EE4010

Electrical Power Systems

Problems on Energy Systems I

1. Plot a graph of the energy consumption doubling time in years as a function of the growth rate of electricity in per cent per year.

2. The consumption of electricity in a certain country has a growth rate of 4% per annum. In how many years will the energy consumption be tripled. [27.47 years]

3. The growth rate in the consumption of electricity in a country drops from 7% per annum to 3% per annum. How many years will it now take for the energy consumption to double. [23 years]

4. A lake of area $500\ \text{km}^2$ is fed from a drainage area of $6000\ \text{km}^2$, including the lake. The level of the water in the lake is 500 m at the beginning of September and 500.5 m at the end of the month. Over this period, the total rainfall is 10 cm with a 40% loss due to evaporation. The only outlet from the lake is a river which supplies a hydro-electric generating station, the head above the turbines being 50 m. The power loss due to friction is 3% of the total available power. If the overall efficiency of the turbine generators is 80%, calculate the average output power. [16.2 MW]

5. (a) A 1 GWe plant operates at an efficiency of 33.33% and uses river water to cool the condensate directly. If the river water temperature gain is not to exceed $10°\text{C}$ as it passes through the condenser, calculate the required river water flow rate in m^3/s. (b) If this station were to use an evaporative cooling tower, calculate the volume of water used in the evaporative cooling, assuming that all of the heat is absorbed in the evaporation of the water. [(a) $48.0\ \text{m}^3/\text{s}$, (b) $0.89\ \text{m}^3/\text{s}$]
   [Water Data: Specific heat of water = 4200 J/kg KHeat of vaporisation = 2.26 MJ/kg]

6. Investigate the operation of a typical electric shower unit, such as, for example, the Mira Zest product. Derive an expression for the shower temperature versus flow rate for the specified power of the unit and compare with the stated performance.
   Research the specifications of the Inniscarra Dam on the River Lee. Hence, estimate the flow rate of water which is required to flow through the turbines of the dam in order to generate the electricity necessary to operate the shower.

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Problems on Energy Systems II

1. Compare the condenser power requirements for two different electrical power generation stations each with a 1000 MWe output power. The first is a coal-fired station has an overall thermal efficiency of 40% and releases 15% of the heat produced in the boiler up the stack. The second station is a nuclear plant with an efficiency of 33.33%. [1125 MWth, 2000 MWth]

2. The thermal efficiency of electrical power stations is often expressed in terms of *heat rate*, which is defined as the thermal input energy required to deliver 1 kWh of electrical output energy. Show that the heat rate is given by

$$Heat\ rate = \frac{3.6}{\eta}\ \text{MJ/KWh}$$

for a power station with an overall efficiency of η.

Consider a power plant with a heat rate of 10.8 MJ/kWh which burns bituminous coal with a 75% carbon content and a calorific value of 27.3 MJ/kg. Approximately 15% of the thermal losses are lost via the stack and 85% of the remaining losses are dissipated to the cooling water which is provided by a river. Environmental regulations require that the maximum temperature rise of the river water is to be limited to $10°\text{C}$.

(a) Estimate the efficiency of the power plant.
(b) Find the mass of coal required per kWh of electrical power delivered.
(c) Estimate the mass of carbon dioxide (CO_2) emissions from the plant per kWh of output power.
(d) Find the minimum flow rate of cooling water per kWh.

[33.33%, 0.396 kg/kWh, 1.09 kg CO_2/kWh, 123.9 kg H_2O/kWh]

3. A combined-cycle, natural gas electrical power plant has an overall efficiency of 52%. Natural gas has an energy density of 55.34 MJ/kg and approximately 77% of the fuel is carbon.

   (a) Explain why the efficiency is considerably higher that the normal open-cycle power station efficiency.

   (b) Calculate the heat rate of the power plant in MJ/kWh.

   (c) Find the mass of CO_2 emitted per kWh of electrical power delivered.

