OCD42

UNIVERSITY OF BOLTON

WESTERN INTERNATIONAL COLLEGE FZE

BENG (HONS) ELECTRICAL AND ELECTRONIC ENGINEERING

SEMESTER ONE EXAMINATION 2019/2020

RENEWABLE ENERGIES

MODULE NO: EEE6016

Date: Wednesday 15th January 2020 **Time: 1:00 PM – 3:30 PM**

INSTRUCTIONS TO CANDIDATES:

There are FIVE questions.

Answer any FOUR questions.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

Q1.

(a) Explain how current is generated in a photovoltaic cell and discuss the VI characteristics using a schematic diagram.

(3 marks)

(b) Compare and contrast different solar cell technologies.

(4 marks)

(c) The electrical load for a residential building situated in the UAE is given in Table 1. The PV panel specification is provided in appendix 1.

Assume,

Average Daily Solar Insolation = 6.3 KWh/m^2 per day

Temperature loss = 90%

Battery losses = 85%

Wiring losses = 97%

Battery depth of discharge = 80%

Inverter Efficiency = 85%

Table 1 - Electrical load of appliances

Loads	**Quantity**	**Watts**	**Hours/day**
TV	1	150	4
Blender	1	500	0.5
Washing machine	1	500	2
Lamps	10	10	5
Microwave	1	1000	0.5
Iron	1	1200	0.5
Refrigerator	1	1200	24
Vacuum cleaner	1	1000	1
water heater	4	4500	2
Ceiling Fan	4	120	3
Air conditioner	4	3800	8
Desktop Computer	2	200	3
Laptop	2	50	5
Motor	1	750	1

Q1 continued over the page

Q1 continued

Design a PV system to meet the load demand by finding the following

(i) PV array size (4 marks)

(ii) Number of PV panels (1 mark)

(iii) Area required and connection of PV panels (2 marks)

(iv) Panel connection (2 marks)

(v) Array voltage and current (1 mark)

(vi) Cost (1 mark)

(vii) Charge controller (1 mark)

(viii) Inverter (2 marks)

(ix) Battery & connections (4 marks)

Total 25 marks

Q2.

A fuel cell employs the reaction below,

ANODE: $2\ A_2 = 4\ A^{++} + 8\ e^-$

CATHODE: $4\ A^{++} + B_2 + 8\ e^- = 2\ A_2B$

All data are at RTP.

The overall reaction, $2\ A_2 + B_2 = 2\ A_2B$, releases 300 MJ per kmole of A_2B product in a calorimeter.

The entropies of the different substances are:

A_2: 200 kJ K−1 kmole−1

B_2: 400 kJ K−1 kmole−1

A_2B: 150 kJ K−1 kmole−1

A_2 and B_2 are gases, whereas A_2B is liquid.

Q2 continued over the page

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Q2 continued…

(a) Calculate the voltage of an ideal fuel cell using this reaction at RTP.

(6 marks)

(b) Estimate the voltage at standard pressure and 50 C.

(3 marks)

(c) Evaluate the heat produced by the ideal fuel cell per kilomole of A_2B, at RTP?

(1 mark)

(d) Assess the voltage of the cell if the gases are delivered to it at 100 MPa? The operating temperature is 25 C.

(7 marks)

(e) If the internal resistance of the cell (operating at RTP) is 0.001, calculate the maximum power the cell can deliver to a load?

(3 marks)

(f) Evaluate the fuel consumption rate of the cell under these conditions?

(3 marks)

(g) What is the efficiency of the cell?

(2 marks)

Total 25 marks

Q3.

A well designed EV1 automobile has an excellent aerodynamics and overall low losses. With an energy supply of 14 kWh, it has a range of over 100 km and uses 100 kW motor for better acceleration. The major issue with the use of NiMH batteries in EV1 automobile is charging time where it takes several hours to fully charge the batteries.

To improve energy efficiency and refueling time, the NiMH batteries are replaced by a fuel cell battery which supplies 100 kW of power.

The V -I characteristic of the available Hydrogen/Oxygen fuel cell operating at RTP is

$$V_L = 1.1 - 550 \times 10^{-6}\, I.$$

The maximum internal heat dissipation capability is 300W.

Product water exits the cell in vapour form. The fuels cells deliver the energy to a power conditioning unit (inverter) that changes the dc input into ac power .The efficiency of this unit is assumed as 100%.

(a) Calculate the voltage supplied by the fuel cell battery (at 100 kW), assuming the smallest possible number of individual cells are used.

(11 marks)

(b) Determine the efficiency of the cell.

(1 mark)

(c) If cruising at 110 km/h require only 20 kW power, estimate in kilogram the amount of hydrogen required to cover a range of 800 km.

(12 marks)

(d) If the hydrogen is stored at 500 atmospheres, calculate the volume it occupy at 298 K?

(1 mark)

Total 25 marks

Please turn the page

Q4.

(a) A Horizontal axis wind turbine (HAWT) is situated close to the edge of the town.

