EE 5200 - Lecture 14

Announcements
- Matlab hmwk to be posted.
- Office hrs: 2:05-2:55pm M,W,F
- Office: EERC 614. Phone: 906.487.2857
- Recommended problems from Ch.3, solutions posted
- Next: Transmission Line Parameters, Chapters 4,5,6

Synchronous Machines - Chapter 3.
- Concepts behind SYNCH exercise set.
- S-S behavior - Xd ; Dynamic behavior - Xd’
- Short-circuit behavior - Xd”; s-s, transient, subtransient

Chapter 4 - Series Resistance of Transmission Lines
- Series Resistance, temperature correction
- Basic stranding, conductor types, ACSR is most common
- Series Resistance, temperature correction

Chapter 5 - Series Inductance of Transmission Lines
- Self inductance, mutual inductance
2) [16 pts] A simplified two-machine representation is used to model a power system. For all practical purposes, this can be analyzed just like two synchronous generators, as shown below.

\[ \vec{E}_{G1} = 1.05 \angle 20^\circ \]

\[ P = 0.75 \text{ p.u.} \]

\[ V_T \angle 0^\circ \]

\[ N \]

\[ \vec{E}_{G2} \]

\[ j0.45 \text{ p.u.} \]

\[ j0.50 \text{ p.u.} \]

a) Find the magnitude of the terminal voltage \( V_T \).

\[ P = \frac{E_a V_T}{j \cdot 0.45} \sin (20^\circ - \phi) \]

b) Calculate the line current \( I \).

c) Calculate the magnitude and angle of the voltage \( \vec{E}_{G2} \).

d) As a check of your calculations, calculate the power flow from G1 to G2 using the total angle difference between their internal voltages and the total reactance between them. How does this compare to the power flowing out of G1?
3) [24 pts] A salient pole synchronous generator has direct axis synchronous reactance of 0.75 per unit and quadrature axis synchronous reactance of 0.50 per unit. It is delivering rated output at 0.8 PF lagging to a load at rated voltage. Armature resistance is neglected. Assuming the phase A terminal voltage at the load is 1.0/0° per unit,

a) Calculate the magnitude and angle of the phase A armature current in per unit.

\[ I_a \]

b) Calculate the torque angle \( \delta \).

\[ \bar{I}_a j X_q \]

Lecture 13 !

c) Calculate the per unit magnitude and angle of \( I_d \) and \( I_q \).

\[ \bar{I}_d \bar{I}_q \]

d) Calculate the per unit magnitude and angle of the internal voltage \( E_i \).

\[ E_i \]

e) Sketch out the phasor diagram, labeling all voltages and currents (i.e. \( E_i, I_d X_q \), etc). Don’t bother to label the actual magnitudes and angles.

\[ \]

f) Calculate the voltage regulation of the generator.
4) [20 pts] Answer any four of the following short concept/essay questions. Be sure to clearly indicate which one you do not want graded, or the first four will be graded.

a) [5 pts] Explain how an off-diagonal element in the system admittance matrix can have a zero value. Is it common for this to happen? In terms of computer memory usage, is it better to describe the system with an impedance matrix or an admittance matrix?

b) [5 pts] Explain what $X_d''$, $X_d'$ and $X_d$ are and explain what type of calculation each is suited for.

c) [5 pts] The voltage at a particular bus is found to be sagging (= too low). There is no generator at this bus. Describe at least two corrective actions that could be taken. Are these economic to carry out?

d) [5 pts] In terms of controlling the P & Q output by a generator, what is the principal effect of adjusting the internal voltage $E_i$? Of adjusting the input torque?

e) [5 pts] Referring to the generator P-Q operating characteristic, explain what limits $Q_{\text{max}}$. What limits $Q_{\text{min}}$?
\[ P = \frac{E_v}{X_s} \]

\[ V_o = \frac{E_v}{X_s} \]

\[ Q = E_v \cos \delta - \frac{1}{X_s} \]

\[ \text{FIGURE 3.14} \]

Loading capability curve for a cylindrical-rotor turbine-generating unit with maximum turbine output = 655 MVA, 24 kV, 0.9 power factor.}

\[ X_s = 172.4 \text{kV} \]

Point \( k \) relates to Example 3.4.
\[ Q = \frac{E_f V_T \cos \delta S}{X_s} - \frac{V_T^2}{X_s} \]

**FIGURE 3.13**
Phasor diagram obtained by multiplying (rescaling) all distances in Fig. 3.12 by \(|V_r/X_d|\).
Fault Current: \( \frac{jXd}{\cos A} \)

\[ S.C. \]

\[ jXd = jXs \]

