Automation Of Energy Systems

Project E

Team Members:

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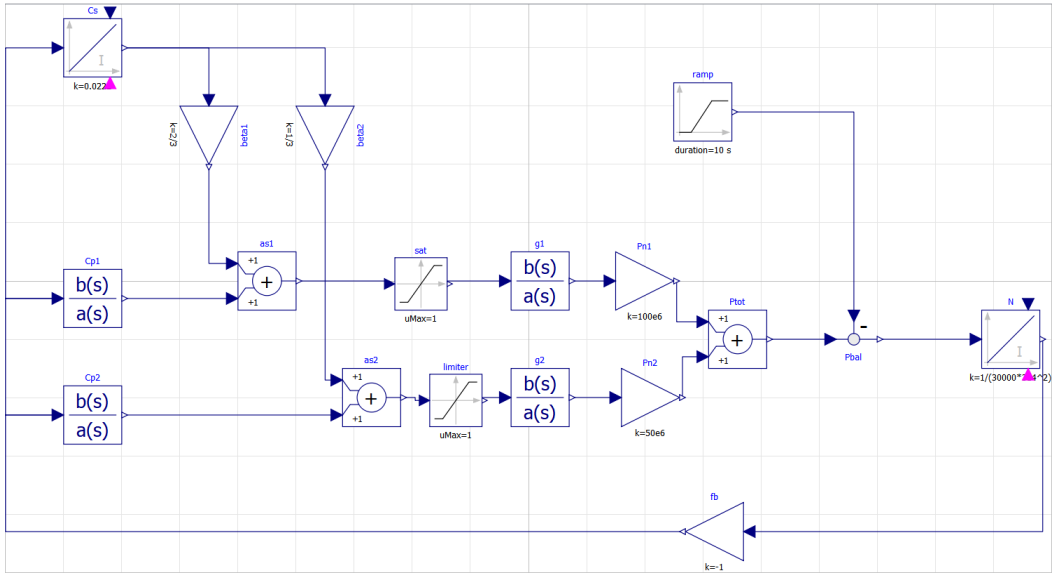
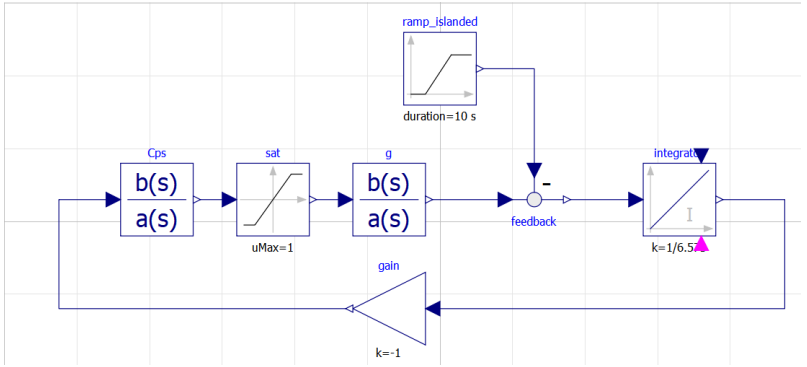
Configuration A

Primary and **Secondary** control

Control scheme



Generators G1 and G2



Islanded case

Configuration A

Primary and **Secondary** control

Resolution:

G1 + G2 Case:
PI Controller was used

Matlab calculations

Gain values obtain by Matlab calculations gave a too slow dynamics

Hidden dynamics was discovered

Trial and Error to find values that satisfy the requirements

Matlab calculations

```
syms s kp1 kp2 ks
tau1=10;
tau2=5;
beta1=2/3;
beta2=1/3;
w0=2*pi*50;
Pn1=100e6;
Pn2=50e6;
J=30e3;
L=((kp1+ks*beta1/s)*Pn1/(1+s*tau1)+(kp2+ks*beta2/s)*Pn2/(1+s*tau2))/(J*w0^2*s);
L= simplifyFraction(L)
%results: L=0.0056*(5*ks+6*kp1*s+3*kp2*s+30*ks*s+30*kp1*s^2+30*kp2*s^2)/s^2*(5*s+1)*(10*s+1)
Ld=(1+100*s)*(1+10*s)*0.025^2;
Ld=expand(Ld)       %results: Ld=(5/8)*s^2+(11/160)*s+1/1600
S=solve( (30*kp1+30*kp2)*0.0056==5/8, (6*kp1+3*kp2+30*ks)*0.0056==11/160, 5*ks==1/1600);
```

	kp1	kp2	ks
matlab	0,37077	3,34946	0,00013
modelica	0.0014	3.35	0.0222

Configuration A

Primary and **Secondary** control

Resolution:

Islanded G3 Case:

PI controller gave a too slow dynamics

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Problematic Hidden Dynamics

↓

Choice of PID Regulation

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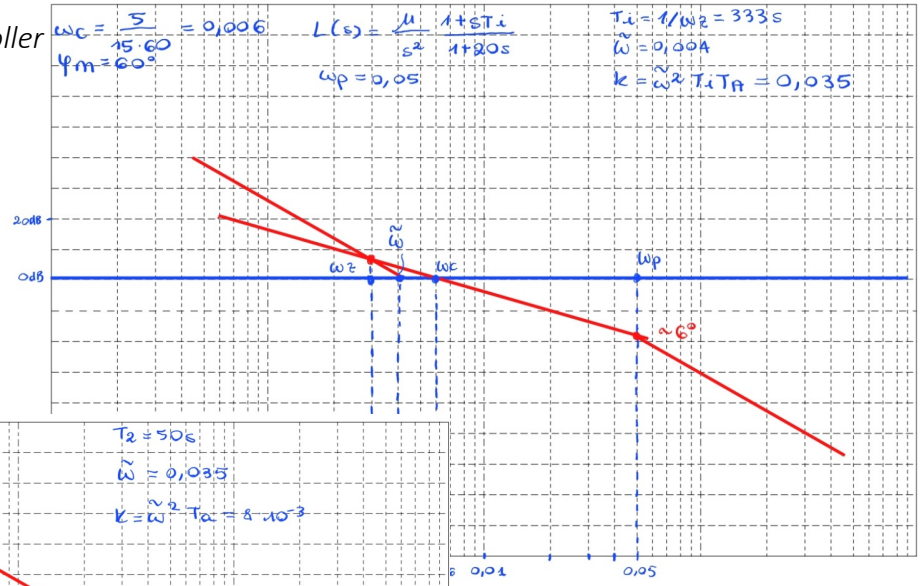
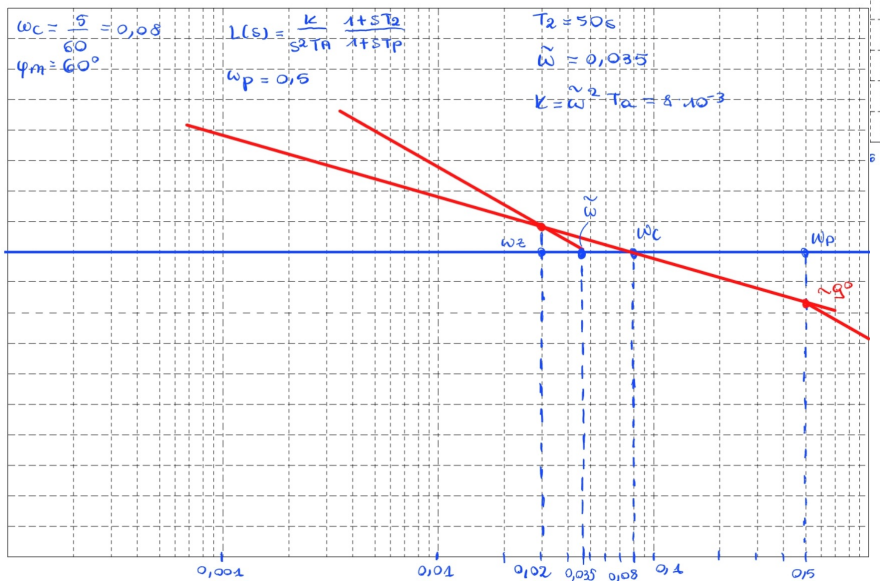
Trial and Error to find values that satisfy the requirements

