LAB#4 Induction motor drive modelling

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- ✓ LAB#4 is aimed at study reference frame, math.models of IM in different frames, and scalar control techniques for IM motors
- ✓ LAB#4 is performed in MATLAB / Simulink

In LAB4_IM_Actuator_modelling.PDF (with simulation results) following topics are presented

1. Transformation between reference frames (Transformation of *abc* variables into *dq (Clarke Transform) and inverse* transformation*, Park's transformation*)

2 Mathematical models of IM in stationary and synchronous reference frames

3. Scalar control of IM: open-loop system

Task 1. Transformation between reference frames (Transformation of *abc* variables into *dq (Clarke Transform) and inverse* transformation, *Park's transformation*) this is your Attendance task #4

1.1. Transformation of *abc* variables into *dq (Clarke Transform) and inverse* transformation

1.1.1 Create blocks of transformation of *abc* variables into *dq and inverse* transformation using MATLAB Simulnk (1st way or 2nd way)

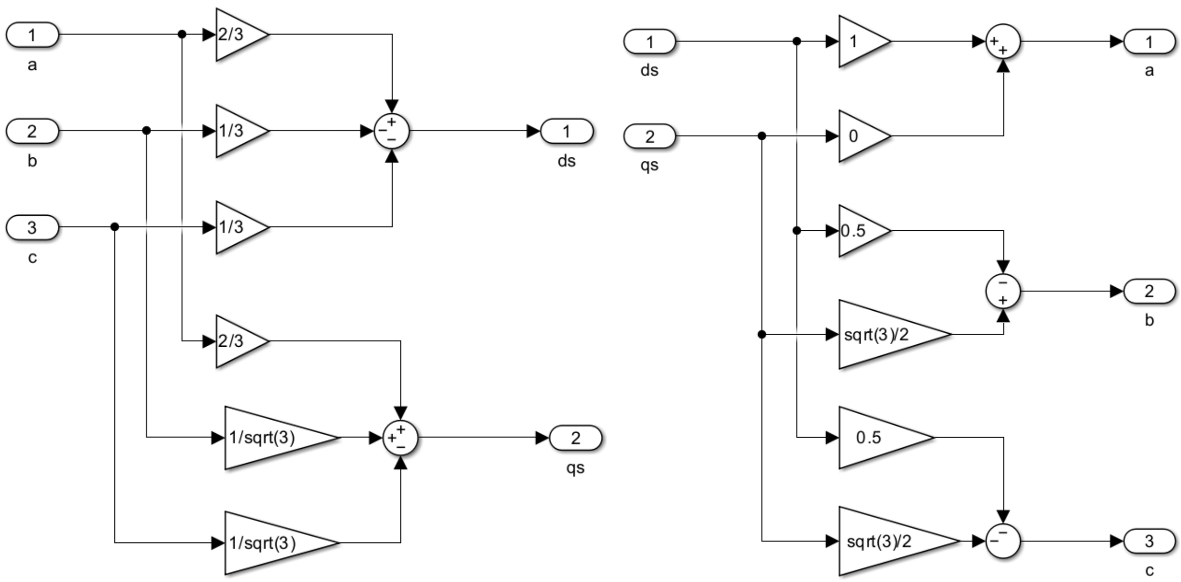


Figure 1. abc2dp & dq2abc models.

1.1.2 Check right work of these blocks

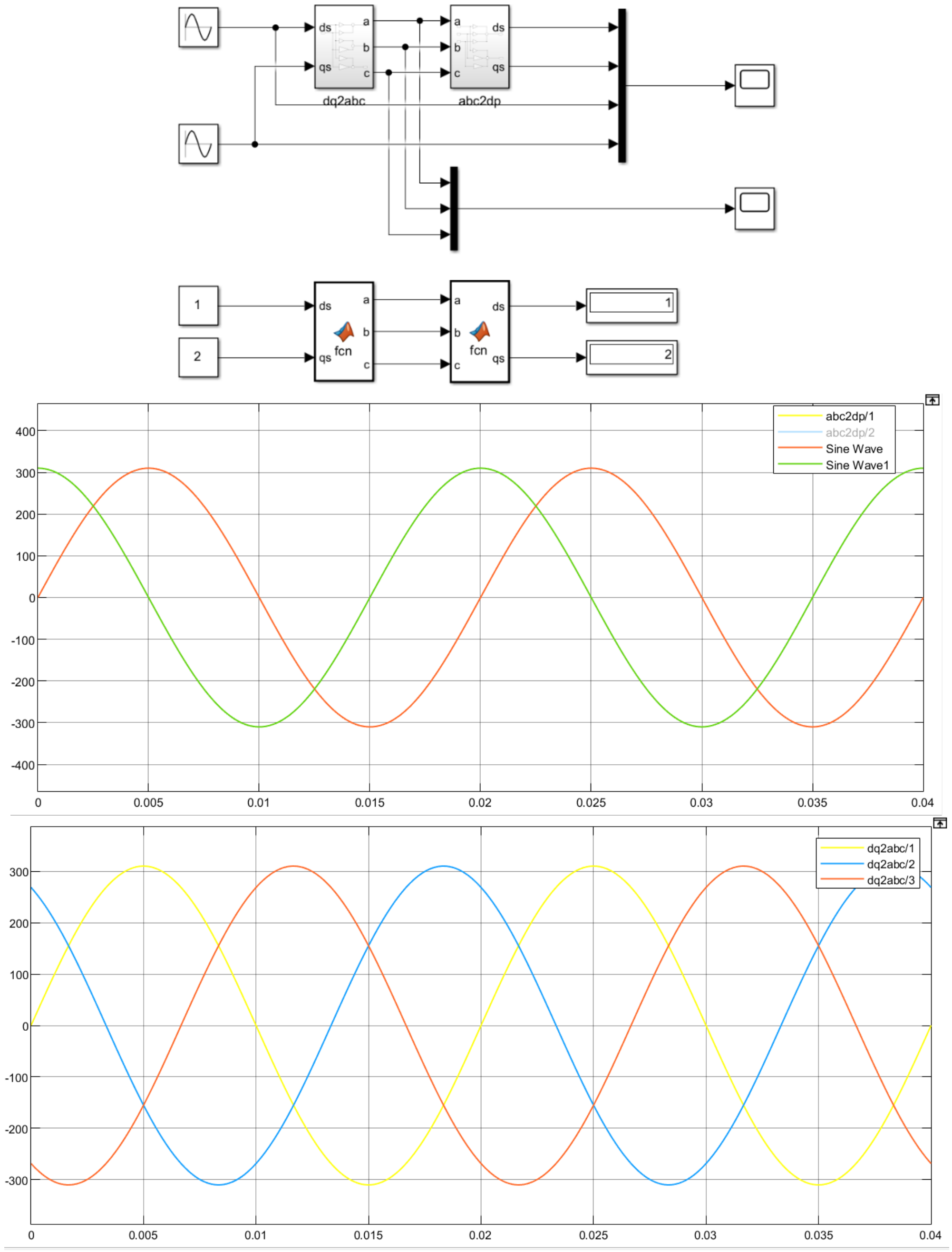


Figure 2. Checking right work of these blocks.

