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

Study Programme	: Bachelor of Science Honours in Engineering
Name of the Examination	: Final Examination
Course Code and Title	**: EEX7432**
	Power System Planning Operation and Control
Academic Year	: 2022/2023
Date	: 20th February 2024
Time	: 0930–1230hrs

General Instructions

1. Read all instructions carefully before answering the questions.
2. This question paper consists of **Seven (7)** questions in **FIVE (05)** pages.
3. Answer **any FIVE questions**. All questions carry **equal marks**.
4. Answer for each question should commence on a new page.
5. Relevant figures and tables are provided with the question paper.
6. This is a Closed Book Test **(CBT).**
7. Answers should be in clear handwriting.
8. Do not use red colour pen.

Question 1

a. Explain why demand forecasting is considered a necessary first step by engineers who are responsible for power system planning. [4 marks]

b. Compare the merits and constraints of econometric modelling against the end-use method for electricity demand forecasting. [4 marks]

c. Tabel Q1 shows the daily electricity generation (GWh) which closely follows the electricity demand in Sri Lanka for a continuous period of 28 days (4 weeks). Figure Q1 shows the plot of this data for the same period. It is seen from the plot that daily generation has a weekly cyclic pattern.

Table Q1

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Weekday	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue
GWh	40.64	41.94	41.17	38.05	33.6	40.23	41.2	42.05	41.55	41.54	38.5	35.7	40.45	41.55

Day	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Weekday	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue
GWh	42.05	43.0	42.67	39.57	36.22	40.5	41.94	42.76	43.9	44.34	41.07	36.95	44.02	44.13

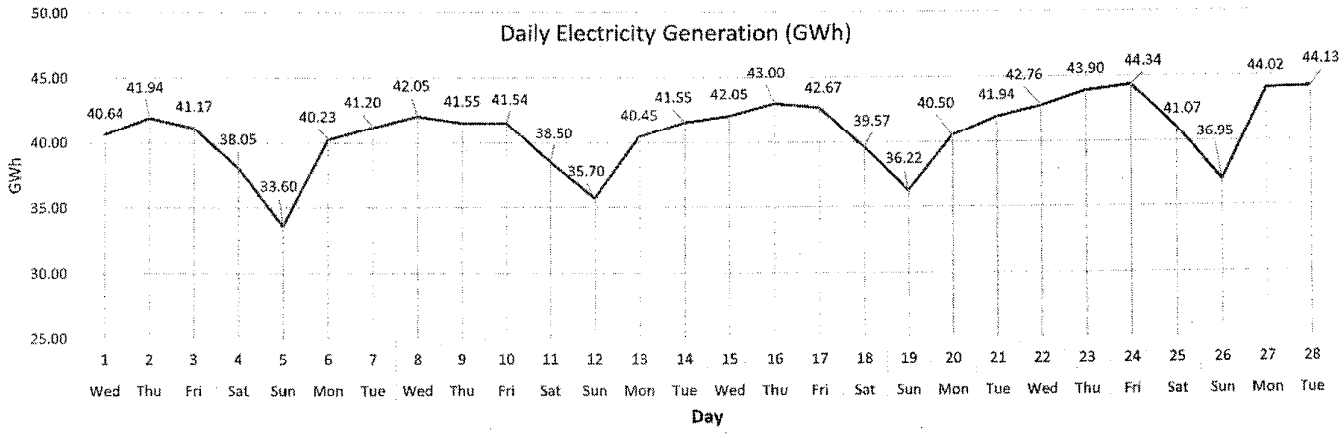


Figure Q1

i. You are asked to forecast the daily electricity generation requirements for the 5th week, i.e., for the day 29 through 35. Suggest a suitable methodology for this forecast. Using the suggested method, forecast the daily generation for Wednesday (day 29) and Sunday (day 33). [8 marks]

ii. What other parameters do you think are required in practice to make a more accurate daily electricity generation forecast? Justify your answer. [4 marks]