S-s.: \( jXd \)

transient: \( jXd' \) - a few seconds (stability)

Subtransient: \( jXd'' \) - up to a few cycles (fault)
3.9 SHORT-CIRCUIT CURRENTS

When an ac voltage is applied suddenly across a series \( R - L \) circuit, the current which flows generally has two components—a dc component, which decays according to the time constant \( L/R \) of the circuit, and a steady-state sinusoidally varying component of constant amplitude. A similar but more complex phenomenon occurs when a short circuit appears suddenly across the terminals of a synchronous machine. The resulting phase currents in the machine will have dc components, which cause them to be offset or \emph{asymmetrical} when plotted as a function of time. In Chap. 10 we shall discuss how the \emph{symmetrical} portion of these short-circuit currents is used in the ratings of circuit breakers. For now let us consider how short circuits affect the reactances of the machine.

A good way to analyze the effect of a three-phase short circuit at the terminals of a previously unloaded generator is to take an oscillogram of the current in one of the phases upon the occurrence of such a fault. Since the voltages generated in the phases of a three-phase machine are displaced 120 electrical degrees from each other, the short circuit occurs at different points on the voltage wave of each phase. For this reason the unidirectional or dc transient component of current is different in each phase.\(^4\) If the dc component of current is eliminated from the current of each phase, the amplitude of the ac component of each phase current plotted versus time, shown in Fig. 3.19, varies approximately according to

\[
I(t) = |E_i| \frac{1}{X_d} + |E_i| \left( \frac{1}{X'_d} - \frac{1}{X_d} \right) e^{-t/T_d} + |E_i| \left( \frac{1}{X''_d} - \frac{1}{X_d} \right) e^{-t/T_d} \tag{3.57}
\]

where \( e_i = \sqrt{2} |E_i| \cos \omega t \) is the synchronous internal or no-load voltage of the machine. Equation (3.57) clearly shows that the armature phase current, with the dc removed, has three components, two of which decay at different rates over the subtransient and transient periods. Neglecting the comparatively small resistance of the armature, the distance \( o-a \) in Fig. 3.19 is the maximum value of the sustained short-circuit current, with the rms value \( |I| \) given by

\[
|I| = \frac{o-a}{\sqrt{2}} = \frac{|E_i|}{X_d} \tag{3.58}
\]

If the envelope of the current wave is extended back to zero time and the first few cycles where the decrement appears to be very rapid are neglected, the

intercept is the distance \( o-b \). The rms value of the current represented by this intercept is known as the *transient current* \( |I'| \), defined by

\[
|I'| = \frac{o-b}{\sqrt{2}} = \frac{|E_i|}{X'_d}
\]  

(3.59)

The rms value of the current determined by the distance \( o-c \) in Fig. 3.19 is called the *subtransient current* \( |I''| \), given by

\[
|I''| = \frac{o-c}{\sqrt{2}} = \frac{|E_i|}{X''_d}
\]  

(3.60)

Subtransient current is often called the *initial symmetrical rms current*, which is more descriptive because it conveys the idea of neglecting the dc component and taking the rms value of the ac component of current immediately after the occurrence of the fault. Equations (3.59) and (3.60) can be used to calculate the parameters \( X'_d \) and \( X''_d \) of the machine when an oscillographic record such as Fig. 3.19 is available. On the other hand, Eqs. (3.59) and (3.60) also indicate the
Transmission Lines:

\[ A \ \boxed{\text{per-phase} \ \frac{G}{A-N}} \]

Short-Circuit
Load-Flow
Stability

Full 3-phase
Coupled L's
and C's

Return Via
earth,
static
wires

Carson's Formula
Conductor types

- ACSR - Alum Covered, Steel Rein.
- 3M
- Southwire.com - ACSR
- ACCR - Composite Core
  - Alum-Zirconium Alloys
  - Less sagging

NESC

Sag
DC Resistance

\[ J = \frac{I}{A} \frac{A}{m^2} \]

\[ R_{DC} = \frac{\rho \cdot L}{A} \]

\[ \rho = \frac{\sigma - m^2}{m} \]

Actually: \( \frac{\sigma - m^2}{m} \)
AC Resistance

\[ R \]

Steel core

\[ P_{\text{Fe}} \gg P_{\text{Al}} \]

2 or more layers of Al.

What is \( J \) thought ACSR?

\( J \) highest in layer next to surface. Proximity effects.