UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE
DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

MAIN EXAMINATION DECEMBER 2012

TITLE OF PAPER: **Power System Analysis and Operation**

COURSE CODE: **EE 552**

TIME ALLOWED: **THREE** HOURS

Student Name:	
Student Number:	

INSTRUCTIONS:

1. Answer all questions.
2. Give your answers on the question paper, and if more space is required, complete your answer on the back of the paper or in your answer book and mention about the place of your answer completion.
3. Put the question sheet inside the answer book upon submission of your exam paper.
   (DON'T FORGET TO SUBMIT BOTH OF THE ANSWER BOOK AND QUESTION PAPER)
4. Marks for different questions are indicated on the beginning of the question.
5. Rough work maybe done in the examination answer book and crossed through.

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This paper starts at page 1 and ends at page 16

Question 1: Solve the following question (8 marks)

Suppose one had three units with fuel-cost models given below:

Unit 1:

$F_1 = 100 + 7P_1 + 0.004P_1^2 \qquad R/h$

Min=170 MW

Max=700 MW

Unit 2:

$F_2 = 600 + 8P_2 + 0.0016P_2^2 \qquad R/h$

Min=100 MW

Max=300 MW

Unit 3:

$F_3 = 400 + 7.5P_3 + 0.002P_3^2 \qquad R/h$

Min=150 MW

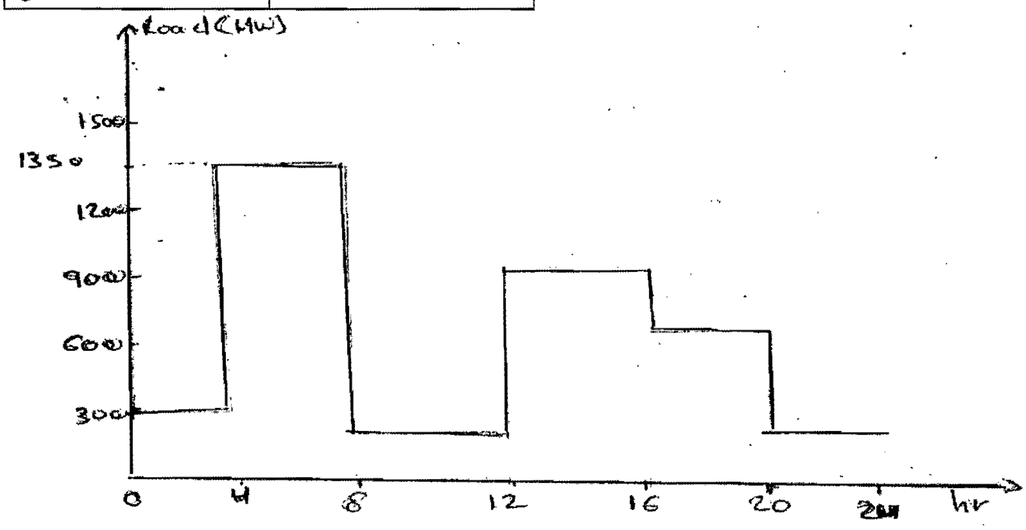
Max=500 MW

a) What is the priority order for commitment of the above three units.

Unit	R/Mwh	Min MW	Max MW

b) Using the priority list method, indicate in the following table the unit commitment schedule of the above three units for the load pattern given below.

Period	Committed units
1	
2	
3	
4	
5	
6	



Question 2: Solve the following question (7 marks)

The fuel-cost models for a three units

$F_1 = 100 + 7P_1 + 0.004P_1^2 \qquad R/h$

$F_2 = 600 + 8P_2 + 0.0016P_2^2 \qquad R/h$

$F_3 = 400 + 7.5P_3 + 0.002P_3^2 \qquad R/h$

Where P_1, P_2, P_3 are in MW.

