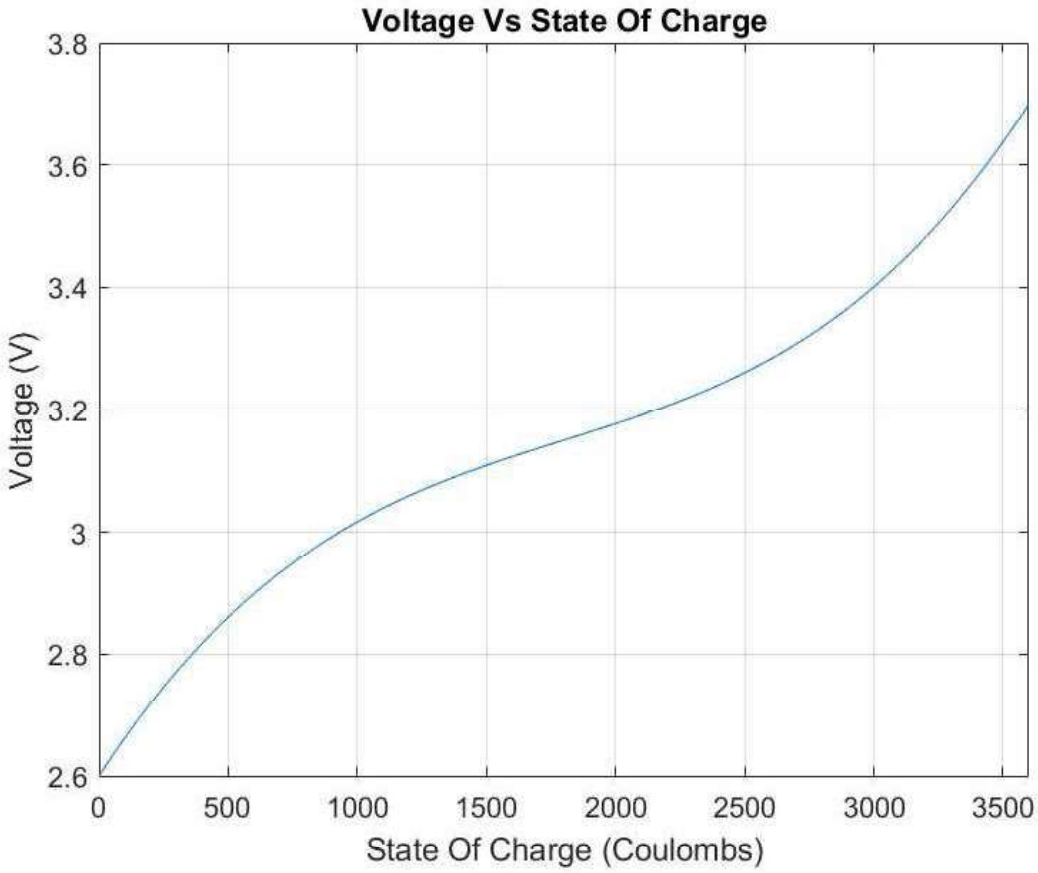
```
%Requirement 1

U=3600;
x=linspace(0,1,1000);
OCV=2.6+2.35*x-3.75*x.^2+2.5*x.^3;
disp("Open Circuit Voltage (OCV) when fully discharged " + OCV(1) + " Volts");
```

```
Open Circuit Voltage (OCV) when fully discharged 2.6 Volts
```

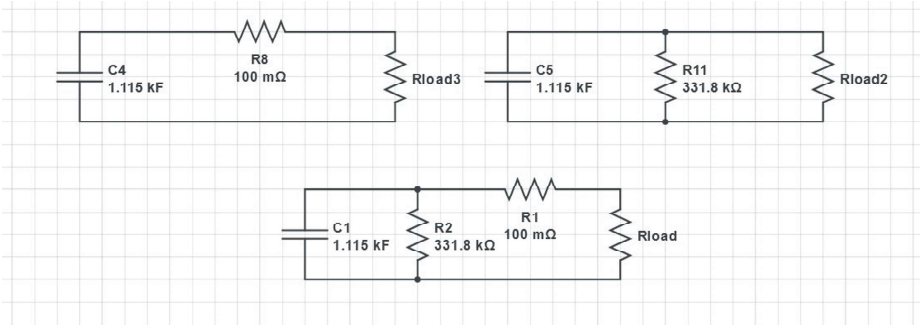
```
disp("Open Circuit Voltage (OCV) when fully charged " + OCV(end) + " Volts");
```

```
Open Circuit Voltage (OCV) when fully charged 3.7 Volts
```

```

col=x.*U;
plot(col,OCV);
figure(1)
title("Voltage Vs State Of Charge")
xlabel("State Of Charge (Coulombs)")
ylabel("Voltage (V)")
xlim([0,3600])
grid on
```



2.



3.

First-Order - Series

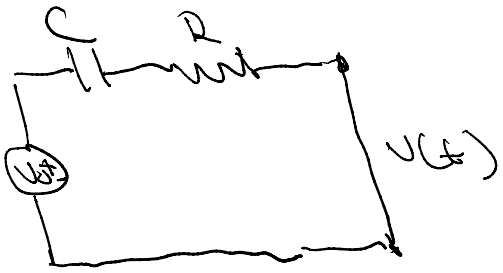
$\dot{x}(t) = Ax + Bu$

$y(t) = Cx + Du$

$x(t) = Q(t)$

$u(t) = I(t)$

$y(t) = V(t)$

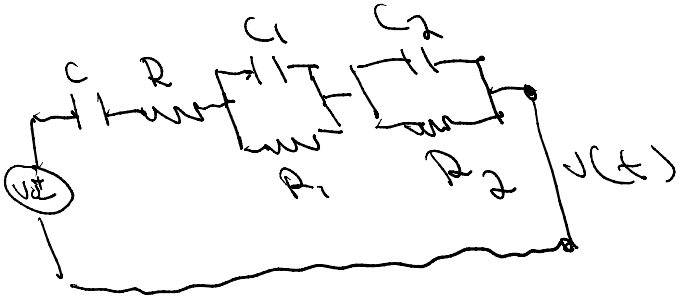


$$\dot{x} = \frac{1}{C} u$$

$$y = V_0 + \gamma x + Ru$$

$\dot{x}(t) = Bu = [1/Q]u$

$y(t) = Cx + Du = [\gamma]x + [R + V_0]u$



Third-Order - 2 RC Pairs

$$\dot{x}_1 = \frac{1}{C} u$$

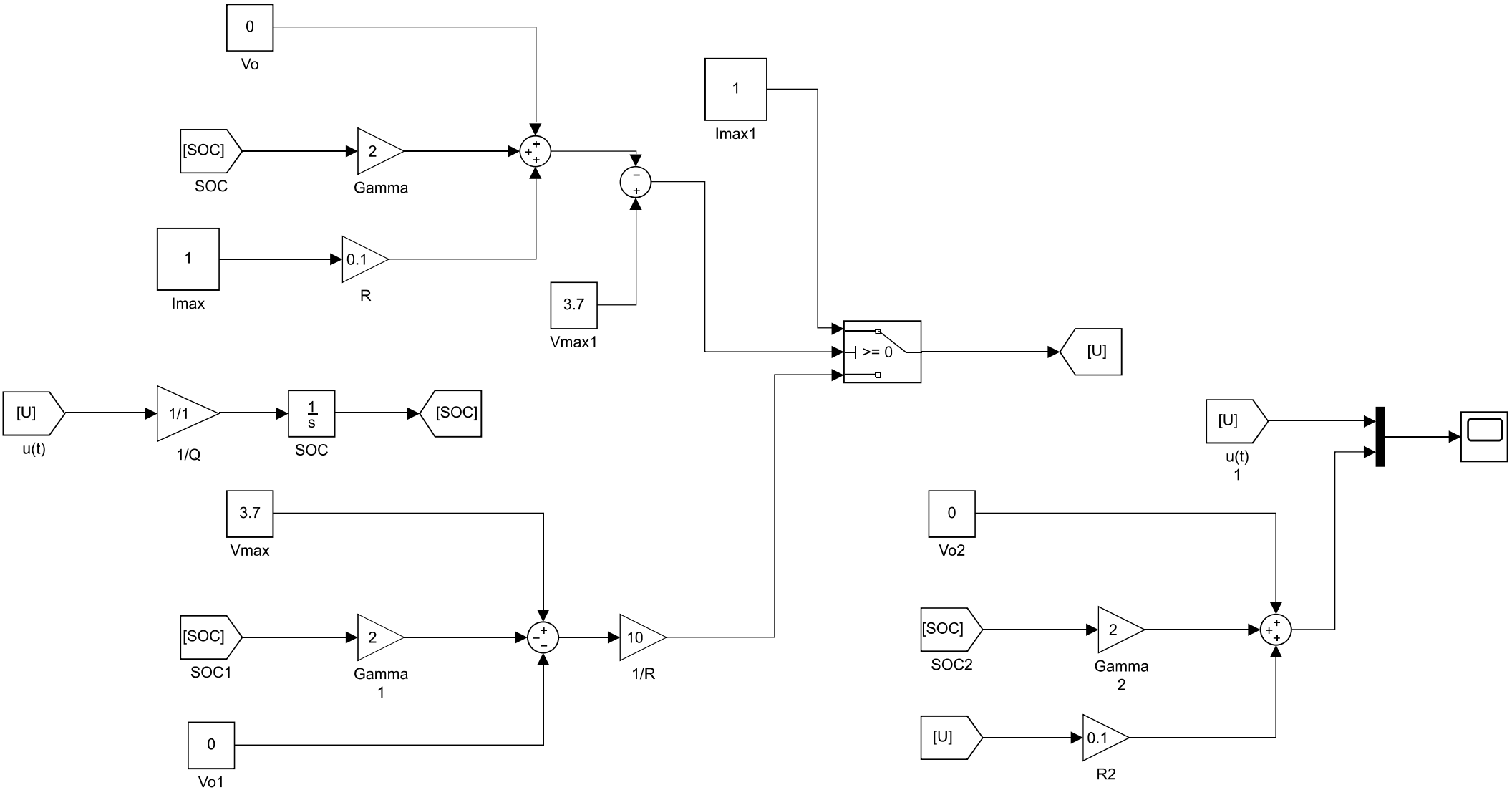
$$\dot{x}_2 = u - \frac{1}{R_1 C_1} x_2$$

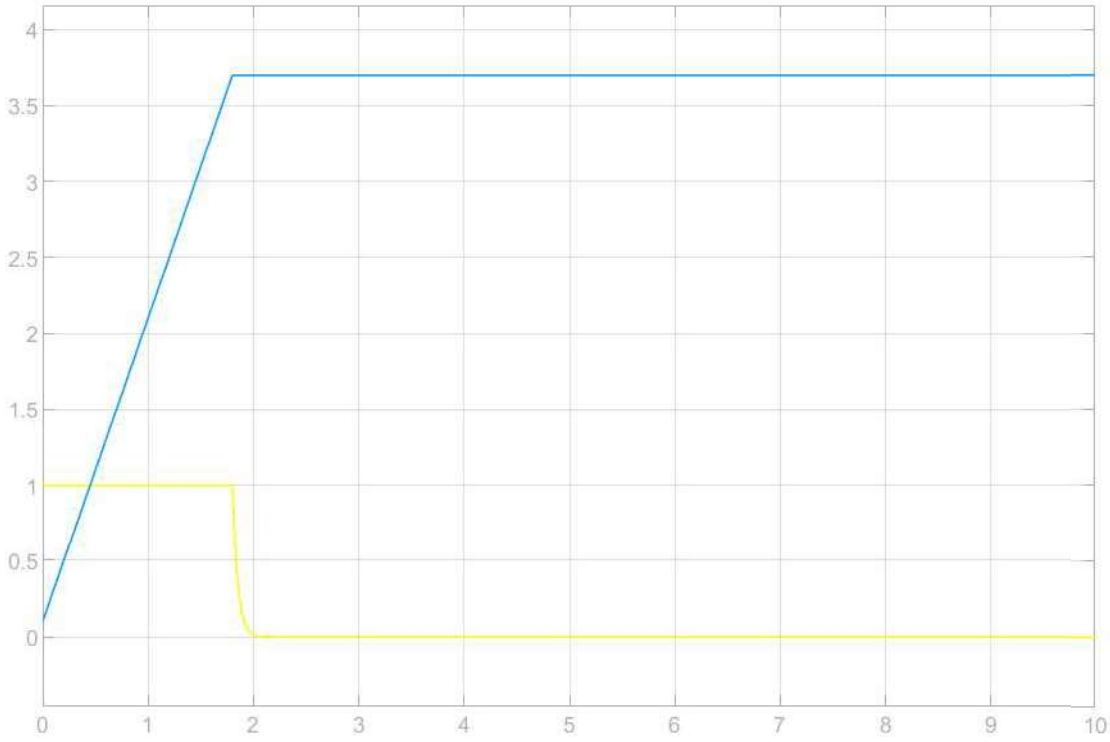
$$\dot{x}_3 = u - \frac{1}{R_2 C_2} x_3$$

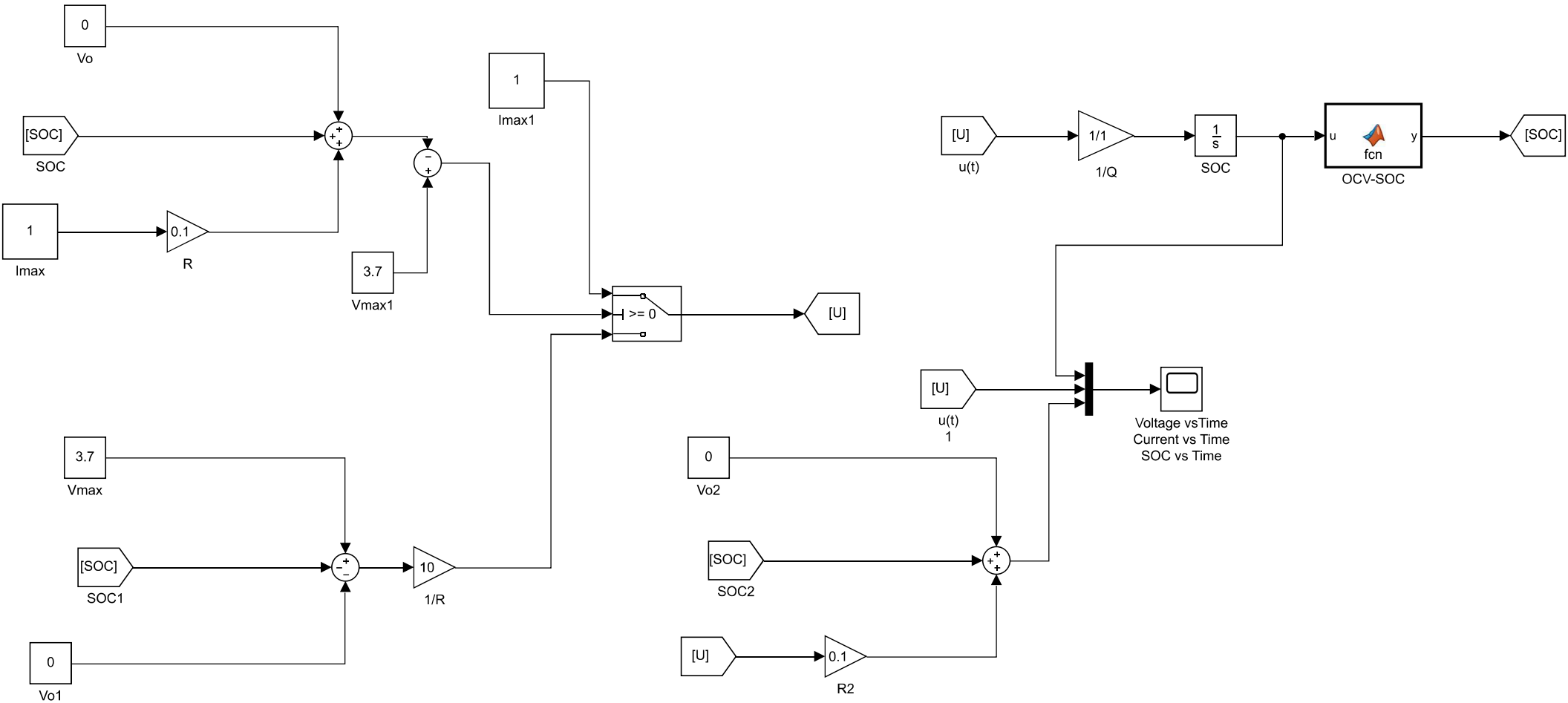
$$y = V_0 + \gamma x_1 + \frac{1}{C_1} x_2 + \frac{1}{C_2} x_3 + Ru$$

