THE OPEN UNIVERSITY OF SRI LANKA
Faculty of Engineering Technology
Department of Electrical & Computer Engineering

Bachelor of Technology Honors in Engineering

Final Examination (2016/2017)
ECX6332: Power Systems Planning

Closed Book

Date: 29th November 2017 (Wednesday) **Time: 9:30 am – 12:30 am**

This paper contains Eight (8) questions. Answer any Five. All questions carry equal marks.
Attach pages 7 and 8 to your answer script if question #8 is answered.

1.

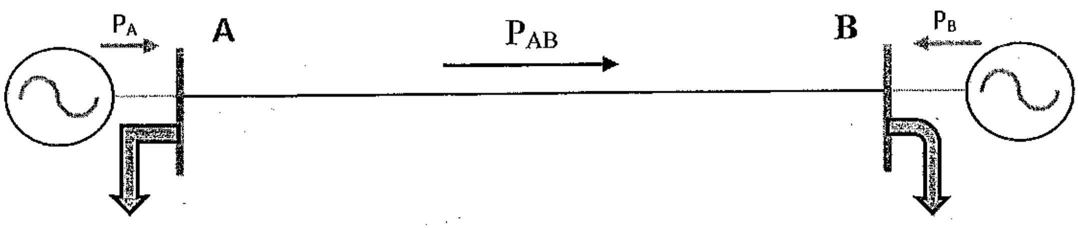

Figure-Q1

Consider the two-bus power system shown figure Q1. The marginal cost of production of the generators connected to buses A and B are as given in the following expressions:

$$MC_A = 20 + 0.03\ P_A \quad €/MWh$$
$$MC_B = 15 + 0.02\ P_B \quad €/MWh$$

Assume that the demand is constant and insensitive to price, that energy is sold at its marginal cost of production and that there are no limits imposed on the out puts of the generators, Calculate the price of electricity at each bus, the production of each generator and the flow on the line for the following cases:

a. The line between buses A and B is disconnected **[4 marks]**

b. The line between buses A and B is in service and has an unlimited capacity **[4 marks]**

c. The line between buses A and B is in service and has an unlimited capacity, but the maximum output of generator B is 1500 MW **[4 marks]**

d. The line between buses A and B is in service and has an unlimited capacity, but the maximum output of generator A is 900 MW. The output of generator B is unlimited **[4 marks]**

e. The line between buses A and B is in service but its capacity is limited to 600 MW. The output of the generators is unlimited. **[4 marks]**

2. **a.** If ρ = density of air (kg/m³), U = mean air velocity (m/s), A = swept area of blades (m²). Show that the theoretical wind-power that can be extracted from a wind turbine is given by $P = \frac{1}{2}.\rho.A.U^3$ W. **[3 marks]**

b. Prove that the maximum wind power from the turbine is produced (without considering all the mechanical losses) when the downstream wind velocity is equal to (1/3) of the upstream wind velocity and it is given by $P = \frac{1}{2}.C_p.\rho.A.V_1^3$ where V_1 is the upstream wind velocity and C_P is the performance(Betz) coefficient and is equal to 0.5926 **[6 marks]**

c. Define the term λ, i.e. Tip Speed Ratio(TSR) used by wind turbine designers? **[3 marks]**

d. An offshore wind turbine with three 50 meter blades rotates at 15 rpm. C_P Vs λ for the turbine is as shown in Figure Q2. Estimate the annual energy that can be harnessed by filling Table Q2. (Assume that the cut-in speed is 5 m/s and cut-out speed is 25 m/s. Also, assume that the density of air = 1.23 kg/m³) **[8 marks]**

