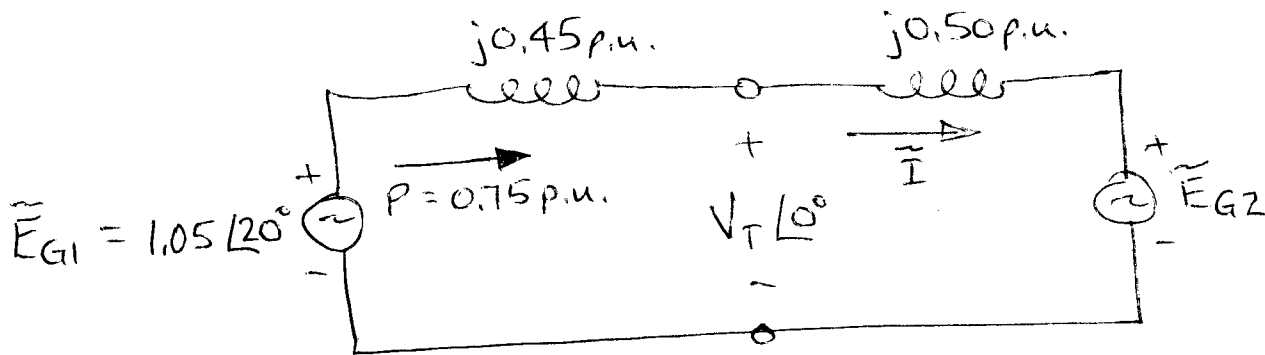1) [20 pts] A 50-MVA delta-wye transformer is rated 115-13.8-kV. It has a standard phase shift of 30° (115-kV side leads 13.8-kV side by 90°). Its self-cooled ("OA" or "ONAN") short-circuit impedance is 0.005 + j0.045 p.u.on the base of the transformer. The wye-side neutral is solidly grounded.

   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) Optional: 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.

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.

$$j0.45\,p.u. \qquad\qquad j0.50\,p.u.$$

$$\tilde{E}_{G1} = 1.05\,\angle 20° \qquad P = 0.75\,p.u. \qquad V_T\,\angle 0° \qquad \tilde{I} \qquad \tilde{E}_{G2}$$

a) Find the magnitude of the terminal voltage V_T.

b) Calculate the line current $\overline{I}$.

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

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 $1.0\underline{/0}°$ per unit,

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

b) Calculate the torque angle δ.

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

d) Calculate the per unit magnitude and angle of the internal voltage E_f.

e) Sketch out the phasor diagram, labeling all voltages and currents (i.e. E_f, $I_q jX_q$, 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** 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_f? Of adjusting the input torque?

e) [5 pts] Referring to the generator P-Q operating characteristic, explain what limits Q_{max}. What limits Q_{min}?