PI controller

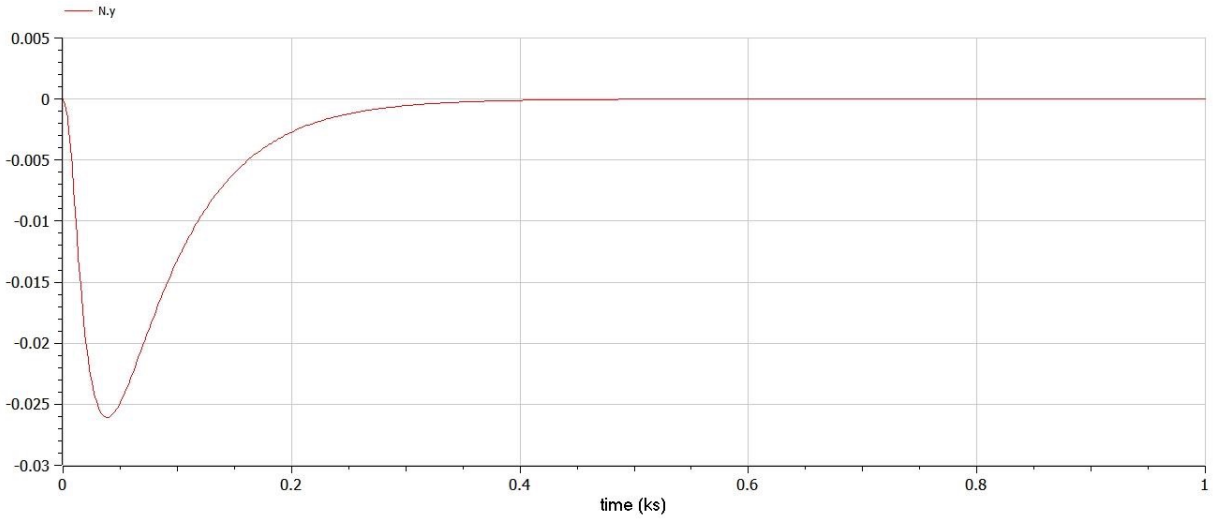




PID controller puts the pole one decade after, so that setting time is smaller

Configuration A

Primary and **Secondary** control



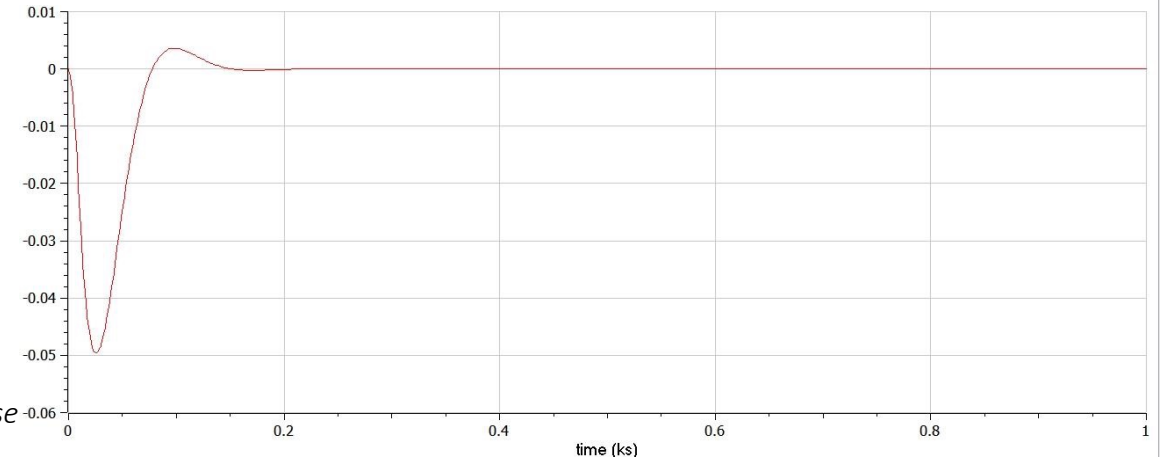
Frequency of the grid with generators G1 and G2

Comments:

1. *Presence of an undershoot*
2. *δω never exceeds a magnitude of 0.03*
3. *Settling time < 400 s*

Comments:

1. *Small amplitude oscillation*
2. *δω never exceeds a magnitude of 0.05*
3. *Settling time < 200 s*