[6.92 MJ/kWh, 0.353 kg CO_2/kWh]

4. A 12 V car battery has a capacity of 100 Ampere hours. Calculate the energy which the battery can store when it is fully charged. Compare this with the energy stored in a full petrol tank of a mid-range car. Also, estimate the time taken to fill the tank at a petrol station and calculate the average power flow to the vehicle during this time.

5. Assume that the average head between two reservoirs in a pumped storage electrical power generating station is 300 m. The reservoirs each have an area of 1 km^2. Calculate the change in the water level of the reservoirs in order to produce an average output power of 200 MW over a period of 6 hours. Assume that the overall efficiency of the system is 70%.

[2.10 m]

6. The rotor of a three-phase, two-pole synchronous generator is cylindrical in shape. It is spinning at 3000 rpm. The rotor has a diameter of 1 m and a length of 4 m. It is fabricated from high-quality steel with a density of 7800 kg/m^3. Calculate the kinetic energy stored in the rotor under these operating conditions. Explain how this stored energy can play a very important role in the operation of an electrical power system.

[151.2 MJ]

7. The maximum tidal head available for a proposed tidal electrical power generating station is 6 m. What is the required area of the tidal bay in order to produce an average output power of 1000 MW, assuming 100% efficiency.

[130 km^2]

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Electrical Power Systems

Problems on Energy Systems III

1. A large hydroelectric power station has a typical head of 324 m and an average flow rate of water through the penstock of $1370\ \mathrm{m^3/s}$. The reservoir behind the dam is composed of a series of lakes covering a total area of $6400\ \mathrm{km^2}$. The efficiency of the combined turbine and generator systems is approximately 94%. Estimate the available output power and the number of days that this power could be sustained if the level of water in the reservoir were allowed to drop by 1 m. Assume that there is no rainfall during this period and that the influx of water from the feeder streams is balanced exactly by evaporation.

   [4.09 GW, 54 days]

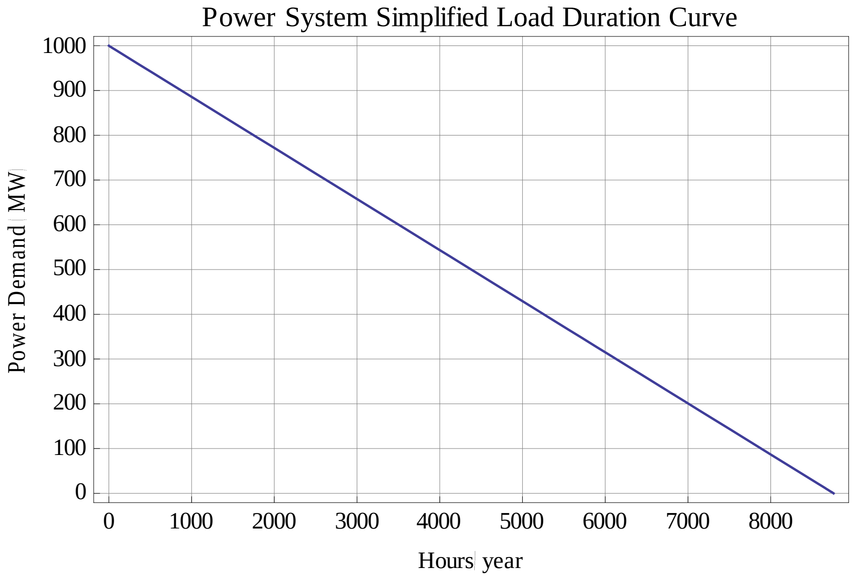
2. The Congo River in Africa discharges at a rate of roughly $1300\ \mathrm{km^3}$ per year. There is a dam on the river at Inga Falls, near Matadi, in the Democratic Republic of Congo. The water drops through a head of approximately 100 m at this point. However, this hydroelectric scheme produces only a relatively small amount of power (Inga 1: 350 MW, Inga 2: 1425 MW) in comparison to the maximum potential of the river. From the data given, estimate the average water flow in $\mathrm{m^3/s}$ and then show that the resource is capable of providing almost 40 GW of power based on an overall efficiency of 96.5%. A proposal, designated Grand Inga, to develop the scheme to its full potential would provide the electrical power requirements of Southern and Central Africa as well as exporting capacity to North Africa and even Southern Europe if the appropriate grid infrastructure is put in place.

