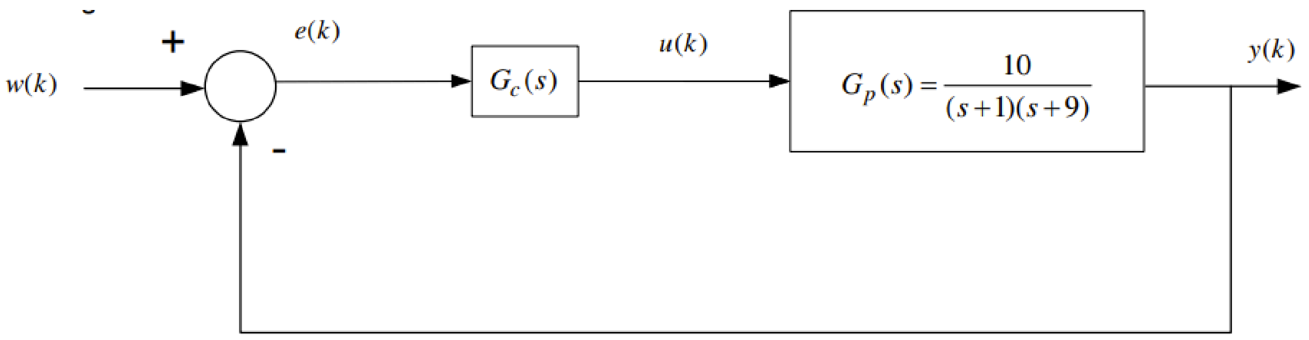
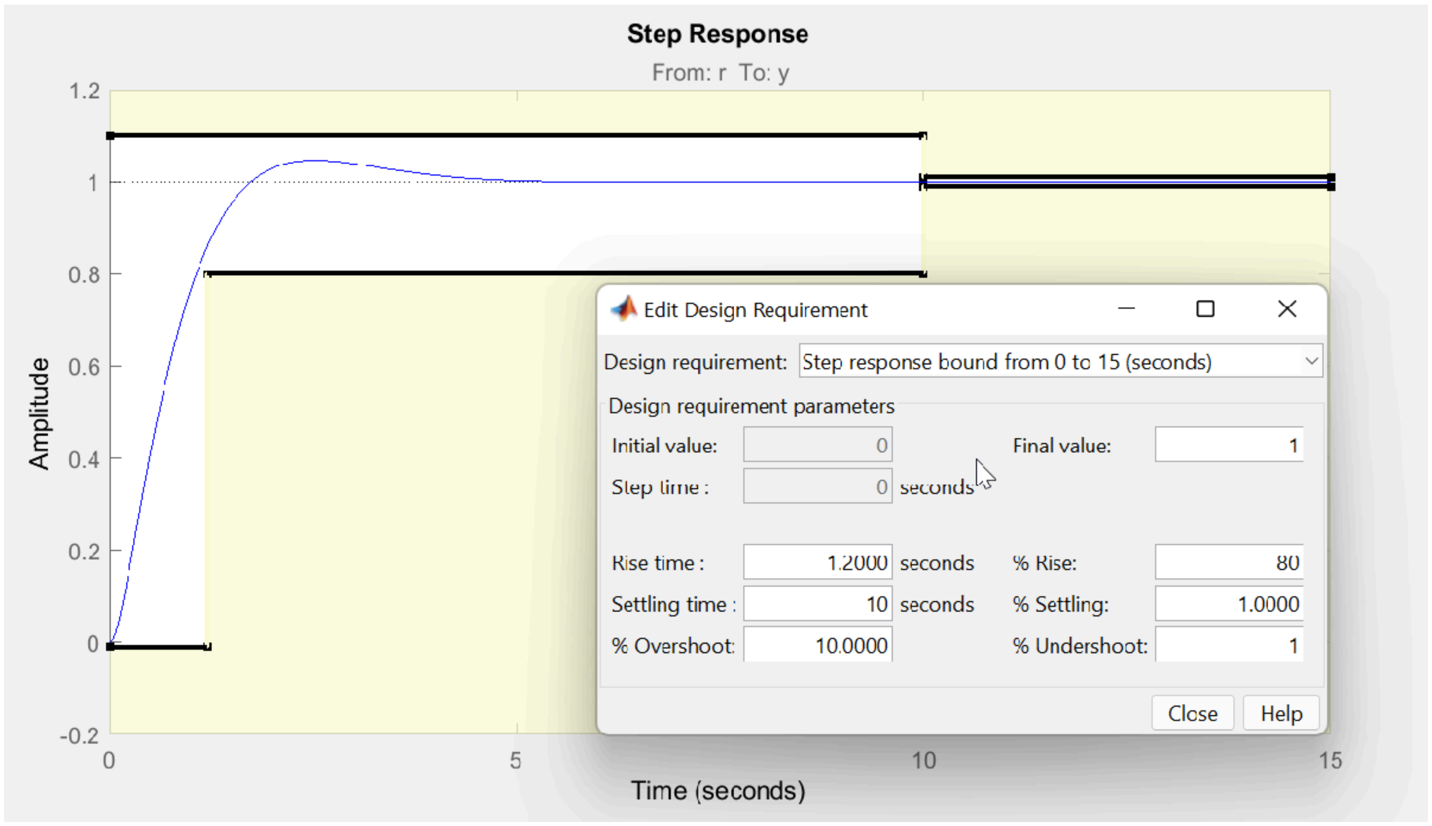
Satellite Control with Fuzzy PI Controller

1) Classic PI Controller

We assume the following closed loop system that controls the orientation angle *y* of a satellite through the controller $G_c(s) = K_p\frac{(s+c)}{s}$, where $c = \frac{K_I}{K_p}$:



We need to tune the parameters of the controller to achieve overshoot < 10% for step input and rise time < 1.2 seconds. We set these requirements in Control System Designer and we select $K_p = 1$ and $c = 1.5$.



