ECE 730
Control of Adjustable Speed Drives

Lab 1
Modeling of Permanent-Magnet Synchronous Machine

Due date: Feb. 9, 2025 (before 11:59PM)

Please upload report on Avenue to Learn:
Assessments> Assignments> Lab 1

Late submissions won't be marked.

Objective

- Modeling and simulation of a three-phase Permanent-Magnet Synchronous Machine using MATLAB-Simulink.
- Implementing vector control of a three-phase Permanent-Magnet Synchronous Machine using MATLAB-Simulink.

Note- You are supposed to be familiar with MATLAB-Simulink and are able to run your simulation either remotely or on your computer.

Procedure: Part 1

Figure 1 shows the block diagram of the Park model of sinusoidal Permanent-Magnet synchronous machines (PMSM).

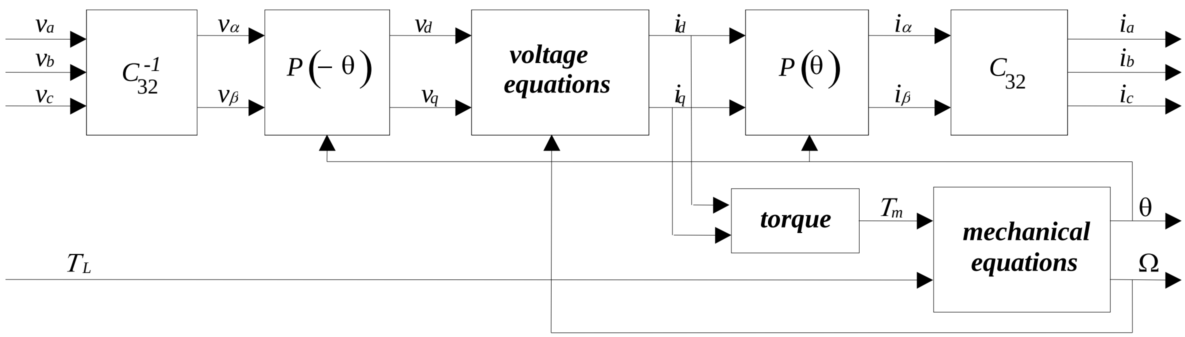

Figure 1- Park model of PMSM.

Voltage equations of the machine are (see Lecture Notes, Topic 1):

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

where $\omega = P_p \cdot \Omega$ is the electrical speed of the rotor, Ω is the mechanical speed and P_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

$$\begin{cases} \psi_d = \psi_d(i_d, i_q) \\ \psi_q = \psi_q(i_d, i_q) \end{cases} \tag{2}$$

In this work, we assume that $\psi_d(i_d, i_q) = L_d i_d + \Psi_f$ and $\psi_q(i_d, i_q) = L_q i_q$. Parameters R_s, L_d, L_q, Ψ_f and P_p are assumed constant. The mechanical model is given by the following equations

$$\begin{cases} J \cdot \frac{d}{dt}\Omega = T_m - f \cdot \Omega - T_L \\ \frac{d}{dt}\theta = P_p \cdot \Omega \end{cases} \tag{3}$$

with (Clarke model): $$T_m = \frac{3}{2} P_p \cdot (\psi_d \cdot i_q - \psi_q \cdot i_d) \tag{4}$$

f and J are the mechanical parameters of the machine and assumed constant. In this study, the load equation is given by:

$$T_L = T_{L0} + k_L \cdot \Omega \qquad (5)$$

Numerical Application: $R_s = 60\ m\Omega, L_d = 1\ mH, L_q = 2\ mH, \Psi_f = 0.167\ \ Wb, P_p = 4,$
$k_L = 0.75\ kg \cdot m^2/s, T_{L0} = 0\ Nm, f\ = 15\ g \cdot m^2/s$ and $J = 100\ g \cdot m^2$.

