Process Control - Project (WiSe 2020/21)

Control of a Multivariable Process

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Newell and Lee Evaporator

Steady State Result

After Successful Mathematical Modeling of the Newell and Lee Evaporator we can use ODE solvers in Matlab . This method solves (integrates) the ODE system in time domain. First of all some arbitrary initial conditions for the differential variables has be specified . Integration (simulation) time has be taken long enough so that the system states reaches the steady state at the final time .

Evaporator Equations Matlab Code

Here all the equations obtained while doing the mathematical modeling are defined including the constants.

```
function dxdt = evapmod(t, x)

global F2 P100 F200 F1 XF1 T1 F3 T200
X2 = x(1);
P2 = x(2);
L2 = x(3);

% Parameters
C = 4; Cp = 0.07;
lam = 38.5; lams = 36.6;  rhoA = 20;
M = 20; UA2 = 6.84;

% Algebraic equations
% Evaporator and steam jacket
T2 = 0.5616*P2 + 0.3126*X2 + 48.43;
T3 = 0.507*P2 + 55;
T100 = 0.1538*P100 + 90;
Q100 = 0.16*(F1 + F3)*(T100 -T2);
F100 = Q100/lams;
F4 = (Q100 - F1*Cp*(T2 - T1))/lam;

%Condenser
Q200 = UA2*(T3-T200)/(1+UA2/(2*Cp*F200));
T201 = T200 + Q200/(F200*Cp);
F5 = Q200/lam;
```

```
%Differential equations
dX2dt = (F1*XF1 - F2*X2)/M;
dP2dt = (F4 - F5)/C;
dL2dt = (F1 - F4 - F2)/rhoA;

%Output
dxdt = [dX2dt dP2dt dL2dt]';
end
```

Matlab Code for Steady State Solution

Here the deceleration of the globe variables and initial conditions are defined. We use ODE45 here to solve the ordinary differential equations. Also the code to plot for steady state solution is defined in this code.

```
close all
clear all
clc

global F2 P100 F200 F1 XF1 T1 F3 T200
% Inputs
F2 = 2;               % [kg/min]
P100 = 194.7;         % [kPa]
F200 = 208;           % [kg/min]
F1 = 10;              % [kg/min];
T1 = 40;              % [°C]
XF1 = 5;              % [%]
F3 = 50;              % [kg/min]
T200 = 25;            % [°C]

%Initial dynamics of the solution
X0 = [ 2 2 7.8];         % Arbitrary Initial Condition
tspan=[ 0  70];      % Simulation Time

[t,x]=ode45(@evapmod,tspan, X0);   % calling the integrator (ODE solver)

figure(1),
plot(t,x), grid on
legend('X_2','P_2','L_2')
xlabel('time (min)')
ylabel('State Variables')
title('Initial dynamics of the solution ')

%Steady state solution at the final time

X0 = [ 2 2 7.8];         % Arbitrary Initial Condition
tspan=[ 0  1000];      % Simulation Time

% tolerance settings  (= higher accuracy) for the Matlab solver to increase
% the accuracy of the numerical solution.
options = odeset('RelTol',1e-6,'AbsTol',[1.0e-6 1.e-06 1.e-06]);
```

```
[t,x]=ode45(@evapmod,tspan, X0, options);

X0ss= x(end,:) ;
X0ss(3) = 1;
save init_ss X0ss;  %final steady state solution for all three is saved in X0ss

figure(2),
plot(t,x), grid on
xlabel('time(min)')
ylabel('State variable')
legend('X_2','P_2','L_2')
title('Steady state solution at the final time ')
```