Design requirement: Step response bound from 0 to 15 (seconds)

Design requirement parameters

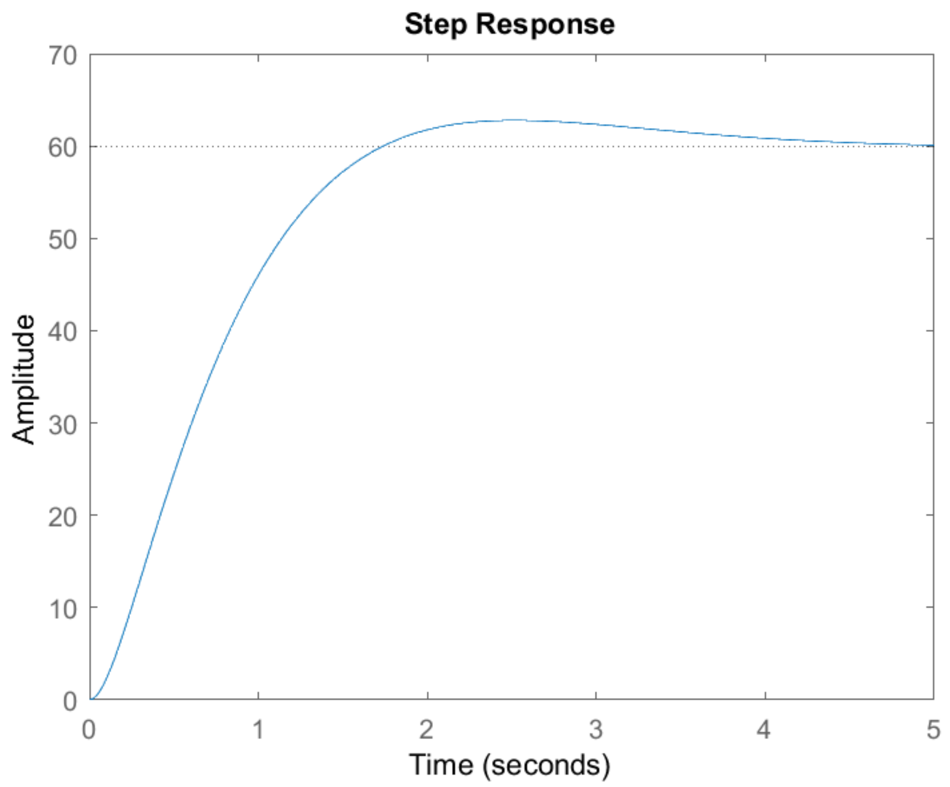
Initial value:	0		Final value:	1
Step time :	0	seconds		
Rise time :	1.2000	seconds	% Rise:	80
Settling time :	10	seconds	% Settling:	1.0000
% Overshoot:	10.0000		% Undershoot:	1

```
clc;
clear;
addpath("lib")
addpath("sim")

Kp = 1;
```

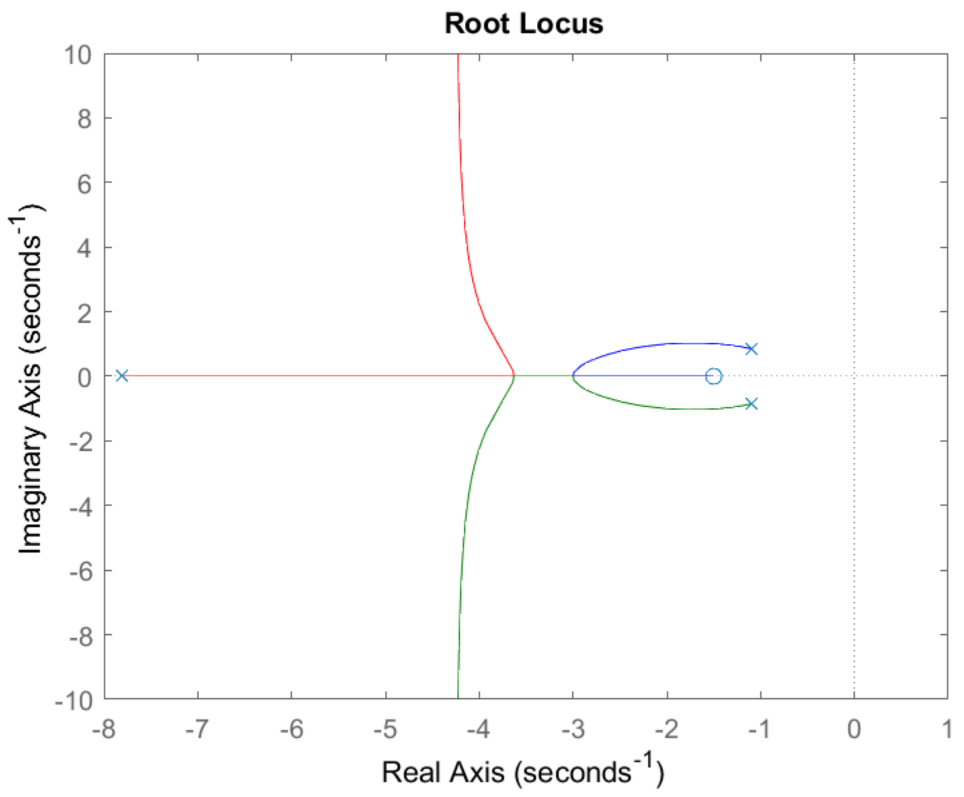
```
Ki = 1.5;
Gc = zpk(-Ki / Kp, 0, Kp);
Gp = zpk([], [-1 -9], 10);

openLoop = Gc * Gp;
sys = feedback(openLoop, 1, -1)
```

```
sys =
 

            10 (s+1.5)

  ------------------------------

  (s+7.814) (s^2 + 2.186s + 1.92)

 

Continuous-time zero/pole/gain model.
```

```

opt = stepDataOptions;
opt.StepAmplitude = 60;

figure()
step(sys,opt)
```



```
figure()
rlocus(sys)
```



