[OCD017]

UNIVERSITY OF BOLTON

WESTERN INTERNATIONAL COLLEGE

BENG (HONS) ELECTRICAL AND ELECTRONIC ENGINEERING

TRIMESTER ONE EXAM 2021/2022

RENEWABLE ENERGIES

MODULE NO: EEE6016

Date: **Thursday 6th January 2022** **Time: 10:00 – 12:30**

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.

The electrical load for a residential building situated in the UAE is given in Table 1.

Given,

Peak sun hours = 5.3

System losses = 0.8

Battery depth of discharge = 60%

Inverter Efficiency = 85%

Table 1 - Electrical load of appliances

Loads	**Quantity**	**Watts**	**Hours/day**
TV	1	100	4
Stereo	1	350	2
Blender	1	500	0.5
Washing machine	1	500	1
Lamps	15	10	5
Microwave	1	1000	0.5
Iron	1	1200	0.5
Refrigerator	1	700	24
Vacuum cleaner	1	600	1
Water heater	4	3500	2
Ceiling Fan	6	120	3
Air conditioner	6	2800	8
Desktop Computer	2	200	3
Laptop	4	200	5
Motor	1	750	1

Q1 continued over the page…

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Q1 continued…

Design a 12V Roof-top off-grid Solar PV System for the given load. The PV panel specification is provided in appendix 1.

i) PV array size

(5 marks)

ii) Array arrangement

(4 marks)

iii) Charge Controller size

(5 marks)

iv) Battery size & arrangements

(3 marks)

v) Inverter sizing

(2 marks)

vi) Wire size

(3 marks)

vii) PV System layout

(3 marks)

Total 25 marks

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Q2.

i) Using a schematic diagram discuss the construction and working principle of Proton Exchange Membrane fuel cell (PEMFC).

(6 marks)

ii) Explain how fuel cells are classified based on temperature of operation and chemical reaction.

(6 marks)

iii) A fuel cell employs the reaction below,

$$A + B \rightarrow AB.$$

Given that for each molecule of AB, 2 electrons circulate in the load and relevant thermodynamic data at STP

Table 2 - Thermodynamic data

	Enthalpy of formation $\overline{\Delta h_f}$ MJ/kmole	$\bar{s}$ **kJ/K mole**
A(g)	0	100
B(g)	0	150
AB(g)	-200	200

Determine the reversible voltage generated by the fuel cell.

(5 marks)

Q2 continued over the page…

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Q2 continued…

iv) Consider an electrolyser in which there are 240 series connected cells each one having the below characteristics,

$$V = 1.520 + 20 \times 10^{-6} \text{ x } I, \text{ operating at } 20{,}000 \text{ A.}$$

Determine the following

a) The total voltage that must be applied.

(2 marks)

b) The hydrogen production rate in kg / day.

(2 marks)

c) The rate of water consumption in m^3 / day.

(2 marks)

d) The heat power rejected.

(2 marks)

Total 25 marks

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Q3.

A well designed EV1 automobile has an excellent aerodynamics and overall low losses. With an energy supply of 15 kWh, it has a range of over 120 km and uses 200 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 refuelling 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 200 kW), assuming the smallest possible number of individual cells are used.

(10 marks)

(b) Determine the efficiency of the cell.

(2 marks)

(c) If cruising at 100 km/h require only 30 kW power, estimate in kilogram the amount of hydrogen required to cover a range of 800 km.

(11 marks)

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

(2 marks)

Total 25 marks

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Q4.

i) Explain the aerodynamics of wind turbine blades and analyse the effect of angle of attack.

(6 marks)

ii) Calculate the air density (a), at 20^0 C (293.15 K), at an elevation of 2500 m (8202 ft). Then (b) find it assuming an air temperature of 10^0 C at 2500 m.

(3 marks)

iii) Suppose a 1500 kW wind turbine with 70 m rotor diameter is mounted at a hub height of 60 m tower with the average wind speed of 24 m/s.

a) Estimate air density and average wind power (in W/m^2) assuming Rayleigh statistics for 15^0 C and -5^0C.

(4 marks)

b) Determine the annual energy production with a 40% turbine efficiency for both 15^0C and -5^0C.

