Lecture 6

Overview of Three-Phase Inverters & Pulse Width Modulation Schemes

Objectives:

- Apply the Buck converter in a three-phase topology to drive an AC motor.
- Discuss Sine-PWM and introduce Space-Vector-PWM.
- Examine regenerative-braking and its similarity to a Boost converter.

Keywords:

Pulse Width Modulation (PWM)
Sine PWM (SPWM)
Phase leg
Space Vector PWM (SVPWM)
Active voltage vector
Zero voltage vector

The Three-Phase Inverter Topology

By combining three Buck converter circuits together on the same DC bus, we can generate three separate AC voltages with equal magnitude. Each branch of two switches is commonly called a phase leg of the inverter.

$$v_a(t) = \frac{V_{DC}}{2}\left[M_i \sin(\omega t) + 1\right], \quad V_{an} = \frac{M_i V_{DC}}{2\sqrt{2}}$$

$$v_{ab}(t) = \frac{\sqrt{3}V_{DC}}{2} M_i \sin(\omega t + 30^\circ), \quad V_{LL} = \frac{\sqrt{3} M_i V_{DC}}{2\sqrt{2}}$$

$$P = 3V_{\phi,rms} I_{\phi,rms} = \sqrt{3} V_{LL} I_{\phi,rms}$$

Using Sinusoidal Pulse Width Modulation

When connecting to a motor, if the three phase-voltages are balanced, the average neutral point voltage of the machine will be centered at ½ V_{DC}. This is advantageous to us, since it removes the DC voltage term.

Maximum phase to neutral voltage when M_i is equal to 1 is $V_{DC}/2$.

$$V_{an,pk} = \frac{V_{DC}}{2}$$

Similarities between Buck & Boost

Regenerative Braking Scenario

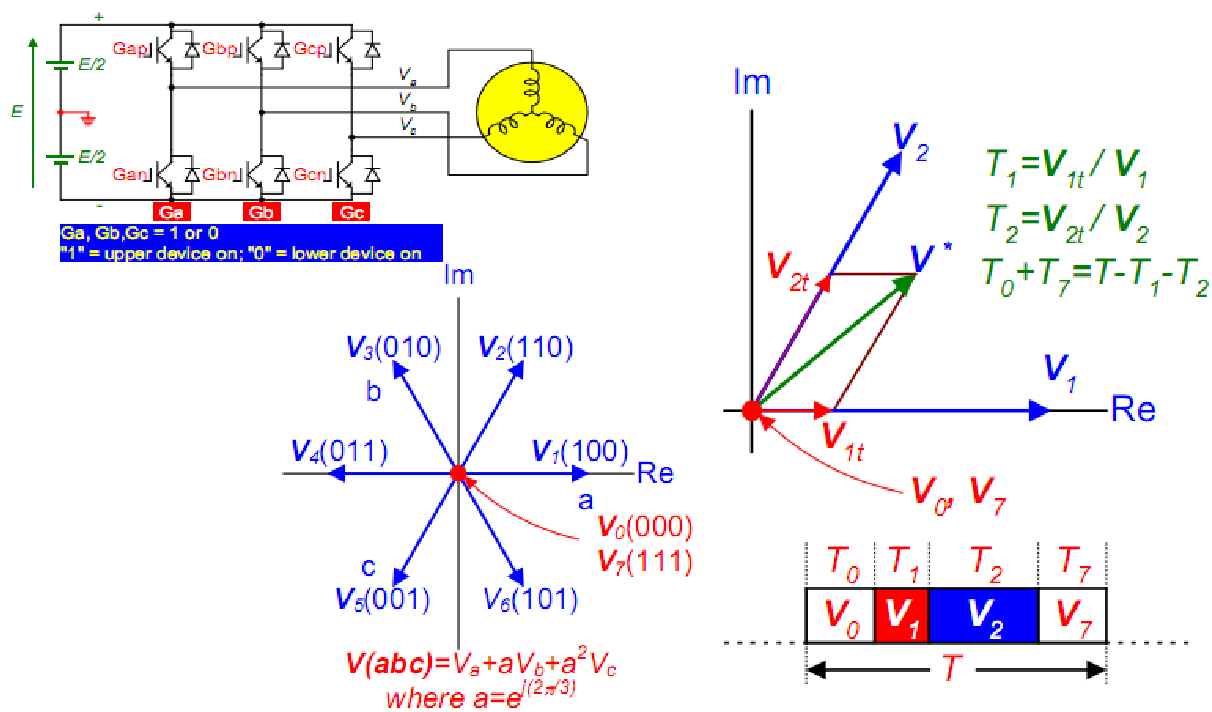
$$\mathbf{V_a} = R_s\mathbf{I_a} + j\omega L_s\mathbf{I_a} + \mathbf{E_a}$$

If current is positive, the inverter voltage will be slightly larger than the BEMF, and will slightly leading it due to the inductor voltage term.

