LAB 4 Induction motor drive modelling

Student Information

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Task0. Data selection and processing

I selected the fifth motor for the experiment, but during the experiment I found that the moment of inertia in the motor data was too small, causing the system to **oscillate too much**, and I couldn't see a better effect in the experiment.

so I increased the value of J value (equivalent to adding a load to the motor):

$$J = 0.6092 \Longrightarrow J = 1.5 \tag{1}$$

Task1. Transformation between reference frames

1.1 Transformation of *abc* variables into *dq and inverse* transformation

1.1.1 Theory

- Transformation of abc variables into dqn variables in the stationary reference frame

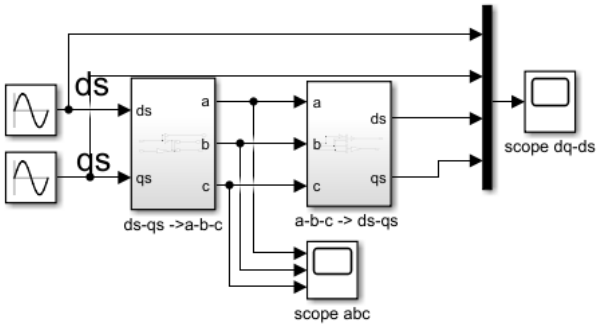
$$\begin{aligned} f_d^s &= \frac{2f_a - f_b - f_c}{3} \\ f_q^s &= \frac{1}{\sqrt{3}}(f_b - f_c) \\ f_n^s &= \frac{2(f_a + f_b + f_c)}{3} \end{aligned} \tag{2}$$

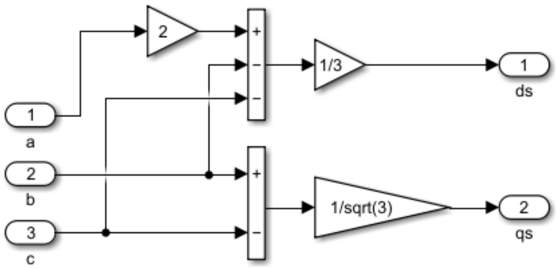
- Inverse transformation $(f_n^s = 0)$

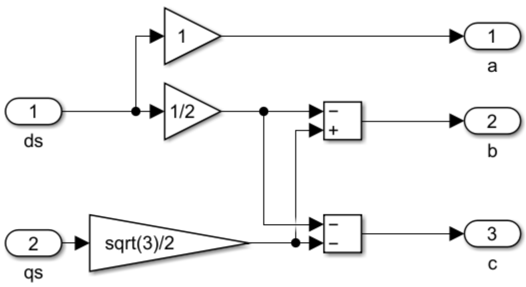
$$\begin{aligned} f_a &= f_d^s \\ f_b &= -\frac{1}{2} f_d^s + \frac{\sqrt{3}}{2} f_q^s \\ f_c &= -\frac{1}{2} f_d^s - \frac{\sqrt{3}}{2} f_q^s \end{aligned} \tag{3}$$

1.1.2 Simulink Model

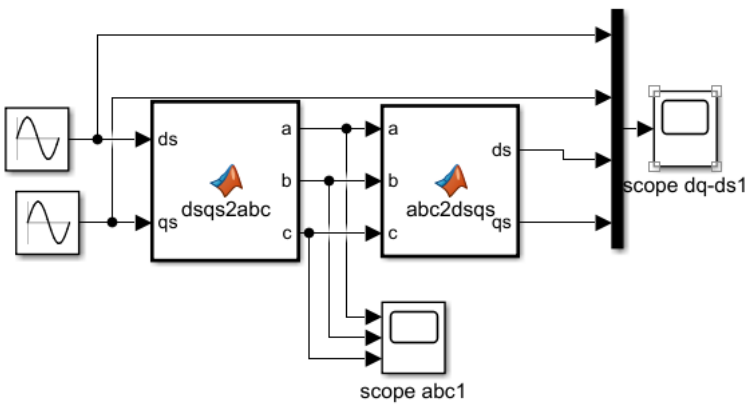
1. $1^{st} way$







2. $2^{nd} way$



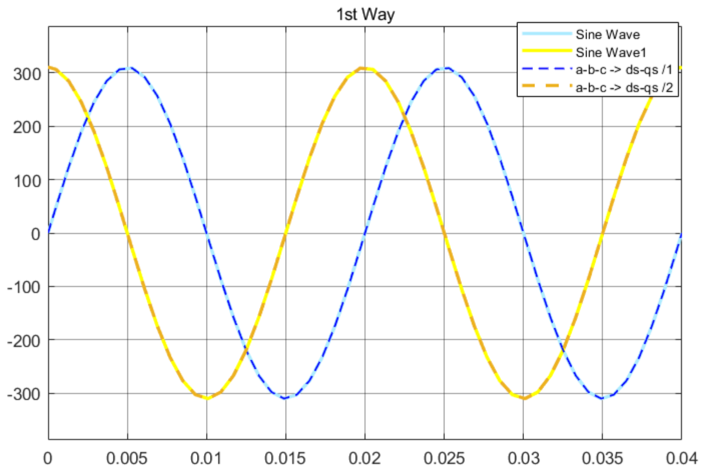

```
function [ds,qs] = abc2dsqs(a,b,c)
ds = (2*a-b-c)/3;
qs = 1/sqrt(3)*(b-c);
```

```
function [a,b,c] = dsqs2abc(ds,qs)
a = ds;
b = -1/2*ds+sqrt(3)/2*qs;
c = -1/2*ds-sqrt(3)/2*qs;
```

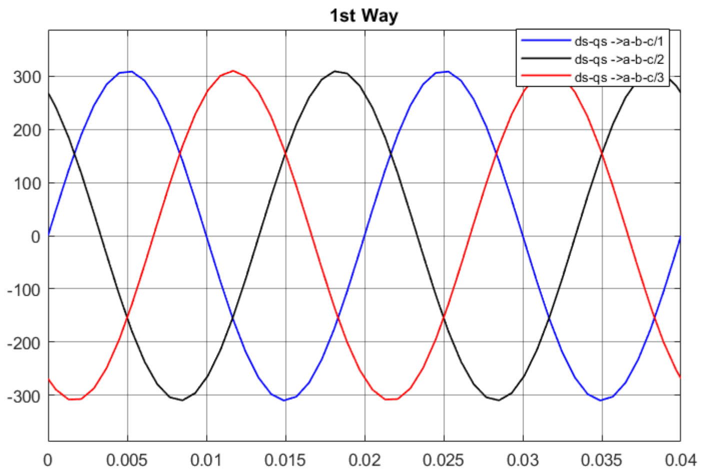
1.1.3 Simulation Result

1. $1^{st} way$

Input Signal && output(ds-qs)

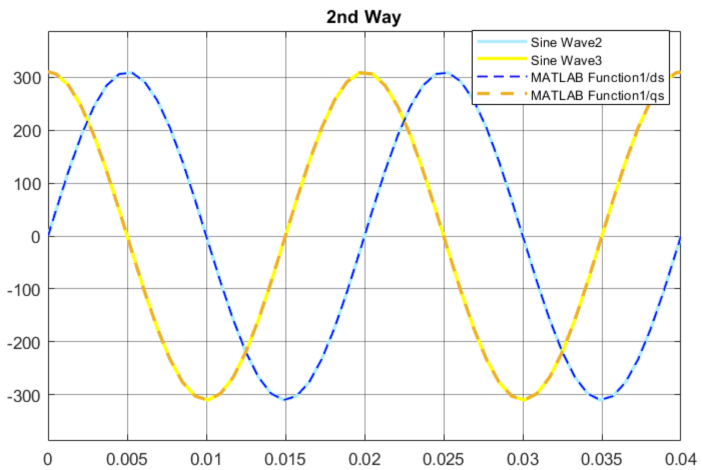


output(a-b-c)