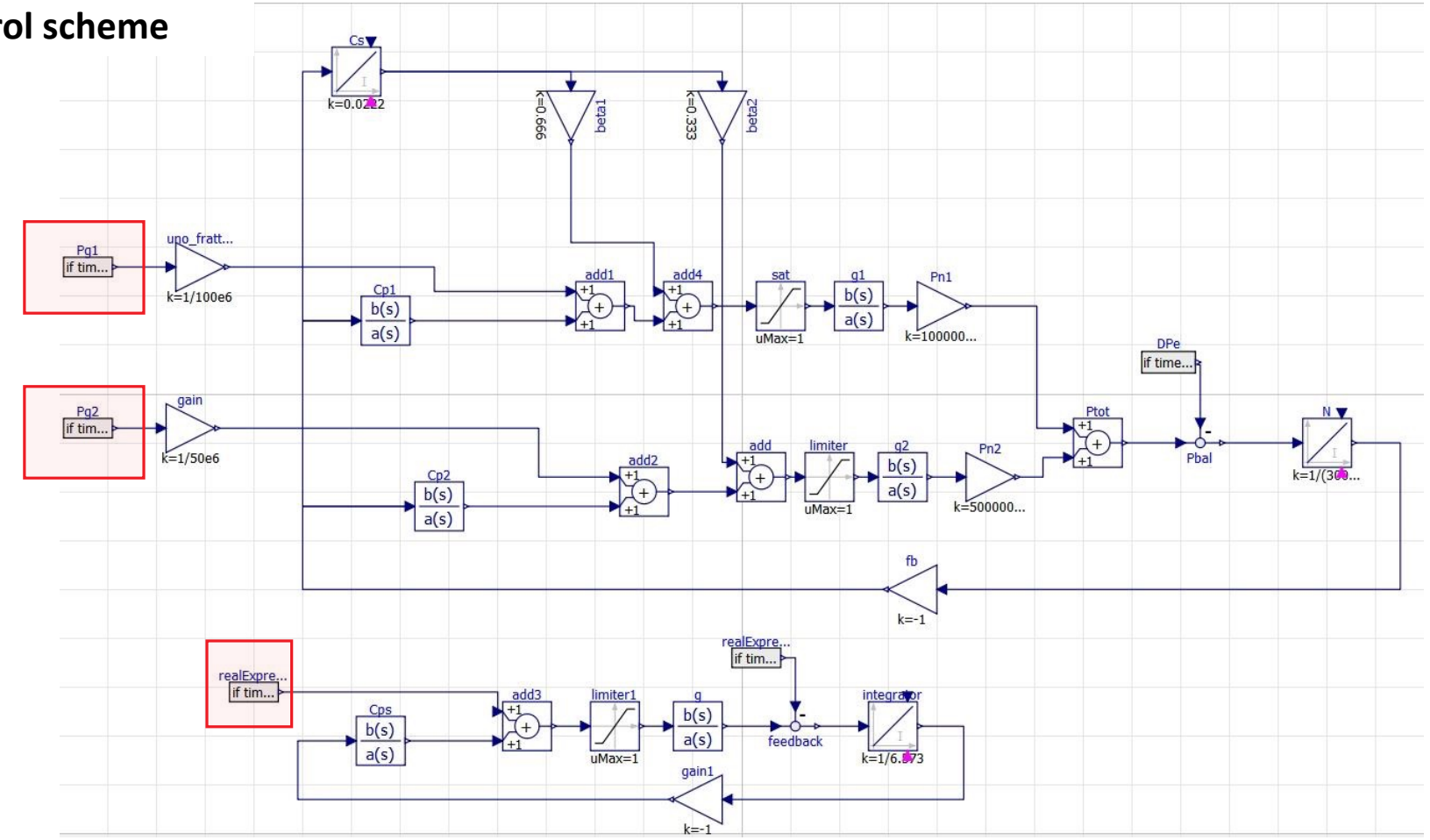


Frequency of the islanded case

Configuration A

Tertiary control

Control scheme



Configuration A

Tertiary control

KKT resolution:

Maxima used to obtain **candidate solutions**

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Solution choice based on **μ** values, **Feasability** and **Minimum Cost**

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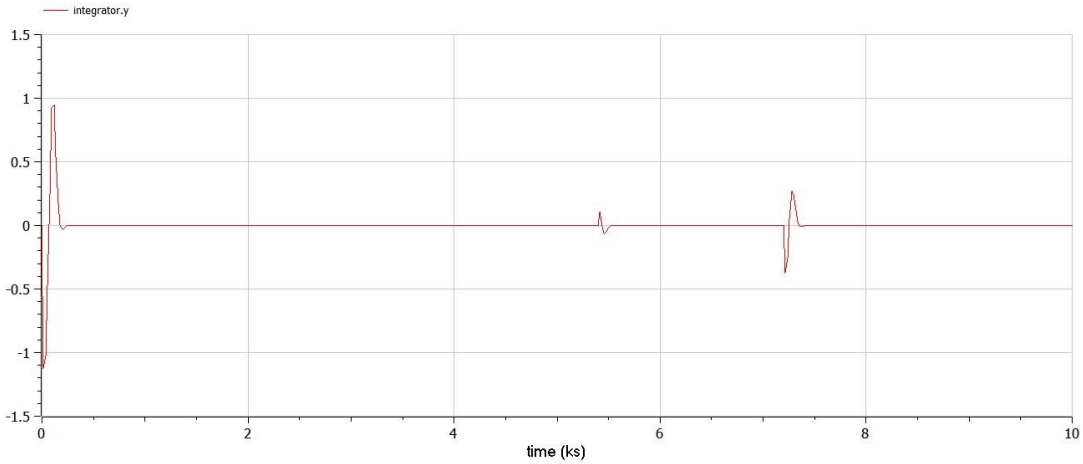
Saturation Detected: **impossible** to implement an **Anti-WindUp** solution!

Configuration A - Tertiary Control: G1+G2 feed L1+L2, G3 feeds L3+L4 [MW]												
	S1		S2		S3		S4		S5		S6	
	L1+L2	L3+L4	L1+L2	L3+L4	L1+L2	L3+L4	L1+L2	L3+L4	L1+L2	L3+L4	L1+L2	L3+L4
Load Request	60	110	70	110	120	110	120	90	110	130	60	130
G1	60	/	70	/	70	/	79.67	/	73	/	60	/
G2	0	/	0	/	0	/	40.33	/	37	/	0	/
G3	/	110	/	110	/	110	/	90	/	130	/	130

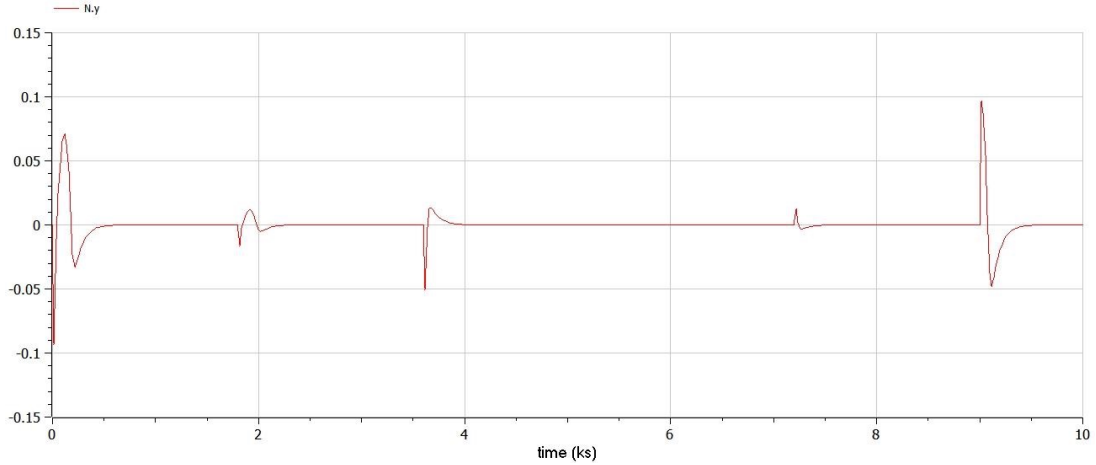
```
Pg1min : 15;
Pg1max : 110;
Pg2min : 7.5;
Pg2max : 55;
Pg3min : 22.5;
Pg3max : 165;
k01: 13538.5;
k11 :-285;
k21 :1.5;
k02:6913;
k12 :-288;
k22 :3;
k03:78401.5;
k13 :-1120;
k23 :4;
c1 : k01+k11·Pg1+k21·Pg1^2;
c2 : k02+k12·Pg2+k22·Pg2^2;
c3 : k03+k13·Pg3+k23·Pg3^2;
f : c1+c3;
Pe:190;
g : Pg1+Pg2+Pg3-Pe;
h1 : Pg1-Pg1min;
h2 : Pg1max-Pg1;
h3 : Pg2-Pg2min;
h4 : Pg2max-Pg2;
h5 : Pg3-Pg3min;
h6 : Pg3max-Pg3;
L : f+lambda·g+mu1·h1+mu2·h2+mu3·h3+mu4·h4+mu5·h5+mu6·h6;
KKTeqs : [diff(L,Pg1),diff(L,Pg2),diff(L,Pg3),
diff(L,lambda),
mu1·diff(L,mu1),mu2·diff(L,mu2),
mu3·diff(L,mu3),mu4·diff(L,mu4),
mu5·diff(L,mu5),mu6·diff(L,mu6)];
S : solve(KKTeqs,[Pg1,Pg2,Pg3,lambda,mu1,mu2,mu3,mu4,mu5,mu6]);
for i:1 thru length(%rnum_list) do S:subst(t[i],%rnum_list[i],S);
float(S);
fvals : float(makelist(subst(S[i],f),i,1,length(S)));
```

