Name:____ ID:______________

ENEL 487 – Electrical Engineering Energy Systems

Winter 2017 Final Examination

Monday, April 17, 2017

Time: 8:00 – 11:00 am

Location: ICT 114 & ICT 116

Instructor: Pouyan (Yani) Jazayeri

- Please note that the official University of Calgary examination regulations are printed on page 2 of this paper.
- Exam consists of 7 problems and 14 pages.
- Write answers in the space provided below each question.
- Show your work neatly in the work area. Otherwise, marks for partially correct answers cannot be given.
- Total marks for the exam is 85.
- Closed book exam. You may not refer to books or notes during the test.
- No wireless devices or earphones allowed during exam.
- Only scientific calculators without formulae storage and text display are allowed.

Question	1	2	3	4	5	6	7	Total
Mark	/15	/10	/10	/12	/10	/18	/10	/85

EXAMINATION RULES AND REGULATIONS

STUDENT IDENTIFICATION

Each candidate must sign the Seating List confirming presence at the examination. All candidates for final examinations are required to place their University of Calgary I.D. cards on their desks for the duration of the examination. (Students writing mid-term tests can also be asked to provide identity proof.) Students without an I.D. card who can produce an acceptable alternative I.D., e.g., one with a printed name and photograph, are allowed to write the examination.

A student without acceptable I.D. will be required to complete an Identification Form. The form indicates that there is no guarantee that the examination paper will be graded if any discrepancies in identification are discovered after verification with the student's file. A Student who refuses to produce identification or who refuses to complete and sign the Identification Form is not permitted to write the examination.

EXAMINATION RULES

1) Students late in arriving will not normally be admitted after one-half hour of the examination time has passed.

2) No candidate will be permitted to leave the examination room until one-half hour has elapsed after the opening of the examination, nor during the last 15 minutes of the examination. All candidates remaining during the last 15 minutes of the examination period must remain at their desks until their papers have been collected by an invigilator.

3) All inquiries and requests must be addressed to supervisors only.

4) The following is strictly prohibited:

    - speaking to other candidates or communicating with them under any circumstances whatsoever;
    - bringing into the examination room any textbook, notebook or memoranda not authorized by the examiner;
    - making use of calculators, cameras, cell-phones, computers, head-sets, pagers, PDA'S or any device not authorized by the examiner;
    - leaving answer papers exposed to view;
    - attempting to read other student's examination papers.

    The penalty for violation of these rules is suspension or expulsion or such other penalty as may be determined.

5) Candidates are requested to write on both sides of the page, unless the examiner has asked that the left hand page be reserved for rough drafts and calculations.

6) Discarded matter is to be struck out and not removed by mutilation of the examination answer book.

7) Candidates are cautioned against writing in their answer book any matter extraneous to the actual answering of the question set.

8) The candidate is to write his/her name on each answer book as directed and is to number each book.

9) During the examination a candidate must report to a supervisor before leaving the examination room.

10) Candidates must stop writing when the signal is given. Answer books must be handed to the supervisor-in-charge promptly. Failure to comply with this regulation will be cause for rejection of an answer paper.

11) If during the course of an examination a student becomes ill or receives word of a domestic affliction, the student must report at once to the supervisor, hand in the unfinished paper and request that it be cancelled.

    If physical and/or emotional ill health is the cause, the student must report at once to a physician/counsellor so that subsequent application for a deferred Final examination is supported by a completed Physician/Counsellor Statement form.

    Students can consult professionals at SU Wellness Center during normal working hours or consult their physician/counsellor in the community.

    Once an examination has been handed in for marking a student cannot request that the examination be cancelled for whatever reason. Such a request will be denied. Retroactive withdrawals will also not be considered.

Problem 1:

Answer the following questions on the <u>scantron sheet</u> provided to you. Correct answers are rewarded 1 point.

1) Per Unit quantity has the same unit/dimension as that of the actual quantity.

- **a)** True
- **b)** False

2) Complete the following sentence: When converted to per unit, the phase voltage and the line-to-line voltage will have the same pu magnitude for____________________________

- **a)** Y connections only
- **b)** Δ connections only
- **c)** Both Y and Δ connections
- **d)** Neither Y nor Δ connections

3) In a Y-connected AC generator, each phase voltage has a magnitude of 90 V (RMS). What is the peak value of the sinusoidal line-to-line voltage at the generator terminals?