1.2. Park’s transformations

1.2.1. Create blocks of Park’s transformations using MATLAB Simulnk (1st way or 2nd way)

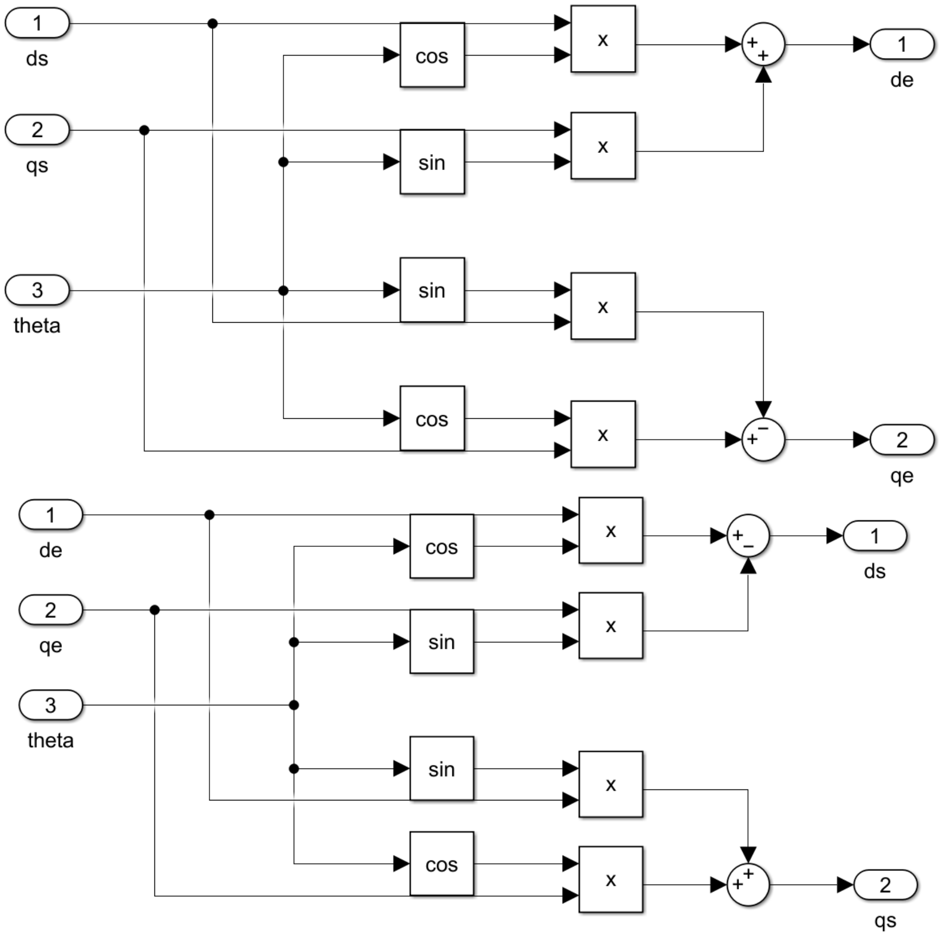


Figure 3. Models of Park’s transformations & the inverse one.

1.2.2. Check right work of these blocks

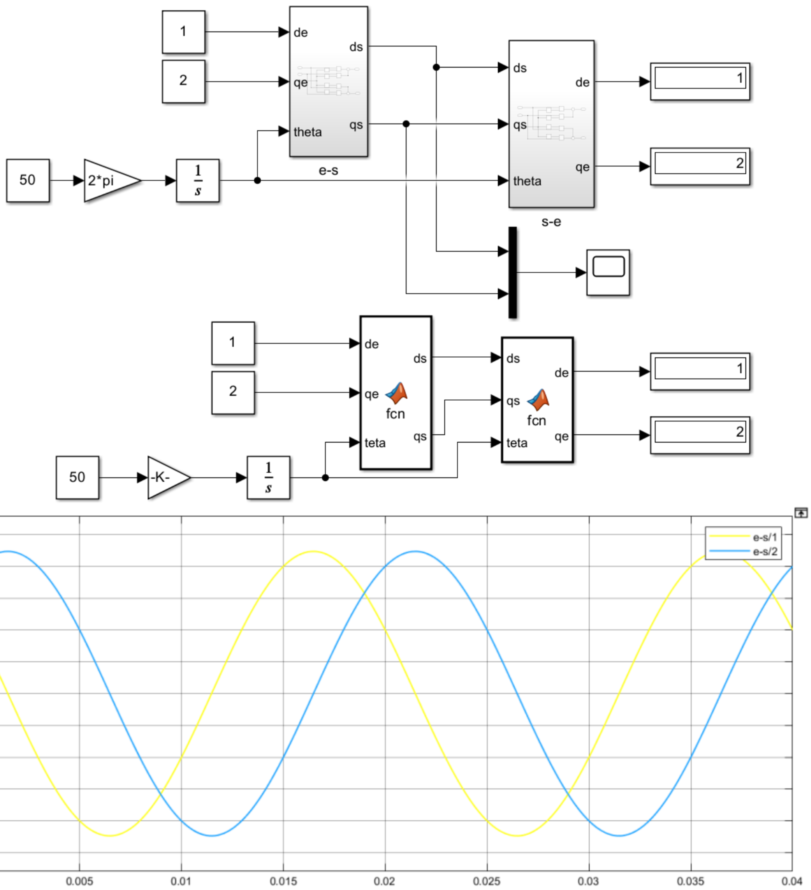


Figure 4. Checking right work of these blocks.

