Compensator Realizations

$$G_{PID}(z;\boldsymbol{K}) \triangleq K_p + \frac{K_i}{1-z^{-1}} + K_d(1-z^{-1}), \qquad \boldsymbol{K} \triangleq [K_p, K_i, K_d]^T.$$ 6.5

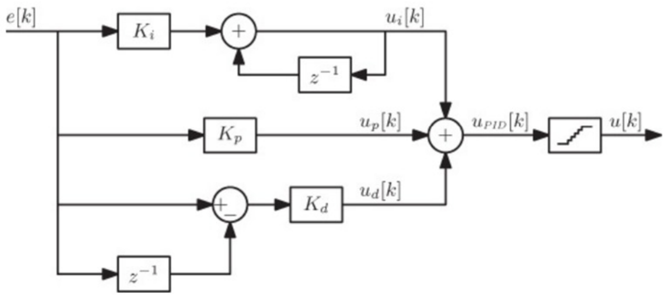


Figure 6.2 Parallel realization of a digital PID compensator.

$$G_{PID}(z;\boldsymbol{b}) \triangleq \frac{b_0+b_1z^{-1}+b_2z^{-2}}{1-z^{-1}}, \qquad \boldsymbol{b} \triangleq [b_0, b_1, b_2]^T.$$ 6.6

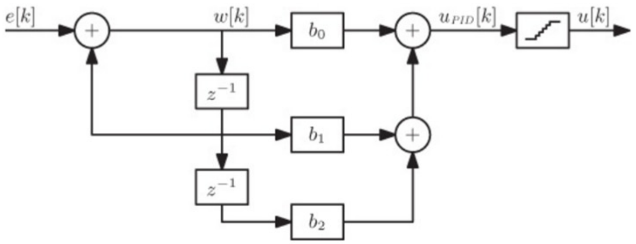


Figure 6.3 Direct realization of a digital PID compensator.

$$G_{PID}(z;\mathbf{c}) \triangleq \frac{K}{1-z^{-1}}\left(1+c_{z_1}z^{-1}\right)\left(1+c_{z_2}z^{-1}\right), \qquad \mathbf{c} \triangleq [K, c_{z_1}, c_{z_2}]^T,$$ 6.8

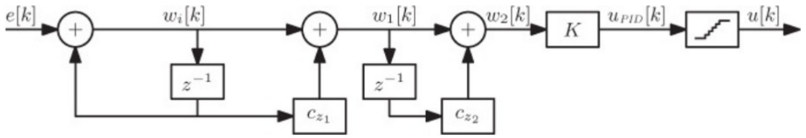


Figure 6.4 Cascade realization of a digital PID compensator.

Parallel Realization

$$u_p[k] = K_p e[k],$$
$$u_i[k] = u_i[k-1] + K_i e[k],$$
$$u_d[k] = K_d(e[k] - e[k-1]),$$
$$u[k] = u_p[k] + u_i[k] + u_d[k]. \quad \text{4.10}$$

The compensator coefficients K_p, K_i, and K_d are the proportional, integral, and derivative gains, respectively.

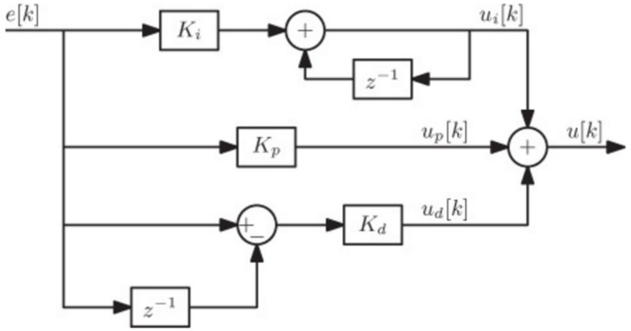
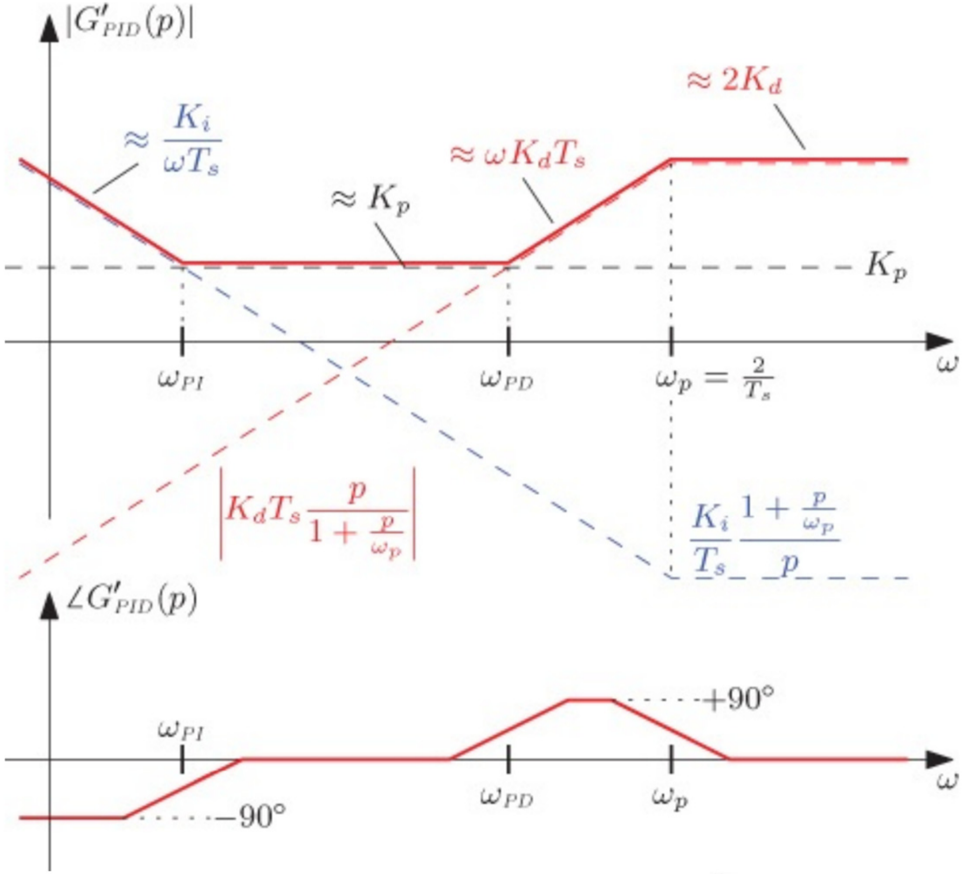


Figure 4.3 Block diagram of a digital PID compensator in the parallel form.

$$G_{PID}(z) = K_p + \frac{K_i}{1-z^{-1}} + K_d(1-z^{-1}).$$

$$G'_{PID}(p) = \underbrace{K_p}_{\text{Proportional term}} + \underbrace{\frac{K_i}{T_s}\frac{1+\frac{p}{\omega_p}}{p}}_{\text{Integral term}} + \underbrace{K_d T_s \frac{p}{1+\frac{p}{\omega_p}}}_{\text{Derivative term}},$$



