EE4-50
EE9-FPN2-10

IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2017

EEE PART IV: MEng and ACGI

SUSTAINABLE ELECTRICAL SYSTEMS

Corrected copy

Thursday, 11 May 10:00 am

Time allowed: 3:00 hours

corrected before exam
Q4 (b)
Figure Q4.1
360 instead of 36

There are FIVE questions on this paper.

Answer FOUR questions.

All questions carry equal marks.

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) : G. Strbac, A. Junyent-Ferre

Sustainable Electrical Systems

Important note: There are five questions in this exam; please answer only four.

Q1. A question about wind power generation

a) The graph in Figure Q1.1 shows the power yield of a wind turbine compared against the available kinetic power in the airflow passing through the turbine for a range of wind speeds within the MPPT (maximum power point tracking) operating region. Relevant parameters about the wind turbine can be found in Table Q1.1.

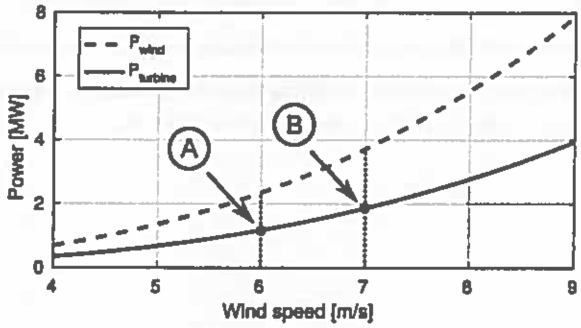

Figure Q1.1 - Power yield and available power from a given wind turbine.

Parameter	Value	Description
D	150 m	Turbine diameter
ρ	1.225 kg/m^3	Density of the air
$P_{turbine}^{rated}$	5 MW	Rated power of the wind turbine
P_{wind}^{A}	2.34 MW	Available power at wind speed A
$P_{turbine}^{A}$	1.17 MW	Power yield at wind speed A
ω_T^A	0.72 rad/s	Turbine speed at wind speed A.

Table Q1.1 - Characteristic data wind from a given wind turbine.

Answer the following questions making sure that the procedure you follow is clear in your answer:

i) Calculate the power coefficient, C_P, of the wind turbine at the operating point A. [1]

ii) Calculate the tip speed ratio, λ, at the operating point A. [1]

iii) Calculate the torque of the turbine at the operating point A. [1]

iv) Calculate the torque of the electric generator at the operating point A knowing that the gearbox ratio is 90 if the efficiency of the gearbox is assumed to be 100%. [1]

v) Calculate the turbine speed at the operating point B. [1]

vi) Calculate the capacity factor of the turbine knowing that the annual yield was 17.5 GWh. [1]

b) Answer the following questions regarding the physical principles of wind power conversion:

i) Estimate the maximum power a wind turbine with a blade diameter of 70 m would be able to generate in a site with a wind speed of

9 m/s and an air density of ρ=1.225 kg/m^3. Make sure that any assumptions you make are very clear. [1]

ii) Explain why the maximum power yield of an ideal actuator disk is obtained when the speed of the airflow downstream is one third (1/3) of the speed of the incoming wind rather than when the speed of the airflow downstream is zero. [2]

c) Answer the following questions regarding wind turbine technologies:

i) List the different modes of operation of a variable speed wind turbine at different wind speeds. Justify the purpose of each mode briefly. [4]

ii) Explain what the pitch mechanism is and how it is used. [4]

iii) Compare the FS-SCIG wind turbine topology against the PMSG wind turbine. Highlight their pros and cons. [3]

Q2. A question about solar photovoltaic (PV) generation

a) The graph in Figure Q2.1 shows the output current of a PV cell against its output voltage for two different irradiation levels.

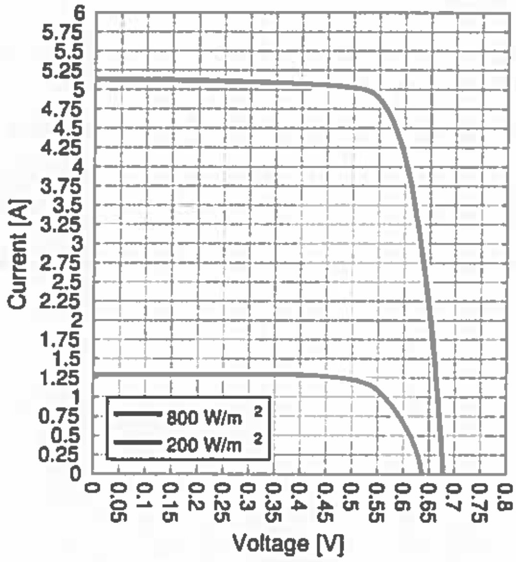

Figure Q2.1- V-I curves of a solar cell.

