Per Unit and Transformer Modeling

1. The three phase ratings of a three-winding transformer are:

primary	Y—connected,	66kV,	15MVA
secondary	Y—connected,	13.2kV,	10.0MVA
tertiary	Δ—connected,	2.3kV,	5MVA

Neglecting resistance, the leakage impedances are

$$Z_{ps} \triangleq Z_p + Z_s = 7\% \text{ on 15MVA 66kV base}$$

$$Z_{pt} \triangleq Z_p + Z_t = 9\% \text{ on 15MVA 66kV base}$$

$$Z_{st} \triangleq Z_s + Z_t = 8\% \text{ on 10MVA 13.2kV base}$$

Find the per-unit impedances of the star-connected equivalent circuit for a base of 15MVA, 66kV in the primary circuit.

(10%)

Line Modeling

2. In power flow study, transmission lines are frequently modeled as a π - equivalent circuit. What are the assumptions made for the derivation of this π - equivalent circuit? Answer by giving multiple choices among the following and for each of your choices, define the term underlined below (e.g., if you select (f), you don't need to make any definition.).

(a) The modeled transmission line is phase-symmetric.

(b) The line conductors are well bundled.

(c) The per phase (zero-sequence) parameter $Z_0 = 0$.

(d) The per phase (positive-sequence) parameter Z_1 equals the per phase (negative-sequence) parameter Z_2, i.e., $Z_1 = Z_2$.

(e) The line is "electrically short", i.e., the line length χ is shorter than the half of line propagation wavelength λ:

$$\chi < \frac{\lambda}{2}$$

(f) None of (a)~(e).

(**Note:** For (a) and (b), you can give a descriptive definition, but for (c), (d) and (e), you are requested to give a mathematical formula for each underlined term.)

(10%)

3. For a lossless transmission line, let $\bar{V}_r$, $\bar{I}_r$ denote the voltage and current at the line receiving end, and let $\tilde{v}$ denote the propagation constant. Assume the line is terminated with a surge impedance $\bar{Z}_c$. Then the voltage at any position (χ) of the line can be expressed as:

$$\bar{V}(\chi)=\cosh \tilde{v}\chi \bar{V}_r+\bar{Z}_c \sinh \tilde{v}\chi \bar{I}_r$$

Prove: $|\bar{V}(\chi)|=V_r$ at all χ. You are requested to give all necessary derivation steps. (5%)

Generator Modeling and Protection

4. The power delivery capability of a synchronous generator can be described by the operating limit curve in Figure 1. As shown, the curve is made up with three curve segments: ab, bc and cd, as well as one straight line segment.

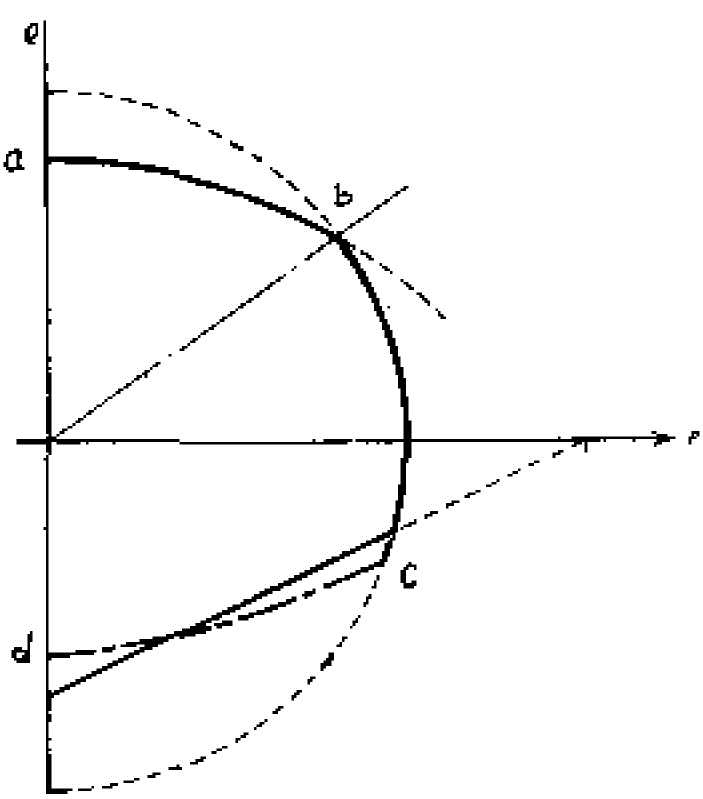


Figure 1

(a) What does curve cd constrain? Answer by giving your multiple choices among the following:
(1) generator's Q output, (2) generator's Q input, (3) stator heating, (4) rotor heating, (5) steady state stability limit, (6) voltage regulator's setting, (7) None of (1)~(6).