Configuration A

Tertiary control



Frequency of the islanded case

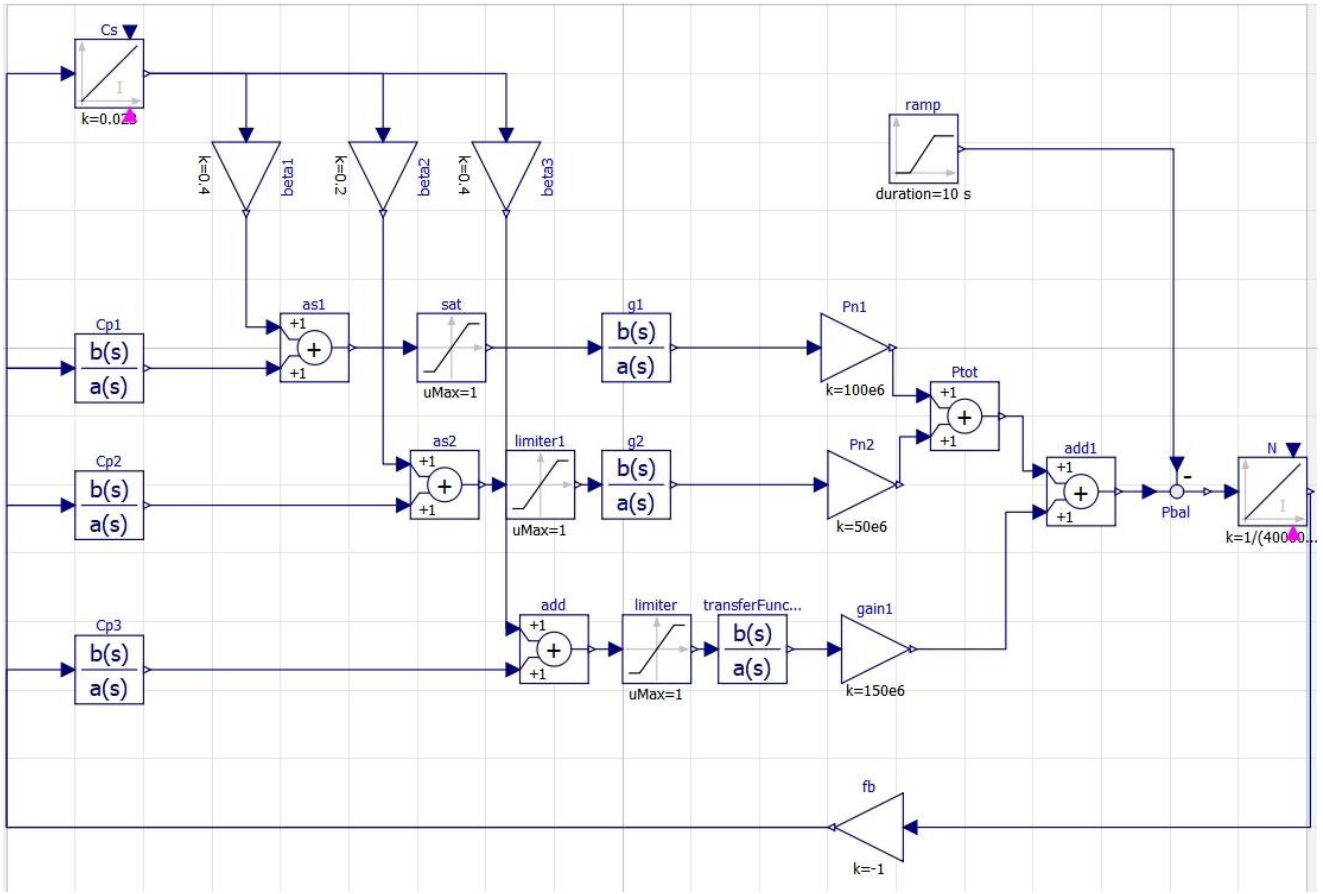


Frequency of the grid with the generators G1 and G2

Configuration B

Primary and **Secondary** control

Control scheme



Generators G1, G2 and G3

Configuration B

Primary and **Secondary** control

Resolution:

PI Controller was used

Matlab calculations

Matlab calculations

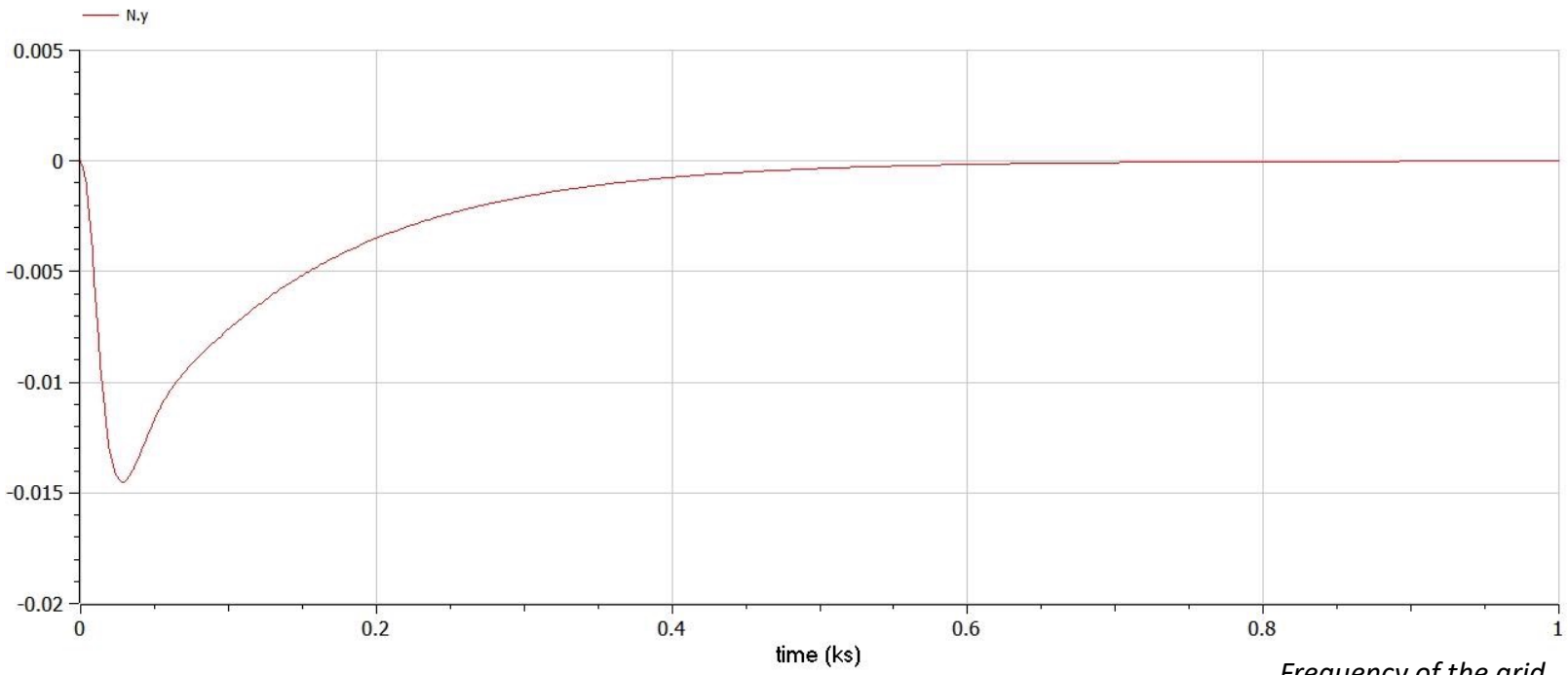
```
syms s kp1 kp2 kp3 ks
tau1=10;
tau2=5;
tau3=20;
beta1=0.4;
beta2=0.2;
beta3=0.4;
w0=2*pi*50;
Pn1=100e6;
Pn2=50e6;
Pn3=150e6;
J=40e3;
L=((kp1+ks*beta1/s)*Pn1/(1+s*tau1) + (kp2+ks*beta2/s)*Pn2/(1+s*tau2) + (kp3+ks*beta3/s)*Pn3/(1+s*tau3)) / (J*w0^2*s);
L= simplifyFraction(L)
%results:
%L=0.025*(11*ks+10*kp1*s+5*kp2*s+15*kp3*s+220*ks*s+250*kp1*s^2+000*kp1*s^3+150*kp2*s^2+1000*kp2*s^3+225*kp3*s^2+750*kp3*s^3+900*ks*s^2)/s^2*(5*s+1)*(10*s+1)*(20*s+1)
Ld=(1+100*s)*(1+10*s)*(1+20*s)*0.025^2;
Ld=expand(Ld) %results: Ld=(25/2)*s^3+2*s^2+(13/160)*s+1/1600
S=solve((1000*kp1+1000*kp2+750*kp3)*0.025==25/2, (250*kp1+150*kp2+225*kp3+900*ks)*0.025==2, (10*kp1+5*kp2+15*kp3+220*ks)*0.025==13/160 , 11*0.025*ks==1/1600);
```