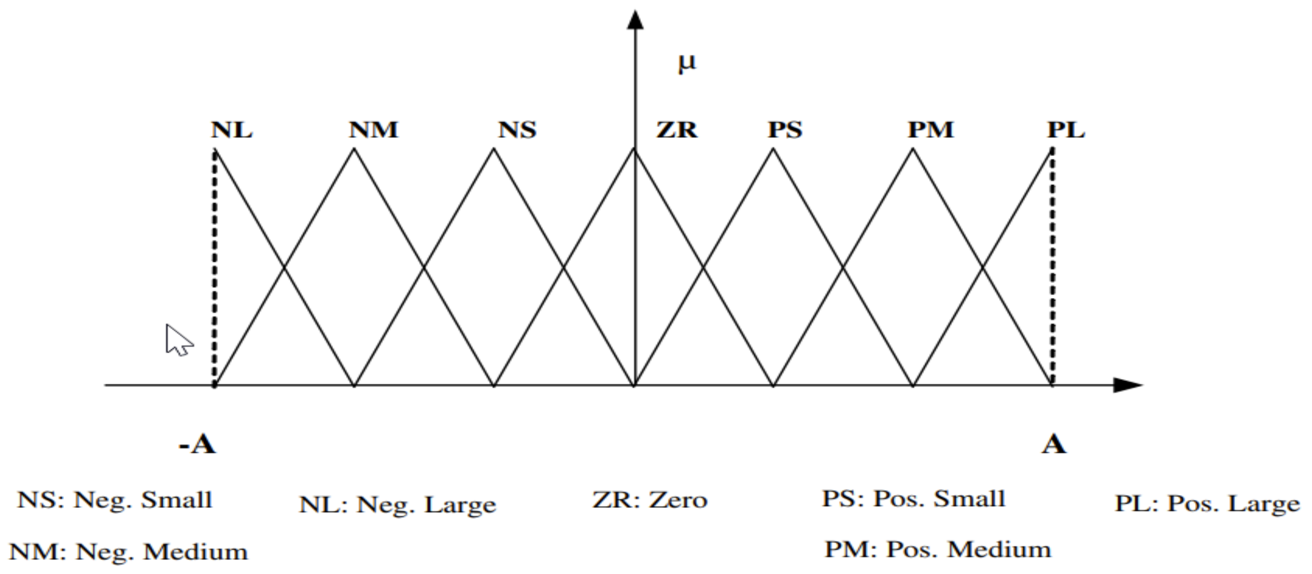
```
stepinfo(sys)
```

```
ans = struct with fields:
        RiseTime: 1.13430959331694
    SettlingTime: 3.72489243934137
     SettlingMin: 0.902579271500868
     SettlingMax: 1.04638896561874
       Overshoot: 4.63889656187384
      Undershoot: 0
            Peak: 1.04638896561874
        PeakTime: 2.5105685222914
```

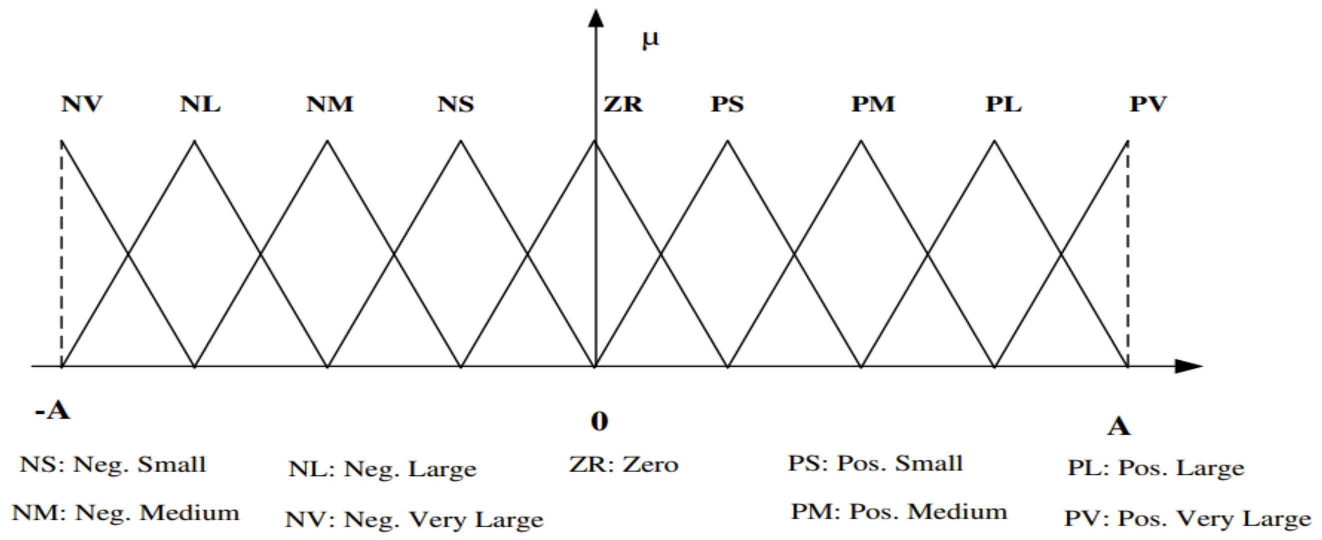
2) Fuzzy PI Controller

Now, we create a PI Fuzzy Logic Controller. We consider as inputs the tracking error *e* and its time derivative $\dot{e}$, while the output is the derivative of the control singal $\dot{u}$.

