[ENG68]

UNIVERSITY OF GREATER MANCHESTER

SCHOOL OF ENGINEERING

MSc in ELECTRICAL & ELECTRONIC ENGINEERING

EXAMINATION SEMESTER 2 - 2024/2025

ADVANCED RENEWABLE ENERGY TECHNOLOGIES

MODULE NO: EEE7008

Date: 14 MAY 2025 **Time: 14:00 - 17:00**

INSTRUCTIONS TO CANDIDATES:

There are SIX questions.

Answer ANY FOUR questions.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

Electronic calculators may be used provided that data and program storage memory is cleared prior to the examination.

CANDIDATES REQUIRE: **Formula Sheet (attached).**

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Question 1

An H-type Vertical-Axis 2-blade wind turbine has the following specifications: Turbine rotational speed=32.6 RPM, Gearbox ratio=23, blade length=7.5 m, blade width=0.8 m ,rotor diameter=15 m. Permanent Magnet Synchronous Generator: star-connected, voltage=415 V line to line, frequency=50 Hz, number of magnetic poles=8, generator efficiency=98%, gearbox efficiency=97%. Wind: wind density 1.2 kg/m^3, blade lift coefficient 0.12α and blade drag coefficient 0.08. you may assume azimuth angle of blade 2=30^o , wind speed=12 m/s.

Determine:

I. The angle of attack of blade 1 and blade 2 α **[6 marks]**

II. The torque coefficient of blade 1 and blade 2 **[3 marks]**

III. The turbine mechanical torque **[5 marks]**

IV. The generator rotational speed **[2 marks]**

V. The high-speed shaft torque **[3 marks]**

VI. The generator output power and current for unity power factor load **[6 marks]**

Total 25 marks

Please turn the page

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Question 2

A 3-phase, 480 V, 50 Hz, 8-pole, star-connected induction machine has the following equivalent circuit parameters in ohms:

R1=0.13, R2=0.13, X1=0.6, X2=0.6, magnetizing admittance=0.004-j0.05 Ω^{-1} referred to stator side. You can assume the turn ratio of stator to rotor winding to be 1:1.

I. Explain with the aid of diagrams and circuits how an induction motor can be used as Induction generator

[10 marks]

II. Calculate the output power and the power factor if it operates as Induction generator in a wind turbine unit rotating at 39 RPM with a gearbox ratio of 20.

[15 marks]

Total 25 marks

Please turn the page

Question 3

I. Prove mathematically that the capacitance of a 3-core cable is

$$C_N = C_e + 3C_c$$

You may need to draw the circuit of the 3-core cable capacitances.

[6 marks]

II. The maximum and minimum stresses in the dielectric of a single core cable are 38 kV/cm (rms) and 9 kV/cm(rms) respectively. If the conductor diameter is 1.8 cm, find (i) the thickness of the insulation and (ii) the operating voltage.

[8 marks]

III. The velocity of the water in a run-of-river hydroelectric plant is 6 m/s . if the presented area of the turbine blades is 14 m^2, find the available power in the water. Assume water density=1000 kg/m^3 .

[3 marks]

IV. What are the energy types in a moving water and write an equation describing the equivalent head of the water? Define each parameter used in this equation.

[8 marks]

Total 25 marks

Please turn the page

Question 4

As a renewable energy engineer, you have been tasked with designing a solar panel system for the Sports center building at the University of Bolton. The building operates at a nominal voltage of 24V and will be powered by solar batteries. The system must meet the building's daily energy demand while considering economic and technical constraints. Below are the key parameters and requirements for the design:

Energy Demand: The building consumes a total of 8,200 watt-hours (Wh) per day. The cost of electricity from the grid is £0.49 per kilowatt-hour (kWh).
Solar Resource: The average daily sunlight available at the location is 2.5 hours.
Solar Modules: The solar panels available on the market have the following specifications:
Peak power (Pmax): 125watts-peak (Wp); Voltage: 12V;
Current: 5.0A; Cost per module: £160

Battery Storage: The batteries available for the system have the following specifications:

Voltage: 12V; Capacity: 100 ampere-hours (Ah); Cost per battery: £55
Usable energy: Only 72% of the battery's capacity can be utilized.
Reserve time: The system must provide backup power for 3.0 days.

Inverter Efficiency: The inverter, which converts DC power from the solar panels and batteries to AC power for the building, has an efficiency of 64%.

Installation Costs: The total cost for the installation of PV panels, including all associated materials, is £1,520.

Please turn the page Q4 Continues…

I. You are required to create a detailed schematic diagram that outlines the interconnection of all components within the system. The schematic must accurately represent the system's architecture in alignment.