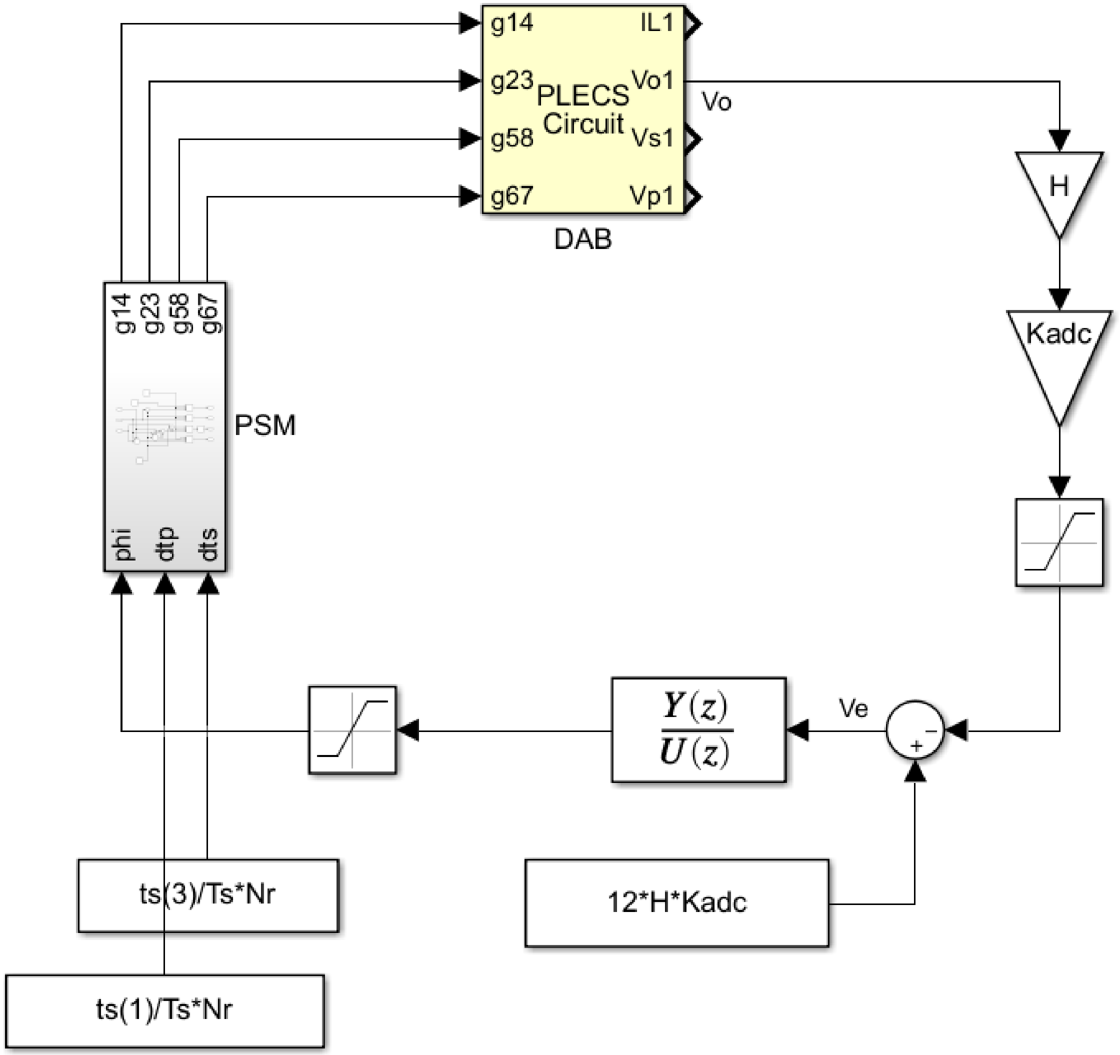
$$G'_{PID}(p) = \underbrace{G'_{PI\infty}\left(1+\frac{\omega_{PI}}{p}\right)}_{PI}\underbrace{G'_{PD0}\frac{1+\frac{p}{\omega_{PD}}}{1+\frac{p}{\omega_p}}}_{PD},$$

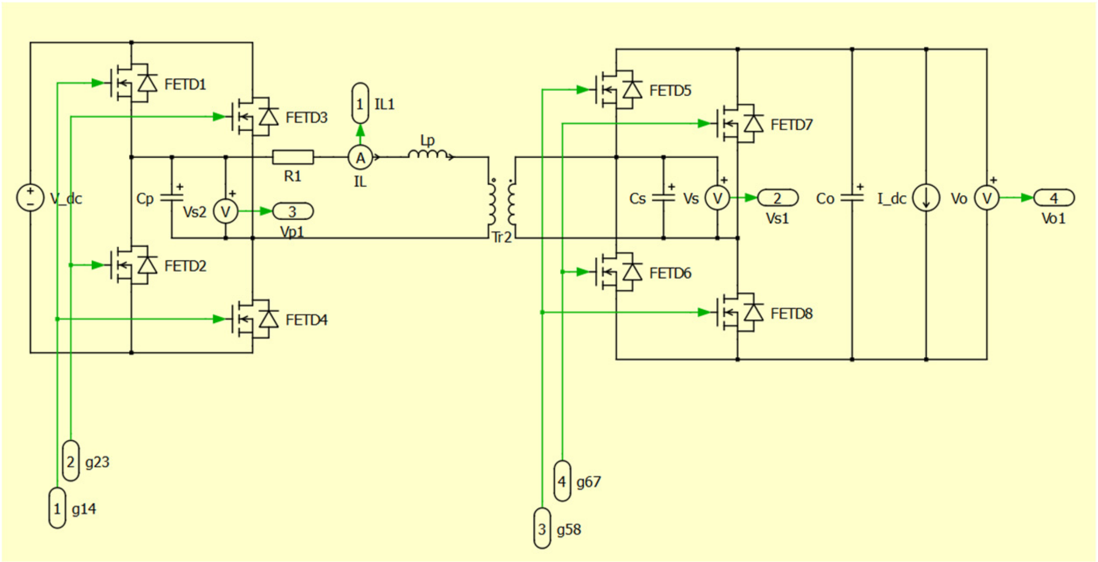
$$K_p = G'_{PI\infty}G'_{PD0}\left(1+\frac{\omega_{PI}}{\omega_{PD}}-\frac{2\omega_{PI}}{\omega_p}\right),$$

$$K_i = 2G'_{PI\infty}G'_{PD0}\frac{\omega_{PI}}{\omega_p},$$

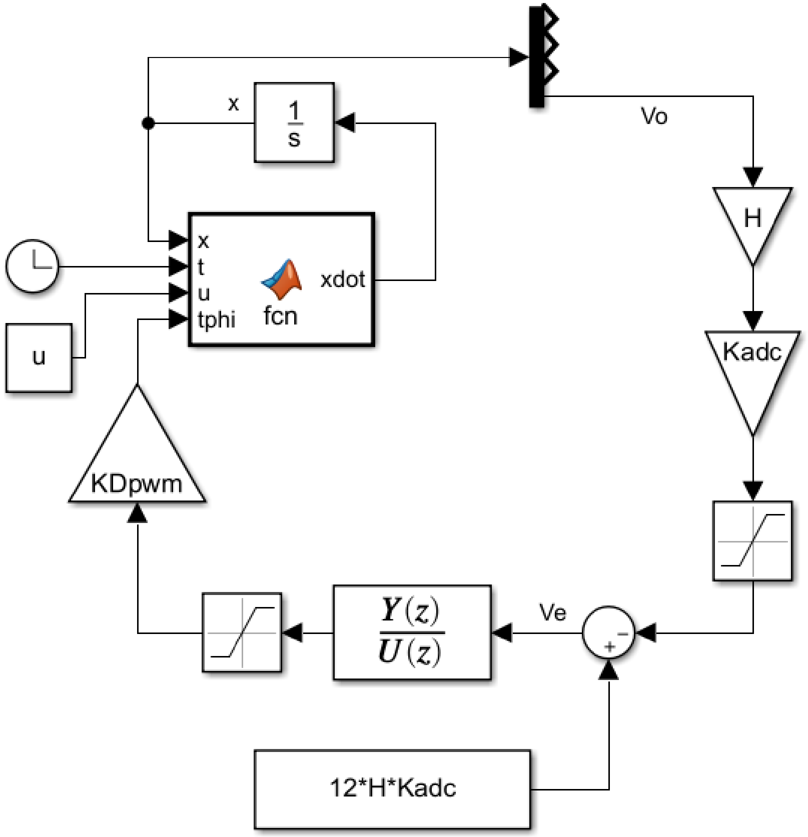
$$K_d = \frac{G'_{PI\infty}G'_{PD0}}{2}\left(1-\frac{\omega_{PI}}{\omega_p}\right)\left(\frac{\omega_p}{\omega_{PD}}-1\right).$$

Simulation (Large Signal)



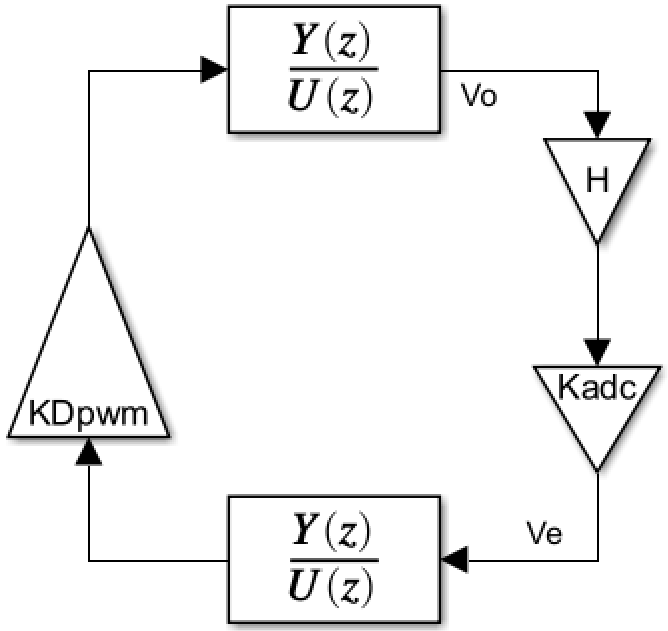


Alternative Simulation (Large Signal)

