The Open University of Sri Lanka
Faculty of Engineering Technology
Department of Electrical & Computer Engineering

Study Programme	: Bachelor of Technology Honours in Engineering
Name of the Examination	: Final Examination
Course Code and Title	**: EEX7432/EEX6832 Power Systems Planning Operation and Control**
Academic Year	: 2020/21
Date	: 09th February 2022
Time	: 0930-1230 hrs.
Duration	: **3 hours**

General Instructions

1. Read all instructions carefully before answering the questions.
2. This question paper consists of **Eight (8)** questions in **Eight (8)** pages.
3. Answer any **Five (5)** questions only. All questions carry equal marks.
4. Answer for each question should commence from a new page.
5. Relevant charts/codes are provided.
6. This is a Closed Book Test (CBT).
7. Answers should be in clear handwriting.
8. Do not use Red colour pen.

1. An electric utility is planning to implement a summer peak TOU metering project for 40,000 residential customers. The peak load pricing period would apply from June through August, six hours per day. Residential customers have the following characteristics:

Energy consumed during summer peak hours: 800 kWh/yr./customer
Energy consumed during summer off-peak hours: 2,200 kWh/yr./customer
Energy consumed during non-summer period: 7,000 kWh/yr./customer
Estimated summer price elasticity of demand at peak load: -0.3
Estimated summer price elasticity of demand during off-peak: -0.1

The proposed TOU rate structure is designed as such annual customer bill is the same as the existing tariff if the customer does not alter the usage profile. The marginal cost of operation and the existing and proposed tariff rates are tabulated in table Q1.

Table Q1 - Tariff and Operation Data

Description	Existing Tariff	Proposed TOU Tariff	Marginal cost of operation
	(LKR/kWh)		
Summer peak rate	8.00	16.00	22.5
Summer off-peak rate	8.00	5.09	4.0
Non-summer period	5.00	5.00	3.0

The failure rate of a TOU meter is estimated to be 0.5% per year and the repair cost is about LKR 10,000. Evaluate the costs and benefits of this project. **[20 Marks]**

2. **a.** Over a period of 3 years, the following performance has been recorded in the log-sheet of a 100 MW and 200 MW generating units operating in a power system.

Table Q2

Event Description	Unit Capacity					
	100 MW			200 MW		
	1st year	2nd year	3rd year	1st year	2nd year	3rd year
Total operating time with full load	3000 h	4000 h	2760 h	7400 h	7200 h	7200 h
Total duration of planned maintenance work	720 h	800 h	740 h	600 h	700 h	900 h
Number of forced outages	15	16	14	24	24	18
Average duration of a forced outage	24 h	44 h	47.5 h	32 h	36 h	44 h
Fuel cost + variable maintenance cost	25 LKR/kWh			20 LKR/kWh		

Calculate Forced Outage Rate for: **1.** 100 MW & **2.** 200 MW units **[5 Marks]**

b. Two-200 MW and one-100 MW units (of characteristics given in Table Q2) are available to serve a power system, for which the load duration curve (LDC) is as shown in Figure Q2.

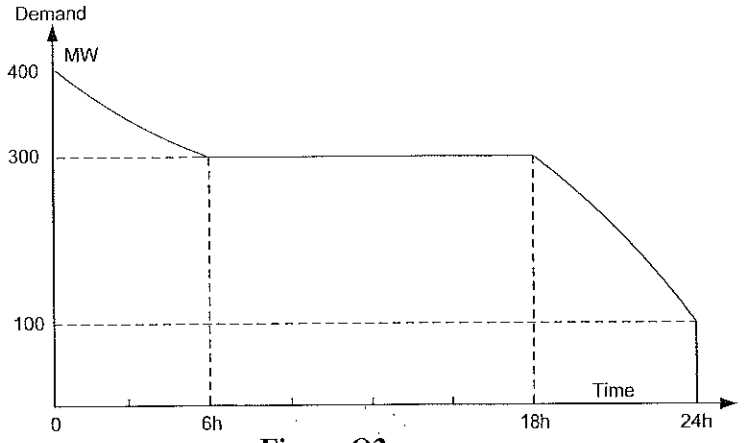


Figure Q2

While stating any assumptions you made with respect to the LDC, determine:

1. The plant factor, energy served and the cost of operation of each plant **[5 Marks]**
2. The loss of load probability (LOLP) **[5 Marks]**
3. The expected energy not served per annum (ENS) **[5 Marks]**