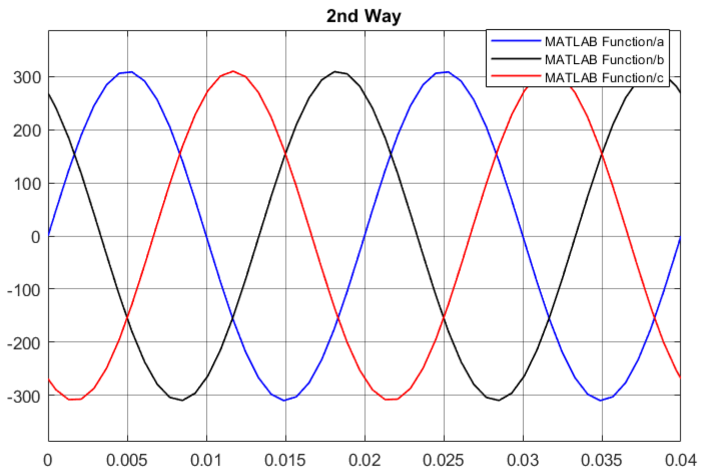


2. $2^{nd} way$

Input Signal && output(ds-qs)



output(a-b-c)



1.2 Transformation between reference frames: *Park's transformation*

1.2.1 Theory

- Transformation of stationary reference frame into rotating reference frame

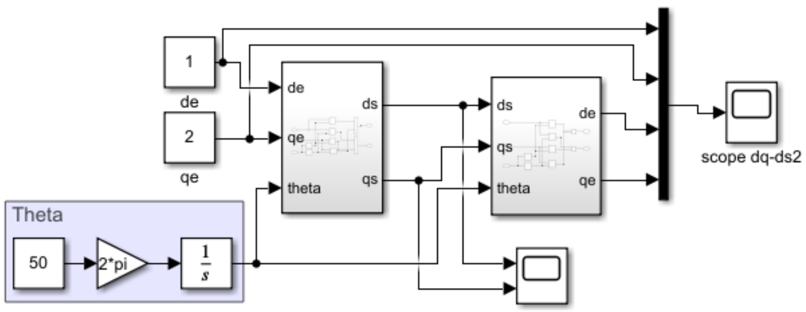
$$\begin{aligned} f_d^e &= f_d^s \cos\theta + f_q^s \sin\theta \\ f_q^e &= -f_d^s \sin\theta + f_q^s \cos\theta \end{aligned} \tag{4}$$

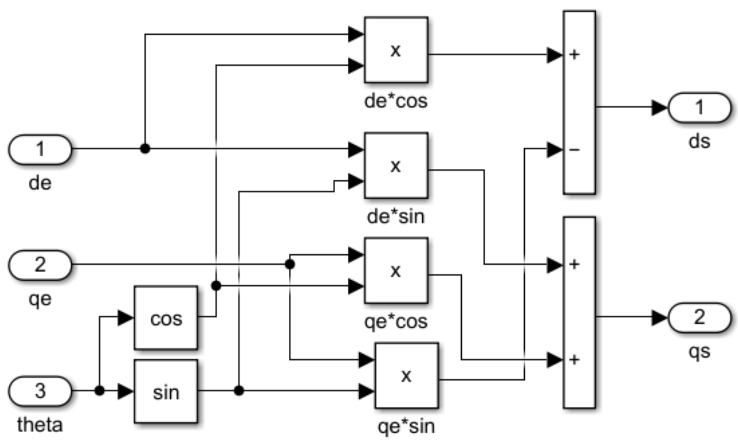
- Inverse transformation of stationary reference frame into rotating reference frame

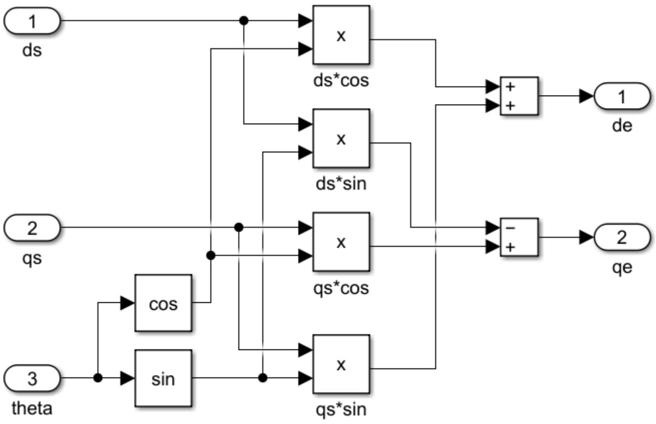
$$\begin{aligned} f_d^s &= f_d^e \cos\theta - f_q^e \sin\theta \\ f_q^s &= f_d^e \sin\theta + f_q^e \cos\theta \end{aligned} \tag{5}$$

1.2.2 Simulink Model

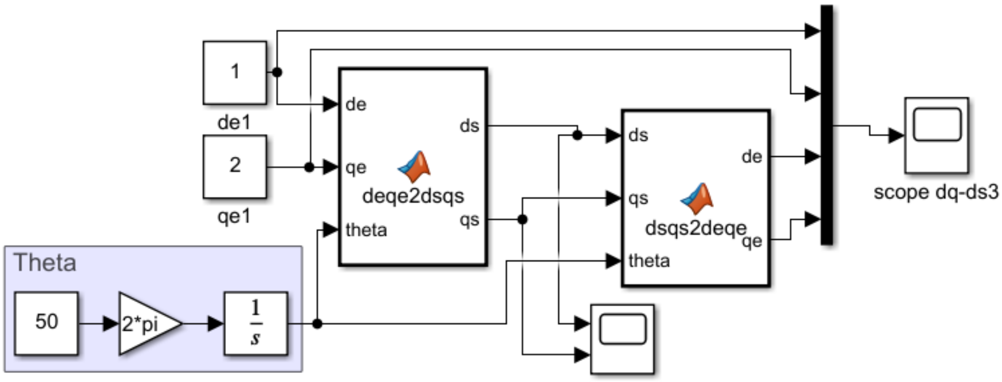
1. $1^{st} way$







2. $2^{nd} way$



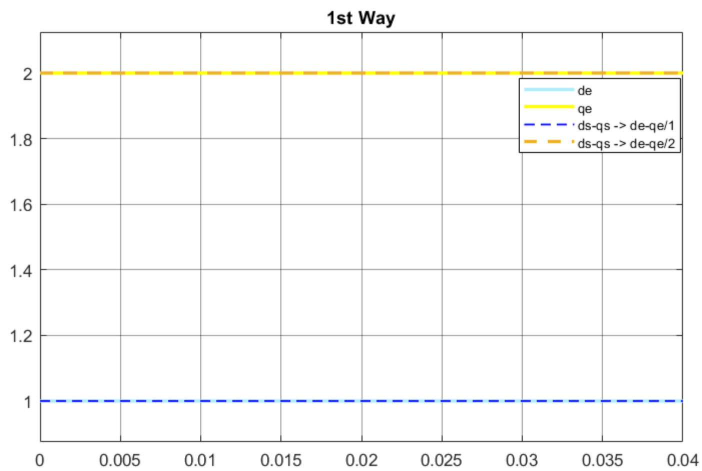

```
function [ds,qs] = deqe2dsqs(de,qe,theta)
ds = de*cos(theta)-qe*sin(theta);
qs = de*sin(theta)+qe*cos(theta);
```

```
function [de,qe] = dsqs2deqe(ds,qs,theta)
de = ds*cos(theta)+qs*sin(theta);
qe = -ds*sin(theta)+qs*cos(theta);
```

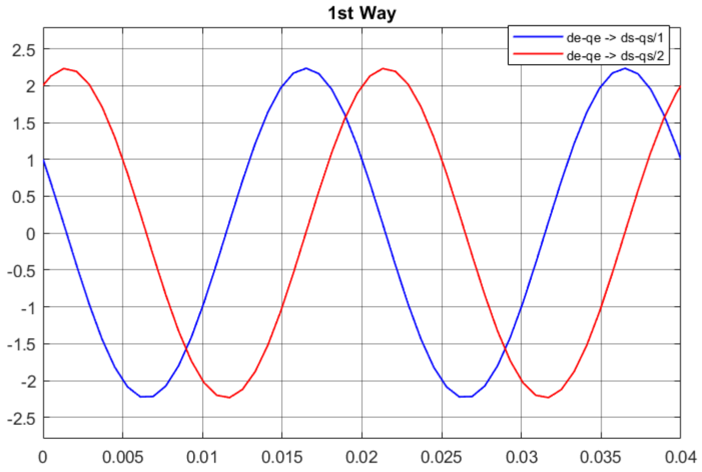
1.2.3 Simulation Result

1. $1^{st} way$

Input Signal && output(de-qe)