Answer the following questions making sure that the procedure you follow is clear in your answer:

i) Sketch the curve of output power against output voltage of the cell and find the approximate coordinates (voltage, current and power) of the maximum power point (MPP) for both irradiation levels. [3]

ii) Calculate the coordinates of the operating point of the cell under an irradiation of 800 W/m^2 if a resistor of 0.13Ω was connected to the terminals of the cell. [3]

iii) A PV panel is formed by connecting 96 cells in series. What would the coordinates of the MPP of the panel be if the irradiation of all cells was 800 W/m^2? [1]

iv) What would the efficiency of the 96-cell panel be at the MPP for an irradiation of 800 W/m^2 if the surface of the PV panel is 1.63 m^2? [1]

v) A small PV panel is formed by connecting 2 cells in series. The panel is subject to partial shading (see Figure Q2.2), which makes one of the cells to receive an irradiation of 800 W/m^2 while the other cell receives only 200 W/m^2. Sketch the approximate V-I curve of the panel under the partial shading condition and find the operating point of both cells if the current of the panel was 1 A. Does the shaded cell generate power under these operating conditions? [3]

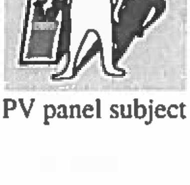

Figure Q2.2- A 2-cell PV panel subject to partial shading.

b) Answer the following questions regarding the solar energy resource and PV generation technology:

i) What is the meaning of the air mass (AM) number and what does AM0 mean? [2]

ii) Would a mechanical solar tracker be useful in a location where most days are cloudy? Justify your answer. [2]

iii) What happens to the duration of the day and the night at the equinox? [1]

iv) What is the problem of having two strings of series-connected PV cells connected in parallel? How can we mitigate the problem? [3]

v) What is the meaning of the "peak power rating" of a PV panel? [1]

Q3. **A question about distributed generation and voltage control**

a) In contrast to the present electricity system that is dominated by conventional generation, a future power system may be characterised by high penetration of renewable and low carbon distributed generation. Answer the following questions:

i) Explain how distributed energy system may achieve higher energy efficiency levels when compared to a large scale centralised one? [3]

ii) Explain why the (present) "fit and forget" approach to distribution network management may limit the amount the amount of Distributed Generators that can be accommodated to the existing networks. [2]

iii) List possible active network management mechanisms and briefly state how these can enhance the ability of the network to accommodate increased capacity of distributed generation. [3]

b) A farm is supplied from a substation through a 3-phase 11kV underground cable of 5 km length which has an impedance of (0.1+j·0.1) Ω/km (see Figure Q3.1). The On-Load Tap Changing (OLTC) transformer is currently set to maintain the voltage at busbar A at 1.03 p.u (+3% of the rated voltage). The farm maximum demand during winter is 5 MW, while the minimum demand during the summer is 1 MW (both with unity power factor). The allowed voltage variation in the 11 kV network is +/- 6%. Answer the questions listed below making sure that the procedure you follow is clear in your answer:

Figure Q3.1- One line diagram of the system in Q3.b.

Answer the following questions regarding a 3-phase PV generation system that will be connected at the farm:

i) What is the maximum amount of PV generation that can be connected at the farm if the power factor of the PV plant is 0.95? [8]

ii) What is the maximum amount of PV generation that can be connected at the farm if the OLTC kept the voltage at busbar A at 1 p.u.? [4]

Q4. A question about security of supply

a) Answer the following questions:

i) Explain the notion and the reason for capacity margin in a modern power system. How can the optimal amount of capacity margin be determined? [3]

ii) Discuss how the level of redundancy in electricity network design changes with the level of connected load. Explain why there is no network redundancy at LV level in most cases. [4]

iii) Explain why it is important to consider the contribution that non-network technologies can make to network security. [3]

b) A load is supplied from a network plus three distributed generators connected at the same busbar (see Figure Q4.1). Two of the generators have the same characteristics and are denoted as G1, while the third generator is G2. The ratings of generators G1 and G2 are 5MW and 10MW, respectively.The availabilities of generators G1 and G2 are 90% and 80%, respectively. The load is represented by a winter load duration curve with 360 hours at peak (1 p.u.) and the rest of the winter at the off-peak level of 0.6 p.u. (see Figure Q4.1).