   [$41233\ \mathrm{m^3/s}$ 39 GW]

3. A fuel rod of uranium oxide has a mass of 22.2 kg when first inserted into a nuclear reactor. If it releases an average of 372.5 kW of thermal energy during its 19 month stay within the core, calculate (i) the total amount of heat energy released and (ii) the theoretical reduction in the mass of the rod due to the energy generated.

   [18.6×10^{12} J 0.207 g]

4. Consider the following very simplified, linear load duration curve for a small power system.



(a) How many hours per year is the load less than 200 MW?

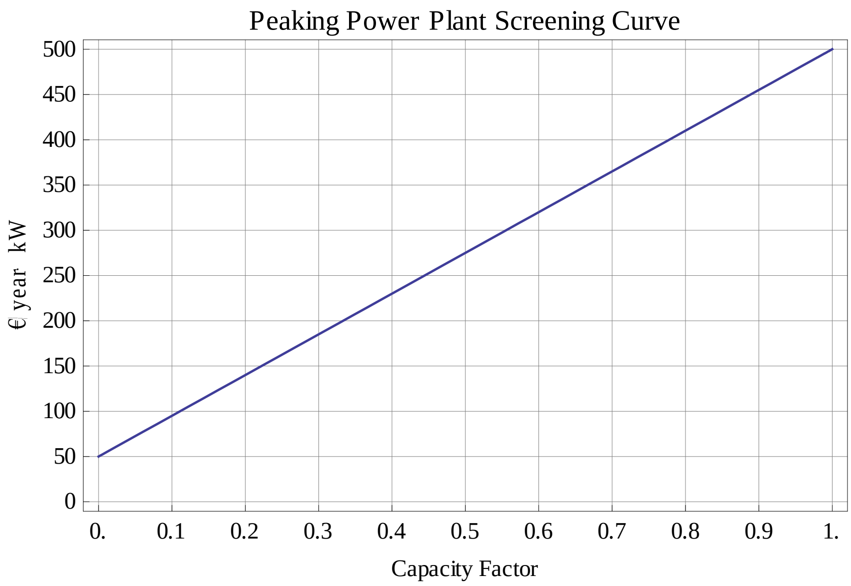
(b) How many hours per year is the load between 300 MW and 600 MW?

(c) If the utility has 500 MW of base-load coal-fired power generation plant, what would the average capacity of this generation asset be?

(d) How many kWh would these coal plants supply to the system?

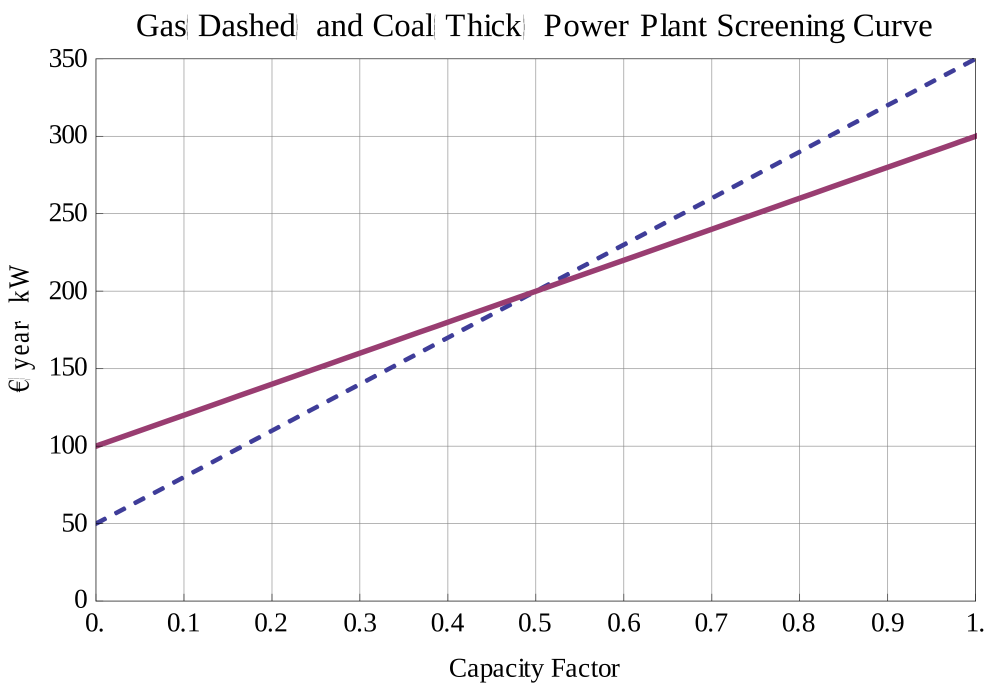
[1760 hrs, 2625 hrs, 0.75, 3.3×10^9 kWh/year]

