EE347 HW5 Nick Porter

Text Questions:

3-9

How does the per-unit system eliminate the problem of different voltage levels in a power system?

By choosing a single S_base value, the per-unit system is able to scale all impedances in the system to that base value. This allows us to treat the whole system as a single line. We are also able to compare internal impedances between components of different sizes.

10-6

What steps are required to solve for the bus voltages in a power system?

- Separate the power system into regions (each region has its own voltage rating)
- Choose an S_base
- Choose a V_base for each region
- Calculate the Y_bus matrix for the power system
- Ignore generators and transformers
- Use possible injection currents at each generator/load to calculate bus voltages
    - Iterate this process until bus voltages converge to a specified tolerance

11-1

What is the purpose of a power-flow diagram?
To be able to easily determine the balance of real and reactive power in a system, and the direction in which each is being provided.

11-6

What techniques can be used to speed up convergence to a solution with the Gauss-Seidel iterative method?
The Gauss-Seidel method uses new calculations rather than previous calculations in its current k element formulas. As each k voltage in the bus voltage vector is calculated, the next k voltage formula uses all the newly computed bus voltages before it, instead of using the bus voltages from the previous iteration.

Text Problems:

3-22

(a)
$S_{base} = 1\ MVA$
$V_{base,1} = 480V$ $V_{base,2} = 13.8kV$ $V_{base,3} = 480V$

$V_{\phi 1} = 277V$ $\qquad V_{\phi 2} = 7967V$ $\qquad V_{\phi 3} = 277V$

$Z_{base,1} = \frac{3V_{\phi 1}^{2}}{S_{base}} = 0.23\Omega$

$Z_{base,2} = \frac{3V_{\phi 2}^{2}}{S_{base}} = 190.4\Omega$

$Z_{base,3} = \frac{3V_{\phi 3}^{2}}{S_{base}} = 0.23\Omega$

T$_1$: $R_{1pu} = 0.01$ $\qquad X_{1pu} = 0.04$

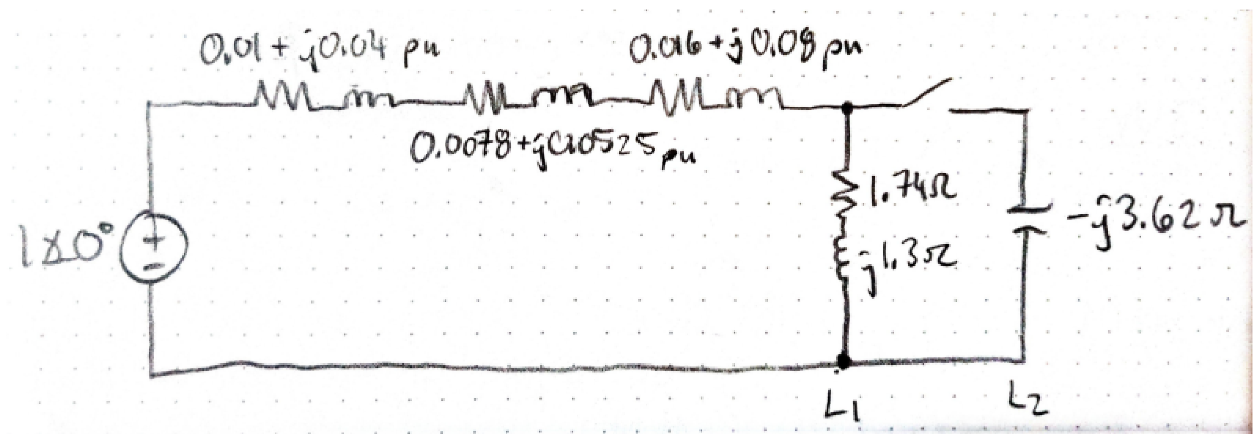
T$_2$: $R_{2pu} = 0.008\frac{V_{\phi 2}}{V_{\phi 2}}\frac{S_{base}}{S_{base,2}} = 2(0.008) = 0.016\Omega$