The membership function for the inputs is defined by the following figure:



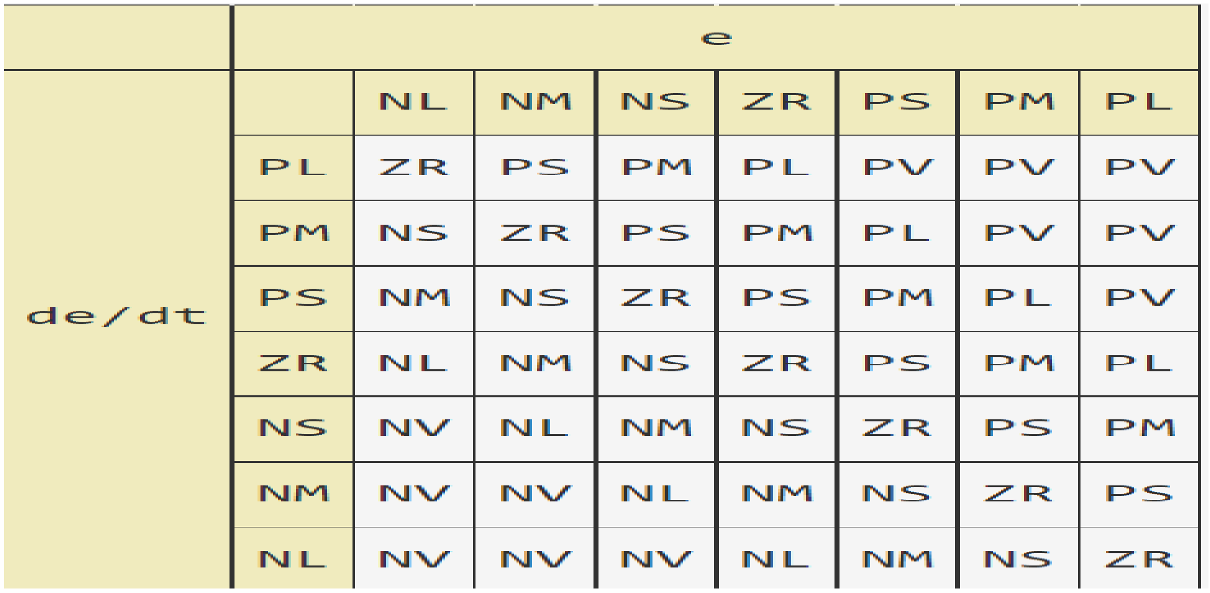
while the membership function of the output is the following:



```
FLC = readfis('FLC')
```

```
FLC = 
  mamfis with properties:

                      Name: "FLC"
                 AndMethod: "min"
                  OrMethod: "max"
         ImplicationMethod: "prod"
         AggregationMethod: "max"
     DefuzzificationMethod: "CenterOfSums"
                    Inputs: [1×2 fisvar]
                   Outputs: [1×1 fisvar]
                     Rules: [1×49 fisrule]
    DisableStructuralChecks: 0
 See 'getTunableSettings' method for parameter optimization.
```

The rules of the controller are defined from the following table, which shows the outputs for all the combinations of inputs:



		e						
		NL	NM	NS	ZR	PS	PM	PL
de/dt	PL	ZR	PS	PM	PL	PV	PV	PV
	PM	NS	ZR	PS	PM	PL	PV	PV
	PS	NM	NS	ZR	PS	PM	PL	PV
	ZR	NL	NM	NS	ZR	PS	PM	PL
	NS	NV	NL	NM	NS	ZR	PS	PM
	NM	NV	NV	NL	NM	NS	ZR	PS
	NL	NV	NV	NV	NL	NM	NS	ZR