- **a)** 90 V
- **b)** 127.3 V
- **c)** 155.9 V
- **d)** 220.5 V
- **e)** None of the above

4) A balanced three-phase generator is connected to three 90Ω load resistors. Each winding in the generator produces 120 V. A common neutral line exists between the generator and the load. How much current flows through the common neutral line?

- **a)** 1.33 A
- **b)** 0 A
- **c)** 2.66 A
- **d)** 3.99 A
- **e)** None of the above

5) In the power flow at the slack (swing) bus, which of the following are unknown:

- **a)** P and Q
- **b)** Q and V
- **c)** V and δ
- **d)** δ and Q
- **e)** None of the above

6) In a large power system, most of the busses are:

- **a)** Slack bus
- **b)** Non-gen (load) bus
- **c)** Gen (PV) bus
- **d)** All of the above
- **e)** None of the above

7) Power flow studies can be used for:

- **a)** Studying the stability of the system
- **b)** Fault calculations
- **c)** Planning the power system expansion
- **d)** All of the above
- **e)** None of the above

8) The magnetic field generated by a transmission line is primarily dependent upon the line's operating voltage and essentially independent of the line current.

- **a)** True
- **b)** False

9) Transformer cores are laminated to reduce eddy current losses

- **a)** True
- **b)** False

10) With balanced three-phase circuits, per-phase analysis is commonly done after converting the Δ -connected loads and generators to equivalent Y-connected loads and generators, thereby solving only one phase of the circuit

- **a)** True
- **b)** False

11) While nonlinear systems may require an iterative solution, a nice characteristic is they are guaranteed to have a single solution.

- **a)** True
- **b)** False

12) The voltage magnitude at any point along the length of any 765 kV transmission line is guaranteed to never exceed that of the sending end.

- **a)** True
- **b)** False

Questions 13 – 15 refer to the following:

A single-phase, 80 kVA, 2400/240 V, 60 Hz distribution transformer has a load connected on the secondary (240 V) winding that consumes 50 kVA at a 0.9 power factor lagging. Assume the load is operating at 225 V. Assume an ideal transformer.

13) What is the voltage on the primary (HV) winding of the transformer?

a) 2400 V

b) 240 V

c) 225 V

d) 2250 V

e) None of the above

14) What is the real and reactive power supplied to the primary (HV) winding of the transformer?

a) 45 kW & 21.8 kVAr

b) 4.5 kW & 2.18 kVAr

c) 42.19 kW & 20.43 kVAr

d) They cannot be calculated with the given information without making any assumptions

e) None of the above

15) What is the magnitude of the load impedance referred to the primary (HV) winding?

a) 1.012 Ω

b) 101.2 Ω

c) 63.28 Ω

d) 0.6328 Ω

e) None of the above

Problem 2:

Two balanced three-phase loads are connected in parallel. Load 1 is Y connected and Load 2 is delta connected. The loads are supplied by a balanced three-phase source. A balanced three-phase transmission line connects the source to the load.

a) The voltage across the load <u>in the per-phase circuit</u> is calculated to be $120\angle{-30^\circ}$ V. Draw a phasor diagram showing all 3 <u>phase</u> voltages at Load 1 (i.e. the voltage across each leg of the Y) and Load 2 (i.e. the voltage across each leg of the Δ.) Label the phasor diagram and show all your work. [5 marks]

b) If the current in Load 1 and Load 2 in the per-phase circuit is calculated to be $5\angle 0^\circ$ A and $5\angle 90^\circ$, respectively, calculate the magnitude of the current in the transmission line. [2 marks]

c) With voltage and current values given in part a) and b), calculate the total three-phase real and reactive power in Load 2. What is the power factor for this load? [3 marks]

Problem 3:

Two three-phase generators supply a three-phase load through separate three-phase lines. The load absorbs a total of 30 kW at unity (1.0) power factor. The line impedance is $0+j1\ \Omega$ per phase between generator G1 and the load, and $0+j2\ \Omega$ per phase between generator G2 and the load. If generator G1 supplies 15 kW (three-phase) at unity power factor with a terminal voltage of 460 V, Determine:

