3 Phase Voltage Source Converters

1. Multiple devices in series (PWM)
2. Modulate modules (submodules) in series (Q0, Q6H)
3. Multi-level converter which also has series devices

- Voltage block
- Submodule
- Half bridge submodule
3 level neutral point clamped converter
Closed loop control

- All 3 topology options can have same current regulator from last time

- The modulating reference/function interacts differently with gate drive.
3 phase system

- 3 wire

A

B

C

\[
I_A + I_B + I_C = 0
\]

\[\rightarrow 2 \text{ degrees of freedom}
\]

(3 if have a 4th wire or ground path)

2 zero sequence

- Stationary reference frame, \(i_a(t), i_b(t), i_c(t)\) are sinusoidal
Synchronous generator

Direct Axis (d-axis)

Park, Blondell
→ 1930's
2 axis equivalent

Quadrature Axis (q-axis)

1) map A, B, C to d, q, axes
(0 axis if grounded)
2) map to rotor reference frame
$$i_d(t)$$

$$i_d$$

$$i_q$$

Rotating ref frame

$$i_{ref}, L_{ref}, l_{ref}$$

$$A_{meas}, L_{Bmeas}, L_{meas}$$

$$i_{meas}, L_{Qmeas}$$
Two Axis Transformation

**Imitation Measured Currents:**

Define array of time and define angular frequency:

\[ t := 0 \text{sec}, 0.0001 \text{sec} \ldots \frac{6}{60 \text{Hz}} \]

\[ \omega := 2 \cdot \pi \cdot 60 \text{Hz} \]

\[ \omega(t) := \omega_0 \quad \text{- frequency is const} \]

**Voltage as a function of time**

\[ V_{\text{mag}} := 15 \text{kV} \]

\[ v_a(t) := \sqrt{2} \cdot V_{\text{mag}} \cdot \cos(\omega(t) \cdot t) \]

\[ v_b(t) := \sqrt{2} \cdot V_{\text{mag}} \cdot \cos(\omega(t) \cdot t - 120 \text{deg}) \]

\[ v_c(t) := \sqrt{2} \cdot V_{\text{mag}} \cdot \cos(\omega(t) \cdot t + 120 \text{deg}) \]

**Transform measured voltage and currents to the stationary dq0 (αβ) reference frame:**

- Use equations from the Clarke Transformation instead of matrix for now

\[ v_{ds}(t) := \frac{2}{3} \left( v_a(t) - 0.5 \cdot v_b(t) - 0.5 \cdot v_c(t) \right) \]

\[ v_{qs}(t) := \frac{v_b(t) - v_c(t)}{\sqrt{3}} \quad \text{Q axis 180 out of phase with some definitions} \]

\[ \{ v_d(t), v_b(t) \} \]

3 stationary Z axis frame
Transformed voltages (note that $v_{ds}(t)$ in phase with $v_a(t)$)

$\theta_r(t) := 2\cdot \pi \cdot 60 \cdot 0Hz \cdot t$

- Now apply rotating reference frame transformation in steps

$v_{dr1}(t) := v_{ds}(t) \cdot \cos(\theta_r(t))$
\[ v_{dr}(t) = v_{dr1}(t) + v_{dr2}(t) \]

\[ v_{q1}(t) = v_{ds}(t) \cdot \sin(\theta r(t)) \]

\[ v_{q2}(t) = v_{qs}(t) \cdot \cos(\theta r(t)) \]

\[ v_{qr}(t) = -v_{q1}(t) + v_{q2}(t) \]
Park's Transformation in Matrix Form

\[ \theta(t) := \omega_0 t \] synchronously rotating reference frame, note that this is generally shifted by \( \pi/2 \) for rotating machines.

\[ P(t) := \frac{2}{3} \begin{pmatrix} \frac{1}{2} & 1 & \frac{1}{2} \\ 1 & \cos\left(\theta(t) - \frac{2 \cdot \pi}{3}\right) & \cos\left(\theta(t) + \frac{2 \cdot \pi}{3}\right) \\ 1 \cos\left(\theta(t) - \frac{2 \cdot \pi}{3}\right) & -\sin\left(\theta(t) - \frac{2 \cdot \pi}{3}\right) & -\sin\left(\theta(t) + \frac{2 \cdot \pi}{3}\right) \end{pmatrix} \]

\[ \Theta(t) = 0 \Rightarrow \text{reduced to Clarke transform} \]
\[ \begin{bmatrix} V_0 \\ V_d \\ V_q \end{bmatrix} = V_{0dq}(t) := P(t) \begin{bmatrix} v_a(t) \\ v_b(t) \\ v_c(t) \end{bmatrix} \]

- Compare to earlier results
- Balanced three phase source, so zero sequence term is zero as expected....