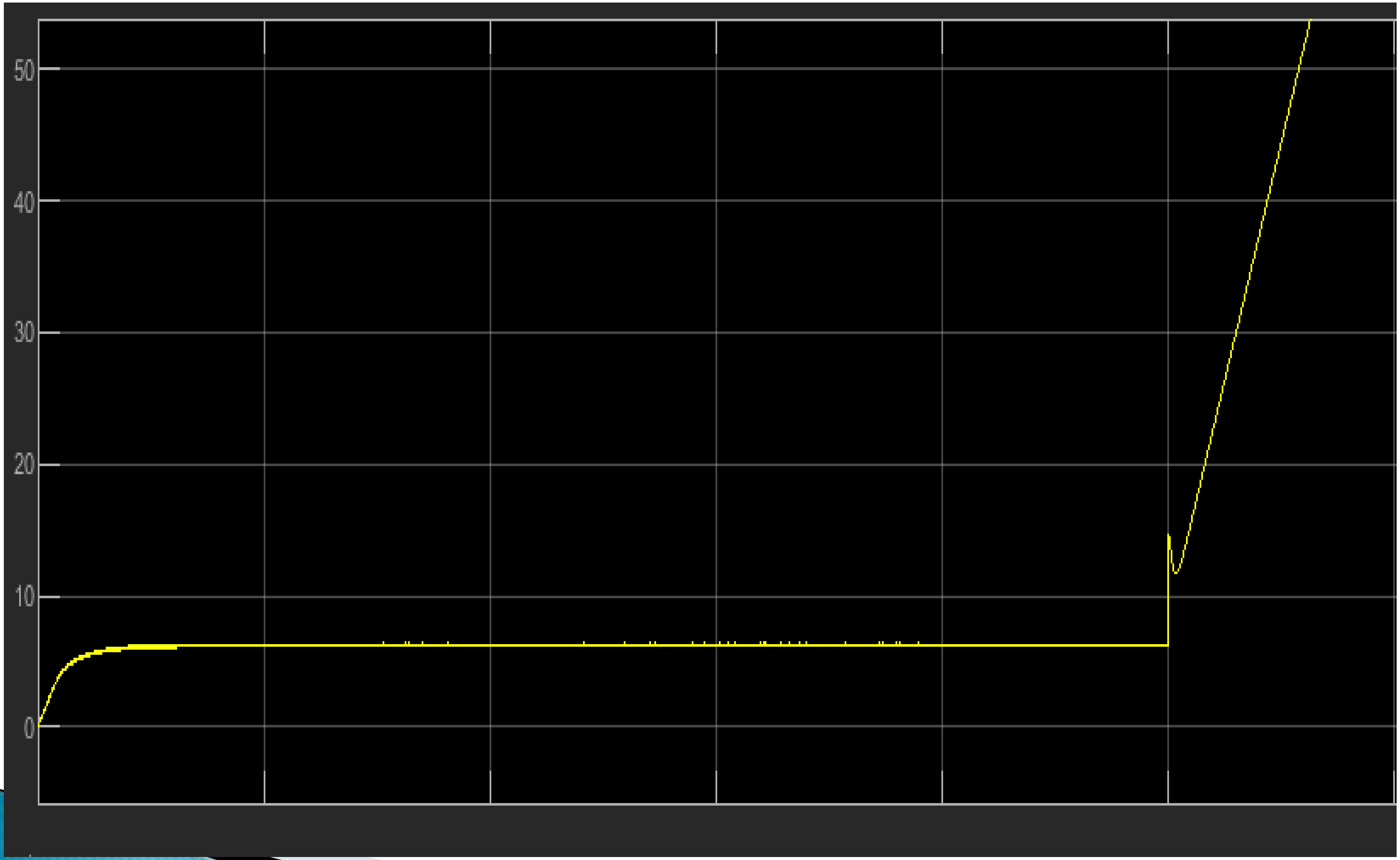
MODEL:



buckboostcm
[Z]
Mosfet Switch
Diode
201
[I]
201
1
Cap
O/p Voltage
-0.0001038
[I]
[V]
Margin Plot
Outer Loop Converter
Inner Loop Converter
30
PI(s)
PI(s)
Saturation block
PWM Generator
[Z]
[V]
Measured output
[I]
Measured Inductor
Activate Wi

VOLTAGE WAVEFORM:

CURRENT WAVEFORM:



THANK YOU !