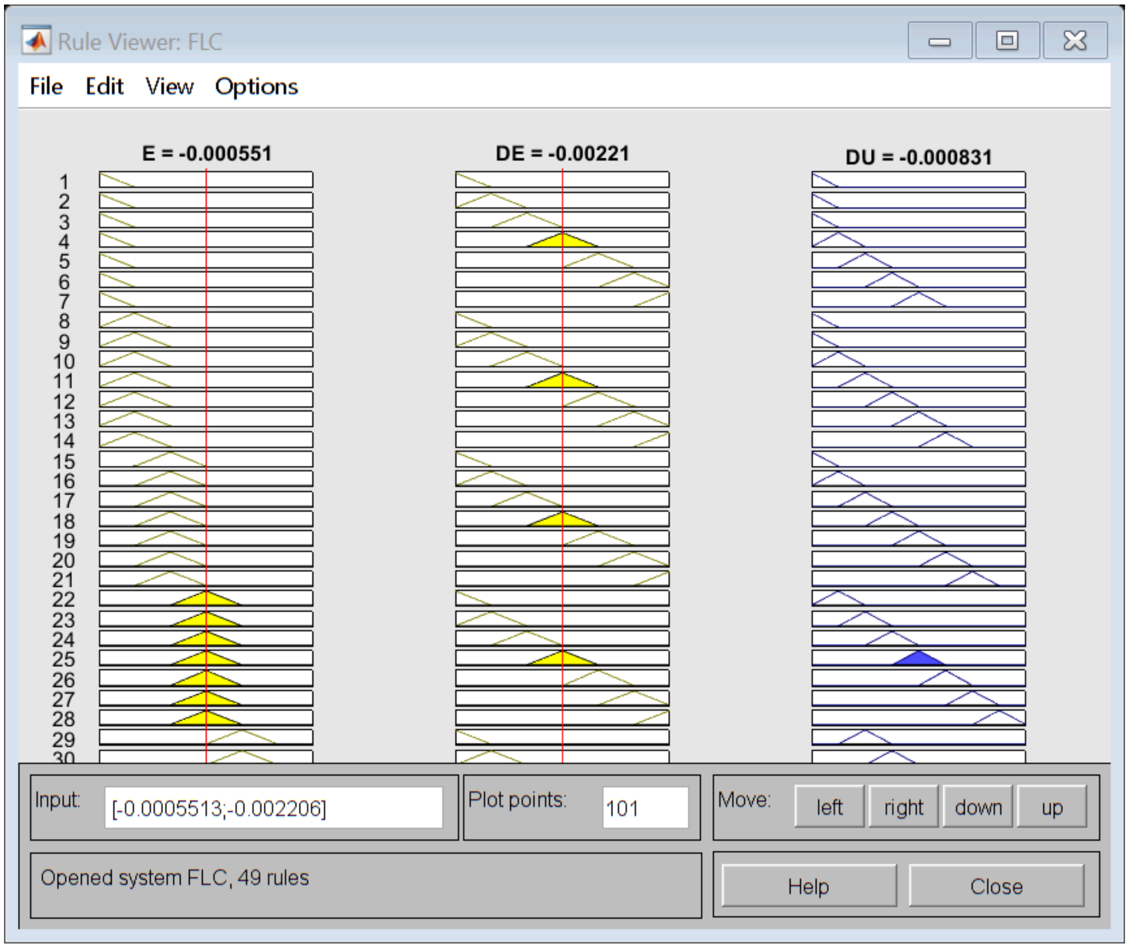
We create the following system on Simulink:

```
FLCSim
```

We normalize and denormalize the reference and output signals respectively, taking under consideration that they are in $[0, 60]$. Also,we use saturation function to fix the inputs of the FLC between -1 and 1 values.

We also tuned the gains of the system to achieve better results than the previous PI controller.

```
sim('FLCSim')
```

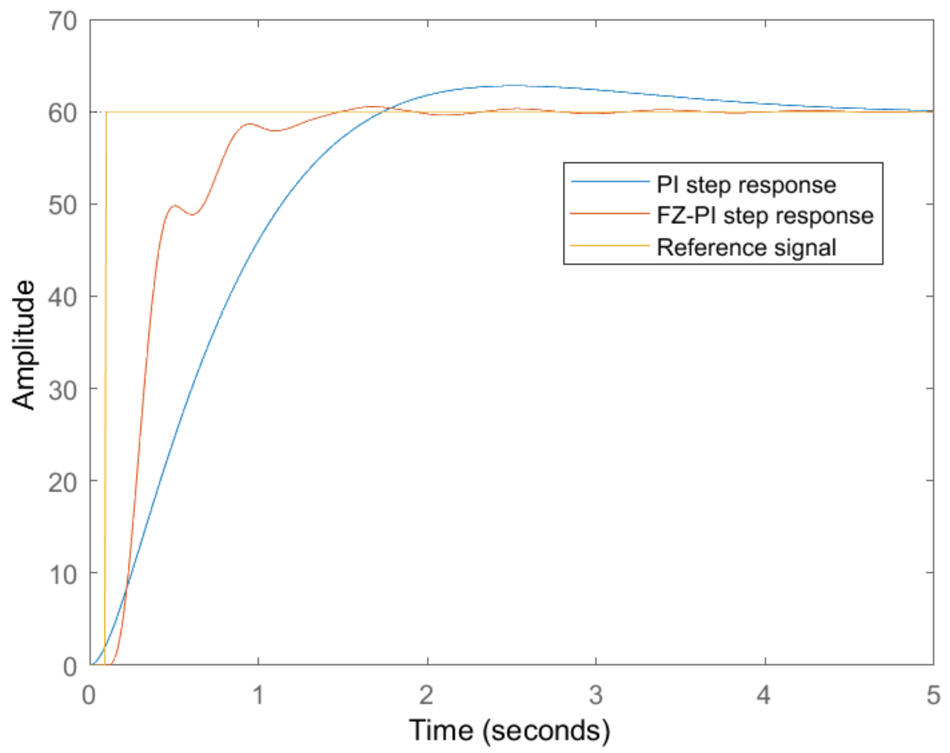


Opened system FLC, 49 rules

a) System respone

In the next figure, the step responses of the two separate controllers alongside the reference are presented.

```
figure()
hold on;
step(sys,opt);
plot(simout.time, simout.signals.values(:, 1), 'color', [0.8500, 0.3250, 0.0980]);
plot(simout.time, simout.signals.values(:, 2), 'color', [0.9290, 0.6940, 0.1250]);
title('');
legend('PI step response', 'FZ-PI step response', 'Reference signal', 'Location', "best");
hold off;
```



