THE OPEN UNIVERSITY OF SRI LANKA
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
BACHELOR OF TECHNOLOGY
ECX 6332-POWER SYSTEMS PLANNING
FINAL EXAMINATION - 2015/2016

Duration - 3 Hrs. **CLOSED BOOK**

Date: 7th December 2016 **Time: 0930-1230 hrs.**

This paper contains Eight (8) questions. Answer any Five. All questions carry equal marks.

1. Sensitivity of the demand (q) for a product to its own price (p) is called the ***self-price elasticity*** (ε_{ii}) and it is defined as the per unit change in demand for a product, caused by per unit change in price of the same product.

$$\text{i.e.} \quad \varepsilon_{ii} = \frac{\left(\frac{dq_i}{q_i}\right)}{\left(\frac{dp_i}{p_i}\right)} = \frac{p_i}{q_i}\left(\frac{dq_i}{dp_i}\right)$$

a. The demand curve for a product is estimated to be given by the expression $q = 200 - p$. Calculate the price and the price elasticity of demand for the following values of the demand: 0, 50, 100, 150 and 200. **[5 Marks]**

b. Repeat the above calculation for the case in which the demand curve is given by the expression: $q = 10000/p$ **[5 Marks]**

If the price of one product causes the impact on demand for another, ***cross-price elasticity*** (ε_{ij}) concept is applicable, and it is defined as the per unit change of demand for one product, resulting from a change of price in another product.

$$\text{i.e} \quad \varepsilon_{ij} = \frac{\left(\frac{dq_i}{q_i}\right)}{\left(\frac{dp_j}{p_j}\right)} = \frac{p_j}{q_i}\left(\frac{dq_i}{dp_j}\right)$$

c. Utilities often offer two-part tariffs to encourage their customers to shift demand from on-peak to off-peak hours under Demand Side Management. Consumption of electrical energy during on-peak and off-peak hours can be considered as substitute products. The table Q1 shows the results of an experiment that a utility has conducted with its two-part tariff. Estimate the ***self-price elasticities*** and ***cross-price elasticities*** of the demand for electrical energy during on-peak and off-peak hours. **[10 Marks]**

Table Q1

	On-peak price	**Off-peak price**	**Average on-peak demand**	**Average off-peak demand**
	P_1	P_2	D_1	D_2
	(€/MWh)	(€/MWh)	(MWh)	(MWh)
Base case	0.08	0.06	1000	500
Experiment-1	0.08	0.05	992	509
Experiment-2	0.09	0.06	985	510

€=Monetary unit

2. The input-output curve of a gas-fired generating unit can be approximated by the following function:

$$H(P) = 120 + 9.3P + 0.0025\,P^2\;MJ/h$$

This unit has a minimum stable generation of 200 MW and a maximum output of 500 MW. The cost of gas is 1.20 €/MJ. Over a 6-hour period, the output of this unit is sold in an open market for electricity at the energy prices shown in the table Q2 below:

Table Q2

Period	**1**	**2**	**3**	**4**	**5**	**6**
Price (€/MWh)	12.5	10	13	13.5	15	11

€= Monetary unit

a. Assuming that this unit is optimally dispatched, is initially on-line and cannot be shut down, calculate its operational profit or loss for this period. **[10 Marks]**

b. Assume that the above unit has a start-up cost of €500 and that it is initially shut-down. Given the same prices as in Table Q2, when should this unit be brought on-line and when should it be shut-down to maximize its operational profit? Assume that dynamic constraints do not affect the optimal dispatch of this generating unit. **[5 Marks]**

c. Repeat the calculation of (**b**) taking into consideration the minimum uptime of this unit, of four hours. **[5 Marks]**

3. Decision makers of a country are comparing the specific life cycle cost of two competitive power plant types to be built, on the basis of prevailing fuel prices and other relevant data shown in table Q3. One is a coal-fired steam power plant and the other one is a LNG-fired CCY power plant.

Table Q3

Plant & fuel type	Coal-fired steam	LNG-fired CCY	Diesel (furnace Oil)
Coal Price	100 US$/Metric-Ton	-	-
LNG Price	-	400 US$/Metric-Ton	-
Furnace Oil Price	-	-	750 US $/Metric-Ton
Heat rate	6300 kcal/kg	13,000 kcal/kg	10,300 kcal/kg
Plant factor	0.8	0.8	0.8
Life time	30 years	30 years	20 years
Plant efficiency	36%	48%	40%
Present value factor	9.427	9.427	8.513
Capital Cost	1500 US$/kW	1300 US$/kW	800 US$/kW
Fixed O&M Cost	3.0 US $/kW-month	0.37 US $/kW-month	2.6 US $/kW-month
Variable O&M Cost	0.005 US $/kWh	0.003 US $/kWh	0.014 US $/kWh

