Following questions include Final Exam Questions of EE7566 and some other exercise questions.

Final Exam Content:

- 4-quadrant operation
- Sensors
- Equivalent J and M calculations
- Creating rotating field and coordinate transformations
- Definition of d-axis and q-axis
- Surface Mount PMSM (SM-PMSM) equivalent circuit, torque, voltage, current and operating limit calculations
- SM-PMSM space vector representation
- Field Oriented Control of SM-PMSM
- Difference between SM-PMSM and IPMSM
- Basic characteristics and equivalent circuit of IM
- V/f control basics of IM
- Drive system configuration and components: Source, rectifier, DC/DC converter, Filter, Braking Resistance, Inverter, Load (Refer to project)
- VSI modulation techniques: Sine-PWM and SV-PWM basics, switch turn-on time calculations, switching sequence, possible voltage limits

Question 1: Vehicle Traction System

You are assigned to design a **fuel cell hybrid electric vehicle** (FCHEV) with the following component specifications and you are also expected to analyze the operating limits of the system. Before you start you are asked to choose a high voltage system configuration.

Battery pack:

Nominal DC link voltage: 390 V (min.: 300 V and max.: 450 V)
Battery nominal charging current: 150 A
Capacity: 5 kWh

Fuel cell system:

Nominal power: 100 kW
Nominal voltage: 300 V (min.: 200 V and max.: 350 V)
Nominal current: 350 A

Electric machine:

Electric machine type: Permanent Magnet Synchronous Machine with Interior Permanent Magnets
Nominal power: 100 kW
Nominal rotational speed: 12000 rpm
Nominal torque: 250 Nm

1.1. Draw the high voltage electric traction system of the fuel cell vehicle by using minimum number of power converters. Explain **briefly** the use each component.

1.2. Considering the fluctuations in battery and fuel cell output voltages, how can we keep the dc-link voltage constant? Discuss advantages and disadvantages of keeping dc-link voltage constant. For example, **a.** how the overall efficiency of the system may get affected, **b.** how the transient response time of the electrical system changes and **c.** how the operating limits of the electric machine changes? Please just make comments.

Question 2: Surface Mounted Permanent Magnet Machine (SMPMSM)

A SMPMSM with the following parameters is given.

$$\Psi_{PM} = 0.25\ Wb$$
$$L_d = 1\ mH$$
$$L_q = 1\ mH$$
$$\boldsymbol{pole\ pair}\ number = 4$$
$$V_{dc} = 400\ V$$
$$\hat{\imath}_S = 250\ A\ (rated\ peak\ value)$$
$$The\ stator\ resisitance\ is\ ignored.$$

2.1 Calculate the nominal torque at the rated current.

2.2 Calculate the base speed in rad/sec (mechanical) corresponding to the rated voltage and torque mentioned above. Assume star connected phase terminals and SV-PWM.

2.3 Draw the space vector diagram (current and voltage space vectors) at nominal torque and base speed, calculate the power factor.

2.4 Calculate the required i_d and i_q currents at 6000 rpm and 100 Nm, field weakening range.

2.5 Draw the space vector diagram at 6000 rpm and 100 Nm.

2.6 Explain the field weakening operation and its importance in vehicle traction applications.

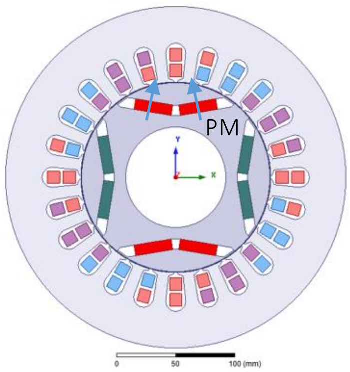
2.7 Draw a standard torque speed characteristics and specify the limiting factors on the limiting line?

2.8 Why do we prefer IPMSM but not SM-PMSM in vehicle traction applications? Give at least two reasons.

Never multiply electrical quantities (inductance and flux linkage) with mechanical frequency and never use electrical frequency to calculate mechanical power!