Hidden dynamics was discovered → **Trial and Error** to find values that satisfy the requirements

	kp1	kp2	kp3	ks
matlab	0,00909	0,47727	0,01818	0,00227
modelica	0.91	4.773	0.182	0.023

Configuration B

Primary and **Secondary** control



Frequency of the grid

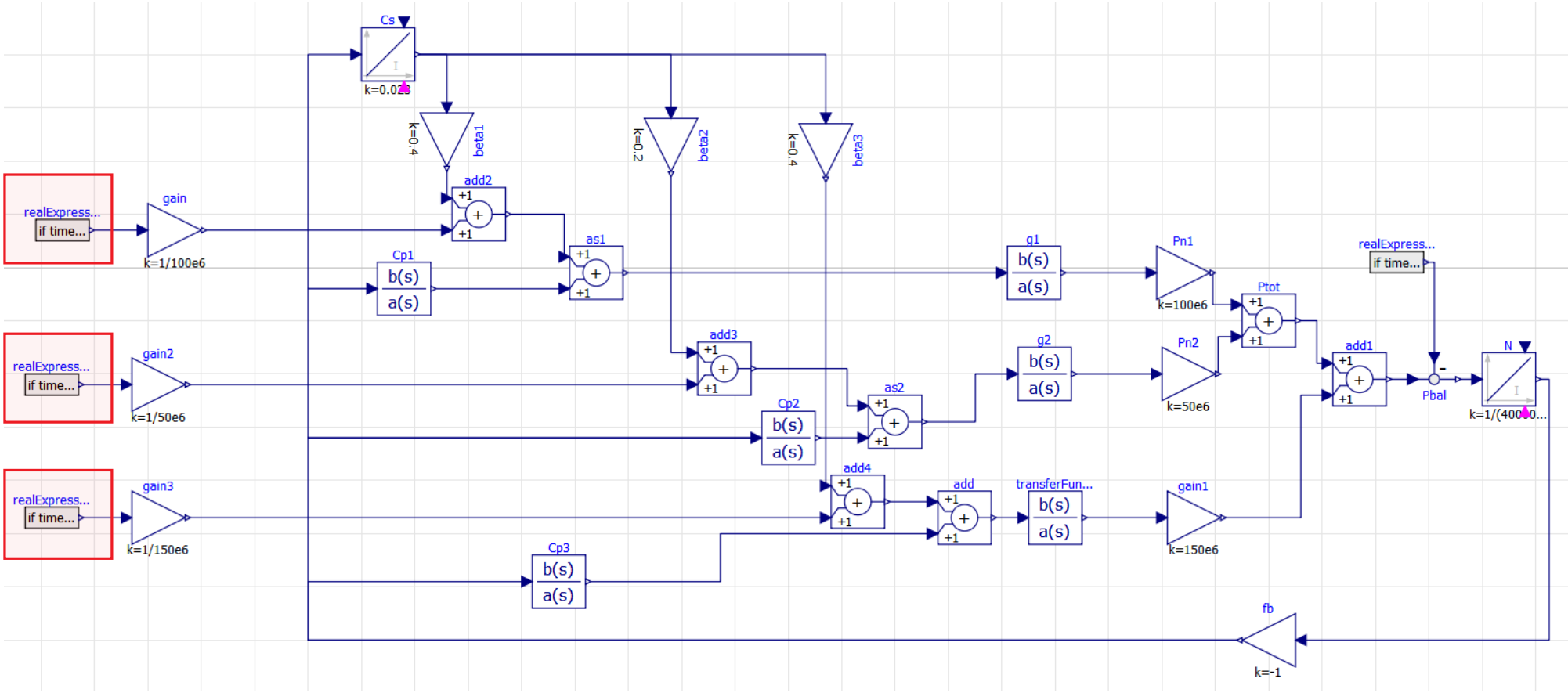
Comments:

1. *Presence of an undershoot*
2. *δω never exceeds a magnitude of 0.05*
3. *Settling time < 400 s*

Configuration B

Tertiary control

Control scheme



Configuration B

Tertiary control

KKT resolution:

G2 cost **neglected**, but **boundaries kept**

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Feasible solutions chosen based on **μ** values and working ranges

↓

Best Pool generator identified for each request depeding on the cost

Configuration B - Tertiary Control: G1+G2+G3 feed L1+L2+L3+L4 [MW]						
	S1	S2	S3	S4	S5	S6
	L1+L2+L3+L4	L1+L2+L3+L4	L1+L2+L3+L4	L1+L2+L3+L4	L1+L2+L3+L4	L1+L2+L3+L4
Load Request	170	180	230	210	240	190
G1	0	0	91.36	76.82	93	0
G2	30	40	0	0	7.5	50
G3	140	140	138.64	133.12	139	140