Hint: you may use the following formulae for least-square-error estimation for the linear curve fitting of the form $Y = a + b.X$

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

Question 2

An electricity customer served at 400V/230V with a contract demand of 100 kVA has the daily load pattern given in the Table Q2.1

Table Q2.1

Time of Day (hrs)	05:30-08:30	08:30-18:30	18:30-20:30	20:30-22:30	22:30-04:30	04:30-05:30
Average Total Load (kW)	10.0	50.0	20.0	10.0	5.0	10.0
Power factor	0.90	0.70	0.80	0.90	0.90	0.90

The above customer is metered with a time-of day tariff under General Purpose Tariff Rate-2 category given in the Table Q2.2

Table Q2.2

	Energy Charge (Rs/kWh)			Fixed Charge (Rs/month)	Demand Charge (Rs/kVA)
	Day Time (05:30-18:30)	Peak Time (18:30-22:30)	Off Peak Time (22:30-05:30)		
General Purpose Rate-2 (contract demand > 42 kVA)	58.00	68.00	48.00	6200.00	2000.00

a. Calculate the energy consumption of the customer during each period of day-time, peak-time and off peak-time of the day. [4 marks]

b. Calculate the maximum demand of the customer. [4 marks]

c. Determine the monthly cost of electricity for the above customer assuming the customer operates at the above load pattern each day for 25 days/month. [4 marks]

d. The customer operates electric pumps of total load 20 kW at power factor 0.7 during the period 08:30-18:30 on normal working days. These pumps are to be replaced with more efficient pumps of total load 12.0 kW, p.f 0.9 operating during the same period. Assume that power factor of rest of the demand during this period remains the same as before.

i. Calculate the new monthly cost of electricity. [4 marks]

ii. If the pump replacement incurs a total cost of Rs. 3.0 million, what would be the simple pay back period in years. [4 marks]

Question 3

a. Using first principles show that the theoretical wind power upstream of a wind turbine could be expressed by the formula $P = \frac{1}{2}\rho A U^3$ where ρ is the density of air, A is swept area of turbine blades and U is the wind speed. [2 marks]

b. What do you understand by the term Betz Coefficient in relation to wind turbines and briefly mention its significance to practical wind turbines. [4 marks]

c. A 100 kW wind power plant is to be constructed in a village financed by a bank loan which needs to be repaid at an annual rate of Rs 5.0 million for 10 years starting from the year of commissioning of the plant. Analysis of wind pattern at the chosen site has shown that the plant could have an annual capacity factor of 0.3 while the expected lifetime is 20 years. Operation and maintenance costs are estimated to be Rs. 2.4 million per annum. Applicable discount rate is 10.0% per annum.

i. Calculate the specific life-cycle cost (levelized cost) per kWh of energy output from the wind plant. [6 marks]

ii. If the selling price of wind energy is Rs. 35.00 per kWh, calculate the expected benefit-cost ratio (BCR) for the project. [4 marks]

iii. What is your opinion on the financial feasibility of the project? [4 marks]

Formulas for calculation of present value (PV) and the PV factor (S) are given below in standard notation:

$$PV = \frac{X}{(1+r)^n} \quad \text{and} \quad S = \sum_{i=1}^{n} \frac{1}{(1+r)^n} = \frac{1}{r}\left[1 - \frac{1}{(1+r)^n}\right]$$

Question 4

The load duration hours calculated for a 7-day period for a small power system consisting of 3 generators A, B, and C are shown in Table Q4. Generator A has a capacity of 100 MW with a FOR of 0.05. Generators B and C are of capacity 50 MW with FOR of 0.1. The merit order of dispatch is A, B, and C.