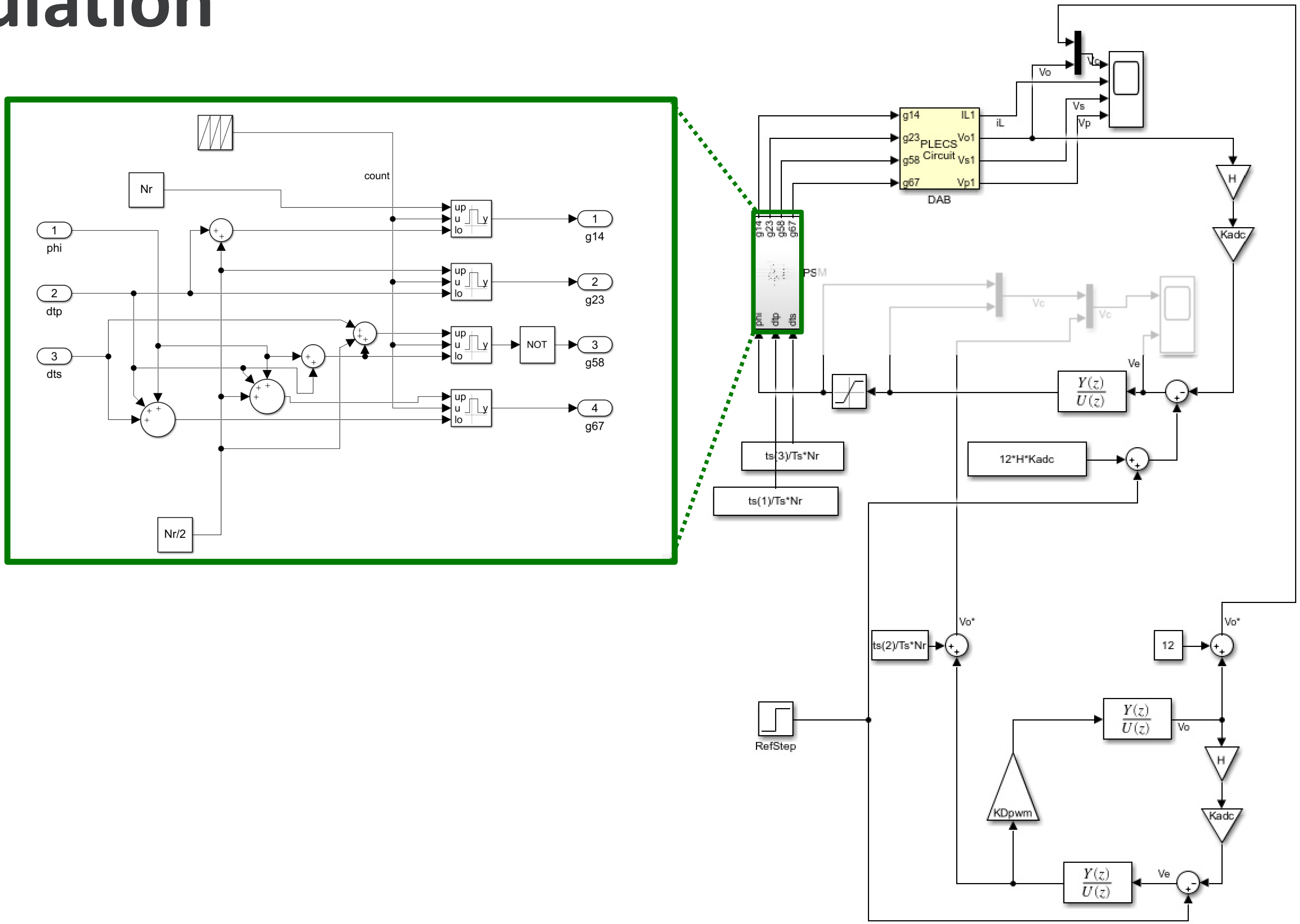


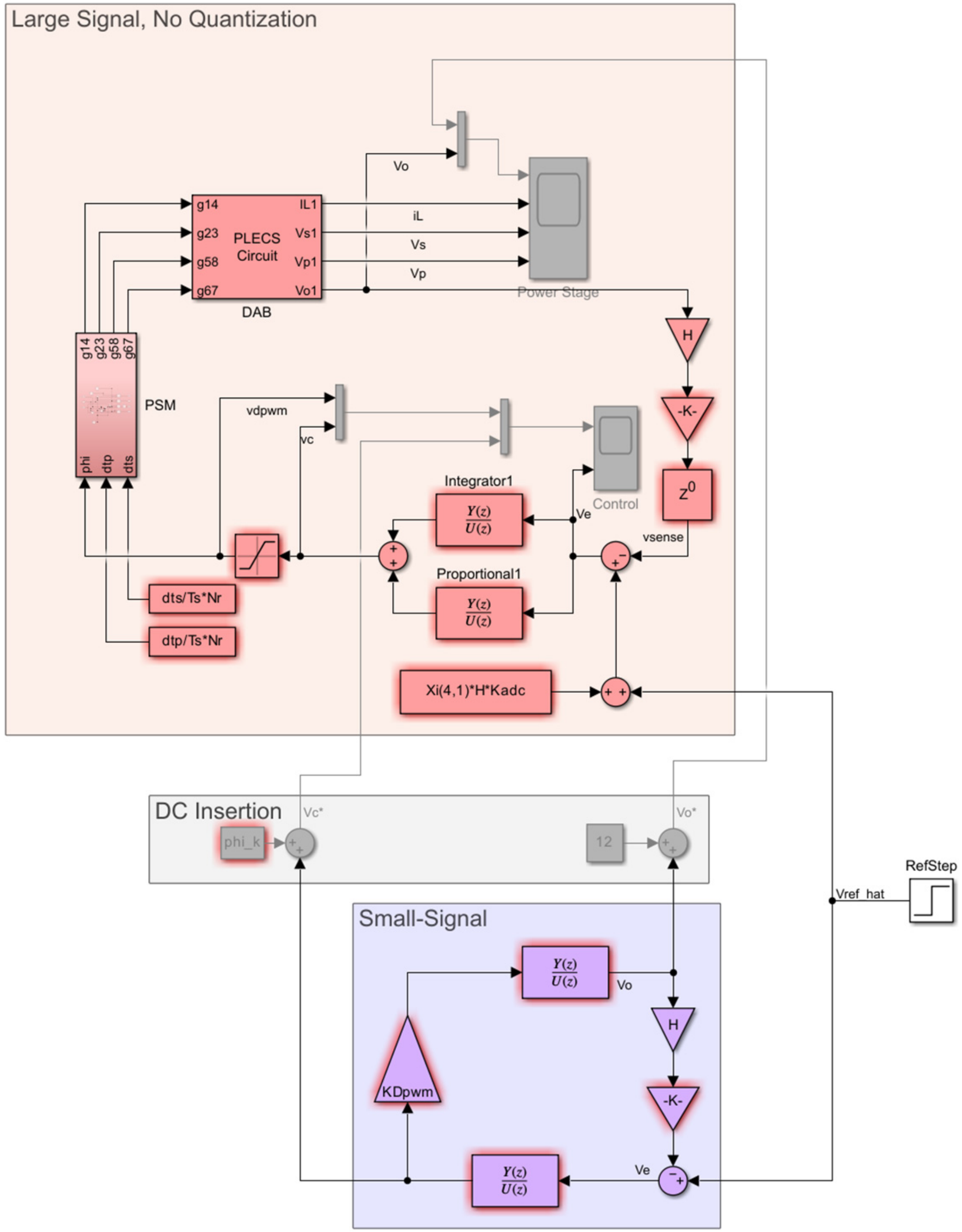

```
function xdot = fcn(x, t,
    u,tphi, A1, A2, B1, B2, Ts)

tp = mod(t,Ts);

if(tp<tphi)
    xdot = A1*x + B1*u;
else
    xdot = A2*x+B2*u;
end
```

Simulation (Small Signal)