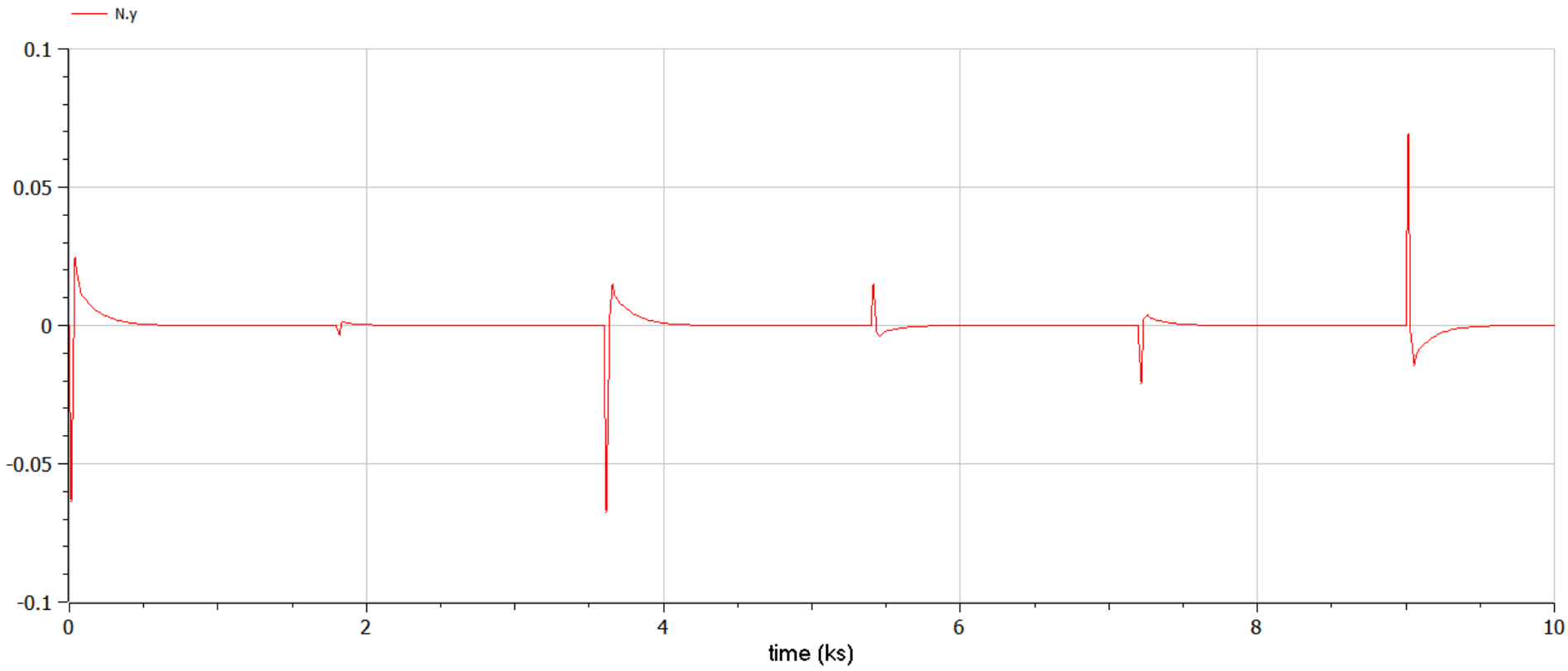
Script Maxima

```
Pg1min : 15;
Pg1max : 110;
Pg2min : 7.5;
Pg2max : 55;
Pg3min : 22.5;
Pg3max : 165;
k01: 13538.5;
k11 :-285;
k21 :1.5;
k02:6913;
k12 :-288;
k22 :3;
k03:78401.5;
k13 :-1120;
k23 :4;
c1 : k01+k11·Pg1+k21·Pg1^2;
c2 : k02+k12·Pg2+k22·Pg2^2;
c3 : k03+k13·Pg3+k23·Pg3^2;
f : c1+c3;
Pe:190;
g : Pg1+Pg2+Pg3-Pe;
h1 : Pg1-Pg1min;
h2 : Pg1max-Pg1;
h3 : Pg2-Pg2min;
h4 : Pg2max-Pg2;
h5 : Pg3-Pg3min;
h6 : Pg3max-Pg3;
L : f+lambda·g+mu1·h1+mu2·h2+mu3·h3+mu4·h4+mu5·h5+mu6·h6;
KKTeqs : [diff(L,Pg1),diff(L,Pg2),diff(L,Pg3),
diff(L,lambda),
mu1·diff(L,mu1),mu2·diff(L,mu2),
mu3·diff(L,mu3),mu4·diff(L,mu4),
mu5·diff(L,mu5),mu6·diff(L,mu6)];
S : solve(KKTeqs,[Pg1,Pg2,Pg3,lambda,mu1,mu2,mu3,mu4,mu5,mu6]);
for i:1 thru length(%rnum_list) do S:subst(t[i],%rnum_list[i],S);
float(S);
fvals : float(makelist(subst(S[i],f),i,1,length(S)));
```