Representative C_p - λ curve

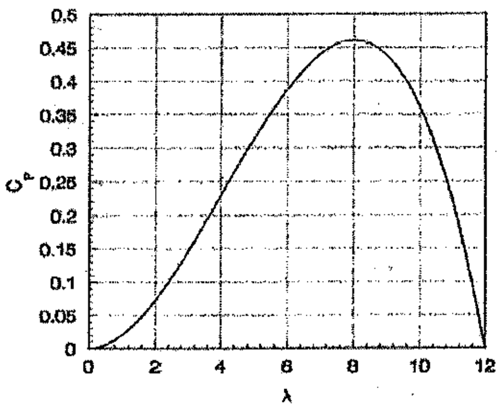

Figure Q2

Table Q2

Wind Speed (m/s)	Time (Hours)	λ Value	C_P Value	Power (kW)	Energy (MWh)
1	521				
3	1407				
5	1831				
7	1769				
9	1386				
11	913				
13	524				
15	249				
17	105				
19	39				
21	12				
23	3				
25	1				
Total					

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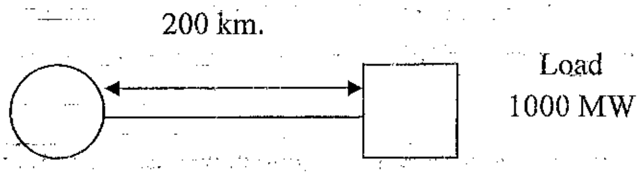
3.



a. What would be the least expensive voltage (380 or 500 kV) to transmit 750MW of power over 200 km along a radial right-of-way to a load centre (Assume zero losses of the line)? (see the line loadability curve provided) **[6 marks]**

b. Recalculate the cost of two alternatives, if single contingency planning criteria is considered. Would you make a solid decision based on your answer? If not, explain why? **[6 marks]**

c. If the loss factor is 0.7 and the maximum losses of 380kV and 500kV lines are 11 MW/line and 5 MW/line respectively, evaluate the cost owing to losses of each alternative? Hence compute the total cost of each project? Which alternate gives you the least cost? **[8 marks]**

Assume the following Data: Note that € represents the monetary currency

Table Q3.1

Voltage Level (kV)	Line cost/km Million €	Substation cost/line terminal Million €
132	0.20	0.85
220	0.30	1.65
380	0.45	3.0
500	0.68	4.0
765	1.30	8.4

Capitalized replacement energy cost = 200 €/MWh
Capitalized replacement capacity cost = 300 €/kW

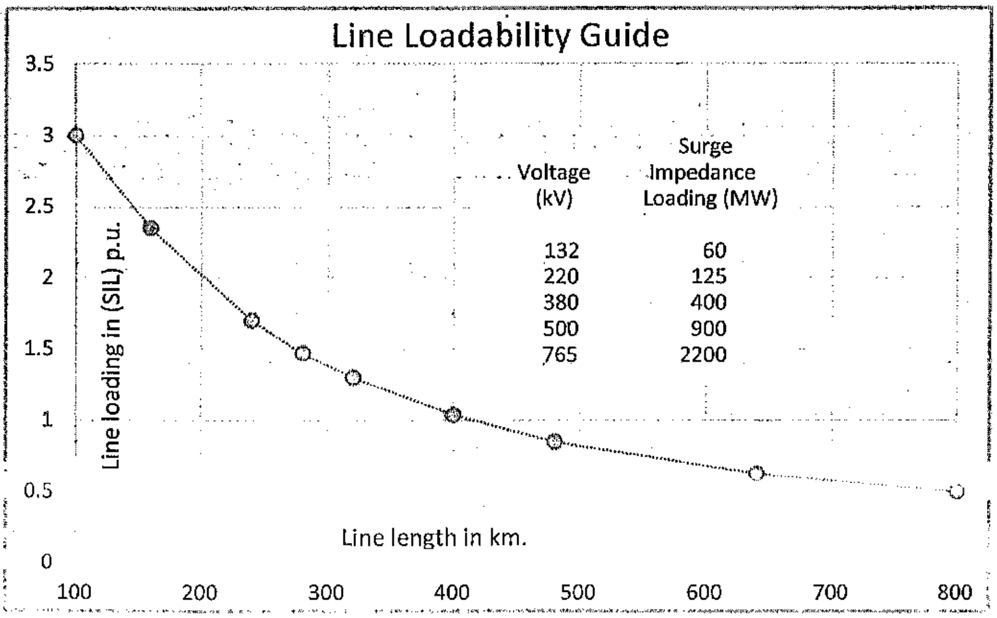


Figure Q3.1

4. A power system is served by three generators where the installed capacities and forced outage rates are given in Table Q4.1.