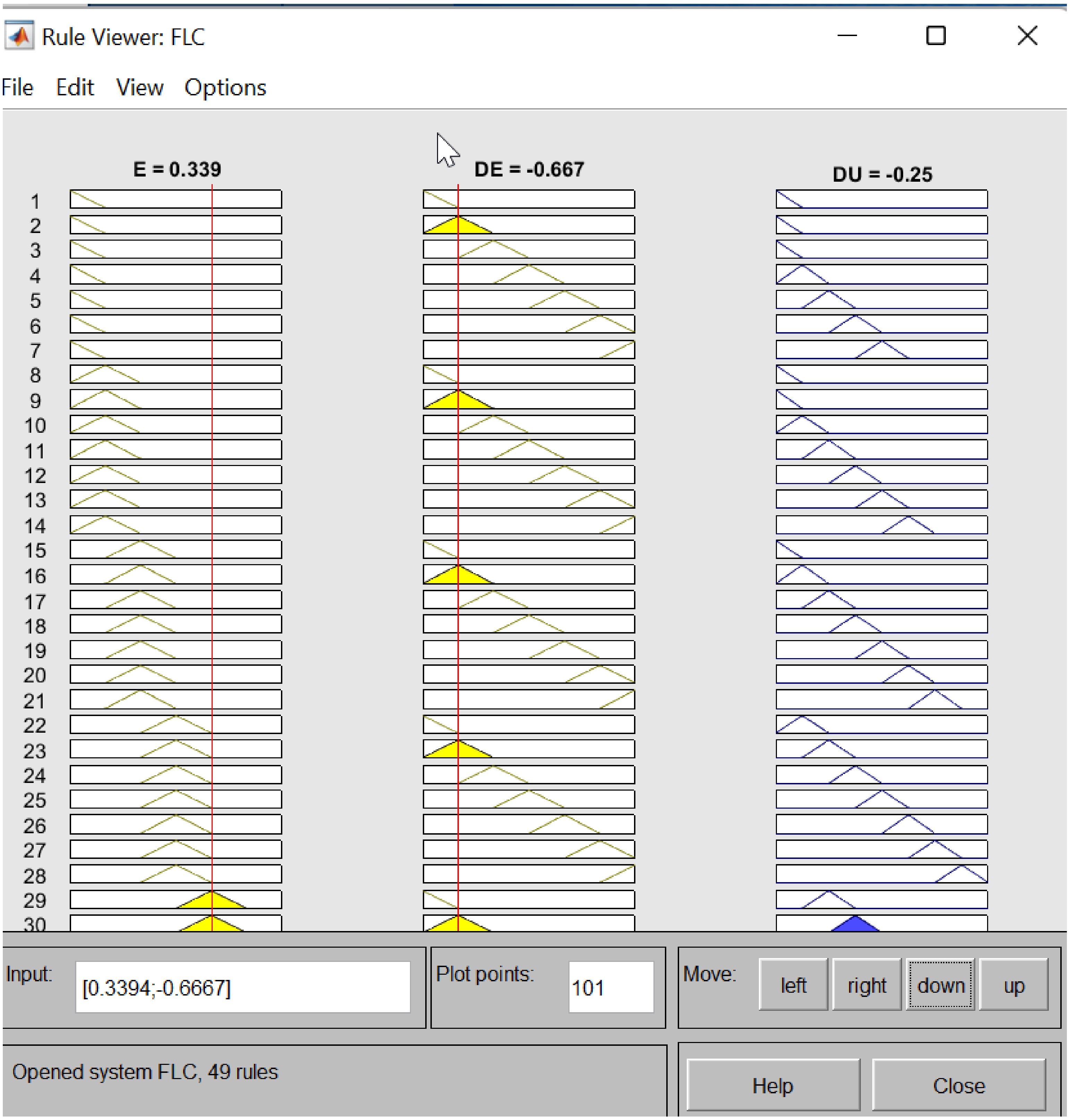
We can validate that the Fuzzy PI Controller performs better in terms of overshoot and rise time:

```
stepinfo(simout.signals.values(:, 1), simout.time)
```

```
ans = struct with fields:
         RiseTime: 0.565326689167668
     SettlingTime: 1.27022998509672
      SettlingMin: 54.466374456069
      SettlingMax: 60.5214889842389
        Overshoot: 0.813574809479944
       Undershoot: 0
             Peak: 60.5214889842389
         PeakTime: 1.67
```