Results

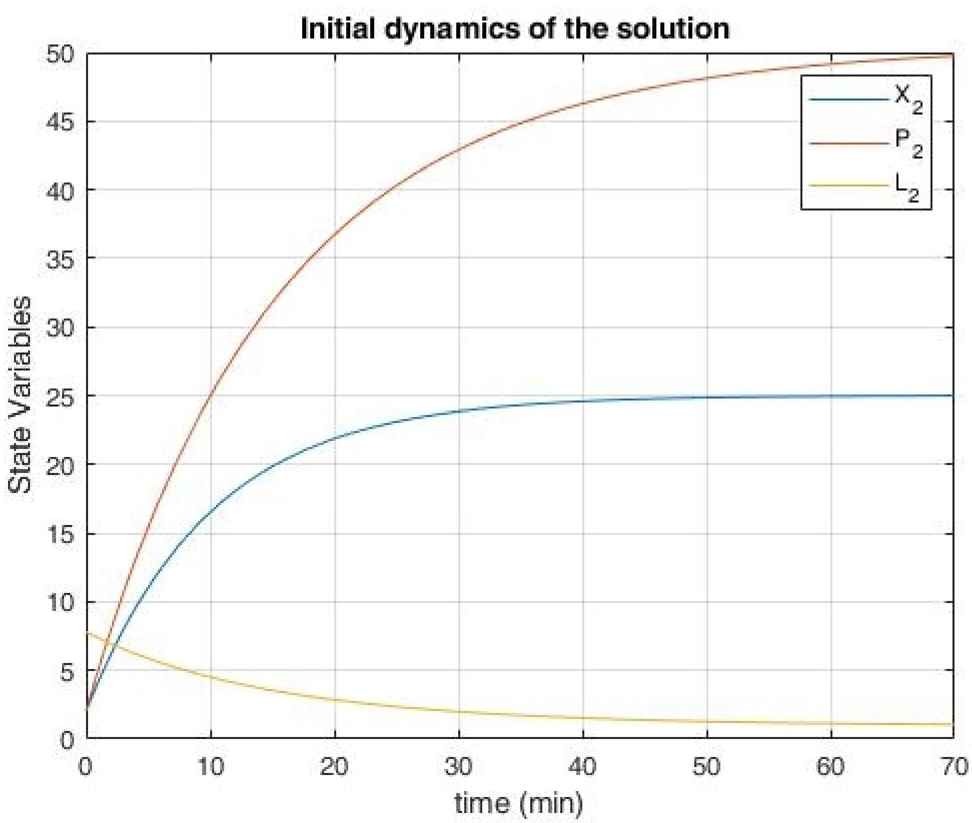

Fig 1 : Initial dynamics of the Controlled (output) variables

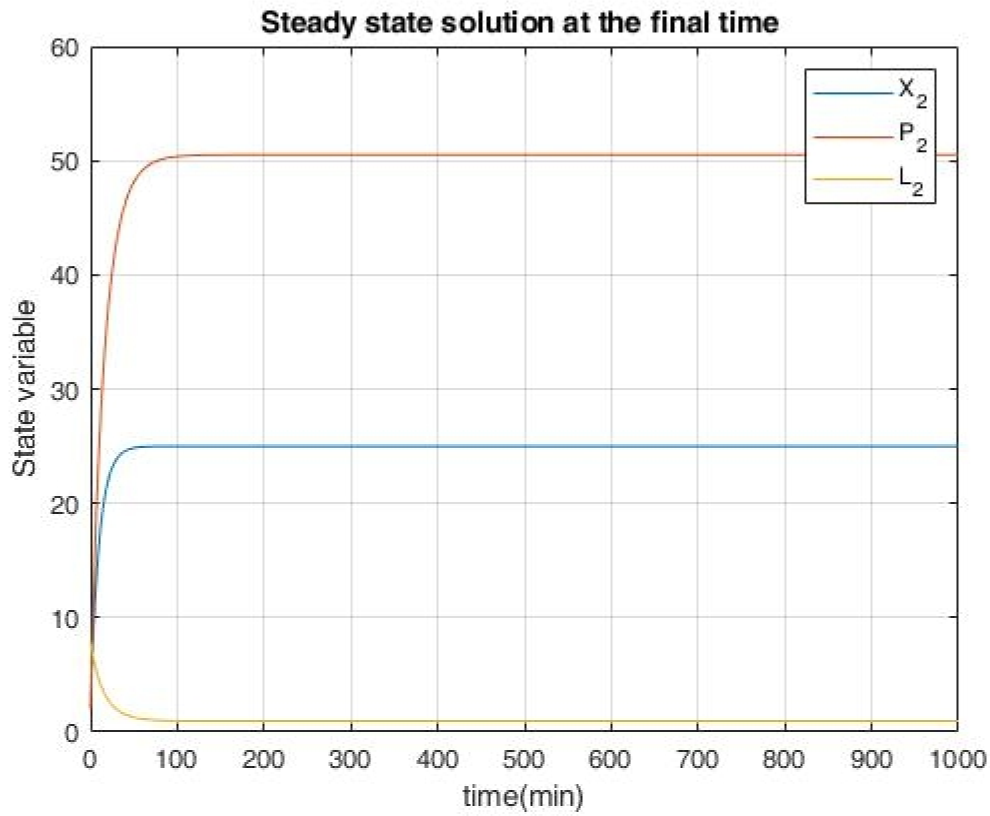

Fig 2 : Steady State Solution of the Controlled (output) variables

Dynamic simulation scenarios

Here we altered some parameters and re-evaluated the three outputs and their updated steady states.

Simulation scenarios : Step change in some disturbances .

i. A step change of + 15 % in the feed flow rate , F1
ii. A step change of - 15 % in the feed flow rate , F1
iii. A step change of + 2 % in the feed composition , x1
iv. A step change of - 2 % in the feed composition, x1

Matlab Code for the above step-changes

```
clear all
clc

global F2 P100 F200 F1 XF1 T1 F3 T200
% Inputs
F2 = 2;                 % [kg/min]
P100 = 194.7;           % [kPa]
F200 = 208;             % [kg/min]
F1 = 10;                % [kg/min];
```

```
T1 = 40;                % [°C]
XF1 = 5;                % [%]
F3 = 50;                % [kg/min]
T200 = 25;              % [°C]

load init_ss   % X0ss will be loaded  with init_ss.mat

% Disturbance scenario : 15 % step increase in F1
F1 = 10;
XF1 = 5;
F1 = F1*1.15 ;

tend = 150;
tspan=[ 0  tend];

options = odeset('RelTol',1e-6,'AbsTol',[1.0e-6 1.e-06 1.e-06]);

[t1,x1]=ode45(@evapmod,tspan, X0ss, options);




% Disturbance scenario : 15 % step decrease in F1
F1 = 10;
XF1 = 5;
F1 = F1*0.85 ;

[t2,x2]=ode45(@evapmod,tspan, X0ss, options);




% Disturbance scenario : 2 % step increase in XF1
F1 = 10;
XF1 = 5;