Exercise: Rotating Field Theory

1. State the rules of creating a rotating field with 2-phases, draw basic stator winding distribution and give the phase currents.
2. State rules of creating a rotating field with 3 phases, draw basic stator winding distribution and give the phase currents.
3. What is the difference between $\alpha\beta$ and dq coordinates?
4. What is definition of d-axes?
5. Show the d-axes of the following geometry.



6. What is the definition of i_d and i_q.
7. What is the definition of L_d and L_q.

8. What are the differences between Brushless DC and Brushed DC Machines?

Question 3: Voltage Source Inverter (VSI) Modulation Techniques

A PMSM with 4 pole pairs is running at 1000 rpm. The phase voltages of this machine are regulated by applying Space Vector Pulse Width Modulation (SV-PWM) with a switching frequency equal to 12 kHz. At $t = t_0$, the reference voltage vector is in the first sector, it has an amplitude equal to $V_{dc}/(2\sqrt{3})$ and α=30 deg as shown in Fig. 2.

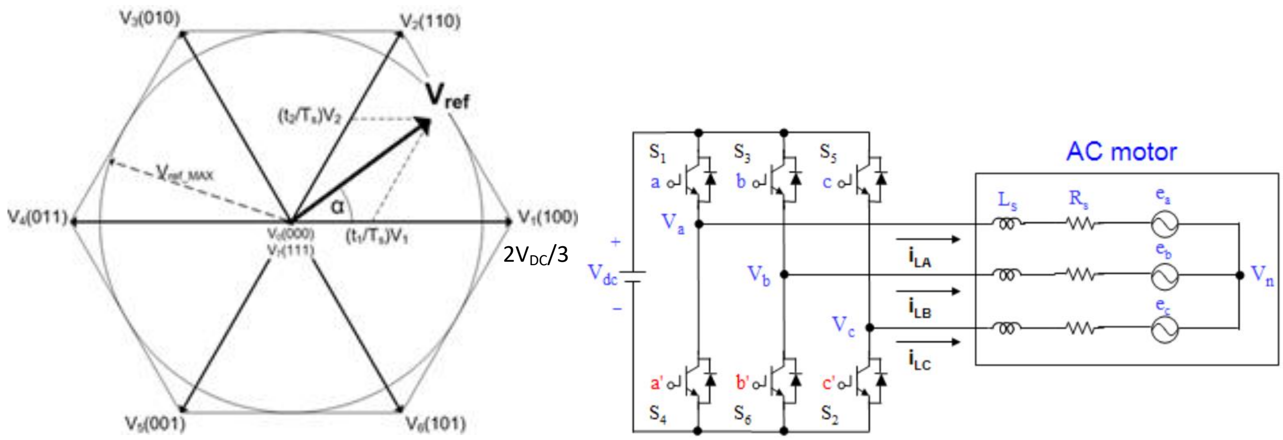


Fig. 2 Reference voltage vector at $t = t_0$ and voltage source inverter.

3 How many times the switching states are calculated in one electric period?

4 State the steps of determining the reference vectors and their duration.

4.1 At $t = t_0 + 0.0075s$, state the voltage vectors, calculate duration of these voltage vectors in terms of switching period T_s and draw the switching table on the template given with regular switching pattern and indicate the switching durations in terms of T_s.

