UNIVERSITY OF SWAZILAND
MAIN EXAMINATION, DECEMBER 2014

FACULTY OF SCIENCE AND ENGINEERING

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

TITLE OF PAPER:	**POWER SYSTEM ANALYSIS AND OPERATION**
COURSE NUMBER:	**EE552**
TIME ALLOWED:	**THREE HOURS**

INSTRUCTIONS:

1. There are five questions in this paper. **Answer any FOUR questions.**
2. Each question carries 25 marks.
3. Marks for different sections are shown on the right hand margin.
4. If you think not enough data has been given in any question you may assume any reasonable values.
5. A sheet containing useful formulae and other information is attached at the end.

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THIS PAPER HAS SEVEN (7) PAGES INCLUDING THIS PAGE

QUESTION 1 ***(25 marks)***

(a) A generator and a motor are connected through a step-up transformer, a transmission line and a step-down transformer. The individual specifications are as follows:

Generator: 3-phase, 35 MVA, 13.8kV, 5%

Step-up transformer: $\Delta - Y$, 30 MVA, 13.2kV/6.6kV(L-L), $R + jX = (0.5 + j7.7)\%$

Transmission line: 70 km long, $r + jx = (0.2 + j0.8)$ Ω/km

Step-down transformer: Three single phase $\Delta - Y$ each rated 8.33 MVA, 110 kV/3.98kV with $R + jX = (0.8 + j8.0)\%$

Motor: Input rated at 25 MVA, 6.6 kV with reactance 25%

Select motor end values as base values (25 MVA and 6.6 $kV_{L\text{-}L}$) as base values, derive and draw the one line per unit impedance diagram. *(15 marks)*

(b) The cost functions of three generators are given by:

$$C_1 = 2900 + 50P_1 + 0.8P_1^2,\ \text{E/h},\quad 100 \le P_1 \le 300\ \text{MW}$$
$$C_2 = 2700 + 55P_2 + 0.9P_2^2,\ \text{E/h},\quad 200 \le P_2 \le 350\ \text{MW}$$
$$C_3 = 3000 + 50P_3 + 0.8P_3^2,\ \text{E/h},\quad 175 \le P_3 \le 400\ \text{MW}$$

The total load demand is 550 MW

(i) Find the economic optimal dispatch of the three generators if no power limits are imposed.

(6 marks)

(ii) What is the new dispatch if the generator limits are enforced? *(4 marks)*

QUESTION 2 ***(25 marks)***

Consider the power system network shown in Fig. Q2 where the generator voltages are given in p.u. values

(a) Calculate the value of p.u reactive power Q_3 in bus 3. *(1 mark)*

(b) Obtain the network admittance matrix $\boldsymbol{Y}_{\mathbf{bus}}$. *(4 marks)*

(c) Choose bus 1 as the slack bus. Using the Fast Decoupled Power Flow Method, find the voltage magnitudes in bus 3 and voltage angles in buses 2 and 3 after two iterations. *(20 marks)*

