ECE 404-TD / 504-TD

ST: T&D APPLICATIONS OF VOLTAGE SOURCE CONVERTERS

SESSION no. 35
ECE 404/504: Homework #5

Due Session 37 (April 17)

1. Implement an averaged model of a three VSC with an AC source voltage of 2.4kV (L-L),  
   \( R = 0.096 \ \Omega \), \( L = 3.82 \text{mH} \) (X/R = 15) and a switching frequency of 3600Hz.  
   A. Determine \( V_{dc} \) if the maximum amplitude of the modulating function is 0.8 and the  
      maximum reactive power the converter can supply is 4MVAR while transferring 0 MW  
      (both measured at the source side of the R-L). Round up to nearest 10 V.  
   C. Generate open loop modulating functions \( (m_a(t), m_b(t), \text{ and } m_c(t)) \) such that \( P=4\text{MW} \)  
      and \( Q=0 \). Verify that the converter supplies this using averaged models.  
   D. Generate open loop modulating functions such that \( P=3.71\text{MW} \) and \( Q=1.5\text{MVAR} \).  
      Verify that the converter supplies this.  
   E. Generate open loop modulating functions such that \( P=3.71\text{MW} \) and \( Q=-1.5\text{MVAR} \).  
      Verify that the converter supplies this.  
   F. Generate open loop modulating functions such that \( P=-3.71\text{MW} \) and \( Q=-1.5\text{MVAR} \).  
      Verify that the converter supplies this.  
   G. ECE 504 students, implement using a switching model. Compare ac currents to those  
      from the averaged models and the fundamental component of converter terminal  
      voltages to averaged model results.

2. Now the VSC from problem 1 has a closed loop control scheme implemented in the  
   synchronously rotating d-q reference frame. Assume that the source voltage is constant.  
   A. Determine the \( i_{dref} \) and \( i_{qref} \) such that \( P=4\text{MW} \) and \( Q=0 \).  
   B. Determine the \( i_{dref} \) and \( i_{qref} \) such that \( P=3.71\text{MW} \) and \( Q=1.5\text{MVAR} \).  
   C. Determine the \( i_{dref} \) and \( i_{qref} \) such that \( P=3.71\text{MW} \) and \( Q=-1.5\text{MVAR} \)  
   D. Determine the \( i_{dref} \) and \( i_{qref} \) such that \( P=3.71\text{MW} \) and \( Q=-1.5\text{MVAR} \)  
   E. ECE 504 students implement cases A-D using closed loop control in your EMT  
      program using averaged models.

Assume PLL \( \rightarrow V_{sq} = 0 \)
\[ P_{out} = -P_{st} \]
\[ Q_{out} = -Q_{st} \]

\[ R \ll X \rightarrow \text{approximate } R=0 \text{ for calculations} \]
\[ S_{ST} = \bar{V}_S \cdot \bar{I}_{ST}^* \]

where:

\[ \Theta_{B_S} = 0 \]
\[ \Theta_{V_T} = \delta \]

\[ = \bar{V}_S \left( \frac{\bar{V}_S - \bar{V}_T}{jX} \right)^* \]

\[ = \left| V_S \right|^2 - \bar{V}_S \bar{V}_T^* \]

\[ \frac{-jX}{-jX} \]

\[ = \left| V_S \right|^2 L_O - \left| V_S \right| \left| V_T \right| |\Theta_{VS} - \Theta_{VT}| \]
\[ S_{55r} = \frac{1}{\pi} \frac{I_{55}^2 \sqrt{\frac{\theta_{90}}{1}}}{\sqrt{I_{55}^2 + I_{55}^2 + \theta_{90}}} \times \frac{1}{\sin(0.5)} \times \frac{\cos(\alpha + 90^\circ)}{-0.5} \times \frac{\sin(\alpha)}{\cos(\theta - 0)} \]

\[ P_{55r} = \text{Re}(S_{55r}) = \frac{1}{\pi} \frac{I_{55}^2 \sqrt{\frac{\theta_{90}}{1}}}{\sqrt{I_{55}^2 + I_{55}^2 + \theta_{90}}} \times \frac{1}{\sin(0.5)} \times \frac{\cos(\alpha + 90^\circ)}{-0.5} \times \frac{\sin(\alpha)}{\cos(\theta - 0)} \]

\[ P_{\text{out}} = -P_{55r} \]
\[ Q_T = \frac{1}{V + 1} \left[ \frac{1}{V + 1} \right] \times \left[ \frac{1}{V + 1} \right] \times \left[ \frac{1}{V + 1} \right] \]

They differ by \( \frac{1}{V} \) in general.

\[ m(t) = M\cos(\omega t + \phi) \]

\( m(T) \) is the amplitude of \( m(t) \).
\[
S_{30} = 3 \varepsilon \left( \frac{V_{\text{as}}^2 \delta_0^2}{|V_{\text{en}}| \left| I_{\text{en}} \right| (\theta_0 - \theta_z)} \right) \\
S_{30} = \Theta \left[ V_{\text{as}}^2 (\theta_0^2 - \theta_z^2) \right] \\
S_{30} = \Theta \left[ V_{\text{as}}^2 \delta_0^2 \right]
\]
\text{of lin}\n\text{Calculation P.Q}
\text{Some \theta \rightarrow \theta_i} \wedge \text{v, \theta_i} \wedge \text{\theta_v} \rightarrow \text{VSAE} \rightarrow \text{SomeAnotherForm}
\text{in ATP}
\text{Easiest way to get P.Q measured}
P and Q output from VSC and Applying Transformations

- Averaged Model Circuit

- Only a single current source on each rail in the DC bus -- take sum in TACS
Synchronous DQ Transform

2*60Hz
Calculate P and Q at PCC

VSD
ID
VSQ
IQ

VSD
IQ
VSQ
ID

VPOSAV
VNEGAV

Correct polarity on measurement calculation
\[ P = \frac{3}{2} (V_{sd} i_d + V_{gs} i_g) \]

From PLL

0

\[ (b) \quad P = P_{o} (\frac{V_s}{V_{sd}}) \]

\[ O = (y_{sd} - V_{sd} i_d) \]

From

\[ V_s = -\frac{Q}{V_{sd}} \]

\[ i_g = \frac{L_s}{V_{sg}} \]
Closed Loop Modulating Functions Controls

$\text{ID}_{\text{ref}} = \frac{2}{3} \text{V}_{\text{so}}$

$K_p = 0.138$

$G(s) = 1$
Convert MD and MQ alpha-beta and then to ABC domain

Inverse transformations

Gain = 1

Gain = -1

Equation 4.47