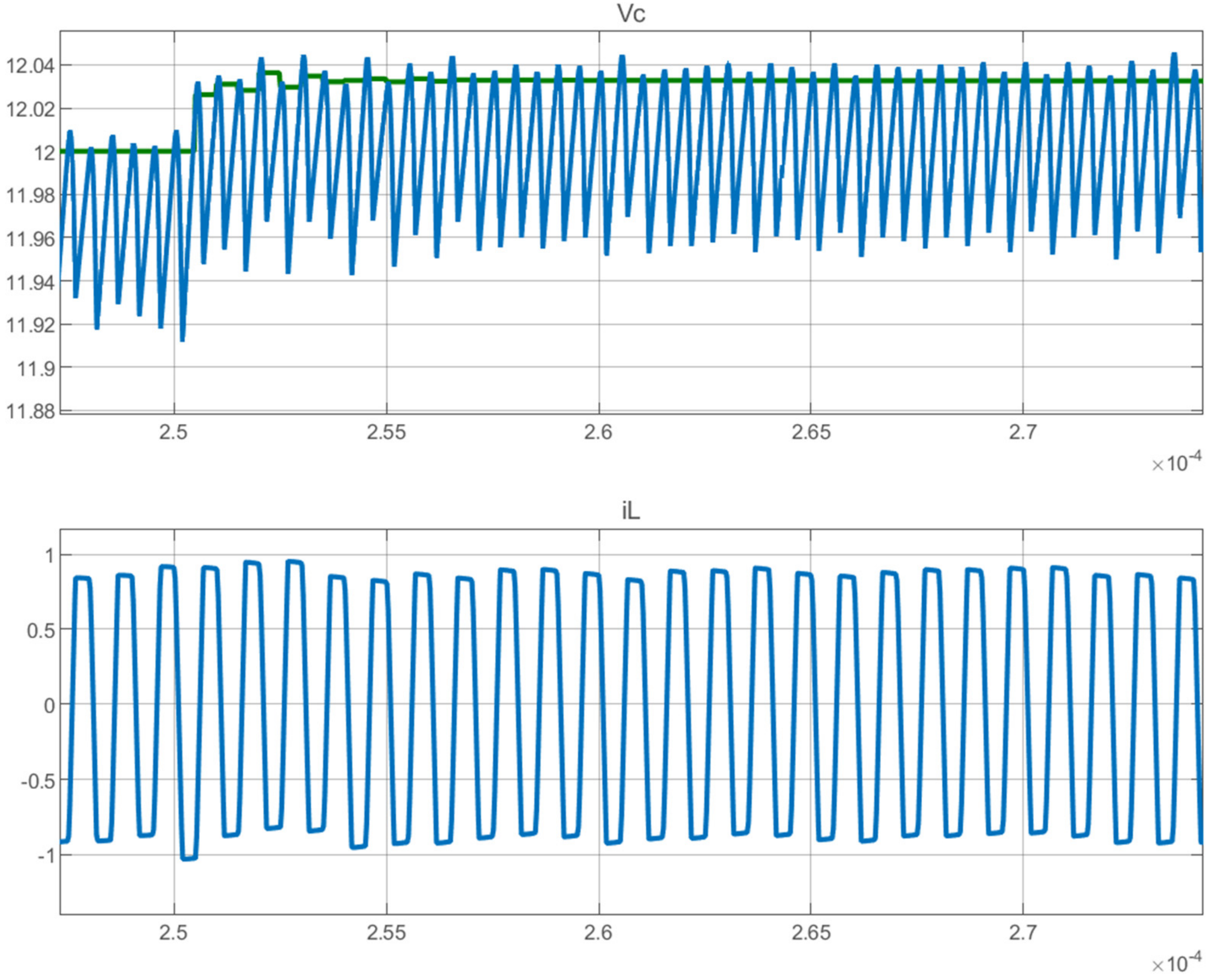


Simulation

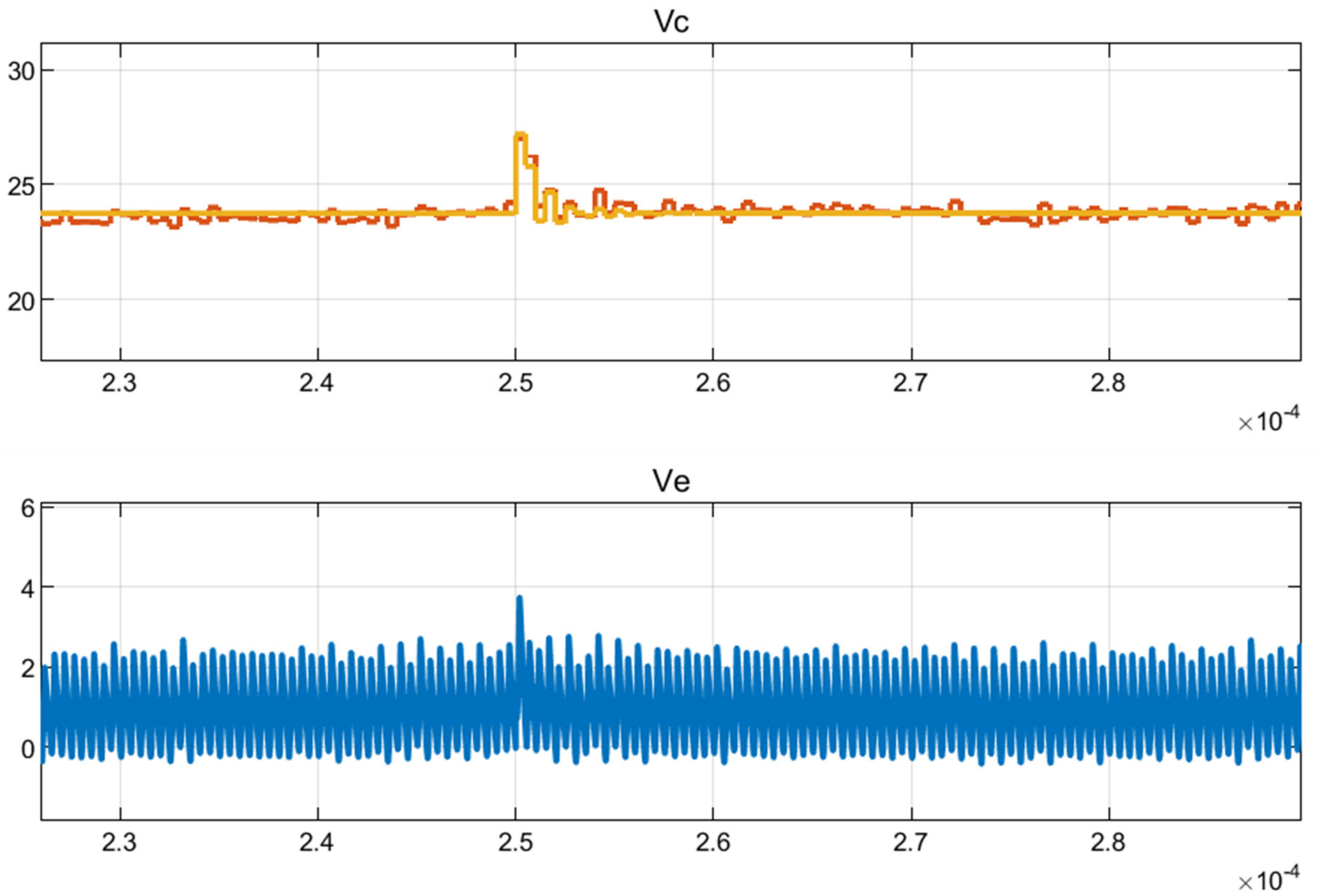

count
Nr
phi
dtp
dts
up
u
lo
y
g14
g23
g58
g67
NOT
Nr/2
PLECS Circuit
DAB
iL
IL1
Vo1
Vs1
Vp1
Vo
Vs
Vp
PSM
H
Kadc
Ve
12*H*Kadc
ts(3)/Ts*Nr
ts(1)/Ts*Nr
ts(2)/Ts*Nr
Vo*
12
RefStep
KDpwm


Large Signal, No Quantization
Vo
g14
g23
g58
g67
PLECS Circuit
IL1
Vs1
Vp1
Vo1
iL
Vs
Vp
DAB
Power Stage
H
PSM
phi
dtp
dts
vdpwm
vc
-K-
Control
Integrator1
Ve
vsense
Proportional1
dts/Ts*Nr
dtp/Ts*Nr
Xi(4,1)*H*Kadc
DC Insertion
Vc*
Vo*
phi_k
12
RefStep
Vref_hat
Small-Signal
Vo
H
KDpwm
-K-
Ve