1.3. Show in your report right work of all these blocks

```
function [ds, qs] = fcn(de, qe, teta)
    ds = de*cos(teta) - qe*sin(teta);
    qs = de*sin(teta) + qe*cos(teta);
```

```
function [a,b,c] = fcn(ds,qs)
    a = ds;
    b = -0.5*ds + qs*sqrt(3)/2;
    c = -0.5*ds - qs*sqrt(3)/2;
```

```
function [ds,qs] = fcn(a,b,c)
    ds = (a*2/3) - (b/3) - (c/3);
    qs = (b/(sqrt(3))) - (c/(sqrt(3)));
```

```
function [de, qe] = fcn(ds, qs, teta)
    de = ds*cos(teta) + qs*sin(teta);
    qe = - ds*sin(teta) + qs*cos(teta);
```

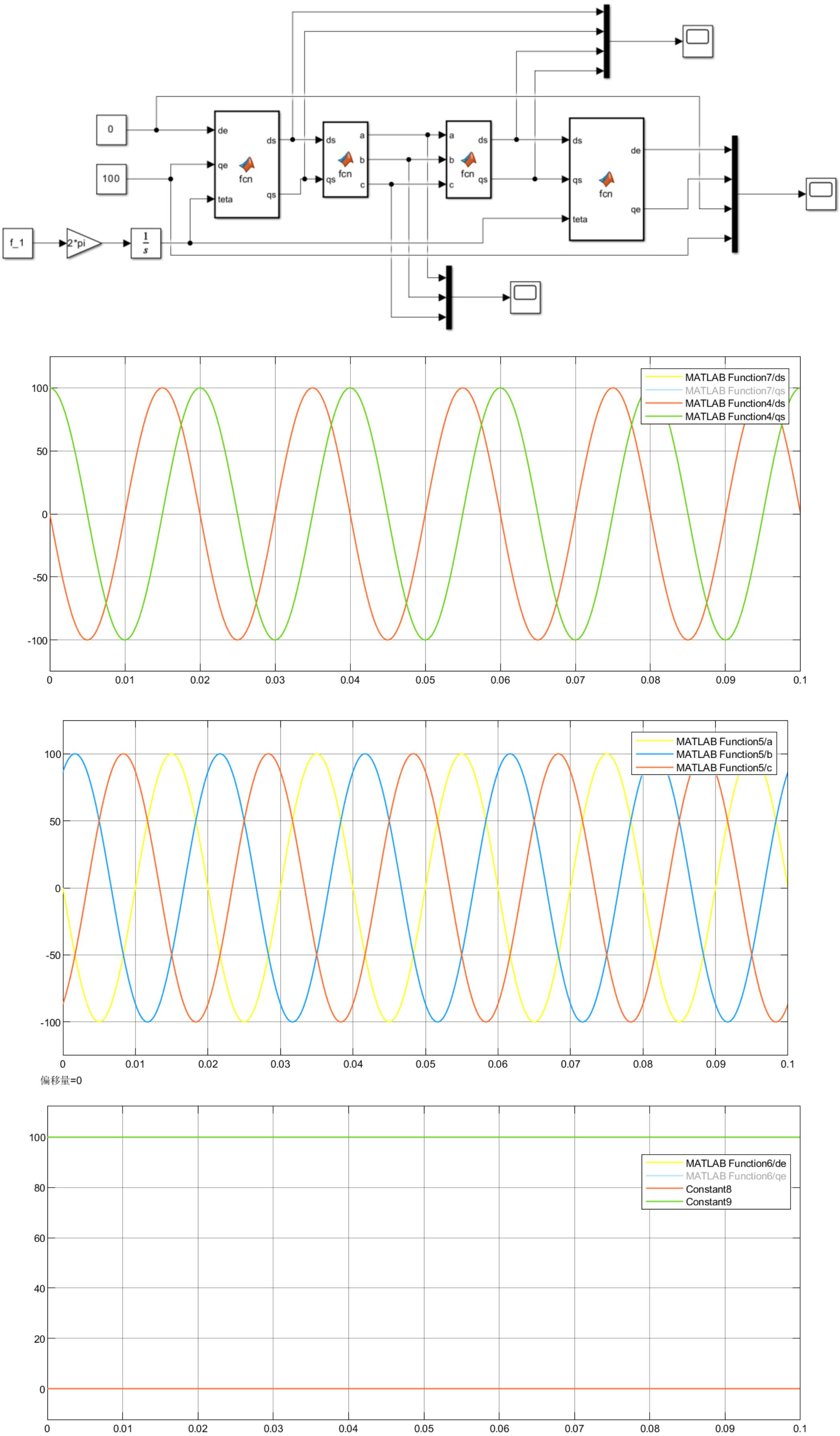


Figure 5. Right work of all these blocks.

Draw conclusions

I implemented Clarke and Park transforms in Simulink. Clarke converted 3-phase to 2-phase (αβ), verified via oscilloscope. Park then transformed to rotating (dq) frame for motor control. Both worked correctly, enabling efficient field-oriented control.

Task 2. Mathematical model of IM in stationary and synchronous reference frames and at input signals of voltage

2.1. Create mathematical model of IM in stationary reference frames. Supply this model by input sinusoidal voltage (nominal values of amplitude and frequency – see table below) and obtain graphs of speed and torque. You need to create *.m file with appropriate variables (see table with IM parameters below)

$$i_{ds}^{s} = \frac{1}{R_{s'}(1+sT_{s'})}\left(u_{ds}^{s} + \frac{K_2}{T_r}\lambda_{dr}^{s} + \omega K_2 \lambda_{qr}^{s}\right)$$

$$i_{qs}^{s} = \frac{1}{R_{s'}(1+sT_{s'})}\left(u_{qs}^{s} + \frac{K_2}{T_r}\lambda_{qr}^{s} - \omega K_2 \lambda_{dr}^{s}\right)$$