The network losses

$P_L = 0.0004P_1^2 + 0.0008P_2^2 + 0.001P_3^2$

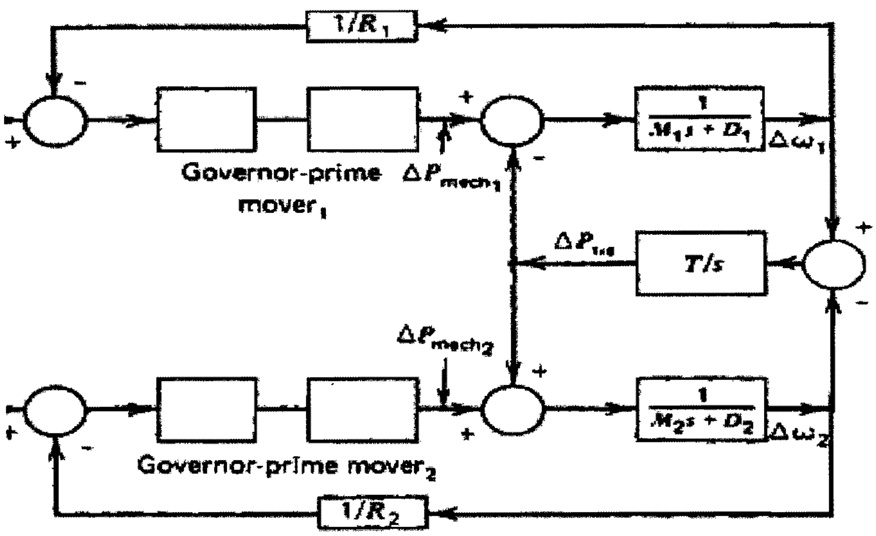
Write the optimal equations that should be solved to determine the economic operating point for the three units when delivering a total load P_R of 1500 MW.

Note: No need to solve the equations.

Question 3: Solve the following questions (15 marks)

a) **List the main objectives of Automatic Generation Control.**

b) **Complete the following diagram to show the Tie-line bias supplementary control for two areas system. From the diagram, give an equation for area control errors ACE1 and ACE2 and the frequency bias factors B1 and B2.**



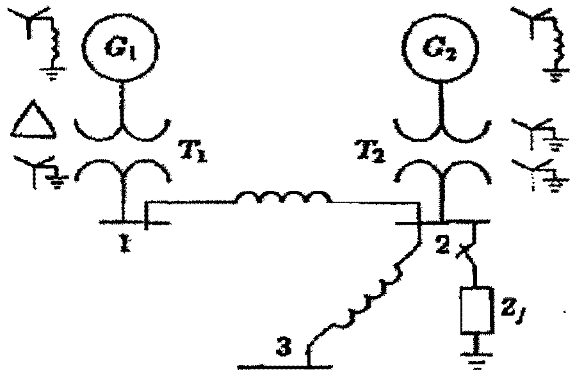
c) You are given two system areas connected by tie line with the following characteristic:

Area 1	**Area 2**
R=0.02 pu	R=0.04 pu
D= 0.9 pu	D=1.2 pu
Base MVA =800	Base MVA =800

A load change of 200 MVA occurs on area 1. What is the new steady state frequency and what is the change in prime movers power and tie line flow? Assume both areas were at nominal frequency (50 Hz) to begin.

Question 4: Solve the following questions (36 marks)

The one-line diagram of a simple power system is shown in the following Figure. The neutral of each generator is grounded through a current limiting reactor of 0.25/3 pu on 100 MVA base. The system data expressed in per unit on common 100 MVA base is tabulated below. The generators are running on no load at their rated voltage and rated frequency with their emfs in phase.



Item	Base MVA	Voltage Rating	X^1	X^2	X^0
G_1	100	33 kV	0.2	0.2	0.05
G_2	100	33 kV	0.2	0.2	0.05
T_1	100	33/245 kV	0.12	0.12	0.12
T_2	100	33/245 kV	0.2	0.2	0.2
L_{12}	100	245 kV	0.16	0.16	0.32
L_{23}	100	245 kV	0.25	0.25	0.8

Part I

1) The objective is to obtain the positive, negative and zero sequence networks for the system having a fault at bus 2 and to calculate the fault current and the phase voltages at the fault point. The fault impedance $Z_f = j0.18$ pu.

a) Obtain the positive sequence network, the bus admittance matrix for the positive sequence network and the Thevenin equivalent network as viewed from faulted bus 2.
(Calculate Z_{22}^1, Y_{bus}^1)

b) Obtain the negative sequence network and the Thevenin equivalent network as viewed from faulted bus 2.
Note: You can directly utilize the results obtained in a.
(Calculate Z_{22}^{2})

c) Obtain the zero sequence network, the bus admittance matrix for the zero sequence network and the Thevenin equivalent network as viewed from faulted bus 2.
(Calculate Z_{22}^{0}, Y_{bus}^{0})

d) Compute the positive, negative and zero sequence fault current during a double line to ground fault at but 2 when the fault impedance $Z_f = j0.18pu$**.**

(Calculate I_2^{012}**)**

e) Compute the positive, negative and zero sequence fault current during a line to line fault at but 2 when the fault impedance $Z_f = j0.18pu$**.**