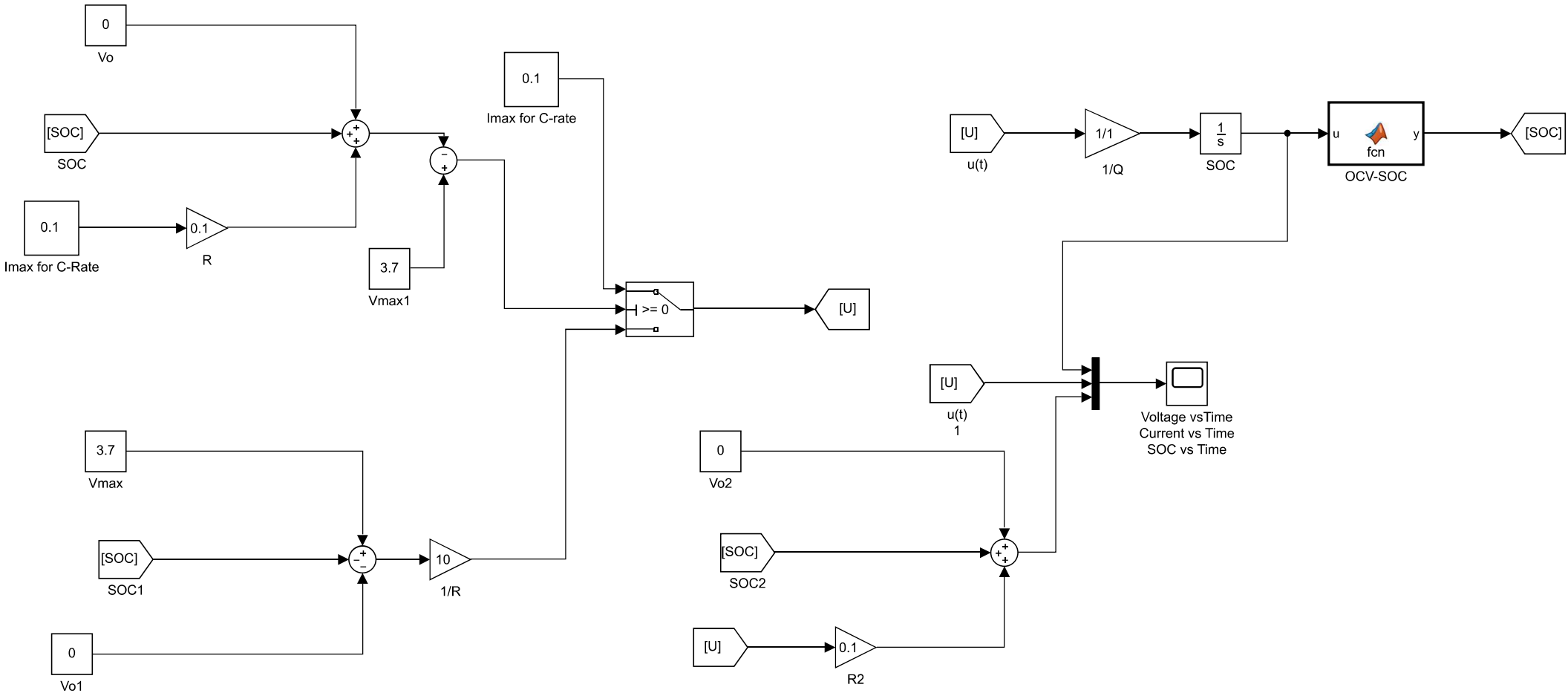
$$\dot{x}(t) = A\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + B\begin{bmatrix} U_1 \\ U_2 \\ U_3 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & \frac{-1}{R_1C_1} & 0 \\ 0 & 0 & \frac{-1}{R_2C_2} \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 1/Q & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} U_1 \\ U_2 \\ U_3 \end{bmatrix}$$

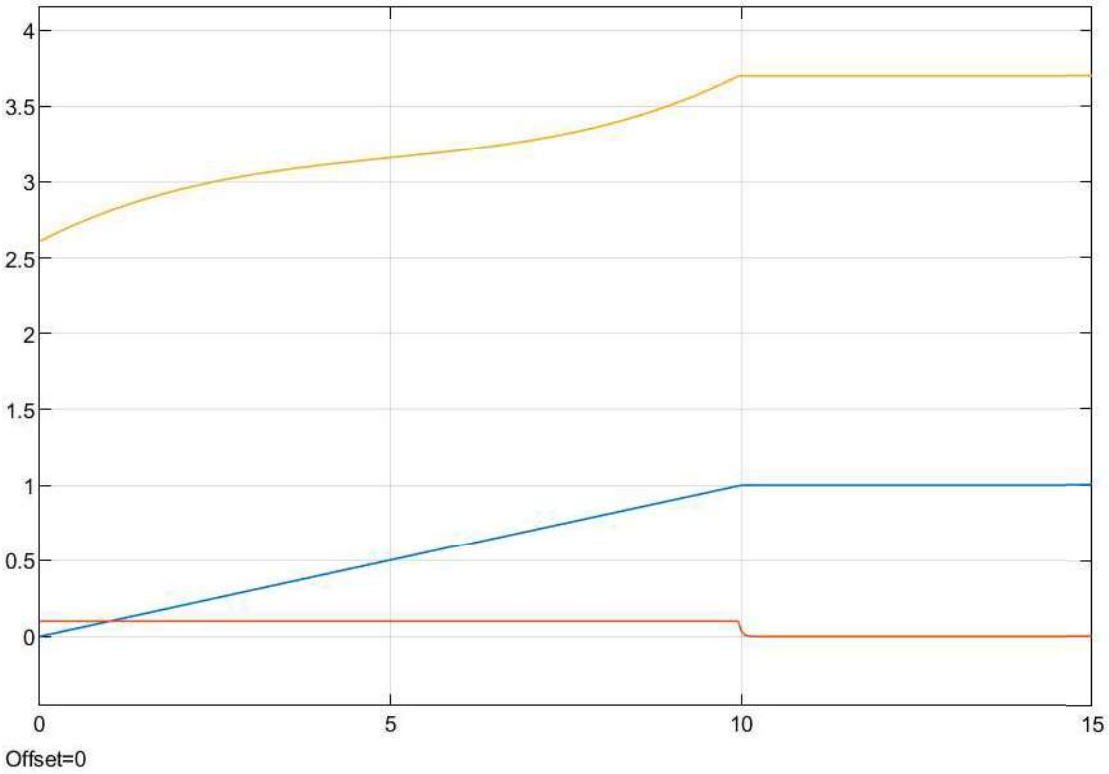
$$Y(t) = C\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + D\begin{bmatrix} U_1 \\ U_2 \\ U_3 \end{bmatrix} = \begin{bmatrix} \gamma & 0 & 0 \\ 0 & 1/C_1 & 0 \\ 0 & 0 & 1/C_2 \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} R+V_0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}\begin{bmatrix} U_1 \\ U_2 \\ U_3 \end{bmatrix}$$

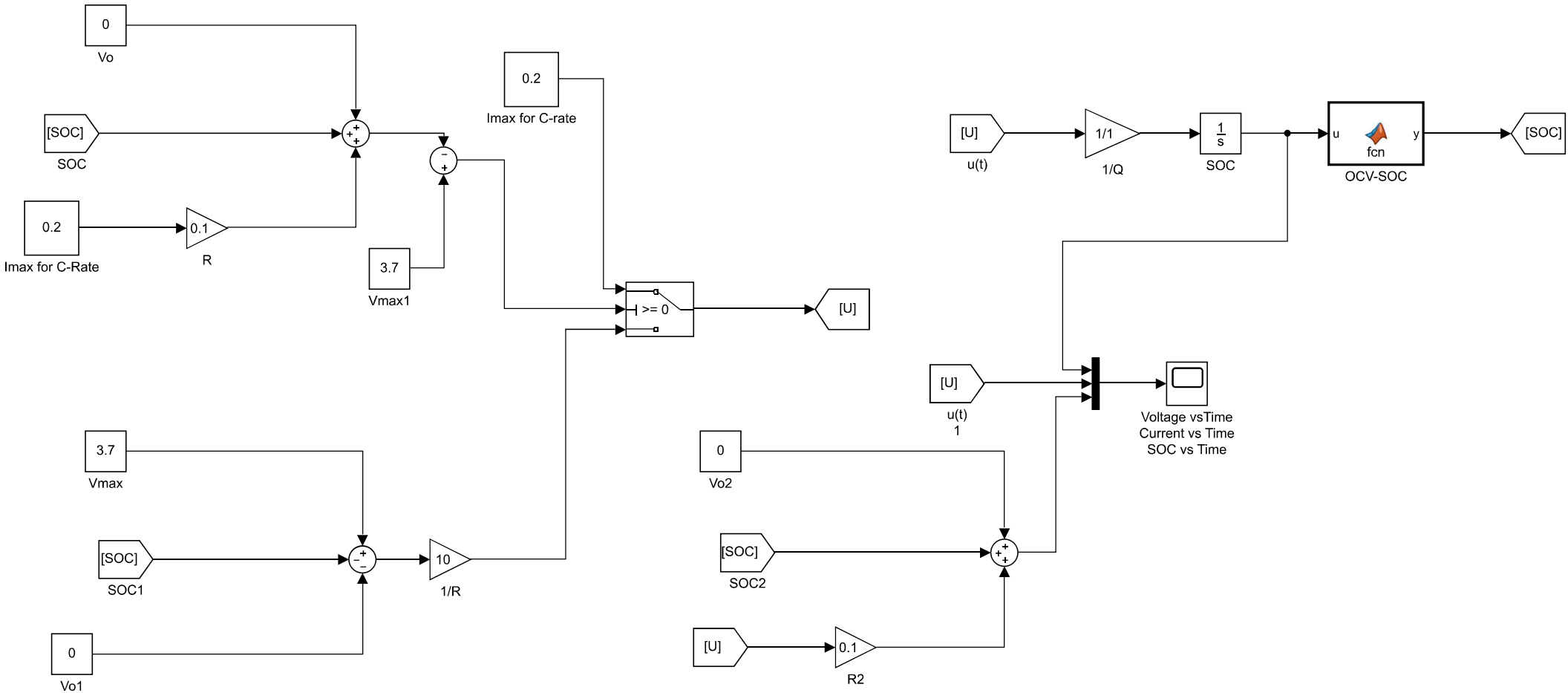

0
Vo
[SOC]
SOC
2
Gamma
1
Imax
0.1
R
3.7
Vmax1
1
Imax1
>= 0
[U]
[U]
u(t)
1/1
1/Q
1
s
SOC
[SOC]
3.7
Vmax
[SOC]
SOC1
2
Gamma
1
10
1/R
0
Vo1
0
Vo2
[SOC]
SOC2
2
Gamma
2
[U]
0.1
R2
[U]
u(t)
1

