EE4-50
EE9-FPN2-10

IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2018

EEE PART IV: MEng and ACGI

Corrected copy

SUSTAINABLE ELECTRICAL SYSTEMS

Thursday, 10 May 10:00 am

Time allowed: 3:00 hours

There are FIVE questions on this paper.

Answer FOUR questions.

All questions carry equal marks.

Answer Questions 1 & 2 in Booklet A
Answer Questions 3, 4 & 5 in Booklet B.

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

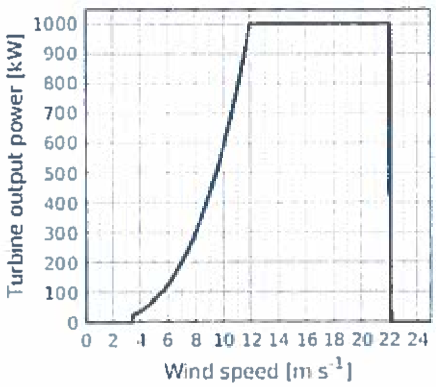
Examiners responsible | First Marker(s) : A. Junyent-Ferre, G. Strbac
Second Marker(s) : F. Teng, A. Junyent-Ferre

Sustainable Electrical Systems 2017-2018

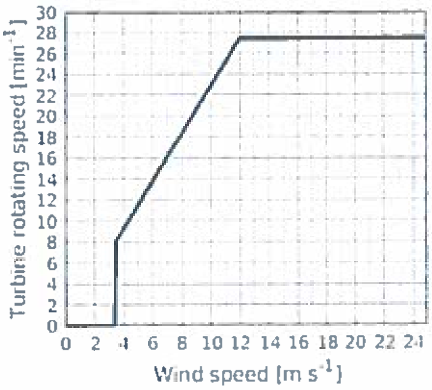
Important note:
There are five questions in this exam paper, answer four of them only.

Q1. A question about wind power generation

a) The plots in figures Q1.1a and Q1.1b show the output power and the rotational speed of a wind turbine for a range of wind speeds. The diameter of the turbine is D=50m and the density of the air is approximately ρ =1.225kg·m^{-3}. Answer the questions described below.



a)



b)

Figure Q1.1- Characteristic power and speed curves of a wind turbine.

i) Calculate the power coefficient of operation, C_P, for the wind speeds, v_w, of 2 m·s^{-1}, 6 m·s^{-1}, 10 m·s^{-1}, 14 m·s^{-1} and 18 m·s^{-1}. Sketch the curve of power coefficient against wind speed compared to the maximum C_P predicted by Betz. [4]

ii) Sketch the curve of turbine torque against wind speed. [2]

iii) Calculate the tip-speed ratio of operation for a wind speed of v_w=8 m·s^{-1}. [1]

iv) Calculate the transformation ratio of the gearbox of the turbine if the electrical generator is designed to turn at 1,500 min^{-1} when operating at full power. [1]

b) The graph in Figure Q1.2 shows the cumulative probability distribution of the wind speed for a site where a wind turbine is installed. Answer the questions described below.

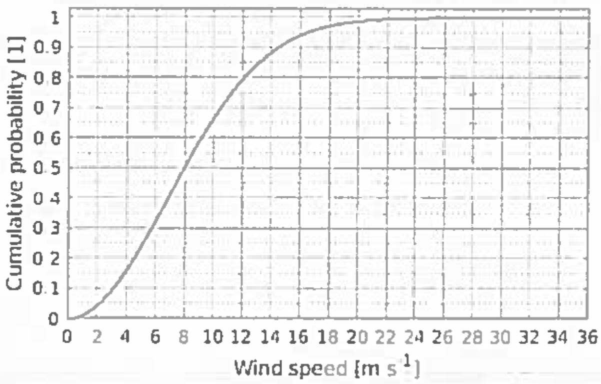


Figure Q1.2- Cumulative probability distribution of the wind speed.

i) Calculate the probability of the wind speed being within the MPPT region of the wind turbine, which in this case is between 4 $m \cdot s^{-1}$ and 10 $m \cdot s^{-1}$. [2]

ii) Calculate the average wind speed of this site. [1]

iii) Generate three simulated wind speed data samples using the following random samples obtained from a uniform probability distribution between 0 and 1: s_1=0.7, s_2=0.1, s_3=0.8. [1]

iv) Wind turbines have an MPPT region of operation and a power reduction region. Describe these two modes of operation briefly and explain why wind turbines are designed to have these two modes of operation. [4]

c) Answer the following question regarding wind generation technologies:

i) Describe (briefly) the DFIG wind turbine topology and the PMSG wind turbine. Highlight their pros and cons. [4]

Q2. A question about solar photovoltaic (PV) generation

a) The characteristic curve of output power against terminal voltage of a PV cell exposed to an irradiation of 13.6 W is shown in Figure Q2.1. Answer the questions listed below.