Table Q4.1

Merit order loading	Plant ID.	Installed Capacity (MW)	F.O.R	Average Cost (€/MWh)
1	A	100	0.1	1000
2	B	100	0.15	1500
3	C	100	0.2	2000

If the generating system above is serving a load described by the chronological load curve shown in Figure Q4.1, do the followings:

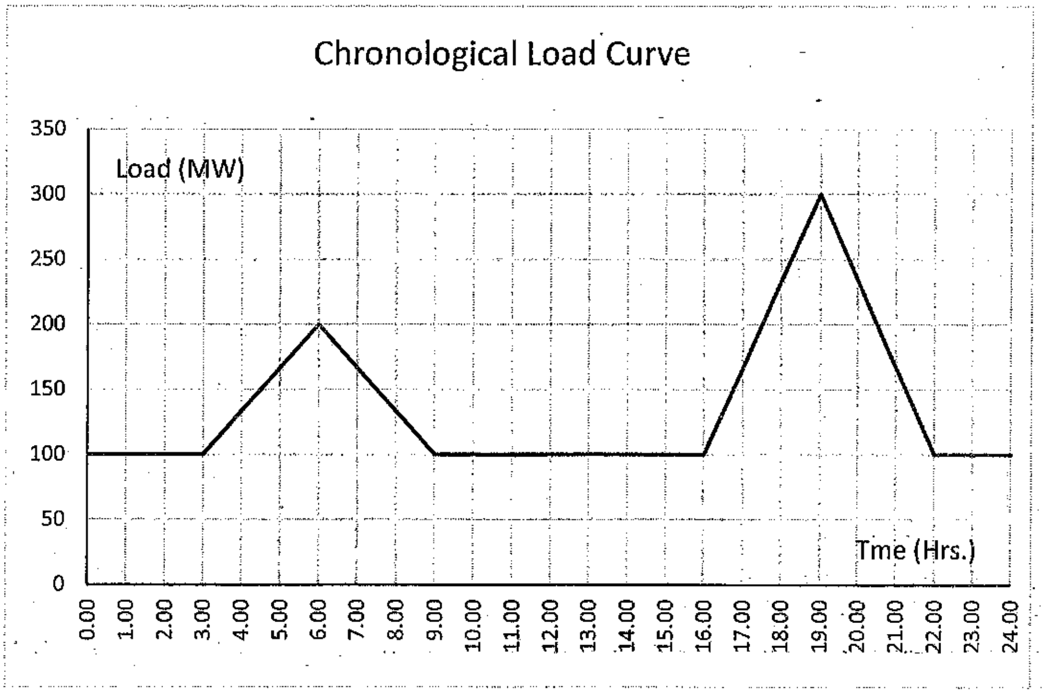


Figure Q4.1

a. Sketch: Load duration curve of the system **[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 and plant factor for each generator **[6 Marks]**

d. Expected production costs of each generator **[6 Marks]**

e. Loss of Load Probability index (LOLP) **[3 Marks]**

f. Energy Not Served (ENS) **[3 Marks]**

5.

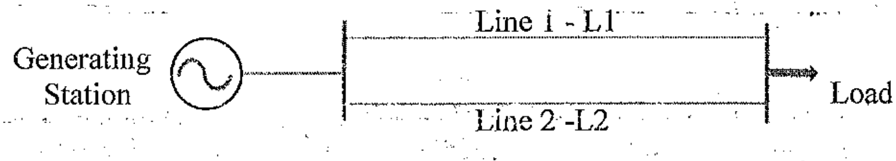


Figure Q5a – Generating/Transmission system

a. Consider the system shown in Figure Q5a consists of a generating station feeding a load through two parallel transmission lines L1 & L2. Given that:

P_G = Probability of generation not satisfying load i.e. {generation deficiency (LOLP)}

P_C (1) = Probability of load exceeding line 1 capacity

P_C (2) = Probability of load exceeding line 2 capacity

P_C (1,2) = Probability of load exceeding combined capacity of line 1 and 2

$R_1(R_2)$ = Probability of line 1 or line 2 being available, i.e. its reliability