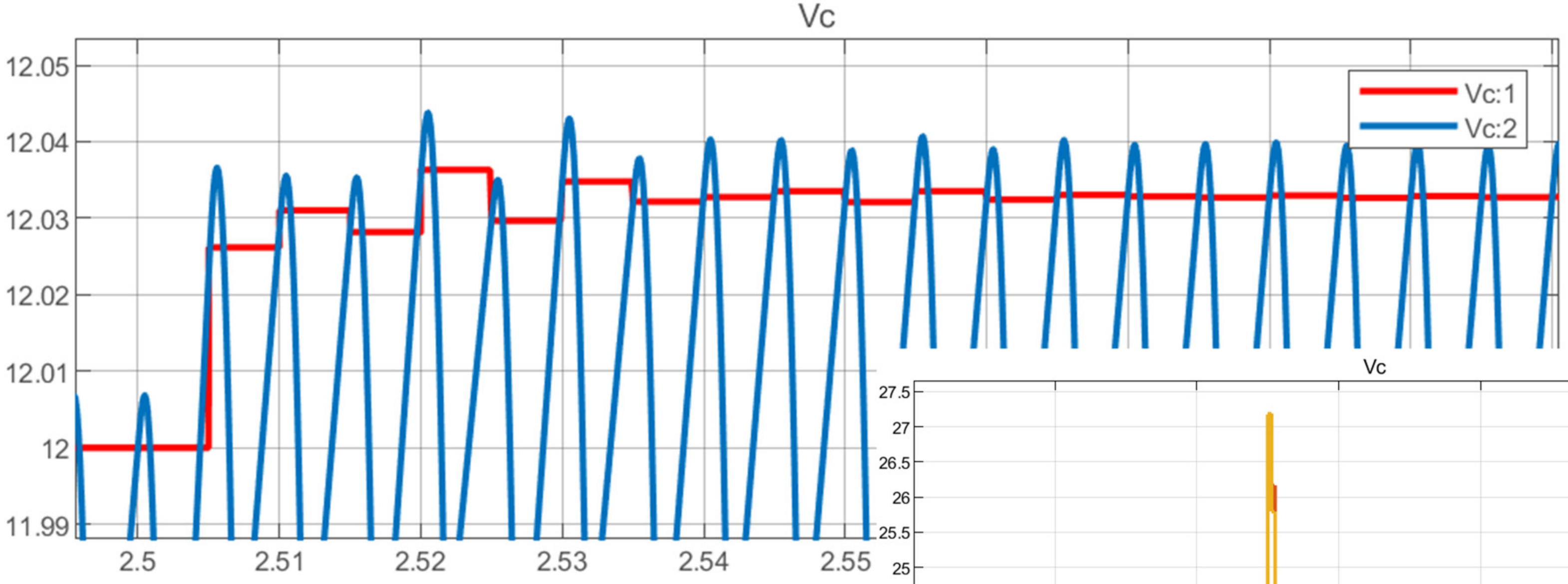
Simulation Results

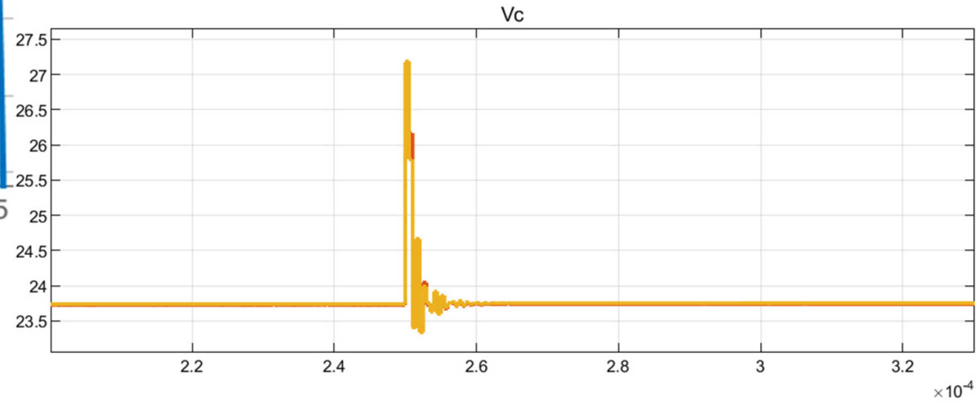


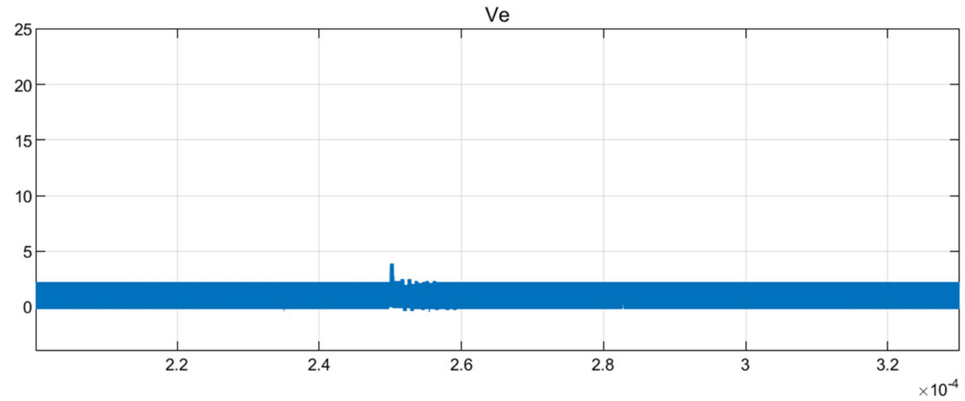
Simulation Results (cont)



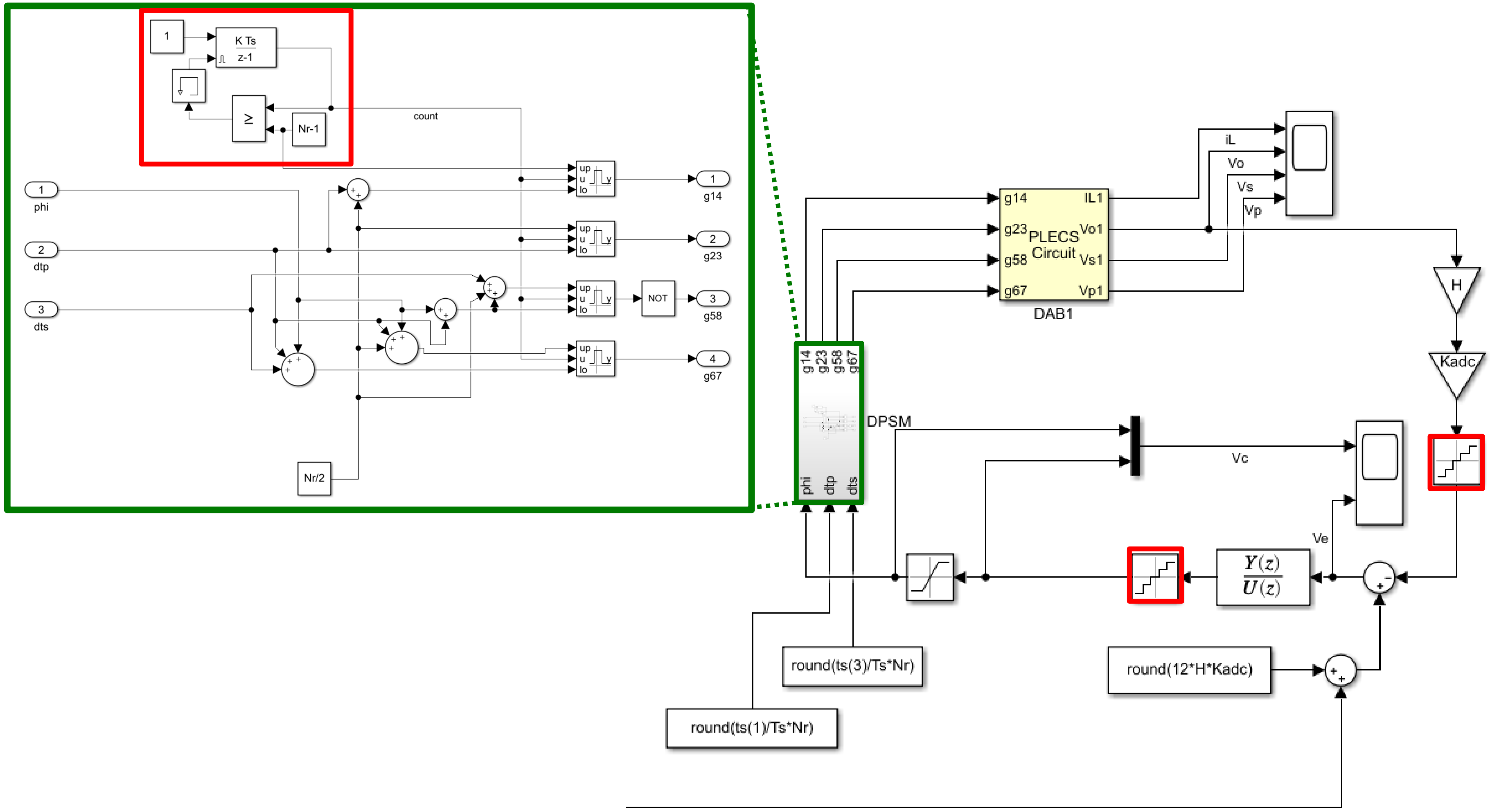
Simulation Results (max step 10ps)