3. a. A power system consists of n thermal generators delivering an amount of power P_{Total} while being optimally dispatched. The heat curve of the i^{th} generator is written as $H_i = a_i + b_iP_i + c_iP_i^2$ MBtu/h where a_i, b_i and c_i are constants and P_i is its generation in MW. Show that when total power generation is increased by ΔP_{Total}, the individual generators can be optimally dispatched at a new dispatch value generating $P_i + \Delta P_i$ where:

$$\Delta P_i = \frac{1/2c_ir_i}{\sum_{i=0}^{n} 1/2c_ir_i}\Delta P_{Total} \quad \text{and} \quad r_i = \text{Fuel rate in €/MBtu, € being the unit of currency}$$

[3 Marks]

b. Show that the increase of the cost of operations of each generator is given by:

$$\Delta F_i = (\lambda + r_ic_i\Delta P_i)\Delta P_i \quad \text{in standard notation} \qquad \textbf{[2 Marks]}$$

c. A company owns three generating units operating with the a, b and c heat curve parameters as given in Table Q3. Making use of the equations developed in deriving in **(a)**, optimally dispatch these three units to supply a total system demand of 400 MW.

[5 Marks]

Table Q3

Unit#	Heat Curve Parameters $H_i = a_i + b_iP_i + c_iP_i^2$ MBtu/h			Fuel Rate (r_i) €/MBtu	Generator limits (MW)	
	a	b	c		P_{min}	P_{max}
1	225	8.4	0.0025	0.80	50	350
2	729	6.3	0.0081	1.02	50	400
3	400	7.5	0.0025	0.90	75	500

d. Calculate the hourly cost of supplying this load. **[3 Marks]**

e. How would you dispatch the above three units if the total demand is increased by 450 MW i.e., $\Delta P_{Total} = 50$ MW ? **[5 Marks]**

f. Calculate the increased total cost in above case **(e).** i.e., ΔF_i **[2 Marks]**

4. a. Table Q4a depicts the characteristics of a generating system with 3 units in operation. Develop a unit commitment priority list for the three generators G_1, G_2 and G_3 based on the full load incremental cost. **[5 Marks]**

Table Q4a

Generator Unit	Parameters of the heat generation equation			Generator limits (MW)		Fuel Cost €/MBtu
	a_n	b_n	c_n	Max	Min	
G_1	510	7.2	0.0016	500	150	3.3
G_2	310	7.8	0.0019	400	100	3.0
G_3	78	8.0	0.005	300	50	3.0
Heat generation equation is in the form of; $H_n \left[\frac{MBtu}{h}\right] = a_n + b_n P_n + c_n P_n^2$						

b. Establish the optimum unit commitment schedule for the load pattern given in figure 4 using a dynamic programming technique. The start-up cost and the shut-down cost of the three generators are given in Table Q4b. State any assumptions made during the calculations. **[15 Marks]**

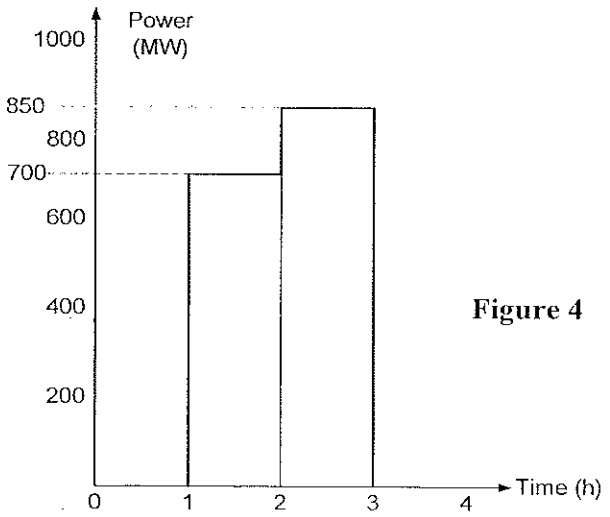


Figure 4

Table Q4b

Generator	Start-up cost (€)	Shut-down cost (€)
G_1	150	50
G_2	100	40
G_3	75	30

5. a. A radial distribution network is shown in figure Q5. Assume that all the failures in feeder sections and the distributors are short circuits which will cause the main breaker at the supply point to operate. The isolation and switching are 0.5 hours, and the failure probability of fuses is 0.1.
Determine the reliability parameters; Failure rate (λ), Outage time (r), Unavailability (U) at load points A and B for the following two cases.