b) Base functionality

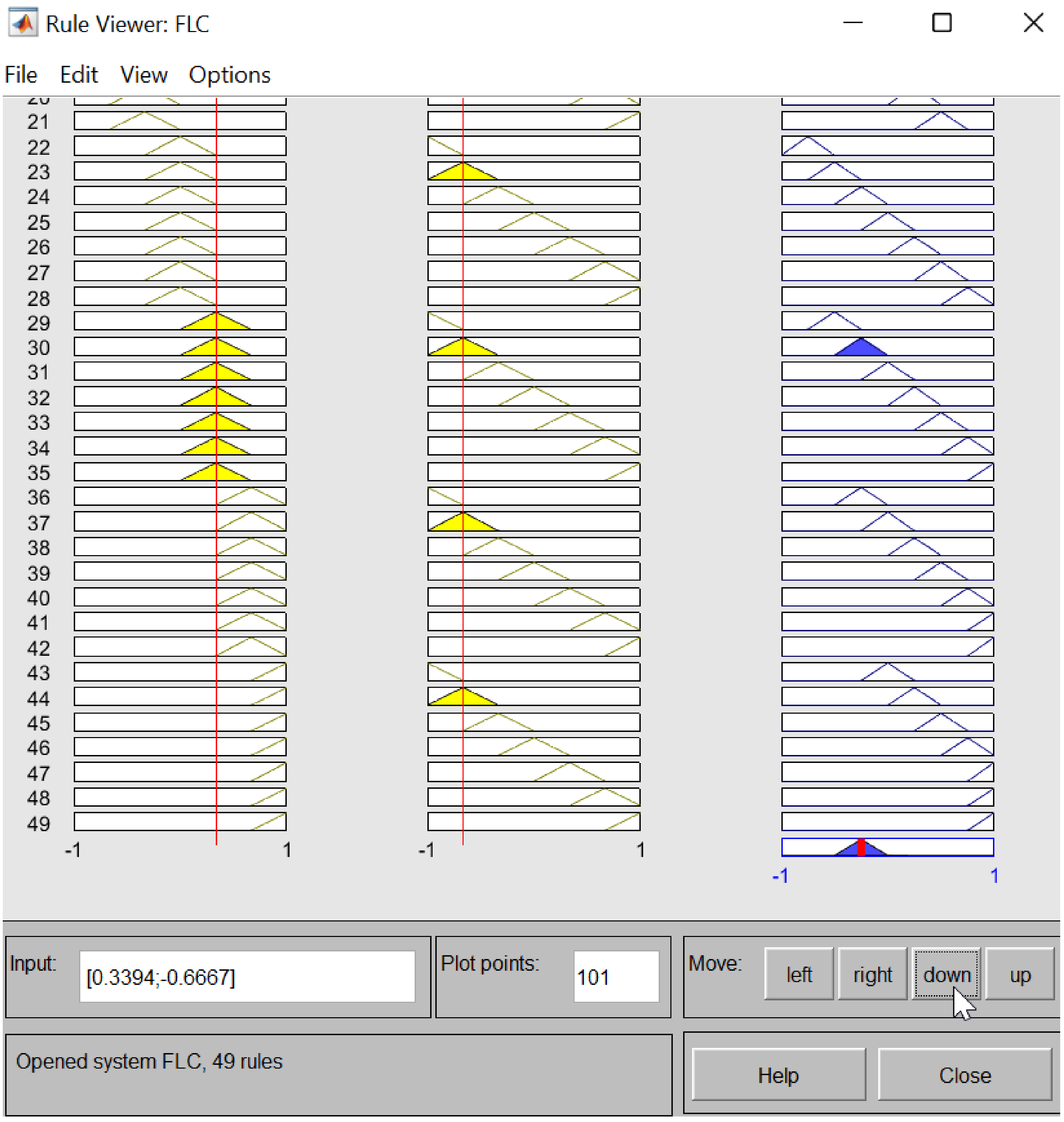
We assume the FLC inputs $e = \mathrm{PS}$ and $\dot{e} = \mathrm{NM}$.



Input: [0.3394;-0.6667]

Plot points: 101

Opened system FLC, 49 rules



Input: [0.3394;-0.6667]

Plot points: 101

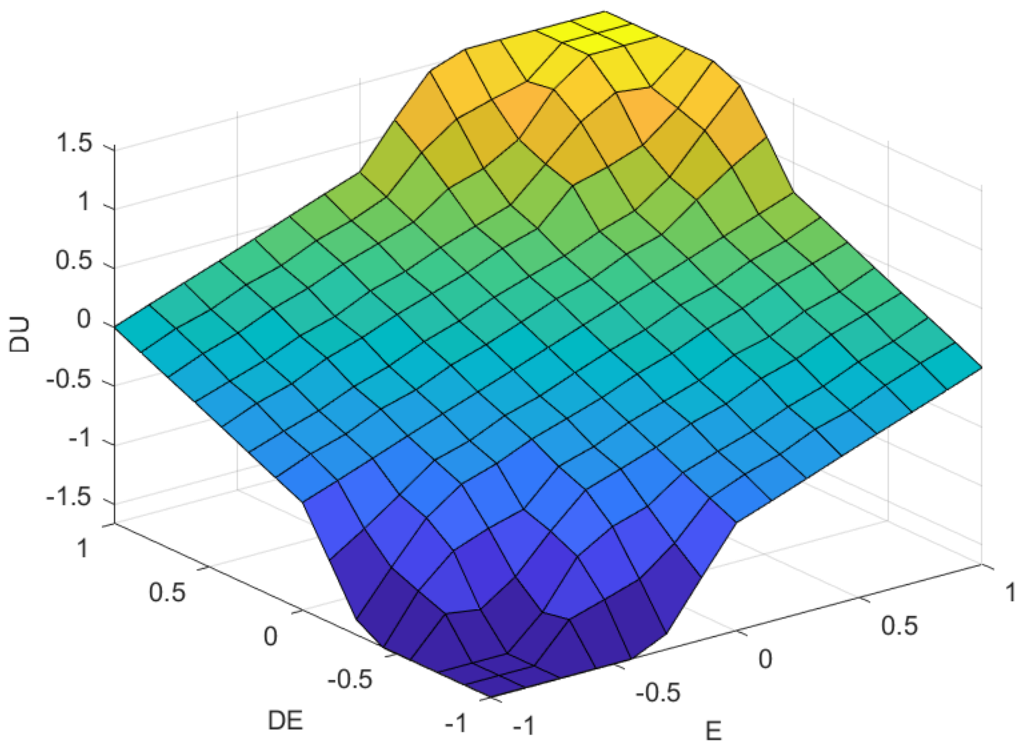
Move:

Opened system FLC, 49 rules

As we see above, rule 30 is activated and the output is $\dot{u} = \mathrm{NS}$.