(i) Determine the wind velocity above 40 metre height, if the wind velocity is 12m/s at 15 metre height. Roughness parameter in the town is 1.2.

(4 marks)

(ii) Evaluate the density of the wind, if the wind speed is 10m/s and the power per area is 103.5 W/m^2 for the first one hour. During the next one hour the wind speed increases to 17m/s and the power per area increases to 1932.5 W/m^2.

(5 marks)

(iii) Calculate the total available wind power and power that can be converted into rotational energy in the turbine, if the wind velocity is 23 m/s and the wind density is 1.76 kg/m^3. The wind turbine has a radius of 4 meter and the wind Power Coefficient, CP is 0.4.

(4 marks)

(iv) Calculate the total annual Energy Production by the wind turbine, if the rated power for the wind turbine is 55 kW at 15m/s wind speed. The estimated capacity factor for the wind is 0.25 and the diameter of the wind turbine is 10 metre.

(2 marks)

(b) Determine the necessary shaft diameters for a vertical axis wind turbine, if the rated power of the generator is 250 kW. The low speed shaft rotates at 50 rpm and the high speed shaft rotates at 1600 rpm. Solid steel shafts are available with recommended maximum stresses of 50 MPa. The gearbox efficiency at rated conditions is 0.94 and the generator efficiency is 0.93.

(10 marks)

(Total 25 Marks)

Please turn the page

Q5.

(a) A Darrieus wind turbine has a cut-in wind speed of 5m/s and a furling speed of 25m/s. If the winds hitting the turbine has a Rayleigh statistics with an average wind speed of 9m/s, calculate

(i) How many hours per year will the turbine be shut down because of excessively high wind speed.

(3 marks)

(ii) How many hours per year will the turbine be shut down because of low wind.

(3 marks)

(iii) What energy will the wind turbine produce for wind blowing at or above the rated speed of 12m/S, if the capacity of the wind turbine is 1MW,

(5 marks)

(iv) The Darrieus has a moment of inertia I = 51,800 kg·m^2. Rated rotor speed is 52 rpm. A circular steel clutch plate is used to start the Darrieus. Thickness of the plate is 25.4 mm. Calculate the minimum radius of the plate if the specific heat capacity is 527 J/kg· ^{o}C and the allowable temperature rise is 100^{o}C. The density of steel is ρ = 7800 kg/m^3

(8 marks)

(b) A 300-kW Darrieus wind turbine was purchased for battery charging. $900 was invested for the installation. Calculate the simple payback in years if the retail rate of electricity is $0.50/kWh and the unit produces 220 kWh per year.

(2 marks)

Q5 continued over the page

Q5 continued

(c) 3.5-kW Darrieus wind turbine with inverter has to be purchased to connect to a grid. $14,000 is allocated for installation of the turbine. Calculate the simple payback in years if the retail rate of electricity is $0.11/kWh and the unit produces 6,000 kWh per year. Analyse the economic impact of the wind turbine that will be installed, with a losing interest at 4% on the installation cost. Assume Annual operation and maintenance cost of $50 per year.

(4 marks)

(Total 25 Marks)

END OF QUESTIONS

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Formula Sheet

PV:

$$\text{PV module Size} = \frac{\text{Total Daily Watt Hours}}{\text{Average Daily Solar Insolation}}$$

$$\text{Actual PV module Size} = \frac{\text{PV module Size}}{\text{Total Losses}}$$

$$\text{No of PV panels} = \frac{\text{Actual PV module Size}}{\text{1 Solar panel Power}}$$

Total Required Area = no of panels x Area of panel

$$\text{Effective area} = \frac{\text{Required area}}{0.7}$$

$$\text{Battery Capacity} = \frac{\text{Daily Load}}{\text{Battery Efficiency}} \quad \text{Watts}$$

Final Battery Capacity = Battery Capacity x 3 (number of sun days) x 80% (depth of discharge) Watt Hrs

$$\text{Amp Hours} = \frac{\text{Watt Hours}}{\text{Volts}} \quad \text{Ah}$$

Given Battery specifications

12V 200AH

$$\text{No of batteries} = \frac{\text{Total Ampere hours}}{\text{Ampere hours of single battery}}$$

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Formula sheet continued

FUEL CELL:

STP (Standard Temperature Pressure): 1 atmosphere, 273.15K

RTP (Reference Temperature Pressure): 1 atmosphere, 298.15K

Heat generation (Second law of thermodynamics):

$$\bar{q} = T\Delta\bar{s}$$

Free Energy:

$$G = H - TS$$

$\Delta G = \Delta H - T\Delta S$ Where ΔH is enthalpy of formation,ΔS is Entropy is temperature

Reversible Voltage:

$$V = \frac{\Delta G}{n_e q N_O}$$

$q=1.6 \times 10^{-19}$

$N_0=6.023 \times 10^{26}$

$$\frac{\partial V}{\partial T} = \frac{V + \frac{\Delta H}{n_e q N_o}}{T}$$

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Enthalpy of Hydrogen $\Delta h = 241.8 \times 10^6$