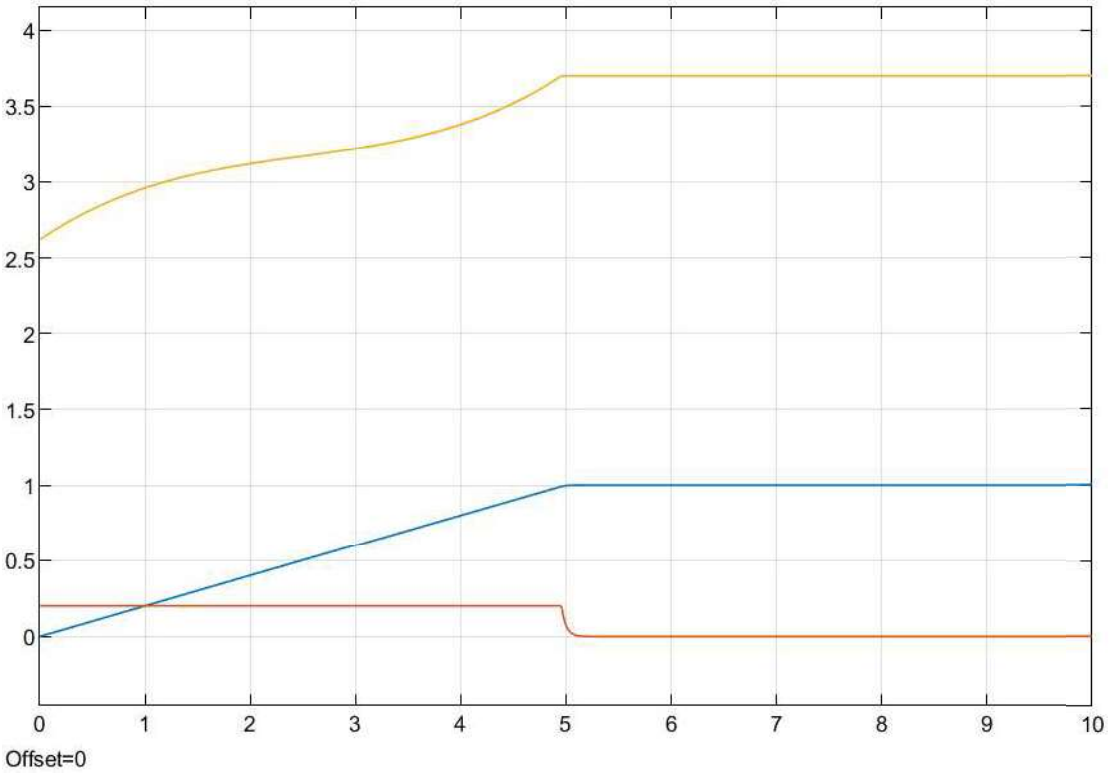

4
3.5
3
2.5
2
1.5
1
0.5
0
0
1
2
3
4
5
6
7
8
9
10

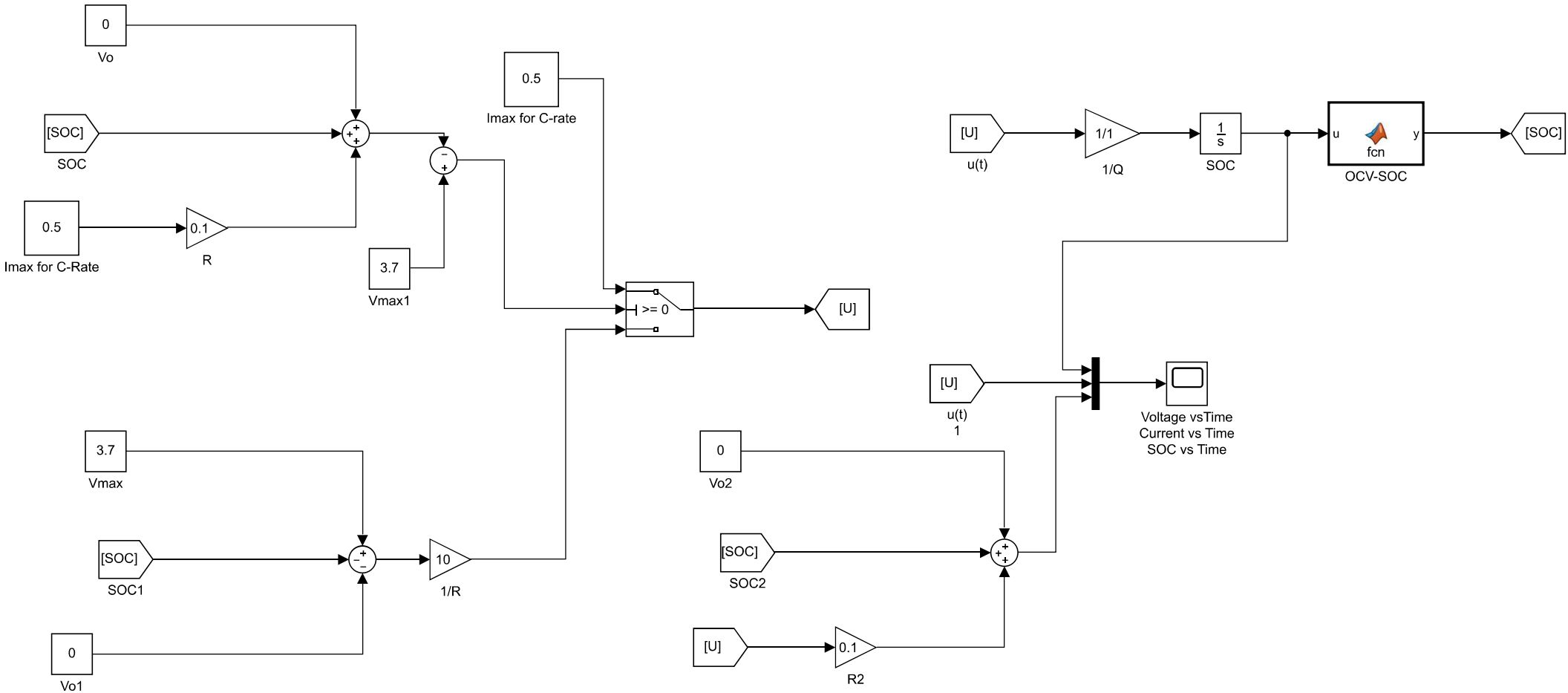

0
Vo
[SOC]
SOC
1
Imax
0.1
R
1
Imax1
3.7
Vmax1
I >= 0
[U]
3.7
Vmax
[SOC]
SOC1
10
1/R
0
Vo1
0
Vo2
[SOC]
SOC2
[U]
0.1
R2
[U]
u(t)
1/1
1/Q
1
s
SOC
u
fcn
y
OCV-SOC
[SOC]
[U]
u(t)
1
Voltage vsTime
Current vs Time
SOC vs Time

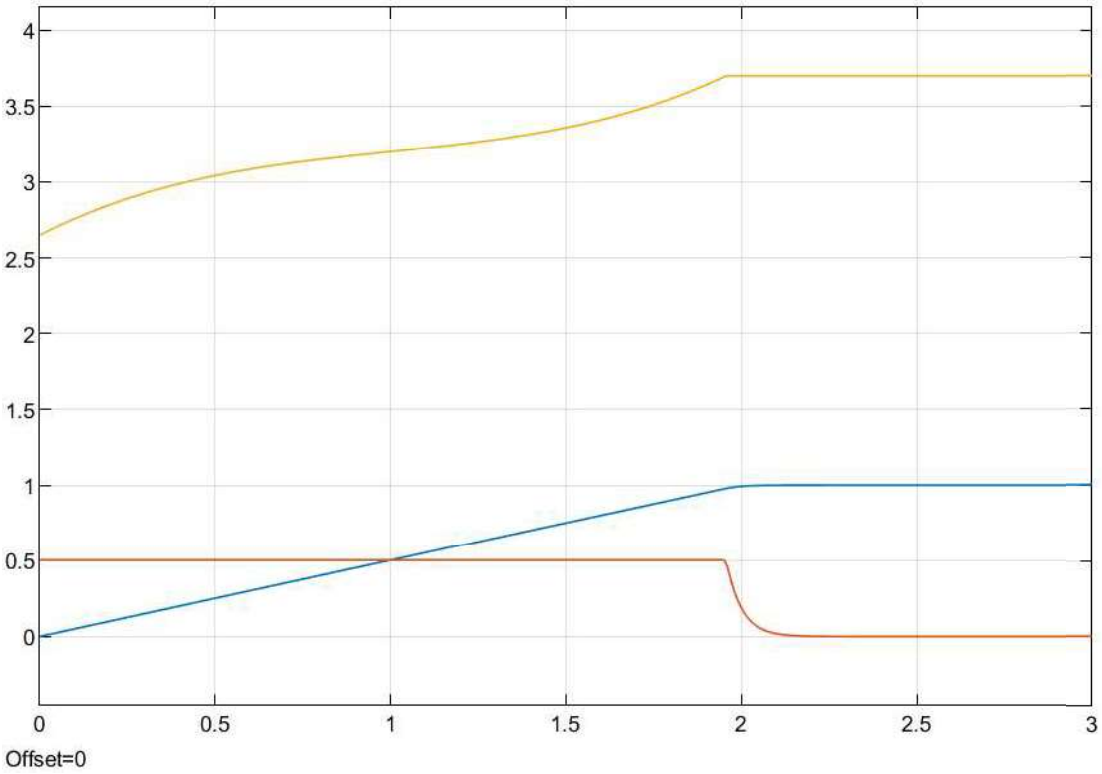

0
Vo
[SOC]
SOC
0.1
Imax for C-rate
0.1
Imax for C-Rate
0.1
R
3.7
Vmax1
>= 0
[U]
[U]
u(t)
1/1
1/Q
1
s
SOC
u
fcn
y
OCV-SOC
[SOC]
[U]
u(t)
1
Voltage vsTime
Current vs Time
SOC vs Time
3.7
Vmax
[SOC]
SOC1
10
1/R
0
Vo1
0
Vo2
[SOC]
SOC2
[U]
0.1
R2

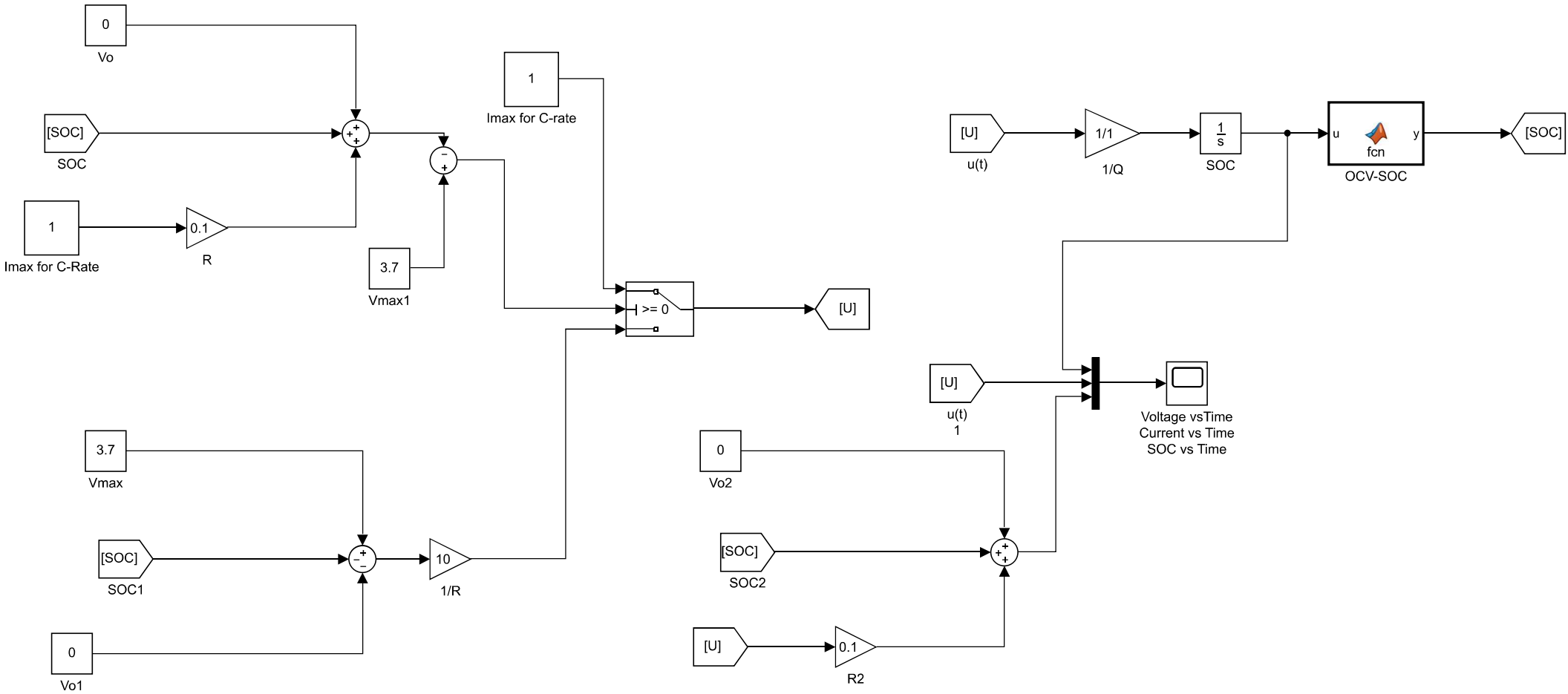

4
3.5
3
2.5
2
1.5
1
0.5
0
0
5
10
15
Offset=0

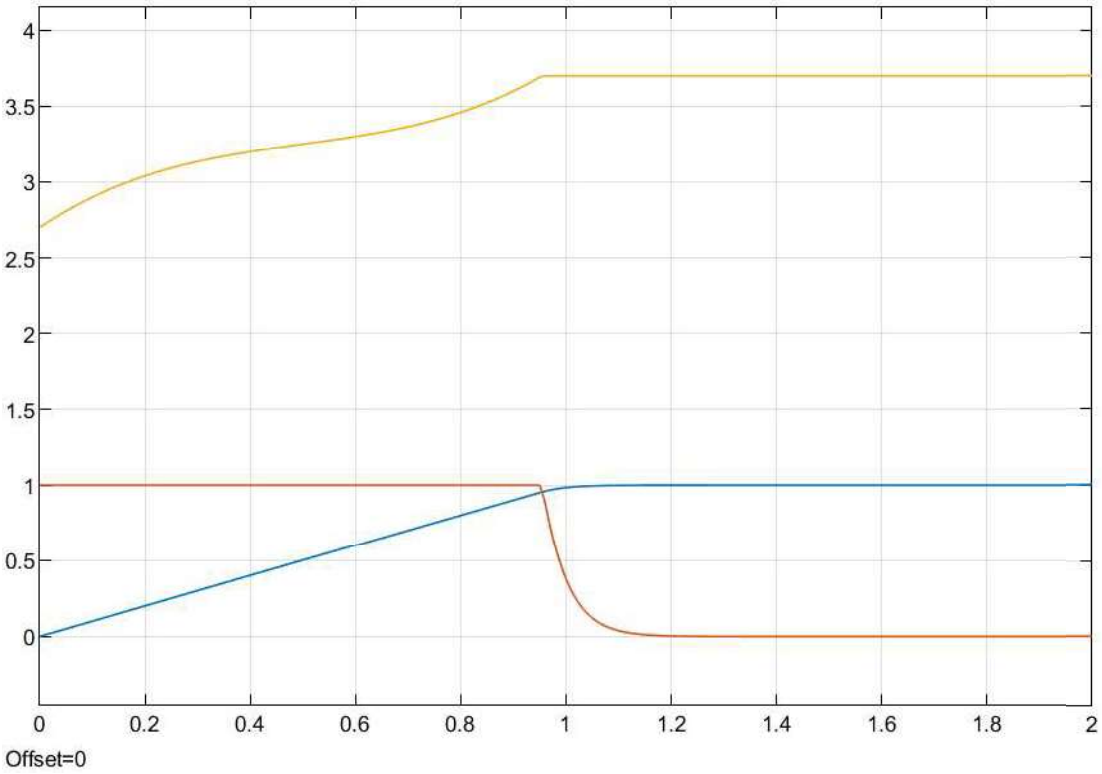

0
Vo
[SOC]
SOC
0.2
Imax for C-Rate
0.1
R
3.7
Vmax1
0.2
Imax for C-rate
>= 0
[U]
3.7
Vmax
[SOC]
SOC1
10
1/R
0
Vo1
[U]
u(t)
1/1
1/Q
1
s
SOC
u
fcn
y
OCV-SOC
[SOC]
[U]
u(t)
1
Voltage vsTime
Current vs Time
SOC vs Time
0
Vo2
[SOC]
SOC2
[U]
0.1
R2