Table Q4

Load Range (MW)	0-50	50-100	100-150	150-200
Number of Hours	8	60	85	15

Using the Remaining Load Duration Curve (RLDC) method, calculate the loss of load probability (LOLP), loss of load expectation (LOLE) and the energy-not-served (ENS) for the above system. [20 marks]

Question 5

a. Show that the specific life-cycle cost (levelized cost) L of a power plant is given by the formula

$$L = \frac{P + M \cdot d}{8760 \cdot C \cdot d} + f + m$$

where the symbols stand for the following economic parameters, [4 marks]

P – All inclusive capital cost per unit of installed capacity (Rs/kW)
M – Annual fixed operation & maintenance cost (Rs/kW)
f – Fuel cost per unit of energy output (Rs/kWh)
m – Variable maintenance cost per unit of energy (Rs/kWh)
Y – Economic lifetime of plant (years)
d – Present value factor corresponding to the life-time Y of the plant
C – Annual capacity factor
L – Specific life-cycle cost, i.e., levelized cost (Rs/kWh)

b. Table Q5 shows the corresponding economic parameters, defined in part (a) above, for three different types of thermal power plants.

Table Q5

	Coal-Fired Steam	Diesel-Fired Combined Cycle	Diesel-Fired Gas Turbine
P (Rs/kW)	300,000	180,000	120,000
M (Rs/kW)	27,000	22,500	20,000
f (Rs/kWh)	55.00	60.00	70.00
m (Rs/kWh)	18.00	20.00	21.00
Y (years)	35	30	25
d (evaluated at 10% discount rate)	9.64	9.43	9.08

i. Develop the screening curve formula for each plant at a discount rate of 10% and determine the range of capacity factor for which each plant is the most economical out of the three. [8 marks]

ii. What type of a power plant out of the above three would be most economical for Sri Lanka power system, if it is to be dispatched as a base load power plant? Justify your reasoning for the given answer. [8 marks]

Question 6

a. Why do you need a spinning reserve for reliable operation of a power system? Give a criterion for estimating spinning reserve requirement for operational purposes. [4 marks]

b. Table Q6.1 provides the typical daily load pattern and the reserve requirements of a power system.

Table Q6.1

Stage	I	II	III
Hours (hr)	0000-0800	0800-1900	1900-2400
Load (MW)	8	12	16
Reserve (MW)	2	4	6

The system is installed with three thermal power plants whose capacities and cost data are given in Table Q6.2.

Table Q6.2

Plant	Capacity (MW)	Marginal energy cost (US$/MWh)	Fixed losses (US$/hr)	Start-up Cost (US$)	Shutdown cost (US$)
A	10	50	15	100	40
B	10	55	12	80	35
C	8	70	5	50	20

i. Assuming merit order dispatch of power plants, determine the feasible combinations of plants that could potentially serve the load and reserve requirements in each period of Table Q6.1. [6 marks]

ii. With the aid of a state diagram, show how you use the backward dynamic programming technique to find the optimum hourly unit commitment schedule. By means of this diagram, calculate the total minimum operating cost of transition from Stage-II to Stage-III. Also determine the corresponding unit commitments and the short run marginal costs of these two stages. [10 marks]

Question 7

a. Discuss briefly how the energy crisis of 2022 in Sri Lanka could have been avoided, or partially mitigated, if the "National Energy Policy and Strategies" of Sri Lanka as published in Gazette Extraordinary No. 2135/61 of 09.08.2019 have been effectively implemented. Your answer should concentrate on the pillars of the national energy policy which would have addressed the crisis directly and most effectively. [5 marks]

b. List the electricity generation technologies that are presently used in the Sri Lanka power system. Discuss both technical as well as economic advantages and limitations of further integration of non-conventional renewable energy sources into the present power system. [5 marks]

c. Modern power systems all over the world are increasingly integrating bulk energy storage technologies for their daily operations. What type of practical bulk energy storage technologies are available for this purpose? Why do modern power systems need such storage facilities? Explain how these facilities help improve the reliability. [5 marks]

d. List four different methods of voltage control in a power system and describe qualitatively how each of those methods help control the system voltage. [5 marks]