Hydrogen production rate:

$$\dot{N}_{H_2} = \frac{I}{2qN_0}$$

$$P_{in=} \mid \Delta\bar{h} \mid \dot{N}_{H_2}$$

$$P_L = I \times V_L$$

$$P_{heat} = P_{in} - P_L$$

$$\eta = \frac{P_L}{P_{in}}$$

$$V = \mu \frac{RT}{p}$$

μ=2.6

R=8314

$$W_{compr} = 2RT\, l_n \frac{P}{P_0}$$

$$V_{compr} = \frac{W_{compr}}{n_e q N_o}$$

$$I_L + \frac{V_{rev}}{R_L + R_{int}}$$

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Formula sheet continued

WIND:

Wind power : $P_w = \frac{1}{2}\rho A u^3$	ρ- wind density in kg/m^3 A -area swept by rotor in m^2 u-velocity of wind in m/s
Extractable power from the wind: $P_m = C_p(\frac{1}{2}\rho A u^3) = C_p P_w$	C_p- power coefficient P_w = wind power
Wind velocity at certain height H: $v = v_0 \frac{ln\left(\frac{H}{z_0}\right)}{ln\left(\frac{H_0}{z_0}\right)}$	Z_0 = Roughness parameter V_0 = Known wind velocity a height H_0
Annual energy production $AEP = CF \times GS \times 8{,}760$	CF = Capacity factor GS= Generator size
Angular velocity of the blade in rad/s $\omega = \frac{2\pi n}{60}$	N = Number of rotation of the blade in rpm.
Tip speed ratio $\lambda = \frac{\omega r}{u}$	r = maximum radius of the turbine in m ω = angular velocity of the blade in rad/s u = wind speed in m/s
Torque in N.M/rad $T = \frac{P}{\omega}$	P = power ω = angular rotation of the blade
Shaft diameter in meter $D = 2r_o = 2\sqrt[3]{\frac{2T}{\pi f_s}}$	T = torque in N.M/rad f_s = maximum stress in Pascle

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Formula Sheet continued

Energy absorbed by the clutch in Joules $U = \frac{I\omega^2}{2}$	I = moment of inertia in kg-m^2 ω = angular rotation of the blade in rad/s
Mass in k.g. $m = \frac{U}{c_p \Delta T}$	U = Energy absorbed in Joules C_P = specific heat capacity in J/kg· °C ΔT = Temperature in °C.
Volume in m^3 $V = \frac{m}{\rho}$	m= mass in k.g. ρ- wind density in kg/m^3
R = Radius in meter $r_o = \sqrt{\frac{V}{\pi L}}$	V = Volume in m^3. L = Thickness in m.
Probability density and cumulative distribution function of the Rayleigh model $P(f(v)) = 1 - e^{\left[-\left(\frac{\pi}{4}\right)\left(\left(\frac{V}{v_m}\right)^2\right)\right]}$	Vm = Rated wind speed V = New wind speed
Simple payback in years SP = IC/(AEP × \$/kWh) $SP = \frac{IC}{(AEP * \frac{\$}{kWh} - IC * FCR - AOM)}$	IC = installation cost AEP = Annual Energy production in Watt \$/kWh = retail rate of electricity AOR = Annual operation and maintenance cost FCR = Fixed Charge Rate

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Appendix 1 - Solar Panel Specifications

150W 12V Solar Panel Specifications:

Max. Power Pmp(W)	150W
Power Tolerance(+/-)	5%
Max. Power Voltage Vmp (V)	18.25
Max. Power Current Imp (A)	8.22
Open Circuit Voltage Voc (V)	22.5
Short Circuit Currenty Isc (A)	8.85
Max. System Voltage VDC	1000/600
Pm Temperature Coefficient(%/K)	-0.4
Isc Temperature Coefficient	4.7
Voc Temperature Coefficient	-2
NOCT-Nominal operating cell temp. (Celsius)	45
Dimension	(1095 x 1605 x 909)

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160W 12V Solar Panel Specifications:

Electrical:	
Power Max (Pm)	160 +/- 5%
Short Circuit Current (Isc)	9.45 A
Max Power Current (Imp)	9.05 A
Maximum Voltage (Vmp)	17.70 V
Open Circuit Voltage (Voc)	21.40 V
Maximum System Voltage	1000 VDC
Mechanical:	
Type	Multi Crystalline
No of Cells in Series	36
Frame Type	Aluminum
Weight	13.00 Kg
Y-Axis Mounting Hole	503 mm
X-Axis Mounting Hole	970 mm
Dimension	(1095 x 503x 970)

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200W 24 V Solar Panel Specifications:

Power Max (Pm)	200 +/- 5%
Short Circuit Current (Isc)	6.10 A
Max Power Current (Imp)	5.70 A
Maximum Voltage (Vmp)	35.20 V
Open Circuit Voltage (Voc)	44.40 V
Maximum System Voltage	1000 VDC
Mechanical:	
Type	Multi Crystalline
No of Cells in Series	72
Frame Type	Aluminum
Weight	20.30 Kg
Dimension	(1095 x 1605 x 909)

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