EE462 & EE464 Project: Design of a SM-PMSM Variable Frequency Drive with Matlab/Simulink

The model that you will build, and your results should be **completely on your own**.

Deadline: 25.06.2023

Definition

Please see the motor ratings of the surface mount PM synchronous machine (SM-PMSM) below.

$P_{nominal} = 400\ kW$

$n_{nominal} = 1500\ rpm$ (rated)

$n_{max} = 2250\ rpm$

Pole number: $\boldsymbol{p = 4}$

$Flux\ linkage$: λ_{PM} = 0.5 Vs (Wb-t)

$L_d = L_q$ = 350 μH

$I_{nominal} = 1700\ A$ (peak)

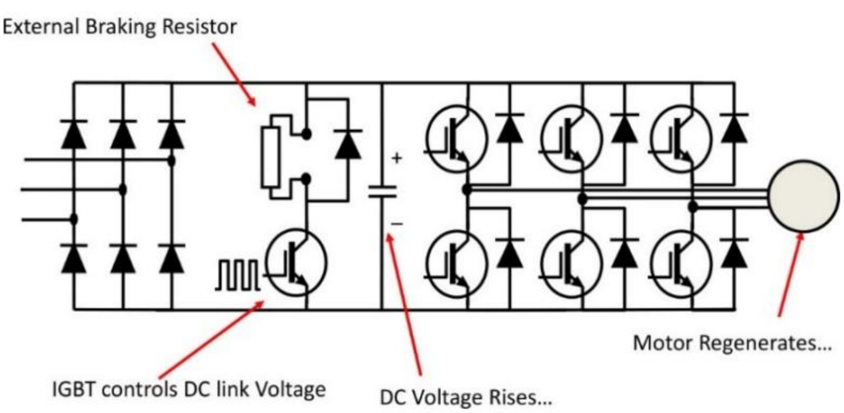
Phase resistance R_s = 16 mOhm

Inertia of the rotor: J_{rotor} = 1 kgm^2

Ignore core losses and mechanical losses such as windage and friction losses.

The available supply is a three-phase AC source 50 Hz, 400$V_{l\text{-}l}$

Assume a 3-phase full-bridge diode rectifier is connected to the grid. The 3-phase motor drive inverter is connected to the diode rectifier as shown below.



Part A: Pre-design Stage

1. Calculate the rated torque of the PMSM.
2. Calculate the maximum applied electrical frequency and choose a switching frequency for your inverter. You can refer to [1].
3. Design a reasonable DC-link filter (C or LC) for the rectifier block. Plot the DC-link voltage waveform by connecting a resistive load equivalent to motor at rated current.

Part B: Sinusoidal PWM

Implement a motor drive using sinusoidal PWM (Sine-PWM), and implement a cascaded speed and current controller using id-iq parameters. You need to implement your OWN Clarke-Park transformation blocks and PWM generation block; however, you can use built-in models for the electrical machine. Also, include the machine inverse model in your control block diagram. (feed forward)

1. Assume a fan load with the given characteristics is connected to the shaft with no gear transmission (direct drive).
    - Inertia of the load: $J_{load} = 240\ kg\ m^2$
    - $T_{load} = 0.09\ \omega^2$

    Simulate and plot the following waveforms during transition of 90% of the rated (nominal) speed to rated (nominal) speed:

    a. Plot speed vs. time
    b. Plot motor 3-phase line-to-line voltages and 3-phase line currents vs. time
    c. Plot torque vs. time
    d. Plot d-q currents
    e. What is the transition time under this condition?

    Note: For a credit, make sure that the axes are visible with large fonts. Also, make sure that you pick a light color for the background of the plots, not black.

2. While the motor is running at rated speed with the fan load in previous question, assume the load is removed ($T_L = 0\ Nm$) and the speed reference is kept constant. Show the performance of the drive by plotting relevant graphs.

3. While the motor is running at rated speed at **no-load**, assume the speed reference is reversed (i.e rotating at the opposite direction at rated speed).
    Comment on if this operation is feasible with the diode rectifier. Design a braking resistor system such that the DC-link voltage does not exceed 600 V.

    a. Plot speed vs. time
    b. Draw the 3-phase line currents during speed reversal and comment on the results.
    c. Plot d-q currents
    d. Plot DC-link voltage

4. While the motor is running at rated speed at half of the rated torque (assume a constant load torque and inertia of the load: $J_{load} = 240\ kg\ m^2$), propose a method to run the motor at %150 of the rated speed without exceeding the rated currents. Calculate the required d-q currents at initial condition and at final condition. Apply these currents and obtain the following graphs.
    a. Plot speed vs. time
    b. Plot d-q currents

Part C: Space Vector PWM (SV-PWM)

1. Repeat Part B using a Space Vector PWM algorithm. You are free to use readily available Simulink blocks in this stage.
2. Plot the 3-phase reference voltage waveforms for the Sine-PWM and SV-PWM for rated operation and comment. You need to transform reference vector in SV-PWM to 3-phace reference frame.
3. Compare the FFT components of the line currents for Sine-PWM and SV-PWM. Comment on the frequency spectrum and amplitudes. Calculate and compare the THD of the line current at rated operating conditions.
4. Explain the main differences between Sine-PWM and SV-PWM. Which would you select for a high-performance drive?

Part D: Component selection

1. Select commercial switching device for the traction inverter. You can select switching array module or discrete devices. Give the important parameters of the device and explain your selection considerations.
2. According to your choice, calculate the loss of the inverter while motor is rotating at rated speed (base) and rated torque. Explain how the selection of switching device affect the loss distribution and thermal management.
3. Select commercial driver for switching device. Explain your selection considerations.

NOTES:

- The aim of this project is not designing the most optimum or the most efficient motor drive system. Whenever you think the performance of the motor drive is not good, just comment on it and discuss how it can be improved.
- If you find unrealistic values (for example 10% efficiency), go back to your design. It’s highly probable that you made a calculation mistake, but if it’s really that low, then you need to modify your design.
- Comments are the most important section of your project report. Please explain both your models and results as detailed as possible.

- You will complete this project in groups.

HINTS:

- When constructing the models, go **step-by-step**. First built a few components, check if it is working as intended, if it works then add new components. Do not try to implement the whole model at once, expect it to work without any problems.
- Always be aware to use **correct units**.
- Understand the **requirements** before propositions.
- Do not forget to cite to any external sources you used.

Project outputs

You have to commit at least the following files until the deadline:

- The Simulink models and/or Matlab .m files
- A project report describing your models in detail (Your simulation results should be embedded in your report).

References

[1] R. Teichmann and S. Bernet, “A comparison of three-level converters versus two-level converters for low-voltage drives, traction, and utility applications,” Industry Applications, IEEE Transactions on, vol. 41, no. 3, pp. 855 – 865, 2005.