A2- Modeling of PM machine

The block diagram of the Park model of sinusoidal Permanent-Magnet synchronous machines (PMSM) is given below.

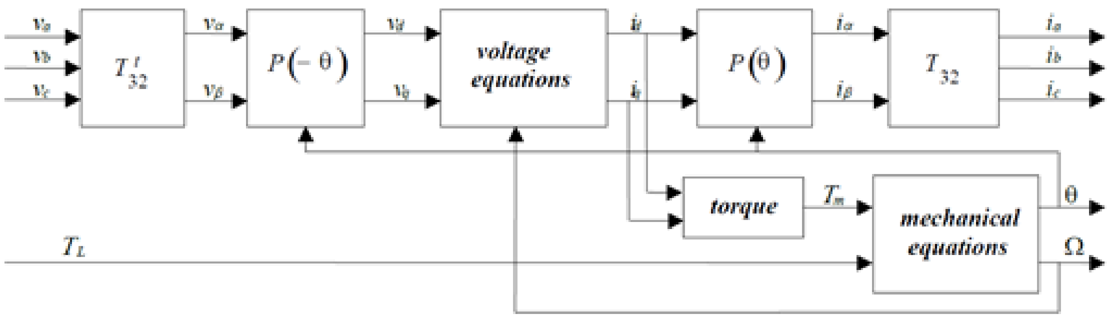


Figure 1: Park Model of PMSM

Voltage equations of the machine are

$$\begin{cases} v_d = R_s \cdot i_d + \frac{d}{dt}\psi_d - \omega \cdot \psi_q \\ v_q = R_s \cdot i_q + \frac{d}{dt}\psi_q + \omega \cdot \psi_d \end{cases} \quad (1)$$

where, $\omega = P.\Omega$ is the electrical speed of the rotor, Ω is the mechanical speed and P is the number of pole pairs. Stator voltages and currents in Park frame are respectively v_d v_q and i_d i_q. Stator flux linkages are given by:

$$\begin{cases} \psi_d = L_d \cdot i_d + \Psi_f \\ \psi_q = L_q \cdot i_q \end{cases} \quad (2)$$

R_s, L_d, L_q, ψ_f and P are the machine parameters and supposed constant. The mechanical model is given by

$$\begin{cases} J \cdot \frac{d}{dt}\Omega = T_m - f \cdot \Omega - T_L \\ \frac{d}{dt}\theta = P \cdot \Omega \end{cases} \quad (3)$$

with:

$$T_m = P \cdot (\psi_d \cdot i_q - \psi_q \cdot i_d) \quad (4)$$

f and J are the mechanical parameters of machine and supposed constant. In this study, the load is proportional to speed.

$$T_L = k_L . \Omega \quad (5)$$

The parameters of the motor are:
R_s = 0.416 Ω, L_d = L_q = 1.365 mH, Ψ_f= 0.41 Vs, P = 4, k_L = 0.034 $kg \cdot m^2/s$.

Mechanical constant parameters:

f = 0.1 $g \cdot m^2/s$ and J = 0.34 $g \cdot m^2$.

Use the suitable transformation matrices:

Park Transformation matrix

$$P(\theta) = \begin{bmatrix} cos\theta & -sin\theta \\ sin\theta & cos\theta \end{bmatrix}$$

abc to alpha-beta transformation matrix

$$T = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix}$$

Tasks

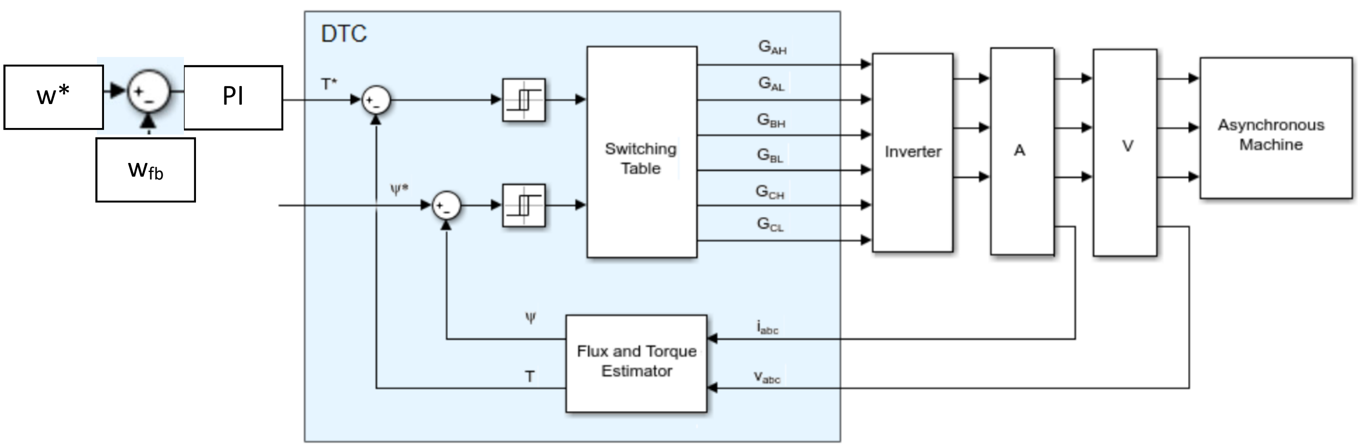
1. Create a MATLAB script for parameters.
2. Implement the model shown in Fig. 1 using Simulink. For this, first we have to put all differential equations under state-space form $\dot{x} = (x, u)$. From Eqs. (1) and (3), there are four differential equations. Once they are built, each equation has to be numerically solved using the block "integrator" in Simulink. To complete the model, Park and alpha-beta transformations have to be implemented (see Fig. 1).
3. Add a three-phase voltage source (three sinus blocks from "Sources" in Simulink library) with:
    - Voltage amplitude: 100 V
    - Voltage frequency: 20 Hz
4. Set the solver as "Fixed-step" and pick "ode4" in the list of the solvers. Select the step-size and the simulation time.
5. Run the Simulink model and comment the following results:
    - Rotor speed
    - Phase currents
    - Motor torque