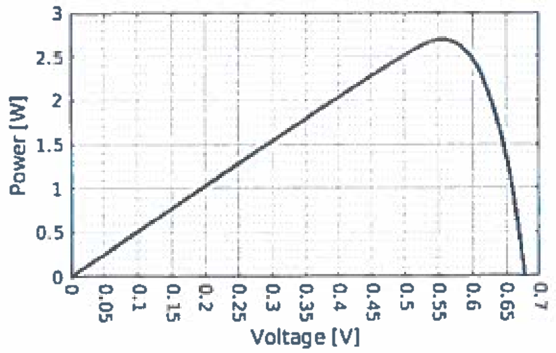


Figure Q2.1 – Output power against terminal voltage of a PV cell under an irradiation of 13.6 W.

i) Calculate the efficiency of the PV panel when operating at the Maximum Power Point (MPP). [1]

ii) Calculate the load resistance we would need to connect to the PV cell in order to extract the maximum energy at the given irradiation. [1]

iii) Estimate the short circuit current of the PV cell when operating at the given irradiation. [1]

iv) Describe briefly how a basic perturb-and-observe MPPT algorithm for PV works. [2]

b) The illustrations in Figure Q2.2 show the shadow cast by an identical vertical pole in two different locations at the same time of the day and on the same day of the year. Answer the questions listed below.

Case 1) 11 Sept, 12 noon, Brussels (Belgium)

Case 2) 11 Sept, 12 noon, Lagos (Nigeria)

Figure Q2.2- Shadow cast by a vertical pole in two different locations (data: a=2.5m, b=2.7m).

i) Estimate the approximate elevation angle of the sun in both cases. [1]

ii) Estimate the approximate AM number in both cases. Explain the meaning of the AM number briefly. [3]

iii) We are told that the direct irradiance over a surface that is perfectly perpendicular to the sun rays in Case 1 is of 200 $W \cdot m^{-2}$. Calculate the total direct irradiance (W) a PV panel of 2 m^2 would receive if it was held horizontally on the ground [2]

iv) Explain briefly what an equinox is. [1]

c) Answer the following questions related to PV technology:

i) A PV generation array with 16 PV panels is to be built. Give an overview of how these would be connected if two different array concepts were used: (a) an array of 4 strings of 4 PV panels with a centralised inverter and (b) an array of 16 PV panel with individual microinverters per each panel. Highlight the potential pros and cons of each of the two configurations. [3]

ii) Draw an approximate characteristic curve of voltage against current of a PV cell and explain how the curve would change if the irradiation of the panel was halved (50%). Give an approximate estimate of how the power yield would change if we know that in both cases the PV cell was operating at the same output voltage, which was lower than the MPP voltage. [3]

iii) Explain briefly what the problem of having two PV cells connected in parallel is and how the problem can be mitigated. [2]

Q3. **A question about distributed generation, voltage control and security of supply**

a) A network planner is considering the connection of a 10 MW wind farm. Two possible connection options are investigated: $\boxed{1}$ the connection of the wind farm to an 11 kV feeder supplied by a 33/11 kV substation and $\boxed{2}$ the connection to a 33 kV feeder supplied by a 132/33 kV substation. In both cases, the On Load Tap Changing (OLTC) transformer is set to maintain the voltage at busbar A at constant 1.03 p.u.(see Figure Q3.1). The allowed voltage fluctuations in both cases are ±6%. The wind farm power factor at full power output is 0.95.

Figure Q3.1- Wind farm connection (same diagram for both options $\boxed{1}$ and $\boxed{2}$).

i) Considering the connection scheme presented in Figure 3.1, determine the maximum possible connection length if the wind farm for both option ($\boxed{1}$) and ($\boxed{2}$). The capacity of the 11 kV circuit is of 810 A and both resistivity and reactivity are of 0.06 Ω per km. The capacity of the 33 kV circuit is of 1,208 A, the resistivity is of 0.046 Ω per km and the reactivity is of 0.101 Ω per km. [6]

ii) Explain the advantages and disadvantages of connecting this wind farm to 11kV ($\boxed{1}$) or 33kV ($\boxed{2}$). [4]

b) Answer the following questions related to the security of supply:

i) Explain the importance of considering the contribution of non-network solutions to network security within network security standards. [2]

ii) Explain briefly the fundamental approach used to quantify the contribution of distributed generation to network security. State one strength and one weakness of the present approach used to quantify the security contribution of distributed generation. [3]

iii) The contribution to security of supply of two identical distributed generation units is 75%. Determine the availability of the distributed generation units considering the normalised load duration curve shown in Figure Q3.2. [5]

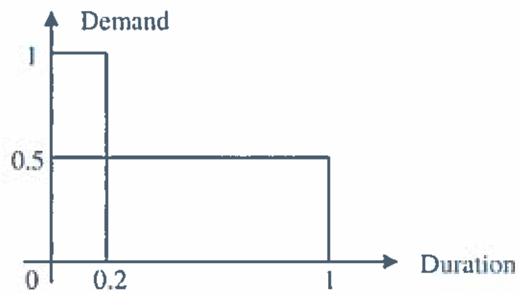


Figure Q3.2- Normalised load duration curve.