(b) Assume the generator rating is 200MW (P_{rating}). Estimate a value for Q_{max}. And indicate P_{rating} and Q_{max} on Figure 1 for power flow study.

(c) During the normal operation, if the exciter is gradually adjusted to raise 20% above the normal excitation voltage, what do you expect to happen? Answer by giving multiple choices of the following:

(1) real-power output (P_{out}) is decreased, (2) power angle (δ) is increased, (3) reactive-power output (Q_{out}) is increased, (4) None of (1) ~(3).

(10%)

5. The loss-of-field of synchronous generator can be detected indirectly by the combined use of several relays. What are these relays? Answer by giving multiple choices of the following:

(a) Differential relay

(b) Impedance relay

(c) Under-voltage relay

(d) Over-speed relay

(e) Reversed Q relay

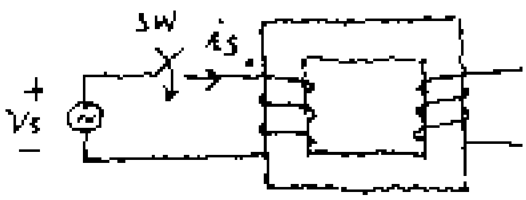
(f) None of (a)~(e)

(5%)

Power System Transients

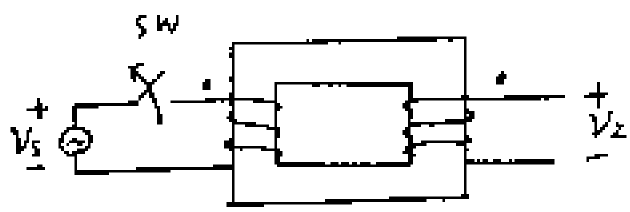
6. Describe the transient problems of the following cases, by sketching their transient waveforms and by giving the methods to reduce the resulted transients:

(a)



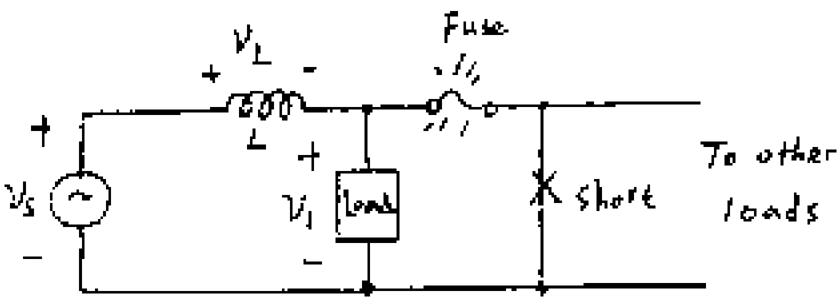
i_s as SW is turned on.

(b)



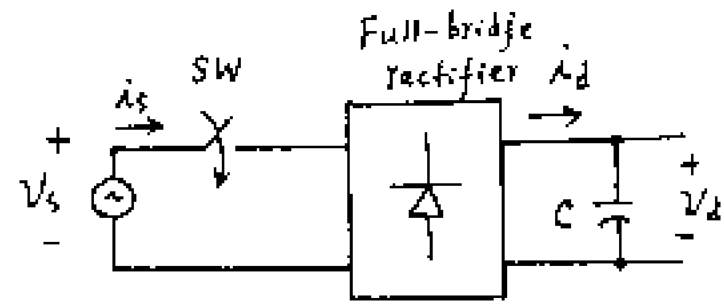
v_2 as SW is turned off.

(c)



v_1 as the fuse is burned out due to the short circuit fault.

(d)



i_s as SW is turned on. (20%)

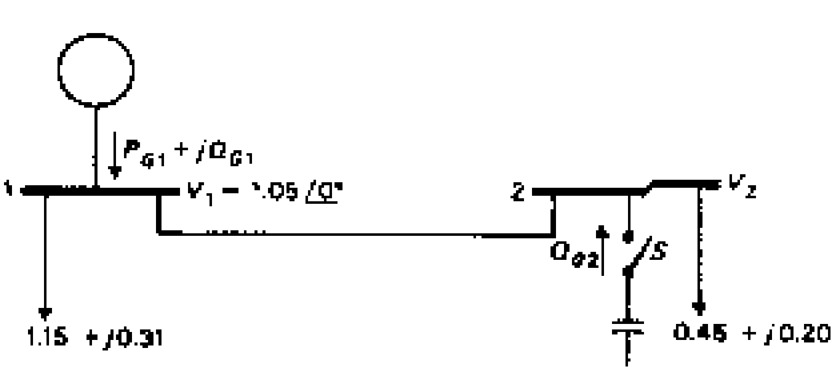
Power Flow

7. What are the assumptions made in power flow modeling for high voltage transmission networks? (8%)

8. For the two-bus system below, the bus-admittance matrix is:

$$Y_{bus} = \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix}$$

where $y_{21} = 1.9\angle 99.2°$, $y_{22} = 1.8\angle -80.5°$, all in pu values.