If the current is negative, the inverter voltage will be slightly smaller than the BEMF, and will slightly lag it due to the inductor voltage term.

Space Vector Pulse Width Modulation

- We assign each of the eight switching states a magnitude and direction, wrt machine windings. Explain why length of voltage vectors is 2/3.
- Explain why zero-voltage vectors do not affect the current in the machine (common-mode voltage only).
- Space vector PWM uses center-aligned PWM pulses.
    - Only one switching action occurs at a time. In one complete switching period, each phase only switches twice.
    - The effective switching frequency is doubled, because the active vectors show up twice (separated by zero vectors) within one switching period.
- Traditionally, the zero-voltage vectors are split evenly, but do not have to be. The different splitting methods lead to other types of PWM algorithms. Discontinuous PWM (DPWM) is a commonly used alternative, since it can reduce switching losses by 1/3.



Calculation of Space Vector Components

Find V_α and V_β components of voltage.

Find V_{1t} and V_{3t} using trig

$$V_{1t} = V_\alpha - \frac{V_\beta}{\tan(60°)} = V_\alpha - \frac{V_\beta}{\sqrt{3}}$$

$$V_{3t} = \frac{V_\beta}{\sin(60°)} = \frac{V_\beta}{\sqrt{3}/2}$$

$$D_1 = \frac{V_{1t}}{\frac{2}{3}V_{DC}} = \frac{\left(3V_\alpha - \sqrt{3}V_\beta\right)}{2V_{DC}}$$

$$D_3 = \frac{V_{2t}}{\frac{2}{3}V_{DC}} = \frac{\sqrt{3}V_\beta}{V_{DC}}$$

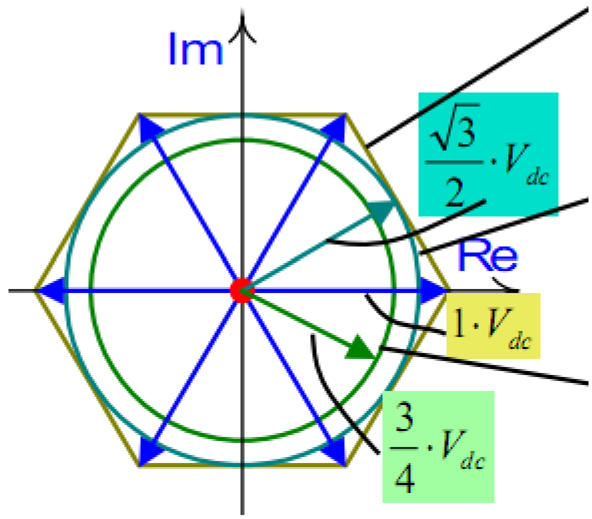
$$D_{0/7} = \tfrac{1}{2}\left(1 - T_1 - T_2\right)$$

$$D_a = \frac{T_1 + T_2 + T_{0/7}}{T_{sw}} \qquad D_b = \frac{T_2 + T_{0/7}}{T_{sw}} \qquad D_c = \frac{T_{0/7}}{T_{sw}}$$

PLOTTING RESULTS OF SVPWM

Voltage Limits of SPWM & SVPWM

- Length of each voltage vector is 2/3 V_{DC}. Show circuit diagram.
- Limit of instantaneous phase voltage is confined to the hexagon. Show vector analysis at 30-deg, using 50% V_1 and 50% V_2.
- The limits of Sine PWM are a circle with radius ½ V_{DC}. Related to PWM method.
- The limit of Space Vector PWM (without over-modulating) is the circle inscribed within the hexagon. It has a radius of $\frac{\sqrt{3}}{3}V_{DC}$.



It is a common claim in textbooks that SVPWM offers a 15% higher output voltage than SPWM.

$$\frac{\sqrt{3}/3}{1/2} = \frac{0.5773}{0.5} = 1.1547$$

This means that the maximum value for the modulation index, using SVPWM, can also be greater than 1.

$$M_i = \frac{|v_{AC}|}{\frac{1}{2}V_{DC}} \quad \text{where } 0 \le M_i \le 1.15 \text{ for SVPWM}$$