EE 458/533 – Power Electronics Controls

Final

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1 Conceptual Questions

1.1 Short Answer

Given a minimum phase system, you can derive the phase plot from the magnitude such that there is a 1-to-1 mapping. Phase is a function of $tan^{-1}(imag/real)$ and so the phase of each pole and zero can be determined.

1.2 Short Answer

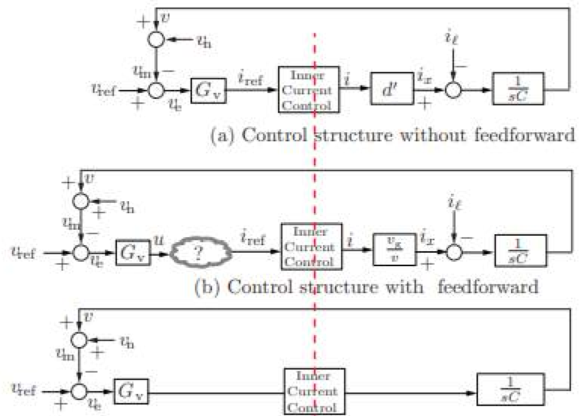
Adding a angle/speed sensor would provide a controller that actively cancels disturbances.

1.3 Short Answer

1.4 Short Answer

2 Boost Voltage Control

- The simulation duration is 30 ms and v_{ref} is fixed at 48 V, and $V_{\text{g}} = 24$ V.
- The load current is initialized at $i_\ell(0) = 2$ A. At $t = 15$ ms, i_ℓ changes from 2 A $\rightarrow$ 4 A.



(a) Control structure without feedforward

(b) Control structure with feedforward

(c) Simplified plant with feedforward

(a) **[10 Points]**: Implement a feed-forward in the voltage controller to remove the dependence on the load current (i_ℓ) and scalar gain (d') by following Figure 3. Since $v = v_{\text{g}}/d'$, we can use this substitution, $d' = v_{\text{g}}/v$ for feed-forward to avoid any potential divide-by-zero error in the simulation. Using Fig.3 (c), we deduce the open loop-gain to be

$$\ell_v(s) = G_v(s)\frac{1}{1+s\tau_{\text{i}}}\frac{1}{sC}. \tag{1}$$

You may use any method to choose your voltage controller gain. Choose a bandwidth (should be less than 1/10-th of the current controller bandwidth) and phase margin of your liking and tailor your design so that $k_{\text{p,v}}, k_{\text{i,v}}$ satisfy that. The only constraint we impose is that the controller should be of a proportional + integral type. With your PI controller, the closed-loop voltage response takes the following form

$$\frac{T_{\text{v}}}{1+T_{\text{v}}} = \frac{k_{\text{p,v}}s + k_{\text{i,v}}}{C\tau_{\text{i}}s^3 + Cs^2 + k_{\text{p,v}}s + k_{\text{i,v}}}. \tag{2}$$

Specify units of $k_{\text{p,v}}$ and $k_{\text{i,v}}$ (hint: use circuit intuition).

Create a single Bode plot overlaid with $T_{\text{i}}/(1+T_{\text{i}})$ and $T_{\text{v}}/(1+T_{\text{v}})$. Comment on the frequency ranges where $T_{\text{i}}/(1+T_{\text{i}}) \approx 1$ and $T_{\text{v}}/(1+T_{\text{v}}) \approx 1$ and how that relates to the speed of the current and voltage loops.

2.1 Implement Feed Forward

"Choose a bandwidth (should be less than 1/10 of the current controller bandwidth) and phase margin of your liking and tailor your design so that $k_{\mathrm{p,v}}, k_{\mathrm{i,v}}$ satisfy that. The only constraint we impose is that the controller should be of a proportional + integral type.

Clarification :

As you know the plant inversion formula for selecting k_p, k_i works as $k_p = wg * a, k_i = w_g * b$, if and only if the plant transfer is of the form $\dfrac{1}{as+b}$ For the voltage controller, the plant is not of the form 1/(as+b). We guarantee that there is a solution for this. These are the following solutions method you can use: Set a target bandwidth and phase margin that you want to achieve. Your controller is of the form $(k_p + (k_i/s))$, your plant transfer multiplied by this controller is given as the loop gain in equation (1). You will get two equations, one to satisfy the gain crossover freq, one for the phase margin. You may or may not approximate the plant by assuming $\dfrac{1}{1+s\tau_i} \approx 1$. Try trial-and-error approach to pick k_p, k_i gains by using bode plots. You could also not use PI controller. You may use your own choice of control, you might lose some points.

In general, if you don't think you can do the feed-forward, proceed without that. If you do not think you can do digital control, proceed only with analog control. If you think you cannot find a PI controller for your voltage controller, you can use a P control. We are going to give partial credit for every question. Give your best attempt."

T_i is the open loop gain of current controller

T_v is the open loop gain of voltage controller

Use switching frequency 10kHz

Parameter	Value
V_{in}	24V
V_{out}	48V
f_{sw}	10kHz
L	1.3mH
R_L	60mΩ
C	$250\mu F$
R	$10\mu F$

Specify units [https://www.infineon.com/dgdl/TLE7242G-TLE8242-2L]

	$k_{p,v}$	$k_{i,v}$
Units	$[V^{-1}]$	$[V^{-1}s^{-1}]$

Choose Bandwidth

	Current Controller $G_c(s)$	Voltage Controller $G_v(s)$)
Bandwidth	$\frac{1}{10}f_{sw} = 1000Hz$	$\frac{1}{10}G_c(s) = 100Hz$

Choose Phase Margin

Choose $\Phi_m = 60$ degrees.

Solve $|\ell_v(s)|= 1$ [Initially assume $\frac{1}{1+s\tau_i} \approx 1$]

$$\left|G_v(s)\frac{1}{1+s\tau_i}\frac{1}{sC}\right|_{\omega=\omega_{bw}=100Hz} = 1$$

$$\left|G_v(j\omega_{bw})\frac{1}{1+j\omega_{bw}\tau_i}\frac{1}{j\omega_{bw}C}\right| = 1$$

$$\left|k_{p,v} + \frac{k_{i,v}}{j\omega_{bw}}\right| \cdot \left|\frac{1}{1+j\omega_{bw}\tau_i}\right| \cdot \left|\frac{1}{j\omega_{bw}C}\right| = 1$$

$$\left|\frac{j\omega_{bw}k_{p,v} + k_{i,v}}{j\omega_{bw}}\right| \cdot \left|\frac{1}{1+j\omega_{bw}\tau_i}\right| \cdot \left|\frac{1}{j\omega_{bw}C}\right| = 1$$

$$\left|\frac{j\omega_{bw}k_{p,v} + k_{i,v}}{j\omega_{bw}}\right| \cdot 1 \cdot \left|\frac{1}{j\omega_{bw}C}\right| = 1$$

$$\left[\frac{\sqrt{(\omega_{bw}k_{p,v})^2 + k_{i,v}^2}}{\omega_{bw}}\right] \cdot \left[\frac{1}{\omega_{bw}C}\right] = 1$$

$$\sqrt{(\omega_{bw}k_{p,v})^2 + k_{i,v}^2} = \omega_{bw}^2 C$$

$$(\omega_{bw}k_{p,v})^2 + k_{i,v}^2 = \omega_{bw}^4 C^2$$

Solve $\angle \ell_v(s) = -\pi + \Phi_m$.

Current controller pole located at $s = \dfrac{1}{\tau_i} = 1000Hz$.

Voltage controller has max bandwidth of 100Hz.

Thus, $G_c(s)$ has zero phase contribution to the voltage controller.

$$\angle\left[k_{p,v} + \frac{k_{i,v}}{j\omega_{bw}}\right] + \angle\left[\frac{1}{1 + j\omega_{bw}\tau_i}\right] + \angle\left[\frac{1}{j\omega_{bw}C}\right] = -\pi + \Phi_m$$

$$\angle\left[k_{p,v} + \frac{k_{i,v}}{j\omega_{bw}}\right] + 0 - \frac{\pi}{2} = -\pi + \frac{\pi}{3}$$

$$\angle\left[k_{p,v} - j\frac{k_{i,v}}{\omega_{bw}}\right] = -\frac{\pi}{6}$$

$$arctan\left(\frac{-k_{i,v}/\omega_{bw}}{k_{p,v}}\right) = -\frac{\pi}{6}$$

$$-\,arctan\left(\frac{k_{i,v}}{\omega_{bw}k_{p,v}}\right) = -\frac{\pi}{6}$$

$$-\left[\frac{\pi}{2} - arctan\left(\frac{\omega_{bw}k_{p,v}}{k_{i,v}}\right)\right] = -\frac{\pi}{6}$$

$$arctan\left(\frac{\omega_{bw}k_{p,v}}{k_{i,v}}\right) = \frac{\pi}{3}$$

Voltage Controller $k_{p,v}$ **and** $k_{i,v}$

	$k_{p,v}$	$k_{i,v}$
$G_v(s)$	0.136	49.35

Current Controller $k_{p,i}$ **and** $k_{i,i}$

	$k_{p,i}$	$k_{i,i}$
$G_c(s)$	8.17	377

Bode Plots

Plot $\dfrac{T_i}{1+T_i}$ and $\dfrac{T_v}{1+T_v}$

$$T_i(s) = (k_{p,i} + \frac{k_{i,i}}{s})\frac{1}{sC}$$

$$T_v(s) = (k_{p,v} + \frac{k_{i,v}}{s})\frac{1}{1+s\tau_i}\frac{1}{sC}$$

$$\frac{T_v}{1+T_v} = \frac{k_{p,v}s + k_{i,v}}{C\tau_i s^3 + Cs^2 + k_{p,v}s + k_{i,v}}$$