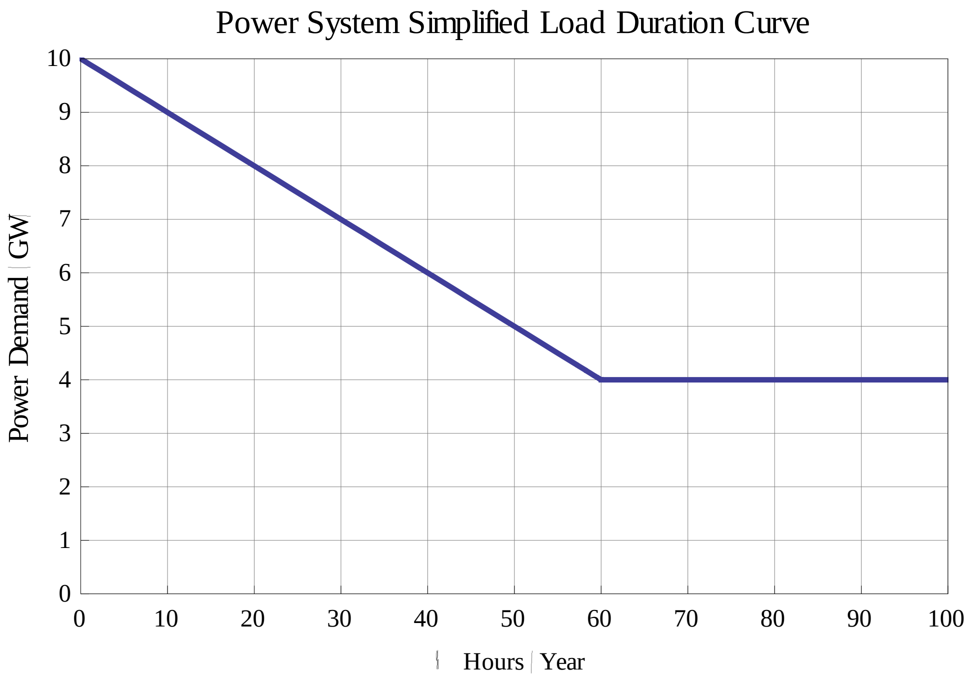
5. If the power system of the previous problem has 400 MW of peaking power plants with the required revenue curve shown below, what would be the cost of electricity of these plants when operated uniquely as peaking units.



[8 cent/kWh]

6. Consider the screening curves for the gas turbines and coal fired power plants illustrated below together with the associated load duration curve for a certain power system.





(a) For a least cost combination of the two type of power plant, how many MW of each kind of plant should the power system have?

[5000 MW Gas, 5000 MW Coal]

(b) What would be the cost of electricity for the gas turbines sized in Part (a) above?