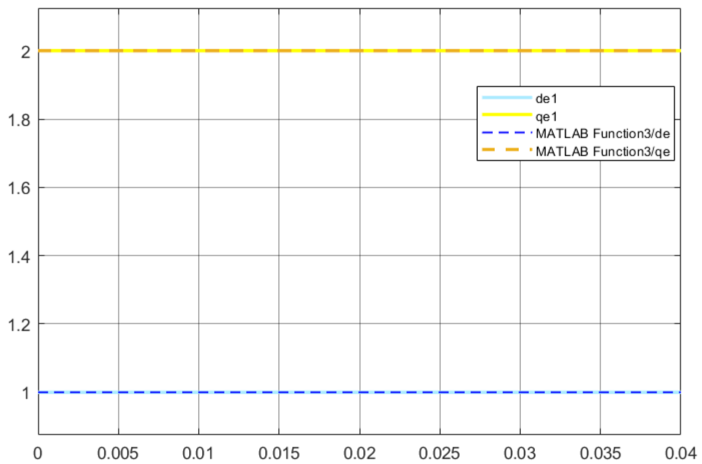


output(ds-qs)

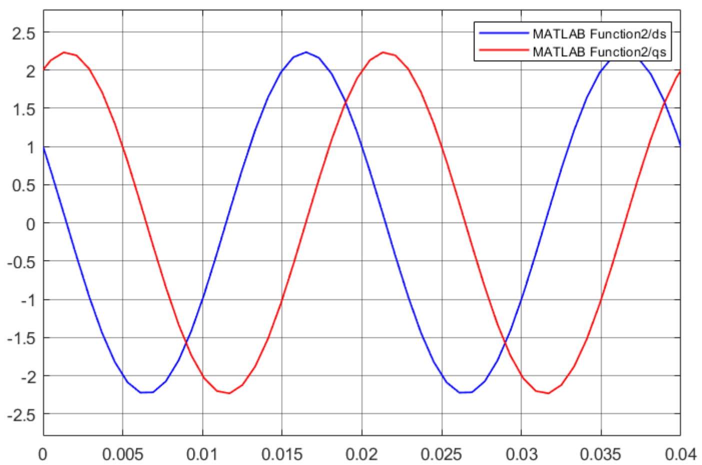


2. $2^{nd} way$

Input Signal && output(de-qe)

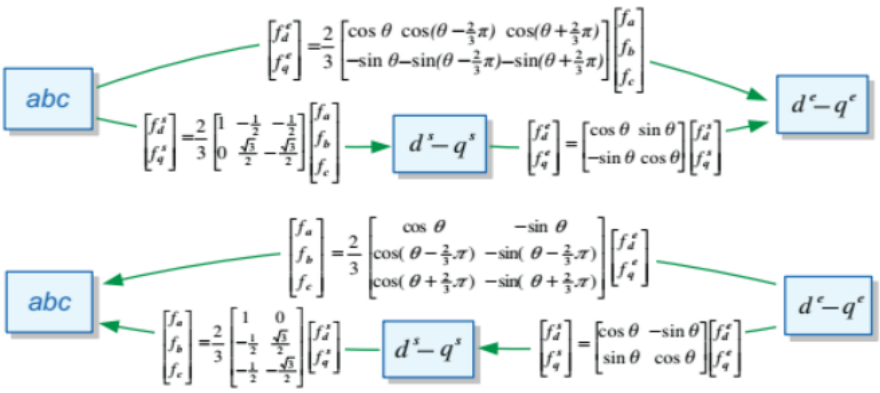


output(ds-qs)

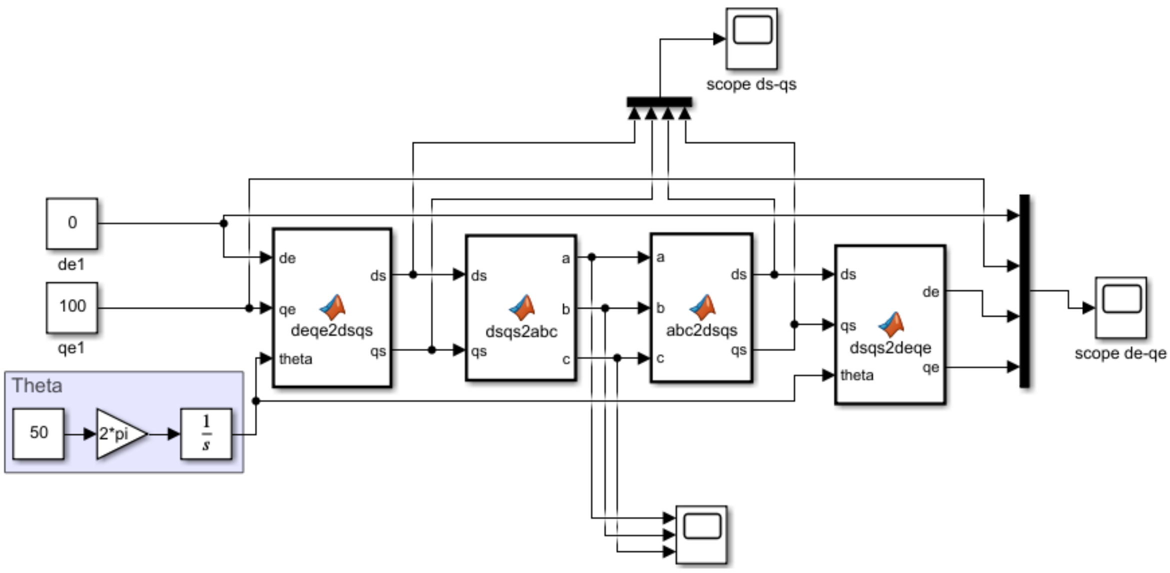


1.3 Transformation between reference frames (Park's transformation, Transformation of abc variables into dq (Clarke Transform) and inverse transformation)

1.3.1 Theory

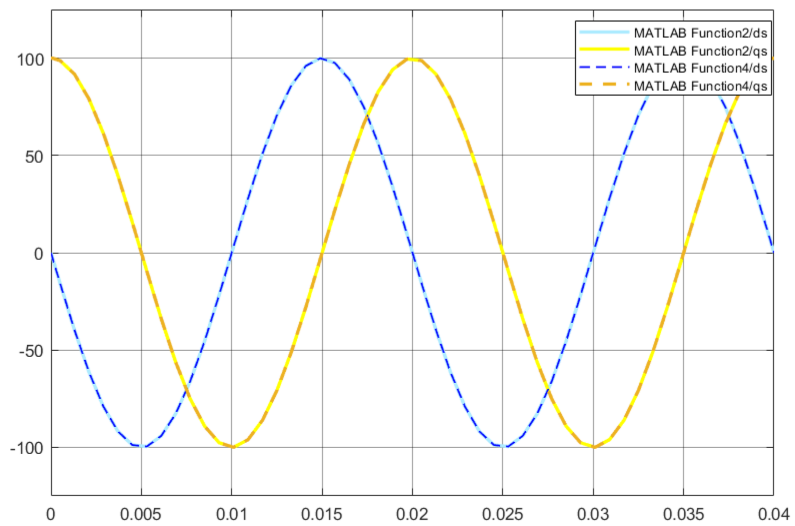


1.3.2 Simulink Model

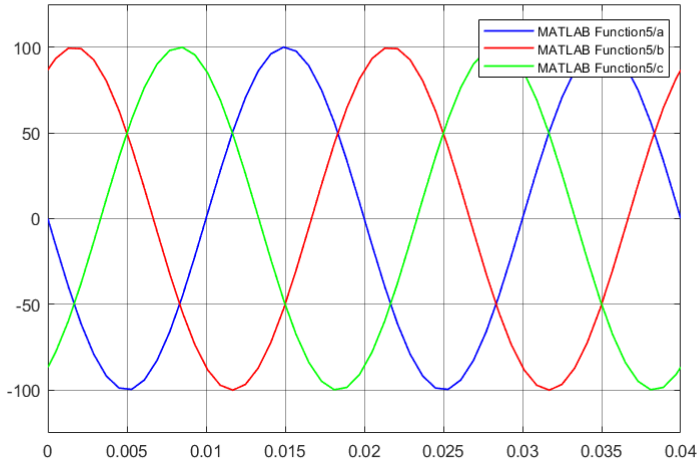


1.3.3 Simulation Result

Output signal(ds-qs)



output(a-b-c)