[4 marks]

II. Calculate the total number of solar modules required to meet the building's daily energy demand, considering the average sunlight hours.

[6 marks]

III. Determine the total number of batteries needed to ensure 3 days of energy reserve, accounting for the usable energy limitation. Additionally, draw the connections of the battery in your model set up.

[7marks]

IV. How long will it take for the cost savings from the solar energy system to offset the total upfront costs of the installation (Payback period).

[4 marks]

V. Assess the economic feasibility of the system by comparing the cost of solar energy to the grid electricity price.

[4 marks]

Total 25 marks

Please turn the page

Question 5

I. Sketch and label the current-voltage (I-V) characteristics of a solar cell both in the dark and under illumination. In your diagram, clearly indicate and explain the significance of the open-circuit voltage (Voc), short-circuit current (Isc), and fill factor (FF).

[5 marks]

II. Describe the formation of the depletion region in a p-n junction and explain the basic operating principle of a solar cell, including how it generates electricity from sunlight.

[5 marks]

III. Distinguishing between series and parallel resistance. Explain how these resistances impact the overall efficiency and performance of the solar cell.

[5 marks]

IV. Enumerate the different types of solar cells and explain the methods used to improve their efficiency.

[5 marks]

V. An industrial fuel cell system is being used to power a pneumatic self-locking device, supplying a steady current of 2A at a voltage of 0.95V for a duration of 4 minutes. During this operation, 30 ml of hydrogen gas is consumed. Given that the calorific value of hydrogen is 11,850 kJ/m^3, calculate the efficiency of the fuel cell in converting chemical energy into electrical energy.

[5 marks]

Total 25 marks

Please turn the page

Question 6

I. In modern industries, fuel cells are increasingly used for clean energy generation. Explain the concept of fuel cells and how they function as an energy source in industrial applications.?

[3 marks]

II. Fuel cells are being adopted in various industries for clean energy generation. Discuss three key advantages and two potential disadvantages of using fuel cells in industrial applications.

[4 marks]

III. A fuel cell is connected to a load through a single-phase inverter as shown in Figure Q6d. The fuel cell produce a DC voltage of 100 V and the pulse width angle=180^o . The fundamental impedances are given on the figure. The load resistor is R_L= 4 Ohms. Calculate:

i. The fundamental load voltage.

[2 marks]

ii. The worst harmonic distortion factor of the load voltage

[4 marks]

iii. The percentage load voltage regulation

[4 marks]

iv. The volt-ampere rating of the inverter switches and the filter

[5 marks]

v. The efficiency

[3 marks]

It is assumed that the harmonics above 7th are negligible. The switch resistance is 20Ohm.

Total 25 marks

End of Questions. Turn over for Formula Sheet.

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Formula sheet

These equations are given to save short-term memorisation of details of derived equations and are given without any explanation or definition of symbols; the student is expected to know the meanings and usage.

Fuel Cell

$$\eta = \frac{W_{el}}{W_{ch}} = \frac{U \cdot I \cdot t}{H_{H2} \cdot V}$$

Efficiency = (V.I.t)/H_{H2}

Avogadro's number = 6.022 x 10^{23}

Faraday's constant = 96485 C

$F_T = \frac{1}{2}\rho S C_t W^2$

$F_{T\ avg} = \frac{1}{2\pi}\int_0^{2\pi} F_\tau(\theta)\, d\theta$

T= F_T. 2R= $\frac{1}{2}\rho C_t\, ARU^2$

$P_{wind} = \omega . T$

$I = \sqrt{{i_d}^2 + {i_q}^2}$, $P_{in} = \tau_{app}\omega_m$

$P_{conv} = \tau_{ind}\omega_m = 3E_A I_A \cos\gamma$

Wind Turbine

$S = c \cdot H$

$S_a = R \cdot L$, $P = \sqrt{3} V_L I_L cos\theta$

$\lambda = \frac{\omega R}{U}$, $\alpha = tan^{-1}(\frac{sin\theta}{cos\theta + \lambda})$

$C_t = C_L sin\alpha - C_d cos\alpha$, $C_p = C_t . \frac{\lambda}{R}$

Permanent Magnet Synchronous machine

$$v_q = -\left(r + \frac{d}{dt}L_q\right)i_q - \omega_r L_d i_d + \omega_r \lambda_{PM}$$

$$v_d = -\left(r + \frac{d}{dt}L_d\right)i_d + \omega_r L_q i_q$$

$$J_g \frac{d\omega_r}{dt} = T_g - T_d - T_e$$

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)\left[\left(L_d - L_q\right)i_q i_d - \lambda_{PM} i_q\right]$$

$$V = \sqrt{{v_d}^2 + {v_q}^2}$$

End of Exam