051

**The Open University of Sri Lanka**
**Bachelor of Technology**
**ECX 6332-Power Systems Planning**
**Final Examination 2008/2009**

**Duration Three Hours**

Date: 20th March 2009 Time: 1400-1700 hrs.

This paper contains Eight (8) questions. Answer any Five. All questions carry equal marks. Graph papers will be available on your request.

1. Prove that the power generated by a hydro power plant is given by

$$P=\rho Qg(H-H_L)\eta_T\eta_G \quad \text{Watt}$$

$\rho$ = Density of water (1000 kg/m$^3$); Q = rate of flow of water (m$^3$/s); g = gravity (9.81 m/s$^2$)
$(H-H_L)$ =h (the level difference between the reservoir and the power plant in meters)
$\eta_T\eta_G$ = efficiency of the turbine and the generator respectively.

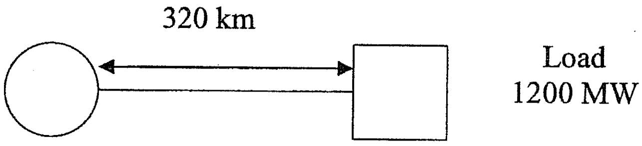
A hydro electric power station has to operate with a mean head of 120 meters and is supplied from a reservoir with a catchment area of 300 square km over which the average rainfall is 120 cm per annum. If 70% of the rainfall is utilized, calculate the power in MW for which the station should be designed. Assume that no head is lost in pipes, penstocks, etc. the mechanical efficiency of the turbine is 90% and efficiency of the generator is 94%.
Also prove that the electricity generated E=0.2766V GWh [where V is monthly release in MCM]
Consider the above power plant with its associated reservoir parameters as given below:

Reservoir Maximum Storage = 120 MCM (MCM=million cubic meters)
Reservoir Minimum Storage = 20 MCM
Monthly irrigation release = 25 MCM
The amount of energy to be delivered every month (target) is 10 GWh
Initial storage of the reservoir is 100 MCM
Maximum turbine discharge = 60 MCM/month One month = 730 h

The monthly inflow pattern for six months is given in the 1st row of the following matrix. Fill up the full matrix for the period February to June.

| Month | Jan. | Feb. | Mar. | Apr. | May | June |
|---|---|---|---|---|---|---|
| Inflow (MCM) | 40 | 60 | 80 | 0 | 0 | 0 |
| Initial reservoir Storage (MCM) | | | | | | |
| Intermediate reservoir storage (MCM) | 120 | | | | | |
| Initial reservoir release (MCM) | 20 | | | | | |
| Extra release required for irrigation (MCM) | | | | | | |
| Generation from initial release (GWh) | | | | | | |
| Generation from irrigation release (GWh) | | | | | | |
| Total generation (GWh) | | | | | | |
| Balance required to meet the target (GWh) | | | | | | |
| Release from the reservoir required (MCM) | | | | | | |
| Total output (GWh) | | | | | | |
| Final storage (MCM) | | | | | | |
| Spill Volume (MCM) | | | | | | |
| Energy deficit (GWh) | | | | | | |

2. What is meant by contingency evaluation in connection with power system security?



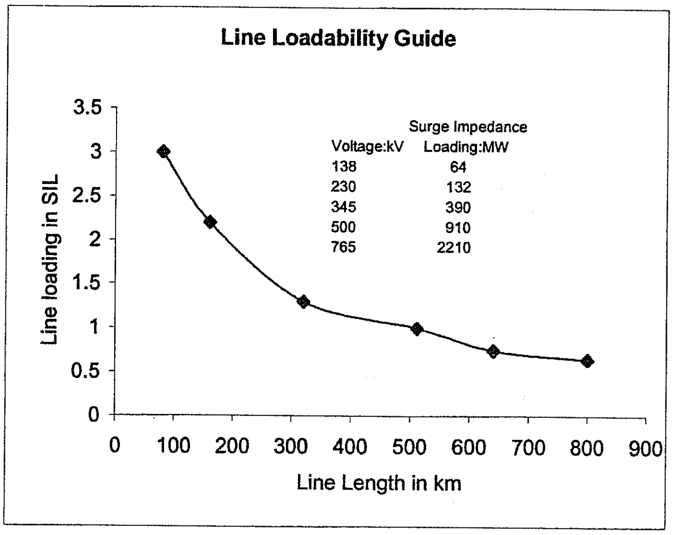

(a) What would be the least expensive voltage option (either 345 or 500 kV) you would select to transmit 1200 MW load located at the end of a 320 km transmission line right-of-way? Assume zero losses of the line

(b) If a single line outage is considered as the planning criteria, what would be the cost of two alternatives in part (a) above? Can you make a decision at this stage based on your answer? If not, explain why?