Task2. Mathematical model of IM in stationary and synchronous reference frames

2.1 Model of IM in stationary reference frame

2.1.1 Mathematical Model of IM in stationary reference frame

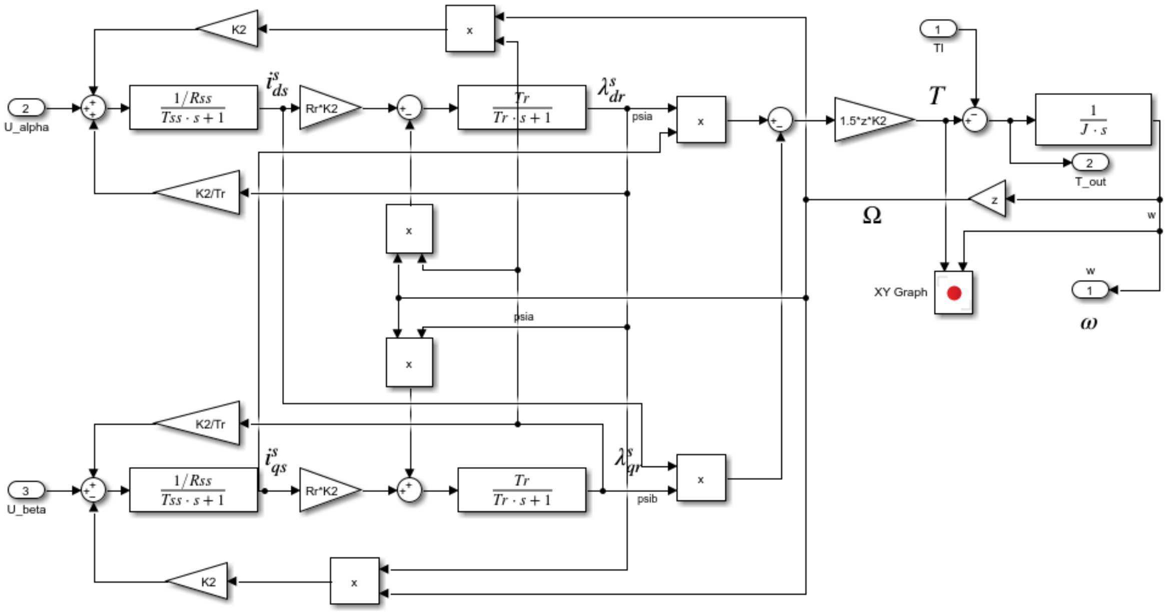
Model:

$$\begin{cases} i_{ds}^s = \frac{1}{R_{ss}(1+sT_{ss})}\left(u_{ds}^s + \frac{K_2}{T_r}\lambda_{dr}^s + \Omega K_2 \lambda_{qr}^s\right) \\ i_{qs}^s = \frac{1}{R_{ss}(1+sT_{ss})}\left(u_{qs}^s + \frac{K_2}{T_r}\lambda^s{}_{qr} - \Omega K_2 \lambda_{dr}^s\right) \\ \lambda_{dr}^s = \frac{T_r}{1+sT_r}\left(R_r K_2 i_{ds}^s - \Omega \lambda_{qr}^s\right) \\ \lambda_{qr}^s = \frac{T_r}{1+sT_r}\left(R_r K_2 i_{qs}^s + \Omega \lambda_{dr}^s\right) \\ T = \frac{3}{2} z_p K_2 \left(\lambda_{dr}^s i_{qs}^s - \lambda_{qr}^s i_{ds}^s\right) \\ \Omega = \frac{T-T_l}{sJ} \quad \omega = \frac{\Omega}{z_p} \end{cases} \tag{6}$$

Parameter calculation in the model :

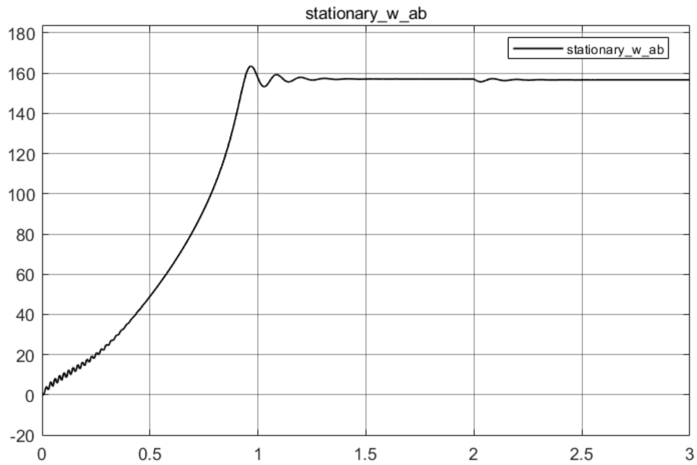
$$\begin{cases} \mathrm{Tr} = \mathrm{Lr}/\mathrm{Rr} \\ \mathrm{K}_1 = \mathrm{Lm}/\mathrm{Ls} \\ \mathrm{K}_2 = \mathrm{Lm}/\mathrm{Lr} \\ \mathrm{Rss} = \left(\mathrm{K}_2^2\right) \cdot Rr + \mathrm{Rs} \\ \mathrm{Lss} = \mathrm{Ls} \cdot (1 - \mathrm{K}_1 \cdot \ \mathrm{K}_2) \\ \mathrm{Tss} = \mathrm{Lss}/\mathrm{Rss} \end{cases} \tag{7}$$