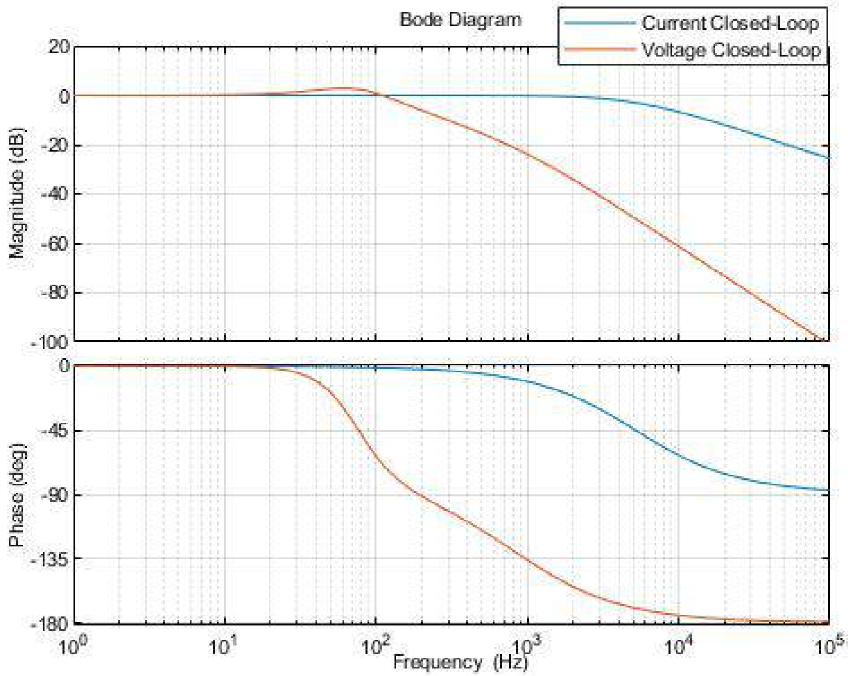


Figure 1: Boost Converter Frequency Responses

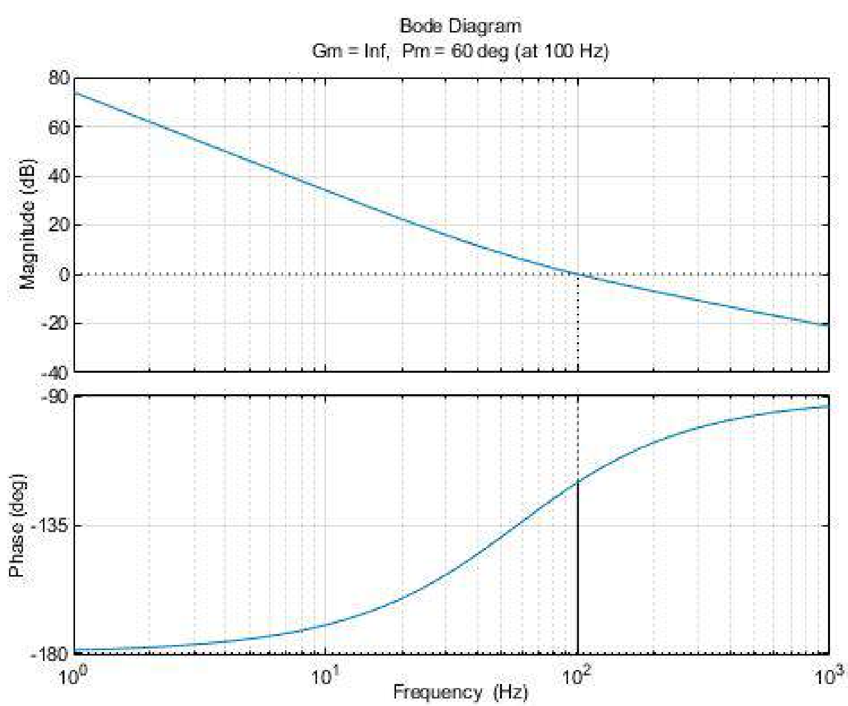


Figure 2: Voltage Controller Open Loop Response

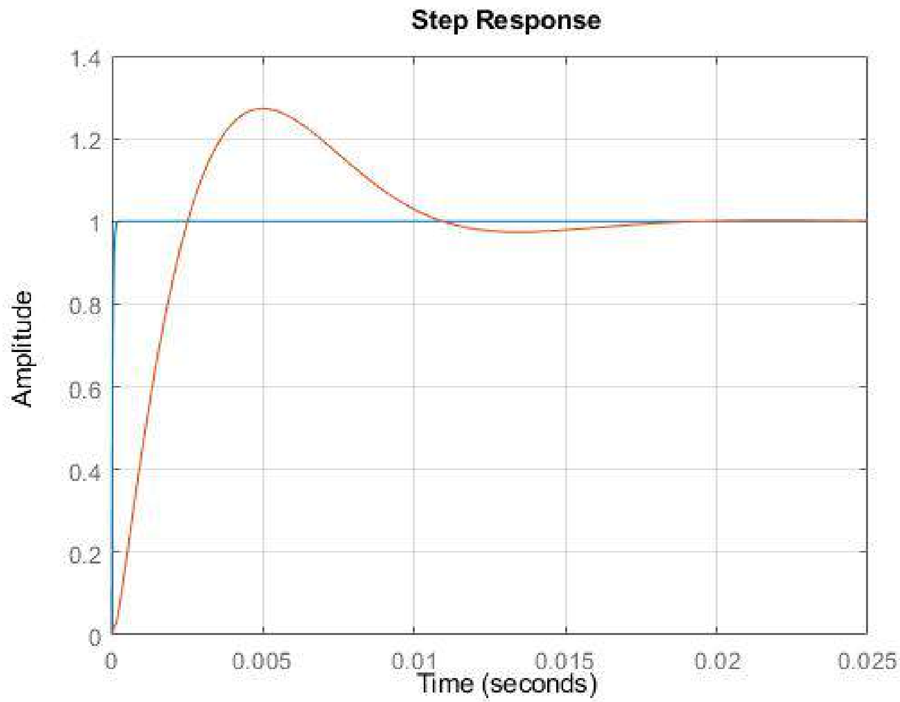


Figure 3: Voltage Controller Step Response

Comment on controller bandwidth-speed relationship

	Model	Frequency Range where $G(s) \approx 1$
Closed-Loop Current Controller	$\frac{T_i}{1+T_i}$	$f \leq 1kHz$
Closed-Loop Voltage Controller	$\frac{T_v}{1+T_v}$	$f \leq 100Hz$

The bandwidth of our controller tells us how fast it can respond to change. Since the bandwidth of the current controller is 10x the bandwidth of the voltage controller, it response much quicker to a sudden input change. A step response is provided to show this result.

Find settling time:

2.2 Solve Inductor Volt-Second and Capacitor Charge Balance Equations

Volt-Seconds

$$\langle v_L(t)\rangle = L\frac{d}{dt}\langle i(t)\rangle = \Big[\langle v_g(t)\rangle - \langle i(t)\rangle R_{on} - \langle v(t)\rangle d'(t)\Big]$$

$$V_L(t) = L\frac{d}{dt}I = V_g - IR_{on} - VD' = 0$$

$$VD' = V_g - IR_{on}$$

$$V = \frac{V_g - IR_{on}}{D'}\bigg|_{I=\frac{V}{D'R}}$$

$$V = \frac{V_g - \frac{V}{D'R}R_{on}}{D'}$$

$$V = \frac{V_g}{D'} - \frac{VR_{on}}{D'^2R}$$

$$V + \frac{VR_{on}}{D'^2R} = \frac{V_g}{D'}$$

$$V = \frac{V_g}{D'} \cdot \frac{1}{1 + \frac{R_{on}}{D'^2R}}$$

Charge Balance

$$\langle i_C(t)\rangle = C\frac{d}{dt}\langle v(t)\rangle = \left[\frac{-\langle v(t)\rangle}{R} + \langle i(t)\rangle d'(t)\right]$$

$$I_C(t) = C\frac{d}{dt}V = \frac{-V}{R} + ID' = 0$$

$$ID' = \frac{V}{R}$$

$$I = \frac{V}{D'R}$$

$$I = \frac{1}{D'R} \cdot \frac{V_g}{D'} \cdot \frac{1}{1 + \frac{R_{on}}{D'^2R}}$$

$$I = \frac{V_g}{D'^2R} \cdot \frac{1}{1 + \frac{R_{on}}{D'^2R}}$$

Solving for D'

$$
\begin{aligned}
V &= \frac{V_g - \dfrac{V}{D'R}R_{on}}{D'} \\
VD' &= V_g - \frac{V}{D'R}R_{on} \\
VD'^2 &= V_g D' - V\frac{R_{on}}{R} \\
VD'^2 - V_g D' + V\frac{R_{on}}{R} &= 0 \\
D' &= 0.4877
\end{aligned}
$$

Solving for I

$$
\begin{aligned}
I &= \frac{V}{D'R} \\
I &= \frac{V}{D'R} \\
I &= 9.842A
\end{aligned}
$$

An additional plot is added with duration of 50ms to show controller is stable.

2.3 Simulate the Dual-Loop System in Continuous Domain

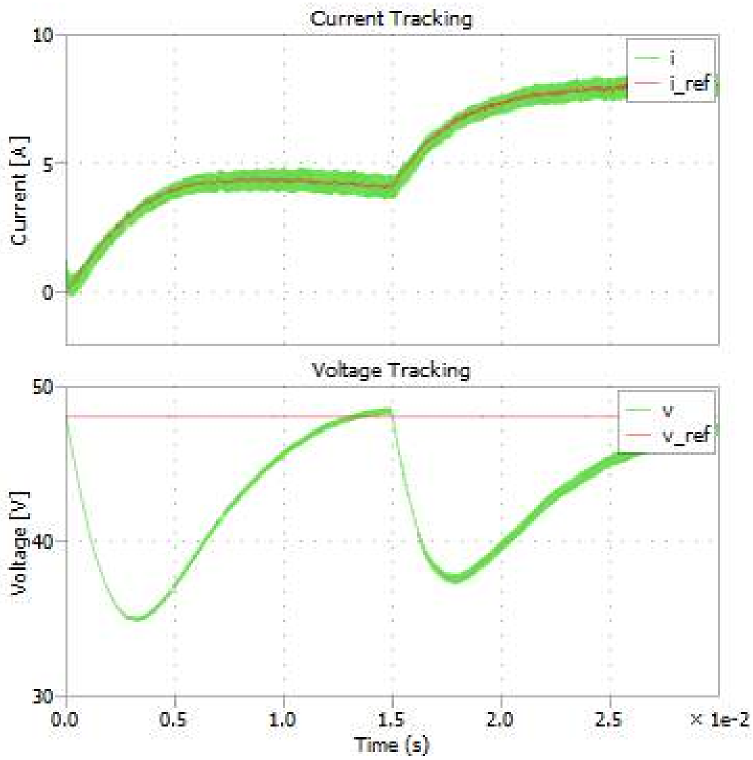


Figure 4: Continuous Time: Feed-Forward Controllers (30ms)

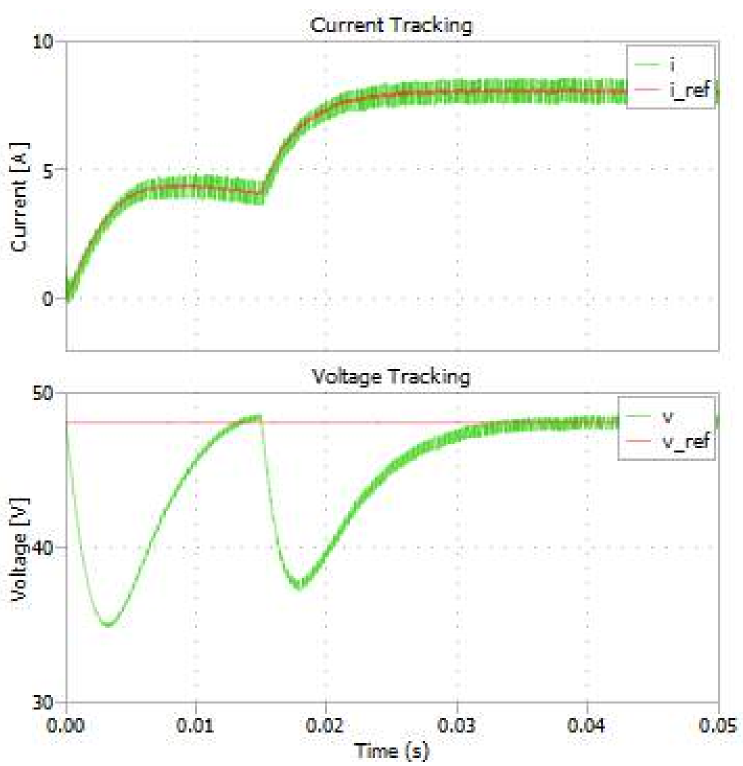


Figure 5: Continuous Time: Feed-Forward Controllers (50ms)

2.4 Simulate the Dual-Loop System with Discretized Controller

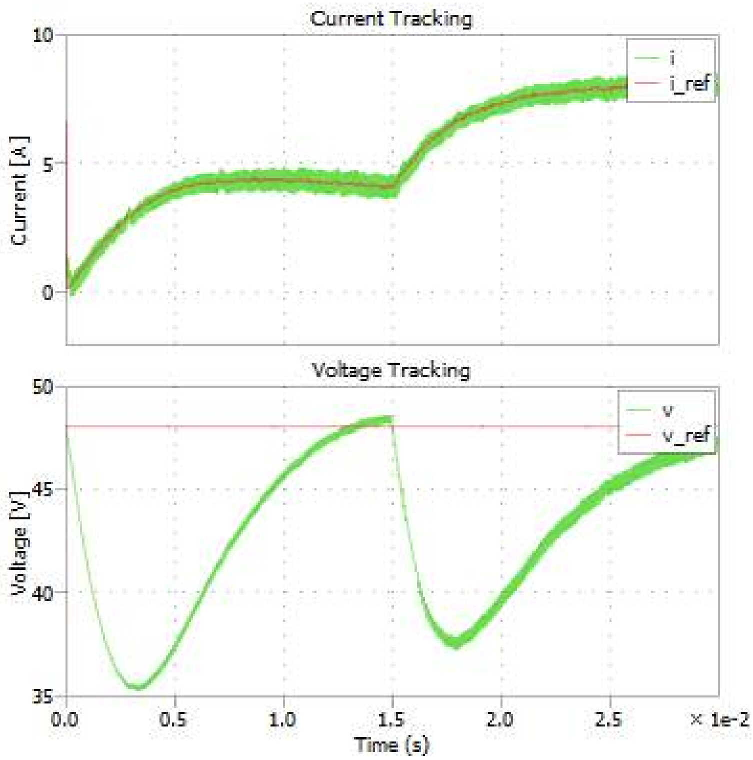


Figure 6: Continuous Time: Feed-Forward Controllers (30ms)

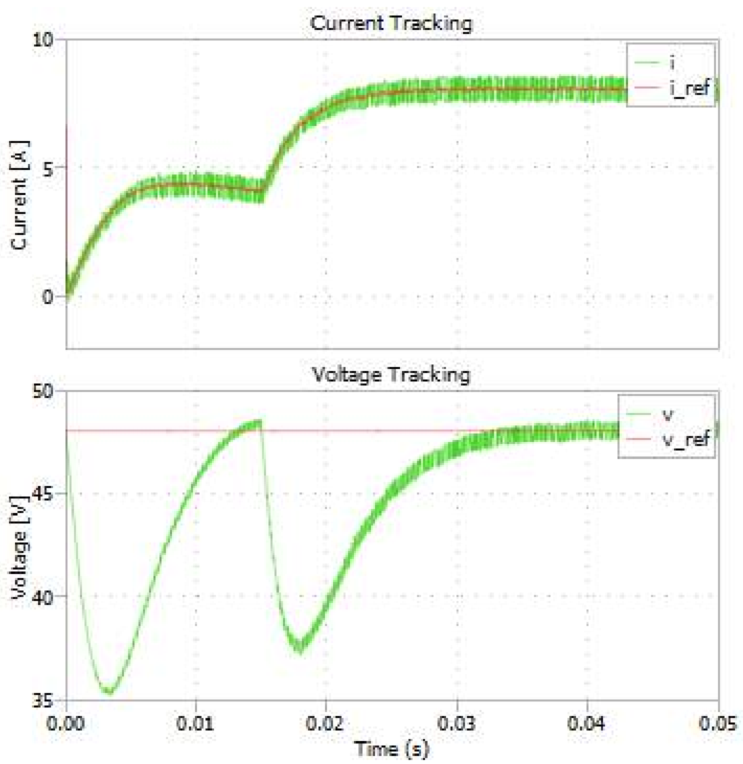


Figure 7: Continuous Time: Feed-Forward Controllers (50ms)