Reminder: Transformation matrices:

Park transformation	αβ-transformation Concordia	αβ-transformation Clarke
$P(\theta) = \begin{bmatrix} cos\theta & -sin\theta \\ sin\theta & cos\theta \end{bmatrix}$	$T_{32} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix}$	$C_{32} = \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix}$

Work through the following steps to build the model and run the simulation:

1) Create a new folder for this lab in your computer and download all the simulation files from Avenue to Learn: *Content> Labs> Lab 1*
2) Run the MATLAB script for parameters and plot dq −currents as function of dq −flux linkages. Comment these functions.
3) Implement the model shown in Fig. 1 using Simulink. For this, first we must put all differential equations under state-space form $\dot{x} = f(x, u)$. From Eqs. (1) and (3), there are four differential equations. Once they are built, each equation must be numerically solved using the block “integrator” in Simulink, hence the use of four integrators in the model. To complete the model, Park and αβ-transformations must be implemented (see Fig. 1).
4) Add the following setting to the three-phase voltage source:
   - Voltage amplitude: $V_m = 300\ V$
   - Voltage frequency: $f_m = 33.3\ Hz$, then $f_m = 100\ Hz$
5) Set the solver as “Fixed-step” and pick “ode4” in the list of the solvers. Set the step-size to “Tsim” and the simulation time (Stop Time) to 1 s.
6) Run the Simulink model and comment the following results:
   - Rotor speed
   - Phase currents
   - Motor torque

The lab report must include:

- Cover page.
- Introduction.
- Obtained results in Q6 and your comments.
- Conclusions.
- MATLAB script and Simulink program.

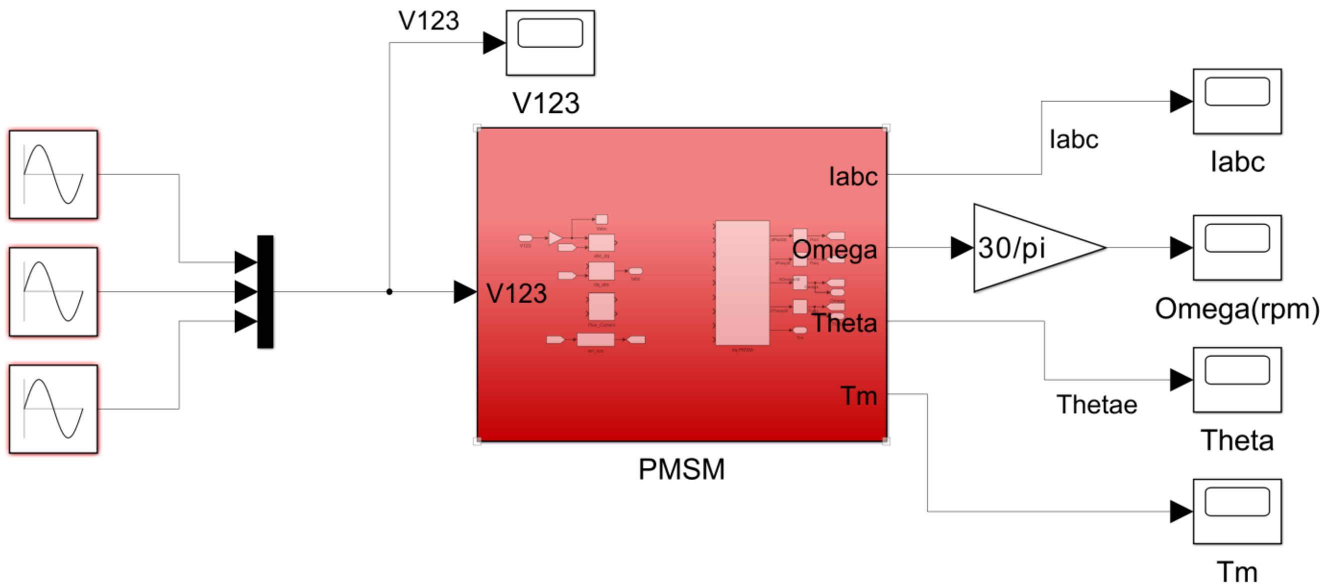

Fig. 1- Simulink program for simulation of PMSM.