XF1 = XF1*1.02 ;

[t3,x3]=ode45(@evapmod,tspan, X0ss, options);




% Disturbance scenario : 2 % step decrease in XF1
F1 = 10;
XF1 = 5;
XF1 = XF1*0.98 ;

[t4,x4]=ode45(@evapmod,tspan, X0ss, options);




% Plot step responses to F1 disurbance scenario
figure(3)

subplot(3,1,1)
grid on
plot(t1,x1(:,1),t2,x2(:,1),'--');
```

```
grid
legend('+15% F1' ,' -15% F1');
xlabel('t (min)')
ylabel('X2 ')
title(' Response of states to disurbance in F1  ')

subplot(3,1,2)
grid on
plot(t1,x1(:,2),t2,x2(:,2),'--');
grid
xlabel('t (min)')
ylabel('P2 ')

subplot(3,1,3)
grid on
plot(t1,x1(:,3),t2,x2(:,3),'--');
grid
xlabel('t (min)')
ylabel('L2 ')




% Plots step states to XF1 disturbance scenario
figure(4);

subplot(3,1,1)
grid on
plot(t3,x3(:,1),t4,x4(:,1),'--');
grid
legend('+2% XF1',' -2% XF1');
xlabel('t (min)')
ylabel('X2 ')
title(' Response of outputs to disturbance in XF1 ')

subplot(3,1,2)
grid on
plot(t3,x3(:,2),t4,x4(:,2),'--');
grid
xlabel('t (min)')
ylabel('P2 ')

subplot(3,1,3)
grid on
plot(t3,x3(:,3),t4,x4(:,3),'--');
grid
xlabel('t (min)')
ylabel('L2 ')




% Plots step states to P100 disturbance scenario
figure(6);

subplot(3,1,1)
grid on
plot(t7,x7(:,1),t8,x8(:,1),'--');
```

```
grid
legend('+15% P100' ,' -15% P100');
xlabel('t (min)')
ylabel('X2 ')
title(' Response of states to disurbance in P100  ')

subplot(3,1,2)
grid on
plot(t7,x7(:,2),t8,x8(:,2),'--');
grid
xlabel('t (min)')
ylabel('P2 ')

subplot(3,1,3)
grid on
plot(t7,x7(:,3),t8,x8(:,3),'--');
grid
xlabel('t (min)')
ylabel('L2 ')
```