Assume 1 kcal= 4.182 kJ & 1 US$= 145 €.

a. Calculate the specific life cycle cost in €/kWh for Coal and LNG Power Plants? **[10 Marks]**

b. Calculate the loss in Billion monetary units (€), if a 300 MW coal-fired power plant which is already in the long term generation expansion plan, is delayed by one year and replaced by the installation of three 100 MW diesel (furnace oil) power plants instead, in the short term? **[5 Marks]**

c. What are the possible impacts on the environment in case of operating a 300 MW coal-fired power plant as against three 100 MW diesel plants? Discuss the steps that you recommend, to reduce the same? **[5 Marks]**

4. Most of the feeders emanating from secondary grid substations are radial lines. Consider the radial distribution network shown in figure Q4a, only with first order events.

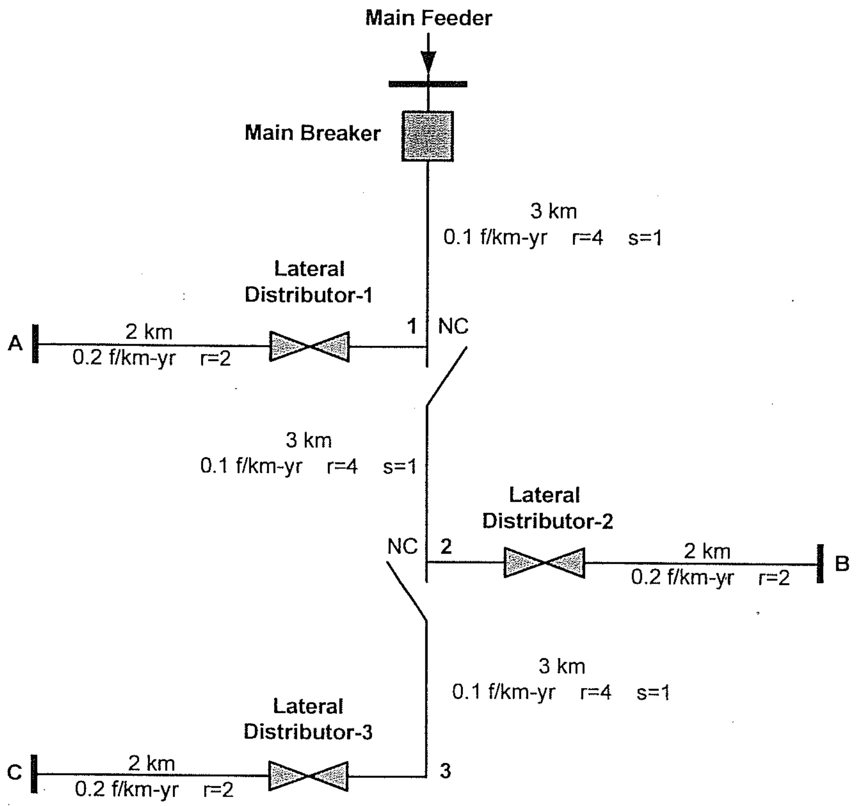

Figure Q4a

Data pertaining to the above radial circuit are:

Main feeder failure rate = 0.1 f/km-yr
Average repair time = 4 h
Each feeder section length = 3 km
Time to manually isolate a feeder section = 1 h

Lateral distributor failure rate = 0.2 f/km-yr
Average repair time = 2 h
Each lateral distributor length = 2 km

The Operating principle would be:

a. All feeder section failures will cause the main breaker to open but a lateral distributor failure will cause only its fuse switch to operate. When a feeder section fails, the nearest isolator is opened and the breaker is re-closed. Compute the reliability indices at load points A, B & C? **[6 Marks]**

b. If the network in Figure Q4a is equipped with an alternative source of supply into section 3 as shown in Figure Q4b, re-compute the reliability indices at load points A, B & C? **[5 Marks]**

c. Compute the customer interruption index before and after connecting the alternative supply to the above radial line if 250 customers are connected at each load point? **[5 Marks]**

d. Compute the energy not supplied before and after connecting the alternative supply, if the average load connected to each load point is 500 kW. **[4 Marks]**

