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**
	:Power Systems Planning Operation and Control
Academic Year	: 2021/2022
Date	: 21st February 2023
Time	: 0930-1230 hrs
Duration	: **3 hours**

General Instructions

1. This question paper consists of **Eight (8)** questions in **Ten (10)** pages.
2. Answer any **Five (5)** questions.
3. All questions carry **equal marks.**
4. **Attach Page [8] to [10] to your answer script if Question 08 is answered and write your index number in the space provided.**
5. Answer for each question should commence from a new page.
6. Relevant figures and tables are attached to this question paper
7. This is a Closed Book Test (CBT).
9. Answers should be in clear handwriting.
10. Do not use Red colour pen.

Question 01

Electricity sales in Sri Lanka from 2012-2021 is given in Table Q1 below:

Table Q1

Year	Sales (GWh)
2012	10,474
2013	10,624
2014	11,063
2015	11,786
2016	12,785

Year	Sales (GWh)
2017	13,431
2018	14,091
2019	14,611
2020	14,286
2021	15,214

Source: Statistical digest reports by CEB, 2012-2021 source ceb.lk

a) Calculate the 10-year simple compound growth rate from the above figures. **[02 Marks]**

b) Fit a trend profile for the above data using linear & exponential variations of the form:

a. Sales = a + b. Time and **[05 Marks]**
b. Sales = $e^{(k_1 . \text{Time} + k_2)}$ **[05 Marks]**

c) Check the goodness of fit (R^2) for the 2 models you have developed under (b) **[02 Marks]**

d) Would you accept the profiles or reject? If so on what basis? **[02 Marks]**

e) Using the simple compound growth rate and the 2 profiles you have developed in (b), calculate the three values for forecast for electricity sales for year 2022. **[02 Marks]**

f) However, according to the CEB Long Term Generation Expansion Plan (2022 – 2041) the forecasted figure for year 2022 was 16,741 GWh. Explain this difference. **[02 Marks]**

You may use the following statistical formulae applicable in least-square estimation method:

or Y= a + b.X of the form

$$a = \left\{ \frac{\sum_{i=1}^{n} y_i \sum_{i=1}^{n} x_i^2 - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} x_i y_i}{n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2} \right\}$$

$$b = \left\{ \frac{n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2} \right\}$$

$$R^2 = \frac{\text{explained variation}}{\text{total variation}} = \frac{\sum_{i=1}^{n} (y_i^e - \bar{y})^2}{\sum_{i=1}^{n} (y_i - \bar{y})^2}$$

Question 02

A power system is served by three generators where the installed capacities and forced outage rates are given in Table Q2.1.

Table Q2.1

Plant ID.	Installed Capacity (MW)	FOR	Average Cost (US$/MWh)
G1	150	0.15	1500
G2	150	0.1	1000
G3	50 100	0.7 0.4	1500

If the generating system above is serving a system described by the chronological load curve shown in Figure Q2.1, do the following:

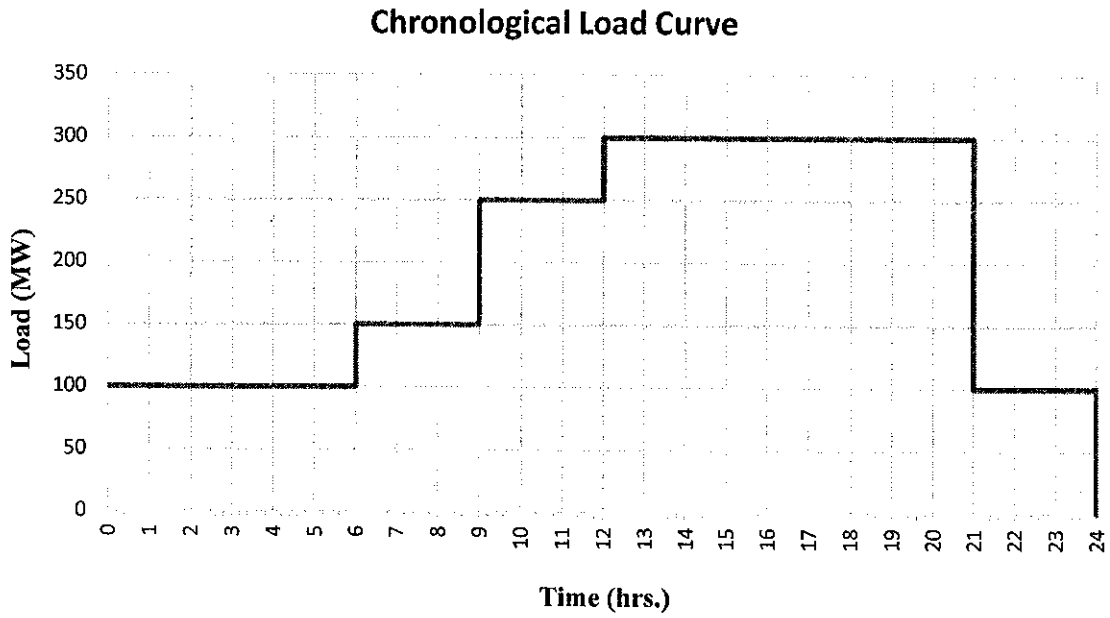


Figure Q2.1

a. Sketch: Load duration curve of the system **[04 marks]**
b. Calculate: Daily energy to be served **[02 marks]**
c. Develop the Remaining Load Duration Curves (RLDCs) for each generator based on merit order dispatch and estimate: energy served, plant factor and expected production costs for each generator **[08 marks]**
d. Loss of Load Probability index (LOLP) & (LOLE) **[03 marks]**
e. Energy Not Served (ENS) **[03 marks]**

Question 03

a. Draw and briefly explain each component of the load-frequency control system of an isolated power system **[05 Marks]**

b. Three identical synchronous machines of rating 200 MW, 50Hz operating in parallel have the following characteristics (Table Q3).

Table Q3

Machine	Speed droop (R)	Speed changer setting
I	3%	60% rated load at rated speed
II	4%	80% rated load at rated speed
III	5%	70% rated load at rated speed

i. Determine the load taken by each machine for a total load of 420 MW and calculate the frequency of operation, if the load increases to 500 MW. **[06 Marks]**

ii. What would be the impact, if the load is increased to 500 MW and then find final frequency and the share of each generator. **[05 Marks]**

iii. What adjustments should be made by the speed changers of the three machines to share the load in (ii) above but with a frequency of 50 Hz. **[04 Marks]**

Question 04

The demand variation throughout a day of an industrial consumer using electricity at 400 V, three phase ac and 50 Hz, is given in Table Q4.1.

Table Q4.1

Time (hours)	00:00-09:00	09:00-15:00	15:00-21:00	21:00-24:00
Total Load (kW)	100	300	700	100
Load Description	LL1 only	LL2+IM1	LL3+IM1+IM2	LL4 only
LL- lighting Load		250 kVA IM1 loads @ 0.8 p.f.	250 kVA IM1 loads @ 0.8 p.f.	
IM- Induction Motor Loads			500 kVA IM2 loads @ 0.6 p.f.	

Assume a utility offers a choice of two electricity tariff schemes for the above consumer as given under in Table Q4.2.

Table Q4.2

Customer Category	Unit Charge (Rs/kWh)			Fixed Charge (Rs/month)	Maximum demand charge (Rs/kVA) per month
	Peak hrs. (18:00-21:00)	Off-peak hrs. (21:00-09:00)	Day hrs (09:00-18:00)		
Industrial					
Indus-1	25.00	25.00	25.00	4,000	1,500
Indus-2	35.00	15.00	29.00	4,000	1,000

Assuming a month of 30 working days:

a. Calculate the load factor of the above consumer. **[02 Marks]**

b. Determine the monthly electricity bills under Indus-1 & Indus-2 and hence advice and help the consumer to select the most attractive tariff. **[05 Marks]**

c. If the working load of 500kVA operating between 15:00 – 21:00 hrs can be shifted and uniformly distributed between 21:00 and 06:00 hrs by an extra working shift, under a newly introduced load management program, calculate the new load factor. **[05 Marks]**

d. Determine the new electricity bills under the new scenario and hence advice the best tariff for the consumer. **[05 Marks]**

e. Calculate the size of the capacitance in μF to be installed to improve the power factor to unity after implementing the load management program. (Assume that the capacitor banks are delta connected). **[03 Marks]**