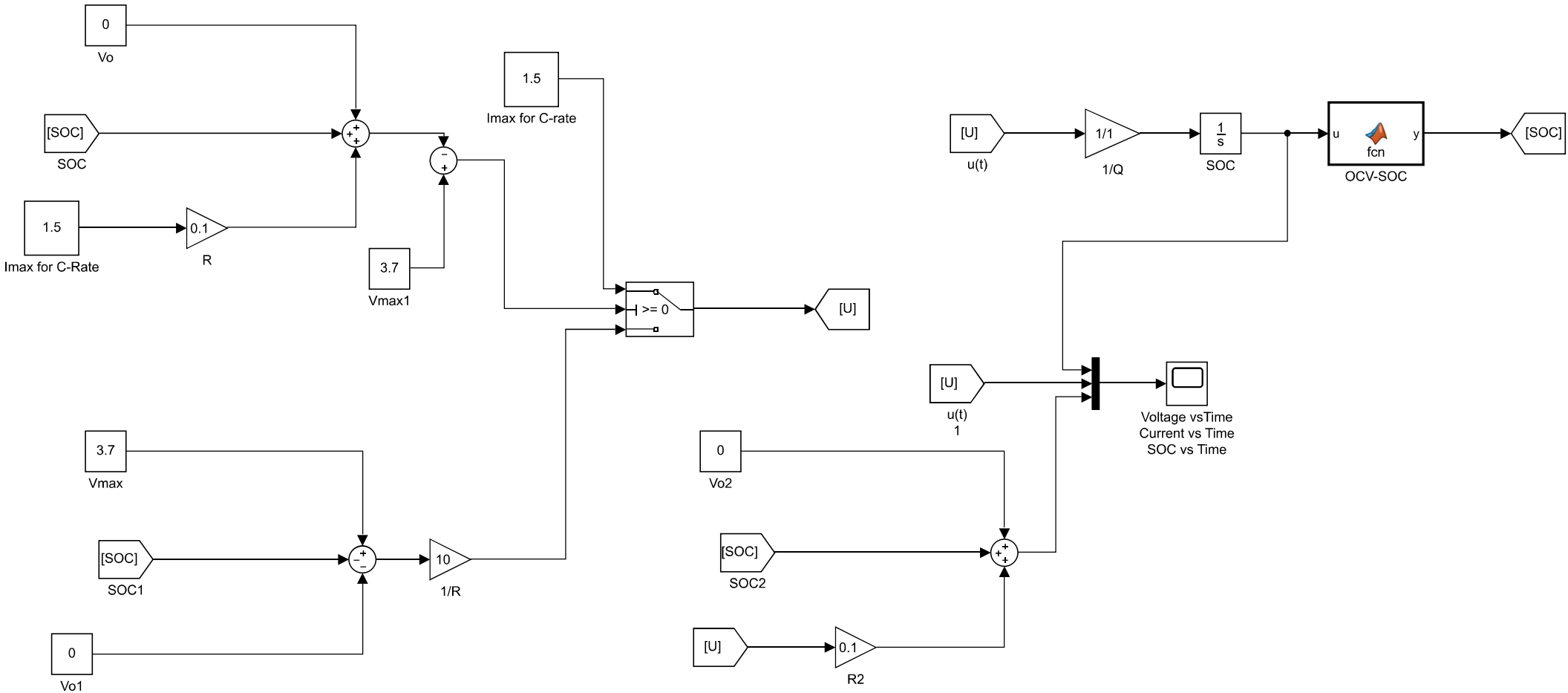

4
3.5
3
2.5
2
1.5
1
0.5
0
0
1
2
3
4
5
6
7
8
9
10
Offset=0

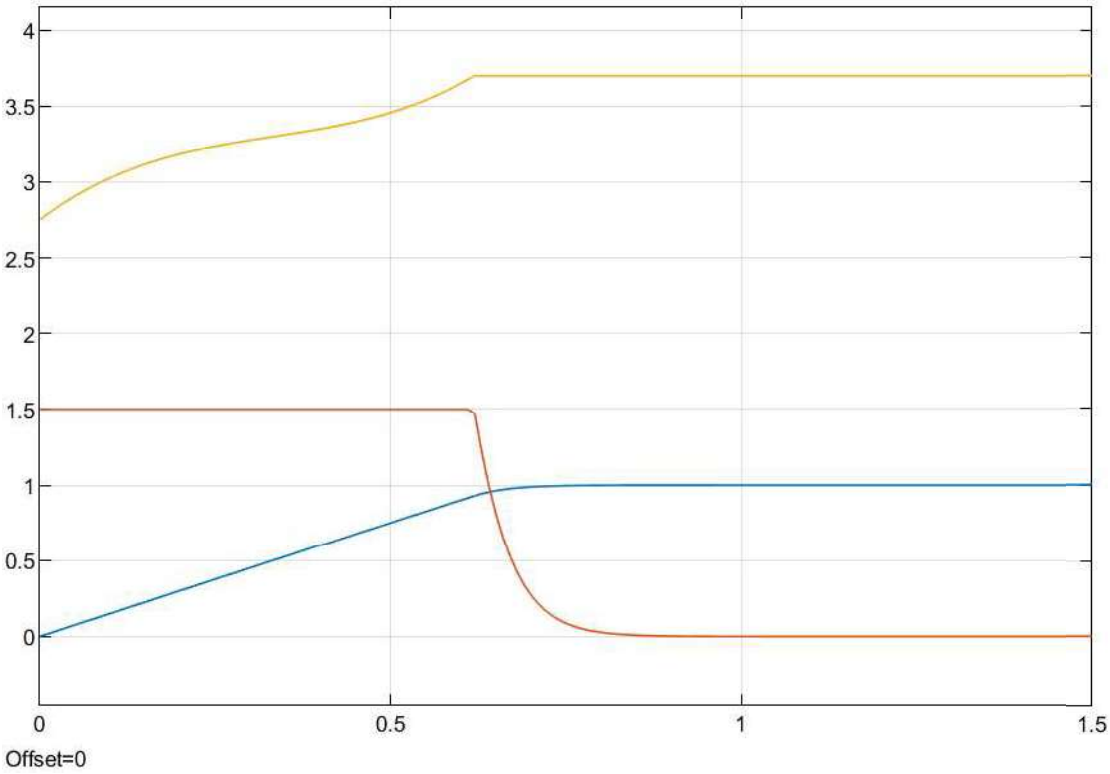

0
Vo
[SOC]
SOC
0.5
Imax for C-Rate
0.1
R
3.7
Vmax1
0.5
Imax for C-rate
>= 0
[U]
3.7
Vmax
[SOC]
SOC1
10
1/R
0
Vo1
0
Vo2
[SOC]
SOC2
[U]
0.1
R2
[U]
u(t)
1/1
1/Q
1
s
SOC
u
fcn
y
OCV-SOC
[SOC]
[U]
u(t)
1
Voltage vsTime
Current vs Time
SOC vs Time

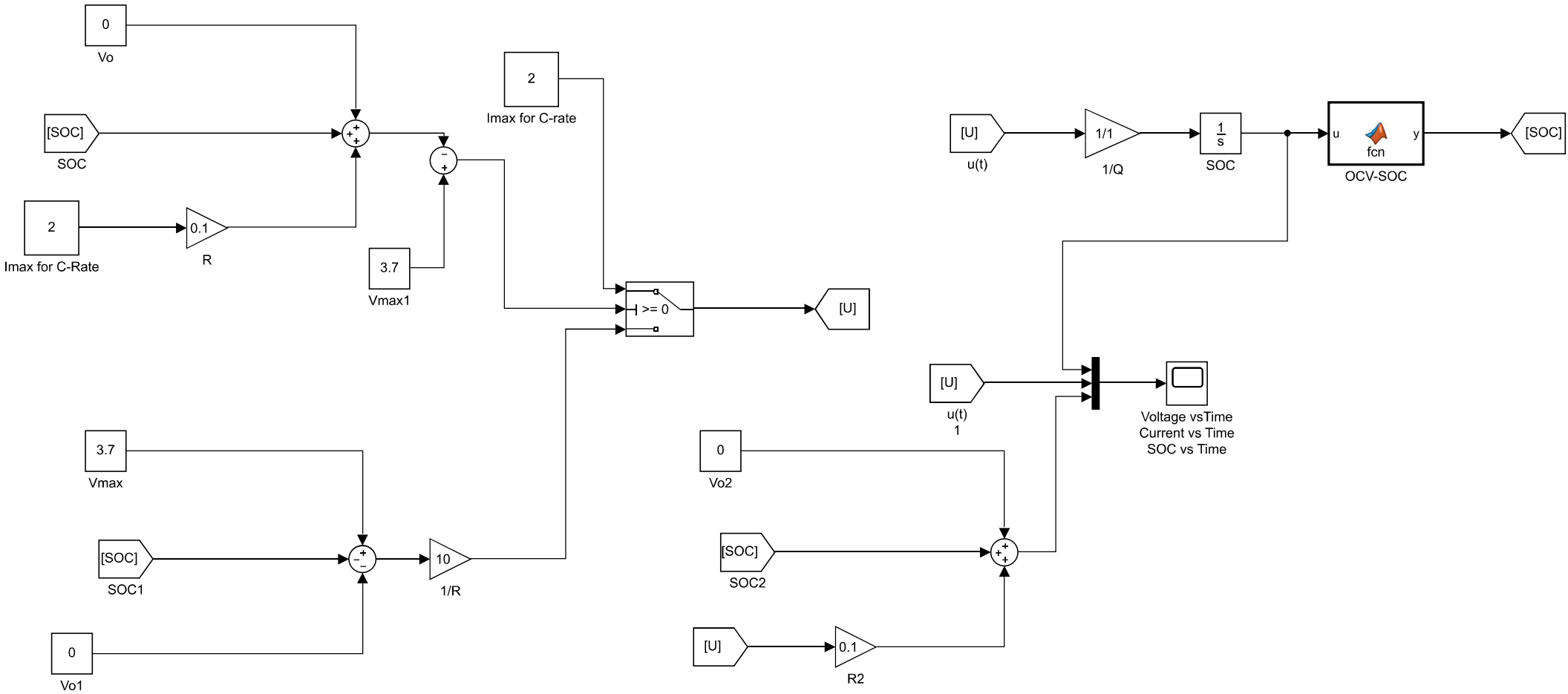

4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.5
1
1.5
2
2.5
3
Offset=0

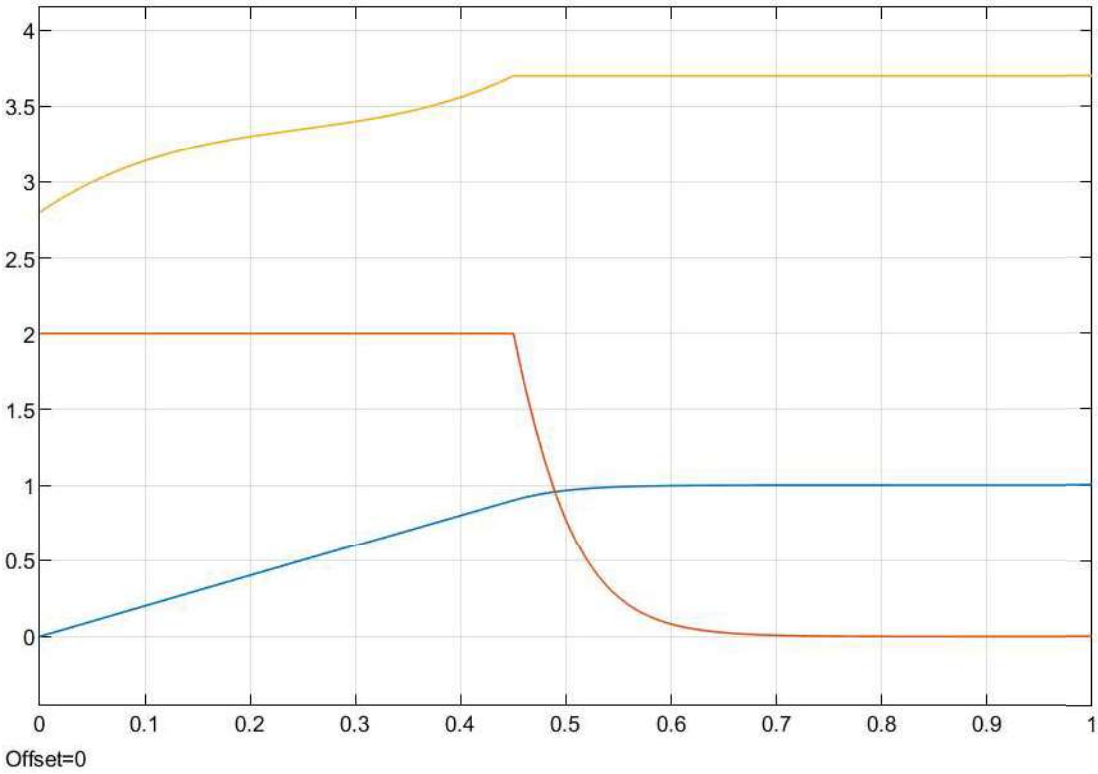

0
Vo
[SOC]
SOC
1
Imax for C-Rate
0.1
R
1
Imax for C-rate
3.7
Vmax1
>= 0
[U]
3.7
Vmax
[SOC]
SOC1
10
1/R
0
Vo1
0
Vo2
[SOC]
SOC2
[U]
0.1
R2
[U]
u(t)
1/1
1/Q
1
s
SOC
u
fcn
y
OCV-SOC
[SOC]
[U]
u(t)
1
Voltage vsTime
Current vs Time
SOC vs Time


4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Offset=0


0
Vo
[SOC]
SOC
1.5
Imax for C-Rate
0.1
R
1.5
Imax for C-rate
3.7
Vmax1
>= 0
[U]
3.7
Vmax
[SOC]
SOC1
10
1/R
0
Vo1
[U]
u(t)
1/1
1/Q
1
s
SOC
u
fcn
y
OCV-SOC
[SOC]
[U]
u(t)
1
Voltage vsTime
Current vs Time
SOC vs Time
0
Vo2
[SOC]
SOC2
[U]
0.1
R2