Configuration B

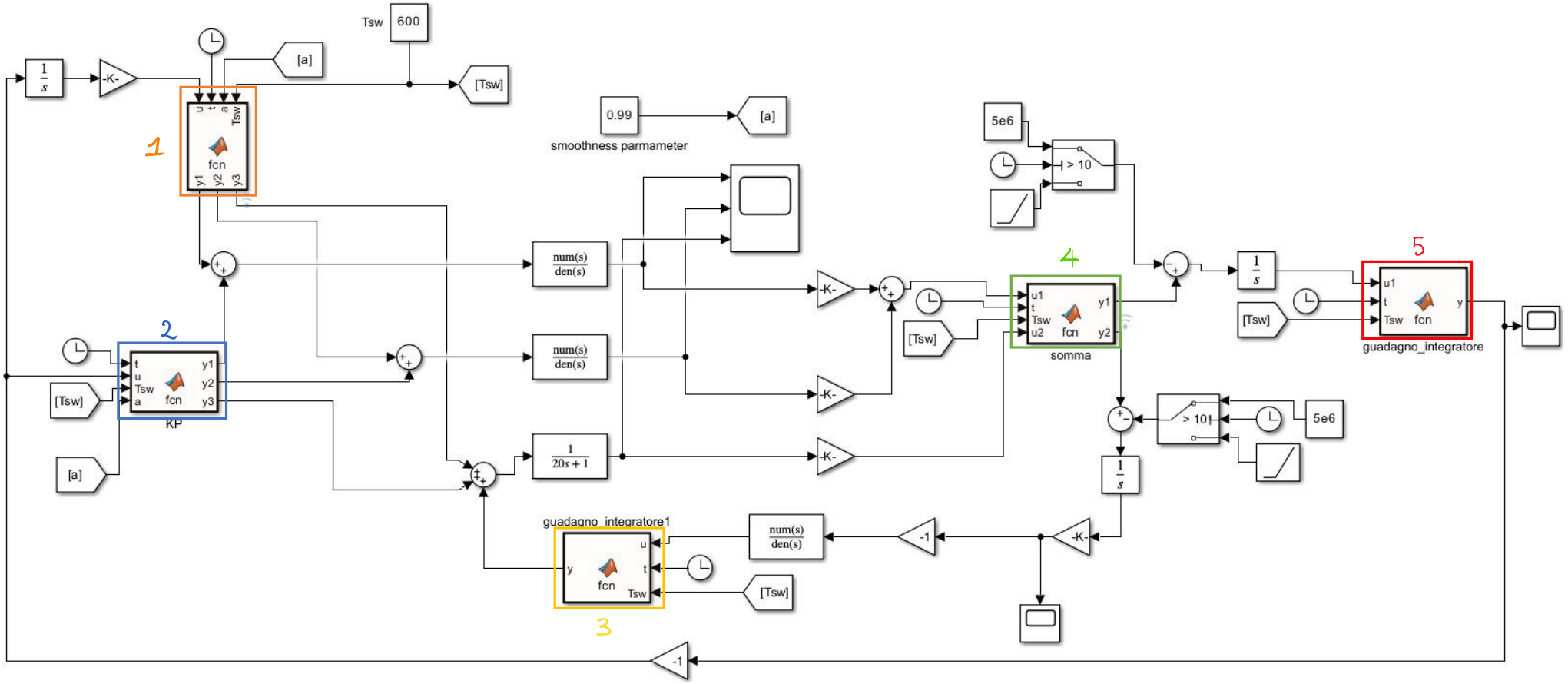
Tertiary control

Frequency of the grid



Configuration Switch

Control scheme



SIMULINK implementation of the configuration

Configuration Switch

From A to B

```
function [y1, y2,y3] = fcn(u, t, a, Tsw)
 if t>Tsw
    y1=(0.4*(1-a^(t-Tsw))+1/3*a^(t-Tsw))*u;
    y2=(0.2*(1-a^(t-Tsw))+2/3*a^(t-Tsw))*u;
    y3=(0.4*(1-a^(t-Tsw)))*u;
  else
    y1=1/3*u;
    y2=2/3*u;
    y3=0;
```

1

```
function [y1, y2,y3] = fcn( t, u, Tsw, a)
if t>Tsw
    y1=(0.91*(1-a^(t-Tsw))+0.014*a^(t-Tsw))*u;
    y2=(4.773*(1-a^(t-Tsw))+3.686*a^(t-Tsw))*u;
    y3=(0.182*(1-a^(t-Tsw)))*u;
else
    y1=0.014*u;
    y2=3.686*u;
    y3=0;
```

2

```
function y = fcn(u,t, Tsw)
if t>Tsw
    y=0;
else
    y=u;
```

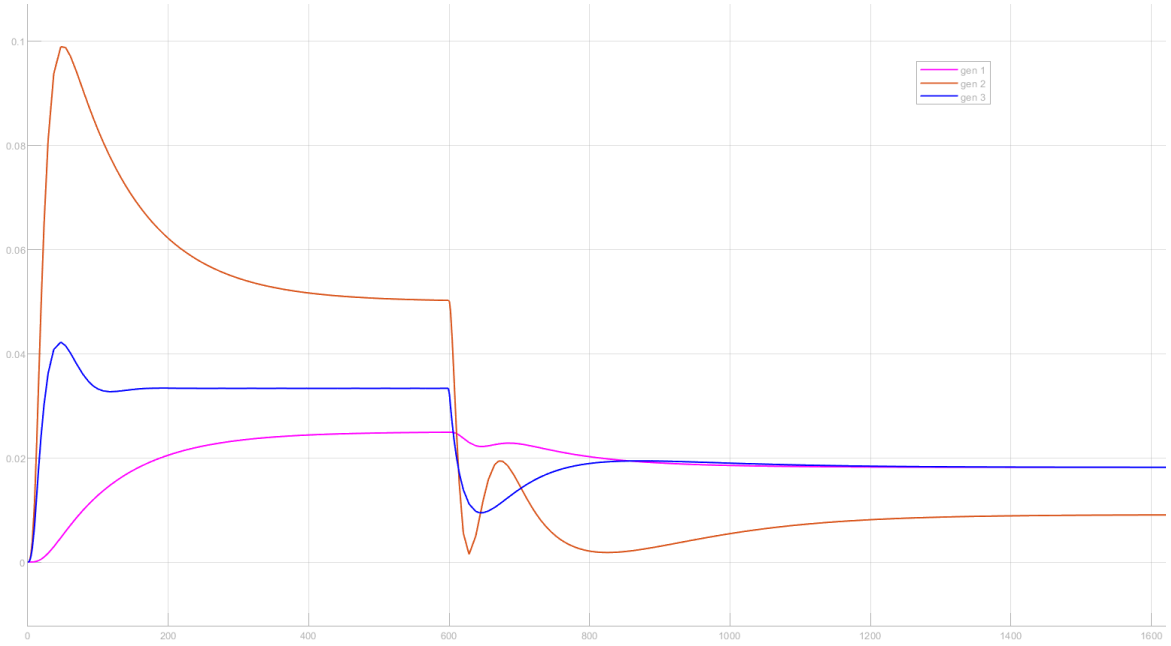
3

```
function [y1, y2] = fcn(u1, t, Tsw, u2)
if t>Tsw
    y1=(u1+u2);
    y2=0;
else
    y1=u1;
    y2=u2;
```

4

```
function y = fcn(u1, t, Tsw)
if t>Tsw
    y=1/(40e3*314^2)*u1;
else
    y=1/(30e3*314^2)*u1;
```

5



Normalized generators output

Configuration Switch

From B to A

```
function [y1,y2,y3] = fcn(u, t, a, Tsw)
 if t<Tsw
    y3=0.4*u;
    y2=0.2*u;
    y1=0.4*u;
  else
    y1=(1/3*(1-a^(t-Tsw))+0.4*a^(t-Tsw))*u;
    y2=(2/3*(1-a^(t-Tsw))+0.2*a^(t-Tsw))*u;
    y3=0.4*a^(t-Tsw)*u;
```

1

```
function [y1, y2,y3] = fcn(u, t, Tsw, a)
if t<Tsw
    y1=0.91*u;
    y2=4.773*u;
    y3=0.182*u;
else
    y1=(0.014*(1-a^(t-Tsw))+0.91*a^(t-Tsw))*u;
    y2=(3.686*(1-a^(t-Tsw))+4.773*a^(t-Tsw))*u;
    y3=0.182*a^(t-Tsw)*u;
```