(Calculate I_2^{012}**)**

Part II

2) Given the bus impedance matrix of the positive, negative and zero sequence networks for the system in Question 4 as follows

$$Z^1_{bus} = Z^2_{bus} = \begin{bmatrix} j0.20361 & j0.1455 & j0.1455 \\ j0.1455 & j0.2182 & j0.2182 \\ j0.1455 & j0.2182 & j0.4682 \end{bmatrix}$$

$$Z^0_{bus} = \begin{bmatrix} j0.1047 & j0.0638 & j0.0638 \\ j0.0638 & j0.234 & j0.234 \\ j0.0638 & j0.234 & j1.034 \end{bmatrix}$$

a) Using the bus impedance matrix, compute fault current in phase a, b and c, phase a voltage at bus 1 and line 12 current in phase a during a balanced three phase fault at but 2 when the fault impedance $Z_f = j0.18pu$.

(Calculate I_2^{abc}, V_1^a, V_2^a, I_{12}^a)

b) Compute the fault current in phase a, b and c, and phase a, b and c voltages at bus 1 during a line to ground fault at bus 2 when the fault impedance $Z_f = j0.18pu$.

(Calculate I_2^{abc}, V_1^{abc})

Question 5: Solve the following questions (14 marks)

Given the following network with

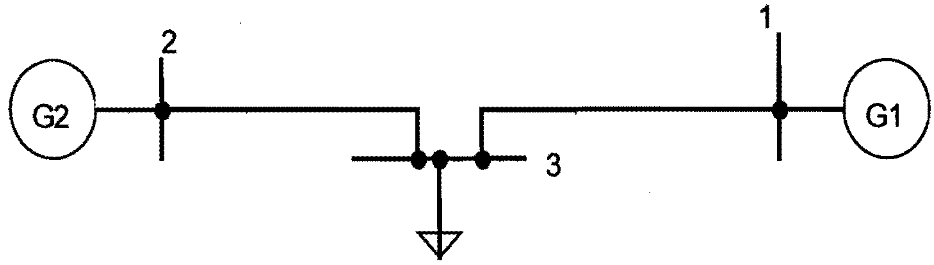
$V_1 = 1\angle 0\ pu \quad Slackbus$

$P_2 = 1.8\ pu \quad |V_2| = 1.05\ pu \quad PVbus$

$P_3 = -2\ pu \quad Q_3 = -1.2\ pu \quad PQbus$

$Y_{L23} = -j8pu$

$Y_{L13} = -j4pu$



The admittance matrix of the system.

$$Y_{bus_{bus}} = \begin{bmatrix} -j4 & 0 & j4 \\ 0 & -j8 & j8 \\ j4 & j8 & -j12 \end{bmatrix}$$

Given that:

$a_{ij} = G_{ij}e_j - B_{ij}f_j$

$b_{ij} = G_{ij}f_j + B_{ij}e_j$

$P_i = e_i \sum_{j=1}^{n}(G_{ij}e_j - B_{ij}f_j) + f_i \sum_{j=1}^{n}(G_{ij}f_j + B_{ij}e_j) = e_i \sum_{j=1}^{n} a_{ij} + f_i \sum_{j=1}^{n} b_{ij}$

$Q_i = f_i \sum_{j=1}^{n}(G_{ij}e_j - B_{ij}f_j) - e_i \sum_{j=1}^{n}(G_{ij}f_j + B_{ij}e_j) = f_i \sum_{j=1}^{n} a_{ij} - e_i \sum_{j=1}^{n} b_{ij}$

$H_{ij} = L_{ij} = a_{ij}f_i - b_{ij}e_i$

$N_{ij} = -J_{ij} = a_{ij}e_i + b_{ij}f_i$

$H_{ii} = -Q_i - B_{ii}|V_i|^2$

$L_{ii} = Q_i - B_{ii}|V_i|^2$

$N_{ii} = P_i + G_{ii}|V_i|^2$

$J_{ii} = P_i - G_{ii}|V_i|^2$

Choose the initial values for unknown bus voltages:

$\theta_2^{(0)} = 0$

$\theta_3^{(0)} = 0$

$|V_3|^{(0)} = 1$

a) Write the system Jacobian matrix in the following form:

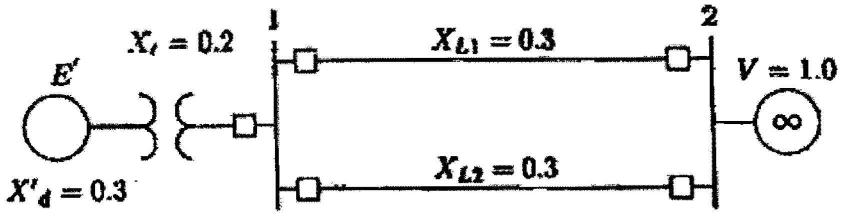
$$\begin{bmatrix} H & N \\ J & L \end{bmatrix} \begin{bmatrix} \Delta\theta \\ \dfrac{\Delta|V|}{|V|} \end{bmatrix} = \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}$$

Note: No need to evaluate any element.

b) Evaluate in the system Jacobian matrix for the first iteration of Newton Raphson the elements $\frac{\partial P_2}{\partial \theta_3}, |V_3|\frac{\partial P_3}{\partial |V_3|}, \frac{\partial Q_3}{\partial \theta_2}, |V_3|\frac{\partial Q_3}{\partial |V_3|}$ **and all elements in the vector** $\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}$.

Question 6: Solve the following questions (20 marks)

A 50 Hz synchronous generator having inertia constant H= 5 MJ/MVA and direct axis transient reactance $X_d^{'} = 0.3$ per unit is connected to an infinite bus through purely reactive circuit. The generator is delivering real power $P_e = 0.7$ per unit, 0.85 power factor lagging to the infinite bus at a voltage V=1 per unit



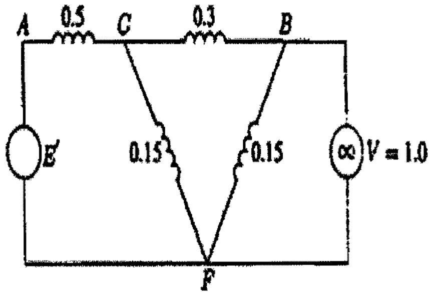
1) If the per unit damping power coefficient is D=0.12 and the input power is increased by a small amount $\Delta P = 0.2$ per unit.

a) Calculate the initial operating angle δ_0.

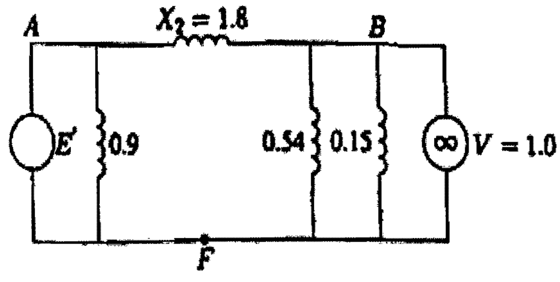
b) Calculate the synchronizing power coefficient P_s, the undamped angular frequency of oscillation ω_n and the damping ratio ξ.

a) Write the linearized swing equation of the system in terms of standard second order differential equation.

2) If a three phase fault occurs at the middle of the second transmission line. The equivalent circuit with the three-phase fault at the middle of line and the equivalent circuit after Y/Δ transformation are shown below. The fault is then cleared and the faulted line is isolated.

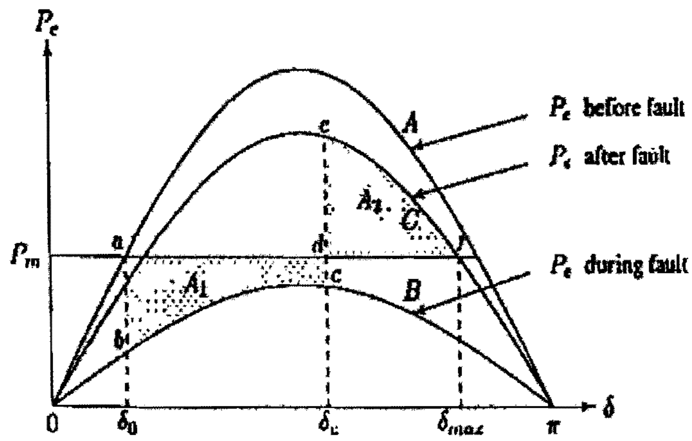


Equivalent circuit with three-phase fault at the middle of one line.



Equivalent circuit after Y-Δ transformation.

a) Write an equation that applies equal area criterion to the figure below.
Note: You don't need to substitute the values in the equation.



Equal-area criterion for critical clearing angle.

b) Write the equations of power angle curve before occurrence of the fault, during the fault and after the faulted line is isolated.

c) Calculate the critical clearing angle that maintains the stability.

$$\cos\delta_c = \frac{P_m(\delta_{\max} - \delta_o) + P_{3\max}\cos\delta_{\max} - P_{2\max}\cos\delta_o}{P_{3maz} - P_{2\max}}$$