Loughborough University

RENEWABLE ENERGY SYSTEMS

(21WSC303)

January 2022 3 Hours

Answer **ALL SEVEN** questions.

All questions carry equal marks (15 marks).

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1. Discuss the transition from the 20th Century energy system to the 21st Century energy systems. Your answer should refer to the following energy system concepts, providing with clear definitions of them:

- Distributed
- Dispatchable
- Intermittency
- Energy Storage
- Flexibility

You may refer to any of the following as examples in your answer, as appropriate:

- Specific energy generation and/or storage technologies.
- Barriers to their successful implementation within the current energy system.
- Space and DHW heating, or personal transport. [15 marks]

2.

a) A three-bladed wind turbine has a 120m rotor diameter and generates the maximum power of 3MW, at a rated wind speed of 10m/s. What is the power coefficient for this turbine? [2 marks]

b) A meteorological mast is installed at a site in flat homogeneous terrain, i.e. the surface roughness is the same in all directions. Wind speed measurements are made at two heights on the mast: 10m and 65m. The long term average wind speeds measured at these two heights were 4.3m/s and 6.6m/s, respectively. Estimate the surface roughness length. [3 marks]

c) Draw a velocity triangle to illustrate the concept of angle-of-attack for a wind turbine blade, showing how it relates to the relative wind speed, blade pitch angle and rotational speed of the rotor. With the aid of this vector diagram, explain why most modern turbine blades incorporate a twist from the root to tip, assuming a constant lift coefficient along the blade. Define all symbols used. [5 marks]

d) A 3MW wind turbine is erected in a site where the average mean wind speed is 6.8m/s at the hub height. It has a hub height of 90m, cut in at 3m/s, is rated at 11m/s, and cut-out at 24m/s. Table 1 shows a power curve for the chosen wind turbine.

Calculate the annual energy yield at the given site from the wind turbine. It is assumed that the reliability of the turbine is 96%. [5 marks]

Wind speed [m/s]	Power [kW]
0 – 3	0
3 – 6	163
6 – 9	677
9 – 11	1534
11 – 24	2000

Table 1: Power curve data

Note: The probability, Q, that a wind speed, u, exceeds a value, v, (assuming the measurements fir a Weibull distribution with scale parameter, C, and shape parameter, k) is given by:

$$Q(u > v) = exp(-(v/C)^k)$$

The value of C can be estimated using $C = 2\bar{u}/\sqrt{\pi}$, where $\bar{u}$ is the mean wind speed at the hub height. You can use $k = 2.0$.

3. You are designing a grid-connected solar PV system and have obtained the manufacturer datasheets of your preferred PV modules and inverter.

The inverter datasheet tells you it is rated at 25 kW and can track the PV array maximum power point in the range 280 to 850 V.

The module datasheet includes the following dimensional and Standard Test Conditions (STC) electrical performance information:

Length	1.8 m
Width	1.0 m
I_{SC} at STC	9.2 A
V_{OC} at STC	45.0 V
I_{MPP} at STC	8.7 A
V_{MPP} at STC	39.1 V

Table 2: PV module parameters

a) Show that the PV module STC efficiency is 18.9% [3 marks]

b) What is the maximum module string length and maximum number of strings in the PV array that is compatible with this inverter? [4 marks]

c) Draw the current-voltage characteristic under Standard Test Conditions of one module, one string, and the full array, as per your answer to part b) above. [5 marks]

d) Explain how you would expect the array current-voltage characteristic to differ from that at STC when operating in real conditions and why that is important to consider when choosing an inverter (you can use further I-V curve sketches to support your answer or describe only in words). [3 marks]

4.

a) Using diagrams, show the differences between a closed cycle steam power system and a combined cycle gas turbine power system. What are the differences in the energy conversion efficiencies of these systems? [8 marks]

b) Describe the differences between gasification and pyrolysis products and processes [7 marks]

5.

a) A planner would like to install a new wind farm to feed a town that takes 100MW of load as shown in Figure 1. Explain from first principles using load flow analysis, if it is feasible for the planner to supply this load at 11kV. [9 marks]

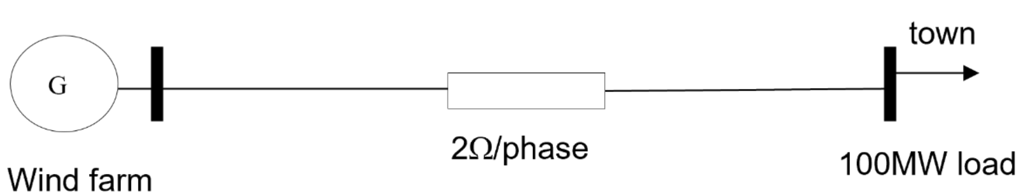

Figure 1 – Wind generator connected to a small town

b) Suggest and discuss alternative supply voltages. [4 marks]

c) What wind farm specific information would the planner need to tell the Network Operator about the generator? [2 marks]

6.