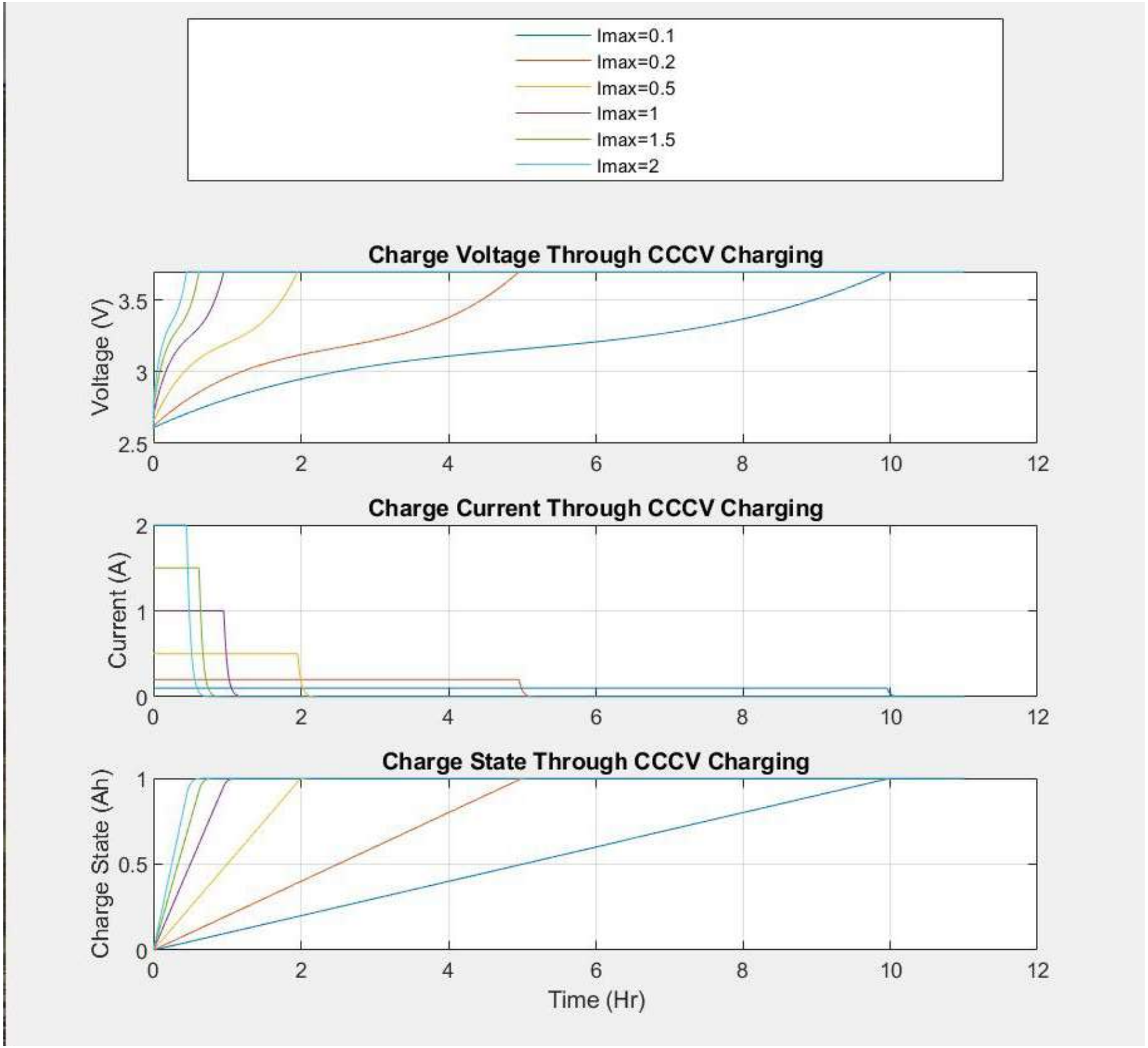

4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.5
1
1.5
Offset=0

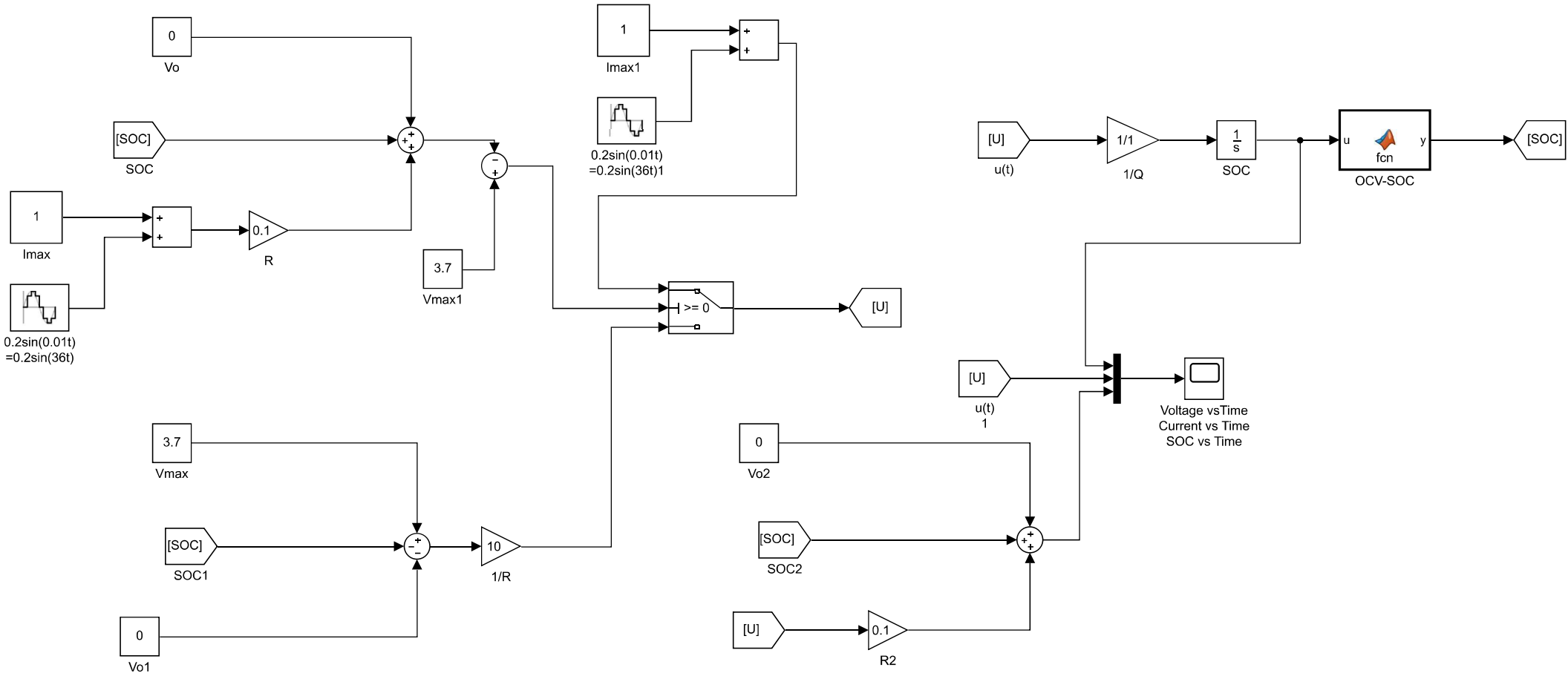

0
Vo
[SOC]
SOC
2
Imax for C-Rate
0.1
R
2
Imax for C-rate
3.7
Vmax1
>= 0
[U]
3.7
Vmax
[SOC]
SOC1
10
1/R
0
Vo1
0
Vo2
[SOC]
SOC2
[U]
0.1
R2
[U]
u(t)
1/1
1/Q
1
s
SOC
u
fcn
y
OCV-SOC
[SOC]
[U]
u(t)
1
Voltage vsTime
Current vs Time
SOC vs Time

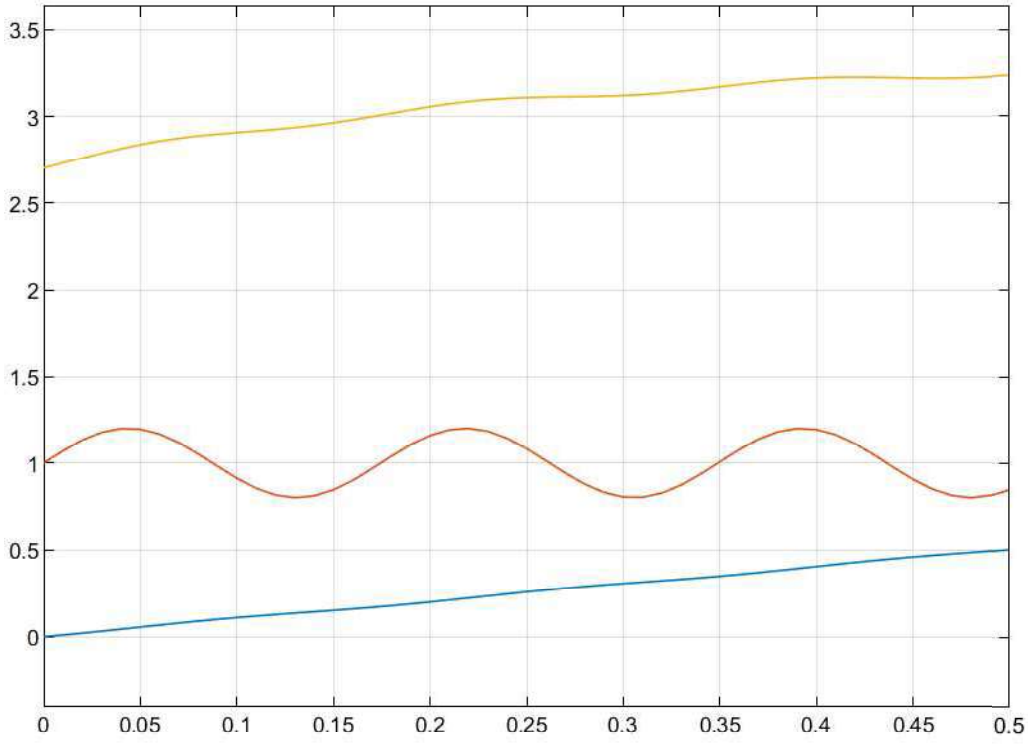

4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Offset=0

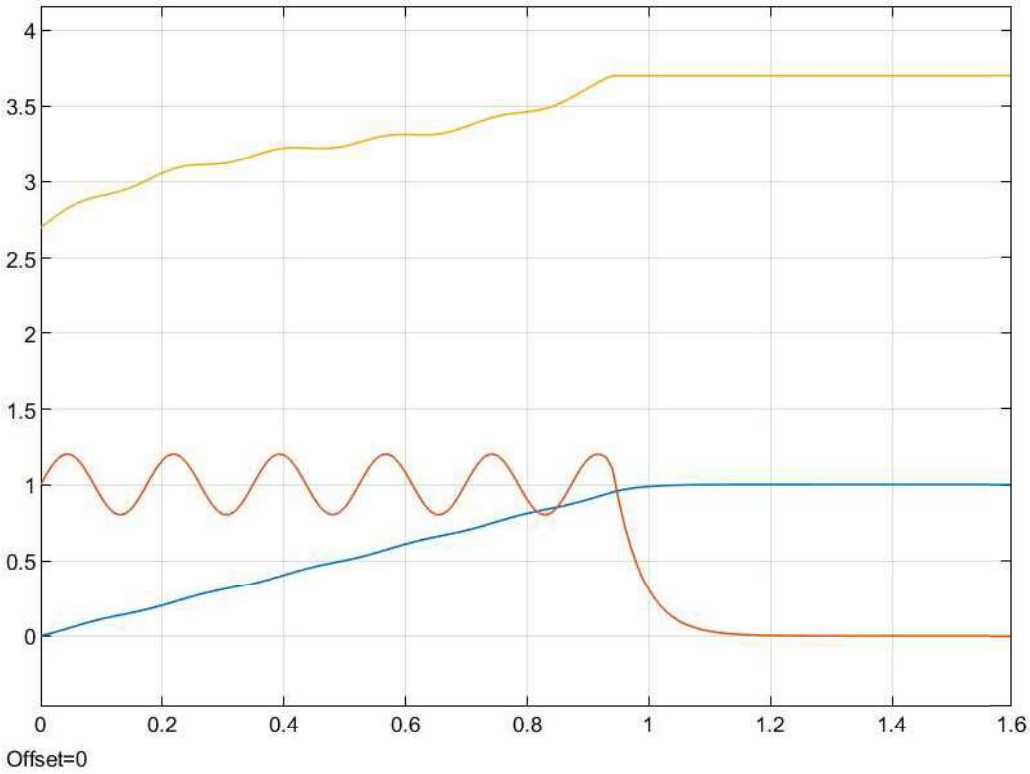
```
%Requirment 4
%Euler Step to Solve ODE
chargeTimehr=11;

Vmax=3.7;
chargeRate=[.1, .2, .5, 1, 1.5, 2];
U=3600;
ESR=0.1;
t=0:3600*chargeTimehr;
I=zeros(length(t),length(chargeRate));
V=zeros(length(t),length(chargeRate));
x=zeros(length(t),length(chargeRate));


for j=1:length(chargeRate)
    Imax=chargeRate(j);

    V(1,j)=2.6;
    I(1,j)=Imax;
    x(1,j)=0;

    for i=2:length(t)
        I(i,j)=cccv(x(i-1,j),Imax,Vmax);
        x(i,j)=x(i-1,j)+(I(i,j)/U);
        V(i,j)=(2.6+2.35*x(i,j)-3.75*x(i,j)^2+2.5*x(i,j)^3)+ESR*I(i,j);
    end

end

t2=t/3600;
fig2=figure('Position', [100, 100, 1024, 1200]);

subplot(4,1,2);
h1=plot(t2,V);
title("Charge Voltage Through CCCV Charging")
%xlabel("Time (s)")
ylabel("Voltage (V)")
grid on
hold on

subplot(4,1,3);
h2=plot(t2,I);
title("Charge Current Through CCCV Charging")
%xlabel("Time (s)")
ylabel("Current (A)")
grid on

subplot(4,1,4);
h3=plot(t2,x);
title("Charge State Through CCCV Charging")
xlabel("Time (Hr)")
ylabel("Charge State (Ah)")
grid on
hold off

hL = subplot(4,1,1);
poshL = get(hL,'position');     % Getting its position

lgd = legend(hL,[h1;h2;h3],'Imax=0.1','Imax=0.2','Imax=0.5','Imax=1','Imax=1.5','Imax=2');
set(lgd,'position',poshL);      % Adjusting legend's position
axis(hL,'off');
clf;
```

```
Warning: Ignoring extra legend entries.
```

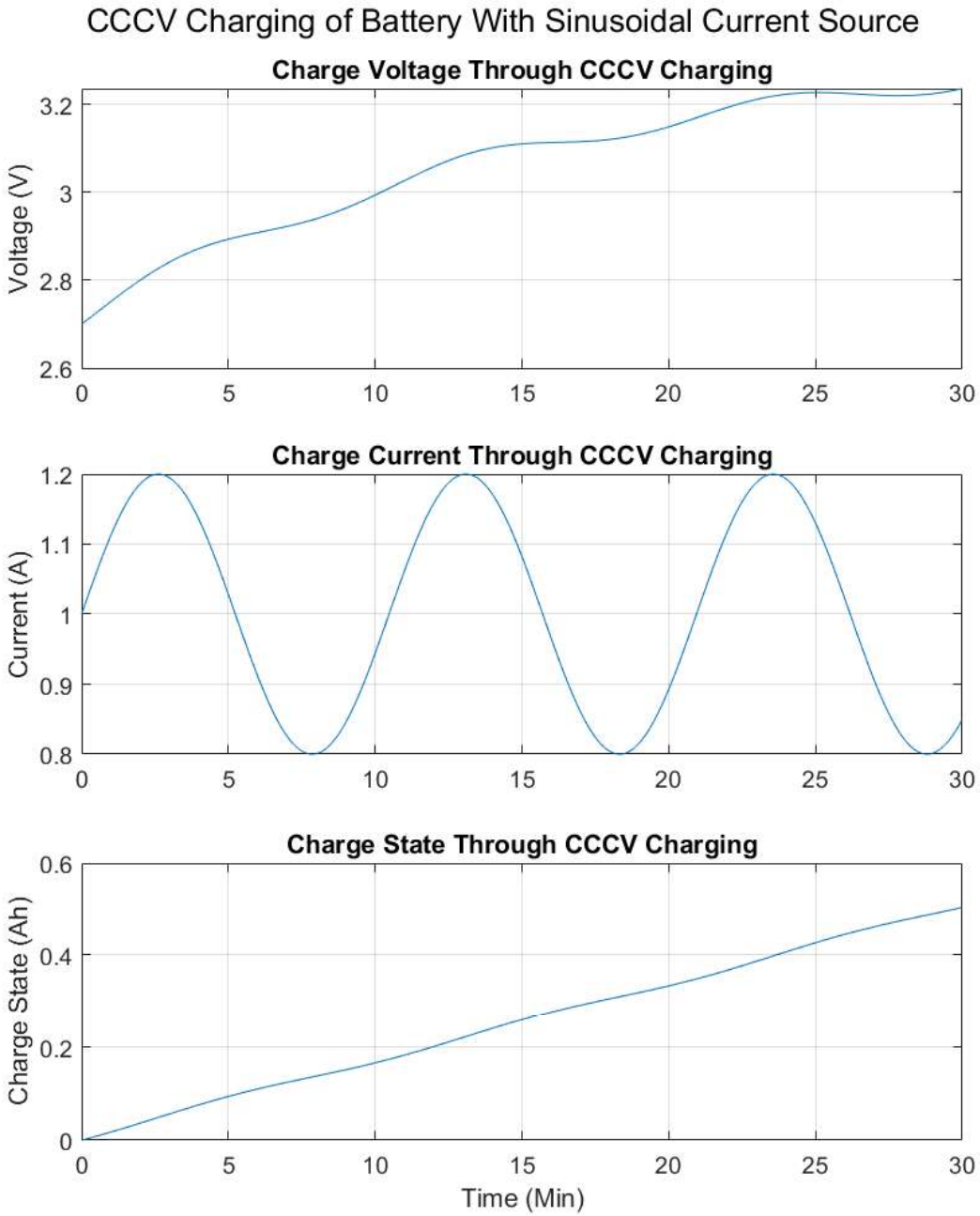

Imax=0.1
Imax=0.2
Imax=0.5
Imax=1
Imax=1.5
Imax=2
Charge Voltage Through CCCV Charging
Voltage (V)
2.5
3
3.5
0
2
4
6
8
10
12
Charge Current Through CCCV Charging
Current (A)
0
1
2
0
2
4
6
8
10
12
Charge State Through CCCV Charging
Charge State (Ah)
0
0.5
1
0
2
4
6
8
10
12
Time (Hr)