4.2 Repeat 3.1 for $t = t_0 + 0.01125\ s$. Specify durations.

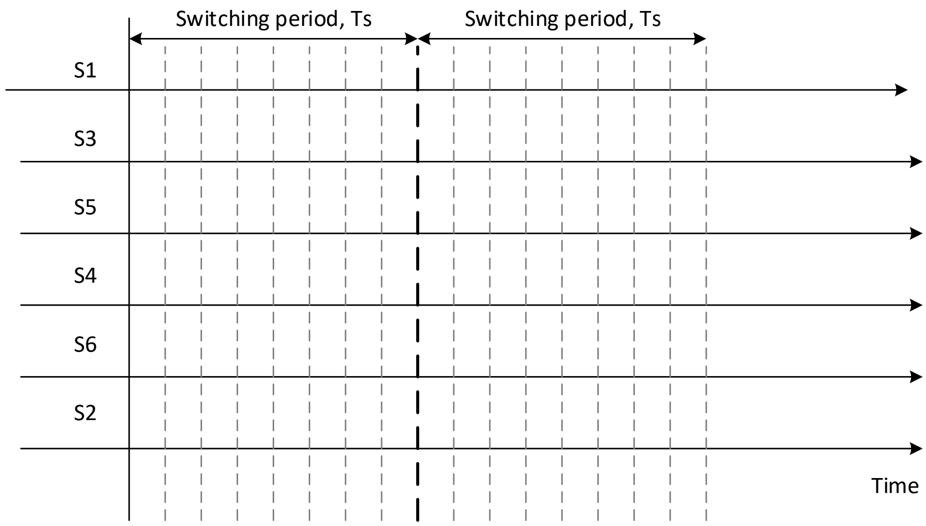
4.3 At $t = t_0 + 0.01125s$, draw the switching table if Sine-PWM was applied. Comment on the main difference in implementation of these modulation techniques.

Hint: $v_{ref\_phaseA}=V_{dc}/(2\sqrt{3})\cos(\omega(t-t_0))$ and $v_{ref\_phaseB}=V_{dc}/(2\sqrt{3})\cos(\omega(t-t_0)-2\pi/3)$

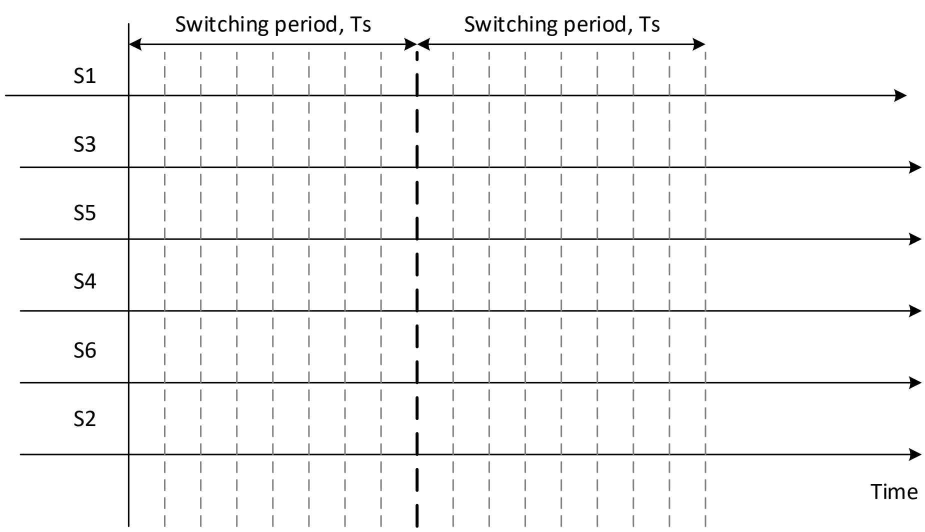
4.4 State two advantageous of SV-PWM compared to Sine-PWM. Which one would you use for a high performance application?