(c) If the loss factor of the load is 0.8 and the maximum losses in the 500 kV and 345 kV lines are 5 MW/line and 11.1 MW/line respectively, evaluate the cost due to losses in each alternative? Hence compute the total cost of each project? Which alternate gives you the least cost?
(Maximum MW loss x Loss factor x 8760 = Annual average loss)
Assume the following Data:

| Voltage Level (kV) | Line cost Million US$/km | Substation /line termination cost Million US$ |
|---|---|---|
| 138 | 0.13 | 0.84 |
| 161 | 0.15 | 0.96 |
| 230 | 0.18 | 1.68 |
| 345 | 0.30 | 2.88 |
| 500 | 0.45 | 4.80 |
| 765 | 0.83 | 8.40 |

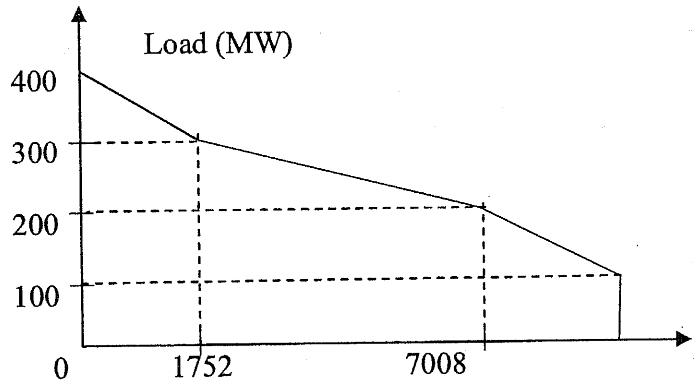
Capitalized replacement energy cost = 200 US$/MWh
Capitalized replacement capacity cost = 300 US$/kW



3. A system has four generators where the installed capacities and forced outage rates are tabulated below:

| Merit order loading | Plant ID. | Installed Capacity (MW) | Forced outage rate (%) |
|---|---|---|---|
| 1 | A | 100 | 0.1 |
| 2 | B | 100 | 0.1 |
| 3 | C | 100 | 0.1 |
| 4 | D | 100 | 0.1 |
| 5 | E | 100 | 0.1 |

If the generating system described above is serving a load described by the following load duration curve (LDC):




Calculate the following:

(a) Loss of load probability (LOLP)
(b) Loss of load expectation (LOLE)
(c) Expected energy-not-served (ENS) per annum

4. Evaluate the failure rate ($\lambda$), average outage time (r), annual outage time (U) and unserved energy of load point "P" of the ring bus-bar configuration shown below:

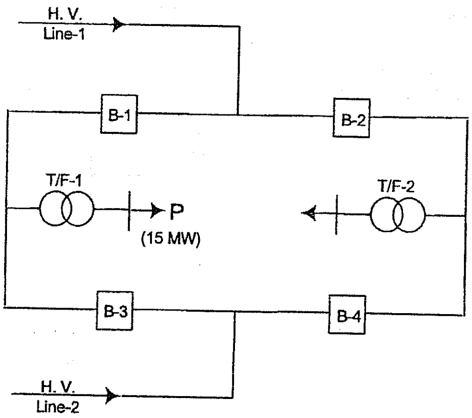
[Assume the reliability data of the components as given in the table. Also consider overlapping forced outages up to second-order and first-order active failures only.]

If stuck breaker conditions are also included in the analysis, what are the additional events you will find and re-compute the results with stuck breaker probability?

**Reliability data**

| Component | $\lambda$ (f/yr) | r (hours) | $\lambda_a$ (f/yr) | s (hours) | $P_c$ |
|---|---|---|---|---|---|
| HV Lines | 0.1 | 10 | 0.10 | 0.50 | - |
| Breakers | 0.05 | 20 | 0.02 | 0.50 | 0.1 |
| Transformers | 0.01 | 50 | 0.01 | 0.55 | - |

$\lambda_a$= Active failure rate $P_c$= Stuck breaker probability s = Switching time



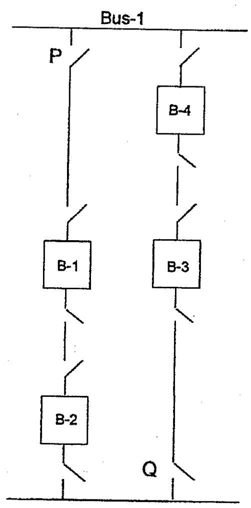

Ring-bus configuration for question #4

5. A new oil-fired steam power plant costs US$ 1500 per kW to construct. Since funds have to be disbursed over the construction period until the power plant is ready for operation, interest during construction calculated at a rate of 10% per year is a total of 18.5% of the total construction cost. The annual maintenance cost is estimated to be US$ 15 per kW per year.