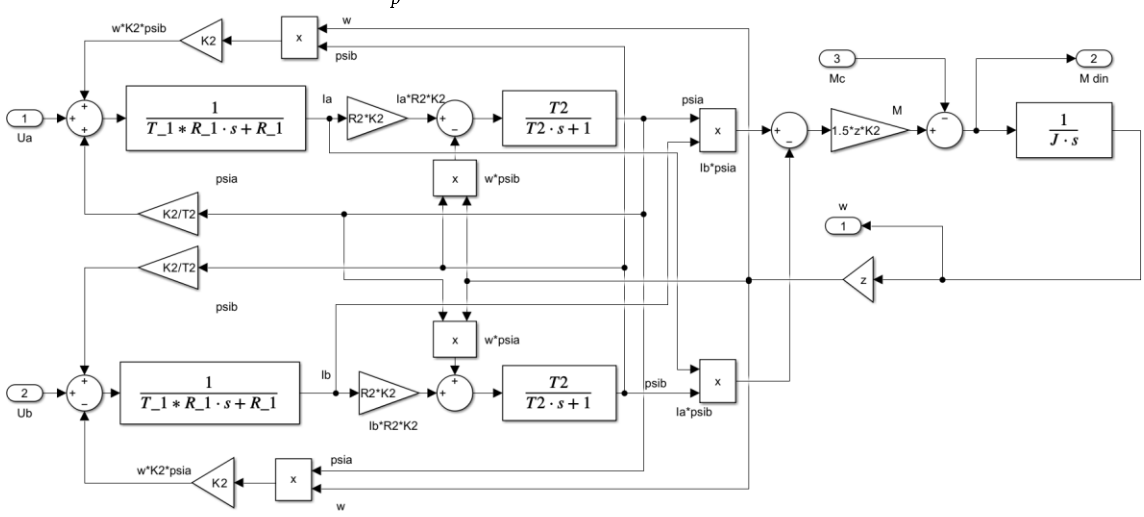
$$\lambda_{dr}^{s} = \frac{T_r}{1+sT_r}\left(R_r K_2 i_{ds}^{s} - \omega \lambda_{qr}^{s}\right)$$

$$\lambda_{qr}^{s} = \frac{T_r}{1+sT_r}\left(R_r K_2 i_{qs}^{s} + \omega \lambda_{dr}^{s}\right)$$

$$T = \frac{3}{2} z_p K_2 \left(\lambda_{dr}^{s} i_{qs}^{s} - \lambda_{qr}^{s} i_{ds}^{s}\right)$$

$$\Omega = \frac{T - T_l}{sJ}$$

$$\omega = \frac{\Omega}{z_p}$$



2.2. Create mathematical model of IM in synchronous reference frames. Supply this model by input sinusoidal voltage (nominal values of amplitude and frequency – see table below) and obtain graphs of speed and torque. You need to create *.m file with appropriate variables (see table with IM parameters below)

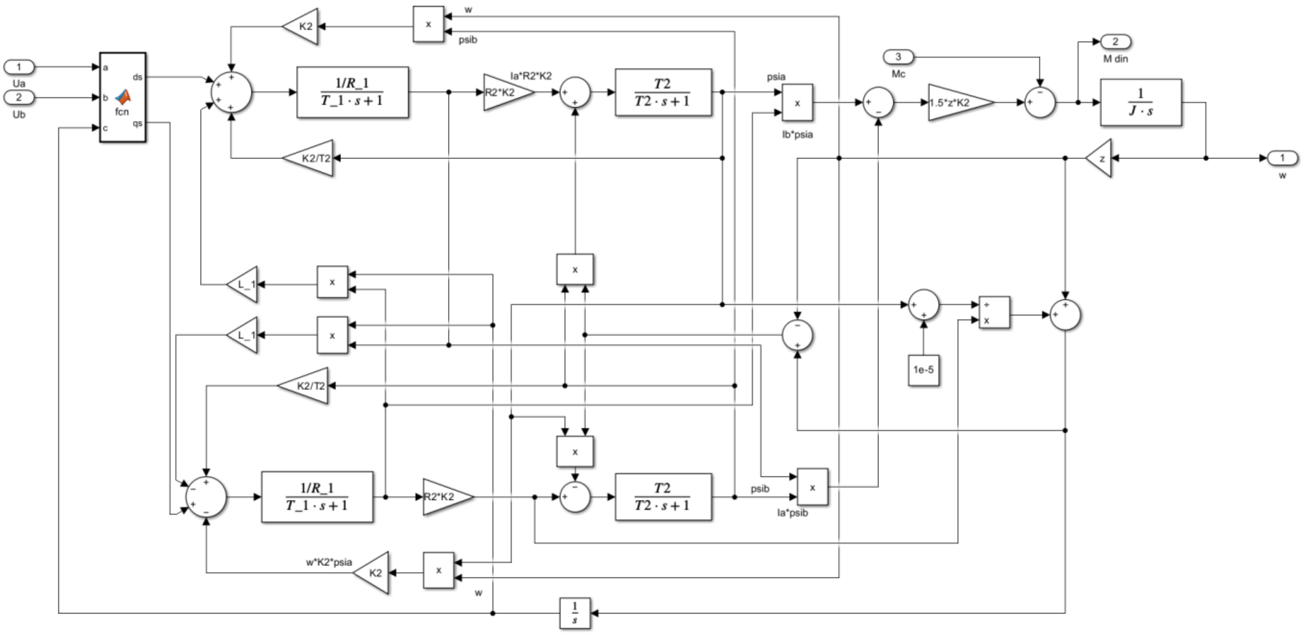
$$i_{ds}^{e}=\frac{1}{R_s(1+sT_s)}\left(v_{ds}^{e}+\omega_e L_s' i_{qs}^{e}+\frac{k_2}{T_r}\lambda_{dr}^{e}+\omega_r k_2\lambda_{qr}^{e}\right)$$

$$i_{qs}^{e}=\frac{1}{R_s(1+sT_s)}\left(v_{qs}^{e}-\omega_e L_s' i_{ds}^{e}+\frac{k_2}{T_r}\lambda_{qr}^{e}-\omega_r k_2\lambda_{dr}^{e}\right)$$

$$\lambda_{dr}^{e}=\frac{T_r}{1+sT_r}\left(R_r k_2 i_{ds}^{e}+(\omega_e-\omega_r)\lambda_{qr}^{e}\right)$$

$$\lambda_{qr}^{e}=\frac{T_r}{1+sT_r}\left(R_r k_2 i_{qs}^{e}+(\omega_e-\omega_r)\lambda_{dr}^{e}\right)$$

$$T=\frac{3}{2}\frac{P}{2}k_2\left(\lambda_{dr}^{e}i_{qs}^{e}-\lambda_{qr}^{e}i_{ds}^{e}\right)$$



2.3. Compare graphs of speed and torque in these models of IM with graphs of speed and torque for Library Simulink Blocks «Asynchronous Machine SI Units» and « Induction Motor »