- Case-1: An isolator is installed at R and distributors are solidly linked at point P&Q
- Case-2: An isolator is installed at R and distributors are connected through fuses at P&Q

[12Marks]

b. Evaluate the following customer and load oriented reliability indices for the Case-2

- System Average Interruption Index *(SAIFI)* **[2 Marks]**
- System Average Interruption Duration Index *(SAIDI)* **[2 Marks]**
- Customer Average Interruption Index *(CAIDI)* **[2 Marks]**
- Average Energy Not Supplied *(AENS)* **[2 Marks]**

SAIFI = (Total number of customer interruptions/Total number of customers served)
SAIDI = (Sum of customer interruption durations/Total number of customers)
CAIDI = (Sum of customer interruption durations/Total number of customer interruptions)
AENS = (Total energy not supplied/Total number of customers served)

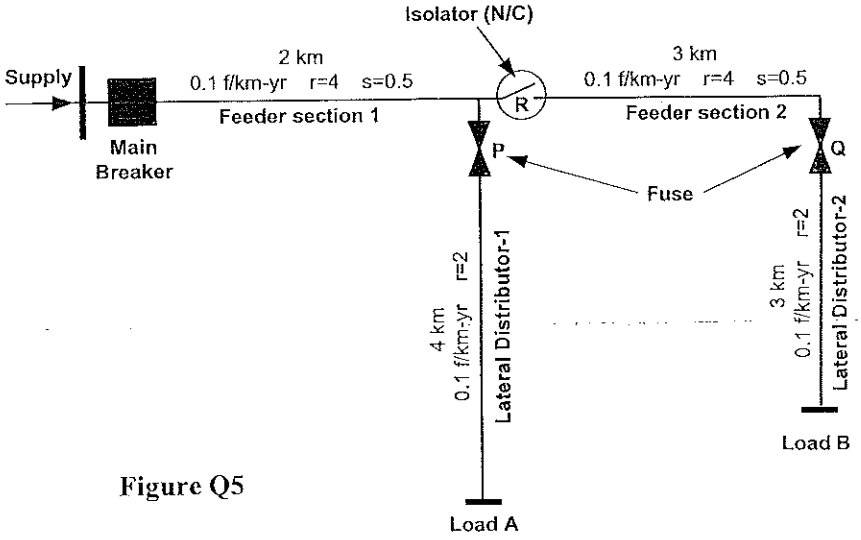


Figure Q5

Data pertaining to the above radial circuit are:

Feeder-1 failure rate = 0.1 f/km-yr
Feeder-1 average repair time = 4 h
Feeder-1 section length = 2 km
Lateral distributor-1 failure rate = 0.1 f/km-yr
Average repair time = 2 h
Lateral distributor-1 length = 4 km

Feeder-2 failure rate = 0.1 f/km-yr
Feeder-2 average repair time = 4 h
Feeder-2 section length = 3 km
Lateral distributor-2 failure rate = 0.1 f/km-yr
Average repair time = 2 h
Lateral distributor-2 length = 3 km

Data for load point A and B

Load point	Number of customers	Average load/customer (W)
A	500	3000
B	700	4000

6. Consider the typical substation configurations Figure Q6.1 & Figure Q6.2 shown below, and the reliability data given in table Q6 for each component:

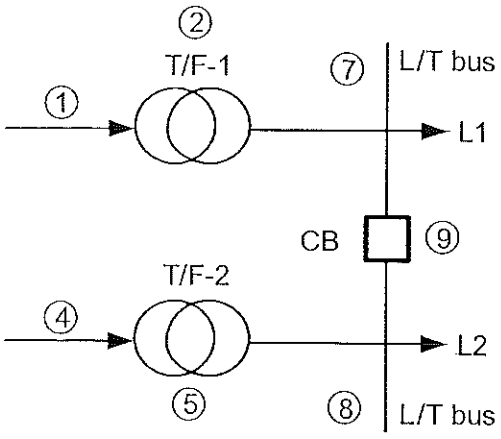


Figure Q6.1

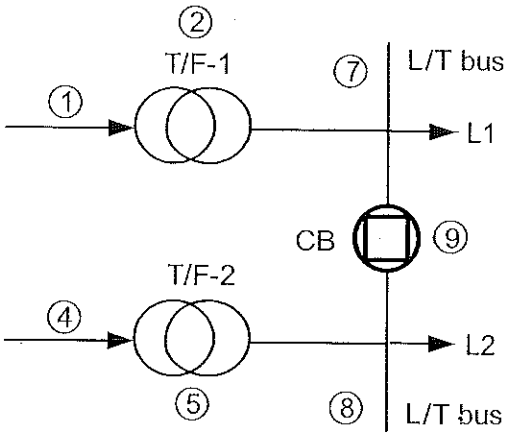


Figure Q6.2

Table Q6

Component	λ(f/yr)	r (hours)	λ_a (f/yr)	S (hours)	P_c
Line-1	0.09	7.33	0.09	1.0	
Line-4	0.09	7.33	0.09	1.0	
Transformers 2 & 5	0.1	50	0.1	1.0	Probability of a breaker getting stuck
7 & 8 (L/T bus bar)	0.024	2	0.024	-	
Breaker 9	0.02	3	0.01	1.0	0.06

λ_a= Active failure rate s = Switching time

a. Neglecting any coordinated/un-coordinated maintenance work performed in this system, evaluate the failure rate (λ), average outage duration (r), annual outage time (Unavailability) at load point L1 & L2 for both substation configurations.

Case (1) L/T bus tie breaker #9 is normally closed **[8 Marks]**

Case (2) L/T bus tie breaker #9 is normally open **[8 Marks]**

b. If the average load connected at bus #7 and #8 are 50 MW each respectively, calculate the total energy not served for each configuration. **[4 Marks]**

7. Identify whether the following statements are TRUE (**T**) or FALSE (**F**) **[1X20 Marks]**

a. Whenever the supply is not equal to the demand, system frequency will always rise.

b. Whenever supply is equal to the demand, system frequency is always at 50 HZ.

c. When the system frequency is stable at 50.1Hz, it indicates that the total generation at that time is higher than the demand.

d. "Enhancing the Share of Renewable Energy" is a POLICY, but "Provide 35% of the energy share from renewable energy sources by 2035" is a GOAL.

e. Whenever there is a load-generation imbalance, automatic governors (on primary load frequency control) will bring back the frequency to 50 Hz.

f. Transient frequency error cannot be eliminated whatsoever even with the "Reset" loop of the governor frequency control.

g. Governors will keep on decreasing the actuator valves and decrease the prime mover output power as long as the frequency remains below the rated frequency (50 Hz)

h. CEB can decide on its own how much of power to be generated from CEB's own Mahaweli hydro power stations.

i. Feeders selected at stage-1 of the under-frequency load shedding (UFLS) scheme are usually residential feeders.

j. The present under frequency load shedding scheme of Sri Lanka monitors both the frequency and rate of change of frequency

k. During a large generator tripping event, CEB mainly relies on the spinning reserve to restore the frequency stability

l. Prevailing Sri Lanka's major primary energy supply source is represented by biomass.

m. Loss of Load Expectation (LOLE) is always expressed in per units.

n. Pumped storage power plants are economical and can be used for load balancing in large coal and nuclear based power systems.

o. Apparent power equals active power when the power factor is 1.0

p. Forecast of net loss, peak load and load factor are the key factors considered while preparation of long-term generation expansion plan in Sri Lanka.

q. Time series analysis is a widely used demand forecasting technique of present-day power system planning studies.

r. Sub-synchronous resonance should be avoided when implementing series compensation

s. Higher the number of lines connected to a node means smaller the short circuit current value at that node.

t. For long high voltage transmission lines where the total reactance is high, series compensation improves the system stability.

8. Following are the **16** MCQ type questions. Pick the correct answer. **[1.25X16 Marks]**

a. Which one of the cost components shown below is **NOT** considered for the computation of Life Cycle Cost?

1. Lifetime of the unit **2.** Variable cost of the generation
3. Capacity cost paid for the investment **4.** Incremental cost of generation

b. The factor that could always influence the rate of change of frequency in the Sri Lanka power system during a sudden generator tripping is:

1. The unit tripped was a peaking plant **2.** The total inertia of the remaining system
3. System voltage **4.** Configuration of the transmission network

c. Unit of regulation of speed governor is:

1. Hz/MW **2.** MW/Hz **3.** Unitless **4.** Hz/MW-Sec

d. A generating station which has a high investment cost and low operating cost is usually operated as a:

1. Peak load station **2.** Base load station **3.** Medium load station **4.** None of the above

e. Three generators are feeding a load of 100 MW. The details of the generators are:

	Rating(MW)	Efficiency(%)	Regulation(pu) on 100 MVA base
Generator-X	100	20	0.02
Generator-Y	100	30	0.04
Generator-Z	100	40	0.03

In the event of increased power demand, which of the following will happen?