2.1.2 Simulink Model

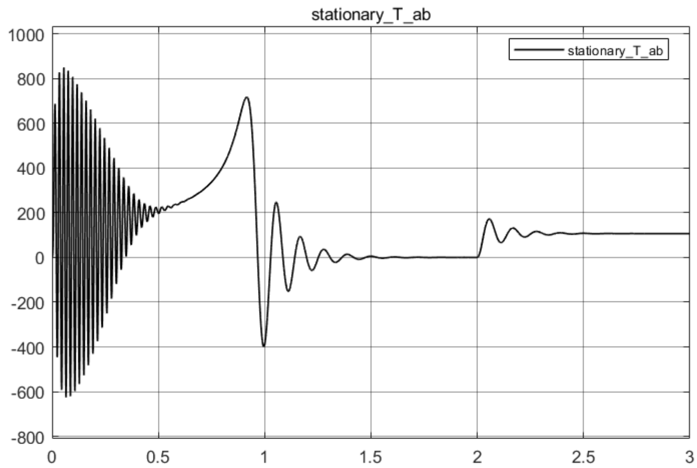


2.1.3 Simulation Result

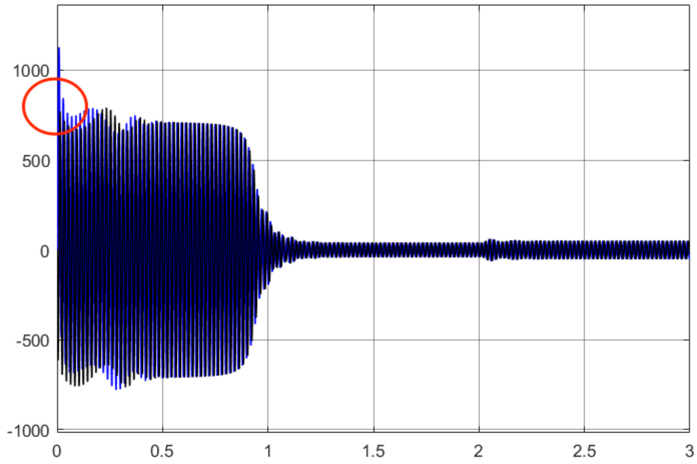
1. Time-Speed



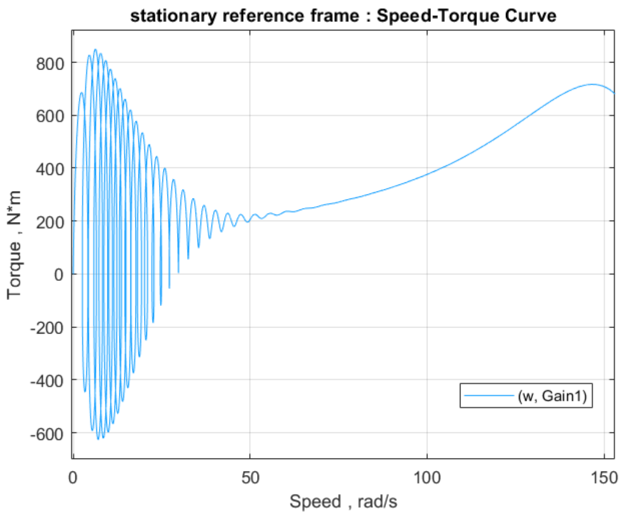
2. Time-Torque



3. Time-Current



4. Speed-Torque



2.2 Model of IM in synchronous reference frame

2.2.1 Mathematical Model of IM in synchronous reference frame

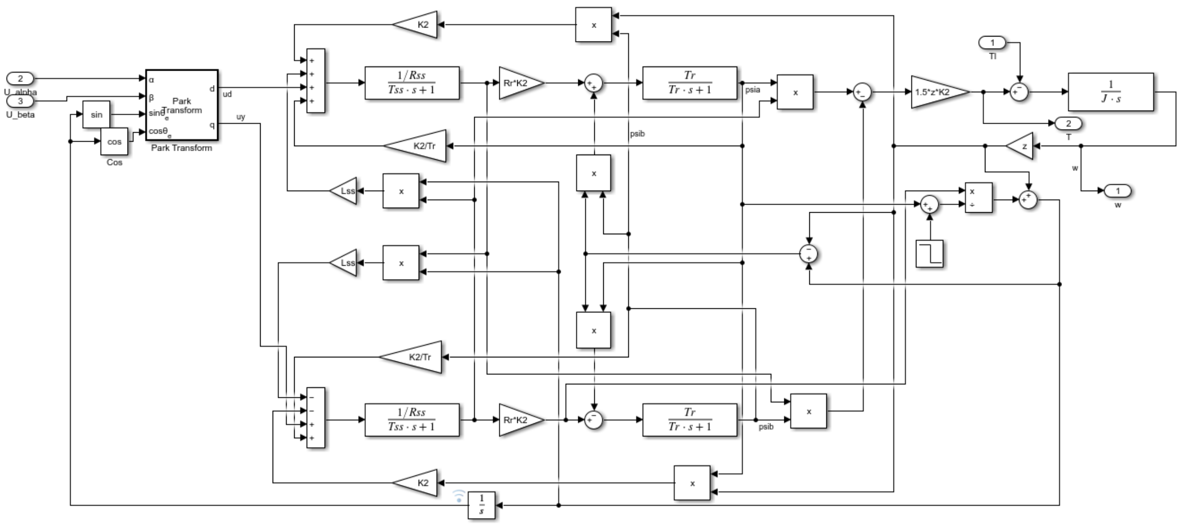
Model:

$$
\begin{cases}
i_{ds}^{e} = \frac{1}{R_{ss}(1+sT_{ss}s)}\left(v_{ds}^{e} + \Omega_e L_{ss} i_{qs}^{e} + \frac{k_2}{T_r}\lambda_{dr}^{e} + \Omega_r k_2 \lambda_{qr}^{e}\right) \\
i_{qs}^{e} = \frac{1}{R_{ss}(1+sT_{ss}s)}\left(v_{qs}^{e} - \Omega_e L'_s i_{ds}^{e} + \frac{k_2}{T_r}\lambda_{qr}^{e} - \Omega_r k_2 \lambda_{dr}^{e}\right) \\
\lambda_{dr}^{e} = \frac{T_r}{(1+sT_r)}\left(R_r k_2 i_{ds}^{e} + (\Omega_e - \Omega_r)\lambda_{qr}^{e}\right) \\
\lambda_{qr}^{e} = \frac{T_r}{(1+sT_r)}\left(R_r k_2 i_{qs}^{e} + (\Omega_e - \Omega_r)\lambda_{dr}^{e}\right) \\
T = \frac{3}{2}\frac{P}{2}k_2\left(\lambda_{dr}^{e} i_{qs}^{e} - \lambda_{qr}^{e} i_{ds}^{e}\right) \\
\Omega_e - \Omega_r = \frac{T - T_l}{sJ} \quad \omega = \frac{\Omega_e - \Omega_r}{z_p}
\end{cases}
\tag{8}
$$

Parameter calculation in the model :

$$
\begin{cases}
\mathrm{Tr} = \mathrm{Lr}/\mathrm{Rr} \\
\mathrm{K}_1 = \mathrm{Lm}/\mathrm{Ls} \\
\mathrm{K}_2 = \mathrm{Lm}/\mathrm{Lr} \\
\mathrm{Rss} = \left(\mathrm{K}_2^2\right) \cdot Rr + \mathrm{Rs} \\
\mathrm{Lss} = \mathrm{Ls} \cdot (1 - \mathrm{K}_1 \cdot \mathrm{K}_2) \\
\mathrm{Tss} = \mathrm{Lss}/\mathrm{Rss}
\end{cases}
\tag{9}
$$