(2 marks)

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

a) Determine the wind velocity at 40 m height if the wind velocity is 14m/s at 20 m height. Roughness parameter in the town is 1.2.

(2 marks)

b) Evaluate the density of the wind, if the wind speed is 10m/s and the power per area is 243.7 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 2910.5 W/m^2.

(4 marks)

c) Calculate the total available wind power and power that can be converted into rotational energy in the turbine if the wind velocity is 21 m/s and the wind density is 1.325 kg/m^3. The wind turbine has a radius of 4 meter and the wind Power Coefficient, CP is 0.3.

(2 marks)

Q4 continued over the page…

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Q4 continued…

d) 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 meter.

(2 marks)

Total 25 marks

Q5.

i) Critically analyse the differences between HAWT and VAWT and provide remarks on the most efficient model of wind turbine with proper justification.

(5 marks)

ii) A wind turbine is designed with an electrical generator rated at 200kW output. The low-speed shafts rotate at 40 rpm and high speed shaft rotates at 1800 rpm. Solid steel shafts are available with recommended maximum stress of 55 MPa. The gearbox efficiency at rated conditions is 0.90 and generator efficiency is 0.85. Determine the necessary shaft diameters.

(6 marks)

iii) A 40-m, three bladed wind turbine produces 600 kW at a windspeed of 14m/s. Air density is the standard 1.225 kg/m3. Under these conditions,

a. At what rpm does the rotor turn when it operates with a TSR of 4.0?

(2 marks)

b. What is the tip speed of the rotor?

(1 mark)

c. What is the efficiency of the complete wind turbine (blades, gear box generator) under these conditions?

(2 marks)

d. If the generator needs to turn at 1800 rpm, what gear ratio is needed to match the rotor speed to the generator speed?

(1 mark)

Q5 continued over the page…

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Q5 continued…

iv) 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

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

(2 marks)

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

(2 marks)

(c) 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.

(4 marks)

Total 25 marks

END OF QUESTIONS

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Formula Sheet

PV:

DC system voltage = Inverter DC input voltage (usually 12, 24 or 48 VDC)

$$\text{Ampere hours} = \frac{\text{Wh}}{\text{DC system voltage}}$$

total average amp-hours per day needed=$1925.3Ah * 1.2$ (to compensate for battery charge/discharge losses.)

$$\text{the total solar array amps required} = \frac{\text{total average amp-hours per day needed}}{\text{average sun-hours per day}}$$

Sizing Solar Arrays with MPPT Charge Controllers

average charging voltage.
Use 13.5 VDC for 12 VDC systems;
27 VDC for 24 VDC systems;
54 VDC for 48 VDC systems.

total PV array wattage required= total solar array amps required * the average charging voltage

$$\text{Required no. of panels} = \frac{\text{PV array wattage}}{\text{Rated power of selected panel}}$$

$$\text{Minimum no. of panels in series in each string} = \frac{\text{Min. MPP voltage of Inverter (V)}}{\text{MPP voltage of PV panel (V)}}$$

$$\text{Maximum no. of panels in series in each string} = \frac{\text{Max. MPP voltage of Inverter}}{\text{O.C. voltage of PV panel (V)}}$$

$$\text{Max. no. of strings per Inverter} = \frac{\text{Max. dc input current of Inverter (A)}}{\text{S.C. current of PV paanel (A)}}$$

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Battery size

$$\text{Battery Capacity (Ah)} = \frac{\text{Total Dailly Watt hours per day x Days of autonomy}}{\text{Battery Efficiency x Depth of Discharge x nominal battery voltage}}$$

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

Inverter size

$$\text{Inverter size} = \frac{\text{Peak Power}}{\text{Inverter Efficiency}}$$

Wire size

Maximum Design current= S.C. Current of PV Panel× No. of string× Safety Factor

$$S = \frac{0.3\ L\ Im}{\Delta V}$$

$$d = \sqrt{4S/\pi}$$

$$\text{Maximum no. of panels in series in each string} = \frac{\text{Max. MPP voltage of Inverter}}{\text{O. C. voltage of PV panel (V)}}$$

$$\text{Max. no. of strings per Inverter} = \frac{\text{Max. dc input current of Inverter (A)}}{\text{S. C. current of PV paanel (A)}}$$