2

```
function y = fcn(u,t, Tsw)
if t<Tsw
    y=0;
else
    y=u;
```

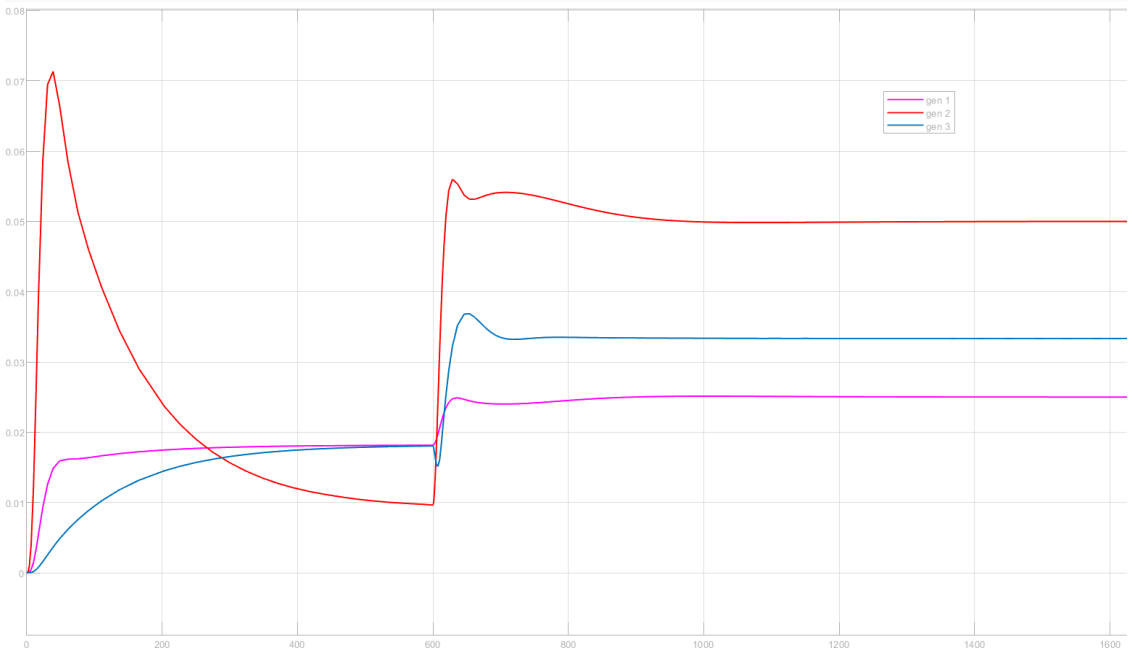
3

```
function [y1, y2] = fcn(u1, t, Tsw, u2, a)
if t<Tsw
    y1=(u1+u2);
    y2=0;
else
    y1=u1;
    y2=u2;
```

4

```
function y = fcn(u1, t, Tsw)
if t<Tsw
    y=1/(40e3*314^2)*u1;
else
    y=1/(30e3*314^2)*u1;
```

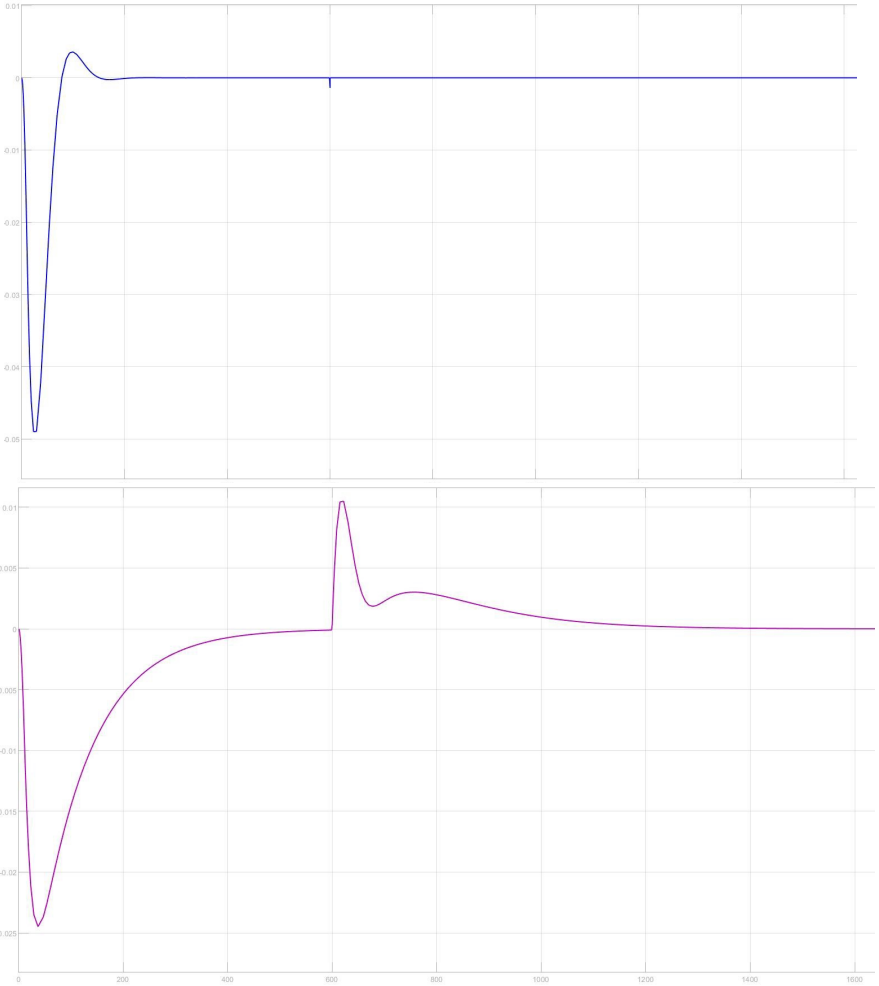
5



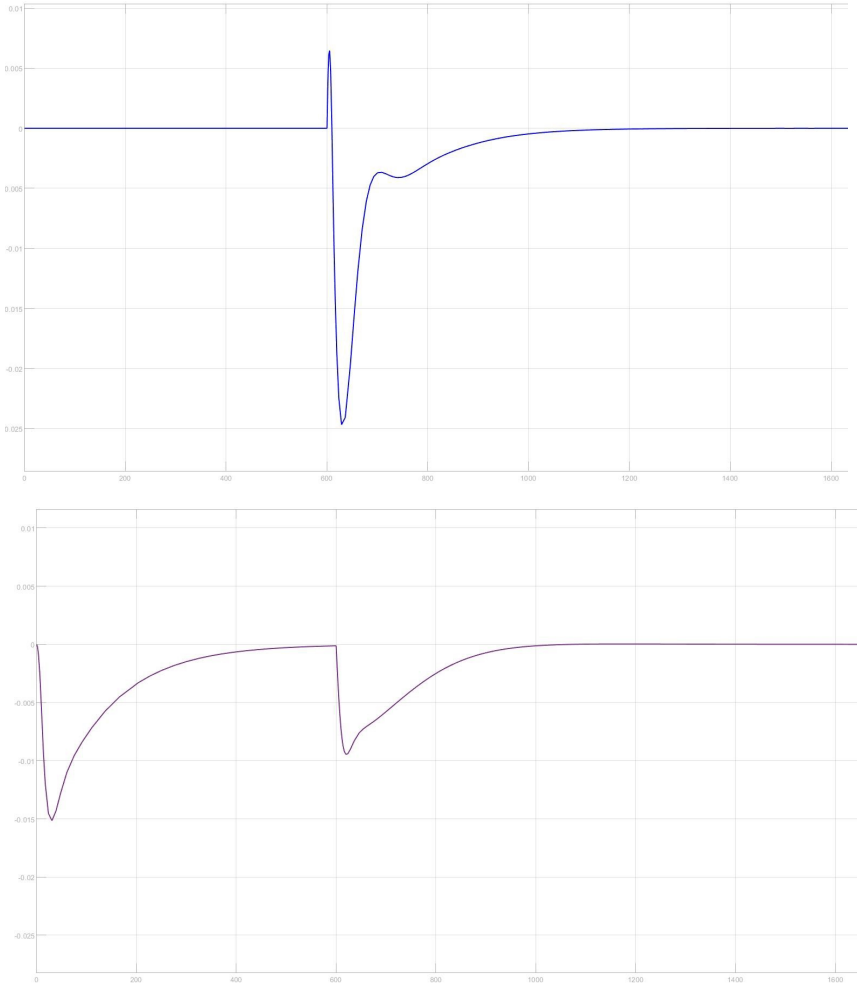
Normalized generators output

Configuration Switch Simulations

From A to B



From B to A



Islanded generator

Generators Grid