EE 5200 - Lecture 14

Topics for Today:

• Announcements
  • Matlab - how was first assignment? Take feedback.
  • Office hrs: 4:05-4:55pm W,F; Saturday 4-6pm
  • Office: EERC 614. Phone: 906.487.2857
  • Recommended problems from Ch.3, solutions posted
  • Homework SYNCH Part 1 - Due 9am Mon Oct 3rd
  • Next: Transmission Line Parameters, Chapters 4,5,6

Synchronous Machines - Chapter 3.
• 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
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 $0^\circ$.
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 $V_t + I_a R_a + jX_q I_a$ 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
1) [20 pts] A 50-MVA delta-wye transformer is rated 115-13.8-kV. It has standard phase shift of 30° (115-kV side leads 13.8-kV side by 30°). Its self-cooled short-circuit impedance is 0.005 + j0.045 p.u. on the base of the transformer.
   a) Convert the impedance to 100 MVA base for system calculations.
   b) Determine its per unit 2x2 admittance matrix values for i) pos and ii) neg sequence, being sure to include the effect of phase shift.
   c) Repeat b) for the situation where the transformer is to connect system buses having base voltages of 115 kV and 12.47-kV. Include phase shift and off-nominal turns ratio.
Next: Synchronous Machines - Chapter 3
- Recommended problems & solns for Ch.3 are posted.

Phasor diagrams - unity, lag, lead
Salient rotor machines - calculation with Xd and Xq
Calculation Example(s)
P & Q flows thru transmission lines
More on admittance matrix [Y] construction
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\[ P_{\text{out}} = \frac{E_a V_T \sin \delta_e}{X_s} \]
\[ Q_{\text{out}} = \frac{E_a V_T \cos \delta_e - \frac{V_T^2}{X_s}}{X_s} \]
\[ P_{out} = \frac{EVT \sin \delta}{X_s} \]

\[ Q_{out} = \frac{EVT \cos \delta - \frac{V_r^2}{X_s}}{X_s} \]

\[ S_{out} = VI^* = P_{out} + jQ_{out} = S_{into \ system} \]

\[ S_m = B_r - LB_s \]

\[ P_{1 \rightarrow 2} = \frac{V_1V_2}{X} \sin(d-\beta) \]
\[ \frac{\Delta P(S)}{\Delta S} = ? \]
Salient vs. Non-Salient

(rotor w/ pole projections)
- Hydra - slower speed.
- More poles.

(round rotor)
- Steam turbine, high speed.
- 2 or 4 pole.

\[ P = \frac{E VT \sin \delta_e}{\frac{X_s}{\text{electrical}} \ \text{gys!}} \]

Torque Angle mech:
\[ \delta_m = \frac{16\pi - 7\theta_s}{\text{mech degrees}} \]

\[ \delta_e = \delta_m \frac{N_p}{2} \]
\[ P_{out} = \frac{E_a V_r}{X_d} \sin \delta + \frac{V_r^2}{2} \left( \frac{X_d - X_q}{X_d X_q} \right) \sin 2\delta \]
KVL: \[ \vec{E}_a = \vec{I}_a(jX_s + R_a) + \vec{V}_t \]

\[ \theta = \frac{\vec{V}_t - \vec{V}}{\vec{V}} \]

\[ \phi = \frac{\vec{I}_a - \vec{I}_a R_a}{\vec{I}_a} \]

CYLINDRICAL ROTOR
KVL: \[ E_A = V_f + I_A R_A + I_f j X_f + I_d j X_f \]
To: ee5200-l@mtu.edu  
From: Bruce Mork <bamork@mtu.edu>  
Subject: d-q synch machine steady-state loading calcs

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In answer to question posed:

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1) determine Ia according to load specified, usually assuming Vt = 1.0 pu at 0°.  
2,3) calculate Ea' to find torque angle delta (this is based observation that since jXdId is parallel to Ea, then Vt + IaRa + jXqla lands you somewhere along the phasor Ea and this allows you to determine delta.  
4) knowing delta, resolve Ia into its 2 components Ia = Id + Iq  
5) then finally, Ea = Vt + IaRa + jXdId +jXqlq.  

As a double-check, Ea must end up with the same angle (delta) that you calculated for Ea'.  
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 Ea' and Ea have different angles, then you messed up somewhere along the line...

Dr. Mork
MEL curves are for 16.2 kV, 17.1 kV & 18 kV. The machine capability will also be reduced as the generator voltage is reduced. This effect is not apparent.

Operation of the generator below maximum voltage may require a change in the MEL setting.
$H_2$ inside Gen

- Reduce windage losses ($P_{mech\ loss}$)
- Reduce $H_2O$ vapor
- Heat transfer/cooling.