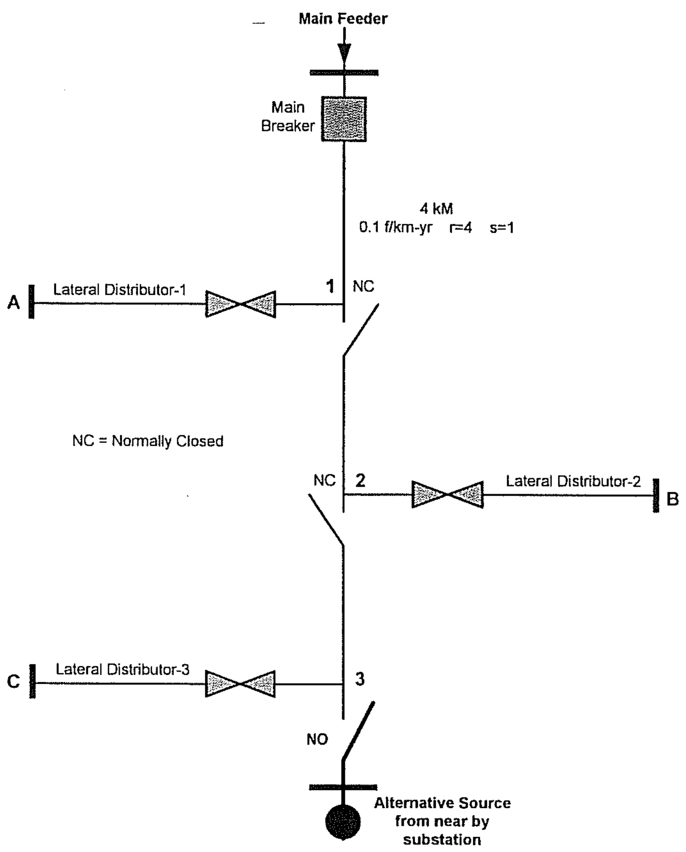

Figure Q4b

5. A power system is served by three generators where the installed capacities and forced outage rates are given in Table Q5a.

Table Q5a

Merit order loading		Plant ID.	Installed Capacity (MW)	F.O.R	Average Cost (€/MWh)
1		A	200	0.1	1000
2		B	100	0.1	1500
3		C	100	0.1	1500

If the generating system above is serving a load described by the chronological load curve shown in Figure Q5, do the followings:

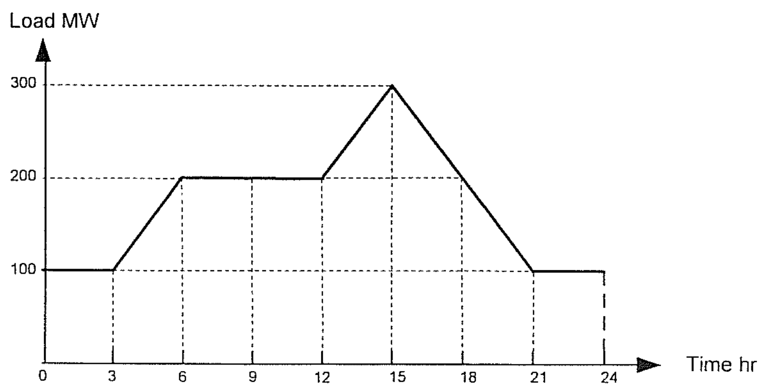

Figure Q5

a. Sketch: Load duration curve **[1 Marks]**
b. Calculate: Daily energy to be served **[1 Marks]**

Develop the Remaining Load Duration Curves (RLDCs) for each generator and estimate:

- **c.** Energy served & plant factor for each generator **[5 Marks]**
- **d.** Expected production costs of each generator **[5 Marks]**
- **e.** Loss of Load Probability index (LOLP) **[4 Marks]**
- **f.** Energy not Served (ENS) **[4 Marks]**

6. Hourly irradiance and temperature variation observed on a domestic roof top are graphically shown in figure Q6a and Q6b, respectively.

a. What would be the hourly maximum possible power and total energy that can be harnessed from a photovoltaic (PV) panel of which the specification are given in table Q6a? **[10 Marks]**

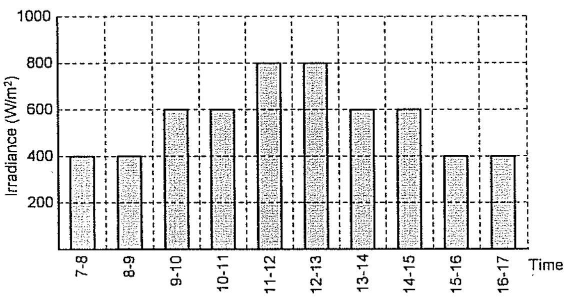

Figure. Q6a-Variation of irradiance with time

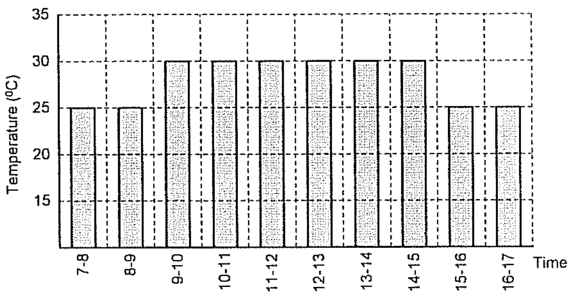

Fig. Q6b-Variation of temperature with time

Table Q6a-PV panel Specifications

Parameter	Value
Open-circuit voltage under STC	36 V
Short-circuit current under STC	8.0 A
Voltage at MPP under STC	30 V
Current at MPP under STC	7.5 A
ΔI_{SC}	0.15% / °C
ΔV_{OC}	-0.3% / °C
Maximum power rating	225 W