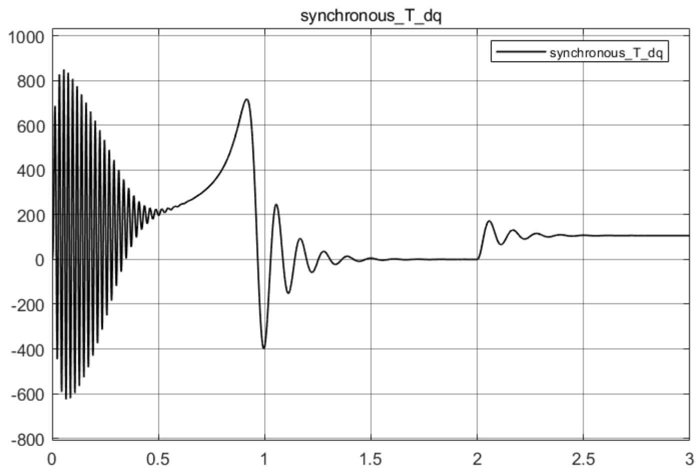
2.2.2 Simulink Model



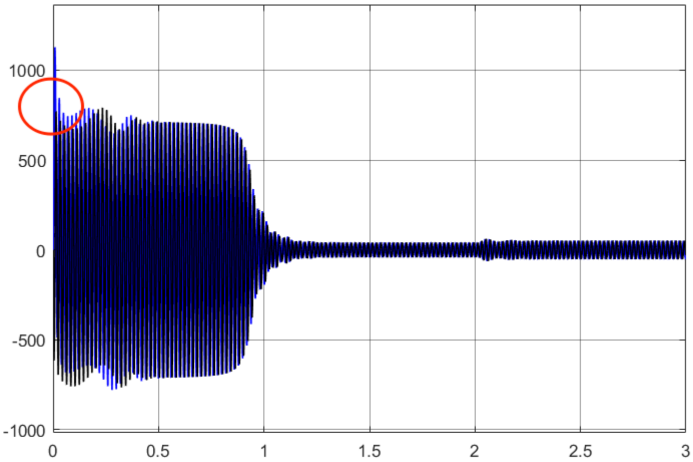
2.2.3 Simulation Result

1. Time-Speed

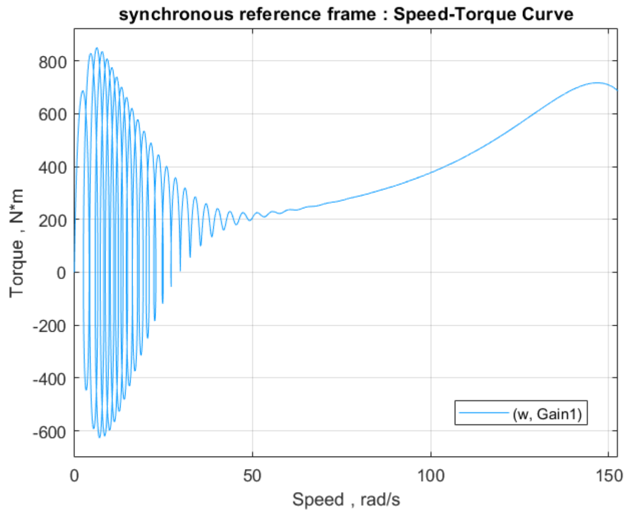
2. Time-Torque



3. Time-Current

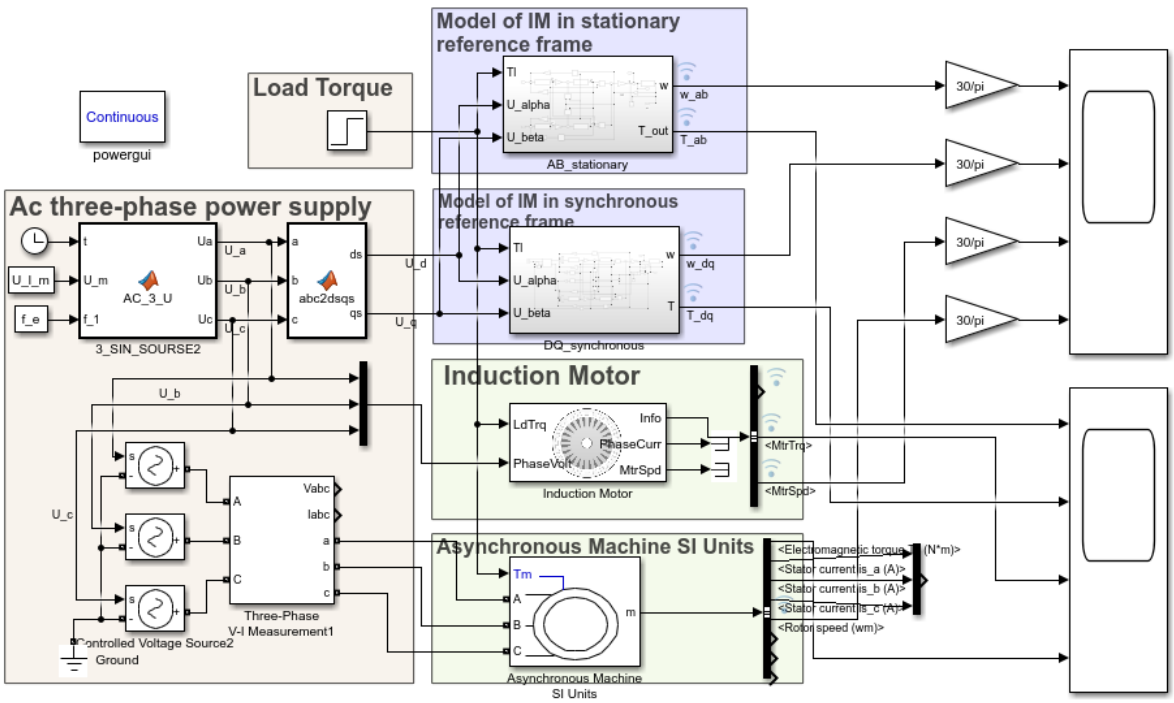


4. Speed-Torque



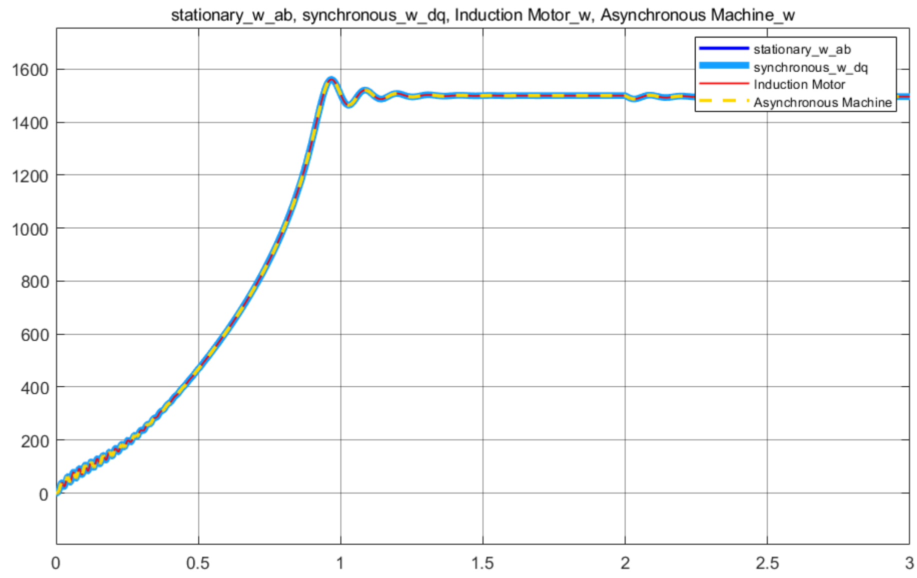
2.3 Compare graphs of speed and torque in Different mathematical and physical models

