ADVANCED CONTROL DESIGN TECHNIQUES FOR POWER CONVERTERS(EE608)

TOPIC: CURRENT MODE CONTROL IN BUCK CONVERTER

FACULTY

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BUCK CONVERTER CURRENT MODE CONTROL

Objective 1: Simulate a closed loop buck converter with current mode control

Objective 2: Obtain the bode plot before and after the controller design and show that a phase margin of 35 degrees is achieved.

Objective 3: Draw the nyquist plot of open loop gain and confirm the same as in 2

Objective 4:Draw the root-locus of the inductor series resistance variation and show the limits of the inductor series resistance variation for stable operation.

CALCULATIONS

f= $100KHz$

Vi= $48V$

Vo= $12V$

$\Delta Vo/Vo = 0.05$

R= 15Ω

L= $100\mu H$

C= $26\mu F$

D= 0.25

$\Delta iL = 2\%$

$\Delta Vo = 5\%$

Outer $loop$

Kp=0.08

Ki=704.03

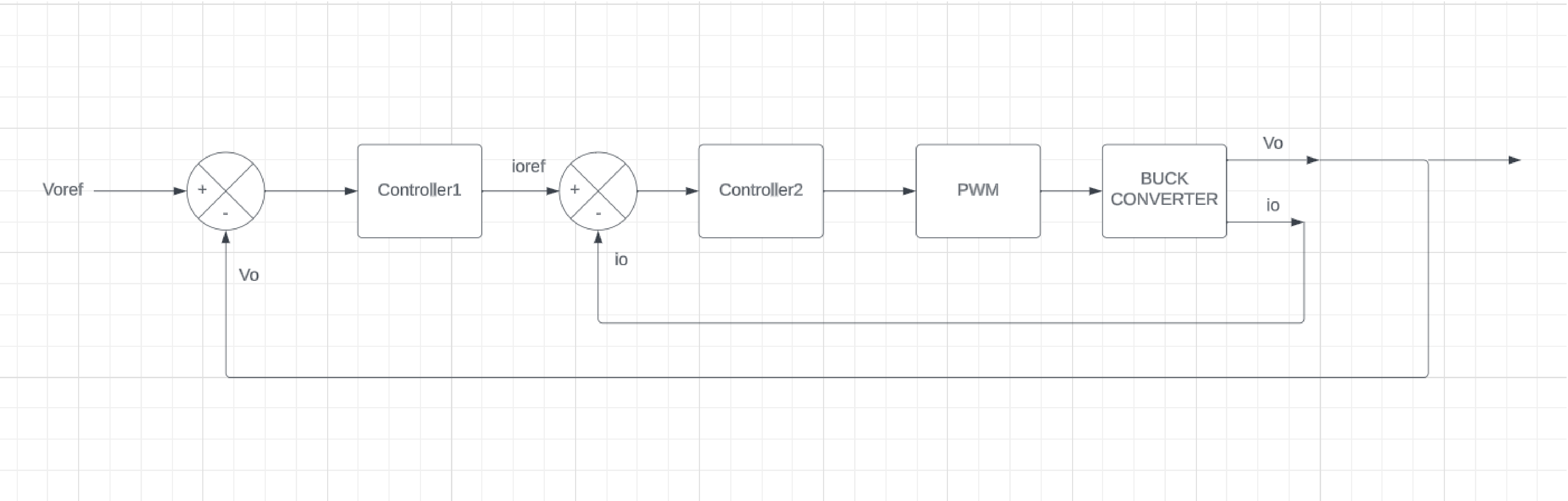
$Inner\ loop$

Kp=0.009

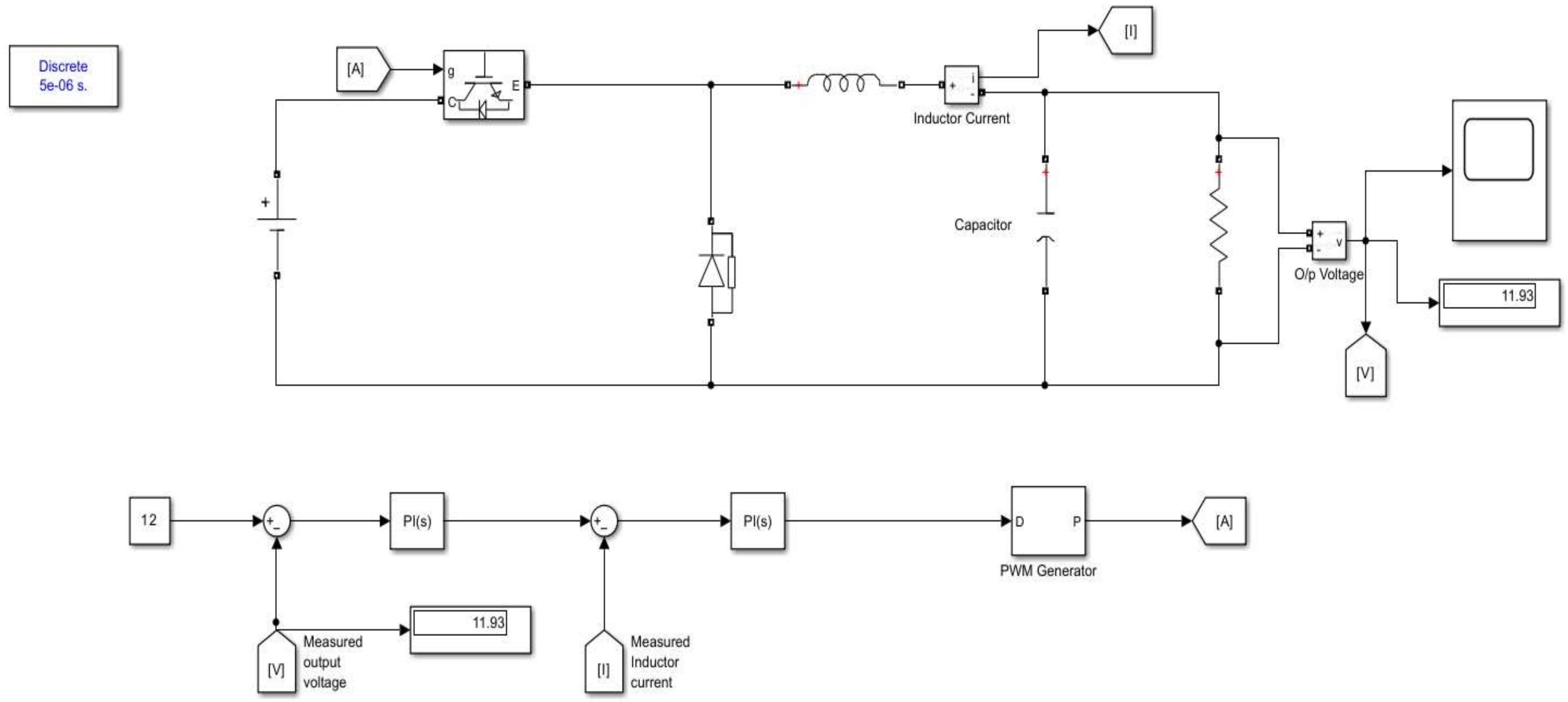
Ki=50.90

- Inner loop is faster than outer loop.
- Some tolerance is also considered.