4.5 How many (switching) states do we have in a 5-phase VSI? How many of them are zero vectors? Draw a 5-phase VSI.

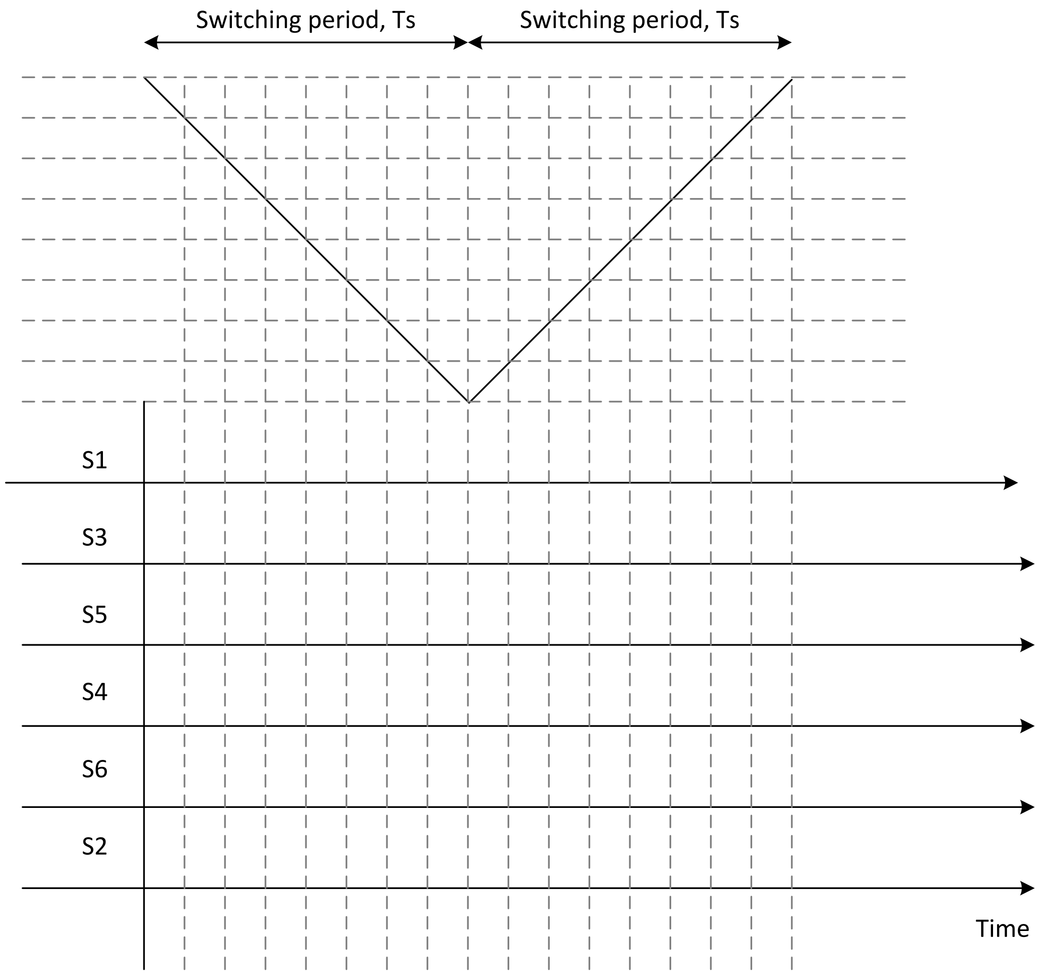
Template for 3.1 (switching points may not coincide with vertical lines):



Template for 3.2 (switching points may not coincide with vertical lines):



Template for 3.3 (switching points may not coincide with vertical lines):