Panel specification

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LG400N2W-V5 I LG395N2W-V5

General Data

Cell Properties(Material / Type)	Monocrystalline / N-type
Cell Maker	LG
Cell Configuration	72 Cells (6 x 12)
Number of Busbars	12EA
Module Dimensions (L x W x H)	2,024mm x 1,024mm x 40 mm
Weight	20.3 kg
Glass(Material)	Tempered Glass with AR Coating
Backsheet(Color)	White
Frame(Material)	Anodized Aluminium
Junction Box(Protection Degree)	IP 68
Cables(Length)	1,200 mm x 2EA
Connector(Type / Maker)	MC 4 / MC

Certifications and Warranty

Certifications	IEC 61215-1/-1-1/2:2016, IEC 61730-1/2:2016, UL 1703
	ISO 9001, ISO 14001, ISO 50001
	OHSAS 18001, PV CYCLE
Salt Mist Corrosion Test	IEC 61701 : 2012 Severity 6
Ammonia Corrosion Test	IEC 62716 : 2013
Module Fire Performance	Type 1 (UL 1703)
Fire Rating	Class C (UL 790, ULC/ORD C 1703)
Solar Module Product Warranty	25 Years

Electrical Properties (STC*)

Model		LG400N2W-V5	LG395N2W-V5
Maximum Power (Pmax)	[W]	400	395
MPP Voltage (Vmpp)	[V]	40.6	40.2
MPP Current (Impp)	[A]	9.86	9.83
Open Circuit Voltage (Voc, ±5%)	[V]	49.3	49.2
Short Circuit Current (Isc, ±5%)	[A]	10.47	10.43
Module Efficiency	[%]	19.3	19.1
Power Tolerance	[%]	0 ~ +3	

* STC (Standard Test Condition): Irradiance 1000 W/m², Cell temperature 25 °C, AM 1.5

Operating Conditions

Operating Temperature	[°C]	-40 ~ +90
Maximum System Voltage	[V]	1,500(UL), 1000(IEC)
Maximum Series Fuse Rating	[A]	20
Mechanical Test Load (Front)	[Pa / psf]	5,400 / 113
Mechanical Test Load (Rear)	[Pa / psf]	3,000 / 63

* Test Load = Design load X Safety Factor (1.5)

Packaging Configuration

Number of Modules per Pallet	[EA]	25
Number of Modules per 40ft HQ Container	[EA]	550
Packaging Box Dimensions (L x W x H)	[mm]	2,080 x 1,120 x 1,226
Packaging Box Gross Weight	[kg]	551

Inverter specifications

Model No.	GT3-17K-D	GT3-20K-D	GT3-22K-D	GT3-25K-D
Input Data(DC)				
Max. DC Power	22.1 kW	26 kW	28.6 kW	32.5 kW
Max. DC Voltage	1000 V	1000 V	1000 V	1000 V
Rated DC Voltage	620 V	620 V	620 V	620 V
Min. DC Voltage to Start Feed In	250 V	250 V	250 V	250 V
Max. DC Current	50 A	50 A	50 A	75 A
MPP(T) Voltage Range	180~960 V	180~960 V	180~960 V	180~960 V
No of MPP Trackers	2	2	2	2
DC Inputs	4	4	4	6
Connectors	MC4	MC4	MC4	MC4
Output Data (AC)				
Max. AC Power	18.7 kW	22 kW	24.2 kW	27.5 kW