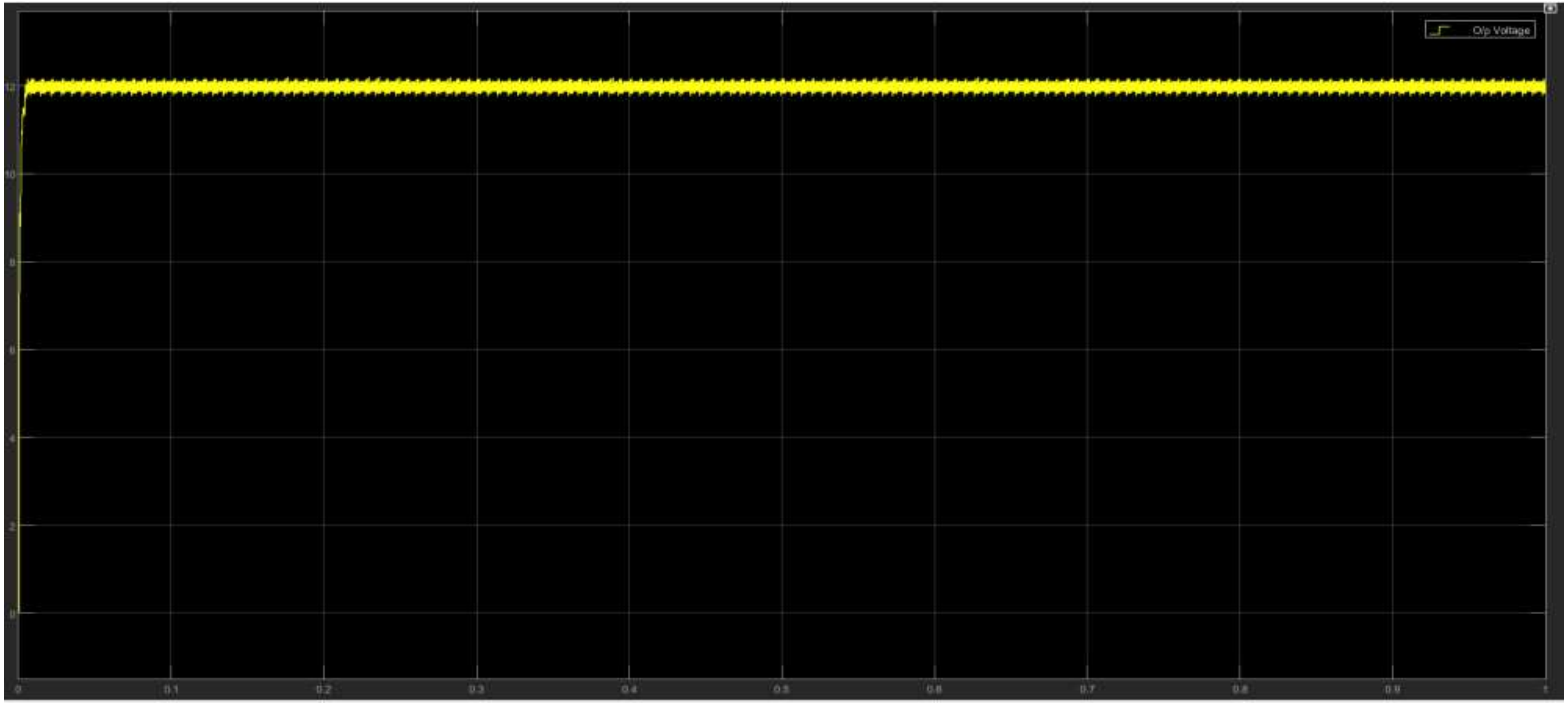
BLOCK DIAGRAM



1. Simulate a closed loop buck converter with current mode control
2. Obtain the bode plot before and after the controller design and show that a phase margin of 35 degrees 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 limits of the inductor series resistance variation for stable operation.



Output Voltage



MATLAB CODE FOR FINDING PHASE MARGIN Without Controller

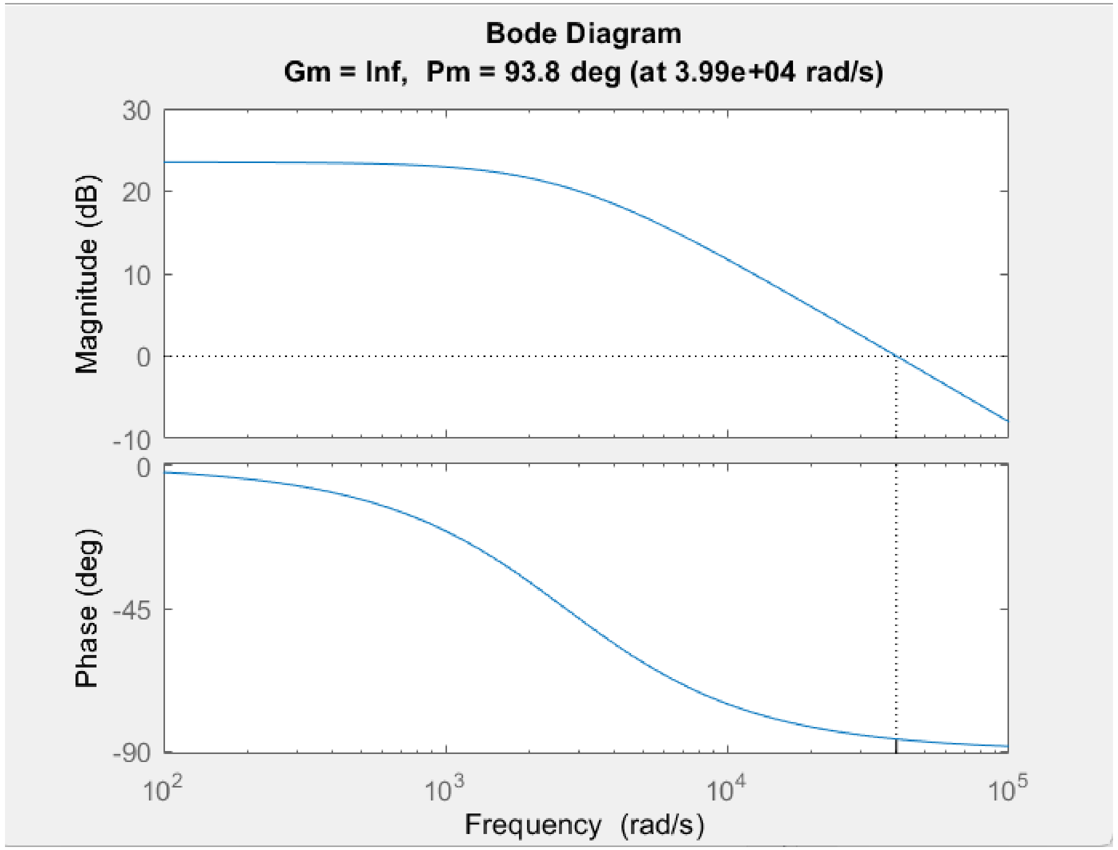
```
clear all;clc;
Vdc=48;
R=15;
L=100e-6;
C=25e-6;
n = [Vdc/L Vdc/(R*L*C)];
d=[ 1 1/(R*C) 1/(L*C)];
t = tf(n,d);   %(iL/d) wo PI
n_1=[Vdc/(L*C)];
d_1=[1 1/(R*C) 1/(L*C)];
t_1=tf(n_1,d_1);   % Vo/d wo PI
disp('\n Transfer Function without PI controller:');
flag= (t_1)/t     % Vo/iL wo PI
```

```
\n Transfer Function without PI controller:

flag =

          1.92e10 s^2 + 5.12e13 s + 7.68e18
  ------------------------------------------------------
  480000 s^3 + 2.56e09 s^2 + 1.954e14 s + 5.12e17

Continuous-time transfer function.
```



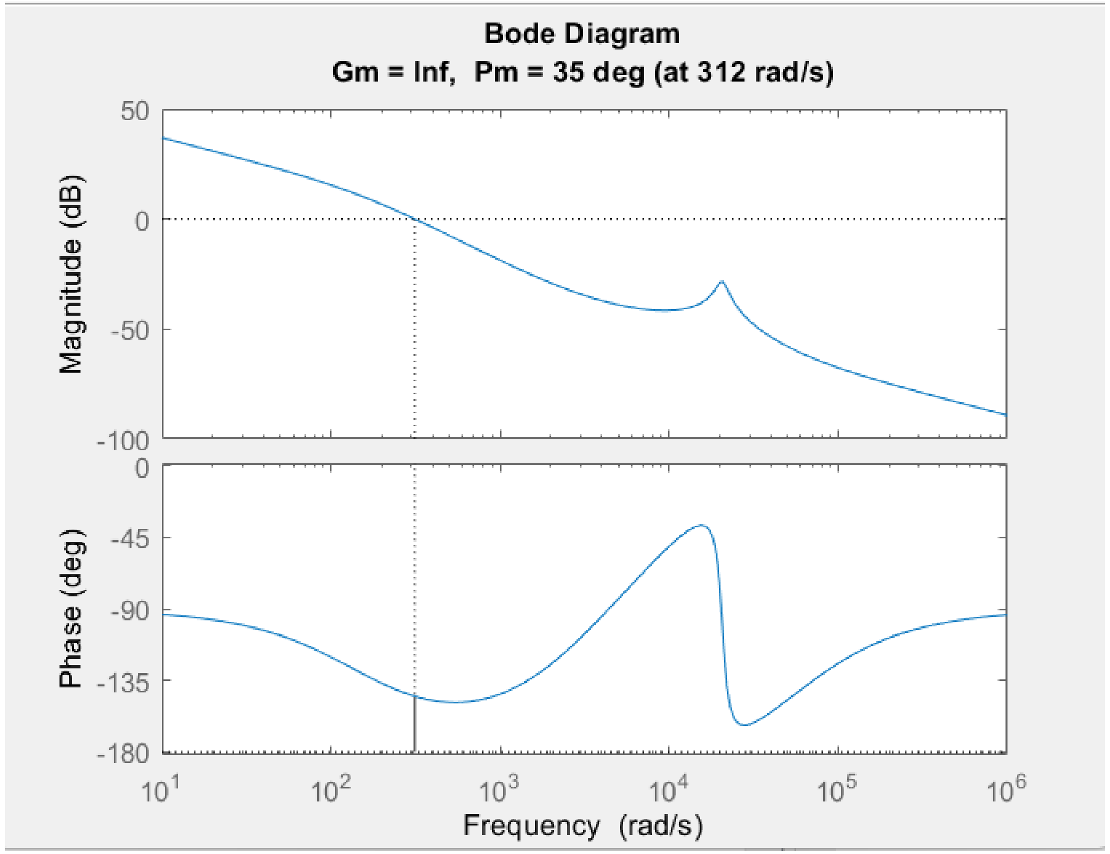
Bode Diagram
Gm = Inf, Pm = 93.8 deg (at 3.99e+04 rad/s)
Magnitude (dB)
30
20
10
0
-10
Phase (deg)
0
-45
-90
10^2
10^3
10^4
10^5
Frequency (rad/s)