(a) Assume the capacitor at bus 2 is out. Estimate $V_2\angle\delta_2$. Answer by giving multiple choices among the following, which are the one closest to the correct answer.

(1) $V_2 = 1.10$, (2) $V_2 = 0.95$, (3) $V_2 = 0.90$, (4) $\delta_2 = +13°$, (5)

$\delta_2 = -13°$

Note: $\sin 13° = 0.225$, $\cos 13° = 0.974$, $\sin 8° = 0.139$, $\cos 8° = 0.990$

(b) Assume the capacitor at bus 2 is energized, and $V_2 = 1.00\,pu$. Estimate Q_{G2} and δ_2 in the same way as in problem (a).

(1) $\delta_2 = +13°$, (2) $\delta_2 = -13°$, (3) $\delta_2 = +8°$, (4) $\delta_2 = -8°$, (5) $Q_{G2} = 0.16$, (6) $Q_{G2} = 0.10$

(c) Compare condition (b) to (a). That is, after the capacitor energization, what do you expect? Answer by giving multiple choices among the following:

(1) Line loss is decreased. (2) Line charge is increased. (3) Generator is closer to over-excitation condition. (4) Line flow is closer to steady state stability limit. (5) The exact value of $|\delta_2|$ is decreased. (6) None of (1)~(5).

(12%)

Fault Analysis

9. Consider the HV industrial power system in Figure 2. Assume a 1ϕ-G fault occurs at the system bus as indicated in Figure 2. Let MVA_{s1} and MVA_{s0} denote the positive- and zero- sequence short circuit capacity at the point of common coupling (PCC) respectively. Also let MVA_b denote the system MVA base.

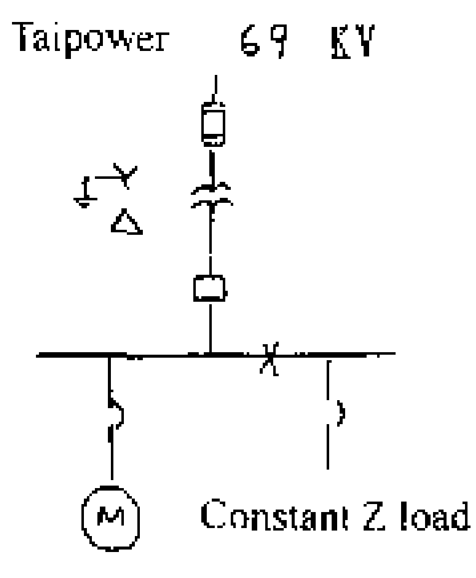


Figure 2

(a) Calculate the equivalent system impedance at PCC: X_{s1}, X_{s2} and X_{s0}

where X_{s1}, X_{s2} and X_{s0} denote the positive-, negative- and zero-sequence reactances respectively. Answer by giving a mathematical formula for calculation of each reactance.

(b) Is $X_{s1} > X_{s0}$ or $X_{s0} > X_{s1}$? Select one and give your reason.

(c) Let X_{m1}, X_{m2}, X_{m0} denote the positive-, negative- and zero- sequence transient reactances in system pu for the motor. Also, let X_{t1}, X_{t2}, X_{t0} denote the positive-, negative- and zero- sequence leakage reactances for the main transformer. Draw the sequence diagram and give the mathematical formula to calculate the fault current I_f.

(15%)

Stability

10. Consider the power system in Figure 3. Suppose a balance 3 ϕ fault occurs at point F.

Figure 3

Line data	Generator data
$X_1 = 0.4$	$E'_q = 1.2$
$X_2 = 0.2$	$P_m = 1.5$
$X_3 = 0.2$	$X'_d = 0.2$

(a) Draw the positive- sequence network for this faulted system. Also indicate Bus #1 on the network diagram.

(b) If the fault is not removed, will the generator be stable? Give numerical calculations to support your answer.

(5%)