$Q_1(Q_2)$ = Probability of line 1 or line 2 being unavailable, i.e. its unavailability or probability of outage. (note that $R_1+Q_1=R_2+Q_2=1$)

Q_S = Probability of total system failure

Prove that the Probability of total system failure for complete system is given by:

$$Q_S = R_1\{R_2[P_G + P_C(1,2) - P_GP_C(1,2)] + Q_2[P_G + P_C(1) - P_GP_C(1)]\} + Q_1\{R_2[P_G + P_C(2) - P_GP_C(2)] + Q_2\}$$

[15 marks]

b. A generating station is serving load characteristics given by the load duration curve of Figure Q5b. It has a maximum value of 290 MW and a minimum value of 100 MW. The LOLP of serving this load by this generating station itself is found to be 0.0391. The load is supplied by two identical lines having an expected failure rate of 1 failure/year and an average repair time of 10 hour. Compute the composite system reliability index Q_S for the system. Assume that the rating of each line is 250 MW. **[5 marks]**

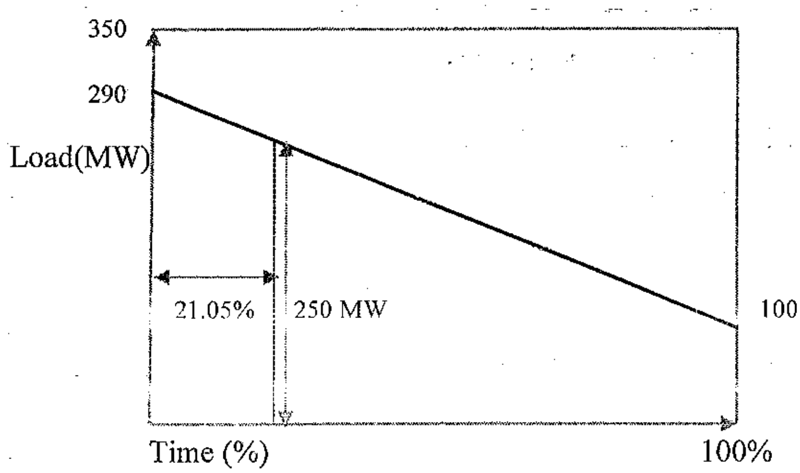


Figure Q5b – Load duration curve

6. A trend analysis performed on electricity sales (S) and generation (G) of a developing country gave the following statistical results from a least-square method.

$$\ln(S) = -114.36 + 0.0623 \times T$$

S is in GWh and T is the time in year (such as 2005, 2006.... etc.)

$$\ln(G) = -124.11 + 0.0675 \times T$$

G is the generation in GWh and T is the time in year (such as 2015, 2016.... etc.)

a. If the annual growth rate of sales in year t is defined as,

$$growth_t = \frac{S_t - S_{t-1}}{S_{t-1}} \times 100\%$$

Calculate the annual growth rates for sales and similarly for the generation indicated by the results of this analysis. Also, comment on the losses in the network. **[10 marks]**

b. The demand growth for electricity is expected to slow-down from 2018 onwards, and is expected to exhibit signs of saturation. If the sales are expected to reach 120,000 GWh per year by the year 2042, develop a model of the form,

$$S^2 = k_1(t + k_2)$$

to forecast the sales in the period 2018-2042, k_1 and k_2 are constants to be derived. t is the year (such as 2018, 2001, etc.). S is the sales in GWh. Results of historic trend analysis may be used to calculate the sales in the year 2017. Using the forecast model, estimate the sales in the year 2027. **[10 marks]**

7. **a.** What does Interest During Construction (IDC) means in project evaluation? **[2 Marks]**

b. Pure capital cost of an 80 MW hydroelectric plant is expected to be 300000 LKR/kW. Construction period is about 4 years and the capital disbursement is expected to be the following:

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

1. Compute IDC and hence the actual project capital cost? (assume 10% discount rate) **[3 marks]**
2. If the operation and maintenance cost is estimated to be 28 million LKR/year, the plant(capacity) factor is to be 45% under average hydrological conditions and the estimated economic life is 50 years, calculate the specific cost per kWh of the power plant. **[15 marks]**