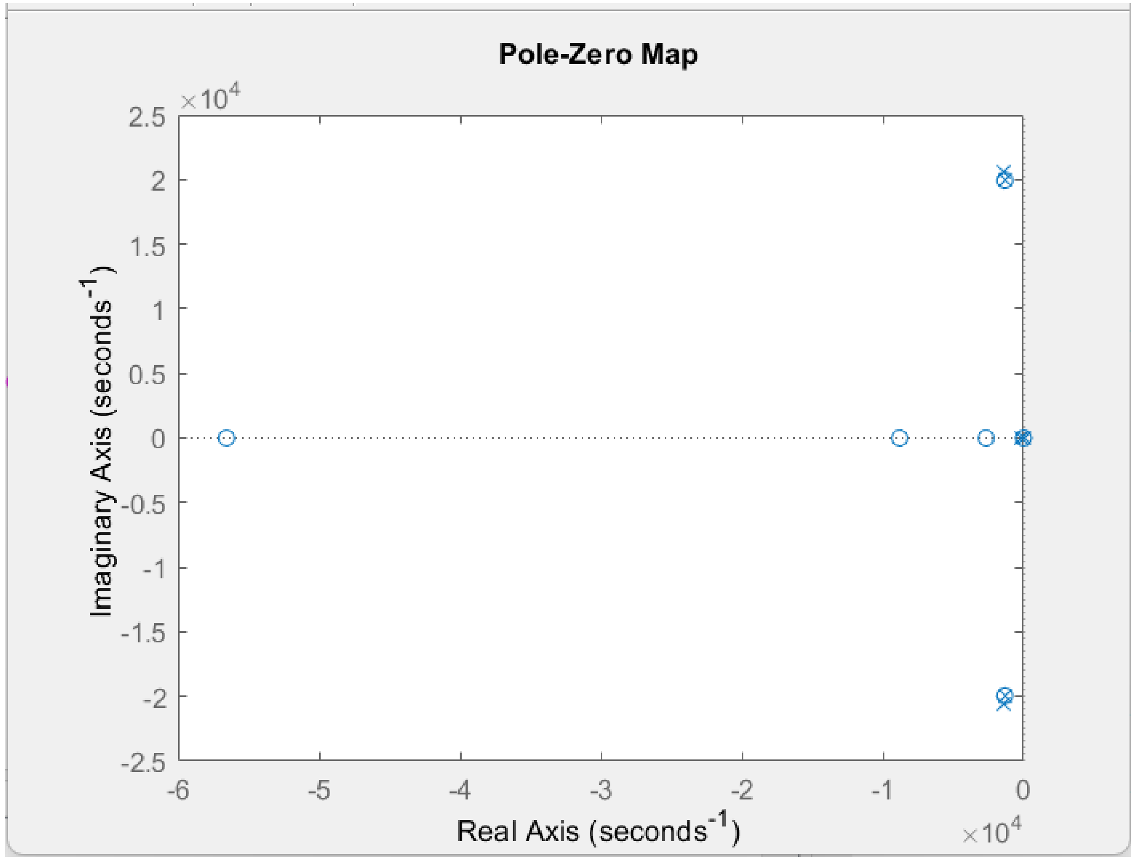
MATLAB CODE FOR FINDING PHASE MARGIN With Controller

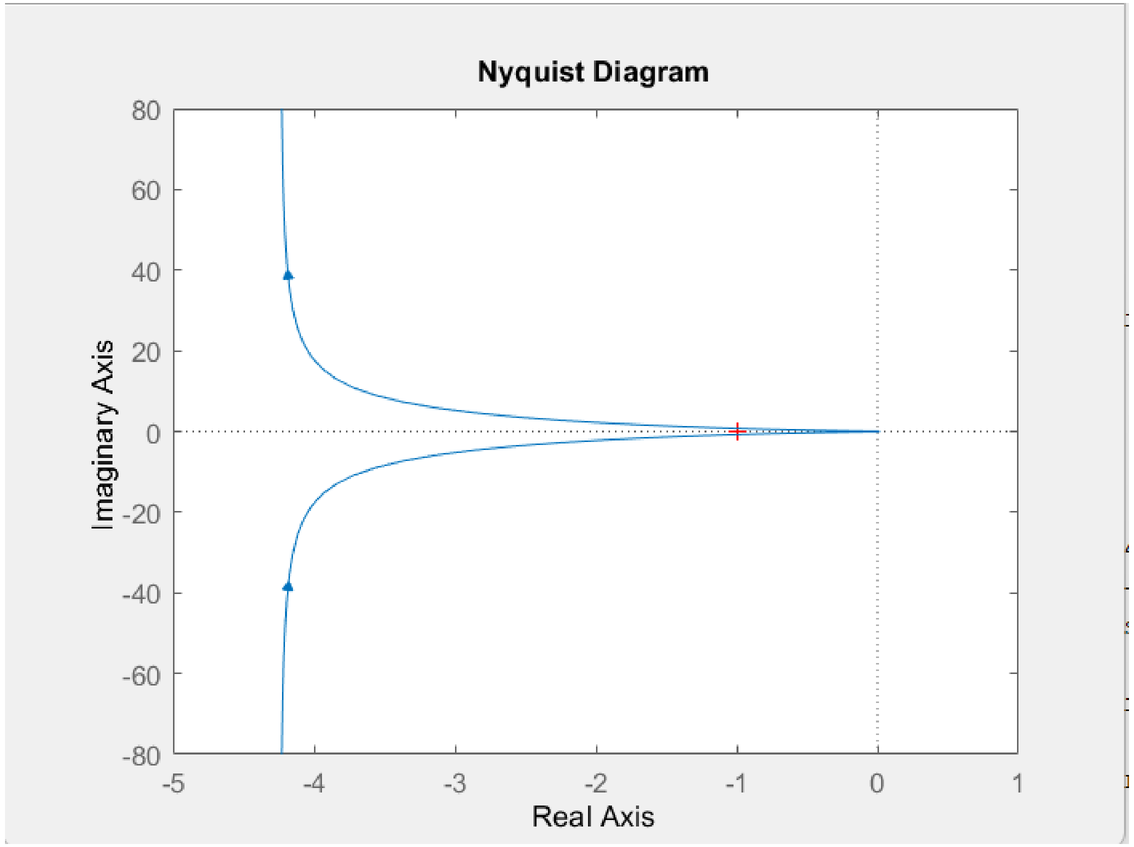
```
kp_i= [0.0009];
a=50.90;
m = [1 0];
ki_i= a*tf(1,m);
 c= kp_i+ki_i;
 t_11=t*c;     %iL/d w PI inner loop
 In= t_11/(t_11+1);
 kp_o= [0.08];
p =704.03;
m_1 = [1 0];
ki_2= p*tf(1,m_1);
 c_2= kp_o+ki_2;
 disp('\n Transfer function after adding PI contoller:')
 flag_2= (In*c_2)
%margin(flag_2);
 %pzplot(flag_2)
%nyquist(flag_2)
%r=0.005:0.02:1
```

```
flag_2 =

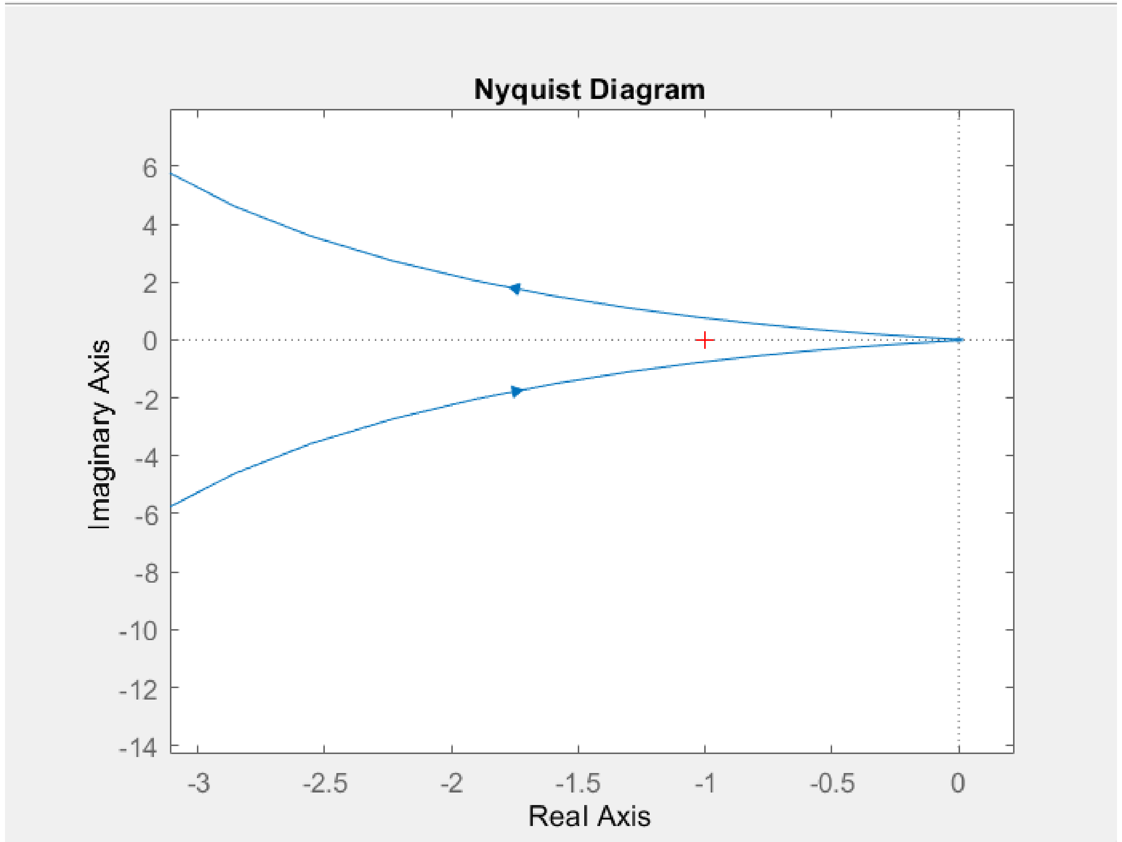
  34.56 s^6 + 2.443e06 s^5 + 4.332e10 s^4 + 1.048e15 s^3 + 9.412e18 s^2 + 1.835e22 s
  ----------------------------------------------------------------------------------
      s^7 + 5765 s^6 + 8.338e08 s^5 + 2.44e12 s^4 + 1.704e17 s^3 + 2.606e19 s^2
```


