IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2003

EEE PART IV: M.Eng. and ACGI

ENVIRONMENTAL & ECONOMIC ISSUES IN POWER SYSTEMS

Thursday, 1 May 10:00 am

Time allowed: 3:00 hours

There are SIX questions on this paper.

Answer FOUR questions.

Corrected Copy

Any special instructions for invigilators and information for candidates are on page 1.

Examiners responsible First Marker(s) : B.C. Pal, D. Popovic
Second Marker(s) : D. Popovic, B.C. Pal

1. (a) Write a one-page essay on 'The World Energy of Today' including insights into supply and consumption of primary energy and electricity. [8]

   (b) Outline the principle of operation of a gas turbine. What are the ways to increase a gas-turbine power plant efficiency? [6]

   (c) Comparing with a hydro power plant, the efficiency of thermal generating stations is much lower. Explain why. [6]

2. (a) Describe the principle of operation, main characteristics and use, advantages and research needs of fuel cells. [8]

(b) Why are nuclear power stations not suited to supply peak load? [4]

(c) The electric utility system has the load duration curve shown in Figure 2.1.

(i) Calculate the annual energy consumption. [4]

(ii) If this energy were consumed at an absolutely uniform rate, what would the peak load be? [4]

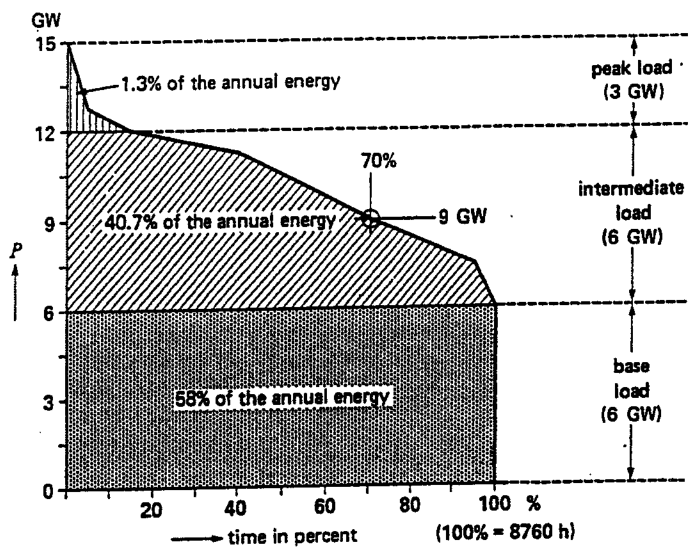

Figure 2.1

3. (a) Write a two-page essay on the Pool vs NETA in the England and Wales electricity market. Describe their main characteristics and differences in terms of market structure, operation and pricing. [8]

   (b) Consider an example two-zone system (zone A and zone B) connected via transmission line. Each zone has a constant load of 100MW. Zone A has a 200MW generator with an incremental cost of \$10/MWh. Zone B has a 200MW generator with an incremental cost of \$20/MWh. Assume both generators bid their incremental costs.

      (i) Calculate the optimal costs of supplying loads. [4]

      (ii) What would be a percentage market inefficiency if there is a 50MW transfer limit? (*Hint:* Compare costs in this case with optimal costs calculated in (i).) [4]

      (iii) In (ii), a generator in zone B has unlimited market power. Why? How could a created market power be limited? [4]

4. Every item in column I in the following table has only one matching item in column II. Associate with each item in column I the relevant item from column II. e.g. if item (1) in column I relates to item (C) in column II, then write **[1]**⟶ **[C]**.

I	II
[1] In the context of OPF, the transformer tap position	**[A]** does not handle the inequality constraint well
[2] FACTS controllers	**[B]** is special condition in AC power system operation
[3] Operation of Static Var Compensator (SVC)	**[C]** does handle the inequality constraints well
[4] Surge Impedance Loading (SIL)	**[D]** is a state variable
[5] Security constraint OPF	**[E]** have greater roles to play in system security
[6] In the context of OPF load bus voltage magnitude	**[F]** controls system voltage rapidly
[7] Unified power flow controller (UPFC)	**[G]** is a series FACTS device
[8] Newton's method in OPF formulation	**[H]** deals with system contingency
[9] Controllable phase shifter (CPS)	**[I]** is a control variable
[10] Interior point methods in OPF formulation	**[J]** can simultaneously control real and reactive power flows through lines
	[K] is a special condition in HVDC power network
	[L] is treated as fixed parameter

[20]

5. (a) What are the structural and functional differences between a static var compensator (SVC) and a static synchronous compensator (STATCOM) ? [5]

   (b) Figure 5.1 shows a simple model of an interconnected power system. Voltages at the two ends are $V_s \angle \delta$ pu and $V_r \angle 0$ p.u. The impedance of the line is purely reactive in nature and is expressed as X_L p.u. Find an expression of real power flow across the system. [5]

   (c) The line of this interconnected system described in part (a) is now equipped with a series capacitor of variable capacitive reactance $X_c = kX_L$ where k is controllable. Find the expression for real power flow across the line and sketch the variation of power with $\angle\delta$ for $k = 0.0, 0.25, 0.5$ and 0.75. With the help of the sketch justify the influence of the series capacitor in transmission power flow control. [10]

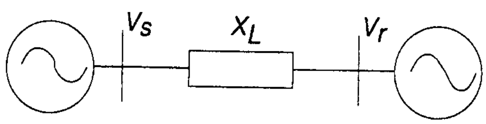

Figure 5.1

6. Figure 6.1 describes a 3-bus power system model. The load at bus 3 is $(3 + j1.5)$ p.u. The generation at bus 2 is fixed at 2.0 p.u. All the bus voltage angles are expressed with respect to that of bus 1. The line parameters are shown in the diagram. The objective is the minimisation of generation at bus 1 which, in the context of this problem, is also equivalent to minimising total power loss in the system. For this objective

   (a) Identify state variables (**x**), control variables (**u**) and fixed parameter (**p**) vectors. [5]

   (b) Formulate the objective function f(**x,u,p**), constraint vector function **g(x,u,p)** with the variables and parameters identified in part (a) and network parameters. The following general formulae can be used for calculating flows out of any bus k in an N bus power system:

$$P_k = \sum_{m=1}^{N} V_k V_m [G_{km} cos(\theta_k - \theta_m) + B_{km} sin(\theta_k - \theta_m)]$$

$$Q_k = \sum_{m=1}^{N} V_k V_m [G_{km} sin(\theta_k - \theta_m) - B_{km} cos(\theta_k - \theta_m)]$$

   where $Y_{km} = G_{km} + jB_{km}$. [8]

   (c) Find the expressions $\frac{\partial f}{\partial \mathbf{x}}$ and $\frac{\partial f}{\partial \mathbf{u}}$ and evaluate them around an operating point where all bus voltages are $1.0\angle 0$ p.u. [7]

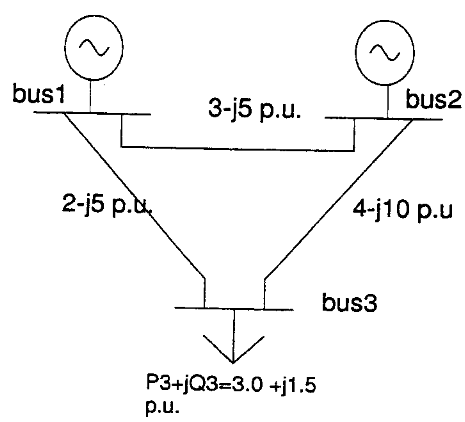

Figure 6.1