B2- Modeling and Speed control of Induction Motor Using Direct Torque Control

1. Develop a dynamic model of induction machine using electrical and mechanical equations. The parameters of the machine are given below.

Power rating	3.7kW
Rated speed	855 rpm
Rated voltage	220V
Rated frequency	60Hz
Rated current	17A
Rated torque	41.3Nm
Poles	8
Stator resistance	0.4 ohm
Rotor resistance	0.4 ohm
Magnetizing inductance	29.4mH
Stator leakage inductance	2.1mH
Rotor leakage inductance	2.5mH

2. DC bus voltage is 330V, switching frequency is 5 kHz. Assume a load torque which is proportional to speed. Verify the model by running the machine model in open loop V/f scheme and observe the three phase currents and machine speed for different excitation voltages and frequencies, maintaining V/f ratio constant
3. Implement the direct torque control strategy using stator flux estimation.



$$\Psi_\alpha = (v_\alpha - i_\alpha R_s)\frac{T_S z}{z-1}$$

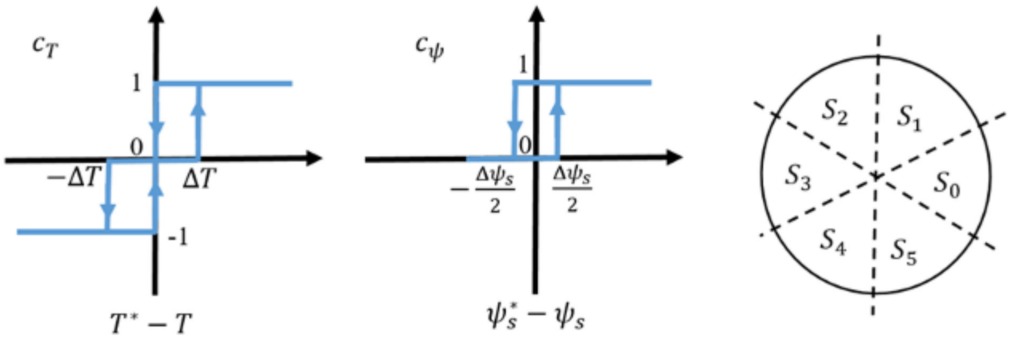
$$\Psi_\beta = (v_\beta - i_\beta R_s)\frac{T_S z}{z-1}$$

Torque and flux estimation can be done using equations:

$$T = \frac{3p}{2} (\Psi_\alpha i_\beta - \Psi_\beta i_\alpha)$$

$$\Psi_s = \sqrt{\psi_\alpha^2 + \psi_\beta^2}$$

4. Implement flux and torque controllers using hysteresis comparators



Assume the reference value of flux to be at the rated value, ψ_s* of 0.8Wb, and flux error band of ±10% for the hysteresis comparator of flux.

5. Implement the look up table for switching voltage vectors based on the outputs of flux and torque hysteresis comparators, and sector location of stator flux:

c_ψ, c_T S(θ)		S_o	S_1	S_2	S_3	S_4	S_5
$c_\psi = 1$	$c_T = 1$	1,1,0	0,1,0	0,1,1	0,0,1	1,0,1	1,0,0
	$c_T = 0$	1,1,1	0,0,0	1,1,1	0,0,0	1,1,1	0,0,0
	$c_T = -1$	1,0,1	1,0,0	1,1,0	0,1,0	0,1,1	0,0,1
$c_\psi = 0$	$c_T = 1$	0,1,0	0,1,1	0,0,1	1,0,1	1,0,0	1,1,0
	$c_T = 0$	0,0,0	1,1,1	0,0,0	1,1,1	0,0,0	1,1,1
	$c_T = -1$	0,0,1	1,0,1	1,0,0	1,1,0	0,1,0	0,1,1

6. Consider a torque error band of ±10% for the hysteresis comparator of torque. Run the machine under Direct Torque Control with fixed torque reference of T_e* = 20Nm. Observe (a) reference and estimated torque, (b) actual and estimated stator flux, and (c) three phase currents.
7. Implement the speed control loop. Perform ramping of reference speed from 0 to 800 rpm in 10 seconds, and observe the actual speed, torque and flux waveforms.
8. Perform step change in load from 0 to 30Nm, at a speed of 500 rpm operation, and observe the speed tracking accuracy of machine speed. Observe the same set of waveforms for load removal in steps of 10Nm from 30Nm to 0 torque over 10 seconds.