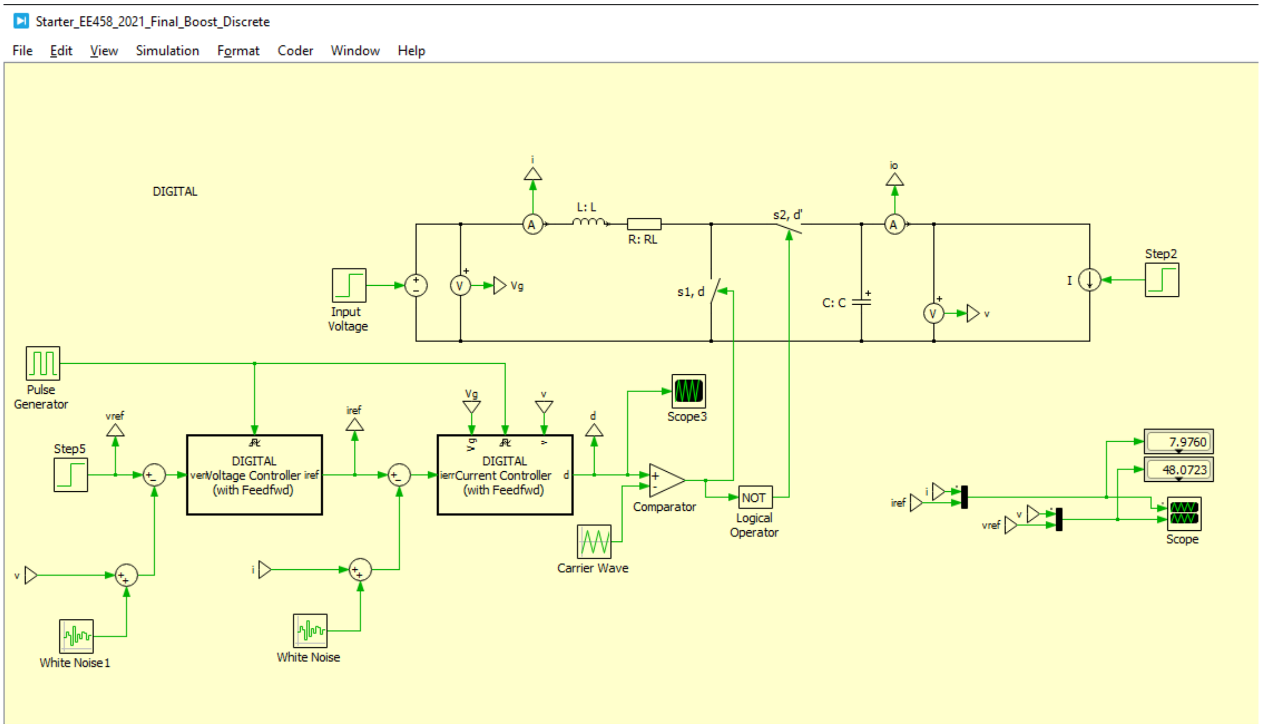


Figure 8: Discrete Time: Boost Converter Model

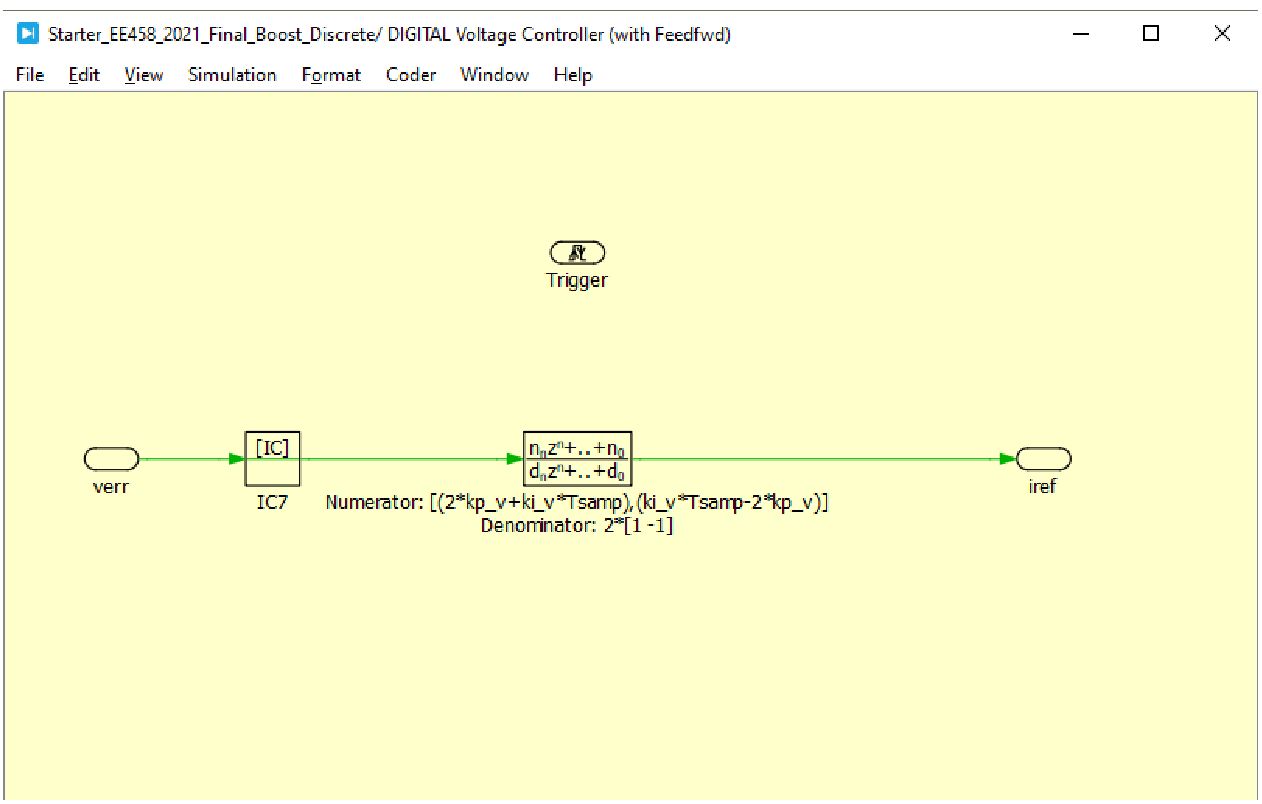


Figure 9: Discrete Time: Voltage Controller

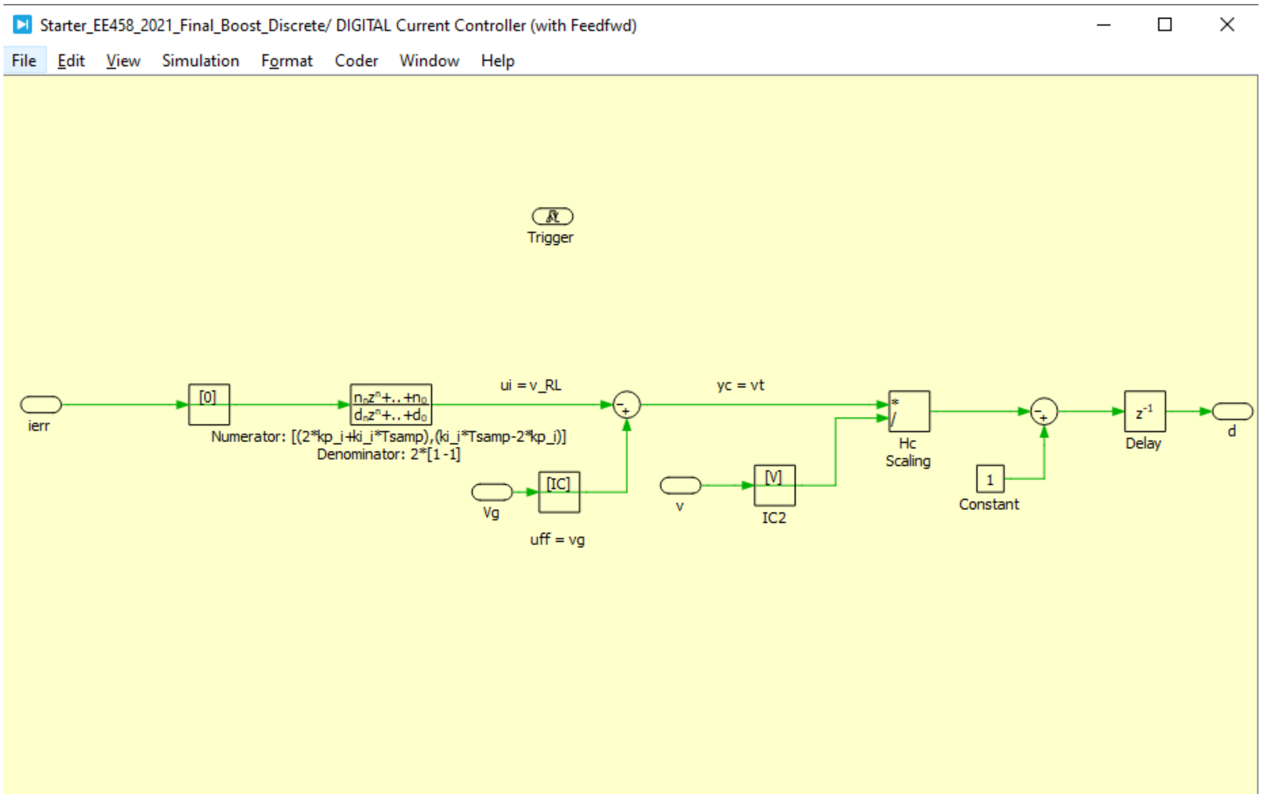


Figure 10: Discrete Time: Current Controller

3 Motor Control and Sensor Path Design

- At $t = 0.5\,\text{s}$, $i_{\text{q,ref}}$ changes from $0\,\text{A} \rightarrow -30\,\text{A}$.
- At $t = 1.0\,\text{s}$, $i_{\text{d,ref}}$ changes from $0\,\text{A} \rightarrow 10\,\text{A}$.
- At $t = 1.5\,\text{s}$, $i_{\text{q,ref}}$ changes from $-30\,\text{A} \rightarrow -20\,\text{A}$.
- At $t = 2.0\,\text{s}$, $i_{\text{q,ref}}$ changes from $-20\,\text{A} \rightarrow +20\,\text{A}$.

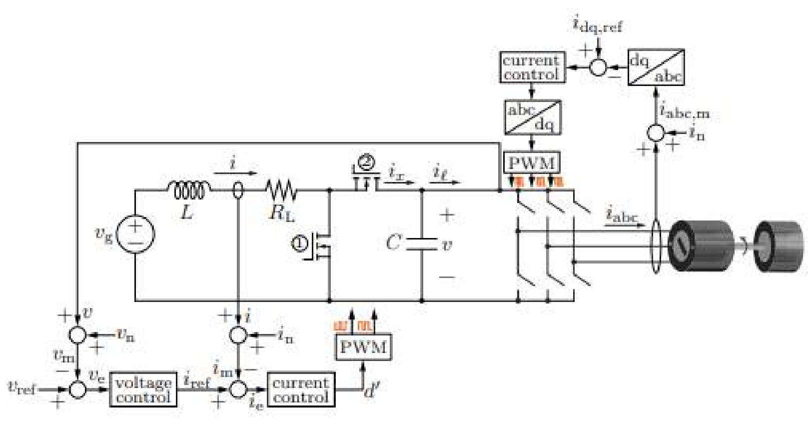


Figure 11: Problem 3

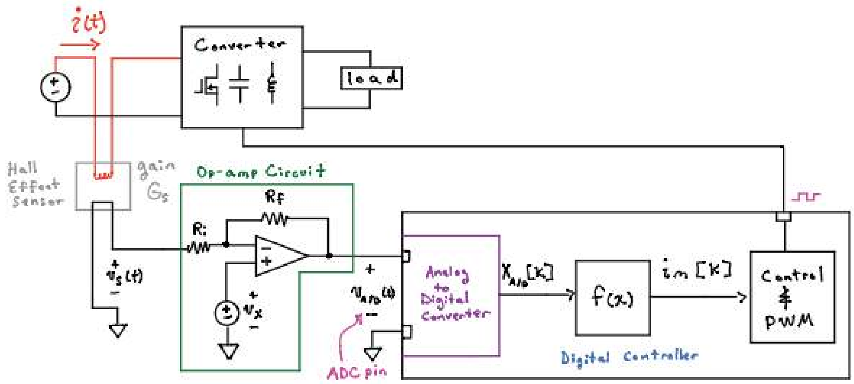


Figure 12: Sensor Schematic

$$V_{FS} = 3V$$
$$\epsilon = 0.1V$$
$$R_i = 100K$$
$$i_{pk} = 40A \text{ (iMax)}$$
$$G_{hall} = \frac{1}{1000} A/A$$
$$R_b = 75\Omega$$
$$G_s = G_{hall} R_b = \frac{1}{1000} \cdot 75 = 0.075$$
$$G_s i_{pk} = 0.075 \cdot 40 = 3$$
$$v_{dc} = 0V$$

$$V_{bias} + G_s i_{pk} < V_{cc}$$
$$V_{bias} = \frac{V_{cc}}{2}$$
$$V_{bias} = \frac{V_{FS}}{2}$$
$$V_{bias} = \frac{3}{2} = 1.5V$$

$$\frac{R_f}{R_i} = \frac{1}{G_s i_{pk}}(\frac{V_{FS}}{2} - \epsilon)$$

$$R_f = \frac{R_i}{G_s i_{pk}}(\frac{V_{FS}}{2} - \epsilon)$$

$$R_f = \frac{100K}{3}(\frac{3}{2} - 0.1)$$

$$R_f = 46.67K\Omega$$

$$v_x = \frac{1}{1 + \frac{R_f}{R_i}}\left(\frac{v_{\bar{a}dc}}{2} + \frac{R_f}{R_i}V_{dc}\right)$$

$$v_x = \frac{1}{1 + \frac{1}{G_s i_{pk}}(\frac{V_{FS}}{2} - \epsilon)}\left(\frac{V_{FS}}{2} + \frac{1}{G_s i_{pk}}(\frac{V_{FS}}{2} - \epsilon)V_{dc}\right)$$

$$v_x = \frac{1}{1 + \frac{1}{3}(\frac{3}{2} - 0.1)}\left(\frac{3}{2} + \frac{1}{3}(\frac{3}{2} - 0.1)0\right)$$

$$v_x = 1.022V$$

$$i_m[k] = \frac{-R_i V_{FS}}{R_f G_s (2^{n_{A/D}} - 1)} x_{A/D}[n] + \frac{R_i}{R_f G_s}\frac{V_{FS}}{2}$$

$$i_m[k] = m x_{A/D}[n] + b$$

$$m = \frac{-R_i V_{FS}}{R_f G_s (2^{n_{A/D}} - 1)}$$

$$m = \frac{-100K \cdot 3}{46.67K \cdot 0.075 \cdot (4095)}$$

$$m = -0.02093$$

$$b = \frac{R_i}{R_f G_s}\frac{V_{FS}}{2}$$

$$b = \frac{100K}{46.67K \cdot 0.075} \cdot \frac{3}{2}$$

$$b = 42.8541$$

$$x_{A/D}[k] = round\left(\frac{V_{A/D}}{V_{FS}} \cdot (2^{n_{A/D}} - 1)\right)$$

$$x_{A/D}[k] = round\left(\frac{V_{A/D}}{3} \cdot (4095)\right)$$

3.1

Calculations shown above.