[5.7 cent/kWh]

Self Learning Exercise

Household Electrical Energy Consumption

Use the following table of typical electrical appliance power and energy requirements to estimate an average daily electrical energy demand for your own household. An Excel spreadsheet template, *Household Energy Requirements - Rev1*, is available in the EE4010 folder on the EEE network. Fill in the appropriate time and usage of equipment and compare the results with the bi-monthly/annual bill for electrical energy.

Note that some appliances, such as dishwashers, washing machines etc. quote energy on a cycle basis, hence the column for usage/day. Other appliances such as showers and cookers are time dependent. Also, appliances, such as TV's, satellite receivers etc. can be placed in stand-by mode and the power consumption in this mode can be very important, as illustrated by the typical power figures quoted in the spreadsheet.

Use the results of Question 2 of Energy Problem Set 1 above to estimate the amount of coal required to produce the total daily electrical energy consumption. Estimate also the amount of carbon dioxide emissions released to the atmosphere at the power station in providing you with this power.

Household Appliance Power/Energy Data Base

	Time-Based Energy Usage			*Cycle-Based*						
Appliance	***Power (W)***	***Power (standby)***	***Time/day***	***Energy/day (Wh)***	***Usage/Day***	***Wh On/day***	***Wh Standby/day***	***Sum Wh/day***	***Coal/day***	***CO2/Day***
Fridge 290 litres.	215			770	0	0		0		
Fridge-freezer 170 litres.				1230	0	0		0		
Dishwasher (12 place setting)	2770			1600	0	0		0		
Washer/Dryer (standard)	2050			950	0	0		0		
Hob and oven**(check)	8000	0	0			0	0	0		
Cooker hood**(check)	220	0	0			0	0	0		
Hoover (standard)	1250	0	0			0	0	0		
Microwave oven (small)	650	0	0			0	0	0		
Microwave (large)	1100	0	0			0	0	0		
Toaster (small)	800	0	0			0	0	0		
Shower (standard)	8000	0	0			0	0	0		
Heater (small)	1000	0	0			0	0	0		
Heater (large)	2000	0	0			0	0	0		
Cloths iron (standard)	1200	0	0			0	0	0		
Cloths iron (steam)	1800	0	0			0	0	0		
Electric blanket (single)	100	0	0			0	0	0		
Electric blanket (double)	100	0	0			0	0	0		
Electric clock	4	0	0			0	0	0		
Electric kettle (1.7 litre)	2750	0	0			0	0	0		
Coffee maker	1200	0	0			0	0	0		
Food processor	400	0	0			0	0	0		
CFL Bulb (100 W equivalent)	18	0	0			0	0	0		
CFL Bulb (75 W equivalent)	14	0	0			0	0	0		
CFL Bulb (60 W equivalent)	11	0	0			0	0	0		
Incandescent bulb (100 W)	100	0	0			0	0	0		
Incandescent bulb (75 W)	75	0	0			0	0	0		
Incandescent bulb (60 W)	60	0	0			0	0	0		
TV (14")	75	5	0			0	120	120		
TV (25"-28")	90	5	0			0	120	120		
TV (>28")	102	0.4	0			0	9.6	9.6		
Cable TV box	12	11	0			0	264	264		
Satellite receiver	18	17	0			0	408	408		
VCR	23	7.5	0			0	180	180		
DVD Recorder*	40	4	0			0	96	96		
Games console*	50	5	0			0	120	120		
Stereo system (large)*	100	10	0			0	240	240		
Stereo system (compact)*	20	2	0			0	48	48		
Clock radio	2	1.5	0			0	36	36		
Desktop computer*	125	80	0			0	1920	1920		
Laptop computer*	60	10	0			0	240	240		
Inkjet printer	25	4	0			0	96	96		
Laser printer*	200	10	0			0	240	240		
Garden strimmer	350	0	0			0	0	0		
Garden mower	1000	0	0			0	0	0		
Garden vacuum	650	0	0			0	0	0		
Actual Electricity Consumption										
October-December										
December - February										
February-April										
April-June										
June-August										
August-October										
Annual kWh/household										
Annual kWh/person										
Average kWh/day										