Presentation of results :

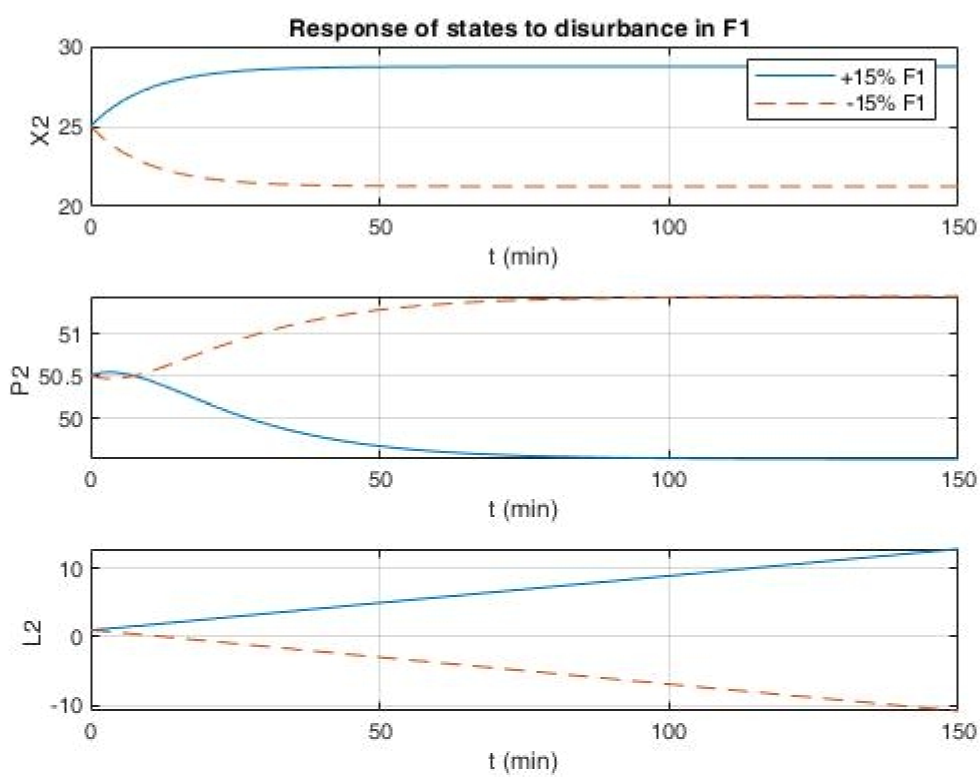

Fig 3 : Steady State Solution of the Controlled (output) variables after step change in F1