$$\frac{R_f}{R_i} = \frac{46.67K}{100K} = 0.47$$

$$v_x = 1.022V$$

3.2

Calculations shown above.

$$m = -0.02093$$

$$b = 42.8541$$

$$i_m[k] = m\ x_{A/D}[n] + b$$

$$i_m[k] = -0.02093\ x_{A/D}[n] + 42.8541$$

3.3

See figures below.

"Comment on how the two sets of simulations (with and without rider) for the sequence of current references in Exam description differ and why."

The motor is capable of achieving much larger speeds without the rider. Similarly, the frequency of the stator and back emf sinusoids are much faster. This results is slightly noisy i_d and i_q currents in the simulations without a rider.

Ideal Sensing

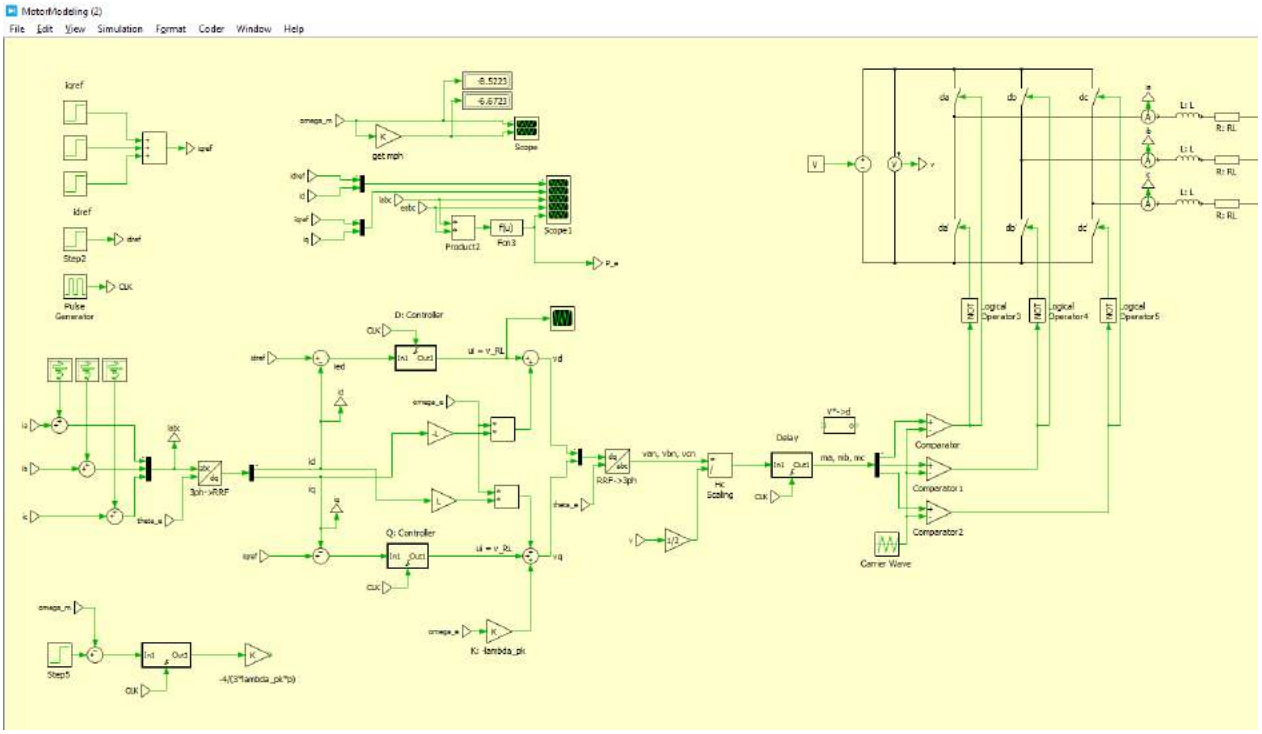


Figure 13: Motor Model with Ideal Sensing

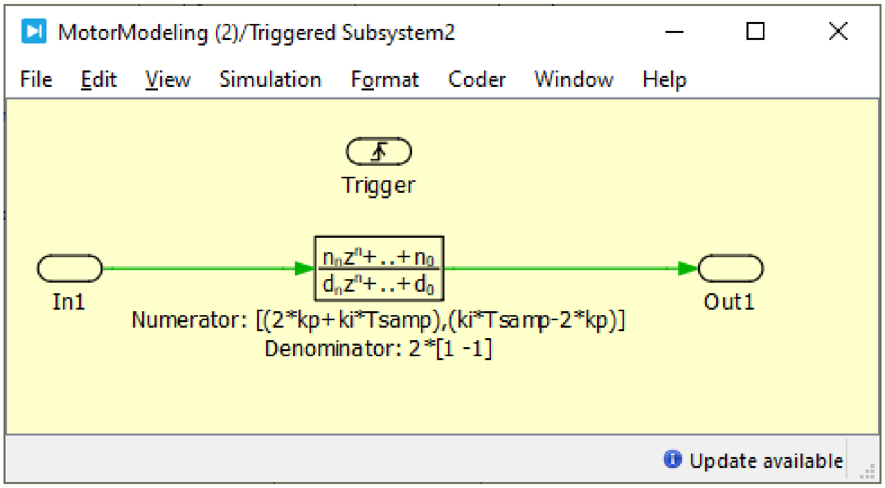


Figure 14: D Controller Model

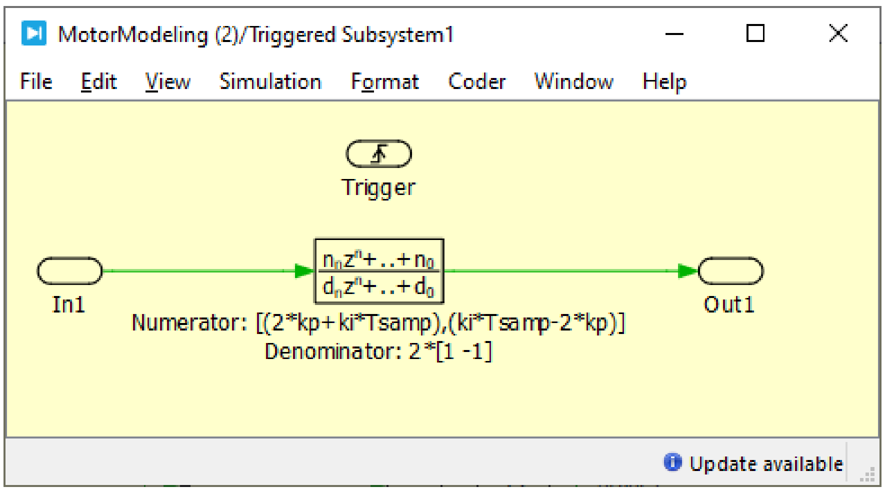


Figure 15: Q Controller Model

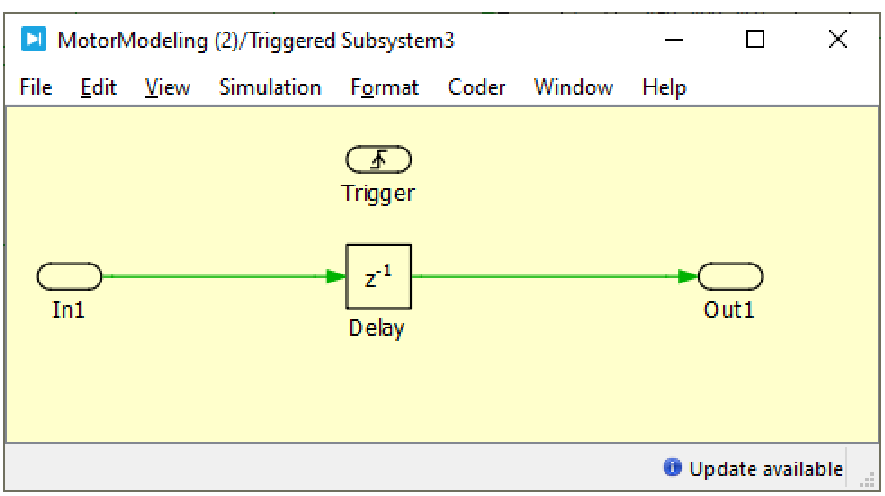


Figure 16: Delay

Ideal Sensing with Rider

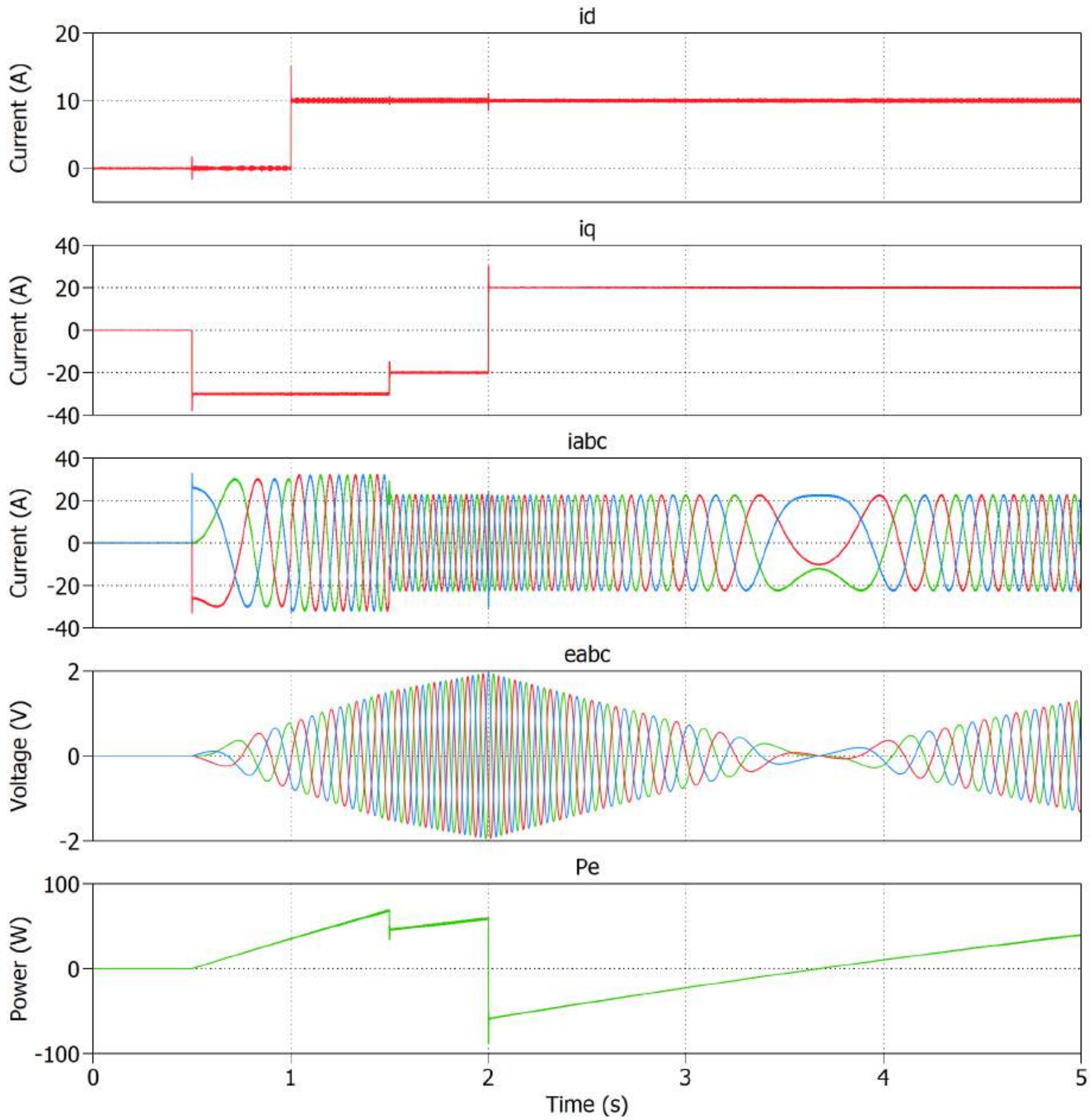


Figure 17: Ideal Sensing with Rider: [$[{i_d}^*, i_d]$, $[{i_q}^*, i_q]$, [3-phase stator currents], [3-phase back EMF], [Electrical Power Absorbed]]