Question 05

a. For a uniformly increasing load on a distribution feeder, show that the voltage drop can be represented by the expression $I_s.z(2l/3)$, where I_s is the rms current at the sending end and z is the impedance per unit length. l is the total length of the line. **[04 Marks]**

b. Over a period of one year, the following performance has been recorded in the log sheet of a 120 MW generating unit in a large power system. Extracted from log-sheet data,

- Plant operates full load for 6560 hours.
- Forced to shut-down completely six times for 700 total hours
- The plant has been taken for 250 hours to conduct planned maintenance.
- The plant was available but not called for 1100 hours.
- Plant de-rated twice to 30% of maximum capacity for 100 hours and de-rated once to 40% for 50 hours.

Estimate the following,

1. Planned outage rate **[02 marks]**
2. Forced outage rate **[02 marks]**
3. Equivalent average repair time **[02 marks]**
4. Equivalent availability **[02 marks]**
5. Maximum energy production for the period **[02 marks]**

c. Table Q5 is a re-production of a part of typical interruption data from a power utility for a feeder circuit for a period of one year. It serves 2,200 customers with a total load of 5 MW. Momentary interruption events are omitted. Calculate the SAIFI, SAIDI, CAIDI and ASAI for this feeder. **[06 marks]**

Table Q5

Date	Time (hrs.: min.)		No. of Cus.
	Start	End	interrupted
11-Jan-2022	1:11 AM	3:11 AM	155
5-Mar-2022	11:26 AM	12:26 PM	652
6-Mar-2022	10:10 AM	10:12 AM	100
8-Apr-2022	8:59 AM	9:14 AM	390
9-Aug-2022	6:23 AM	6:43 AM	365
20-Aug-2022	8:20 AM	8:45 AM	930
10-Nov-2022	3:45 AM	9:00 AM	670
19-Dec-2022	6:10 AM	1:50 PM	1480

Use following definitions as appropriate

$$SAIFI = \frac{\sum Total\ number\ of\ customers\ interrupted}{Total\ number\ of\ customers\ served}$$

$$SAIDI = \frac{\sum Customer\ interruption\ duration}{Total\ number\ of\ customers\ served}$$

$$ASAI = \frac{Customer\ hours\ service\ availability}{Customer\ hours\ service\ demands}$$

$$CAIDI = \frac{SAIDI}{SAIFI}$$

Question 06

a. What are the key parameters to be considered in fixing main characteristics of primary equipment of a substation? **[02 Marks]**

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

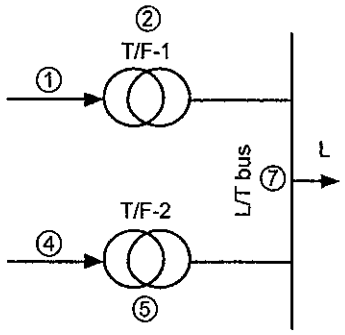


Figure Q6.1

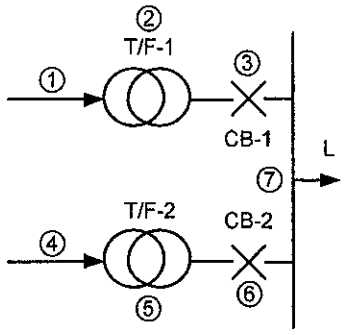


Figure Q6.2

Table Q6

Component	λ(f/yr)	r (hours)	λ_a (f/yr)	S (hours)
Line - 1	0.05	20	0.04	0.04
Line - 4	0.05	20	0.04	0.04
Transformer - 2	0.01	200	0.01	1.0
Transformer - 5	0.01	180	0.01	1.0
L/T bus bar - 7	0.005	5	0.005	-
Breaker 3	0.02	18	0.005	1.0
Breaker 6	0.02	18	0.005	1.0