$X_{2pu} = 2(0.04) = 0.08\Omega$

$Z_{line,pu} = \frac{Z_{line}}{Z_{base,2}} = \frac{1.5+j10\Omega}{190.4\Omega} = 0.00788 + j0.0525\Omega$

$Z_{L1,pu} = \frac{Z_{L1}}{Z_{base,3}} = \frac{0.5\measuredangle 36.87°\Omega}{0.23\Omega} = 1.74 + j1.3\Omega$

$Z_{L2,pu} = \frac{Z_{L2}}{Z_{base,3}} = \frac{-j0.833\Omega}{0.23\Omega} =- j3.62\Omega$



(d)

Switch closed:

$Z_c = (0.01 + j0.04) + (0.00788 + j0.0525) + (0.016 + j0.08) + \frac{(1.74+j1.3)(-j3.62)}{1.74+j1.3-j3.62}$

$Z_c = 2.745 + j0.1675\Omega = 2.75\measuredangle 3.5°\Omega$

$I = \frac{V}{Z}$

$I_c = \frac{1.0\measuredangle 0°}{2.75\measuredangle 3.5°} = 0.364\measuredangle - 3.5°$

$P_{line,pu} = I^2 R_{line}$

$= (0.364)^2(0.00788) = 0.001044\, p.u.W$

$P_{line} = P_{line,pu} S_{base} = 1.04\, kW$

Switch open:

$Z = (0.01 + j0.04) + (0.00788 + j0.0525) + (0.016 + j0.08) + 1.74 + j1.3$

$Z = 1.774 + j1.47\Omega = 2.3\measuredangle 40°\Omega$

$I_o = \frac{1.0\measuredangle 0°}{2.3\measuredangle 40°} = 0.435\measuredangle - 40°$

$P_{line,pu} = (0.435)^2(0.00788) = 0.001491\, p.u.W$

$P_{line} = P_{line,pu}S_{base} = 1.5\, kW$

The effect of adding load 2 to the system reduces the power loss by greatly reducing the phase difference in the line current caused by the load.

10-7

$S_{base} = 40\, MVA \qquad V_{base,2} = 128\, kV$

6 regions separated at each transformer. The transformer ratios are all the same:

$a = 138kV/13.8kV = 10$

$V_{base,1} = V_{base,3} = V_{base,6} = \frac{V_{base,2}}{a} = 12.8\, kV$

$V_{base,2} = V_{base,4} = V_{base,5} = 128\, kV$

$Z_{base} = \frac{V_{base}}{S_{base}}$

$Z_{base,1} = Z_{base,3} = Z_{base,6} = 4.096\Omega$

$Z_{base,2} = Z_{base,4} = Z_{base,5} = 409.6\Omega$

Impedances for transformers and generators/motors are found by:

$Z_{pu,sys} = Z_{pu,given}\left(\frac{V_{given}}{V_{base}}\right)^2\left(\frac{S_{base}}{S_{given}}\right)$

$Z_{G1} = (0.03 + j0.8)\left(\frac{13.8kV}{12.8kV}\right)^2\left(\frac{40MVA}{40MVA}\right) = 0.0349 + j0.930\Omega$

$Z_{M2} = 0.0697 + j1.86\Omega$

$Z_{M3} = 0.128 + j4.254\Omega$

$Z_T = 0.0465 + j0.232\Omega$

Line impedances are found by:

$Z_{pu,sys} = \frac{Z}{Z_{base}}$

$Z_{L1} = \frac{10+j50}{409.6} = 0.0244 + j0.1221\Omega$

$Z_{L2} = Z_{L3} = \frac{5+j30}{409.6} = 0.0122 + j0.0732\Omega$

10-8

Calculate the bus admittance matrix Ybus and the bus impedance matrix Zbus for the power system from 10-7

$$\hat{Y}_{bus} = \begin{bmatrix} Y_a + Y_b & -Y_a & -Y_b \\ -Y_a & Y_a + Y_c & -Y_c \\ -Y_b & -Y_c & Y_b + Y_c \end{bmatrix}$$

