Topics for Today:

- Announcements
- Matlab - how did it go?
- Office hrs: 4:05-5:55pm W,F
  Office: EERC 614. Phone: 906.487.2857
Next: Transmission Line Parameters, Chapters 4,5,6

Synchronous Machines - Chapter 3. (View the review video!)

- Basic internal structure of machines, cylindrical vs. salient
- Field windings
- Calculation with Xd and Xq.
- Calculation Example(s)
- Concepts behind SYNCH exercise set.
- S-S behavior - Xd; Dynamic behavior - Xd'
- Short-circuit behavior - Xd''; s-s, transient, subtransient

Recommended problems from Ch.3, solutions posted
Three-Winding Y-Y-D Auto-Transformer - Interpretation of Factory Test Data

Split Rock #10 and #11

Bruce More, Jun 25, 2005

C:\R/SC/\HV/FMR/3WIND.xls

= Input Data

(All other cells are locked)

Winding Ratings, OA

<table>
<thead>
<tr>
<th>KVL-L</th>
<th>MVA</th>
<th>Current</th>
<th>BASE RAT</th>
<th>BASE, 10/BASE, TER</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>345</td>
<td>240</td>
<td>401.63</td>
<td>485.94 1190.25 1899.29</td>
</tr>
<tr>
<td>X</td>
<td>118</td>
<td>240</td>
<td>1174.27</td>
<td>58.02 139.24 221.02</td>
</tr>
<tr>
<td>Y</td>
<td>13.8</td>
<td>63</td>
<td>2635.73</td>
<td>3.02 1.90 3.02</td>
</tr>
</tbody>
</table>

Binary Short Circuit Tests (Using Base of Winding Source):

Source | Shorted Test MVA ISOURCE ISHORT PMEAS R, Ohms QCALC %MEAS %RCALC %XCALC
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>345</td>
<td>118</td>
<td>240</td>
<td>1174.27</td>
<td>58.02 139.24 221.02</td>
<td></td>
</tr>
<tr>
<td>118</td>
<td>13.8</td>
<td>63</td>
<td>2635.73</td>
<td>3.02 1.90 3.02</td>
<td></td>
</tr>
</tbody>
</table>

On 100-MVA Base:

ZHX = 53.82 2.43% 0.0452% 2.43%
ZHY = 71.87 17.29% 0.2450% 17.28%
ZXY = 57.26 13.94% 0.2434% 13.93%

Calculate 3-Winding Star- and Delta-Equivalent Short-Circuit Impedances:

Terminal

<table>
<thead>
<tr>
<th>R, Ohms</th>
<th>PAC</th>
<th>P Check</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>0.259</td>
<td>PHX = 209.365</td>
</tr>
<tr>
<td>X</td>
<td>0.0335</td>
<td>PHY = 95.448</td>
</tr>
<tr>
<td>Y</td>
<td>0.0042</td>
<td>PXY = 95.688</td>
</tr>
</tbody>
</table>

Ratings of Actual Coils, OA

<table>
<thead>
<tr>
<th>kVPH</th>
<th>MVA</th>
<th>Current</th>
<th>BASE RAT</th>
<th>BASE, 10/BASE, TER</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>131.06</td>
<td>52.64</td>
<td>401.63</td>
<td>485.94 1190.25 1899.29</td>
</tr>
<tr>
<td>C</td>
<td>66.13</td>
<td>52.64</td>
<td>727.64</td>
<td>88.16 139.24 221.02</td>
</tr>
<tr>
<td>D</td>
<td>13.80</td>
<td>21.00</td>
<td>1521.74</td>
<td>9.67 5.71 9.07</td>
</tr>
</tbody>
</table>

Calculate Auto transformer Coil Impedances Based on Conservation of Short-Circuit P & Q:

Coil | IRATED KVRATED R, Ohms X, Ohms PAC P Check |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>H-X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Series</td>
<td>131.06</td>
<td>52.64</td>
<td>401.63</td>
</tr>
<tr>
<td>Common</td>
<td>727.64</td>
<td>66.13</td>
<td>0.0509</td>
</tr>
<tr>
<td>Delta</td>
<td>1521.74</td>
<td>13.80</td>
<td>0.0116</td>
</tr>
</tbody>
</table>

Short-Circuit Test Conditions in Each Coil:

Test:

<table>
<thead>
<tr>
<th>H-X</th>
<th>H-Y</th>
<th>X-Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coil</td>
<td>KVRATED</td>
<td>PAC</td>
</tr>
<tr>
<td>Series</td>
<td>131.06</td>
<td>52.64</td>
</tr>
<tr>
<td>Common</td>
<td>727.64</td>
<td>66.13</td>
</tr>
<tr>
<td>Delta</td>
<td>1521.74</td>
<td>13.80</td>
</tr>
</tbody>
</table>

Synthesized Short-Circuit Tests for S-C windings:

Test:

<table>
<thead>
<tr>
<th>S-C</th>
<th>S-D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coil</td>
<td>KVRATED</td>
</tr>
<tr>
<td>Series</td>
<td>131.06</td>
</tr>
<tr>
<td>Common</td>
<td>727.64</td>
</tr>
<tr>
<td>Delta</td>
<td>1521.74</td>
</tr>
</tbody>
</table>