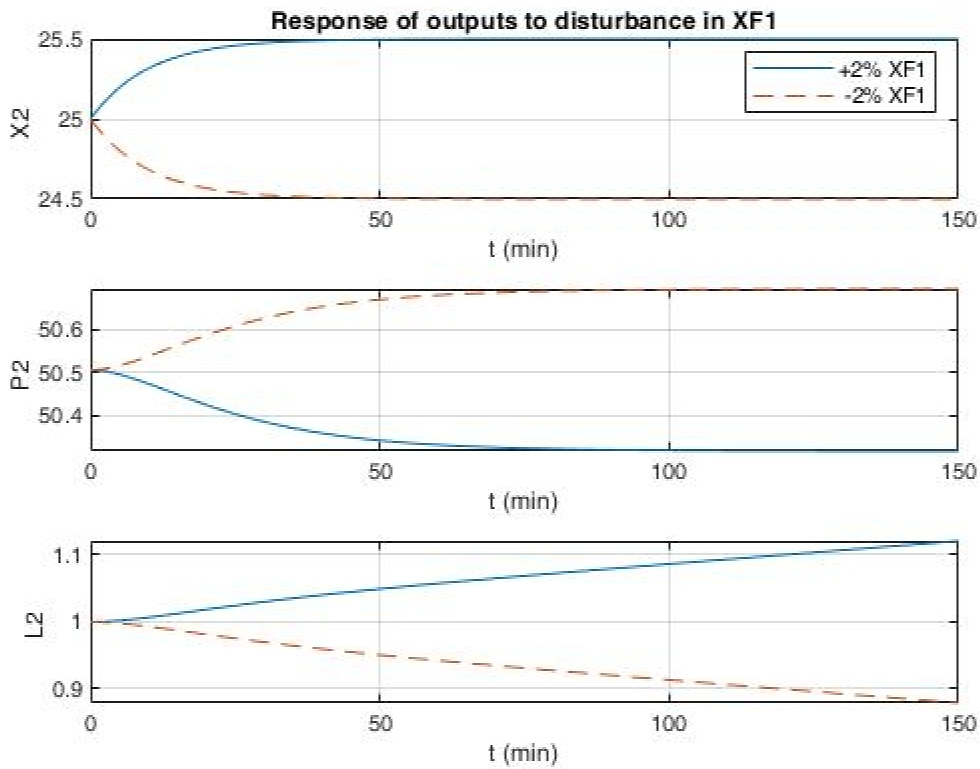

Fig 4 : Steady State Solution of the Controlled (output) variables after step change in XF1

Additional simulation scenarios : Step change in some manipulated variables

i. A step change of + 15 % in F200
ii. A step change of - 15 % in F200
iii. A step change of + 15 % in P100
iv. A step change of - 15 % in P100