Bode Diagram
Gm = Inf, Pm = 35 deg (at 312 rad/s)
Magnitude (dB)
Phase (deg)
Frequency (rad/s)


Pole-Zero Map
Imaginary Axis (seconds^{-1})
Real Axis (seconds^{-1})

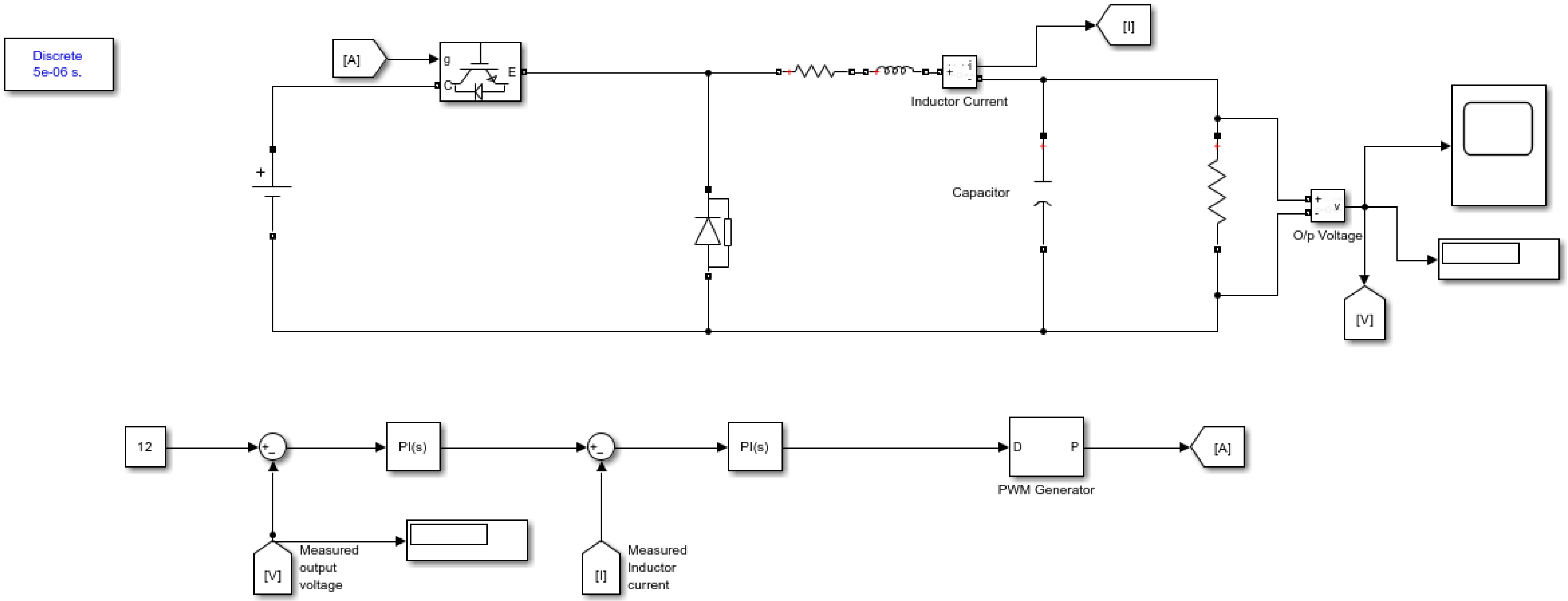


Nyquist Diagram
Imaginary Axis
Real Axis
80
60
40
20
0
-20
-40
-60
-80
-5
-4
-3
-2
-1
0
1



Nyquist Diagram
Imaginary Axis
Real Axis
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-3
-2.5
-2
-1.5
-1
-0.5
0

Draw the root-locus of the inductor series Resistance variation and show the limits of the inductor series resistance variation for stable operation.