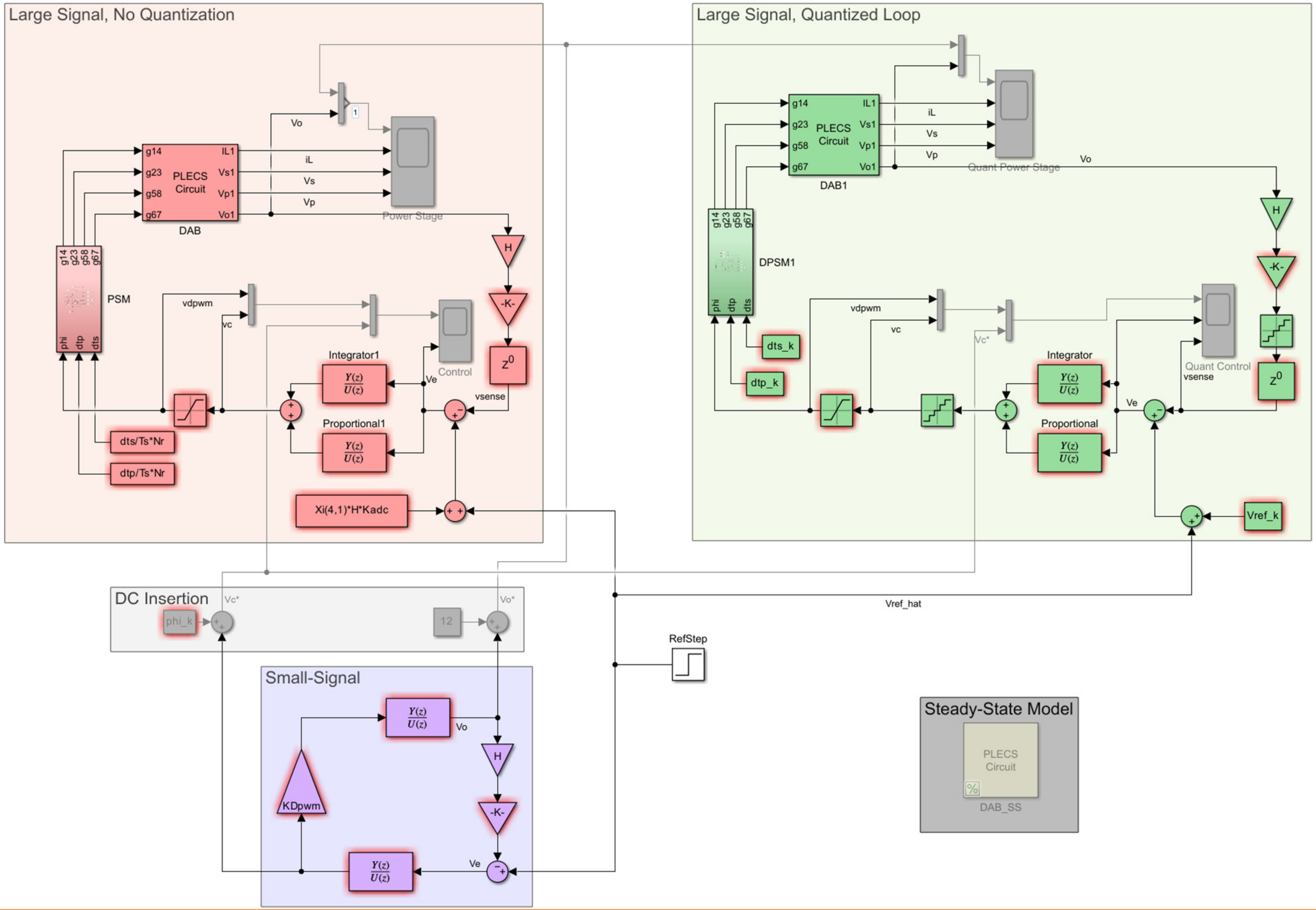




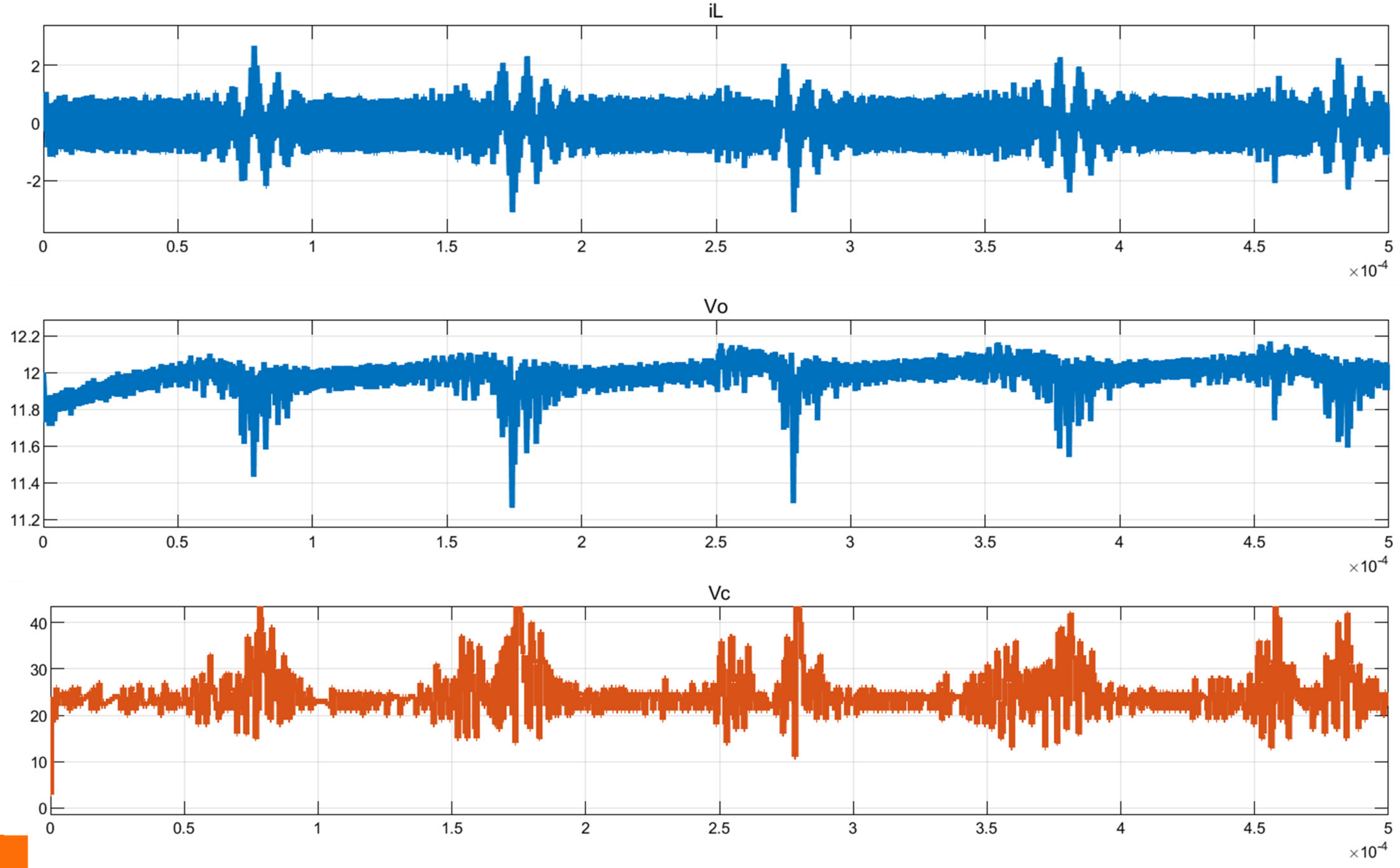


Quantization



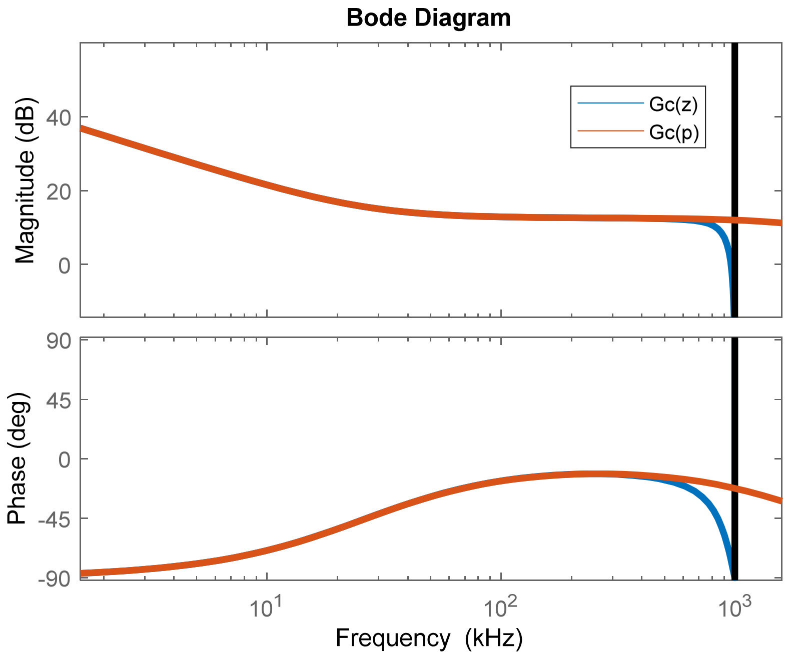

Large Signal, No Quantization
PLECS Circuit
DAB
g14
g23
g58
g67
IL1
Vs1
Vp1
Vo1
iL
Vs
Vp
Vo
Power Stage
PSM
phi
dtp
dts
vdpwm
vc
Control
Integrator1
Proportional1
Ve
vsense
H
-K-
dts/Ts*Nr
dtp/Ts*Nr
Xi(4,1)*H*Kadc
Large Signal, Quantized Loop
DAB1
DPSM1
Quant Power Stage
Quant Control
dts_k
dtp_k
Integrator
Proportional
Vref_k
Vc*
Vref_hat
DC Insertion
phi_k
12
Vo*
RefStep
Small-Signal
KDpwm
Steady-State Model
DAB_SS