0
Vo
[SOC]
SOC
1
Imax
0.1
R
0.2sin(0.01t)
=0.2sin(36t)
3.7
Vmax1
1
Imax1
0.2sin(0.01t)
=0.2sin(36t)1
>= 0
[U]
3.7
Vmax
[SOC]
SOC1
10
1/R
0
Vo1
[U]
u(t)
1/1
1/Q
1
s
SOC
u
fcn
y
OCV-SOC
[SOC]
[U]
u(t)
1
Voltage vsTime
Current vs Time
SOC vs Time
0
Vo2
[SOC]
SOC2
[U]
0.1
R2


3.5
3
2.5
2
1.5
1
0.5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5


4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Offset=0

```
chargeTimehr=0.5;

Vmax=3.7;
U=3600;
ESR=0.1;
t=0:3600*chargeTimehr;
I=zeros(length(t),1);
V=zeros(length(t),1);
x=zeros(length(t),1);

V(1)=2.7;
I(1)=1+0.2*sin(0.01*0);
x(1)=0;

for i=2:length(t)
    I(i)=req7curr(x(i-1),t(i),Vmax);
    x(i)=x(i-1)+(I(i)/U);
    V(i)=(2.6+2.35*x(i)-3.75*x(i)^2+2.5*x(i)^3)+ESR*I(i);

end

t2=t/60;
fig2=figure('Position', [100, 100, 1024, 1200]);
sgtitle("CCCV Charging of Battery With Sinusoidal Current Source")
subplot(3,1,1);
h1=plot(t2,V);
title("Charge Voltage Through CCCV Charging")
%xlabel("Time (s)")
ylabel("Voltage (V)")
grid on
hold on

subplot(3,1,2);
h2=plot(t2,I);
title("Charge Current Through CCCV Charging")
%xlabel("Time (s)")
ylabel("Current (A)")
grid on

subplot(3,1,3);
h3=plot(t2,x);
title("Charge State Through CCCV Charging")
xlabel("Time (Min)")
ylabel("Charge State (Ah)")
grid on
hold off
```

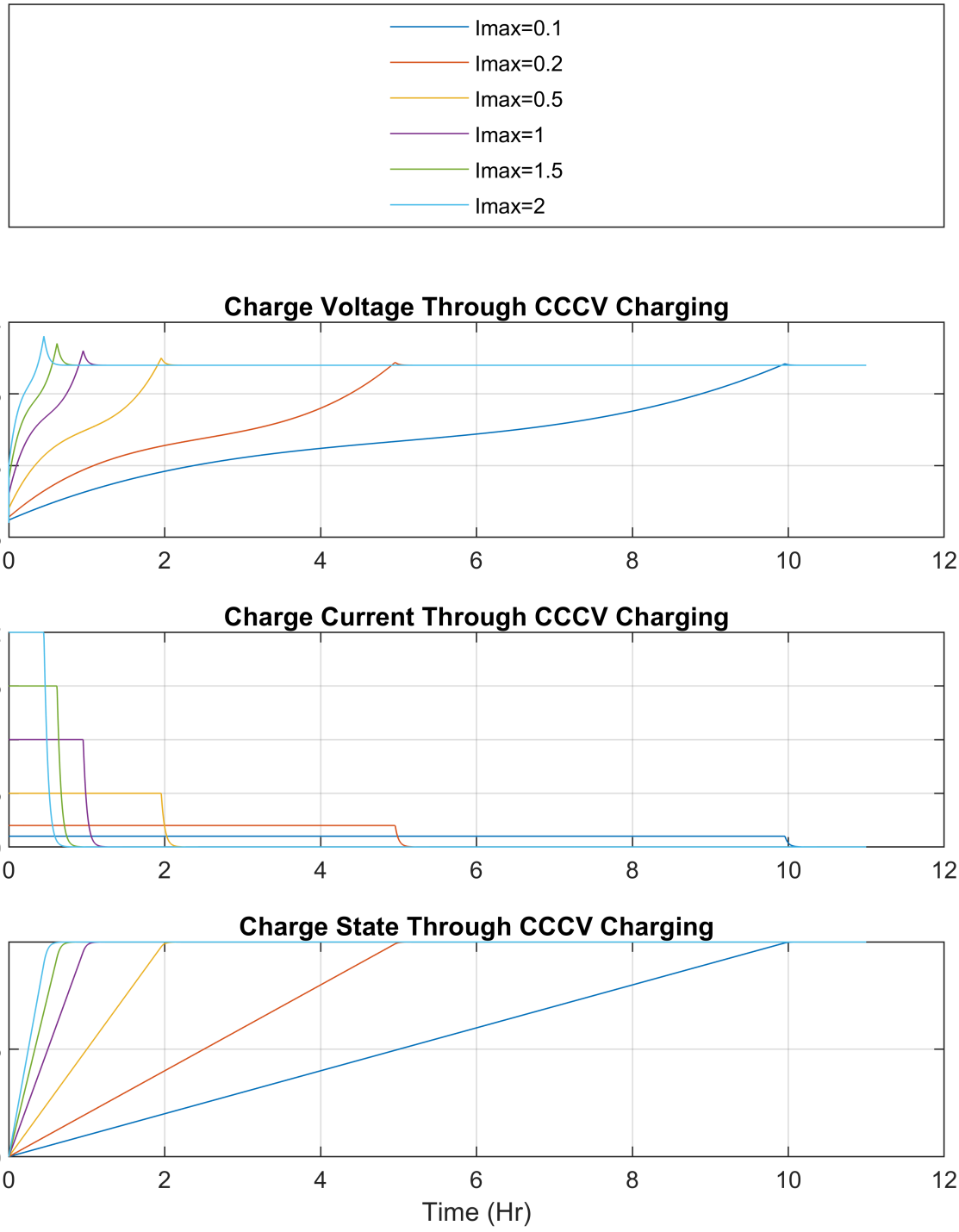

CCCV Charging of Battery With Sinusoidal Current Source
Charge Voltage Through CCCV Charging
Voltage (V)
3.2
3
2.8
2.6
0
5
10
15
20
25
30
Charge Current Through CCCV Charging
Current (A)
1.2
1.1
1
0.9
0.8
Charge State Through CCCV Charging
Charge State (Ah)
0.6
0.4
0.2
0
Time (Min)

```
%Requirment 9
%Euler Step to Solve ODE
chargeTimehr=11;

Vmax=3.7;
chargeRate=[.1, .2, .5, 1, 1.5, 2];
dt=0.01;
U=3600/dt;
ESR=0.1;
t=0:dt:3600*chargeTimehr;
I=zeros(length(t),length(chargeRate));
V=zeros(length(t),length(chargeRate));
x=zeros(length(t),length(chargeRate));
x2=zeros(length(t),length(chargeRate));
x3=zeros(length(t),length(chargeRate));

    R1=0.01;
    R2=0.01;
    C1=600;
    C2=10;

for j=1:length(chargeRate)
    Imax=chargeRate(j);

    V(1,j)=2.6;
    I(1,j)=Imax;
    x(1,j)=0;

    for i=2:length(t)
        I(i,j)=cccv(x(i-1,j),Imax,Vmax);
        x(i,j)=x(i-1,j)+(I(i,j)/(U));
        x2(i)=I(i-1,j)-x2(i,j)/(R1*C1);
        x3(i)=I(i-1,j)-x3(i,j)/(R2*C2);
        V(i,j)=(2.6+2.35*x(i,j)-3.75*x(i,j)^2+2.5*x(i,j)^3)+ESR*I(i,j)+x2(i)/C1+x3(i)/C2;
    end

end

t2=t/3600;
fig2=figure('Position', [100, 100, 1024, 1200]);

subplot(4,1,2);
h1=plot(t2,V);
title("Charge Voltage Through CCCV Charging")
%xlabel("Time (s)")
ylabel("Voltage (V)")
grid on
hold on

subplot(4,1,3);
h2=plot(t2,I);
title("Charge Current Through CCCV Charging")
```

```
%xlabel("Time (s)")
ylabel("Current (A)")
grid on

subplot(4,1,4);
h3=plot(t2,x);
title("Charge State Through CCCV Charging")
xlabel("Time (Hr)")
ylabel("Charge State (Ah)")
grid on
hold off

hL = subplot(4,1,1);
poshL = get(hL,'position');     % Getting its position

lgd = legend(hL,[h1;h2;h3],'Imax=0.1','Imax=0.2','Imax=0.5','Imax=1','Imax=1.5','Imax=2');
```

```
Warning: Ignoring extra legend entries.
```

```
set(lgd,'position',poshL);      % Adjusting legend's position
axis(hL,'off');
```




```
%Reponse

%This is different than Requirement 5 since
```

This is different than Requirement 5 since voltage surpasses peak and then falls back to constant due to additional

```
%voltage surpasses peak and then falls back to constant due to additional RC pairs
%At slower dynamics by increasing Capacitance, Voltage no longer spikes and graph
```

At slower dynamics by increasing Capacitance, Voltage no longer spikes and graph appears similar to Requirement 5

```
%appears similar to Requirement 5
```

```
%Requirment 10
%Euler Step to Solve ODE
chargeTimehr=11;
p=[.05,.50,.95];
ga=2.36-3.75*2*p+2.5*3*p.^2
```

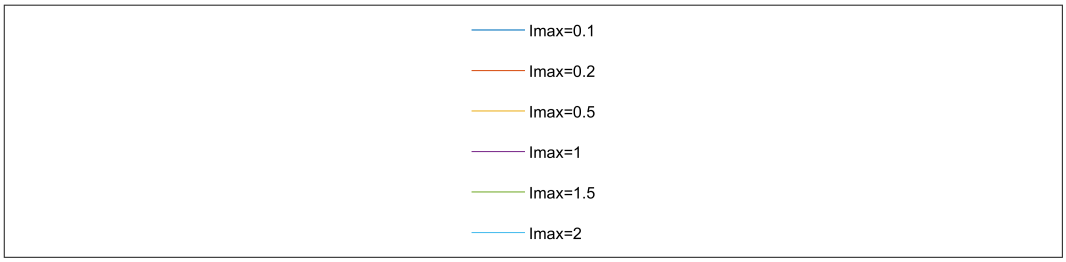
```
ga = 1×3
    2.0037    0.4850    2.0037
```

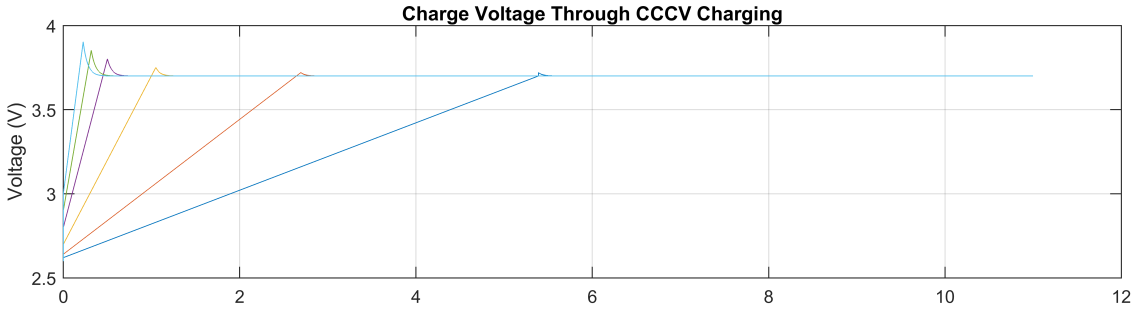
```
for k=1:length(ga)

    gamma=ga(k)
    Vmax=3.7;
    chargeRate=[.1, .2, .5, 1, 1.5, 2];
    dt=0.01;
    U=3600/dt;
    ESR=0.1;
    t=0:dt:3600*chargeTimehr;
    I=zeros(length(t),length(chargeRate));
    V=zeros(length(t),length(chargeRate));
    x=zeros(length(t),length(chargeRate));
    x2=zeros(length(t),length(chargeRate));
    x3=zeros(length(t),length(chargeRate));

    R1=0.01;
    R2=0.01;
    C1=600;
    C2=10;



    for j=1:length(chargeRate)
        Imax=chargeRate(j);

        V(1,j)=2.6;
        I(1,j)=Imax;
        x(1,j)=0;

        for i=2:length(t)
            I(i,j)=cccv3(x(i-1,j),x2(i-1,j),x3(i-1,j),Imax,Vmax,gamma);
            x(i,j)=x(i-1,j)+(I(i,j)/(U));
            x2(i)=I(i,j)-x2(i,j)/(R1*C1);
            x3(i)=I(i,j)-x3(i,j)/(R2*C2);
            V(i,j)=(2.6+gamma*x(i,j))+ESR*I(i,j)+x2(i)/C1+x3(i)/C2;
        end

    end
    x2;
    V;

    t2=t/3600;
    fig2=figure('Position', [100, 100, 1024, 1200]);
```

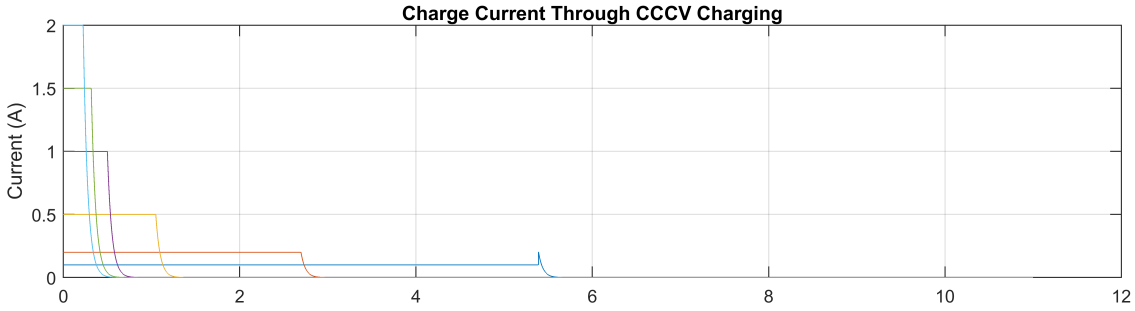
```
subplot(4,1,2);
h1=plot(t2,V);
title("Charge Voltage Through CCCV Charging")
%xlabel("Time (s)")
ylabel("Voltage (V)")
grid on
hold on

subplot(4,1,3);
h2=plot(t2,I);
title("Charge Current Through CCCV Charging")
%xlabel("Time (s)")
ylabel("Current (A)")
grid on

subplot(4,1,4);
h3=plot(t2,x);
title("Charge State Through CCCV Charging")
xlabel("Time (Hr)")
ylabel("Charge State (Ah)")
grid on
hold off

hL = subplot(4,1,1);
poshL = get(hL,'position');     % Getting its position

lgd = legend(hL,[h1;h2;h3],'Imax=0.1','Imax=0.2','Imax=0.5','Imax=1','Imax=1.5','Imax=2');
set(lgd,'position',poshL);      % Adjusting legend's position
axis(hL,'off');
hold off


fig3=figure('Position', [100, 100, 1024, 1200]);

subplot(4,1,2);
h1=plot(t2,x);
title("CCCV Charging Charge State Of Battery")
%xlabel("Time (s)")
ylabel("Charge State (Ah)")
grid on
hold on

subplot(4,1,3);
h2=plot(t2,x2);
title("CCCV Charging Charge State Of Capacitor 1")
%xlabel("Time (s)")
ylabel("Charge State (C)")
grid on

subplot(4,1,4);
h3=plot(t2,x3);
title("CCCV Charging Charge State Of Capacitor 2")
xlabel("Time (Hr)")
ylabel("Charge State (C)")
```