λ_a= Active failure rate s = Switching time

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 L for both substation configurations. If the average load connected at bus #7 is L=75 MW, calculate the total energy not served for both the configurations. **[12 Marks]**

c. If the un-served energy cost is estimated to be 250 LKR/kWh and the extra cost involved in converting the substation shown in Figure Q6.1 to Figure Q6.2 is estimated to be 1.2 million LKR, what would be the simple pay-back period of the extra cost involved in converting the substations? **[06 Marks]**

Question 07

a. A long-distance overhead transmission (O/H) line is delivering P_{OLD} MW load at $V_1\angle\delta_1$ sending end voltage and $V_2\angle\delta_2$ receiving end voltage. The power delivered is given by $P_{old} = \frac{V_1 V_2 Sin(\delta_1 - \delta_2)}{X_L}$. Show that the required capacitance to be installed in series with the O/H line to achieve y% of the total line compensation is given by $\frac{100P_{OLD}}{2\pi f V_1 V_2 y Sin(\delta_1 - \delta_2)}$ F.

What would be the enhancement of power transfer capability, if the line compensation is 60 %. **[08 Marks]**

b. Briefly explain the concept of a "pumped storage power plant" and its usefulness in Sri Lanka power system **[04 Marks]**

c. For a certain small power system, the maximum and minimum power demands are 40 MW and 10 MW respectively. Its load duration curve can be approximated as shown in figure Q7. Hydropower available at the time of minimum regulated flow is just sufficient to cater to a peak load of 50 MWh/day. Further, it has been observed that it will be economical to pump water from the tailrace to the reservoir by utilizing the steam power plant during the off-peak periods and thus running the station at 100% load factor. Determine the maximum capacity of the pumped storage hydropower plant and the steam plant. Assume the efficiency of the steam conversion to be 60%. **[08 Marks]**

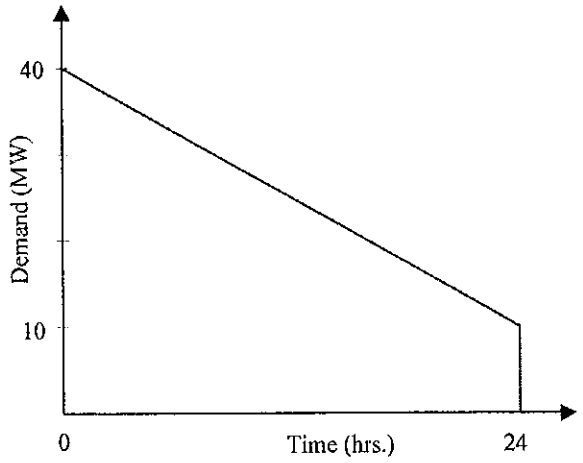


Figure Q7

Index Number: .....

Question 08

Following are 16 multiple-choice questions which will cover most of your course content. Each question carries **1.25** marks. Underline the correct answer and attach the three pages (8 to 10) to your answer script. Write your index number in the space given at the top of each page. Fault attempts will not have negative impact and therefore try all.

a. Identify the correct statement of the following

1. Ceylon Electricity Board was established in 1972
2. Energy that ultimately reach the useful level is known as final energy
3. Public Utilities Commission of Sri Lanka (PUCSL) was established in by Act no. 20 of 2009
4. Sensitivity studies are essential in planning studies

b. Find the wrong statements of the following

(i) Pelton bucket runners are an example for impulse type of turbines
(ii) Electrostatic precipitators used to remove fine dust particles stored in coal yards
(iii) Super chargers of diesel plants are installed between engine intake and air inlet
(iv) Commercial nuclear power plants produce heat by nuclear fusion

1. (i) & (iii) **2.** (i), (vi) **3.** (ii) & (iv) **4.** (ii) & (iii)

c. Find the correct statements of the following

(i) Photovoltaic (PV) and Concentrated solar thermal (CSP) are widely used two technologies in solar electric power generation
(ii) The present Non-Conventional Renewable Energy (NCRE) technologies used in Sri Lanka are mini-hydro, wind, biomass/dendro, tidal and solar
(iii) Doubling the wind speed gives eight times the wind power
(iv) Cold sea water is an integral part of the two established types of Ocean Thermal Energy Conversion (OTEC) systems: closed cycle and open cycle