Details of Synthesized Binary Short Circuit Tests for S-D windings (Using Base of Source Winding):

| Source | Shorted Test MVA ISOURCE ISHORT PCALC QCALC R, Ohms X, Ohms %ZCALC %RCALC %XCALC |
|-------|--------|--------|--------|--------|--------|--------|--------|
| 131.06 | 68.13 | 401.63 | 727.64 | 1093.56 14013.58 1295.38 28.958 0.1649 8.87 S-C |
| 131.06 | 68.13 | 401.63 | 727.64 | 1093.56 14013.58 1295.38 0.1371 13.20 S-D |
| 68.13 | 13.80 | 65.00 | 308.25 | 1521.74 953.58 5530.58 0.330 19.42 73.76 |

On 100-MVA Base:

ZSC = 53.82 5.62% 0.1044% 5.62%
ZSD = 76.25 20.89% 0.2747% 20.89%
ZCD = 57.26 13.94% 0.2434% 13.93%

Calculate 3-Winding Star- and Delta-Equivalent Short-Circuit Impedances:

% on 100-MVA Base

<table>
<thead>
<tr>
<th>R</th>
<th>X</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZS</td>
<td>0.0797%</td>
<td>6.32%</td>
</tr>
<tr>
<td>ZC</td>
<td>0.0395%</td>
<td>-0.70%</td>
</tr>
<tr>
<td>ZD</td>
<td>0.2068%</td>
<td>14.83%</td>
</tr>
<tr>
<td>ZS-D</td>
<td>0.1838%</td>
<td>5.32%</td>
</tr>
<tr>
<td>ZS-D</td>
<td>0.6500%</td>
<td>-11.17%</td>
</tr>
<tr>
<td>ZD-D</td>
<td>0.3547%</td>
<td>12.32%</td>
</tr>
</tbody>
</table>

Coil Resistances:

Calculate [A] matrix:

<table>
<thead>
<tr>
<th>RS, Ohms</th>
<th>0.3490</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC, Ohms</td>
<td>0.0500</td>
</tr>
<tr>
<td>RD, Ohms</td>
<td>0.0118</td>
</tr>
</tbody>
</table>

| VD | 0.203 |
| VD | 0.105 |
| VC | 0.520 |

XS-C / (XS-C + XS-D) 20.95% |
XS-D / (XS-C + XS-D) 20.95% |
XS-D / (XS-C + XS-D) 13.93% |

[ ]
\[ I_{\text{circ}} = \frac{\Delta V}{j \cdot 4} = -j \cdot 1.25 \text{ p.u.} \]

\[ \Delta V = 1.05 \text{ p.u.} \]
Circuit theory

\[ I_1 = I_{1a} + I_{1b} \]

\[ I_2 = I_{1a} + I_{1b} = \frac{160^\circ - \tilde{V}_2}{j \cdot 2} + \left( \frac{160^\circ - \frac{V_2}{1.05}}{j \cdot 2} \right) \frac{1}{1.05} \]

\[ \frac{\sqrt{V_2}}{0.8 + j \cdot 5} \]

KCL:

\[ \Rightarrow \tilde{V}_2 = 0.963 (150^\circ) \text{ p.u.} \]
Energization Testing of Var Meters
Next: Synchronous Machines - Chapter 3

- Recommended problems & solns for Ch.3 are posted.
- Phasor diagrams - unity, lag, lead
- Salient rotor machines - calculation with \( X_d \) and \( X_q \).
- Calculation Example(s)
- P & Q flows thru transmission lines
- More on admittance matrix \([Y]\) construction
S. S - Power Flow

Trans - Step

S. Time - Switching

[Diagram with electrical symbols and connections]
First of all, notation-wise, the internal induced voltage of the synch machine is called \( E_a \) in some references (voltage induced on armature windings) and in other references it's called \( E_f \) (since induced voltage on armature is due to magnitude of field current according to open-circuit characteristic of machine).

In answer to question posed:

Yes, \( I_q \) by definition is exactly in phase with \( E_a \). Referring to Fig. B-5 in Appendix B reference,

1) determine \( I_a \) according to load specified, usually assuming \( V_t = 1.0 \) pu at 0°.
2,3) calculate \( E_a' \) to find torque angle delta (this is based observation that since \( jX_d I_d \) is parallel to \( E_a \), then \( V_t + I_a R_a + jX_q I_q \) lands you somewhere along the phasor \( E_a \) and this allows you to determine delta.
4) knowing delta, resolve \( I_a \) into its 2 components \( I_a = I_d + I_q \)
5) then finally, \( E_a = V_t + I_a R_a + jX_d I_d + jX_q I_q \).

As a double-check, \( E_a \) must end up with the same angle (delta) that you calculated for \( E_a' \). So, the very good thing about this is that there is a double-check built into the calculations, you can immediately see if your answer seems to be correct, i.e. if \( E_a' \) and \( E_a \) have different angles, then you messed up somewhere along the line...

Dr. Mork