UNIVERSITY OF SWAZILAND
MAIN EXAMINATION, DECEMBER 2016

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:

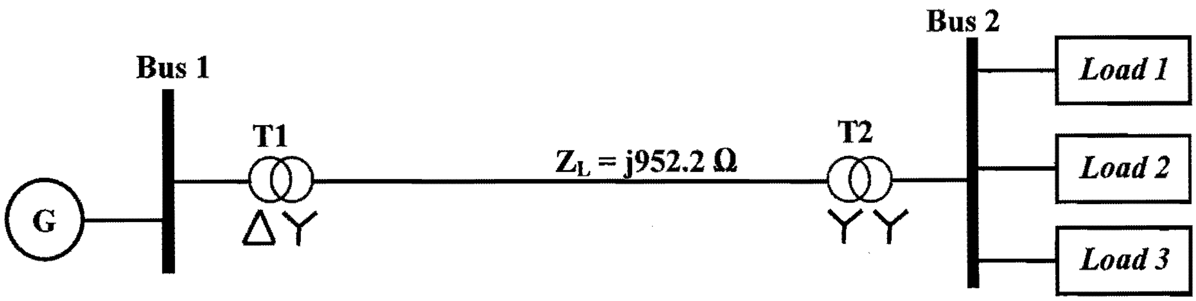
1. There are five questions in this paper. **Answer any FOUR questions.**
2. Each question carries 25 marks.
3. Marks for different sections are shown on the right hand margin.
4. If you think not enough data has been given in any question you may assume any reasonable values, and state them.
5. A sheet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

THIS PAPER IS NOT TO BE OPENED UNTIL PERMISSION HAS BEEN GIVEN BY THE INVIGILATOR

THIS PAPER HAS SEVEN (7) PAGES INCLUDING THIS PAGE

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

The one-line diagram of a power network is shown in Fig. Q.1. The generator G supplies three loads through a transmission line with transformers T1 and T2 at each end of the line. The phase-to-neutral voltage on bus 2 is $V_2 = 2.402$ kV .



The data for the system components are:

Generator G: 4 MVA, 16.9 kV, $X = 0.2$ pu
Transformer T1: Δ-Y, 4 MVA, 13.8/138 kV, $R = 0.1$ pu, $X = 0.2$ pu
Transformer T2: Y-Y, 2 MVA, 138/4.16 kV, $R = 0.05$ pu, $X = 0.1$ pu
Three-phase load 1: 500 kW, 0.8 p.f. lagging
Three-phase load 2: 625 kVA, 0.8 p.f. lagging
Three-phase load 3: 1.25 MVA, 750 kVAr leading
Transmission line: $Z_L = j952.2\ \Omega$

(a) Determine the total complex load power delivered from bus 2, expressing it in the form $S = P + jQ$. *(7 marks)*

(b) Express the total load as an equivalent Y-connected impedance. *(2 marks)*

(c) Obtain and draw the one-line p.u. impedance diagram of the network, using a voltage base of 138 kV in the transmission line section and a system base MVA of 2 MVA. *(12 marks)*

(d) Use the one line diagram to calculate the voltage on bus 1. *(4 marks)*

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

(a) A loss-less power system has to serve a load of 250 MW. There are two generators (G1 and G2) in the system with cost curves C1 and C2 respectively defined as follows:

$$C_1(P_{G1}) = P_{G1} + 0.055P_{G1}^2$$
$$C_2(P_{G2}) = P_{G2} + 0.03P_{G2}^2$$

What is the economic dispatch of the two generators? *(10 marks)*

(b) At a 220 kV substation of a power system, it is given that the three-phase fault level is 4000 MVA and the single-line to ground fault level is 5000 MVA. Neglecting the resistance and the shunt susceptances of the system:

i) Calculate the positive sequence driving point reactance at the bus. *(5 marks)*

ii) Calculate the zero sequence driving point reactance at the bus. *(5 marks)*

(c) A 500 MVA, 50 Hz, 3-phase turbo-generator produces power at 22 kV. The generator is Y-connected and its neutral is solidly grounded. Its sequence reactances are: $X_1 = X_2 = 0.15$ pu and $X_0 = 0.05$ pu. It is operating at rated voltage and disconnected from the rest of the system (no load). Determine the magnitude of the sub-transient line current for a single line to ground fault at the generator terminals in pu. *(5 marks)*

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

A three-bus power system is shown in Fig.Q2 with all the admittance values connecting the buses expressed in per unit on a base of 100 MVA. Assume that bus 1 is the slack bus with a voltage of $V_1 = 1.04\angle 0°$ pu. Other scheduled generation and load powers are as indicated on the appropriate buses. The objective is to determine the voltage magnitudes and angles using the Fast Decoupled Power Flow Method.

