ECE 529

Utility Applications of Power Electronics

Session 20
ECE 529: Homework #3

Due Session 24 (March 10)

1. Implement and test the performance of closed loop control using an averaged model of a three phase VSC rated at 2300 V\(_{AC}\) and 5 MVA. The converter is connected to an AC source voltage of 2.5 kV (1.1\(_{p}\)) through a \( R = 0.0096 \Omega \), \( X_s = 0.144 \) ohm \( (X/R = 15) \)

Now the VSC from problem hw 2 has a closed loop control scheme implemented in the synchronous rotating d-q reference frame. Assume that the source voltage is constant and is a 0 degree reference angle on phase A.

A. Determine gains \( k_i \) and \( k_p \)
B. Determine the \( i_{\text{deref}} \) and \( i_{\text{qref}} \) such that \( P=5 \) MW and \( Q=0 \).
C. Determine the \( i_{\text{deref}} \) and \( i_{\text{qref}} \) such that \( P=4.0 \) MW and \( Q=1.9 \) MVAR.
D. Determine the \( i_{\text{deref}} \) and \( i_{\text{qref}} \) such that \( P=4.0 \) MW and \( Q=-1.9 \) MVAR
E. Determine the \( i_{\text{deref}} \) and \( i_{\text{qref}} \) such that \( P=-4.0 \) MW and \( Q=-1.9 \) MVAR
F. Implement cases B-E using closed loop control in your EMT program using averaged models with fixed current references entered. Verify that currents track the current references with plots and that the power measured at point of common couple matches the desired levels. (Make sure you update constants needed for the closed loop controller to use your gains from part A).
G. Implement cases B-E using closed loop control in your EMT program using averaged models. Verify that measured real and reactive power tracks the power references at the point of common couple coupling. Also plot the synchronous reference frame currents and one cycle of the phase domain currents.
Feedback control system

- Output depends on generated feedback system
  » Closed loop system focused on output
- Reacts to changes in the signals fed back
  » All disturbances are detected
  » Responds to errors between measured output and set point
- Can overcome incomplete information or noise
  » PID control -- tuning
- Can "linearize" non-linear process
- Can decouple (cancel) physical cross-coupling

Feedforward control

- Passes scaled/filtered signal to process
- Acts as disturbance rejection
  » Prevents known disturbances from effecting process
  » Only acts on selected variables
  » Especially when combined with feedback control
  » Requires accurate model of the system
- Open loop
  » Poor design can lead to instability
Grid Following Control of Three Phase VSCs in Synchronous Reference Frame

Closed Loop Modulating Functions Controls

\[ V_{SD} = \frac{1}{1+sE_{dc}} \]

\[ K_i = 1.176 \]

\[ K_p = 0.138 \]

\[ G(s) = 1 \]

\[ V_{POS}AV \]

\[ V_{NEG}AV \]

\[ \text{PI Controller} \]

\[ \gamma = \text{sms} \]

\[ R_L \]

\[ I_{D \text{measured}} \]
Look back at $\text{dc}/\text{dc}$ on single phase $\text{dc}/\text{ac}$

- $V_{\text{meas}}$
- $V_{\text{FF}}$
- $K_p$
- $K_i$
- $m(t)$
- Divide by $V_{\text{a4/2}}$ (per unit)

Choose gains $K_i, K_p$

to cancel $L$ in $\text{La Place}$ domain pole

$$\frac{V_T - V_S}{R + sL} = i_q(s)$$
- Control design implemented in synchronous reference frame

- Current regulators
  - \( i_d, i_q \) constant in steady-state
  - Simplifies control design

- Only two controllers needed
  - \( i_d, i_q \) (300, 3-wire, ungrounded system \( i_o = 0 \))
Look at phase a

\[ V_{at}(t) = V_{as}(t) + i_a R + L \frac{di_a}{dt} \]

\[ L \downarrow \rightarrow \text{(no mutual coupling)} \]

\[ V_{at}(s) = V_{as}(s) + I_{A}(s)[R + sL] \]

3D version

\[
\begin{bmatrix}
V_{a(s)} \\
V_{b(s)} \\
V_{c(s)}
\end{bmatrix}
\Rightarrow
V_{ABC-T(s)} = V_{ABC_S}(s) + I_{ABC_S}(s)[R] + I_{ABC_S}(s)s[L]
\]
- **Park's Transformation**

→ apply in Laplace domain, \( \mathfrak{L} \)

\( \text{in time domain } v_{odq+}(t) = P(\theta) \text{ labc}(t) \)

\[
\begin{bmatrix}
P(s)
\end{bmatrix}
\begin{bmatrix}v_{ABC+}(s)\end{bmatrix} = 
\begin{bmatrix}
P(s)
\end{bmatrix}
\begin{bmatrix}v_{ABC-}(s)\end{bmatrix} + 
\begin{bmatrix}
P(s)
\end{bmatrix}
\begin{bmatrix}I_{ABC}(s)\end{bmatrix} \begin{bmatrix}IR\end{bmatrix} + s \begin{bmatrix}L\end{bmatrix}
\]

\( v_{odq+}(s) \)

↓

↓ go back to time domain
In stationary lab frame \( \theta = 0 \)

\[
P(\theta) = \frac{1}{2} \begin{bmatrix}
    \cos(\theta) & \sin(\theta) \\
    -\sin(\theta) & \cos(\theta)
\end{bmatrix} \frac{1}{2}
\]

\[
\begin{pmatrix}
    \cos(2\theta) & \sin(2\theta) \\
    -\sin(2\theta) & \cos(2\theta)
\end{pmatrix}
\]

Park's transformation.
\[ \left[ P(\Theta) \right] \nu_{abc}(t) = \left[ P(\Theta) \right] \nu_{abc}(t) + \left[ P(\Theta) \right] \nu_{abc}(t) \left[ R \right] \\
+ \left[ L \right] \frac{d}{dt} \left[ \left( P(\Theta) \right) \nu_{abc}(t) \right] \]

\[ \frac{d}{dt} \left( A(t) \cdot B(t) \right) = B(t) \cdot \frac{dA}{dt} + A \cdot \frac{dB}{dt} \]

When we do this with

\[ P(\Theta) \nu_{abc}(t) \rightarrow \begin{bmatrix} 0 & d & 0 \\
0 & 0 & 0 \\
0 & -3 & 0 \end{bmatrix} \]

Stationary reference frame, P(\Theta) does not depend on time.