$$= \begin{bmatrix} 0.72 - 4.507j & -0.329 + 1.64j & -0.351 + 1.793j \\ -0.329 + 1.64j & 0.7 - 3.97j & -0.351 + 1.793j \\ -0.351 + 1.793j & -0.351 + 1.793j & 0.709 - 3.82j \end{bmatrix}$$

$$\hat{Z}_{bus} = \hat{Y}_{bus}^{-1}$$

$$= \begin{bmatrix} 0.028 + 0.587j & 0.007 + 0.469j & 0.012 + 0.497j \\ 0.007 + 0.469j & 0.046 + 0.685j & 0.019 + 0.543j \\ 0.012 + 0.497j & 0.019 + 0.543j & 0.057 + 0.742j \end{bmatrix}$$

Problem 1:

Base power is 100 MVA.

Buses 19 and 20 exist in the same region, so they have the same V_{base} which I will define as 500kV, since that is the primary rating of the transformer connected to bus 19. Real power flows from bus 19 to bus 20 such that $P_{19,20} = 43\ p.u.W$. The line impedances between bus 19 and 20 are: $r_{pu} = 0.002$, $x_{L,pu} = 0.0155$, $x_{C,pu} = 0.032$. The power factor was chosen to be $PF = 0.97$.

$$I_{base} = \frac{S_{base}}{\sqrt{3} \cdot V_{base}} = 115.5\ A$$

$$Z_{base} = \frac{V_{base}}{\sqrt{3} \cdot I_{base}} = 2500\ \Omega$$

$$V_{\phi base} = \frac{V_{line}}{\sqrt{3}} = 287\ kV$$

The per-phase per-unit values are:

$P_{\phi} = P_{19,20}/3 = 14.78$ p.u.

$S_{\phi load} = \frac{P_{\phi}}{PF} = 14.78$ p.u.

$V_{\phi R} = 1.0\angle 0°$ p.u. by definition such that $V_{\phi R} \cdot V_{\phi base} = V_{\phi} = \frac{V_{base}}{\sqrt{3}}$

$I_{\phi R} = \frac{S_{\phi load}}{\sqrt{3} \cdot V_{\phi R}} = 8.53$ p.u.

$Z = Z_{\phi pu} = r_{pu} + jx_{L,pu}$
$Y = x_{C,pu}$
$V_{\phi drop} = I_{\phi R} Z_{\phi pu} = 0.0171 + j0.132 = 0.133\angle 83°$ p.u. V

For each of the short, medium, and long transmission line models, Vs was determined in order to find voltage regulation using A,B,C,D coefficients. The calculations were scripted in python using per-unit values.

$$U = \begin{bmatrix} A & B \\ C & D \end{bmatrix}$$
$[V_S, I_S]^T = U[V_R, I_R]^T$
$VR\% = \frac{|V_S - V_R|}{V_R} \times 100$

Short model:
$A = 1$ $\quad B = Z = r_{pu} + jx_{L,pu}$ $\quad C = 0$ $\quad D = 1$

$VR_{short} = 5.602\%$

Medium model:
$A = \frac{YZ}{2} + 1$ $\quad B = Z$
$C = Y\left(\frac{YZ}{4} + 1\right)$ $\quad D = A$

$VR_{med} = 5.577\%$

Long model:
$\gamma d = \sqrt{ZY}$
$Z' = Z \cdot \frac{sinh(\gamma d)}{\gamma d}$
$Y' = Y \cdot \frac{tanh(\gamma d/2)}{\gamma d/2}$
$A = \frac{Y'Z'}{2} + 1$ $\quad B = Z'$
$C = Y'\left(\frac{Y'Z'}{4} + 1\right)$ $\quad D = A$