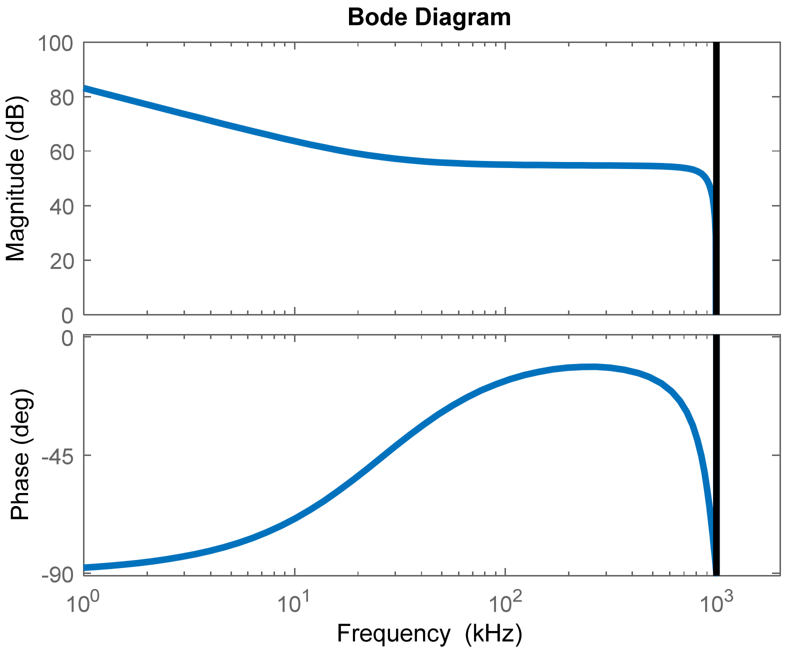
Simulation with Quantization



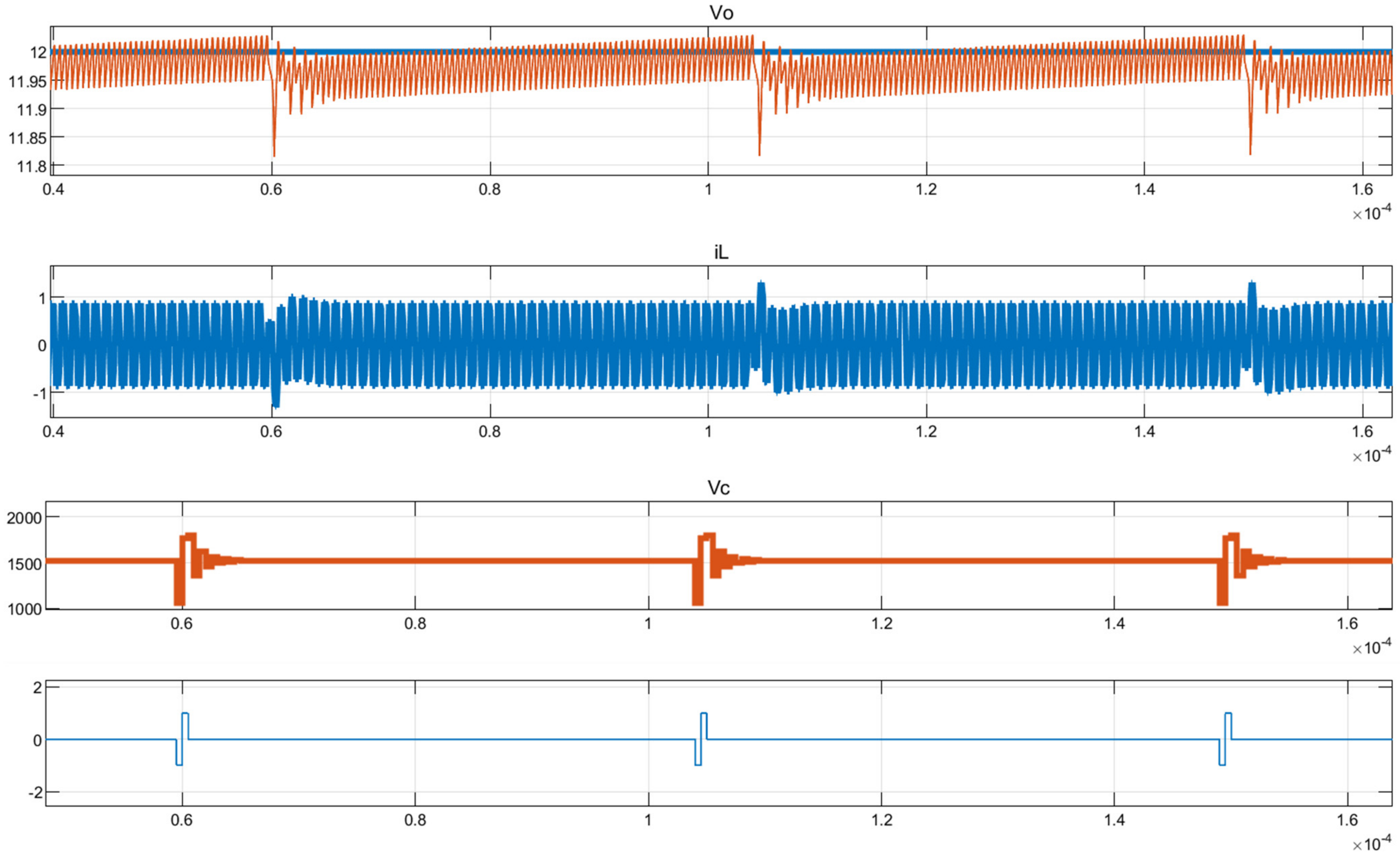
Quantization Impact

New Compensator



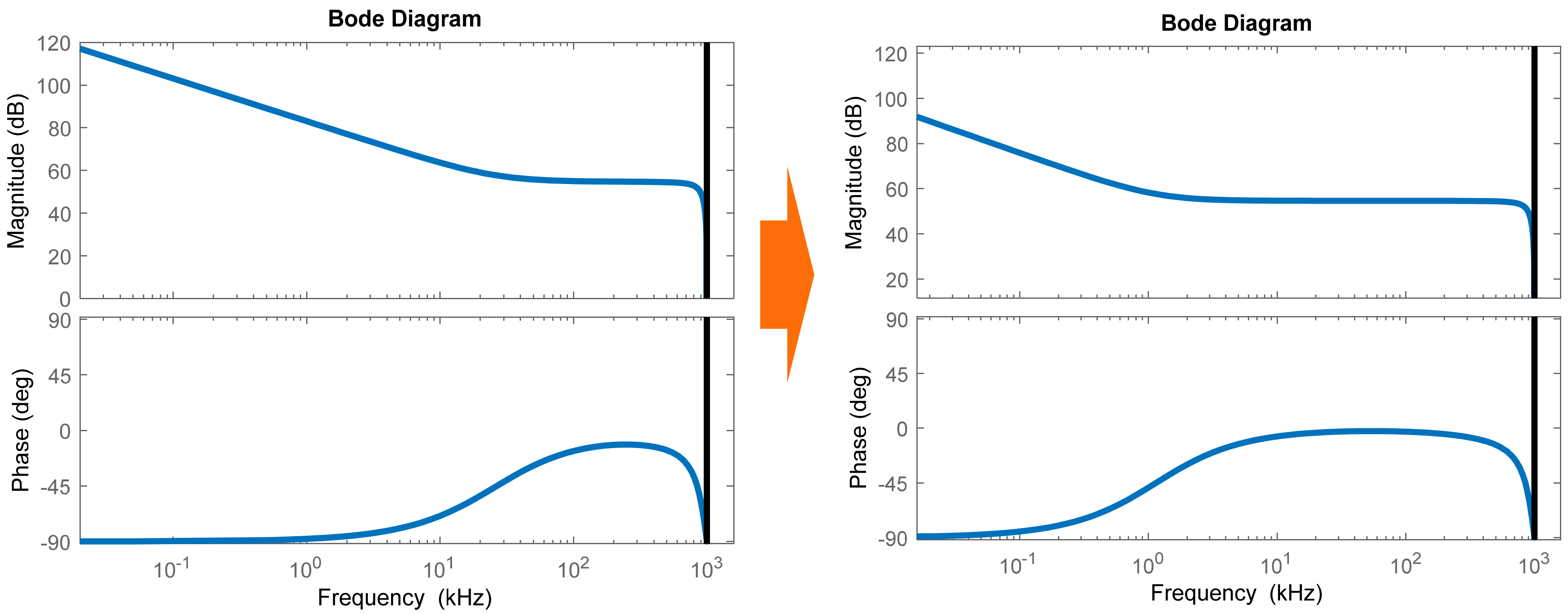


High Res Modulator

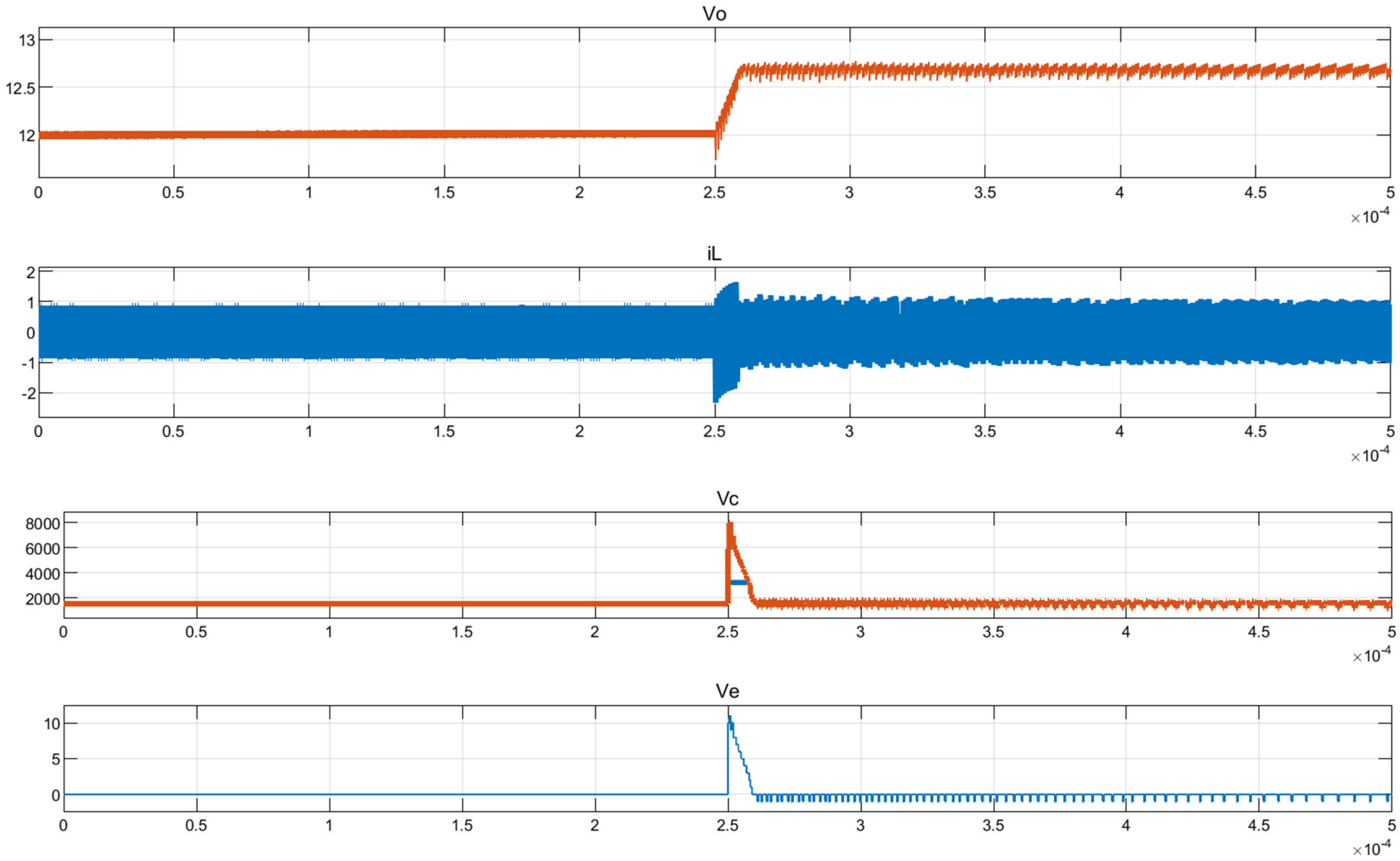


Integral Gain

New Compensator

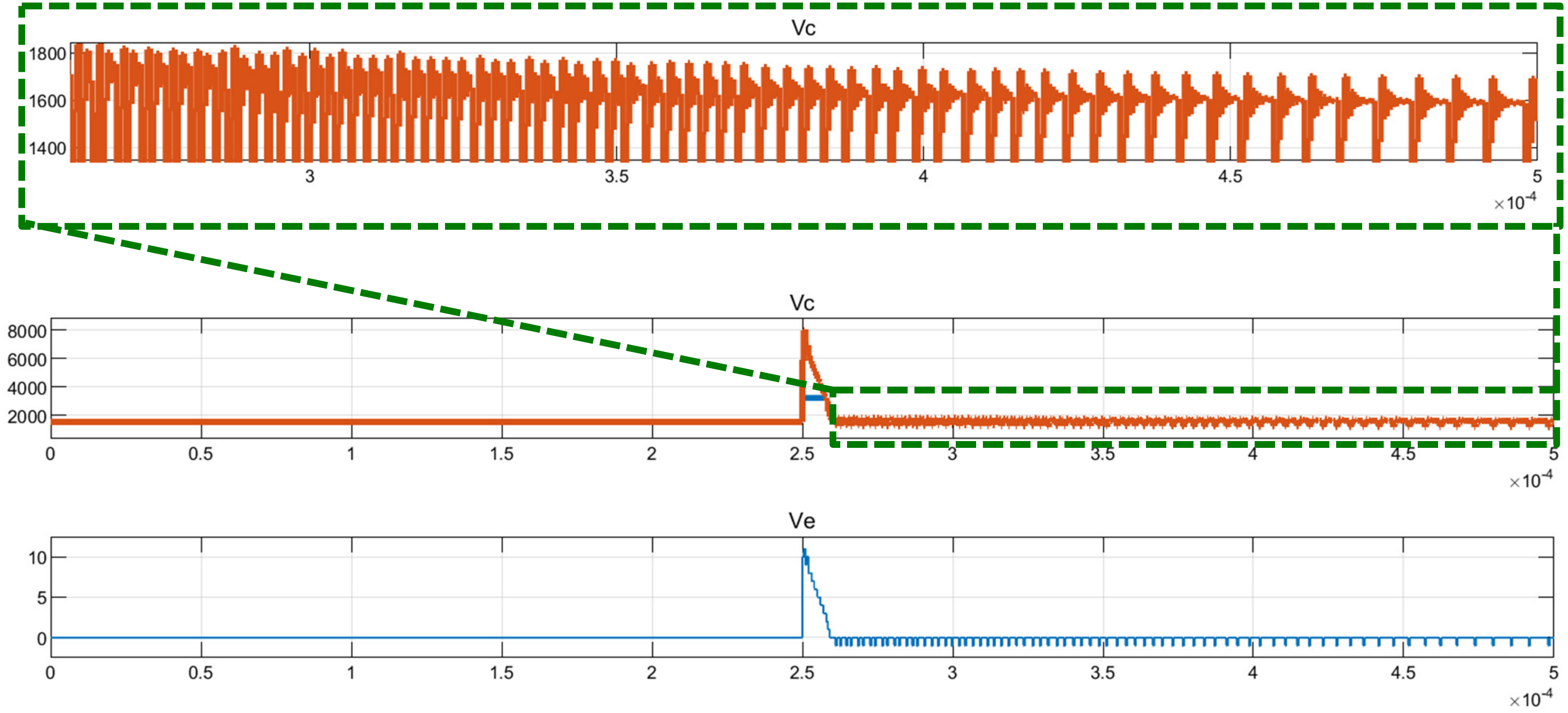


Low Ki



Vo
13
12.5
12
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
$\times 10^{-4}$
iL
2
1
0
-1
-2
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
$\times 10^{-4}$
Vc
8000
6000
4000
2000
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
$\times 10^{-4}$
Ve
10
5
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
$\times 10^{-4}$

Low Ki



Vc
1800
1600
1400
3
3.5
4
4.5
5
×10^-4
Vc
8000
6000
4000
2000
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
×10^-4
Ve
10
5
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
×10^-4