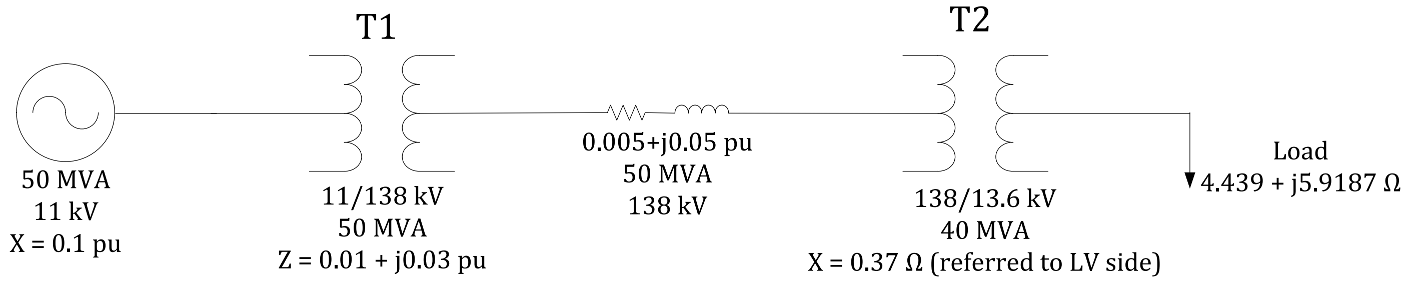
a) The real power supplied by generator G2. [2 marks]

b) Magnitude of the line-to-line voltage at the load terminals. [3 marks]

c) The reactive power supplied by generator G2. [5 mark]

Problem 4:

The single line diagram of a three-phase system is shown below.



Using a power base of 50 MVA and a voltage base of 11kV in the generator zone,

a) Draw the impedance diagram for this system with all impedances shown in pu. Show all your calculations. [6 marks]

b) If the per unit voltage at the load terminal is calculated to be 1.1 pu, what is the line-to-line voltage in kV at the load terminal? [2 marks]

c) If the per unit current in the transmission line is 1 pu, what is the line current in Amps at the load? [2 marks]

d) If the real power losses in the line are 0.005 pu, what is the total three phase real power losses in the line in MW? [2 marks]

Problem 5:

A three-phase, 60-Hz, completely transposed 345 kV, 200 km line has two 795 kcmil 26/2 ACSR conductors per bundle and the following impedance and admittance values: $z = 0.032 + j0.35\ \frac{\Omega}{\text{km}}$ $\quad y = j4.2\ \times 10^{-6}\ \frac{\text{S}}{\text{km}}$

The load at the receiving end of the line is 700 MW at 0.99 pf leading and at 95% of rated voltage.

a) Determine the ABCD parameters for the nominal π circuit. [3 marks]

b) Determine the sending end voltage $\mathbf{V}_s$, current $\mathbf{I}_s$, and real power P_s. [4 marks]

c) We have decided to represent this line with a short line model. Please show how we can calculate ABCD parameters of a short line using circuit analysis, and then calculate them for this line. [3 marks]

Problem 6:

In a three bus system, bus 1 is the swing/slack bus with a voltage of $1\angle 0^{\circ}$ pu, bus 2 is a non-gen/load bus with a load of 2+j0.5 pu, and bus 3 is a PV bus with 1.0 pu real power generation and 1.0 pu voltage. The per unit line impedances are j0.1 between busses 1 and 2, j0.4 between busses 1 and 3, and j0.2 between busses 2 and 3. Bus 2 also has a power factor correction capacitor with impedance of –j0.2 pu connected to it.

a) Create the admittance matrix Y_{bus} for this system. [4 marks]

b) Create the X vector for this system. [3 marks]

c) Write and simplify the active and reactive power flow equations at bus 3. Plug in all the known variables, expand the equations, keep the angles in degrees, and simplify as much as possible. [4 marks]

d) Find the expression (and if possible, the value) of the following elements in the Jacobian matrix: [7 marks]

i. Row 3, column 2 of J_{11}
ii. Row 3, column 3 of J_{12}
iii. Row 3, column 1 of J_{21}

Problem 7:

For the system of equations:

$$f_1(\mathbf{X}) = 10\, x_1 \sin x_2 + 2$$

$$f_2(\mathbf{X}) = 10\, (x_1)^2 - 10\, x_1 \cos x_2 + 1$$

a) Using the Newton-Raphson method, determine the values of x_1 and x_2 after the first iteration. Use $x_1 = 1$, $x_2 = 0$ as an initial guess. [7 marks]

b) Is $x_1 = 0.5$, $x_2 = 0$ a good initial guess? Why or why not. [3 marks]

Addition workspace (if needed)

Constants/Conventions

ε	$8.85\text{x}10^{-12}$
r'	$0.7788 \cdot r$
D_{SL}	$\sqrt{D_S \cdot d}$ $\sqrt[3]{D_S \cdot d^2}$ $1.091\sqrt[4]{D_S \cdot d^3}$
D_{SC}	$\sqrt{r \cdot d}$ $\sqrt[3]{r \cdot d^2}$ $1.091\sqrt[4]{r \cdot d^3}$