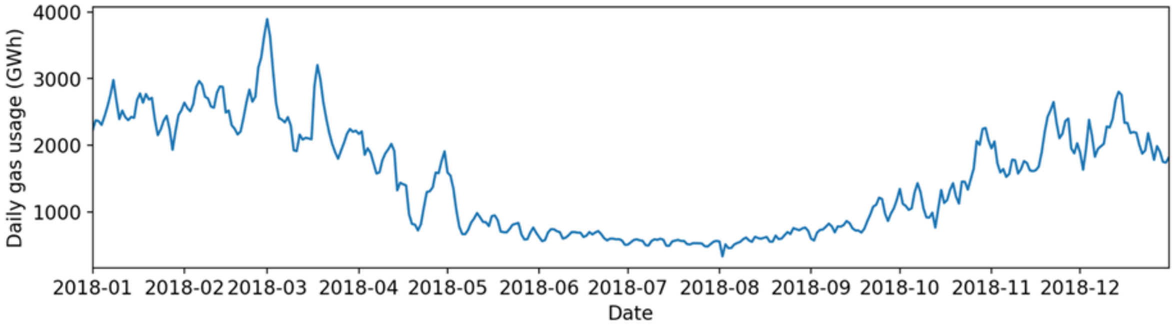

Figure 2: GB gas demand

a) The graph above shows a timeseries of GB gas demand (excluding electricity generation and large industry). Referring to the general features of the timeseries, explain why it is difficult to provide heat demands with only renewable generation. [2 marks]

b) The average capacity factor for offshore wind is 40%. Estimate what level of wind generation (in GW) would be required to provide an equivalent amount of heat as the total heat demand over the year. Explain your reasoning. [3 marks]

c) The potential energy contained within a Pumped Hydro plant is given by $E = mg\Delta H$, where ΔH is the height difference between the lower and upper reservoirs. Assuming the upper reservoir is at 550m and the lower reservoir at 30m, and the upper reservoir has a usable volume of 4.2 million m3, what is the stored energy in GWh? [2 marks]

d) Referring to Figure 2, do you think Pumped Hydro likely to be a good future option for 'storing' heat? If not, suggest another storage type which may be appropriate in future. Explain your reasoning. [3 marks]

e) In the period 9-9:30am in the morning, the electricity for a certain region of the grid is generated from 3GW of wind, 500MW of CCGT generation, 500MW of Coal and 100MW of Other generation.

	Wind	Coal	Other	CCGT
Emissions (g/kWh)	0	980	300	394

Table 3: Plant emissions

Using the information in Table 3, calculate the average carbon intensity of the grid at this time in g_{CO_2}/kWh. [1 mark]

f) 200MW of wind is being curtailed. Why may we not be able to reduce CCGT further and use more wind? [1 mark]

g) Explain why GB has so successfully managed to reduce its electricity-based emissions over the last two decades but why this strategy poses challenges in getting to net-zero. [3 marks]

7.

a) Explain what is “Net-Zero Carbon Building (nZEB)” and list three strategies that can be adopted by the UK to achieve nZEB in the future. [5 marks]

b) A typical English house usually consumes 280.3 Wh/m^2/y of energy just for space heating purpose, which is equivalent to 32W/m^2. In order to save energy bills, you decide to change the existing Combi-boiler of your house into a Ground Source Heat Pump, with COP equal to 3.4.

Assume the floor area of your house is 120m^2. Your Ground Source Heat Pump (GSHP) will be installed at 2.2m depth below the ground level. Consider the soil condition is sandy soil with 50% saturation. During the operation of GSHP, the average temperature drop of the ground loop will be maintained as 10°C.

i. Using Table 4 to calculate your answer, what area of soil would need to be occupied for installing such a GSHP? [6 marks]

ii. Your neighbour suggests you install air source heat pump rather than a ground source heat pump. From efficiency point of view, using the scientific reason, explain to your neighbour why you choose to have a GSHP? (Which one is generally having higher efficiency, ground source heat pump or air source heat pump? And why?) [4 marks]

	thermal conductivity κ (W/m/K)	heat capacity C_V (MJ/m^3/K)	length-scale z_0 (m)	flux $A\sqrt{C_V \kappa \omega}$ (W/m^2)
Air	0.02	0.0012		
Water	0.57	4.18	1.2	5.7
Solid granite	2.1	2.3	3.0	8.1
Concrete	1.28	1.94	2.6	5.8
Sandy soil				
dry	0.30	1.28	1.5	2.3
50% saturated	1.80	2.12	2.9	7.2
100% saturated	2.20	2.96	2.7	9.5
Clay soil				
dry	0.25	1.42	1.3	2.2
50% saturated	1.18	2.25	2.3	6.0
100% saturated	1.58	3.10	2.3	8.2
Peat soil				
dry	0.06	0.58	1.0	0.7
50% saturated	0.29	2.31	1.1	3.0
100% saturated	0.50	4.02	1.1	5.3

Table 4: Key characteristics of different types of soil

You may find the following equations helpful in answering this question:

- Heat transfer rate Q through the building envelope layer: Q=U*A*ΔT

  Where U - U value of the building envelope layer (W/m^{2}K)

  ΔT - Temperature difference (°C)

- The U value of a series building components (1, 2,….n) can be calculated as:

$$U = \frac{1}{R_1 + R_2 + \cdots \ldots + R_n}$$

- The efficiency of a heat engine: $\boldsymbol{\varepsilon} = \frac{T_2}{T_1 - T_2} = \frac{1}{\frac{T_1}{T_2} - 1}$

- The COP of a heat pump: $COP = \frac{Q_H}{W_{net,in}} = \frac{Q_H}{Q_H - Q_L} = \frac{1}{1 - (Q_L/Q_H)}$

- Average heat flux q_s that can be extracted from soil $q_s = \kappa \frac{\Delta T}{h}$

  Where, ΔT is the temperature difference of the soil, in kelvin;

h is the depth between the soil level and the surface of the soil, in meters

κ is the thermal conductivity of the soil, in W/mK.

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