Ideal Sensing with Rider

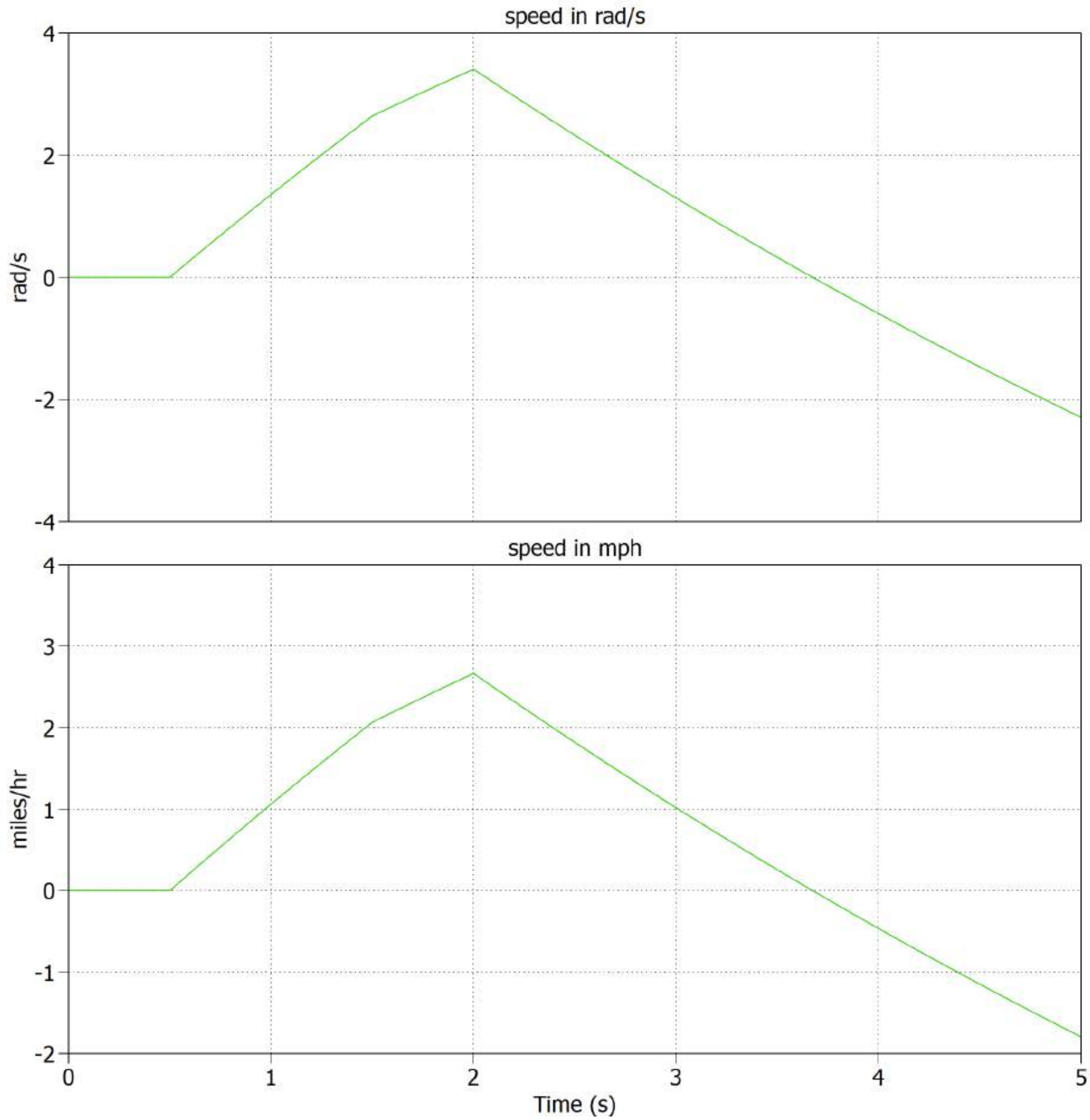


Figure 18: Ideal Sensing with Rider: Bike Speed rad/s and mph

Ideal Sensing without Rider

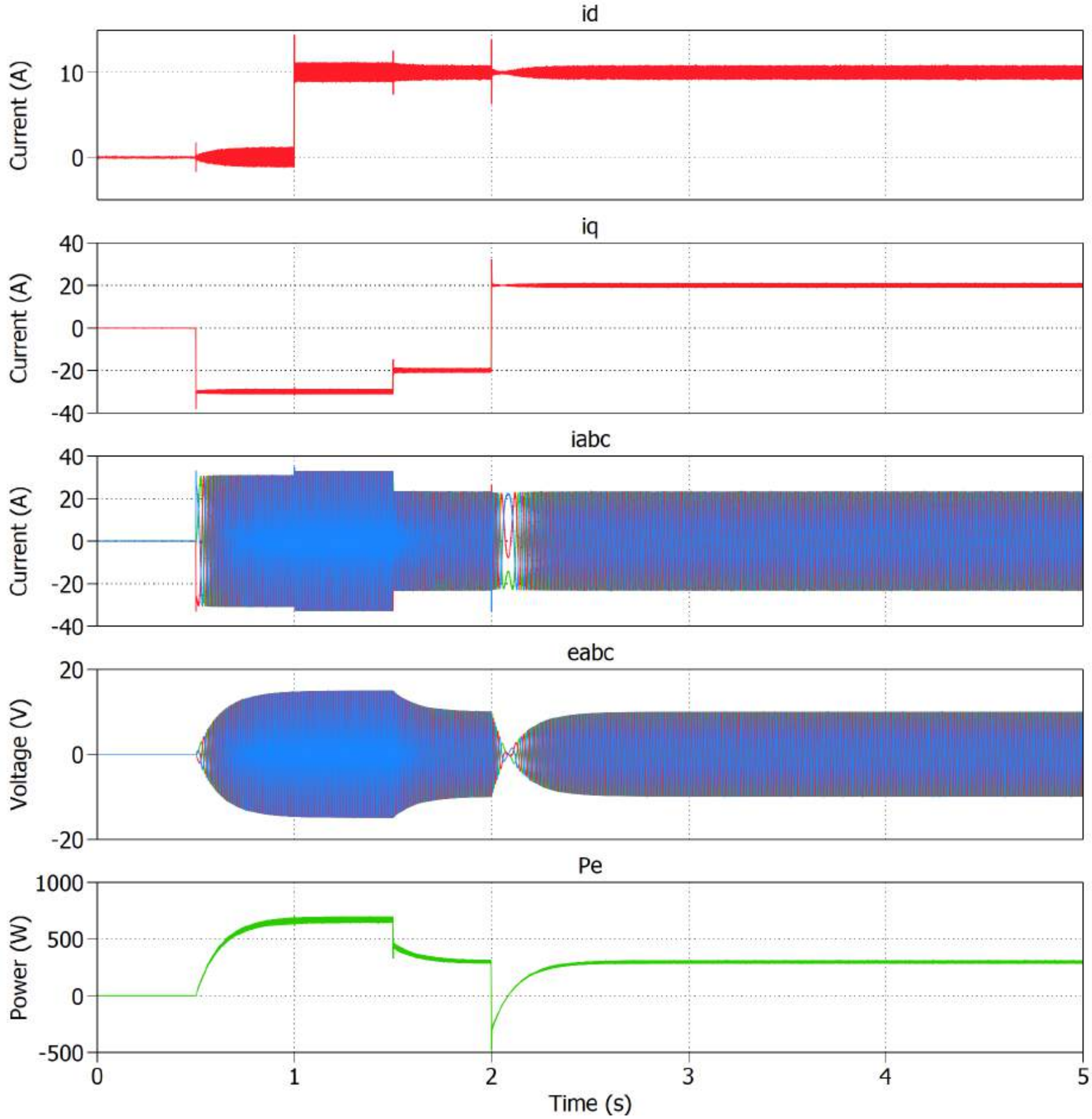


Figure 19: Ideal Sensing without Rider: [[$i_d{}^*, i_d$], [$i_q{}^*, i_q$], [3-phase stator currents], [3-phase back EMF], [Electrical Power Absorbed]]