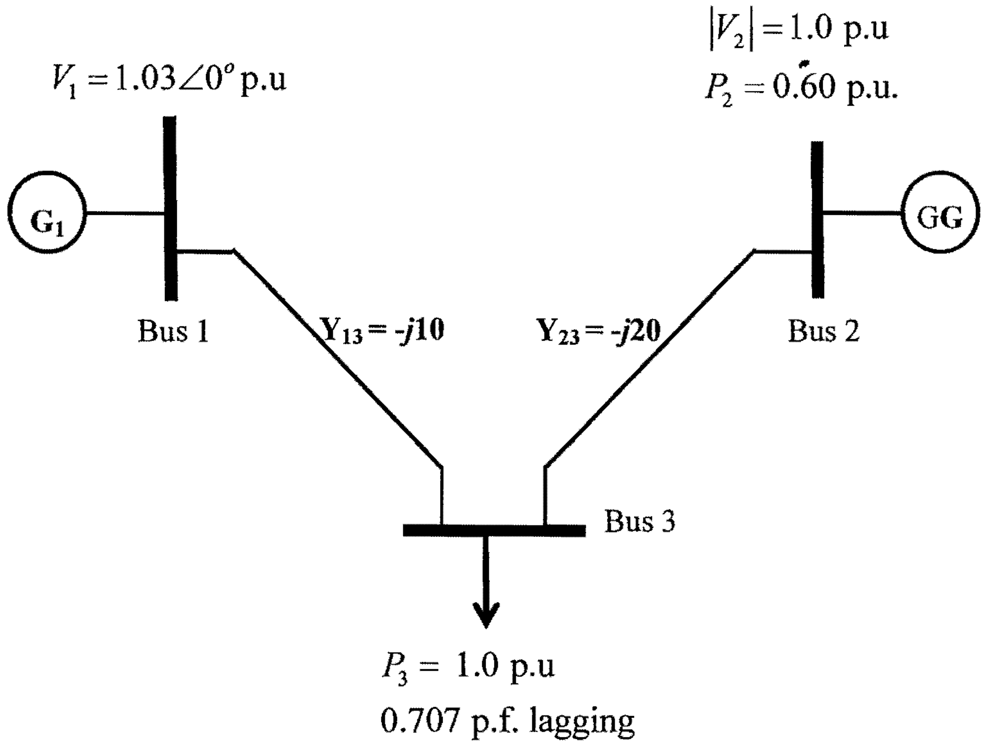

Fig. Q2

QUESTION 3 ***(25 marks)***

Consider the network shown in Fig.Q3. The motor draws a current with 0.92 lag power factor at its rated MVA and kV. A solid (bolted) three-phase to ground fault occurs at the terminals of the motor.

Choose a base of 100 MVA and 33 kV in the generator and calculate the fault current in kA.

(25 marks)

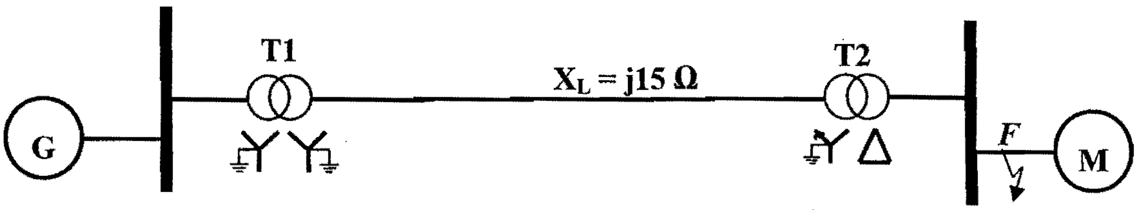

Fig. Q3

Data:

Generator G:	100MVA, 33 kV, $X'' = 0.25$ p.u.
Transformer T1:	100 MVA, 33 kV/ 66 kV, $X = 0.15$ p.u.
Transmission line:	$X_L = 15\ \Omega$
Transformer T2:	100 MVA, 66 kV/ 11 kV, $X = 0.15$ p.u.
Motor M:	50 MVA, 11 kV, $X'' = 0.2$ p.u.

QUESTION 4 ***(25 marks)***

A 4-bus electrical power network has the following $\boldsymbol{Z}_{\mathbf{bus}}$ sequence matrices.

$$Z_{bus1} = Z_{bus2} = j\begin{bmatrix} 0.05 & 0.01 & 0.03 & 0.02 \\ 0.01 & 0.06 & 0.04 & 0.03 \\ 0.03 & 0.04 & 0.05 & 0.02 \\ 0.02 & 0.03 & 0.02 & 0.05 \end{bmatrix}$$

$$Z_{bus0} = j\begin{bmatrix} 0.01 & 0.06 & 0.04 & 0.06 \\ 0.06 & 0.07 & 0.01 & 0.01 \\ 0.04 & 0.01 & 0.03 & 0.01 \\ 0.06 & 0.01 & 0.01 & 0.01 \end{bmatrix}$$

Assuming a 1.0 p.u. pre-fault voltage profile throughout the network and using the $\boldsymbol{Z}_{\mathbf{bus}}$ matrix method calculate the fault currents and the resulting phase voltages at the faulted buses for the following types of faults:

(a) A solid single line-to-ground fault at phase *a* of bus 4. *(8 marks)*

(b) A solid line-to-line fault between phase *b* and *c* of bus 2. *(8 marks)*

(c) A double line-to-ground fault at phases *b* and *c* of bus 3. *(9 marks)*

QUESTION 5 *(25 marks)*

(a) Three-phase 400 V (line-to-line) loads at a farm are fed from a 10 kV (line-to-line) bus through an overhead line and a local three-phase transformer. The transformer is rated 10/0.4 kV, 250 kVA, X_{eq} = 10 % (=0.1 p.u.), while the line has a series impedance of *j*20 Ω per phase. The 10 kV bus can be modelled as a voltage source with nominal voltage behind a per phase reactance of 1Ω.

(i) Use nominal voltages and 250 kVA as base values to derive a one-line per phase p.u. reactance diagram of the system. The loads need not be specified. *(6 marks)*

(ii) Compute a per unit single-phase Thévenin equivalent of the system feeding the 400 V bus. *(2 marks)*

(iii) Determine the three-phase short circuit carrying capacity (short circuit MVA) of the 400 V bus. *(4 marks)*

(b) A synchronous generator G supplies two motors M1 and M2 over a transmission line with transformers T1 and T2 at each end as shown in Fig. Q5.

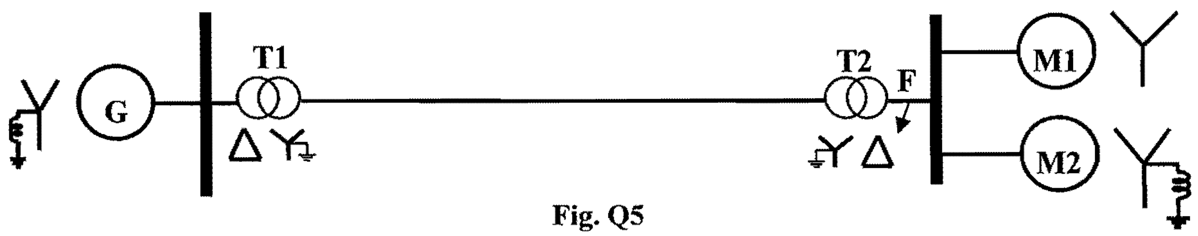

Fig. Q5

The sub-transient p.u. data for the system components are:

Generator G: $E_g'' = 0.9$ p.u, $X_d'' = X_1 = X_2 = 0.11$ p.u, $X_0 = 0.06$ p.u.

Motor M1: $E_m'' = 0.9$ p.u, $X_d'' = X_1 = X_2 = 0.14$ p.u, $X_0 = 0.08$ p.u.

Motor M2: $E_m'' = 0.9$ p.u, $X_d'' = X_1 = X_2 = 0.28$ p.u, $X_0 = 0.16$ p.u.

Transformers: $X_1 = X_2 = X_0 = 0.01$ p.u.

Transmission line: $X_1 = X_2 = 0.33$ p.u, $X_0 = 0.99$ p.u.

Earthing reactances of Generator G and Motor 2: *j*1.03 p.u

A line-to-ground bolted fault occurs at point *F* on bus *a* of the delta side of transformer T2. The pre-fault currents may be neglected.

(i) Draw the positive sequence, negative sequence and zero sequence networks of the system. *(6 marks)*

(ii) Calculate the fault current using symmetrical components. *(7 marks)*

USEFUL FORMULAE (some of which you may need)

$$R_1 = \frac{R_B R_C}{R_A + R_B + R_C}, \qquad R_A = \frac{R_1 R_2 + R_2 R_3 + R_1 R_3}{R_1}$$

$$P_i = \sum_{n=1}^{N} |Y_{in} V_i V_n| \cos(\theta_{in} + \delta_n - \delta_i)$$

$$Q_i = -\sum_{n=1}^{N} |Y_{in} V_i V_n| \sin(\theta_{in} + \delta_n - \delta_i)$$

$$-[B'][\Delta\delta] = \frac{\Delta P}{|V|}$$

$$-[B''][\Delta V] = \frac{\Delta Q}{|V|}$$