2.3.1 Simulink Model

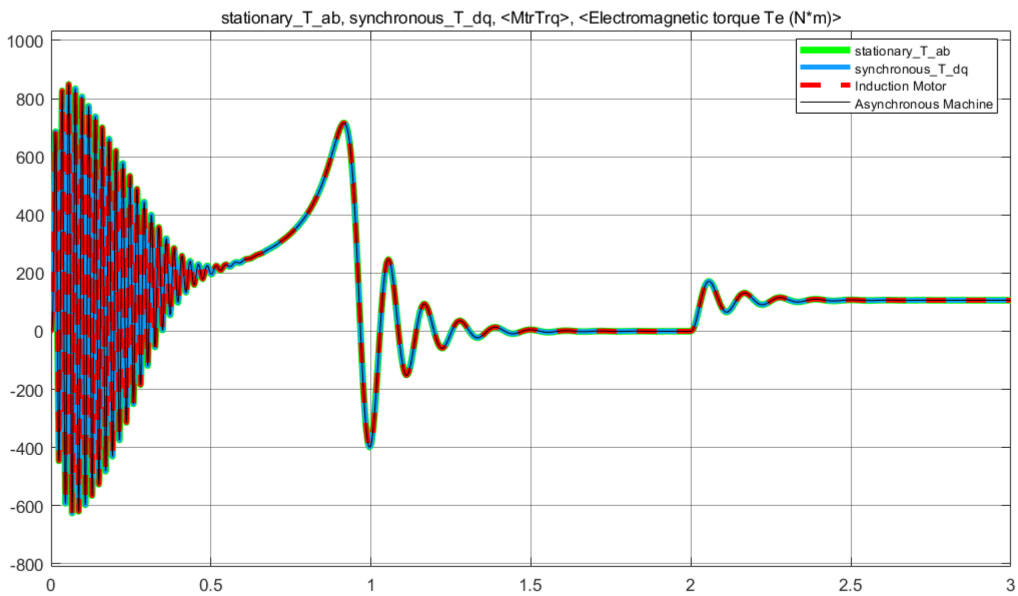


2.3.2 Simulation Result

1. Time-Speed



2. Time-Torque

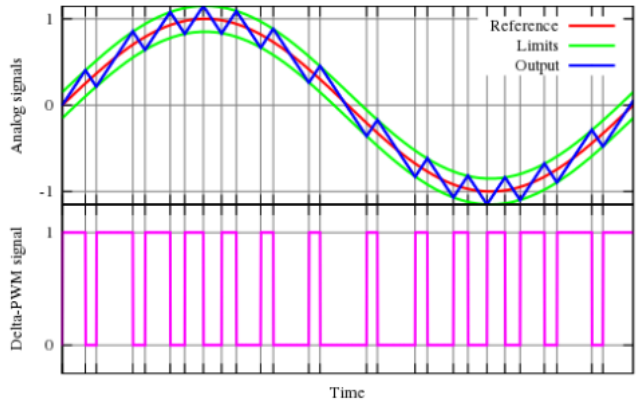


2.4 Add in scheme hysteresis current regulators.

2.4.1 Theory

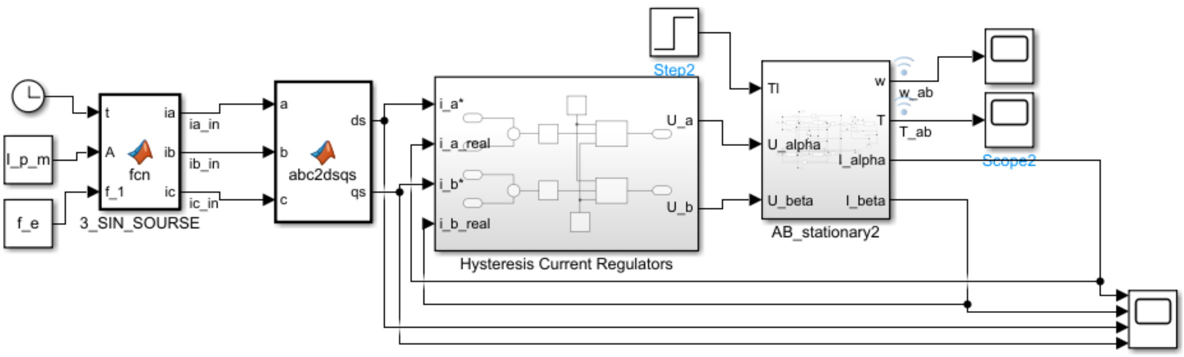
The method can be reduced to "tracking" the current in the region of permissible deviations from the current value of the set or reference signal.

As shown in the figure below, this method has a domain that allows the current to change. Once the current change exceeds this domain, the switch is toggled to control the current.

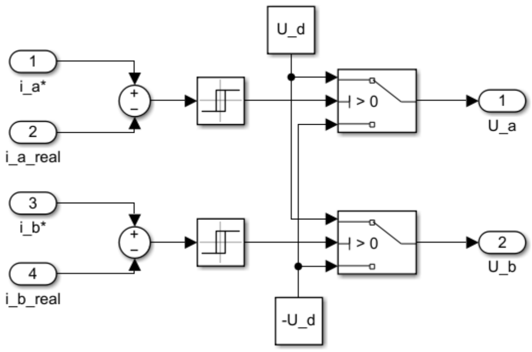


2.4.2 Simulink Model

Model :

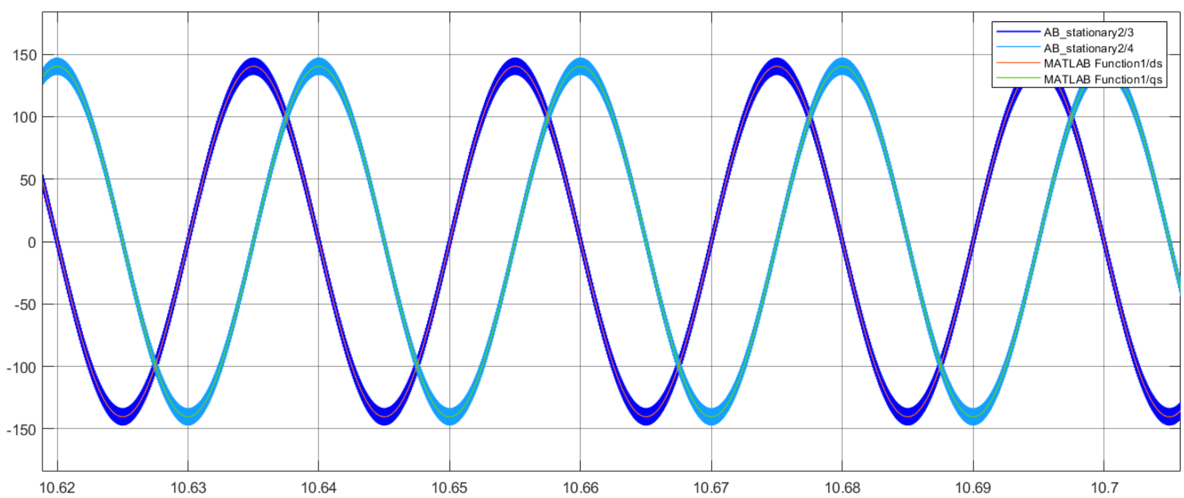


Hysteresis Current Regulators :

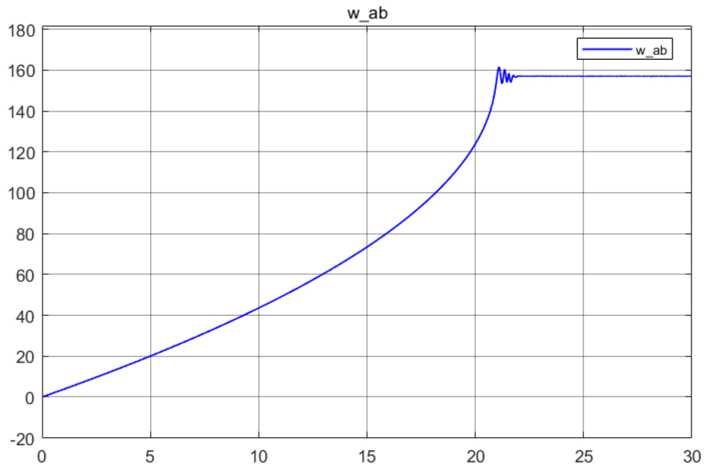


2.4.3 Simulation Result

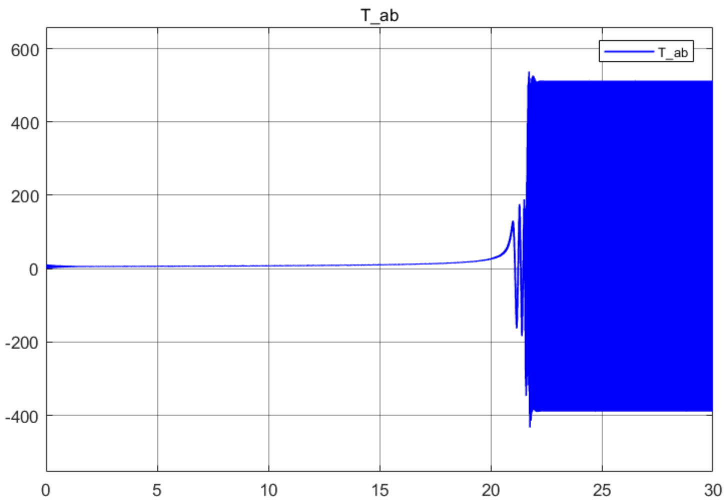
1. Current



2. Time-Speed



3. Time-Torque



Task3. Scalar control of IM: open-loop system

3.1 Theory

This lab uses the constant voltage-frequency ratio control (V/f control) in the scalar control of the open-loop system.

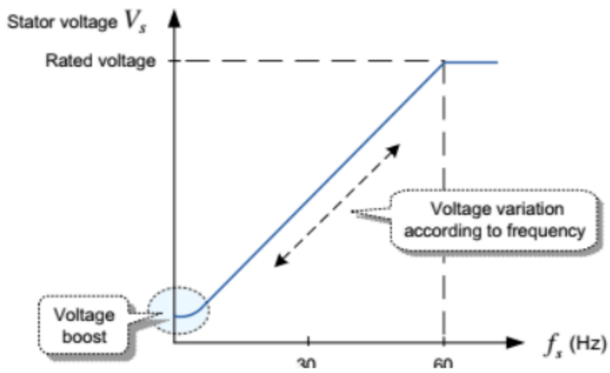
Scalar Control :

The so-called scalar control is to control only the size of the variable.

voltage-frequency ratio control (V/f control):

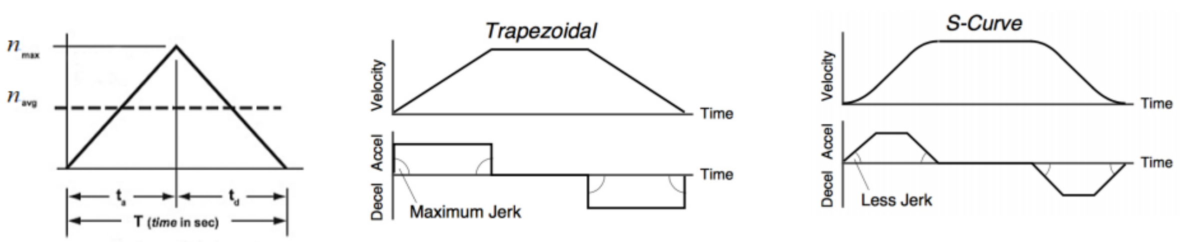
V/F Ratio constant control is a basic control method for variable frequency speed regulation of asynchronous motors. Its basic starting point is to control the constant magnetic flux and realize torque control.