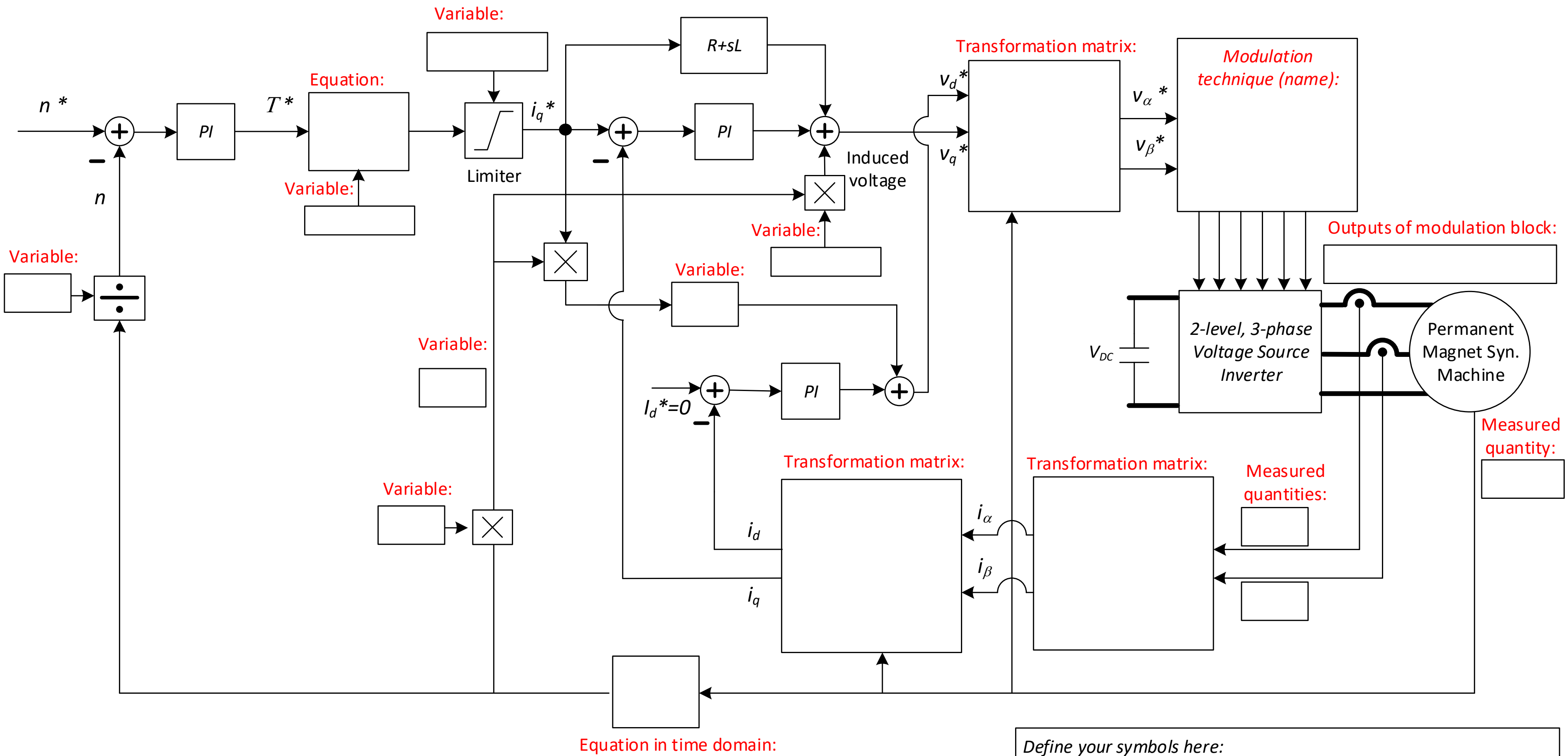
Control Block

Exercise 4:

1. Draw control diagram for the speed control of a SMPMSM machine with Sine-PWM in the base speed range.
2. What is motivation of including inverse machine model in the control blocks?
3. Which measurements are necessary?
4. Name possible speed sensors, which one would you use?
5. Which measurements do we need in a IM drive to apply open loop V/f control?
6. What is the significance of V/f control?

Question 4: Control Block Diagram

4.1 Fill the blanks in the following control block diagram.
4.2 Is this control block diagram applicable in field weakening region, why?
4.3 Is this control block diagram meaningful for IPMSM machine, why?
4.4 What is basic motivation of applying Field Oriented Control (FOC)?
4.5 In a IM (Induction Machine) drive, do we apply plus or minus d-axis current?



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