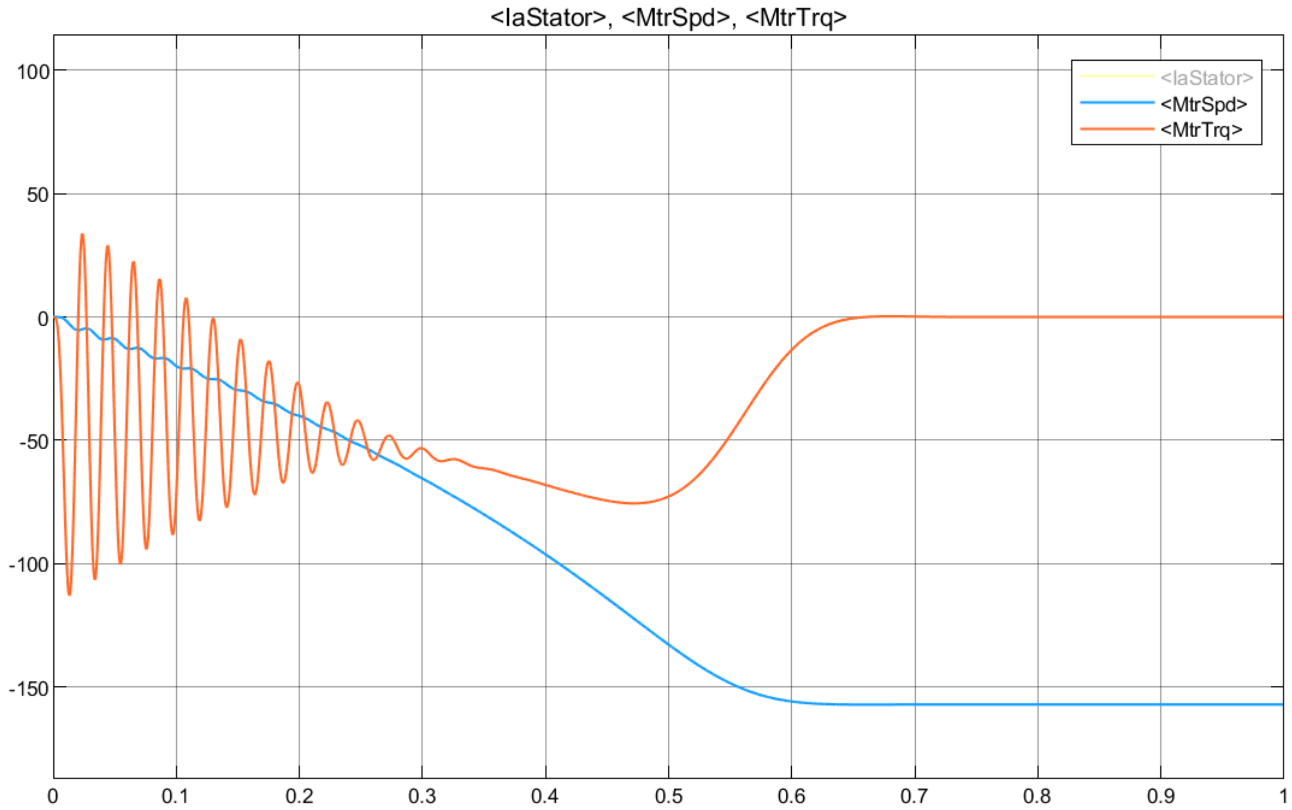


Figure 6. speed and torque in Induction Motor.