The basic principle of V/F control is: when the motor operating frequency is high, the stator voltage and the stator frequency are kept in a year-on-year change. When the operating frequency of the motor is low, in order to offset the influence of the stator winding voltage drop on the motor torque, the stator voltage is properly compensated to ensure an approximately constant magnetic flux.

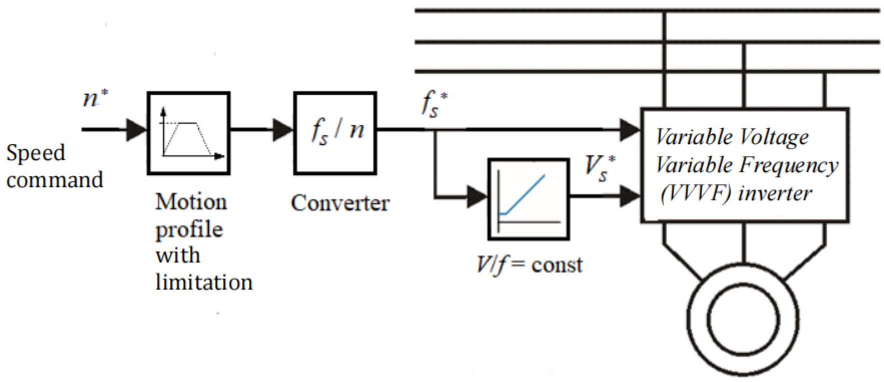


Motion profiles :

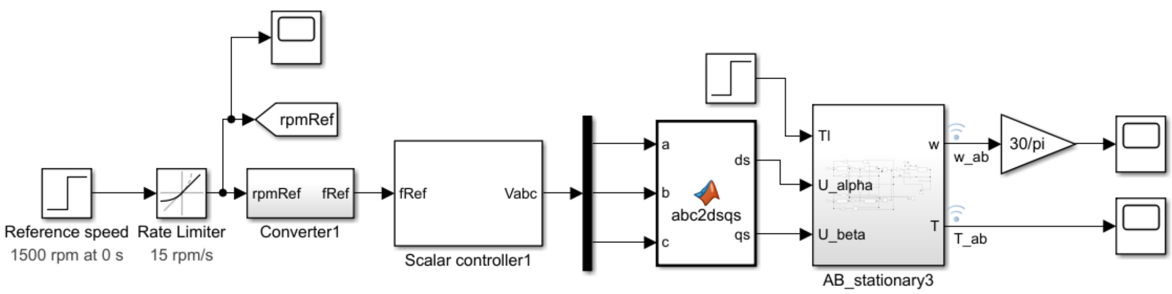
forms a slowly increasing input signal. In this case, the increase in speed in the electric drive will not lead to large amplitude in the torque and current that are observed during direct start



Control system block diagram:



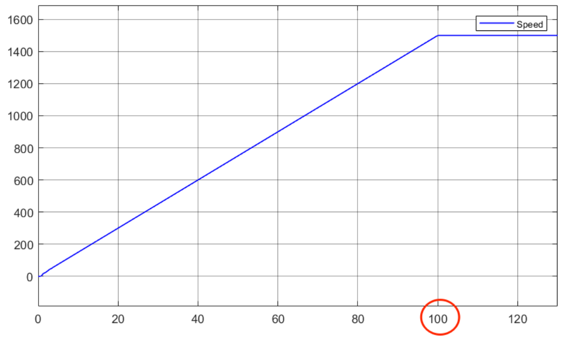
3.2 Simulink Model

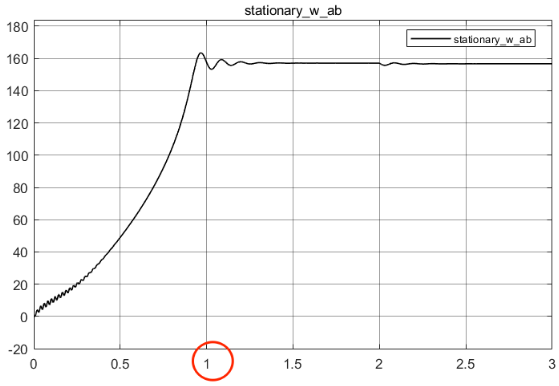


3.3 Simulation Result

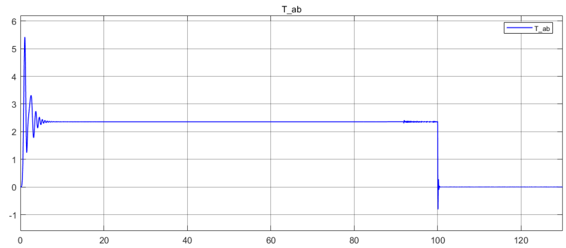
The left side of the figure below is the result of using scalar control, and the right side is the result of not using control

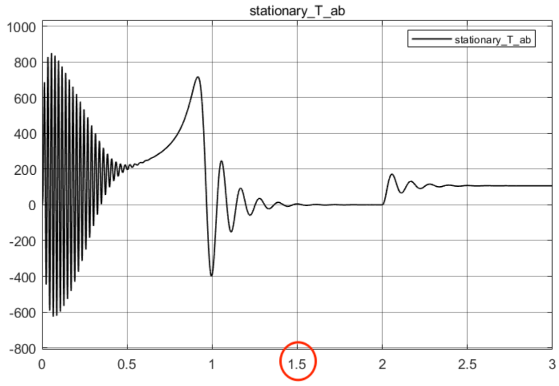
1. Time-Speed



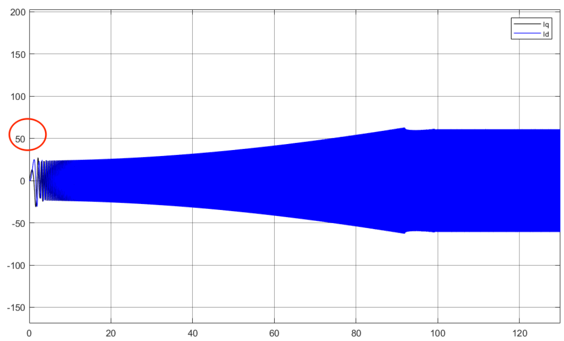


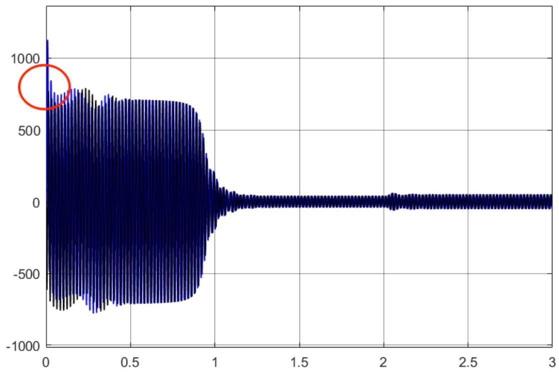
2. Time-Torque





3. Time-Current





4. Conclusion

1. Using coordinate transformation, we can easily establish the equation of the motor and model it.
2. From the experimental results, it can be seen that when the motor is directly started, the speed, current and torque of the motor all oscillate greatly. In real life, this situation is easy to cause damage to the motor because it exceeds the maximum allowable range of the motor.
3. It can be seen from the experimental results that the use of current hysteresis regulators can make the current of the motor fluctuate within a small range of rated current, and the speed increase is slower than direct start, but the torque output fluctuates greatly
4. It can be seen from the experimental results that after using the voltage-frequency ratio control in Scalar control, the fluctuation range of torque and current is greatly reduced, which can effectively protect the safety of the motor during startup