Ideal Sensing without Rider

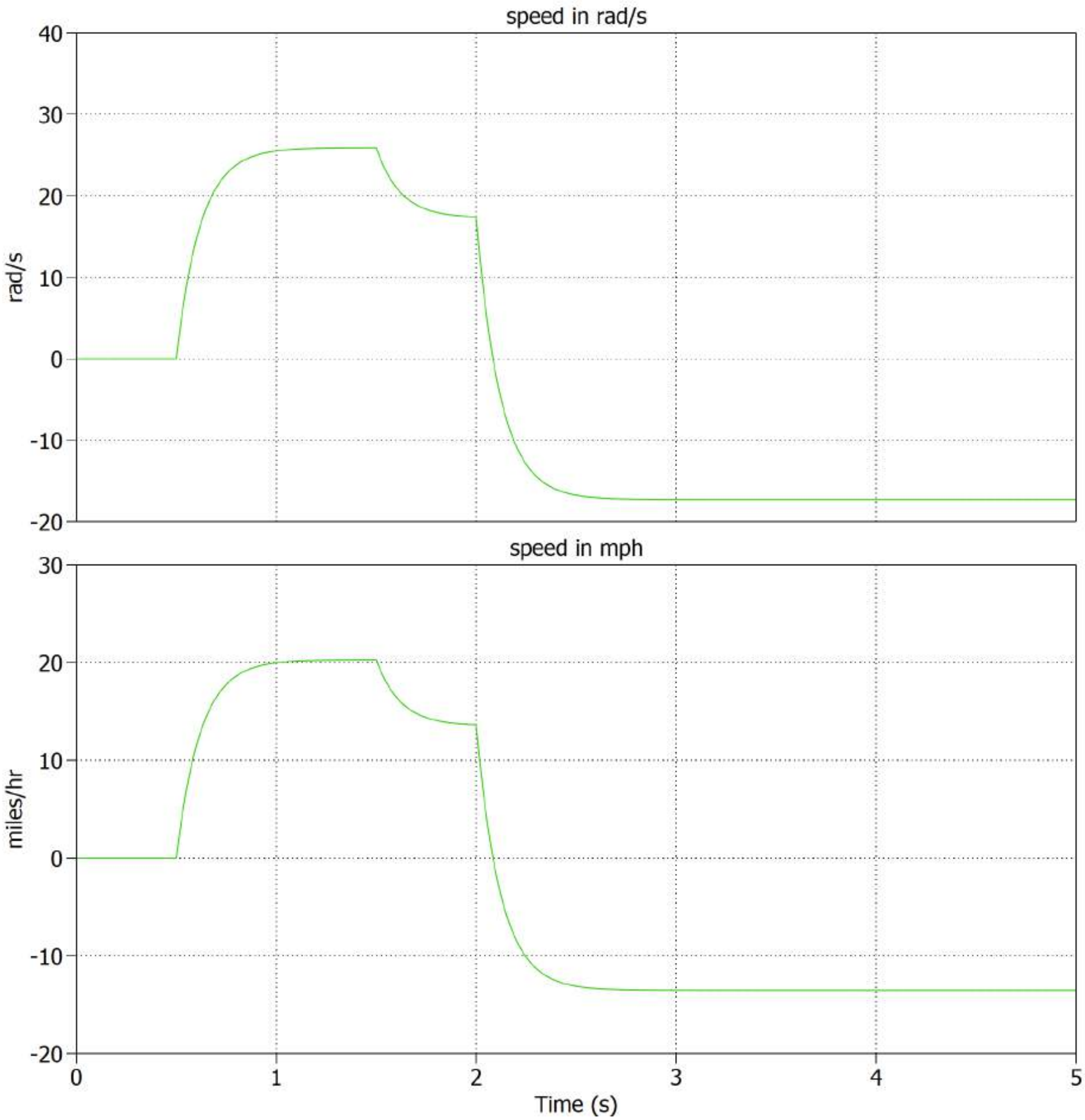


Figure 20: Ideal Sensing without Rider: Bike Speed rad/s and mph

Hall Sensor

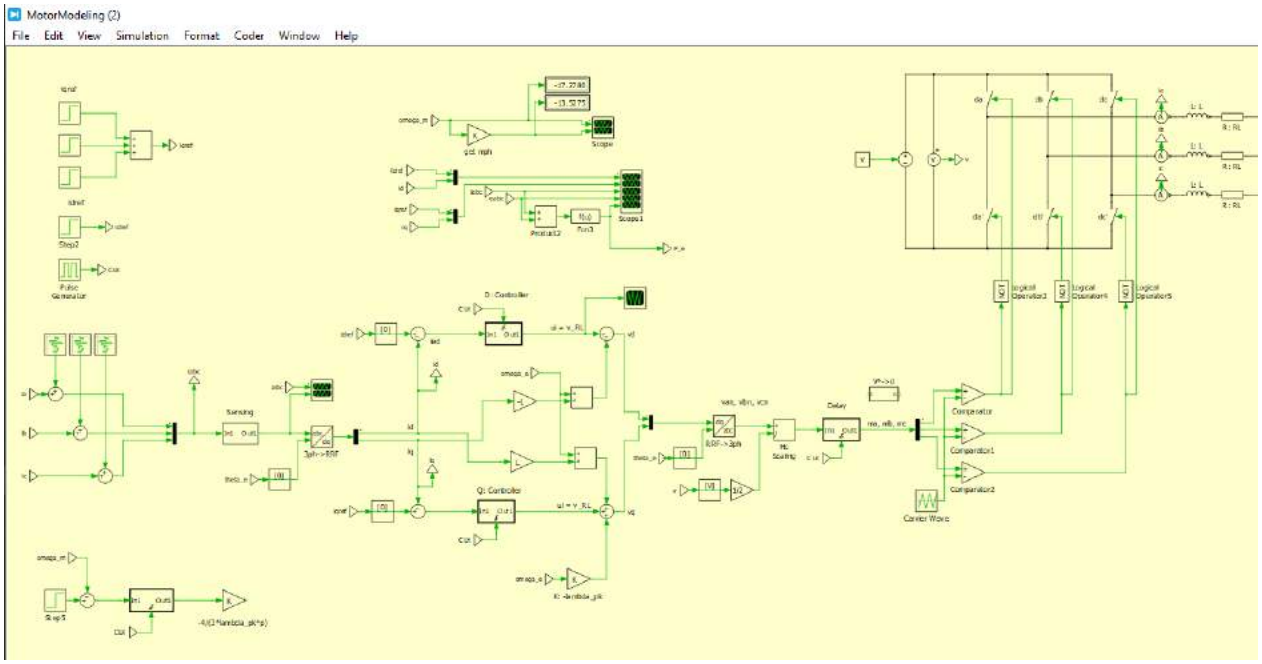


Figure 21: Motor Model with Hall Sensor and ADC

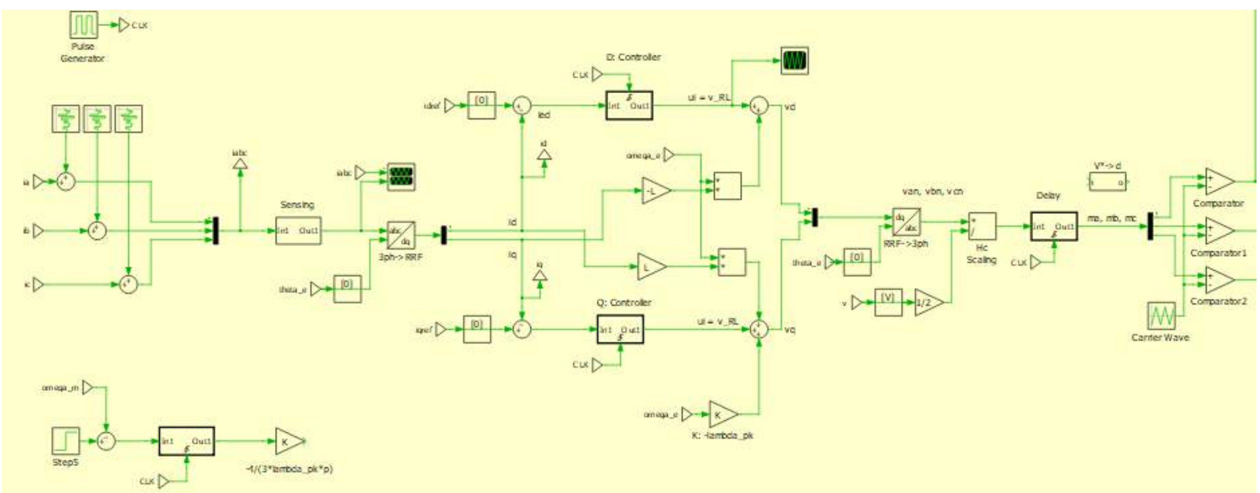


Figure 22: Motor Controller Zoomed-In

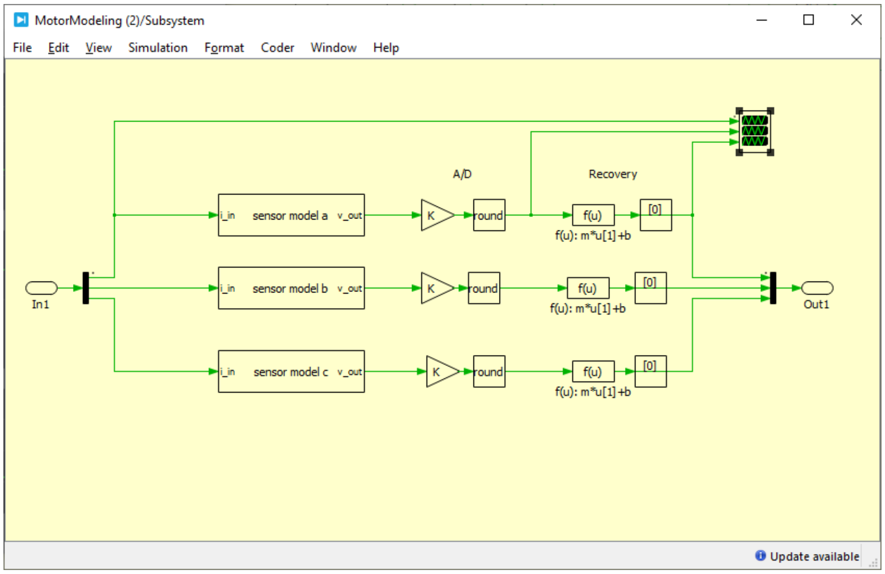


Figure 23: Hall Sensor and ADC

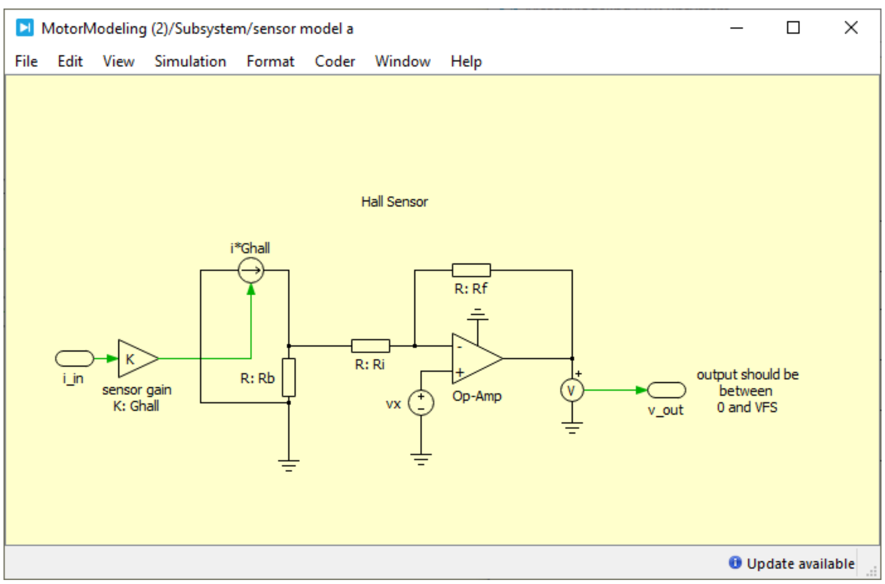


Figure 24: Hall Sensor

Actual Sensing with Rider

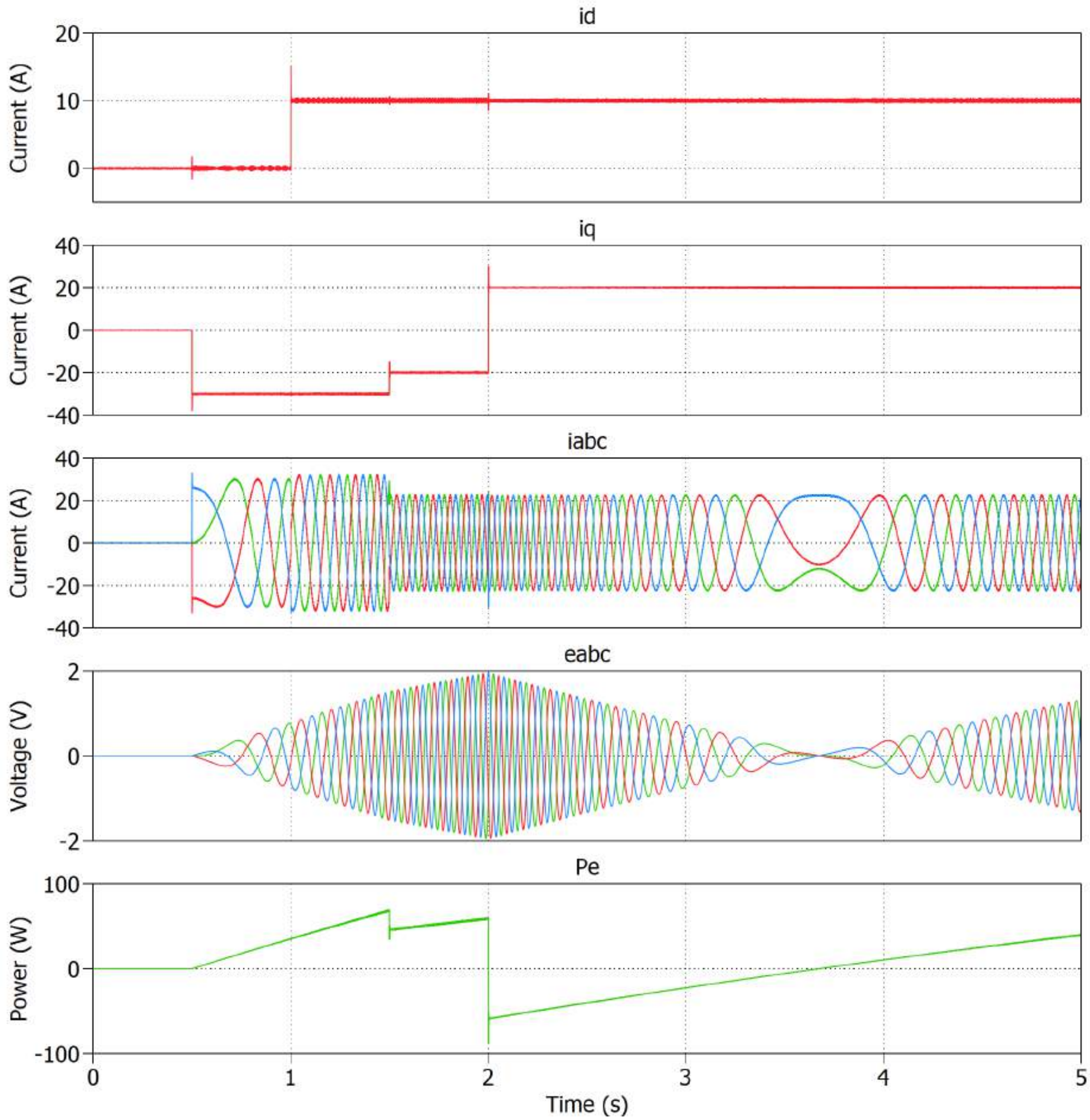


Figure 25: Actual Sensing with Rider: [$[{i_d}^*, i_d]$, $[{i_q}^*, i_q]$, [3-phase stator currents], [3-phase back EMF], [Electrical Power Absorbed]]