   The gross efficiency of the plant is expected to be 40%. The cost of fuel oil to be used is US$ 50 per barrel, while the heat content of the fuel is 6 GJ/Barrel. During operation, it costs 0.25 US cts/kWh for additional maintenance work.

   The plant has an economic life of 35 years. Using a discount rate of 10%, develop an expression for specific life-cycle cost as a function of the annual capacity factor.

6.




Substation configuration for Question #6

a) Identify the substation configuration and components given in the above figure.
b) How many line positions (entry/exit) can be established with the above configuration?
c) List the equipments that are needed to convert the above to one-and-half breaker configuration?

d) Discuss the advantages and disadvantages of both configurations.

e) By installing P & Q initially, what advantage will you have later when converting it to one-and-half breaker configuration?

f) How do you connect two incoming transmission lines and two transformers *reliably* into this converted substation? Re-draw the substation configuration (single line diagram) showing the lay-out.

g) If you are requested to connect two more line-exit positions (in addition to the above 2 line-entry positions) to the above configuration, how do you re-arrange the components of the substation in most reliable manner? Draw the one line diagram.

7. Describe the speed-droop characteristics of a governor installed in a power plant?

Two generators rated 500 MW and 600 MW are operating in parallel. The speed-droop characteristics of their governors are 4% and 5% respectively from no load to full load. Assuming that the generators are operating at 60 Hz at no load, how would a load of 1100 MW be shared between them? What would be the system frequency at this load? Assume that the governor operation is linear.

8. (a) If the demand for electricity in a town in year t is defined as

$$D_t = kI_t^{\alpha} \times P_t^{\beta}$$

Where $D_t$= per capita demand for electricity in kWh
$I_t$= per capita income of the customer group, in constant currency
$P_t$= Price of electricity per kWh, in constant currency
k = constant

Show that α and β signify income and price elasticity of demand, respectively.

(b) The demand elasticity model in (a) above gave the following results from a regression analysis, using data for the past 15 years

| | |
|---|---|
| α = 1.38 | t-statistics =5.59 |
| β = -0.39 | t-statistics = -1.82 |
| k = -10.31 | t-statistics = -3.69 |

Coefficient of determination ($R^2$) =0.818

Comment on the results, highlighting the statistical significance of the driving variables and the goodness of fit.

The electric utility expects to reduce the present prices of electricity by 15% at the beginning of next year, while the economic (i.e. income) growth next year is expected to be 6% with respect to this year. Estimate the expected change in demand for electricity next year, as a percentage of the demand this year.