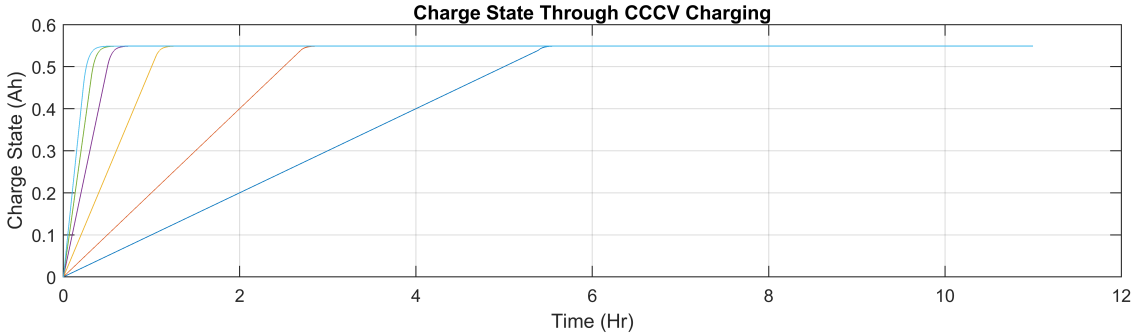
```
    grid on
    hold off

    hL = subplot(4,1,1);
    poshL = get(hL,'position');     % Getting its position


    lgd = legend(hL,[h1;h2;h3],'Imax=0.1','Imax=0.2','Imax=0.5','Imax=1','Imax=1.5','Imax=2');
    set(lgd,'position',poshL);      % Adjusting legend's position
    axis(hL,'off');
end
```

```
gamma = 2.0037
Warning: Ignoring extra legend entries.
```

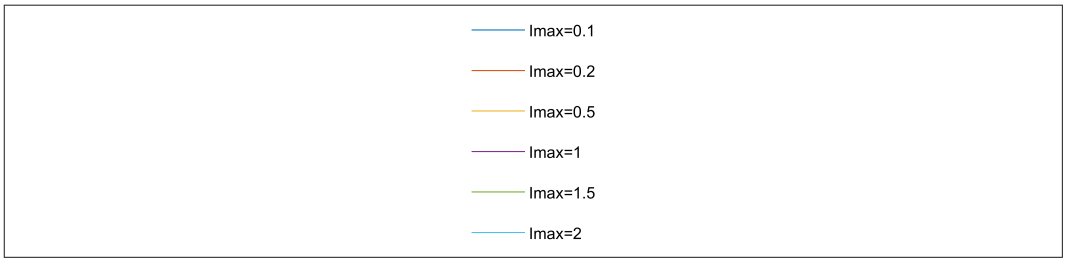


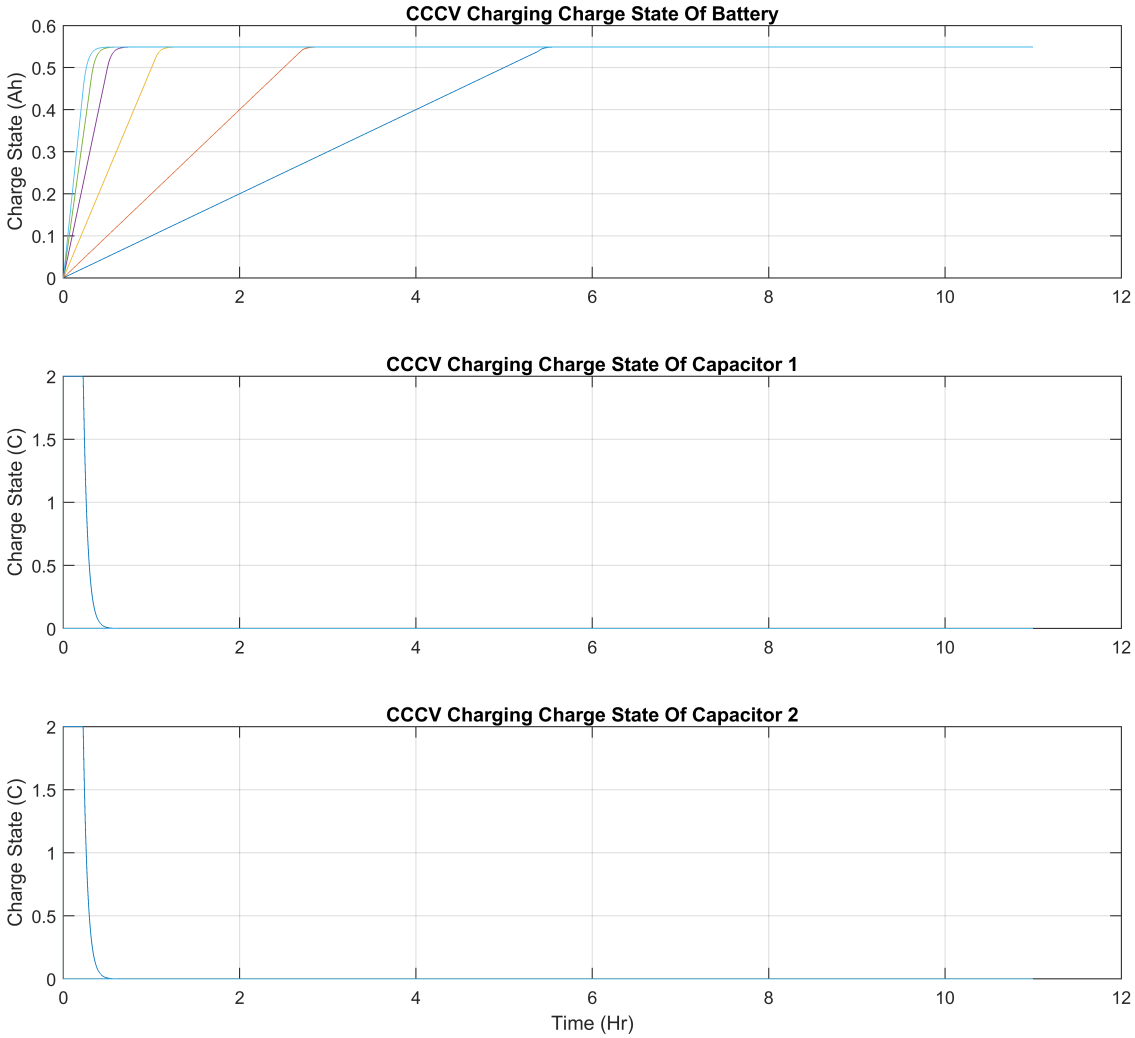




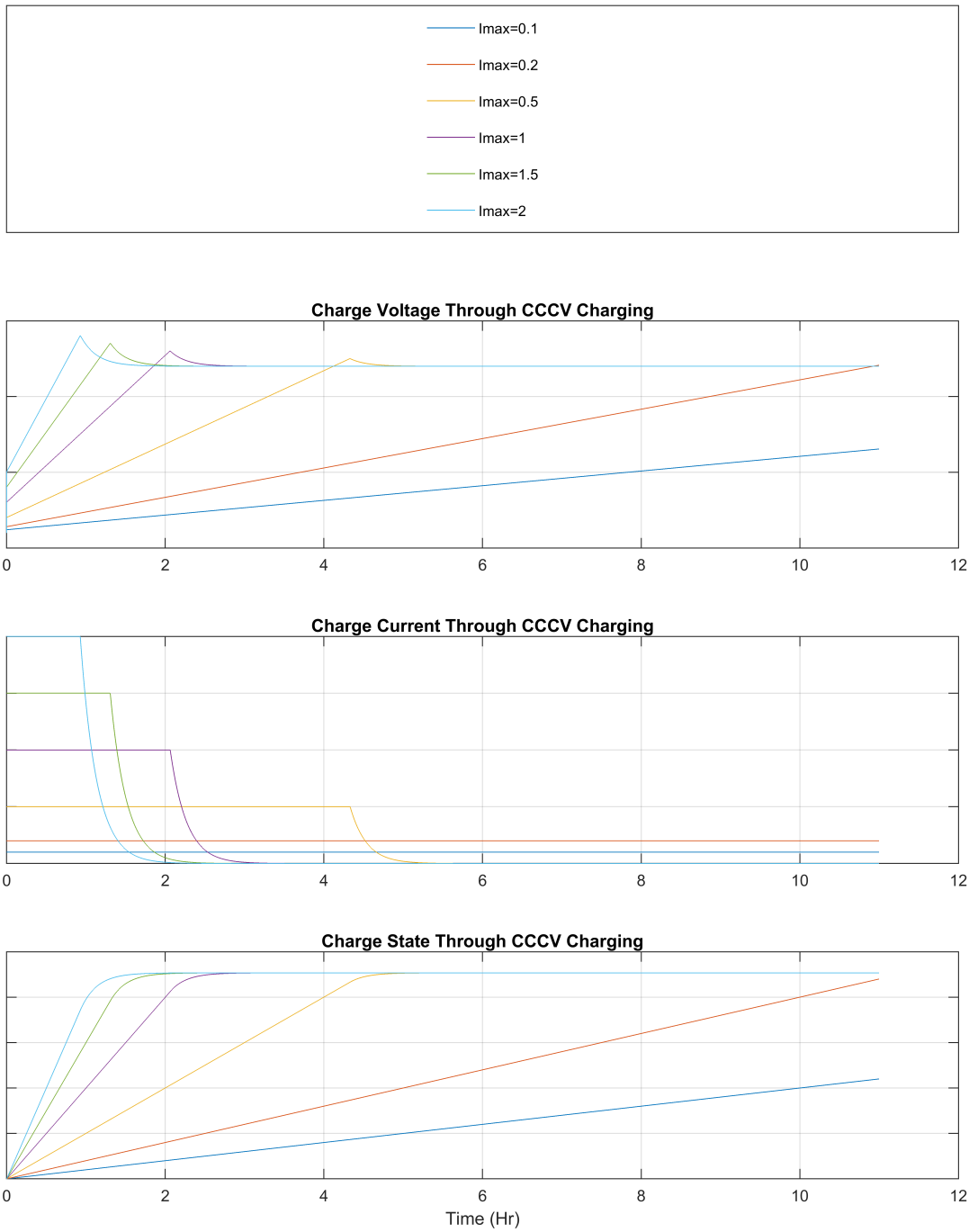


Warning: Ignoring extra legend entries.

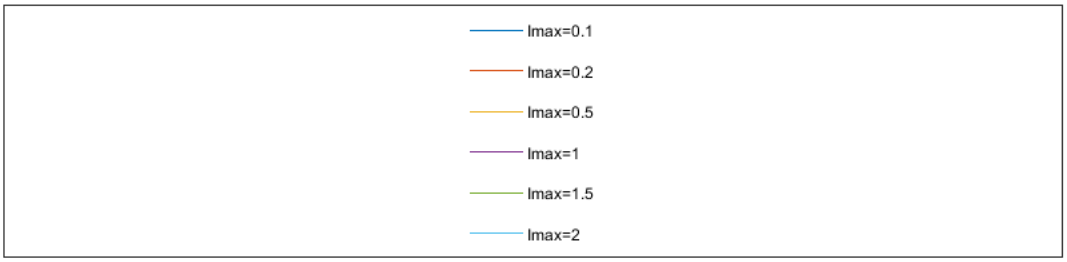


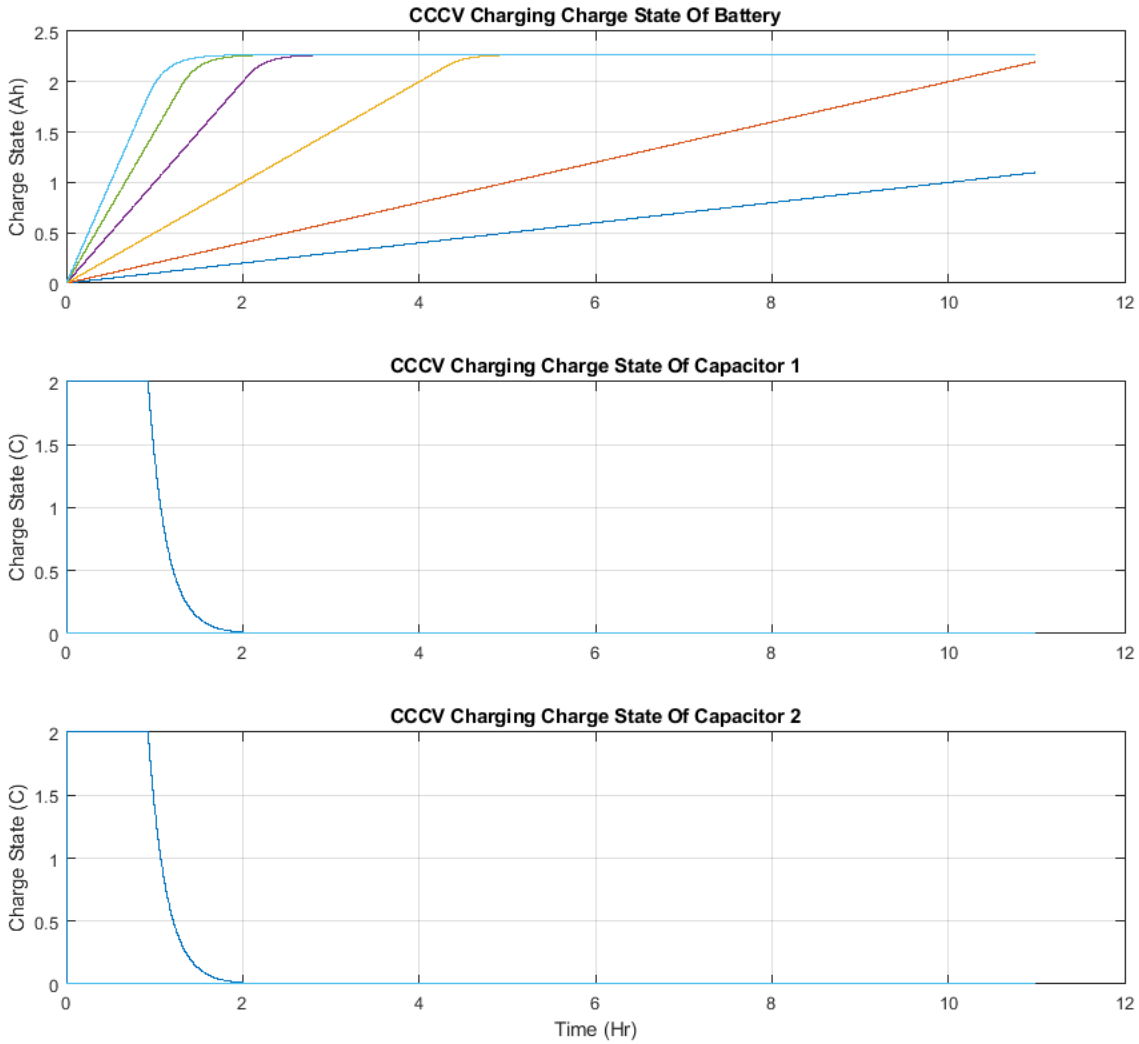



```
gamma = 0.4850
Warning: Ignoring extra legend entries.
```