Matlab Code for the above step-changes

```
%Additional Task
clear all
clc

global F2 P100 F200 F1 XF1 T1 F3 T200
% Inputs
F2 = 2;                 % [kg/min]
P100 = 194.7;           % [kPa]
F200 = 208;             % [kg/min]
F1 = 10;                % [kg/min];
T1 = 40;                % [°C]
XF1 = 5;                % [%]
F3 = 50;                % [kg/min]
```

```
T200 = 25;            % [°C]

load init_ss    % X0ss will be loaded  with init_ss.mat


% Disturbance scenario : 15 % step increase in F200
F1 = 10;
XF1 = 5;
F200 = 208;
F200 = F200*1.15;

tend = 150;
tspan=[ 0  tend];

options = odeset('RelTol',1e-6,'AbsTol',[1.0e-6 1.e-06 1.e-06]);

[t5,x5]=ode45(@evapmod,tspan, X0ss, options);


% Disturbance scenario : 15 % step decrease in F200
F1 = 10;
XF1 = 5;
F200 = 208;
F200 = F200*0.85 ;


tspan=[ 0  tend];

options = odeset('RelTol',1e-6,'AbsTol',[1.0e-6 1.e-06 1.e-06]);

[t6,x6]=ode45(@evapmod,tspan, X0ss, options);


% Plots step states to F200 disturbance scenario
figure(5);

subplot(3,1,1)
grid on
plot(t5,x5(:,1),t6,x6(:,1),'--');
grid
legend('+15% F200' ,' -15% F200');
xlabel('t (min)')
ylabel('X2 ')
title(' Response of states to disurbance in F200  ')

subplot(3,1,2)
grid on
plot(t5,x5(:,2),t6,x6(:,2),'--');
grid
xlabel('t (min)')
ylabel('P2 ')

subplot(3,1,3)
grid on
plot(t5,x5(:,3),t6,x6(:,3),'--');
grid
xlabel('t (min)')
ylabel('L2 ')
```

```
% Disturbance scenario : 15 % step increase in P100
F1 = 10;
XF1 = 5;
F200 = 208;
P100 = 194.7;
P100 = P100*1.15;

tend = 150;
tspan=[ 0  tend];

options = odeset('RelTol',1e-6,'AbsTol',[1.0e-6 1.e-06 1.e-06]);

[t7,x7]=ode45(@evapmod,tspan, X0ss, options);


% Disturbance scenario : 15 % step decrease in P100
F1 = 10;
XF1 = 5;
F200 = 208;
P100 = 194.7;
P100 = P100*0.85 ;

tspan=[ 0  tend];

options = odeset('RelTol',1e-6,'AbsTol',[1.0e-6 1.e-06 1.e-06]);

[t8,x8]=ode45(@evapmod,tspan, X0ss, options);

% Plots step states to P100 disturbance scenario
figure(6);

subplot(3,1,1)
grid on
plot(t7,x7(:,1),t8,x8(:,1),'--');
grid
legend('+15% P100' ,' -15% P100');
xlabel('t (min)')
ylabel('X2 ')
title(' Response of states to disurbance in P100  ')

subplot(3,1,2)
grid on
plot(t7,x7(:,2),t8,x8(:,2),'--');
grid
xlabel('t (min)')
ylabel('P2 ')

subplot(3,1,3)
grid on
plot(t7,x7(:,3),t8,x8(:,3),'--');
grid
xlabel('t (min)')
ylabel('L2 ')
```

Presentation of results :