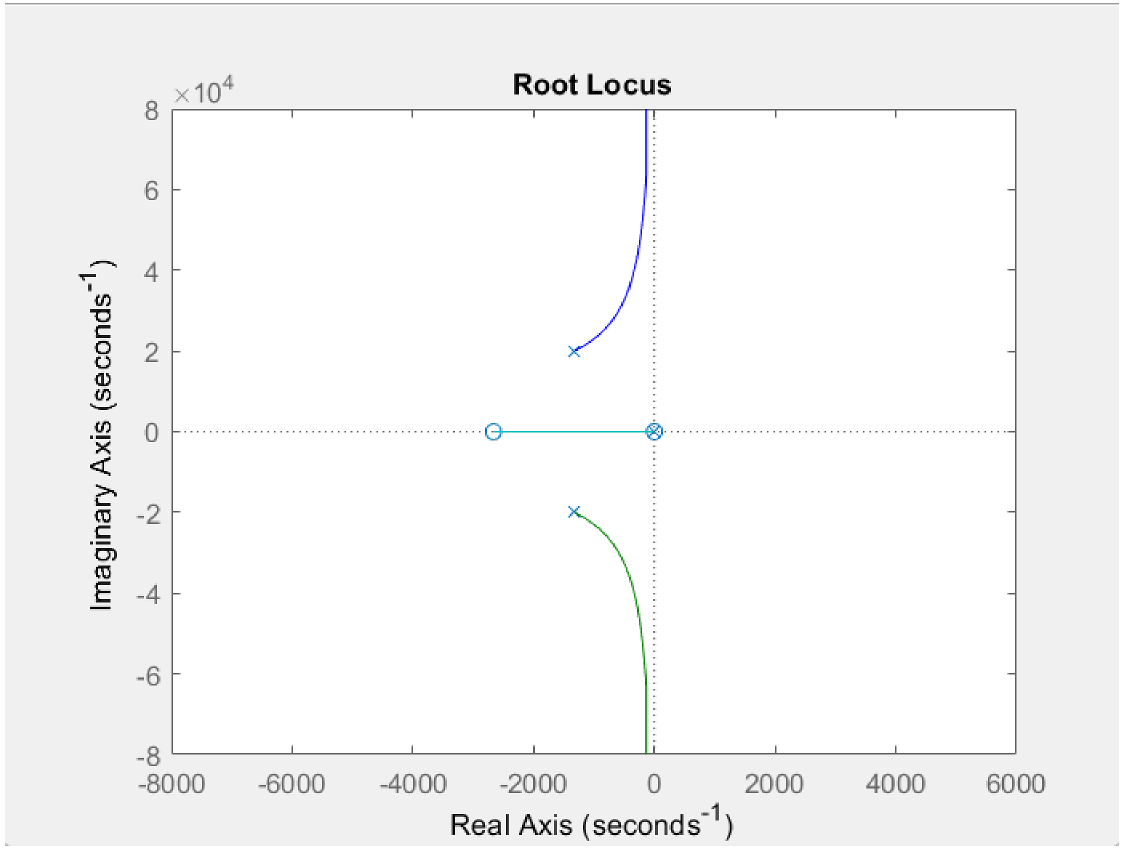
```
\n Transfer Function of iL/d::
                    Vdc
------------------------------------------
      /  2   / r    1  \      1      r   \
C L R | s  + | - + --- | s + --- + ----- |
      \      \ L   C R /     C L   C L R /

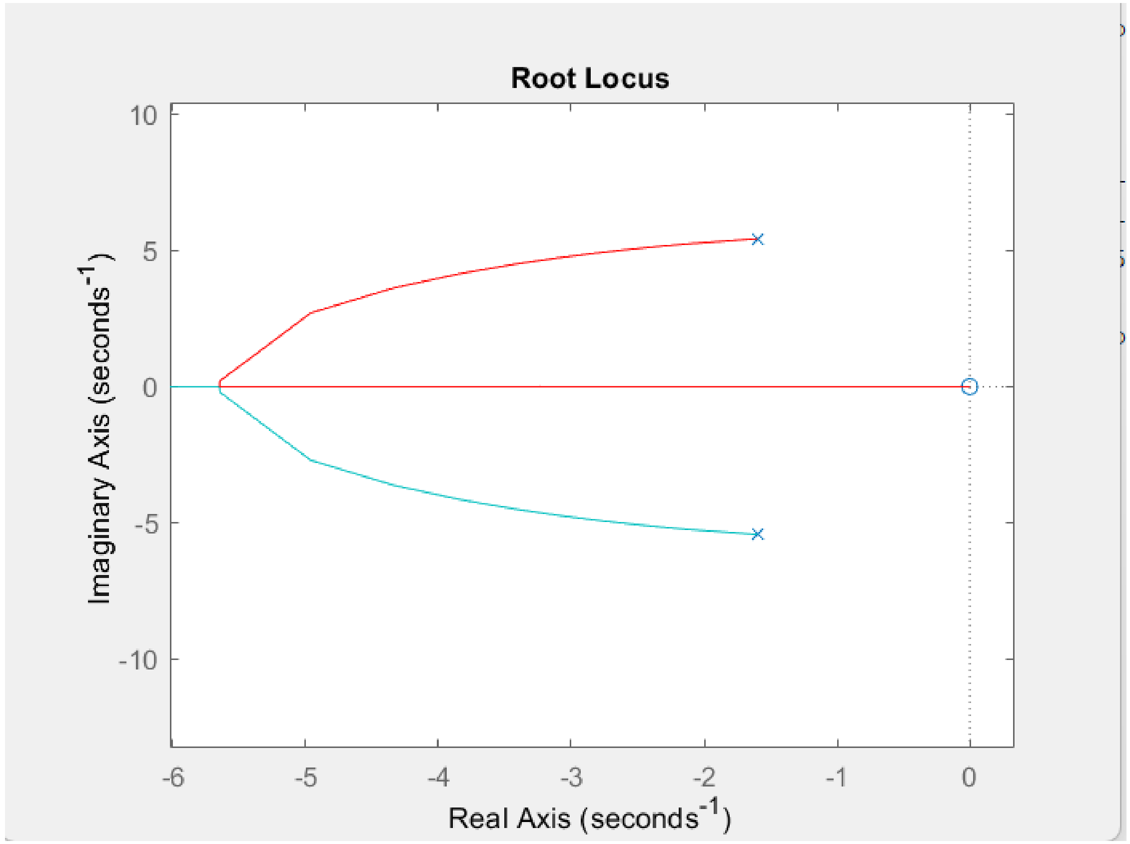
\n Transfer function of open loop:
                               /       kii \
               Vdc (ki + kp s) | kpp + --- |
                               \        s  /
----------------------------------------------------------
                        2                     3          2
Vdc ki + R s + r s + L s  + Vdc kp s + C L R s  + C R r s

Expression with "r" factored out from the denominator:
                             2
    Vdc ki kii + Vdc kp kpp s  + Vdc kii kp s + Vdc ki kpp s
---------------------------------------------------------------
      3    2         3      2                      2          4
(C R s  + s ) r + L s  + R s  + Vdc ki s + Vdc kp s  + C L R s
```

```
Num = [(R*C) 1 0 0];
den = [(R*L*C) L R (Vdc*(kp_i)) (Vdc*(a)) 0];
disp('\n Transfer function with controller::');
pop=tf(Num,den)
rlocus(pop);
```

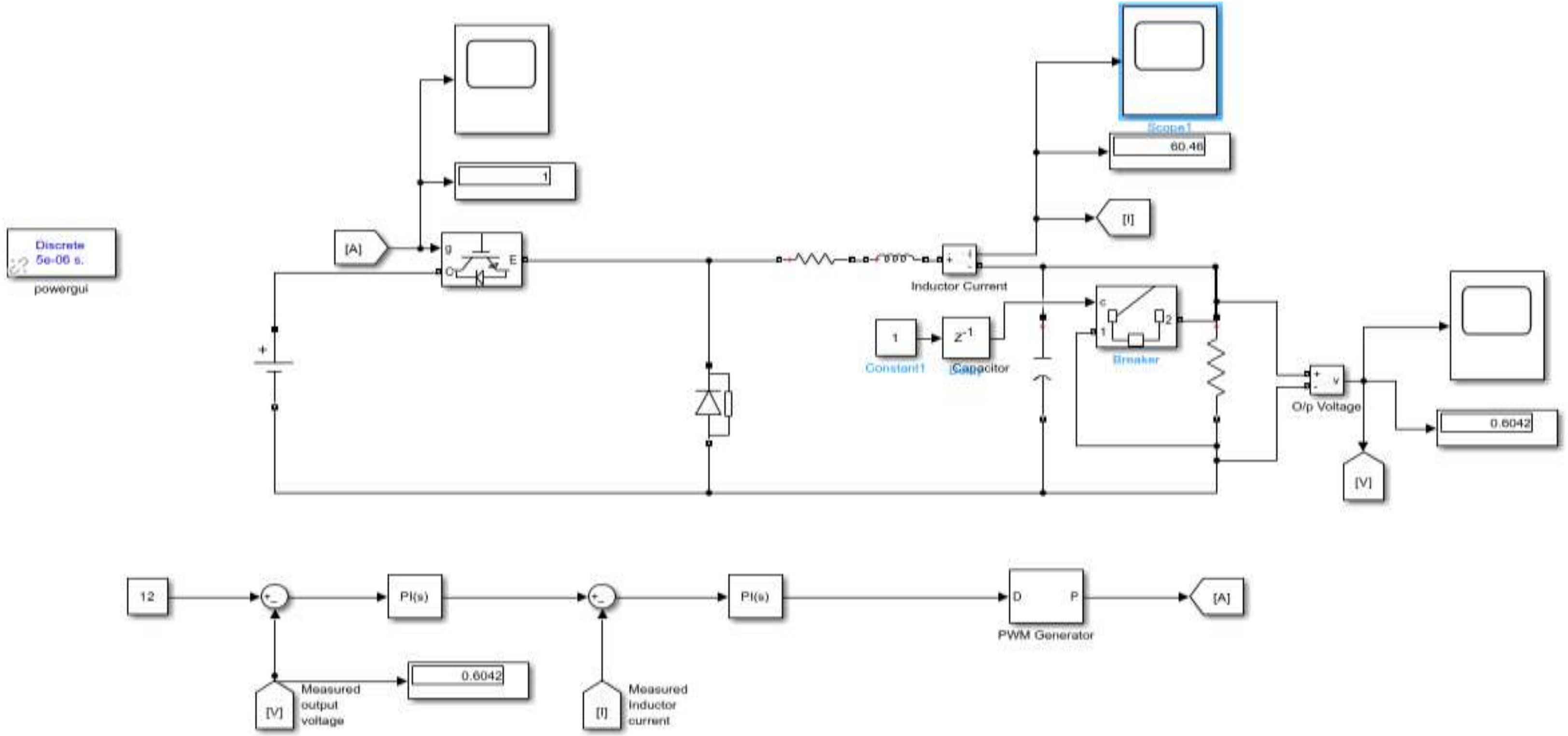
```
kp_i=1; %kp inner
a=10;  %ki inner
```