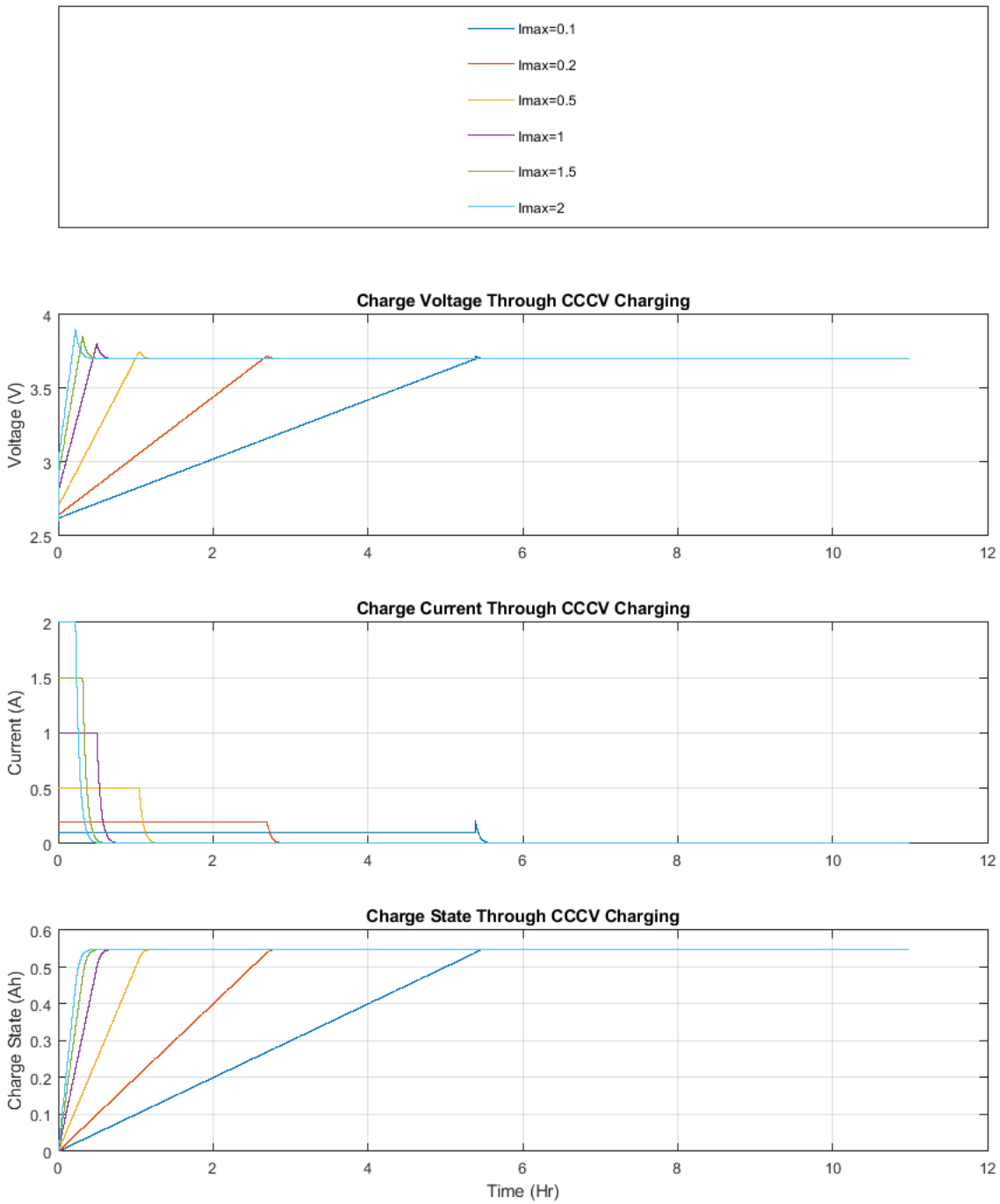



```
Warning: Ignoring extra legend entries.
```

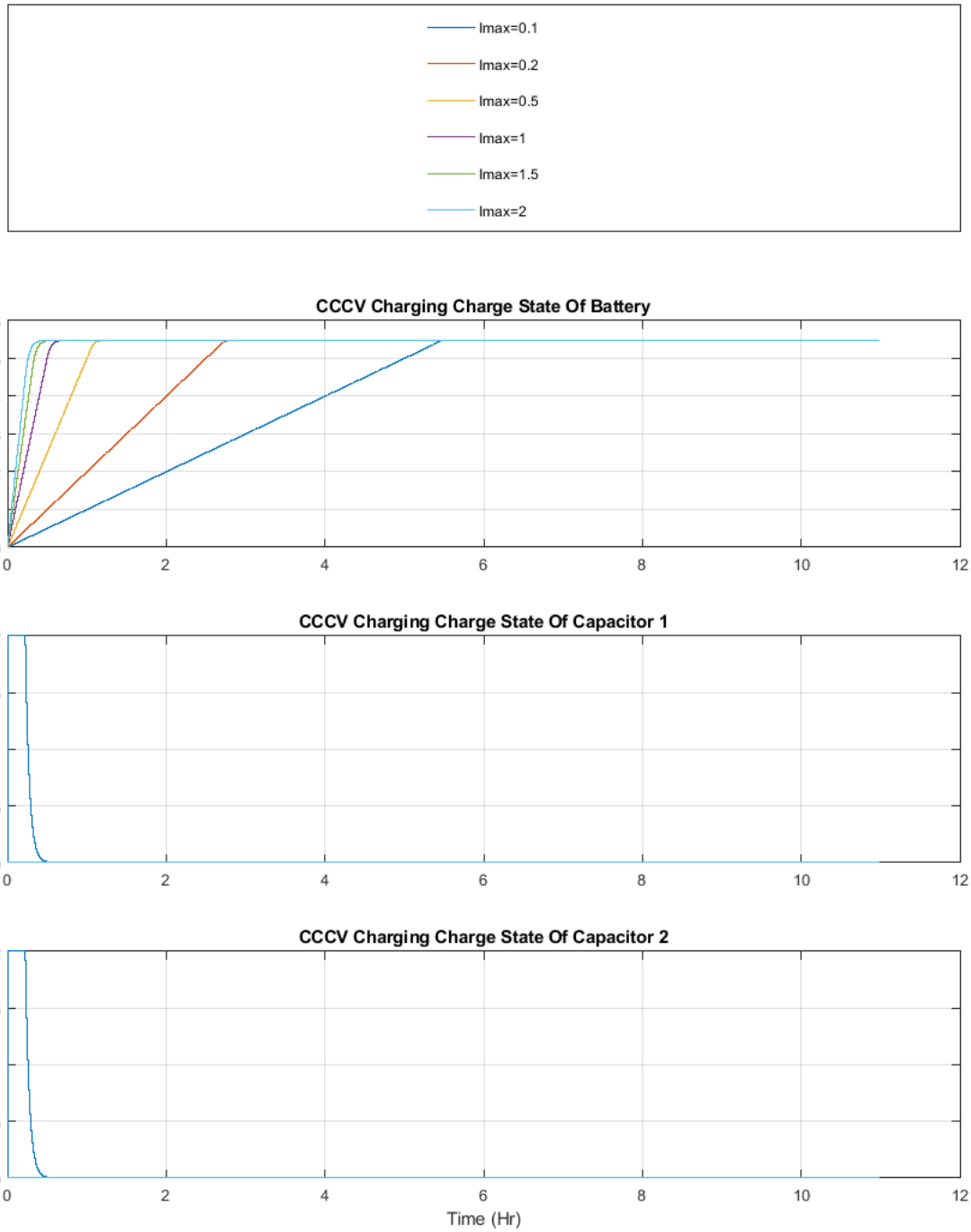





```
gamma = 2.0037
Warning: Ignoring extra legend entries.
```




```
Warning: Ignoring extra legend entries.
```



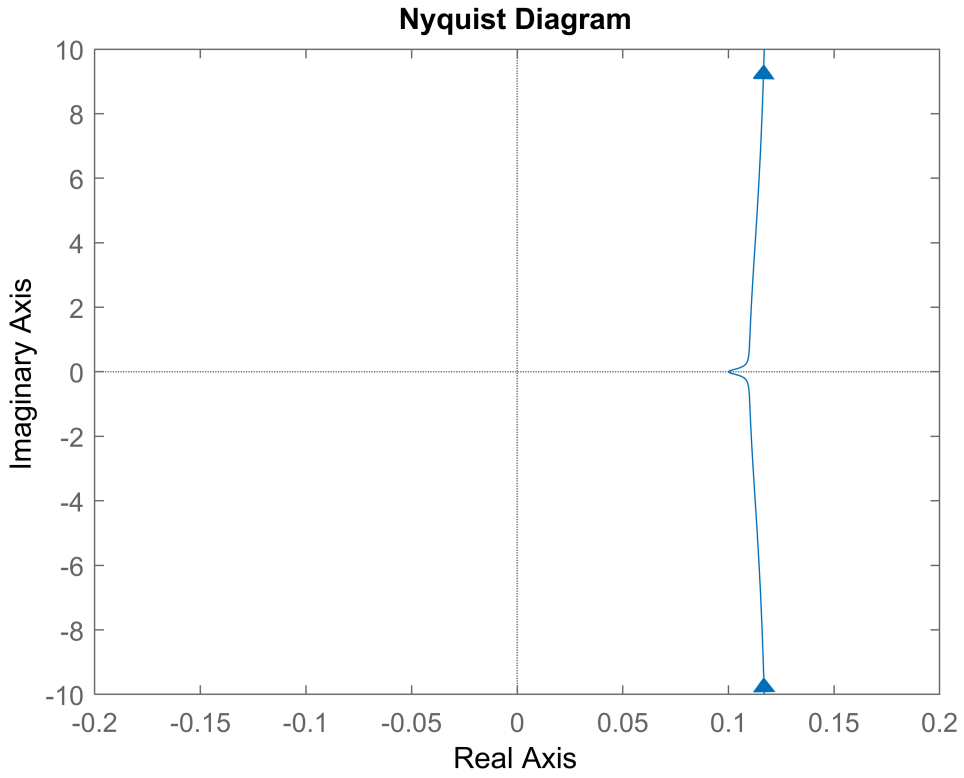

```
Warning: Error occurred while executing the listener callback for event POST_REGION defined for class
matlab.internal.language.RegionEvaluator:
Error using getByteStreamFromArray
Out of Memory during serialization

Error in matlab.internal.editor.figure.SerializedFigureState/serialize

Error in matlab.internal.editor.FigureProxy/createWebFigureSnapshot
```

```
Error in matlab.internal.editor.FigureManager

Error in matlab.internal.editor.FigureManager

Error in matlab.internal.editor.FigureManager.saveSnapshot

Error in matlab.internal.editor.FigureManager.snapshotAllFigures
```

```
%Req 11
%Approximation
x=[0:0.001:1]
```

```
x = 1×1001
         0    0.0010    0.0020    0.0030    0.0040    0.0050    0.0060    0.0070 ···
```

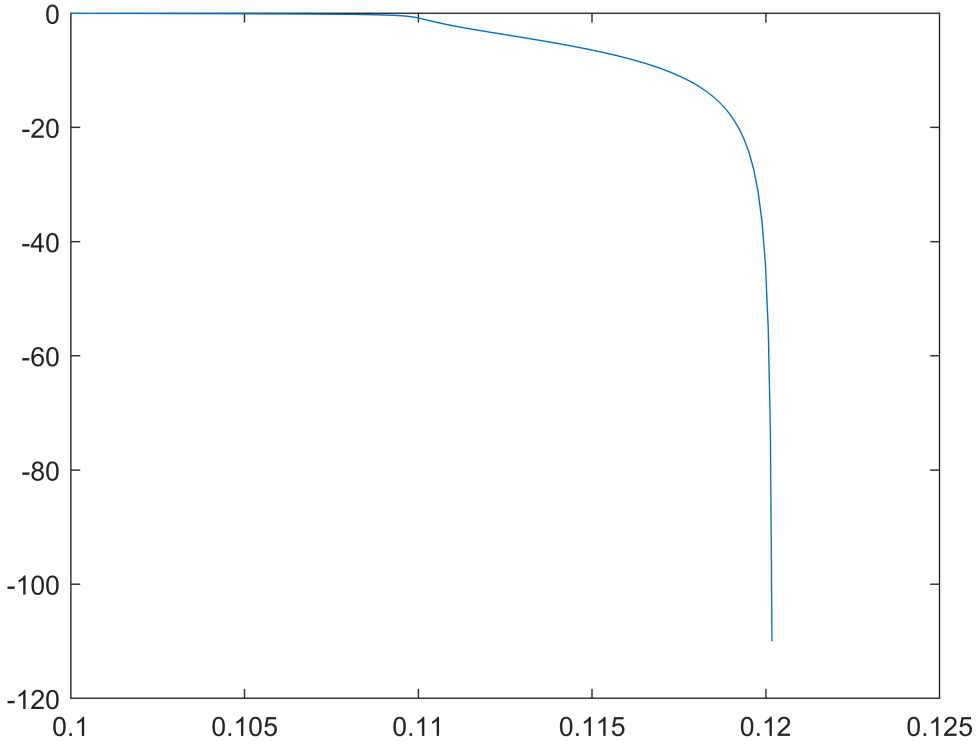
```
OCV=(2.6+2.35*x-3.75*x.^2+2.5*x.^3);
%5
G1=(OCV(5)-OCV(4))/(0.001);
%50
G2=(OCV(501)-OCV(500))/(0.001);
%95
G3=(OCV(951)-OCV(950))/(0.001);
%Full Gavg
G4=(OCV(1001)-OCV(1))/(1);

%Direct Integration
x1=0.05;
%5
g1 = 2.35 - 2*3.75*x1 + 2.5*3*x1^2;
x2=0.5;
%50
g2=2.35-2*3.75*x2+2.5*3*x2^2;
%90
x3=0.95;
g3=2.35-2*3.75*x3+2.5*3*x3^2;

Q=1;
G=1.1;
R=0.1;
R1=0.01;
R2=0.01;
C1=600;
C2=10;

 A = [0 0 0; 0 -1/(R1*C1) 0; 0 0 -1/(R2*C2)];
 B = [1/Q; 1; 1];
 C = [G 1/C1 1/C2];
 D = [R];
 nyquist(ss(A,B,C,D))
 xlim([-0.2 0.2])
```




```
[num,den] = ss2tf(A,B,C,D)
```

```
num = 1×4
    0.1000    2.2183   11.3833    1.8333
den = 1×4
    1.0000   10.1667    1.6667         0
```

```
omega = [0.01:0.005:1000];
s= sqrt(-1)*omega;
impedance = (0.1*(s.^3) + 2.2183*(s.^2)+11.3833*s +1.8333)./(1*(s.^3) + 10.1667*(s.^2)+1.6667
plot(real(impedance),imag(impedance))
```


0
-20
-40
-60
-80
-100
-120
0.1
0.105
0.11
0.115
0.12
0.125