c) 3D output surface

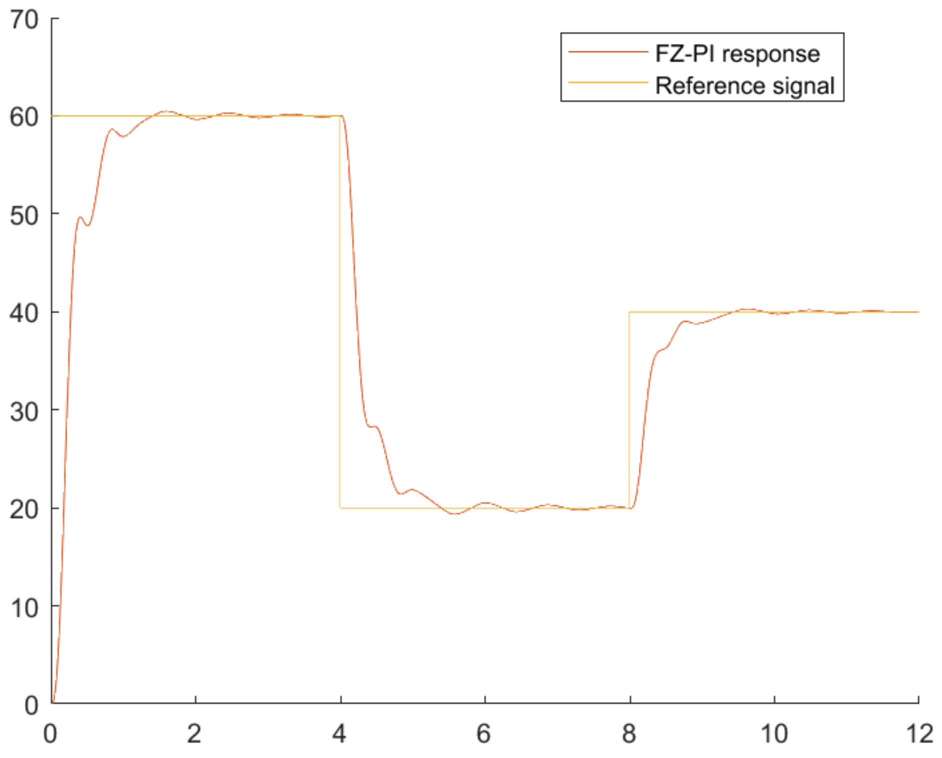
```
figure()
gensurf(FLC)
```



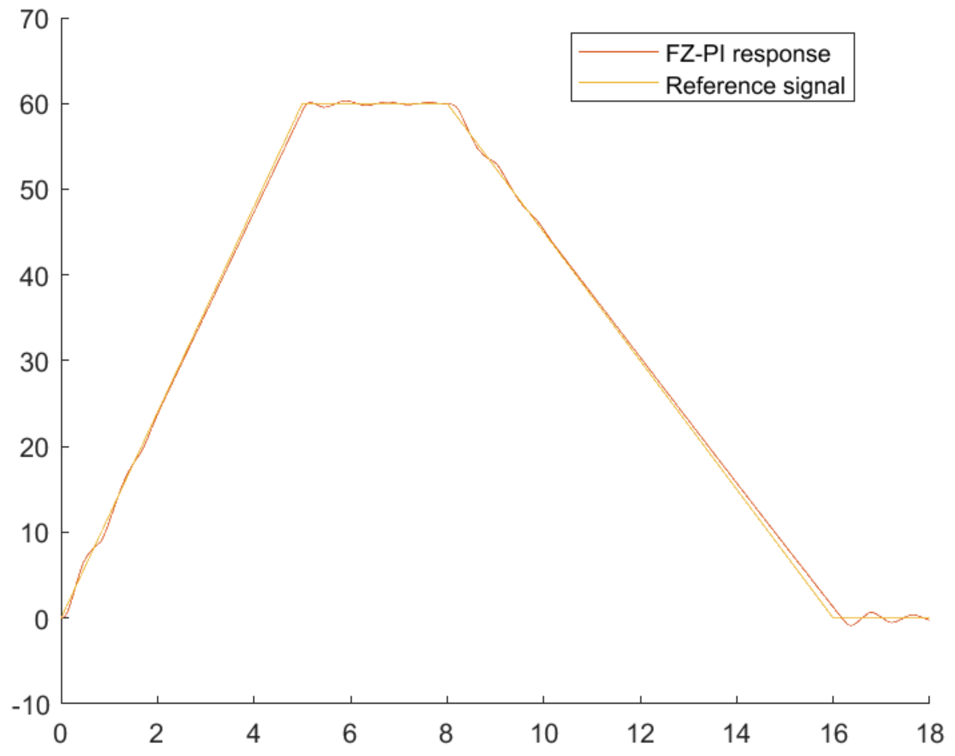
d) Custom input signals

Now we test the ability of the controller to track custom inputs signals. The results of the simulations are presented below. The tracking is very accurate, with low overshoots and high rise times. There are some little oscillations too.

```
sim('FLCSim2')

figure()
hold on;
plot(simout.time, simout.signals.values(:, 1), 'color', [0.8500, 0.3250, 0.0980]);
plot(simout.time, simout.signals.values(:, 2), 'color', [0.9290, 0.6940, 0.1250]);
legend('FZ-PI response', 'Reference signal', 'Location', "best");
hold off;
```



```
sim('FLCSim3')
figure()
hold on;
plot(simout.time, simout.signals.values(:, 1), 'color', [0.8500, 0.3250, 0.0980]);
plot(simout.time, simout.signals.values(:, 2), 'color', [0.9290, 0.6940, 0.1250]);
legend('FZ-PI response', 'Reference signal', 'Location', "best");
hold off;
```


FZ-PI response
Reference signal
70
60
50
40
30
20
10
0
-10
0
2
4
6
8
10
12
14
16
18