correction

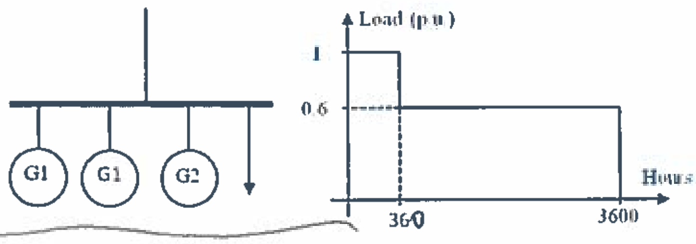

Figure Q4.1- Generator set and load duration curve.

i) Calculate the combined contribution to security of supply of the three generators. [10]

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

Demand-side response

a) Complete the following task:

i) Explain the phenomenon of load payback (or load recovery) that can be encountered when utilising demand-side response (DSR) schemes, and how it may affect the volume of service delivered by DSR. [4]

b) A local distribution grid has a demand profile during peak hours as shown in Figure Q5.1a. The network operator (DNO) has an option to contract with DSR providers that can alter their net demand profile at any given time in line with the profile illustrated in Figure Q5.1b: a load reduction by 25 kW in one hour is followed by a load recovery of 15 kW in the next.

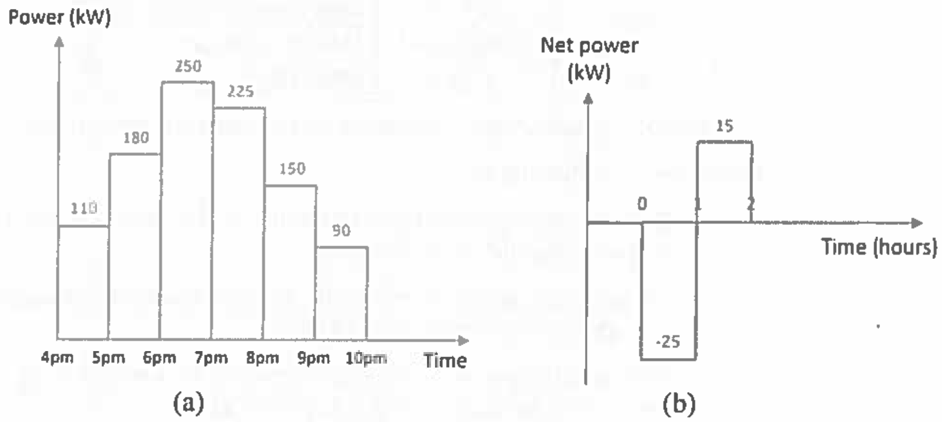

Figure Q5.1- Demand profile of the distribution network (a) and Net demand profile of the DSR (b).

Answer the following questions:

i) Which DSR utilisation strategy should the operator pursue in order to achieve the maximum possible peak reduction if it establishes a contract with **one** DSR provider? [2]

ii) Which DSR utilisation strategy should the operator pursue in order to achieve the maximum possible peak reduction if it establishes contracts with **two** DSR providers? [2]

iii) Find the new peak demand after the use of the DSR in both cases (i and ii above) [2]

Hydraulic power generation

c) 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.

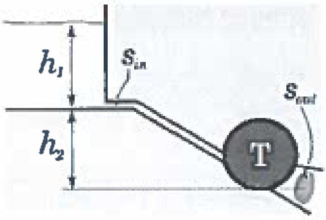

Figure Q5.2- Diagram of the dam.

Parameter	Value	Description
h_1	5 m	Water depth upper reservoir.
h_2	15 m	Height penstock
S_{in}	0.01 m^2	Cross-section of the inlet
S_{out}	0.03 m^2	Cross-section of the outlet
ρ	1,000 kg/m^3	Density of water
$\dot{m}$	5 kg/s	Mass flow

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

Complete the following tasks

i) Calculate the speed of the water at the intake (where S_{in}) and at the output of the turbine (where S_{out}). [2]

ii) Calculate the gauge pressure (the difference with the atmospheric pressure) at the water intake (where S_{in}). [1]

iii) Calculate the power yield of the turbine if we know that the gauge pressure at the output (where S_{out}) is 98 kPa. [2]

Offshore power transmission

d) Answer the following questions regarding transmission technologies:

i) Why is the transmission distance that can be reached using HVAC with cables much shorter than the distances that can be reached using overhead lines? [2]

ii) Enumerate the potential benefits of multi-terminal HVDC when compared to point-to-point HVDC- [1]

iii) Enumerate the advantages of XLPE-insulated HVDC cable when compared to MI-insulated cable. [2]