STC = Standard Test Conditions [T=25°C and Irradiance 1000 W/m²]

b. If the house owner opts for the net-metering and his monthly (30 days) energy consumption is 450 kWh, compute the number of PV panels required to break-even his monthly energy consumption? Assume that the invertor efficiency is 100%. **[5 Marks]**

c. Based on the following cost figures, calculate the simple payback period of the total PV net-metering installation. You may use Table Q6b for domestic electricity tariff plan. **[5 Marks]**

Cost of a 225 W PV solar panel	25,000 LKR
Cost of a 3500 W 12/230 V 50 Hz pure sinusoidal invertor	150,000 LKR
Other associated equipment cost	40,000 LKR

Table Q6b-Tariff Plan for Domestic purpose

Monthly Consumption (kWh)	Unit Charge (LKR/kWh)	Fixed Charge (LKR/Month)
0-60	7.85	N/A
61-90	10.00	90.00
91-120	27.75	480.00
121-180	32.00	480.00
>180	45.00	540.00

7. A single area consists of two generating units, rated at 400 and 800 MVA, with speed droop characteristics of 4% and 5% on their respective MVA ratings. The two generators are running in parallel sharing 700 MW. Gen-1 supplies 200 MW and Gen-2 supplies 500 MW at 60 Hz. The load is now increased by 130 MW.

   a. Find the steady-state frequency deviation and the new generation on each unit. Assume that there are no frequency-dependent loads i.e. $D = (\partial p_D/\partial f) = 0$ **[10 Marks]**

   b. If the load varies by 0.8% for every 1% change in frequency, find the steady-state frequency deviation of the power system and the new generation on each generators. **[5 Marks]**

   c. Explain why the total generation in (b) is less than the 130 MW load change. **[5 Marks]**
   (Hint: Assume Base MVA= 1000 MVA)

8. Answer as True or False **with respect to the power system in Sri Lanka**. Where there is more than one answer given, select the correct answer from the list.

   a. Whenever supply is equal to the demand, system frequency will always be at 50 Hz. **[1.5 Marks]**

   b. Whenever supply is equal to the demand, system frequency can remain stable at any frequency within normal operating range. **[1.5 Marks]**

   c. When frequency is at 49.8 Hz, it indicates that the total generation at the time is less than the demand. **[1.5 Marks]**

   d. Steady-state system frequency can be different from bus-bar to bus-bar. **[1.5 Marks]**

   e. Which one of the cost components shown below is <u>**NOT**</u> considered for economic dispatch or unit commitment decision? **[2 Marks]**

      1. Start-Stop cost of the generator
      2. Variable cost of generation (LKR/kWh)
      3. Capacity cost paid for the investment
      4. Incremental cost of generation

   f. Whenever there is a load-frequency imbalance, automatic governors (on primary load frequency control) will bring back the frequency to 50 Hz. **[1.5 Marks]**

   g. Governors will keep on increasing the turbine actuator valves and increase the prime mover output power as long as the frequency is below the rated frequency, and falling. **[1.5 Marks]**

h. Governors will keep on increasing the actuator valves and increase the prime mover output power as long as the frequency remains below the rated frequency (50 Hz) **[1.5 Marks]**

i. CEB can decide on its own how much of power to be generated from CEB's own hydro power stations. **[1.5 Marks]**

j. Feeders selected to stage-1 of the under frequency load shedding (UFLS) scheme are usually non-industrial residential feeders. **[1.5 Marks]**

k. The present under frequency load shedding scheme of Sri Lanka monitors both the frequency and rate of change of frequency **[1.5 Marks]**

l. During a large generator tripping event, CEB mainly relies on the spinning reserve to restore the frequency stability **[1.5 Marks]**

m. Out of the listed below, which is the factor that could always influence the rate of change of frequency in the Sri Lanka power system during a sudden generator tripping? **[1.5 Marks]**

1. Whether the generator tripped was operating at the time as a base load power plant or as a peaking plant
2. The total inertia of the remaining system
3. System voltage
4. Configuration of the transmission network