$VR_{long} = 5.577\%$

Efficiency:
For each model's value of I_S,
$P_{loss} = I_S^2 \cdot r_{pu}$

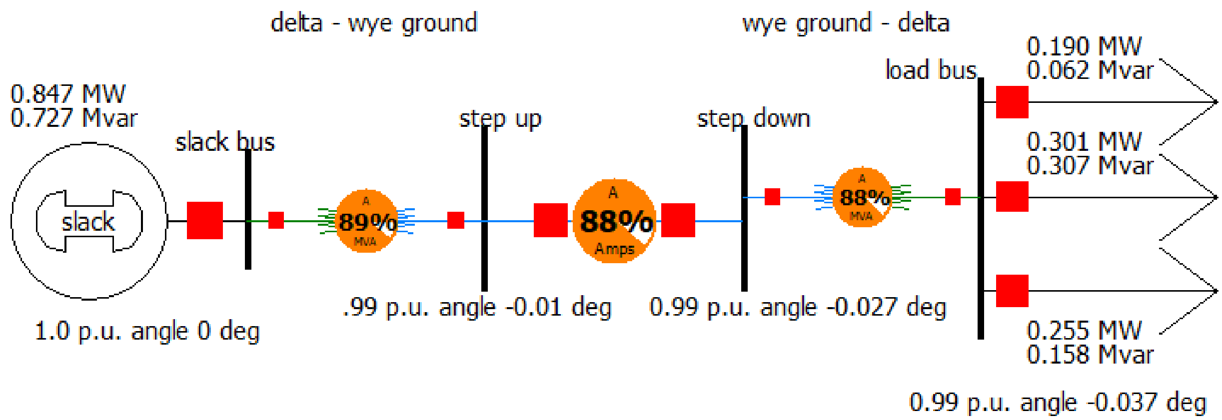
$$\eta = \frac{P_{\phi}}{P_{\phi}+P_{loss}}$$

$$\eta_{short} = 98.995\%$$

$$\eta_{med} = \eta_{long} = 98.997\%$$

Problem 2:

In order to allow for the extra load without overloading the transformers and transmission lines, the power rating limits were increased. The step-up transformer was changed to a rating of 1.25 MVA, the transmission line was changed to a rating of 1.15 MVA, and the step-down transformer was changed to a rating of 1.15 MVA.



Problem 3:

When the power_flow.m program is run on the OOEP_Initial file, the output shows several buses out of tolerance:

	Line Flow			
To Bus	MW	MVAr	MVA	Line status
Mulga	-22.92	0.58	22.92	under
Myall	150.00	138.22	203.97	3.97 over
Bunya	22.92	-0.32	22.92	under
Satinay	177.26	144.44	228.66	under
Myall	-49.21	-40.92	64.00	under
Satinay	-50.60	-34.07	61.00	1.00 over
Bunya	-147.09	-123.66	192.16	under

Satinay	-2.50	10.24	10.54	under
Mallee	49.75	43.43	66.03	6.03 over
Mulga	-173.60	-126.14	214.59	under
Myall	2.51	-10.20	10.50	under
Mallee	51.09	36.35	62.70	under

Lines 3, 5, and 6 to Myall, Mallee, and Satinay are exceeded.

Capacitive compensation is added to Myall, Mallee, and Satinay buses and the program is rerun.

				Line Flow			
Bus	Volts (pu)	Cap (MVAr)	To Bus	MW	MVAr	MVA	Line status
Bunya	1	0	Mulga	-23.55	0.60	23.55	under
			Myall	148.36	80.43	168.76	under
Mulga	1	0	Bunya	23.55	-0.32	23.55	under
			Satinay	176.63	89.19	197.87	under
Mallee	0.951	62	Myall	-49.10	-10.96	50.31	under
			Satinay	-50.68	-2.05	50.72	under
Myall	0.963	25	Bunya	-146.37	-70.46	162.45	under
			Satinay	-2.88	13.08	13.39	under
			Mallee	49.41	12.38	50.94	under
Satinay	0.958	15	Mulga	-173.89	-75.48	189.57	under
			Myall	2.89	-13.01	13.33	under
			Mallee	51.00	3.50	51.12	under

FE Problem 1:

(C) An over-excited synchronous generator

(A) and (B) are both heating elements, so they have unity PF. A squirrel-cage motor is an inductive load.

FE Problem 2:

(D) 5