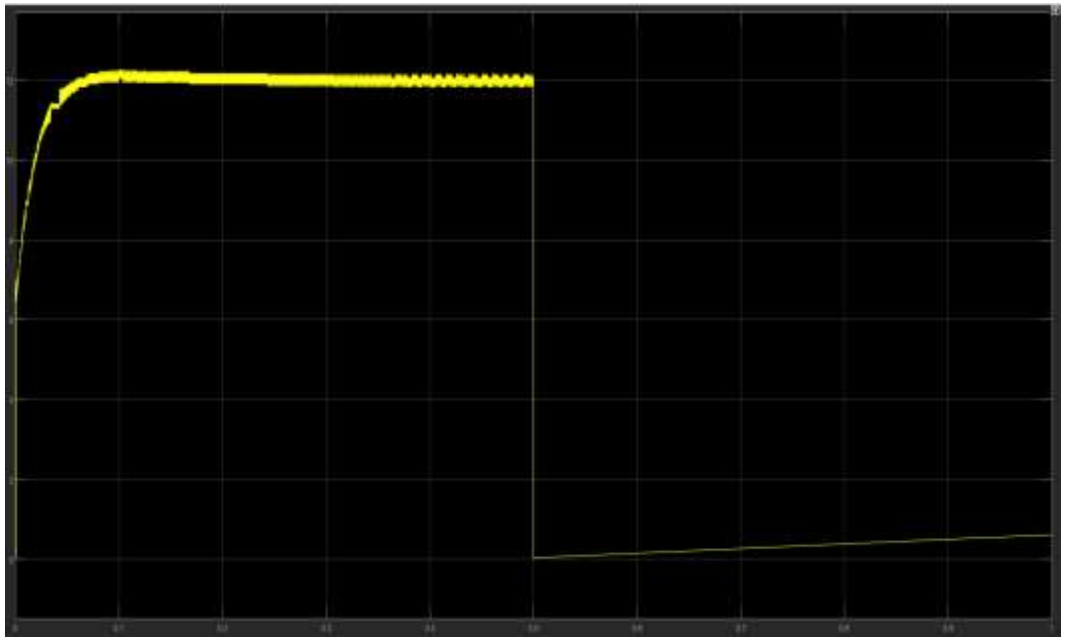




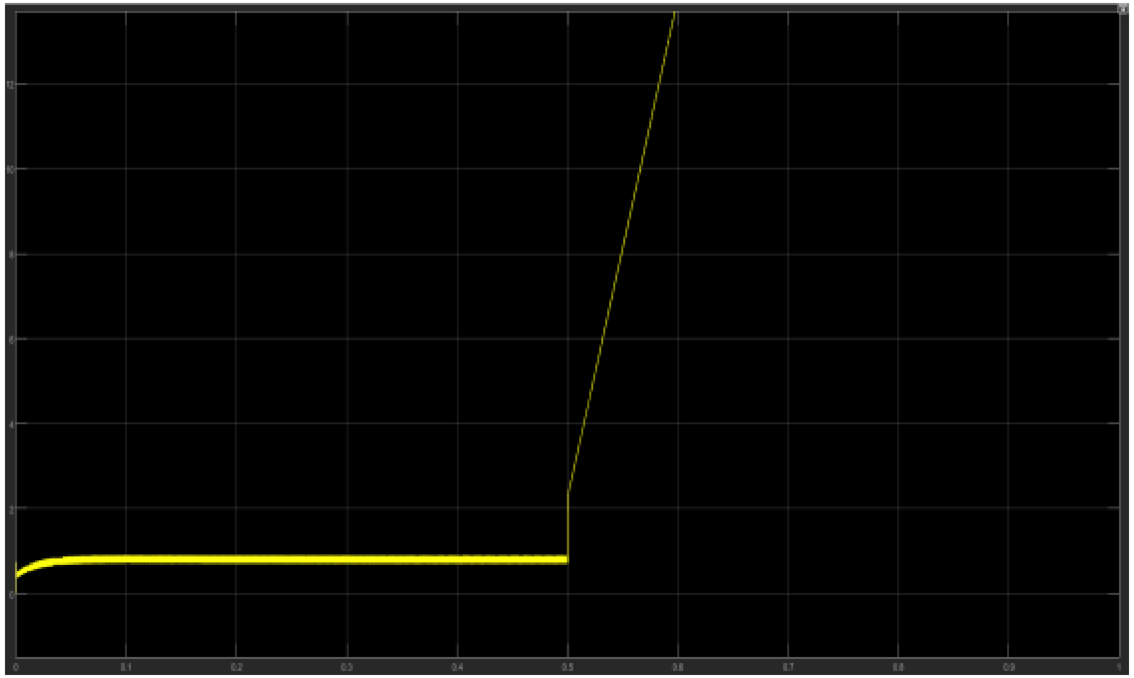
EXTRA TASKS

SHORT CIRCUIT



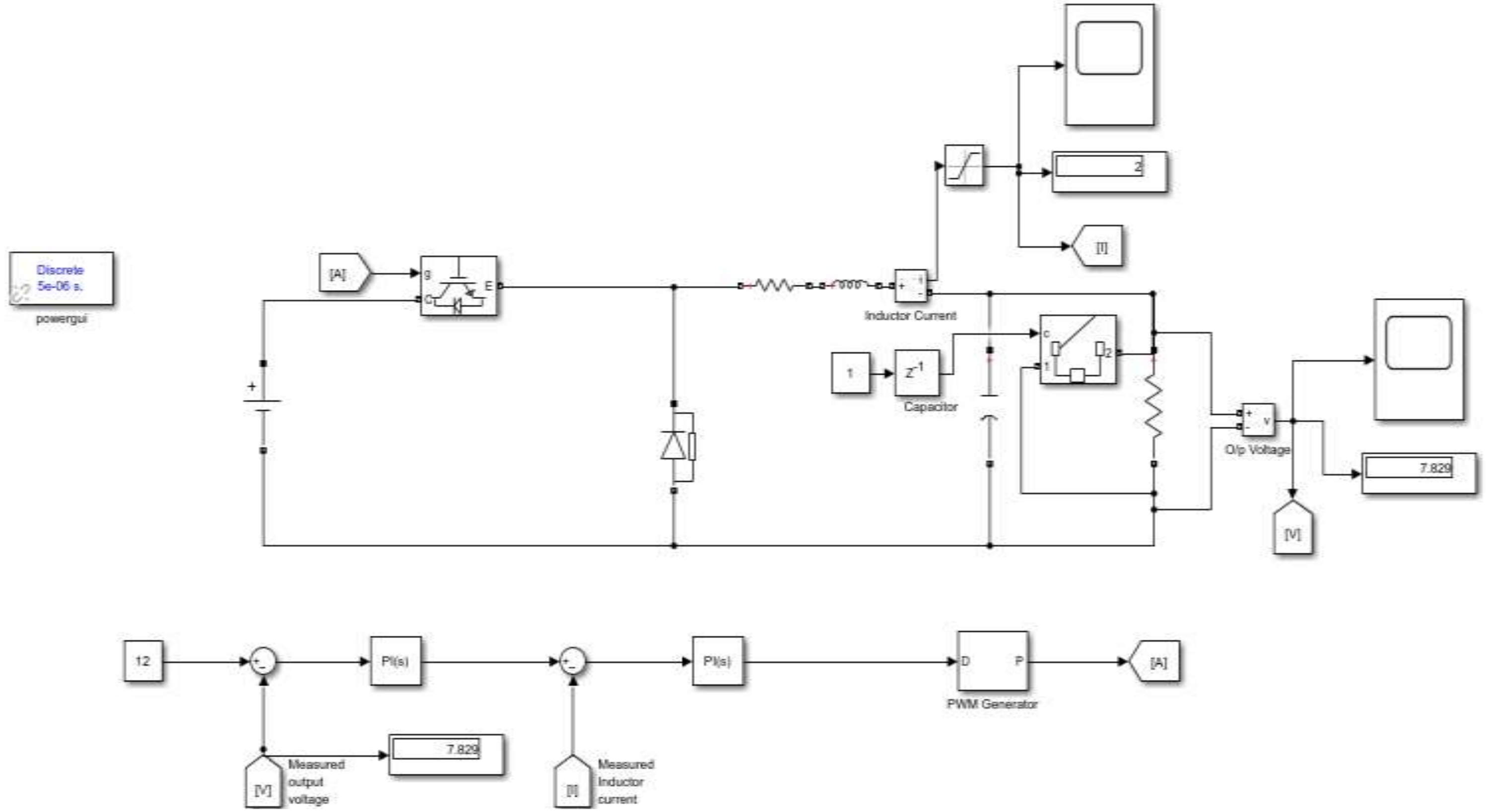


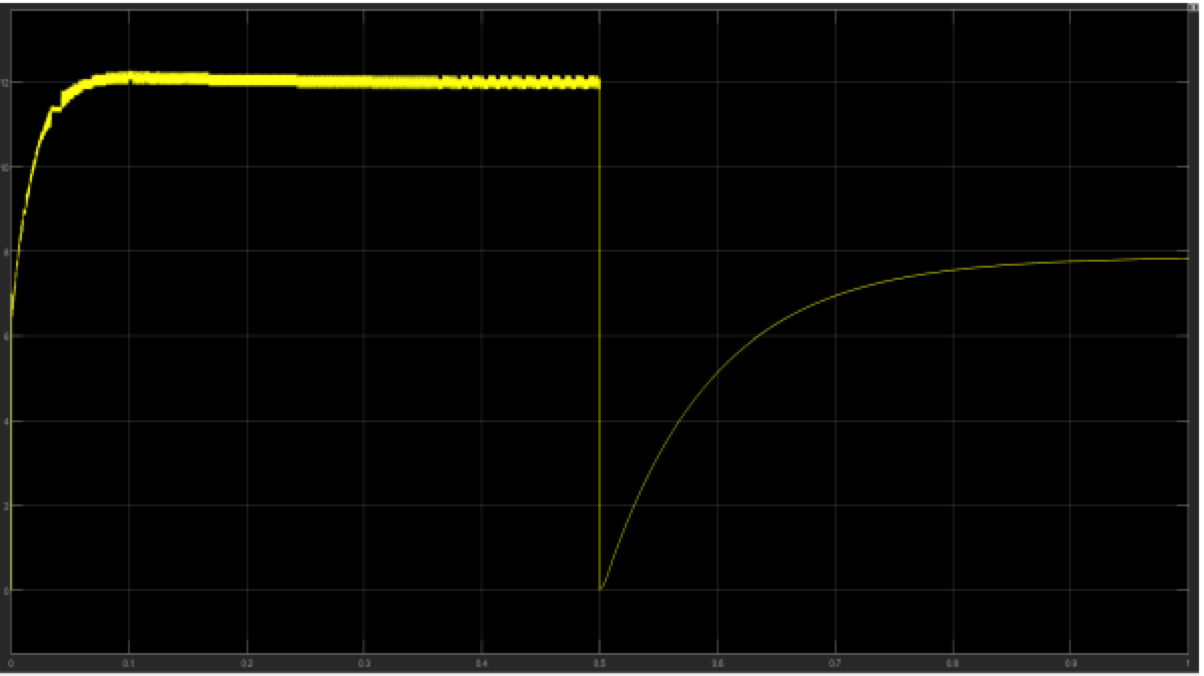
Voltage Profile



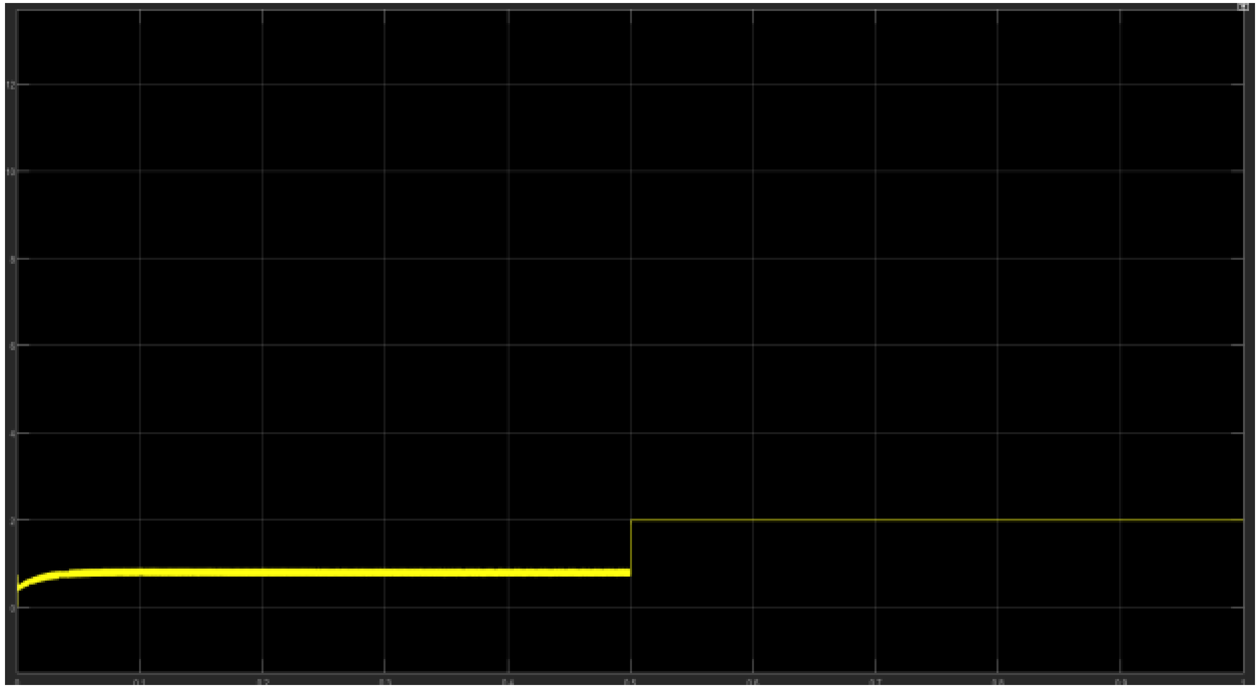
Current Profile

SHORT CIRCUIT WITH SATURATION BLOCK



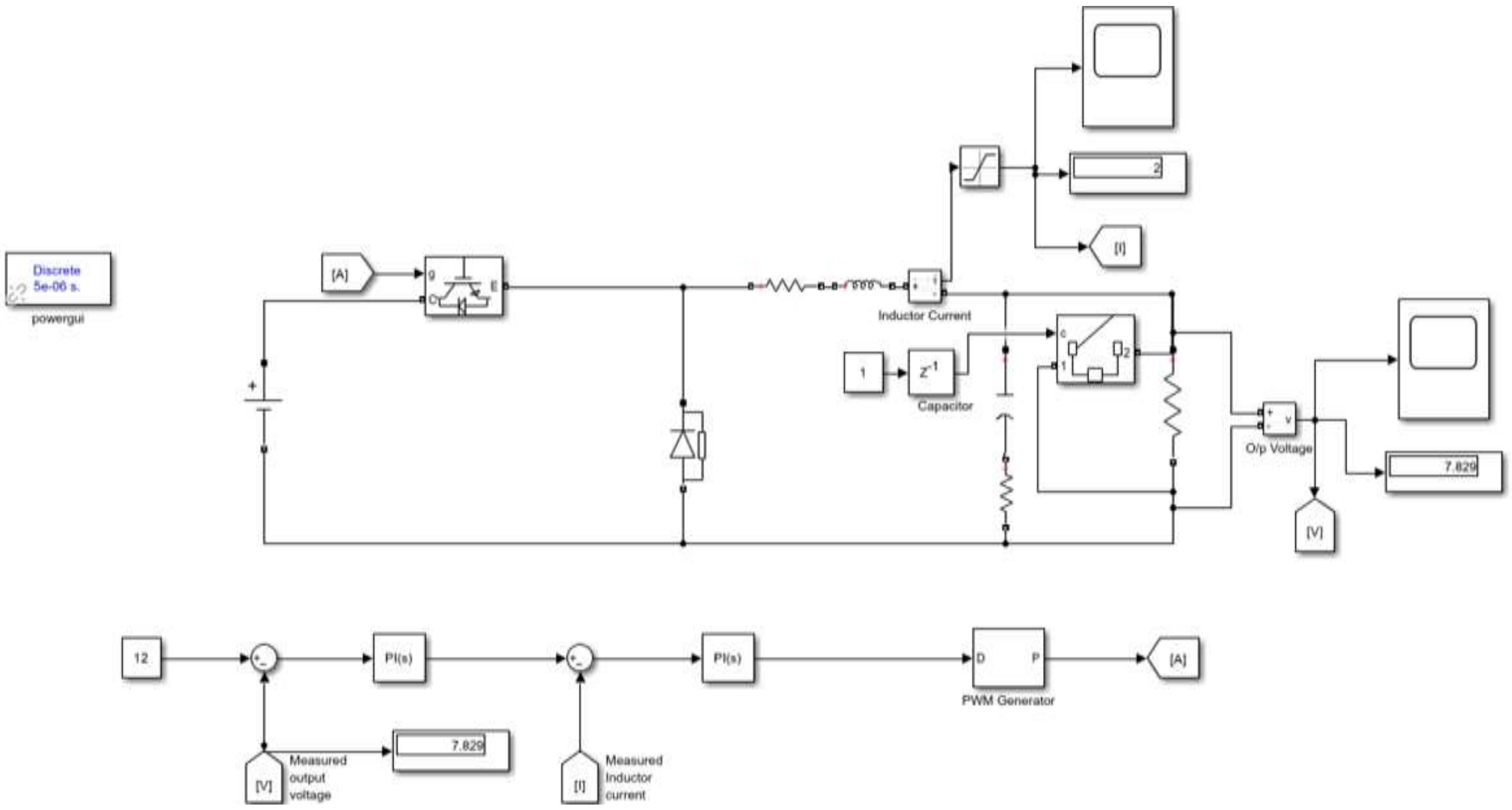


Voltage Profile



Current Profile

Resistance variation and show the limits of the Capacitor series resistance variation for stable operation.



```
\n Transfer Function of iL/d::
                   Vdc (L - C Rc Rl)
-------------------------------------------------------
   2          /  2      L + Rl      Rl s (L + C R Rc) \
C L  (R + Rc) | s  + ------------ + ----------------- |
              |      C L (R + Rc)        2            |
              \                       C L  (R + Rc)   /

\n Transfer function of open loop:
                                                        /       kii \
                                        Vdc (ki + kp s) | kpp + --- | (L - C Rc Rl)
                                                        \        s  /
-----------------------------------------------------------------------------------------------------------------------------