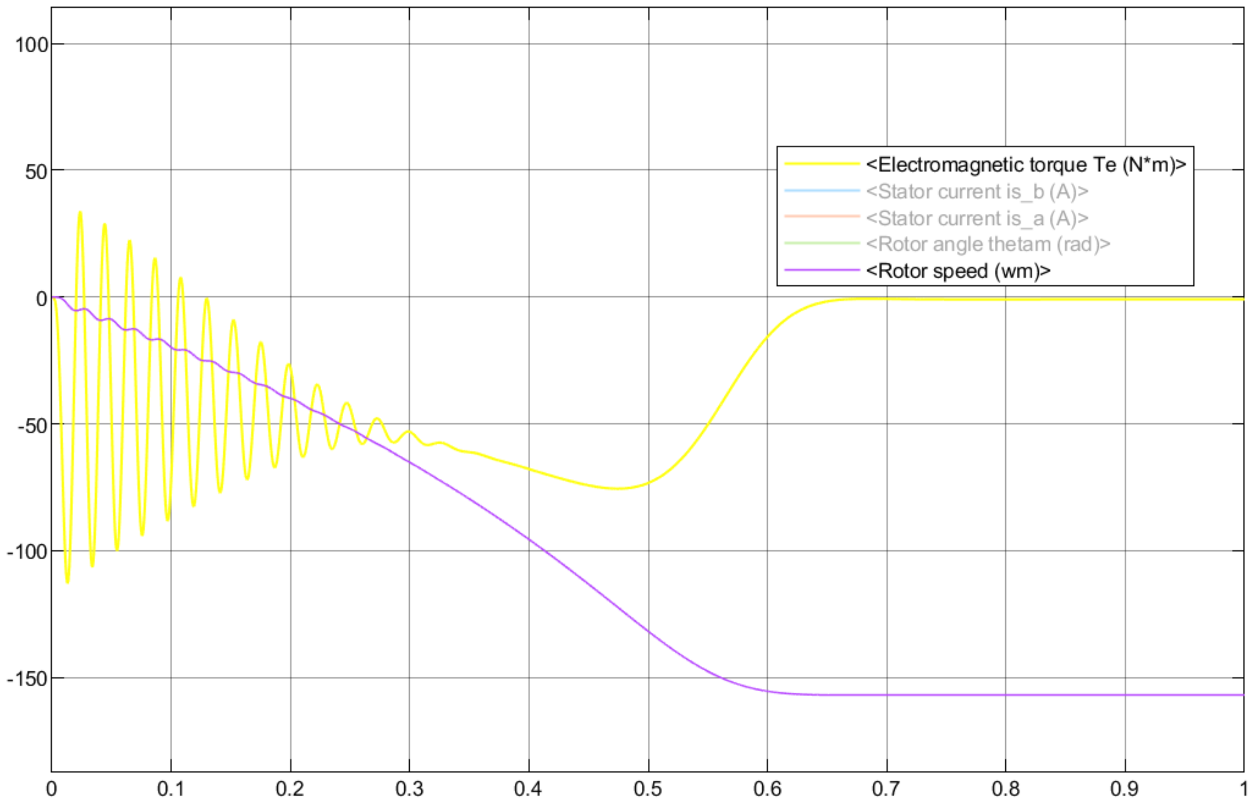


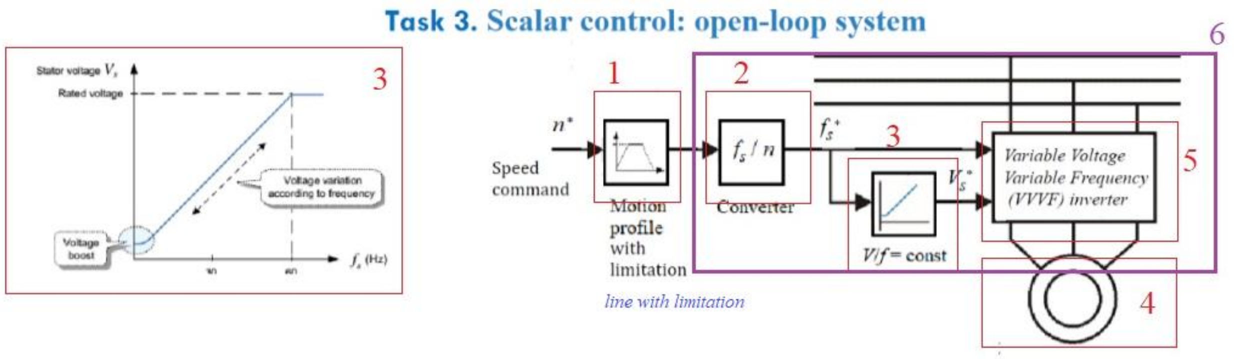
Figure 6. speed and torque in Asynchronous Machine SI Units.

Draw conclusions

The matching speed, torque, and speed-torque characteristics between the Induction Motor and Asynchronous Machine blocks confirm the models' accuracy. The coordinate system choice has no impact on the induction motor model's fundamental trends.

Task 3. Open-loop scalar control of IM (~~not necessary, additional task~~)

3.1. Create mathematical model of open loop scalar control system with any math. model of IM that created above with linear motion profile
3.2. Show results in open-loop scalar control system with/without motion profile



1 - slope (ramp with saturation)
2 - only coefficient (formula no-load speed for IM)
3 - only coefficient V/f
4 - block of IM (previous TASK2 in LAB4)
5- inverter (3ph sourse) with V_abc in the output
6- this combination of blocks is "Scalar controller" that you used in 3.1

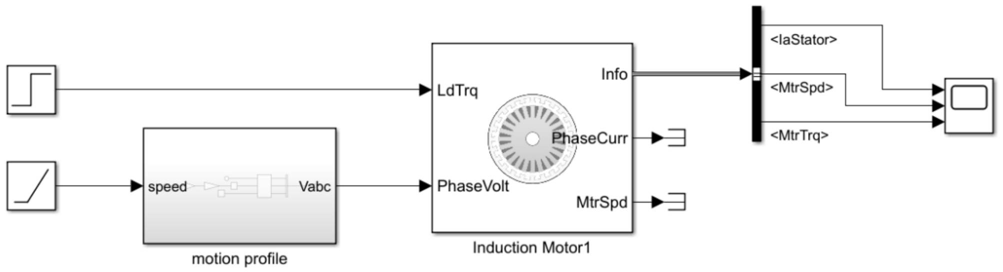


Figure 7. Scalar control: open-loop system.

Simulation of IM that created with linear motion profile

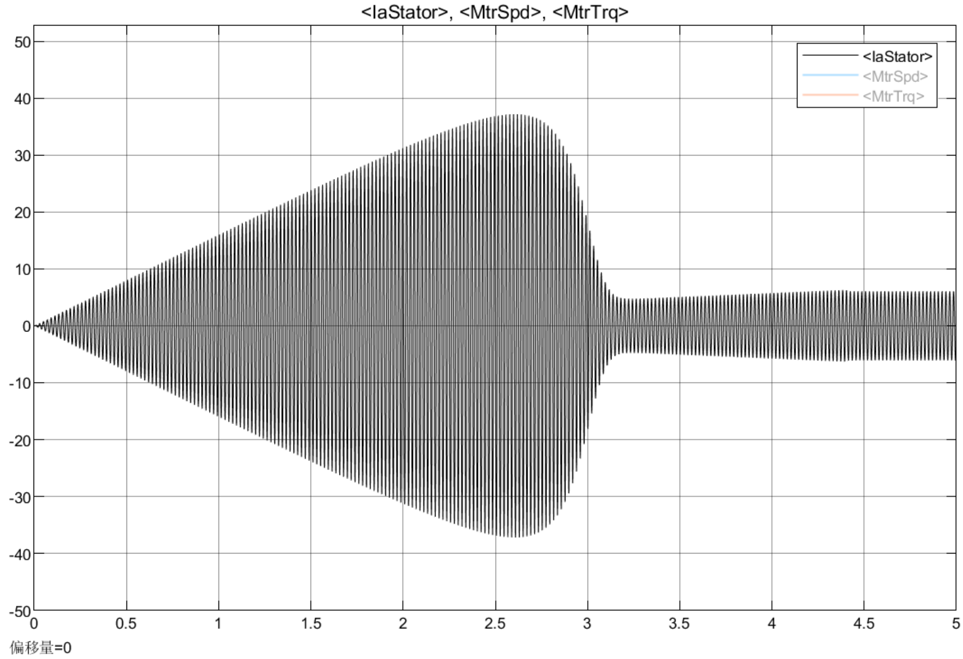


Figure 8. Current: with linear motion profile and No load.