Actual Sensing with Rider

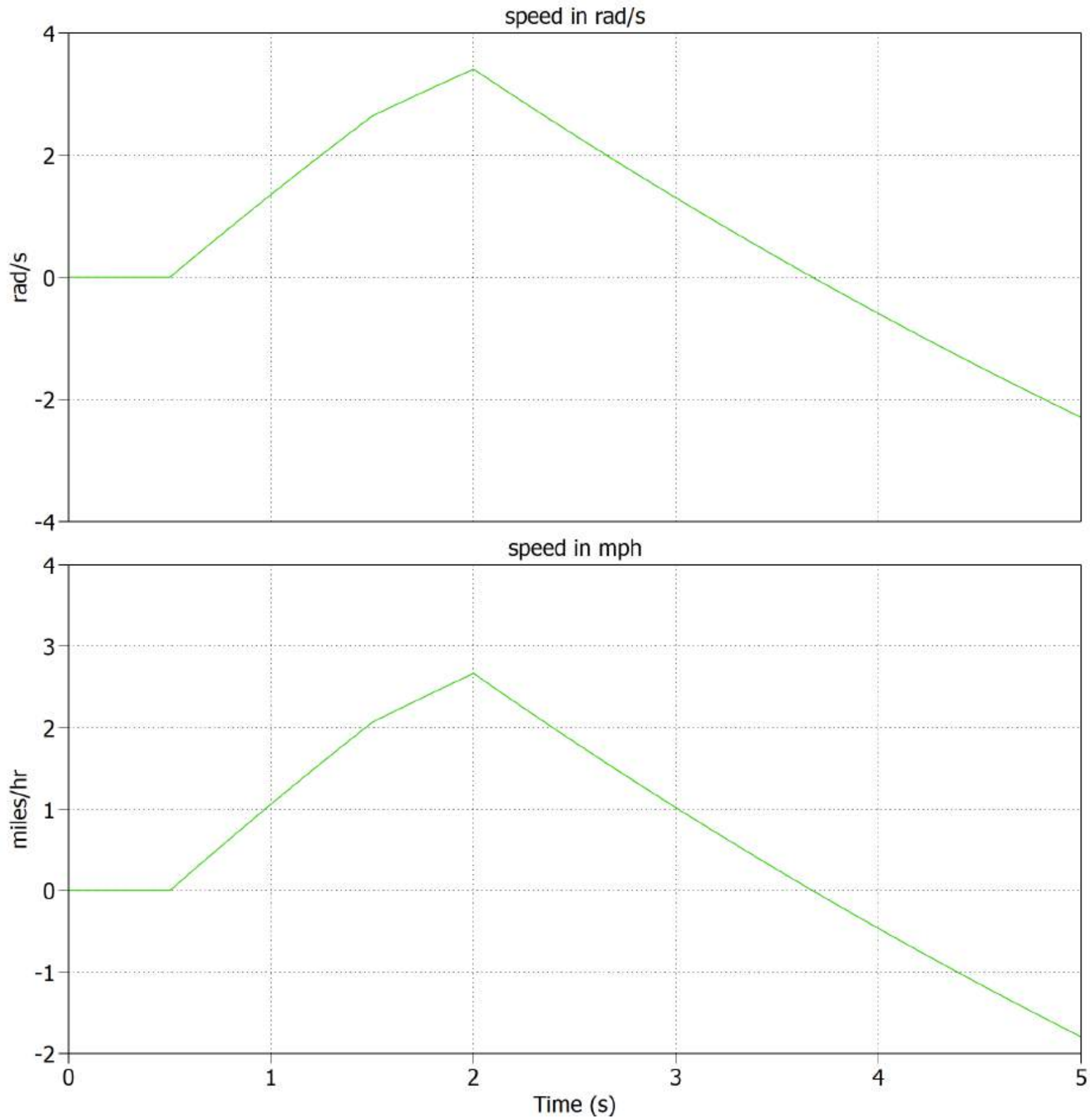


Figure 26: Actual Sensing with Rider: Bike Speed rad/s and mph

Actual Sensing without Rider

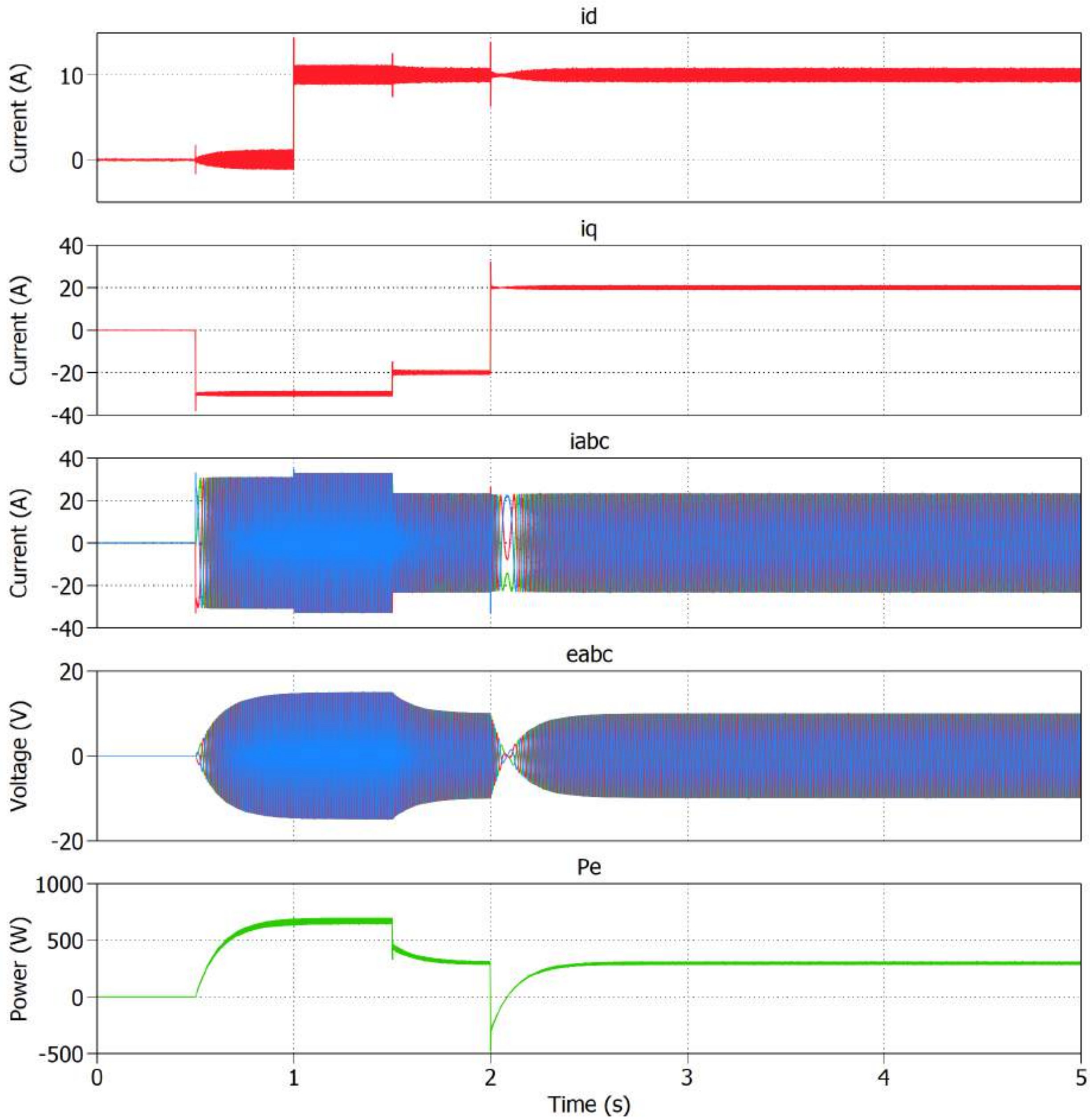


Figure 27: Actual Sensing without Rider: [$[{i_d}^*, i_d]$, $[{i_q}^*, i_q]$, [3-phase stator currents], [3-phase back EMF], [Electrical Power Absorbed]]