 2                               2      2    3      2     3                                            2
L  s + L Vdc ki + L Rl s + L Rl s  + C L  R s  + C L  Rc s  + L Vdc kp s - C Rc Rl Vdc ki + C R Rc Rl s  - C Rc Rl Vdc kp s

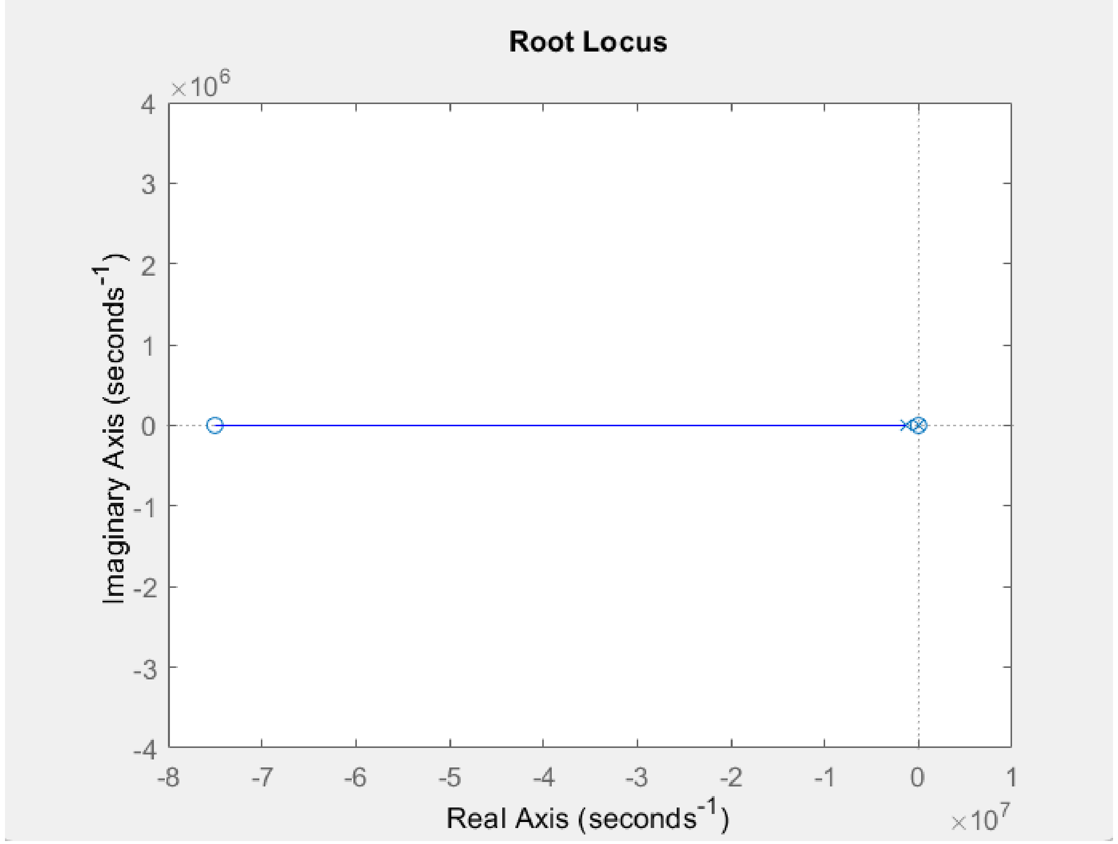
Expression with "Rc" factored out from the denominator:
                                                                            2                                                                       2
(C Rl Vdc ki kii + C Rl Vdc kii kp s + C Rl Vdc ki kpp s + C Rl Vdc kp kpp s ) Rc - L Vdc ki kii - L Vdc kii kp s - L Vdc ki kpp s - L Vdc kp kpp s
----------------------------------------------------------------------------------------------------------------------------------------------------
                 2  4           3                2                        2  2          2          3             2      2    4
          (- C L   s  - C R Rl s  + C Rl Vdc kp s  + C Rl Vdc ki s) Rc - L   s  - L Rl s  - L Rl s  - L Vdc kp s  - C L  R s  - L Vdc ki s
```

```
\n Capacitor series resistance Added!!
\n Transfer function with controller::

pop =

  2.5e-13 s^4 + 1.875e-05 s^3 - 5.4e-08 s^2 - 0.003054 s