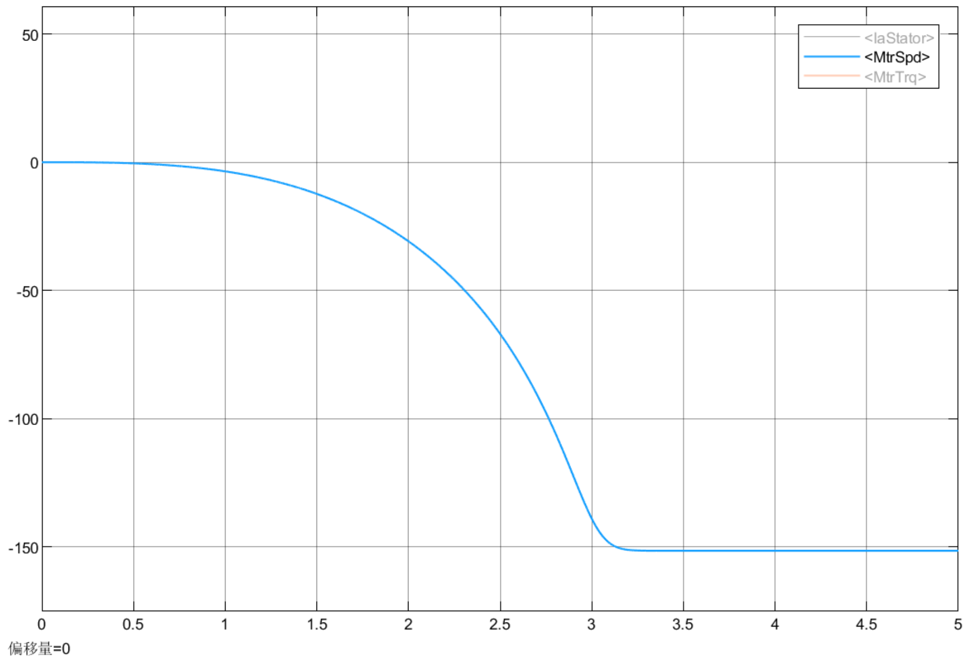


Figure 9. Speed: with linear motion profile and No load.

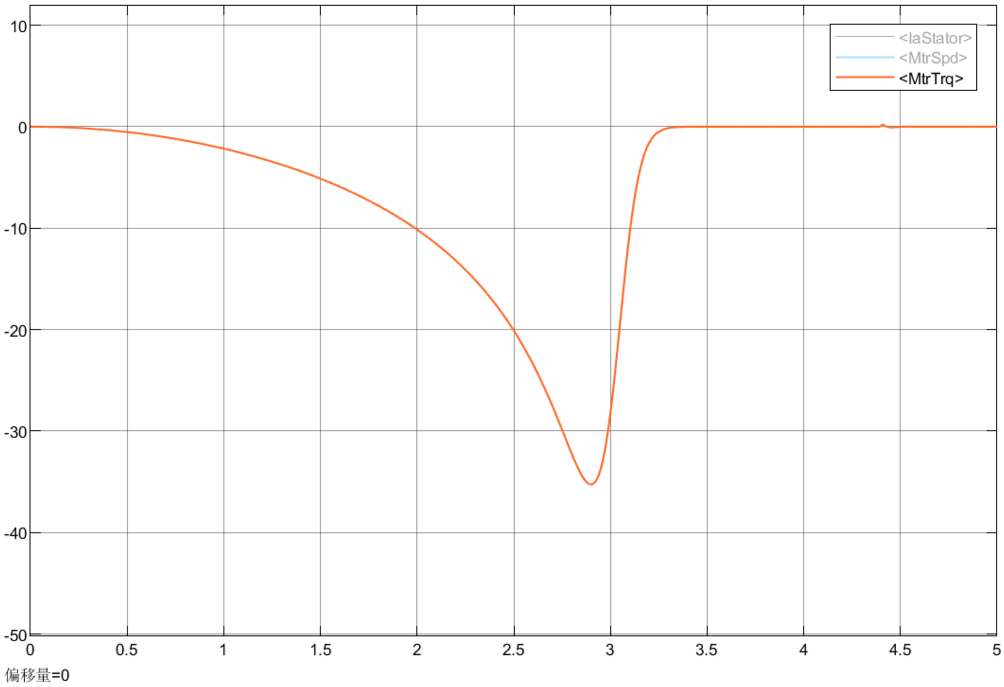


Figure 8. Torque: with motion profile and No load.

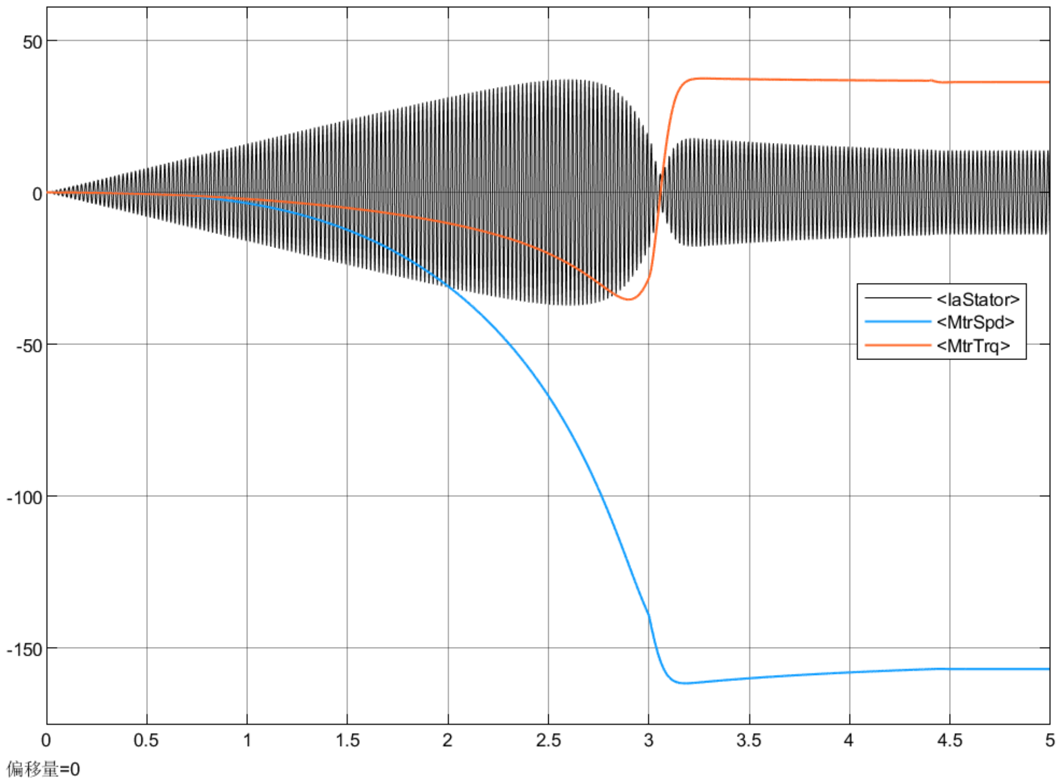


Figure 9. Scalar control: open-loop system with motion profile and load.