1. (i) & (iii) **2.** (i), (vi) **3.** (ii) & (iv) **4.** (ii) & (iii)

d. A power system has two generating stations P_1 and P_2. The incremental production cost characteristics are,

$$\frac{\partial F_1}{\partial P_1} = 30.25 + 0.65\, P_1 \frac{LKR}{MWhr};\ where\ 10\ MW \le P_1 \le 100\ MW$$

$$\frac{\partial F_2}{\partial P_2} = 19.5 + 0.26\, P_2 \frac{LKR}{MWhr};\ where\ 10\ MW \le P_2 \le 100\ MW$$

If two power stations are suppling150 MW demand, the possible optimum dispatch schedule of P_2 and P_1 would be,

1. 65, 85 MW **2.** 50, 100 MW **3.** 100, 50 MW **4.** 85, 65 MW

e. Which one of the cost components shown below is NOT considered for economic dispatch or unit commitment decision?

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

Index Number: .....

f. A steam power station has an overall efficiency of 20% and 0.6kg of coal is burnt per kWh of electrical energy generated. Calculate the calorific value of fuel?

1. 6827 kcal/kg 2. 7167 kcal/kg 3. 6530 kcal/kg 4. 8627 kcal/kg

g. Annual maintenance cost of a plant is estimated to be 5MRs. Find the net present value of 15years of maintenance work based on time value of money. Take 8% as the discount rate.

1. 44.7MRs. 2. 46.3 MRs. 3. 40.6 MRs. 4. 42.8 MRs.

h. What is the standard ACSR conductors used in high voltage transmission systems (132 kV & 220 kV) in Sri Lanka?

1. Dove 2. Zebra 3. Lynx 4. Bear

i. A hydroelectric power station has a reservoir area 2.4km^2 and capacity 5MCM. The effective head of water is 100m. the penstock, turbine and generator efficiencies are 95%, 90% and 85% respectively. Calculate approximate total electrical energy that can be generated from the power station

1. 780 MWh 2. 650 MWh 3. 835MWh 4. 990 MWh

j. Find the required capacity of a static VAR compensator to be installed at a bus with ± 5% voltage fluctuation. Take the short circuit capacity as 7000MVA.

1. ±350 MVAr 2. ±1400 MVAr 3. ±140 MVAr 4. ±35 MVAr

k. Pure capital cost of a power plant is expected to be P LKR/kW. Construction period is about 4 years and the capital disbursement is expected to be the following:

1st year = 20% 2nd year = 30% 3rd year = 40% 4th year = 10%

Compute Interest During Construction (IDC)? (Assume 8% discount rate)

1. 27.28 2. 25.32 3. 22.46 4. 21.59

l. If two power system areas of following characteristics are connected by a tie-line, what would be the settling frequency and power flow in the tie-line? Assume both were at their normal frequency. i.e. 50Hz

1. 49.93 Hz, 33.6 MW
2. 48.96 Hz, 35.4 MW
3. 49.1, 36.3 MW
4. 48.92 Hz, 36.3 MW

Index Number: .....

m. Justifying the choice of HVDC transmission are:

(i) Economic transmission over long distance
(ii) Generation of less harmonics
(iii) Increased transmission capacity within a fix corridor
(iv) Frequency and phase dependent power transfer

1. Statements i & ii are acceptable
2. Statements i & iii are acceptable
3. Statements i & iv are acceptable
4. All statements are acceptable

n. In what bus bar configuration that requires a separate bus coupler?

1. Mesh bus configuration
2. Breaker-and-a-half configuration
3. Double bus bar single breaker configuration
4. Double bus bar double breaker configuration

o. A 3-ϕ, 5 kW induction motor has a p.f. of 0.75 lagging. A Δ-connected capacitor bank is used to improve the pf to 0.9 lagging. Determine the kVAr rating of the capacitors connected in each phase.

1. 0.592 kVAr **2.** 0.663 kVAr **3.** 0.891 kVAr **4.** 0.750 kVAr

p. A power station has a maximum demand of 15MW. The annual load factor is 50% and the capacity factor is 40%. Determine the reserve capacity of the plant.

1. 3250 kW
2. 3000 kW
3. 3750 kW
4. 4000 kW