General

Single Phase $\overline{\text{S}}$: $\overline{S} = \overline{V} \cdot \overline{I}^*$

Q for L and C: $Q_L = \frac{V^2}{X_L}$ $\quad Q_C = \frac{V^2}{X_C}$

Y Connection: $\overline{V_{ll}} = \sqrt{3}\angle 30^{\text{o}} \cdot \overline{V_\phi}$

Δ Connection: $\overline{I_l} = \sqrt{3}\angle{-30}^{\text{o}} \cdot \overline{I_\phi}$

3 Phase Power: $\overline{S_{3\phi}} = 3 \cdot \overline{V_\phi} \cdot \overline{I_\phi^*}$

$S = \sqrt{3} \cdot V_{ll} \cdot I_l$

$P = S \cdot pf \qquad S^2 = P^2 + Q^2$

Per Unit

Single Phase:

$S_{\text{base},1\phi} = P_{\text{base},1\phi} = Q_{\text{base},1\phi}$

$I_{\text{base}} = \frac{S_{\text{base},1\phi}}{V_{\text{base,L-N}}}$

$Z_{\text{base}} = R_{\text{base}} = X_{\text{base}}$

$Z_{\text{base}} = \frac{V_{\text{base,L-N}}}{I_{\text{base}}} = \frac{V^2_{\text{base,L-N}}}{S_{\text{base},1\phi}}$

Three Phase:

$S_{\text{base},3\phi} = 3 \cdot S_{\text{base},1\phi}$

$V_{\text{base,L-L}} = \sqrt{3}V_{\text{base,L-N}}$

$I_{\text{base}} = \frac{S_{\text{base},3\phi}}{\sqrt{3}V_{\text{base,L-L}}}$

$Z_{\text{base}} = \frac{V^2_{\text{base,L-L}}}{S_{\text{base},3\phi}}$

Change of Base: $Z_{\text{pu,new}} = Z_{\text{pu,old}} \left(\frac{V_{\text{base,old}}}{V_{\text{base,new}}}\right)^2 \frac{S_{\text{base,new}}}{S_{\text{base,old}}}$

Transmission Lines

Line Inductance:

$L = 2\text{x}10^{-7} \cdot \ln\frac{D}{D_s}$

or $L = 2\text{x}10^{-7} \cdot \ln\frac{D_{eq}}{D_S}$

or $L = 2\text{x}10^{-7} \cdot \ln\frac{D_{eq}}{D_{SL}}$

Line Capacitance:

$C_{an} = \frac{2\pi\varepsilon}{\ln\frac{D}{r}}$

or $C_{an} = \frac{2\pi\varepsilon}{\ln\frac{D_{eq}}{r}}$

or $C_{an} = \frac{2\pi\varepsilon}{\ln\frac{D_{eq}}{D_{SC}}}$

Line Equations:

$\gamma = \sqrt{z \cdot y}$

$Z_c = \sqrt{\frac{z}{y}}$

$$I(x) = I_R \cosh(\gamma x) + \frac{V_R}{Z_c} \cdot \sinh(\gamma x)$$

$$V(x) = V_R \cosh(\gamma x) + I_R Z_c \sinh(\gamma x)$$

Nominal π Model:

$A = D = 1 + \frac{YZ}{2}$

$B = Z$

$C = Y(1 + \frac{YZ}{4})$

Eq π Model:

$Z' = Z\,\frac{\sinh(\gamma l)}{(\gamma l)}$

$\frac{Y'}{2} = \frac{Y}{2}\,\frac{\tanh\frac{(\gamma l)}{2}}{\frac{(\gamma l)}{2}}$

For: $x = a + jb,$

$$\cosh(x) = \cosh(a)\cos(b) + j\sinh(a)\sin(b)$$

$$\sinh(x) = \sinh(a)\cos(b) + j\cosh(a)\sin(b)$$

Power Flow

$$f_i = P_{gen,i} - P_{load,i} - \sum_{k=1}^{N} V_i V_k G[i,k]\cos(\delta_i - \delta_k) - \sum_{k=1}^{N} V_i V_k B[i,k]\sin(\delta_i - \delta_k)$$

$$f_{N+i} = Q_{gen,i} - Q_{load,i} - \sum_{k=1}^{N} V_i V_k G[i,k]\sin(\delta_i - \delta_k) + \sum_{k=1}^{N} V_i V_k B[i,k]\cos(\delta_i - \delta_k)$$