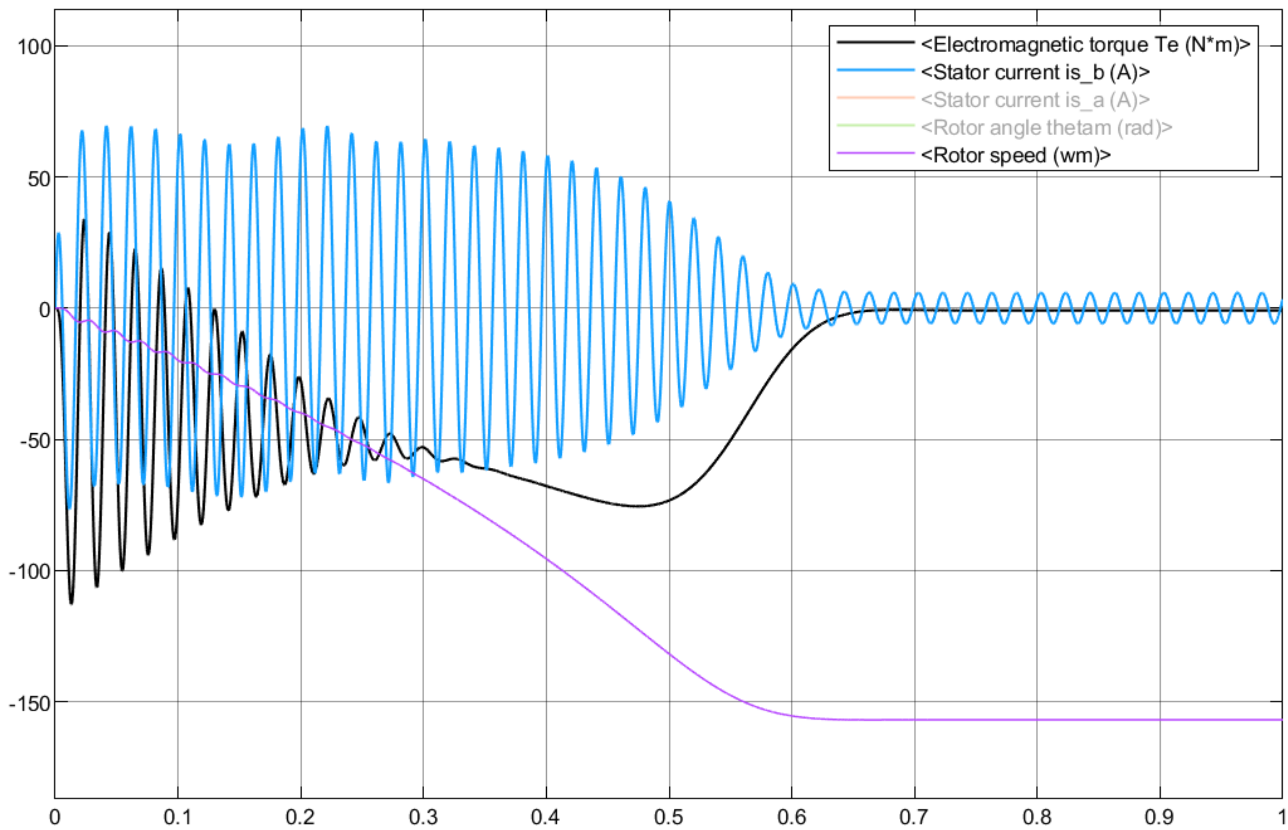


Figure 10. Scalar control: open-loop system without motion profile and No load.

Draw conclusions：

Through my simulations of the open-loop scalar control system, I observed striking differences between using and omitting motion profiles. When implementing motion profiles, I witnessed significantly smoother motor operation - the speed ramped up gradually, torque stabilized quickly after initial transients, and current peaks were substantially reduced. In contrast, without motion profiles, I noticed much harsher system behavior: abrupt speed acceleration, persistent torque oscillations, and dangerously high current spikes. These results clearly showed me how motion profiles serve as a crucial protective measure, effectively mitigating mechanical and electrical stresses during motor starts. While they do introduce a slightly slower response, I concluded this is a worthwhile trade-off for the dramatically improved operational smoothness and reduced equipment stress they provide. The simulation outcomes reinforced my understanding that motion profiles are essential for reliable, stable induction motor operation in open-loop scalar control systems.

		a_1	a_2	a_3	a_4	a_5
U_s	rated phase voltage, V	220	220	220	220	220
f_s	rated frequency , Hz	50	50	50	50	50
I_n	rated current, A	1.58	2.66	11.1	54.97	99.31
Lm	mutual inductance, H	.624	.447	.164	.0489	.0287
Ls	stator inductance, H	.663	.484	.169	.05	.0294
Lr	rotor inductance, H	.7015	.476	.1715	.051	.0297
Rs	stator resistance, Ohm	16.39	9.53	1.32	.16	.067
Rr	rotor resistance, Ohm	15.08	5.619	.922	.078	.032
J	moment of inertia , kg*m2	.00108	.00255	.0202	0.2202	0.6092
Pn	rated power, W	550	1100	5500	30000	55000
s_n	nominal slip	0.075	0.056	0.035	0.019	0.014
z	pairs of poles	2	2	2	2	2
i_lim	ratio of max current	4.5	4.5	4.5	4.5	4.5

% Data of IM type 4A80A4 (example a_1)

global Lm Lr Rr I_n J_m f_e Tn z s_n i_lim

```
U_s=220;                    % rated phase voltage, V
f_s=50                      % rated frequency , Hz
I_n=1.58                    % rated current, A
Lm=0.624                    % mutual inductance, H
Ls=0.663                    % stator inductance, H
Lls=Ls-Lm                   % stator leakage inductance, H
Lr=0.7015                   % rotor inductance, H
Llr=Lr-Lm                   % rotor leakage inductance, H
Rs=16.39                    % stator resistance, Ohm
Rr=15.08                    % rotor resistance, Ohm
J_m=0.0108                  % moment of inertia, kg*m2
Pn=550                      % rated power, W
s_n=0.075                   % nominal slip
z=2                         % pairs of poles
Tn=Pn*z/((1-s_n)*2*pi*f_s) % rated torque, Nm
i_lim=4.5                   % ratio of max current

Tr = Lr/Rr
K1 = Lm/Ls
K2 = Lm/Lr
R_s = (K2^2)*Rr+Rs
R_r = (K1^2)*Rs+Rr
L_s = Ls*(1-K1*K2)
L_r = Lr*(1-K1*K2)
T_s = L_s/R_s
T_r = L_r/R_r

U=U_s;
U_m=sqrt(2)*U_s                   % amplitude of rated phase voltage, V
```