Actual Sensing without Rider

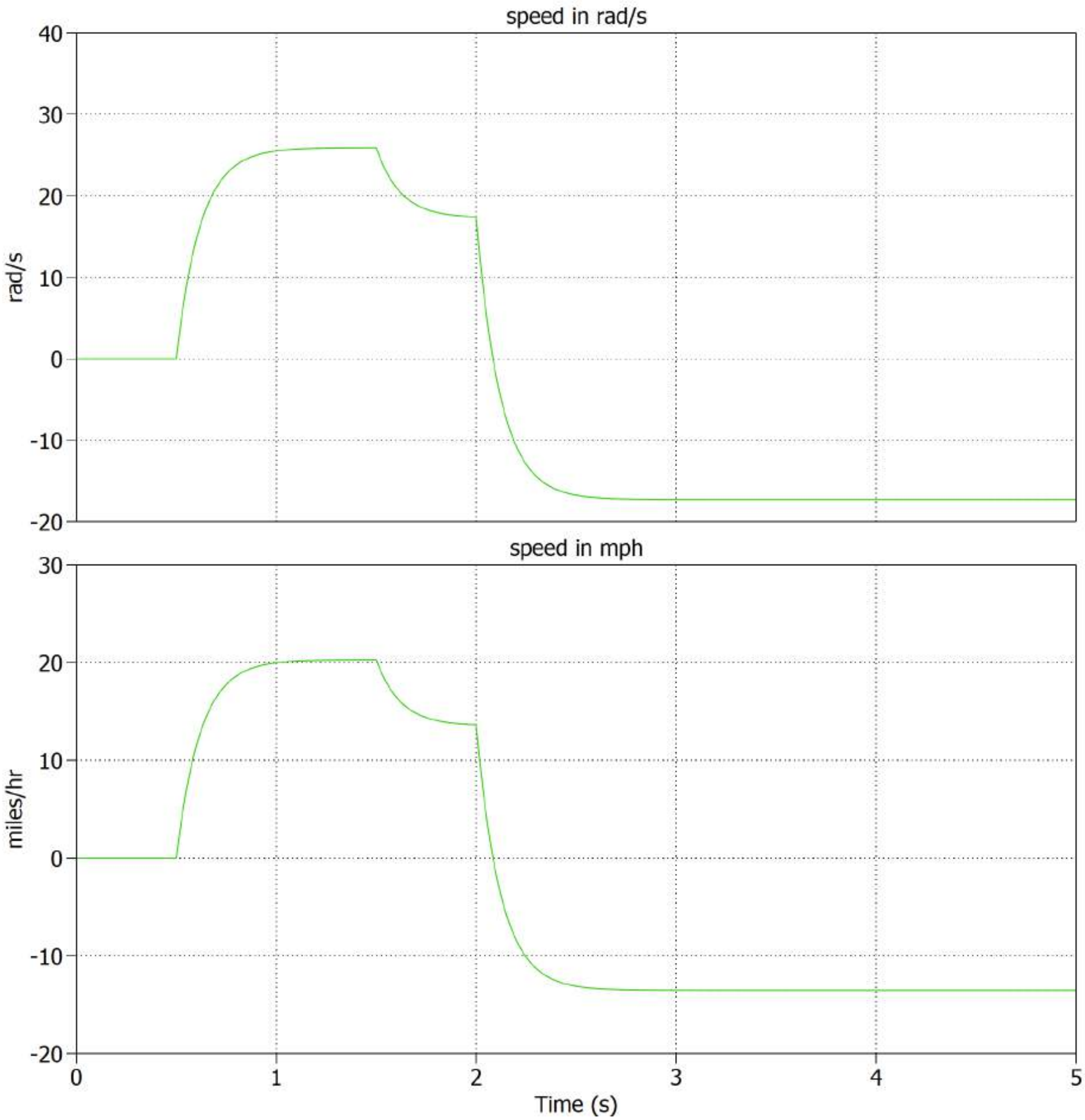


Figure 28: Actual Sensing without Rider: Bike Speed rad/s and mph

Reconstructed Current

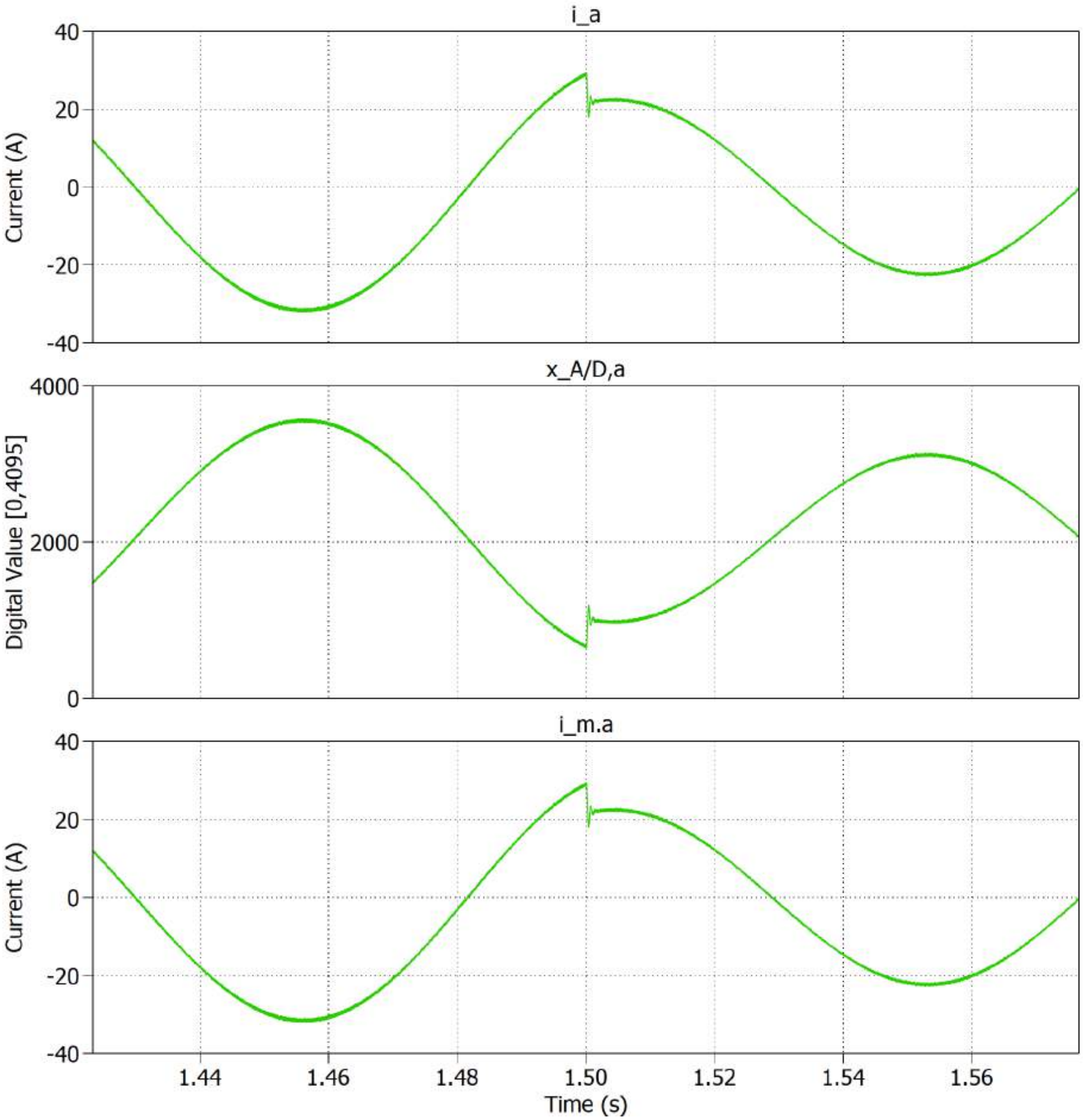


Figure 29: Motor Stator Currents $[i_a, x_{A/D,a}, i_{m,a}]$

4 System integration

4.1

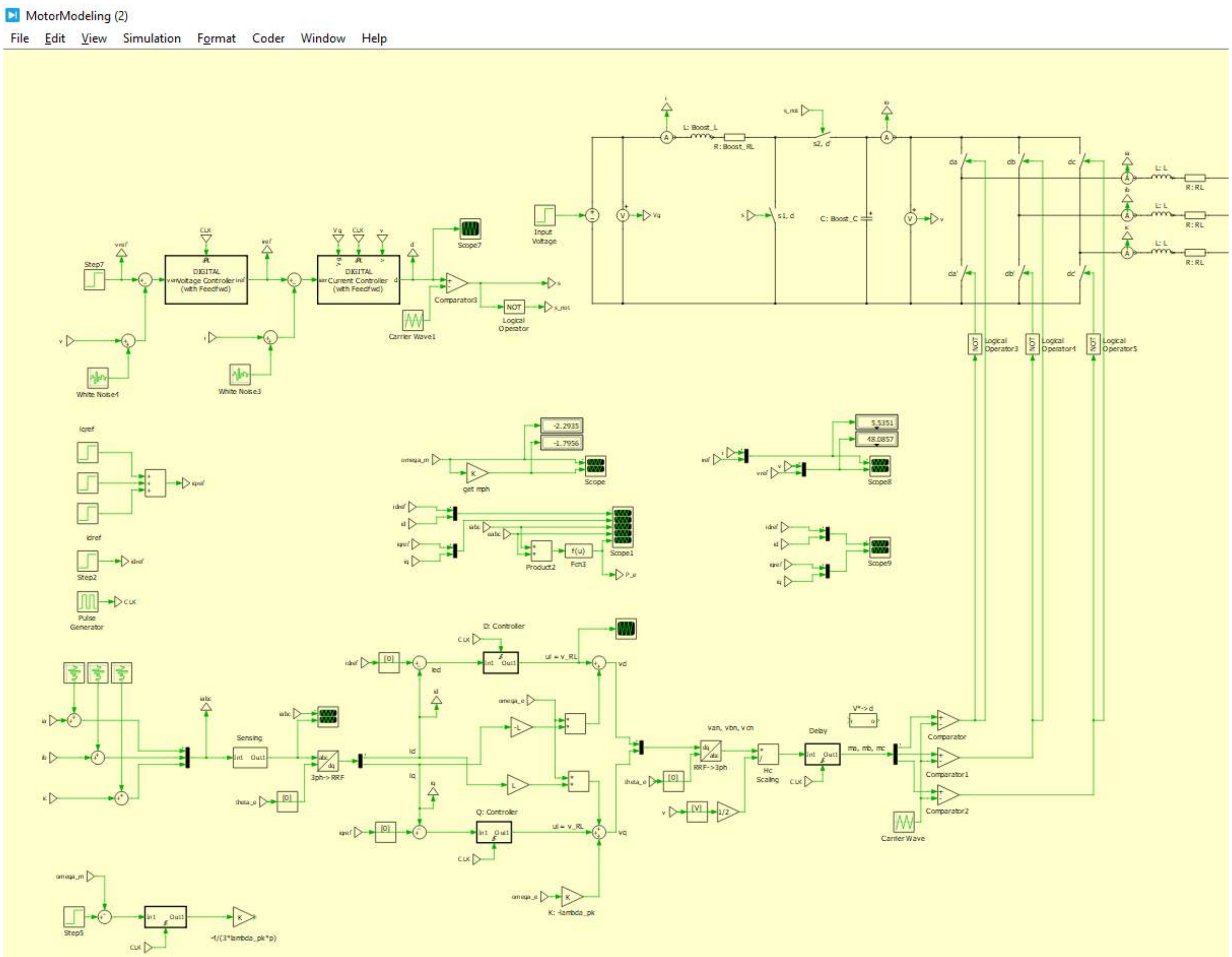


Figure 30: Integrated Motor and Boost Converter

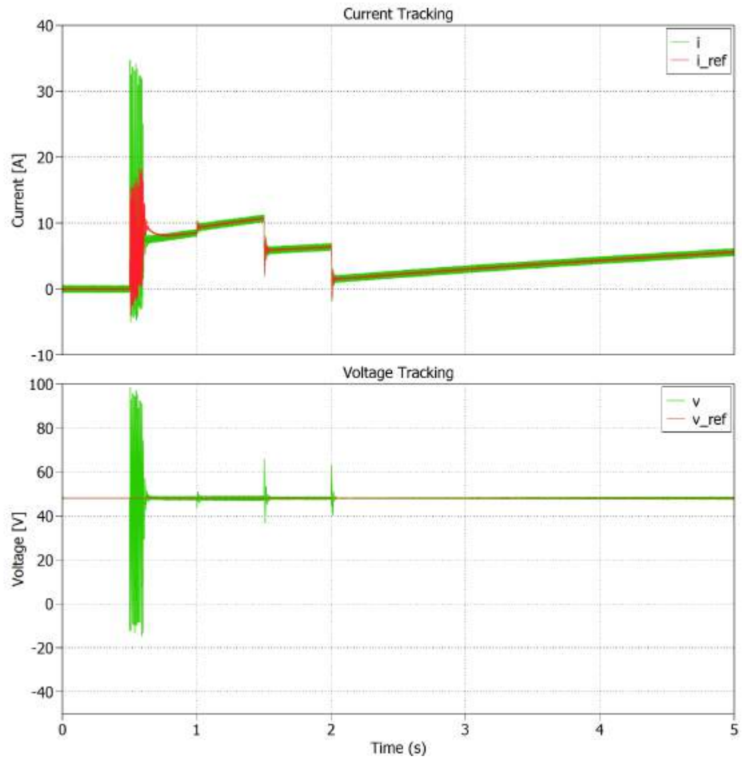


Figure 31: Integrated System [$[i_{ref}, i]$, $[v_{ref}, v]$]

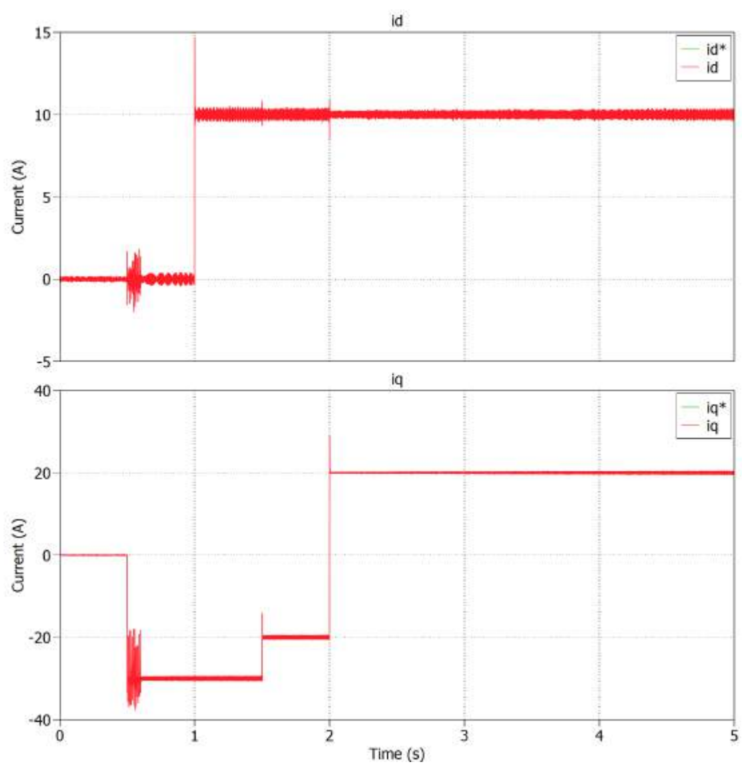


Figure 32: Integrated System [$[i_d^*, i_d]$, $[i_q^*, i_q]$]

5 Submission Files

```
Starter_EE458_2021_Final_Boost.plecs
Starter_EE458_2021_Final_Boost_Discrete.plecs
MotorModeling(2).plecs
```

MATLAB

```
s = tf('s');
opts = bodeoptions;
opts.FreqUnits = 'Hz';

% Switching Frequency
fsw = 10e3;

% Inductive branch
L = 1.3e-3;      % inductance [H]
RL = 10e-3;      % winding resistance [Ohms]

% Capacitive branch
C = 250e-6;      % output capacitance [F]
Rc = 10e-3;      % cap ESR [Ohms]

% 1st Order Current Controller
tau_i = 10/(2*pi*fsw);
omega_i = 1/tau_i;
ki_i = RL/tau_i;
kp_i = L/tau_i;
C_simp = kp_i + ki_i/s;

% Plant P(s)
P = 1/(s*C);

% Current Controller
kpi = L/tau_i; %2*zeta*omega_0*L - RL
kii = RL/tau_i; %omega_0^2*L
%kpi = 8.17;
%kii = 377;
Ci = kpi + kii/s;

% Current Open-Loop Gain
Li = Ci*P;

% Current Closed-Loop Gain
CLi = Li/(Li+1);

% Voltage Controller
% kpv = 0.0785;
% kiv = 85.47;
kpv = 0.136;
kiv = 49.35;
Cv = kpv + kiv/s;

% Voltage Open-Loop Gain
Lv = Cv*P;

% Voltage Closed-Loop Gain
CLv = (kpv*s + kiv)/(C*tau_i*s^3+C*s^2+kpv*s+kiv);
```

```
% Bode
bode(CLi,CLv,opts);
legend('Current Closed-Loop','Voltage Closed-Loop');
legend('Position',[0.64345,0.85732,0.25179,0.067857]);
grid on;
step(CLi,CLv)
grid on;

margin(Lv,opts);
grid on;
```

PLECS Initialization Commands

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Simulation Time
tStop = 5;
fsw = 10e3;              % switching frequency [Hz]
Tsw = 1/fsw;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%  Boost Power Stage Design
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
VgNom = 24;              % Battery nominal voltage [V]
Vnom = 48;                        % nominal output voltage [V]
Rload = 10;      % Boost Stage Rated Power [W]

% Inductive branch
Boost_L = 1.3e-3;        % inductance [H]
Boost_RL = 10e-3;        % winding resistance [Ohms]

% Capacitive branch
Boost_C = 250e-6;        % output capacitance [F]
Boost_Rc = 10e-3;        % cap ESR [Ohms]

% initial conditions %PUT YOUR CALCULATIONS HERE
Iload0 = 2;      % initial load current [A]
Vg0 = VgNom;     % initial battery voltage [V]
Vref0 = Vnom;    % initial voltage command [V]
I = 1;  % initial inductor current [A] %PUT YOUR CALCULATIONS HERE
Iref0 = I;               % inital reference current [A]
%V = Vref0;              % initial cap voltage [V]
Dp0 = 1;         % initial duty %PUT YOUR CALCULATIONS HERE

% step changes and events
IloadFinal = 4; % final reference current [A]

% current control loop
tau_i = 10/(2*pi*fsw);
omega_i = 1/tau_i;

ki_i = Boost_RL/tau_i;
kp_i = Boost_L/tau_i;

% voltage control loop %PUT YOUR SOLUTION BELOW FOR CONTROL DESIGN
kp_v = 0.136; %PUT YOUR CALCULATIONS HERE
ki_v = 49.35; %PUT YOUR CALCULATIONS HERE

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% dc side and drive
V = 48;                  % dc nominal voltage [V]

%Stator parameters
L = 240e-6;                       % stator inductance [H]
RL = 125e-3;             % stator resistance [Ohms]
lambda_pk = 0.024;       % peak flux linkage [Vs/rad]
p = 24*2;                         % pole pairs
```

```
% mechanical parameters
radius = 0.7/2; % tire radius, "700c" tire diam ~ 0.7m
radStoMph= 2.23694; % 1 rad/s ~ 2.23694 mph
Jwheel = 0.12;          % rotational inertia [kg*m^2]
RiderMass = 75; % rider mass, 75 kg ~ 165 lbs
Jrider = RiderMass*radius^2;    % inertia from rider
Jnet = Jwheel + Jrider; % total inertia
beta = 1000e-3; % friction coefficient [Nms/rad]

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Sensing Design
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
iMax = 40;
Ghall = 1/1000;
VFS = 3;
epsilon = 0.1;
Gs = 0.075;
Ri = 100e3;
Rf = 46.67e3;
Rb = 75;
vx = 1.022;
m = -0.02093;
b = 42.8541

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Control Design
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Tsamp = Tsw;
Fsamp = 1/Tsamp;

%tau_i = 10/(2*pi*fsw)
ki = RL/tau_i; %omega_0^2*L
kp = L/tau_i; %2*zeta*omega_0*L - RL

tau_w = 100/(2*pi*fsw)
kiw = beta/tau_w; %omega_0^2*L
kpw = Jnet/tau_w; %2*zeta*omega_0*L - RL
```