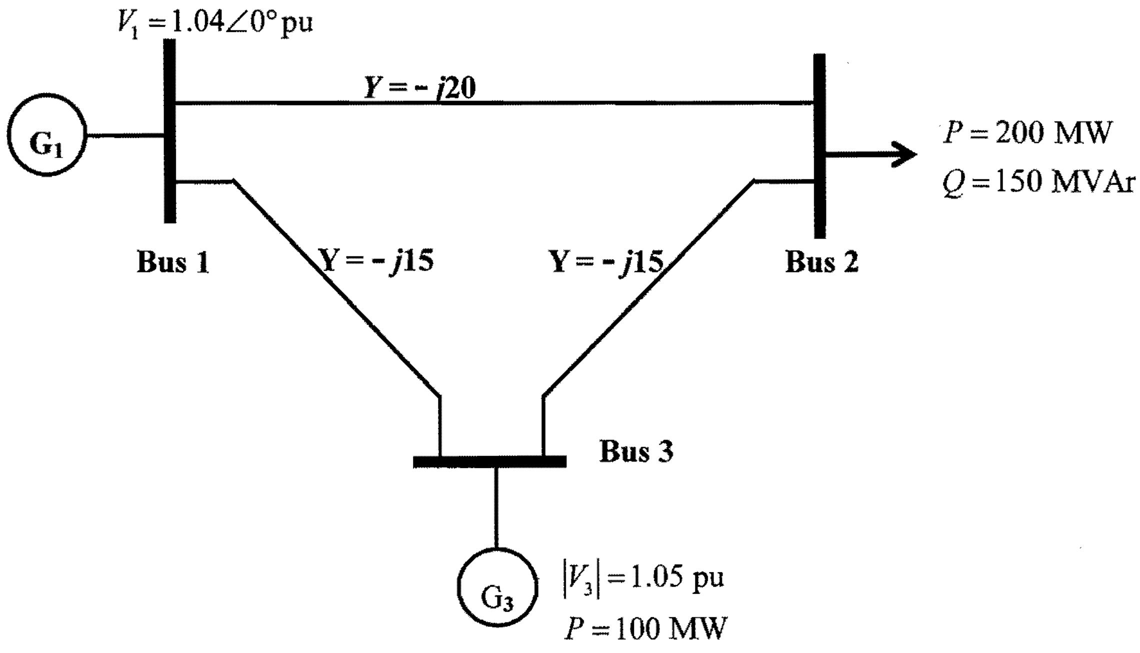


Fig. Q2

(a) Obtain the admittance matrix $[Y_{bus}]$ of the system. *(3 marks)*

(b) Determine the decoupled matrices $[B']$, $[B'']$ and their inverses $[B']^{-1}$, $[B'']^{-1}$ *(6 marks)*

(c) Choose bus 1 as the slack bus. Using the Fast Decoupled Power Flow Method, find the voltage magnitude in bus 2 and voltage angles in buses 2 and 3 after one iteration. *(16 marks)*

QUESTION 4 *(25 marks)*

(a) A three-phase alternator generating unbalanced voltages is connected to an unbalanced load through a 3-phase transmission line. The transmission line is properly transposed with impedance $j0.5$ pu per phase and the load is star connected with impedances :

$$Z_a = j2.5,\ Z_b = j3.5 \text{ and } Z_c = j4.5 \text{ in pu.}$$

The neutral of the alternator and the star point of the load are solidly grounded. The phase voltages of the alternator are

$$E_a = 10\angle 0°,\ E_b = 10\angle -90°,\ E_c = 10\angle 120°$$

Determine the positive sequence component of the load current. *(11 marks)*

(b) A 4-bus electrical power network has the following $\boldsymbol{Z_{bus}}$ 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 $\boldsymbol{Z_{bus}}$ matrix method calculate the fault currents and the resulting phase voltages at the faulted buses for a solid single line-to-ground fault at phase *a* of bus 4. *(14 marks)*

QUESTION 5 *(25 marks)*

A 50-Hz synchronous generator has a transient reactance of 0.18 per unit and an inertia constant of 5.69 MJ/MVA. The generator is connected to an infinite bus through a transformer and a double circuit transmission line, as shown in Fig.Q5. Resistances are neglected and reactances, expressed on a common MVA base, are marked on the diagram. The generator is delivering real power of 0.8 per unit to bus bar 1. Voltage magnitude at bus 1 is 1.2 pu. The infinite bus bar voltage is constant at $V = 1.0\angle 0°$ pu.

(a) Determine the no load generated voltage. *(10 marks)*

(b) Determine the swing equation before a fault occurs, as in the form given by

$$\frac{H}{\pi f_0}\frac{d^2\delta}{dt^2} = P_m - P_{\max}\sin\delta$$ *(5 marks)*

(c) If a three-phase to ground solid fault occurs in the middle of one of the double circuit transmission lines, find the swing equation while the fault exists. *(10 marks)*

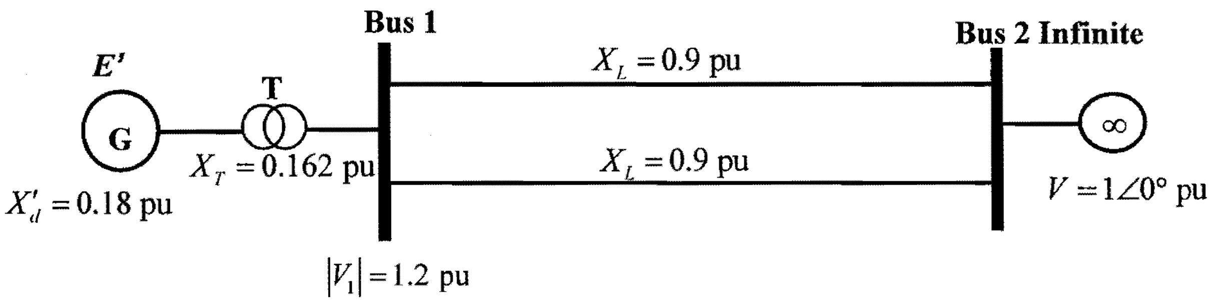


Fig.Q5

USEFUL FORMULAE (some of which you may need)

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

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

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

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

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