## Present Worth Factors

| No. of years | Discount rate(%) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 |
| 1 | 0.98 | 0.96 | 0.94 | 0.93 | 0.91 | 0.89 | 0.88 | 0.86 | 0.85 | 0.83 |
| 2 | 1.94 | 1.89 | 1.83 | 1.78 | 1.74 | 1.69 | 1.65 | 1.61 | 1.57 | 1.53 |
| 3 | 2.88 | 2.78 | 2.67 | 2.58 | 2.49 | 2.40 | 2.32 | 2.25 | 2.17 | 2.11 |
| 4 | 3.81 | 3.63 | 3.47 | 3.31 | 3.17 | 3.04 | 2.91 | 2.80 | 2.69 | 2.59 |
| 5 | 4.71 | 4.45 | 4.21 | 3.99 | 3.79 | 3.60 | 3.43 | 3.27 | 3.13 | 2.99 |
| 6 | 5.60 | 5.24 | 4.92 | 4.62 | 4.36 | 4.11 | 3.89 | 3.68 | 3.50 | 3.33 |
| 7 | 6.47 | 6.00 | 5.58 | 5.21 | 4.87 | 4.56 | 4.29 | 4.04 | 3.81 | 3.60 |
| 8 | 7.33 | 6.73 | 6.21 | 5.75 | 5.33 | 4.97 | 4.64 | 4.34 | 4.08 | 3.84 |
| 9 | 8.16 | 7.44 | 6.80 | 6.25 | 5.76 | 5.33 | 4.95 | 4.61 | 4.30 | 4.03 |
| 10 | 8.98 | 8.11 | 7.36 | 6.71 | 6.14 | 5.65 | 5.22 | 4.83 | 4.49 | 4.19 |
| 11 | 9.79 | 8.76 | 7.89 | 7.14 | 6.50 | 5.94 | 5.45 | 5.03 | 4.66 | 4.33 |
| 12 | 10.58 | 9.39 | 8.38 | 7.54 | 6.81 | 6.19 | 5.66 | 5.20 | 4.79 | 4.44 |
| 13 | 11.35 | 9.99 | 8.85 | 7.90 | 7.10 | 6.42 | 5.84 | 5.34 | 4.91 | 4.53 |
| 14 | 12.11 | 10.56 | 9.29 | 8.24 | 7.37 | 6.63 | 6.00 | 5.47 | 5.01 | 4.61 |
| 15 | 12.85 | 11.12 | 9.71 | 8.56 | 7.61 | 6.81 | 6.14 | 5.58 | 5.09 | 4.68 |
| 16 | 13.58 | 11.65 | 10.11 | 8.85 | 7.82 | 6.97 | 6.27 | 5.67 | 5.16 | 4.73 |
| 17 | 14.29 | 12.17 | 10.48 | 9.12 | 8.02 | 7.12 | 6.37 | 5.75 | 5.22 | 4.77 |
| 18 | 14.99 | 12.66 | 10.83 | 9.37 | 8.20 | 7.25 | 6.47 | 5.82 | 5.27 | 4.81 |
| 19 | 15.68 | 13.13 | 11.16 | 9.60 | 8.36 | 7.37 | 6.55 | 5.88 | 5.32 | 4.84 |
| 20 | 16.35 | 13.59 | 11.47 | 9.82 | 8.51 | 7.47 | 6.62 | 5.93 | 5.35 | 4.87 |
| 21 | 17.01 | 14.03 | 11.76 | 10.02 | 8.65 | 7.56 | 6.69 | 5.97 | 5.38 | 4.89 |
| 22 | 17.66 | 14.45 | 12.04 | 10.20 | 8.77 | 7.64 | 6.74 | 6.01 | 5.41 | 4.91 |
| 23 | 18.29 | 14.86 | 12.30 | 10.37 | 8.88 | 7.72 | 6.79 | 6.04 | 5.43 | 4.92 |
| 24 | 18.91 | 15.25 | 12.55 | 10.53 | 8.98 | 7.78 | 6.84 | 6.07 | 5.45 | 4.94 |
| 25 | 19.52 | 15.62 | 12.78 | 10.67 | 9.08 | 7.84 | 6.87 | 6.10 | 5.47 | 4.95 |
| 26 | 20.12 | 15.98 | 13.00 | 10.81 | 9.16 | 7.90 | 6.91 | 6.12 | 5.48 | 4.96 |
| 27 | 20.71 | 16.33 | 13.21 | 10.94 | 9.24 | 7.94 | 6.94 | 6.14 | 5.49 | 4.96 |
| 28 | 21.28 | 16.66 | 13.41 | 11.05 | 9.31 | 7.98 | 6.96 | 6.15 | 5.50 | 4.97 |
| 29 | 21.84 | 16.98 | 13.59 | 11.16 | 9.37 | 8.02 | 6.98 | 6.17 | 5.51 | 4.97 |
| 30 | 22.40 | 17.29 | 13.76 | 11.26 | 9.43 | 8.06 | 7.00 | 6.18 | 5.52 | 4.98 |
| 31 | 22.94 | 17.59 | 13.93 | 11.35 | 9.48 | 8.08 | 7.02 | 6.19 | 5.52 | 4.98 |
| 32 | 23.47 | 17.87 | 14.08 | 11.43 | 9.53 | 8.11 | 7.03 | 6.20 | 5.53 | 4.99 |
| 33 | 23.99 | 18.15 | 14.23 | 11.51 | 9.57 | 8.14 | 7.05 | 6.20 | 5.53 | 4.99 |
| 34 | 24.50 | 18.41 | 14.37 | 11.59 | 9.61 | 8.16 | 7.06 | 6.21 | 5.54 | 4.99 |
| 35 | 25.00 | 18.66 | 14.50 | 11.65 | 9.64 | 8.18 | 7.07 | 6.22 | 5.54 | 4.99 |
| 36 | 25.49 | 18.91 | 14.62 | 11.72 | 9.68 | 8.19 | 7.08 | 6.22 | 5.54 | 4.99 |
| 37 | 25.97 | 19.14 | 14.74 | 11.78 | 9.71 | 8.21 | 7.09 | 6.22 | 5.54 | 4.99 |
| 38 | 26.44 | 19.37 | 14.85 | 11.83 | 9.73 | 8.22 | 7.09 | 6.23 | 5.55 | 5.00 |
| 39 | 26.90 | 19.58 | 14.95 | 11.88 | 9.76 | 8.23 | 7.10 | 6.23 | 5.55 | 5.00 |
| 40 | 27.36 | 19.79 | 15.05 | 11.92 | 9.78 | 8.24 | 7.11 | 6.23 | 5.55 | 5.00 |