A bank loan of LKR 15000 million is approved for the construction of above project subject to the payment of bank loan + interest = Annual payment of LKR 4000 million for 10 years starting from the end of 5th year after completion of the project [i.e. Five (5) year grace period for both capital and interest]

Assume: 10% discount rate and $S = \left[\frac{(1+r)^n - 1}{r(1+r)^n}\right]$. *Where S is the Present Value Factor and r is discount rate for an interval n. n is the total number of intervals.*

25

8. Following are the 16 multiple type questions. Each question carries **1.25** marks. Underline the correct answer and attach the two pages to your answer script.

   a. A generating station which has a high investment cost and low operating cost usually operated as a:
   1. Peak load station **2.** Base load station **3.** Medium load station **4.** None of the above

   b. Out of the following plant categories:
   (i) Nuclear (ii) Run-of-River (iii) Pumped Storage
   Power plants operated on base load on a power system are:

   1. (i) and (ii) **2.** (ii) and (iii) **3.** (i) only **4.** (i), (iii)

   c. An interconnected power system has the following power plants
   (i) Nuclear (ii) Steam (iii) Gas Turbine (iv) Hydro with storage
   (v) Run-of-River (vi) Pumped Storage
   Which of the power plants are suitable to be used only for supplying peak loads?

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

   d. Unit of regulation of speed governor is:
   1. Hz/MW **2.** MW/Hz **3.** Unitless **4.** Hz/MW-Sec

   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-1	100	20	0.02
Generator-2	100	30	0.04
Generator-3	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-3 will share more power compared to generator-1
   3. Generator-1 will share more power compared to generator-2
   4. Generator-2 will share more power compared to generator-3

   f. A power system needs injection of reactive power at:

   1. Off-peak load **2.** Peak load **3.** Both peak and off-peak load **4.** Full load

   g. In a 400 kV power network, 360 kV is recorded at a 400 kV bus. The reactive power injected by a shunt capacitor rated for 50 MVAR, 400 kV connected at the bus is:

   1. 61.73 MVAR **2.** 55.56 MVAR **3.** 45.0 MVAR **4.** 40.5 MVAR

h. For a thermal power plant, the input characteristic is given by $S = 8 + P + 0.08P^2$ where S and P are heat input and power output, respectively in MW. The maximum thermal efficiency would be

1. 26.5% 2. 30.5% 3. 34.5% 4. 38.5%

i. The long-term load forecast is required for

1. Operation of plant 2. Economic operation of plant
3 Planning an addition of generating capacity 4. Both 2 & 3.

j. The permissible variation of frequency in Sri Lanka power system is

1. ±1% 2. ±3% 3. ±5% 4. ±10%

k. What is the correct expression for Area Control Error (ACE) for an interconnected two area power system, if ΔP_t is the incremental tie line power deviation, Δf is frequency deviation and b is frequency dependent coefficient?

1. $ACE = b\Delta P_t + \Delta f$ 2. $ACE = \Delta P_t + b\Delta f$ 3. $ACE = \frac{1}{b}\Delta P_t + \Delta f$ 4. $ACE = \Delta P_t + \frac{1}{b}\Delta f$

l. During load shedding:

1. System voltage is reduced 2. System frequency gains
3. System loads are switched off 4. Both 2 and 3

m. The most economical limit of power factor (pf) correcting is governed by:

1. Original pf 2. Relative cost of the power supply and pf correction equipment
3. Both (1) and (2) 4. None of the above

n. A 3-ϕ, 11 kV, 50 Hz, 200 kW load has a pf of 0.8 lag. A Δ-connected 3-ϕ capacitor is used to improve the pf to unity. The capacitance per phase of the capacitor in microfarads is:

1. 3.948 2. 1.315 3. 0.439 4. 11.844

o. A power plant having three 25 MW identical generating units having 0.1, F.O.R can meet 50 MW constant load with approximate LOLE of:

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

p. A reserve generating capacity of a power plant which is in operable condition and available for service, but not in operation is called as:

1. Cold reserve 2. Hot reserve 3. Spinning reserve 4. Firm reserve