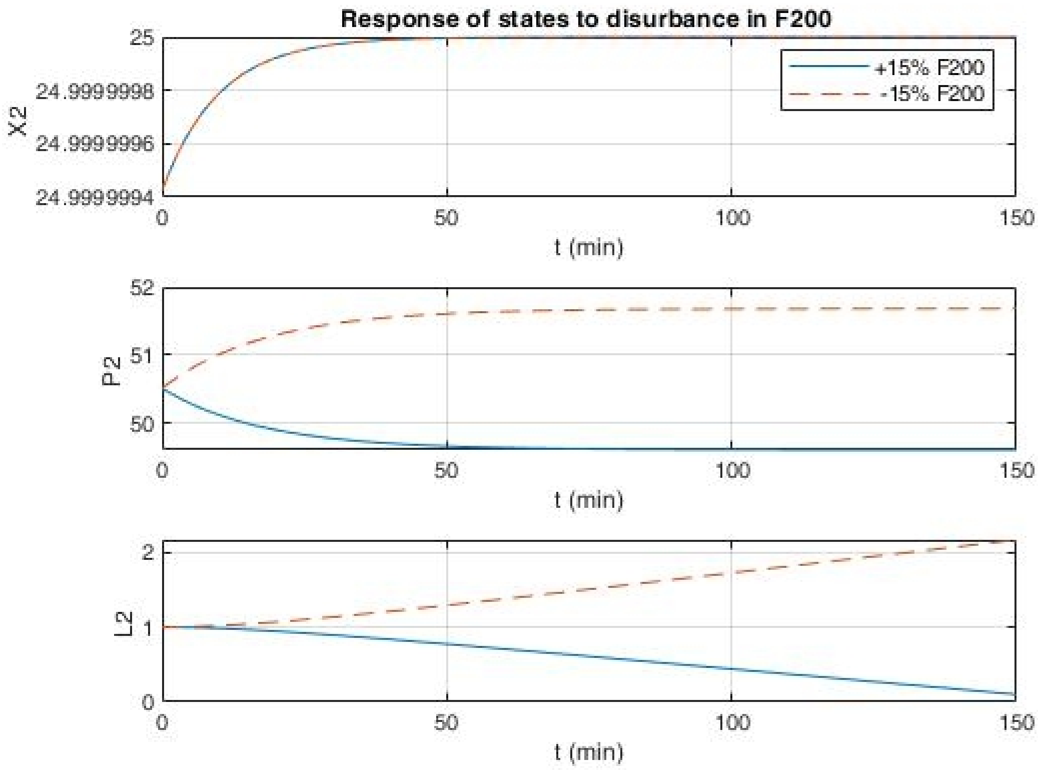

Fig 5 : Steady State Solution of the Controlled (output) variables after step change in F200

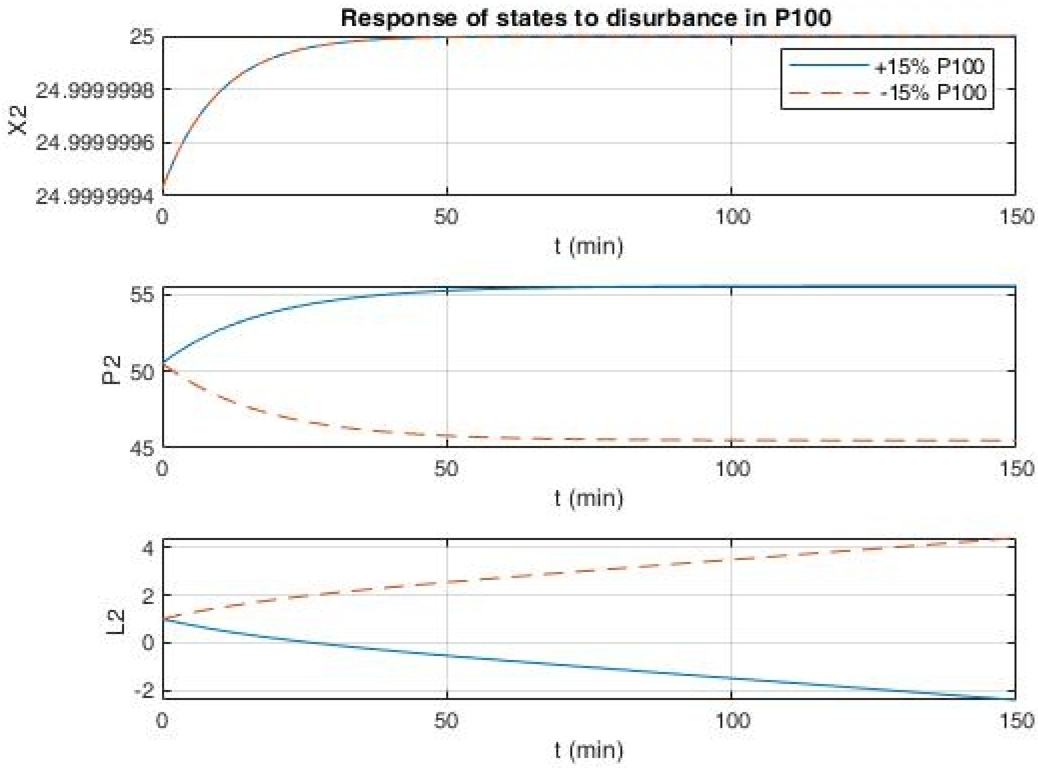

Fig 6 : Steady State Solution of the Controlled (output) variables after step change in P100

References

- Two Tank Example Provided by Professor