1. All the generators will share equal power
2. Generator-Z will share more power compared with generator-X
3. Generator-Y will share more power compared with generator-Z
4. Generator-X will share more power compared with generator-Y

f. A power system consists of 2-synchronous generators. Governor-turbine characteristics corresponding to the generators are $P_1=50(51-f)$, $P_2=100(50-f)$ where f denotes the system frequency in Hz, and P_1 and P_2 are respectively, the power outputs (in MW) of turbines. If the transmission network is lossless, the system frequency for a total load of 550 MW is:

1. 46.7 Hz **2.** 48.0 Hz **3.** 48.5 Hz **4.** 49.0 Hz

g. The annual load duration curve of a power supply system may be considered as a straight line rising from 36 MW to 60 MW. The load factor of the system is:

1. 0.2 **2.** 0.4 **3.** 0.6 **4.** 0.8

h. A power plant with three 10 MW identical generating units each with a forced outage rate of 0.1 can meet a 20 MW constant load with an approximate LOLE of:

1. 40 minutes/day **2.** 350 minutes/day **3.** 1 minutes/day **4.** 38 minutes/day

i. A 3ϕ, 11 kV, 50 Hz, 1.2 MW balanced load operate at 0.8 power factor lagging. A delta connected 3ϕ capacitor bank is used to improve the power factor to unity. The capacitance per phase of the capacitor in microfarads is:

1. 2.63 **2.** 2.50 **3.** 7.89 **4.** 7.5

j. Fault level at a bus operating at 132 kV is found to be 1000 MVA. If the line voltage at this bus falls below its nominal voltage by 5 kV, the reactive power injection required at this bus to re-establish the original voltage would be:

1. 38 **2.** 40 **3.** 36 **4.** 42

k. For a thermal power plant, the input characteristic is given by $S = 4 + P + 0.04P^2$ where S and P are heat input and power output, respectively, in MW. The maximum thermal efficiency of the plant would be:

1. 55.5% **2.** 60.5% **3.** 34.5% **4.** 40.5%

l. Incremental fuel costs for a power plant consisting of 3 generating units are:

$$IC_1 = 20 + 0.2\,P_1, \qquad IC_2 = 20 + 0.4\,P_2, \qquad IC_3 = 25$$

Min. & Max. loads on each unit are 50 MW & 400 MW. Plants are operating on economic load dispatch to supply a total power demand of 1GW. Power generated by each unit in MW is:

1. $P_1 = 400$ $P_2 = 200$ $P_3 = 400$ **2.** $P_1 = 200$ $P_2 = 400$ $P_3 = 400$
3. $P_1 = 250$ $P_2 = 450$ $P_3 = 300$ **4.** $P_1 = 300$ $P_2 = 400$ $P_3 = 200$

m. The incremental transmission loss for a 2-plant system is given by:

1. $B_{11}(P_1)^2 + B_{12}(P_2)^2 + 2B_{12}P_1P_2$ **2.** $B_{11}(P_1)^2 + 2B_{12}P_1P_2 + B_{22}(P_2)^2$
3. $B_{22}(P_1)^2 + 2B_{12}P_1P_2 + B_{11}(P_2)^2$ **4.** $\begin{bmatrix} 2B_{11}P_1 + 2B_{12}P_2 \\ 2B_{22}P_2 + 2B_{12}P_1 \end{bmatrix}$

n. Unit commitment is:

1. Economic schedule among different units
2. Planning of generating units for future load increase
3. Optimal combination of units for operation at any one time
4. To choose proper units from thermal, hydro and nuclear plants

o. Shunt connected controllable var compensators will:

I. Improve power transfer capability
II. Improve power system stability
III. Improve power transfer capability but deteriorate power system stability
IV. Improve power system stability but reduce power transfer capability

1. (iii) is correct **2.** (iv) is correct
3. Both (i) and (ii) are correct **4.** (i) is correct all others are wrong

p. In static Var compensators using thyristors,

1. Filters are not necessary
2. The dominant harmonic is 2^{nd}
3. Filters are needed for 5^{th} and 7^{th} harmonic
4. Capacitors are switched on the high voltage side only