  ------------------------------------------------------
    3.75e-12 s^4 + 5e-06 s^3 + 9.33e-06 s^2 + 0.2443 s

Continuous-time transfer function.
```

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L=100e-6;
C=25e-6;
r=0.05;
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d=[ 1 1/(R*C) 1/(L*C)];
t = tf(n,d);   %(iL/d) wo PI
n_1=[Vdc/(L*C)];
d_1=[1 1/(R*C) 1/(L*C)];
t_1=tf(n_1,d_1);   % Vo/d wo PI
disp('\n Transfer Function without PI controller:');
flag= (t_1)/t     % Vo/iL wo PI
kp_i= [0.0009];
a=50.90;
m = [1 0];
ki_i= a*tf(1,m);
 c= kp_i+ki_i;
 t_11=t*c;     %iL/d w PI inner loop
 In= t_11/(t_11+1);
 kp_o= [0.08];
p =704.03;
m_1 = [1 0];
ki_2= p*tf(1,m_1);
 c_2= kp_o+ki_2;

Num = [((L^2)*C) (C*R*r) (-(C*r*Vdc*(kp_i))) (-(C*r*Vdc*(50.90))) 0];
den = [(R*(L^2)*C) (L*r) ((L^2)+(L*r)+(L*Vdc*(kp_i))) (L*Vdc*(50.90))
disp('\n Transfer function with controller::');
pop=tf(Num,den)
rlocus(pop);
```

REFERENCE

[1] Hasan Sucu, Taner Goktas, Muslum Arkan ,“Design, Simulation and Application of Buck Converter with Digital PI Controller ”,Balkan journal of electrical & computer engineering, Vol. 9, No. 2, April 2021.

[2] P.C. Sen, Zaohong Yang, “DC-TO-DC buck Converters with novel current mode control” , 1999 IEEE

THANK YOU