Q4. A question about low carbon heat

a) Give a very brief description of the following types of low carbon heating systems:

i) Air source heat pump (ASHP). [2]

ii) District heating. [2]

iii) Hydrogen heating. [2]

iv) Resistive heating (Direct electric). [2]

b) A comparison of each of the aforementioned types can be made by using a "spider gram" as shown in Figure Q4.1 where "1" is ranked "Best" and 4 is the "Worst". Answer the question described below.

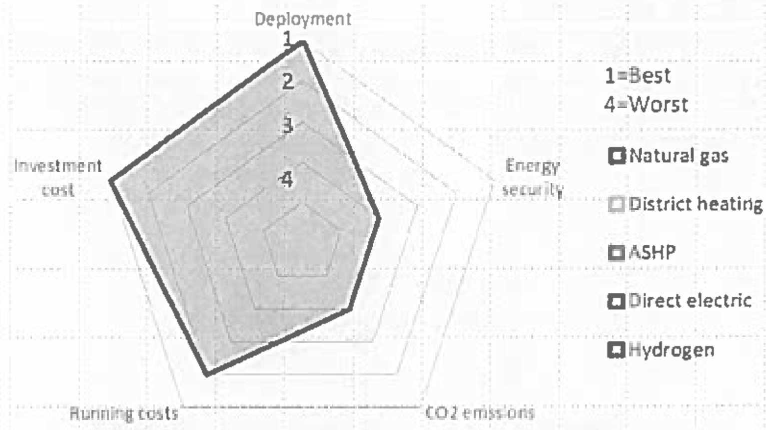


Figure Q4.1- Diagram comparing the features of different heating systems

i) Plot each of the low carbon heating systems on a spider gram (natural gas is shown as an illustration) and comment very briefly on the result. [6]

c) A householder is trying to decide on whether to purchase a low cost resistive heating system or a more expensive air source heat pump system. The data are shown in Table Q4.1. Answer the question described below.

	Heating system fixed costs	Running costs	Efficiency
Resistive heating	£150/year	£0.15/kWh	100%
Air source heat pump	£750/year	£0.15p/kWh	300%

Table Q4.1- Characteristics of different heating systems.

i) What is the annual heat demand whereby the total annual costs of both heating systems are the same? [3]

d) The householder's been advised that they can have a hybrid heat pump for the same fixed cost as standard ordinary air source heat pump. Explain why they might have similar fixed costs and what would be the system related benefits of a hybrid heat pump. [3]

Q5. **A combined question about demand-side response, hydro power generation and offshore power transmission**

Demand-side response

a) Answer the following questions:

i) Explain why energy supply companies may be interested in changing demand profiles of their customers. [3]

ii) Explain the concept of demand response and give an example of a demand response activity. [4]

iii) Explain the concept of EU appliance labelling scheme, what is the policy objective and how it may be met. [3]

Hydraulic power generation

b) A micro hydraulic generation system consists of an upper water reservoir that feeds a penstock that goes to a turbine that generates power (see Figure Q5.2). The characteristics of the system and its operating point are summarised in Table Q5.1. Answer the questions listed below.

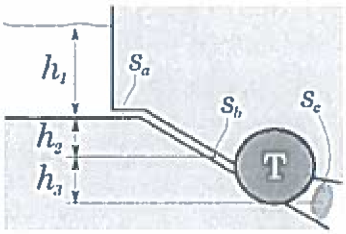


Figure Q5.2- A micro hydraulic generation system.

Parameter	Value	Description
h_1	6 m	Water depth upper reservoir.
h_2	5 m	Distance #2
$h3$	1 m	Distance #3
S_a, S_b	0.1 m^2	Cross-section of the inlet
S_c	0.3 m^2	Cross-section of the outlet
ρ	1,000 kg/m^3	Density of water
$\dot{m}$	400 kg/s	Mass flow under normal operation

Table Q5.1-Characteristic parameters of the micro-hydro system

i) Consider the situation where the intake valve of the turbine is shut and no water is flowing. Calculate the gauge pressure (the difference with the atmospheric pressure) in S_a and S_b. [1]

ii) Consider a normal operation point where the mass flow is $\dot{m}$ = 400 kg/s. Calculate the speed of the water in S_a, S_b and S_c. [1]

iii) Calculate the gauge pressure in S_a and S_b under normal operation. [1]

iv) Calculate the power extracted from the water if we know that the pressure in S_c under normal operation is of p_c=30 kPa. [2]

v) Would a Kaplan turbine be a suitable choice for this application? Justify your answer briefly. [1]

Offshore power transmission

c) Answer the following questions related to HVDC transmission:

i) Explain briefly why the critical distance at which HVDC transmission becomes a better solution than HVAC is different when using overhead lines and when using underground cables. [2]

ii) List the potential advantages of VSC-HVDC when compared to LCC-HVDC. [2]