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Battery specification

Items	Parameter
Battery Type	48V 400ah lithium deep cycle battery (LiFePo4)
Nominal Voltage	51.2V
Nominal Capacity	400Ah
Energy	20480WH
Dimensions (L x W x H)	927 x 460 x 475 mm (36.5 x 18.1 x 18.7")
Weight	198kg (436.5 lbs)
Case Material	ABS/Iron case
Certifications	CE/ISO/UN38.3/MSDS
Efficiency	99%
Self Discharge	<1% per Month
Series & Parallel Application	max. 4 series or 4 parallel connected application
Peak Discharge Current	400A (<5s)
BMS Discharge Current Cut-Off	550A (±20A, 9±2ms)
Operation Temperature Range	-20~60°C
Voltage at end of Discharge	57.6V
Working Voltage	44.8-57.6V
Discharge Temperature	-4 to 140 °F (-20 to 60 °C)
Charge Temperature	32 to 113 °F (0 to 45 °C)
Storage Temperature	23 to 95 °F (-5 to 35 °C)
Cycle Life	> 3000 cycles
Self-Discharge Rate	Residual capacity: ≤3%/month; ≤15%/years
	Reversible capacity: ≤1.5%/month; ≤8%/years
Storage Temperature & Humidity Range	Less than 1 month: -20°C~35°C, 45%RH~75%RH
	Less than 3 months: -10°C~35°C, 45%RH~75%RH
	Recommended storage environment: 15°C~35°C, 45%RH~75%RH

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:

$$G = H - TS$$

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

Reversible Voltage:

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

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

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

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

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 Wind Energy

Equations	**Variables**
$v/v_0 = [\ln(H/Z)] / [\ln(H_0/Z)]$	v- unknown velocity (m/s) at height H in m. v_0- velocity (m/s) at reference height H_0 in m Z - surface roughness length in m.
Tip speed ratio, $\lambda = \omega R/V = 4\pi/n$	ω- angular velocity in rad/s R- rotor radius in m V- velocity of wind in m/s n- no: of blades in the turbine
$C_p/C_T = \lambda$	Cp-Turbine power co-efficient CT-Torque co-efficient
Pturbine = Cp x Pwind Pwind = ρAV3/2 Pturbine = T x ω	Cp- power coefficient ρ-air density in kg/m3 A -area swept by rotor in m2 V-velocity of wind in m/s T- Torque
$P = P_0 e^{-1.185\times10^{-4}\text{H}} = 1(\text{atm})\cdot e^{-1.185\times10^{-4}\text{H}}$	P_0=reference pressure of 1 atm H=Height in m
$PV = nRT$	P= absolute pressure (atm) V = volume (m^3) n = mass (mol) T = absolute temperature (K); $K = {}^\circ C + 273.15$ R = ideal gas constant = $8.2056*10^{-5}$ $m^3 \cdot atm \cdot K^{-1} \cdot mol^{-1}$
$\rho = \dfrac{P \times \text{M.W.} \times 10^{-3}}{RT}$	P=Pressure(atm) ρ=Standard air density= 1.225 kg/m3 M.W=Equivalent molecular weight of air= 28.97 T = absolute temperature (K); $K = {}^\circ C + 273.15$ R = ideal gas constant = $8.2056*10^{-5}$ $m^3 \cdot atm \cdot K^{-1} \cdot mol^{-1}$
$\rho_{z,t} = \dfrac{353.1}{273.15+t} exp(-0.0342 * \dfrac{z}{273.15+t})$	ρz,t - air density z - hub height in m t - temperature in 0C

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$P_{avg\ in\ W/m^2} = 1.91 * \frac{1}{2}\rho v^3$ (Rayleigh)	ρ - air density v - wind velocity
$Annual\ Energy\ E_{annual} = 8760 * C_p * P_{avg\ in\ W/m^2} * A$	Cp - power coefficient A – Area
$F\ (V \leq v)\Big\|_{Rayleigh} = 1 - e^{-\left[\frac{\pi}{4}\left(\frac{v}{\bar{v}}\right)^2\right]}$	v – velocity $\bar{v}$ = average wind speed
Ph = ρh * Q * g * h	Ph - hydraulic power ρh - density of water Q – water flow rate g – acceleration due to gravity h – height
D = 2 * 3√ (2T/πfs)	D – diameter of the shaft T – torque fs – stress
J = πr04/2 ρa = ρ l I = J ρa	J – Area moment of Inertia r0 – radius ρa - area surface density l - length I – mass moment of inertia
ts = ω I /TR U = I ω2/2 m = U/ Cp ΔT V = m/ρ r0 = √ (V/πL)	ts – time reuired by rotor to accelerate ω – angular veloctity TR – rated torque I – moment of inertia U – energy absorbed by clutch Cp - specific heat capacity ΔT – temperature rise V – volume m- mass r0 – radius L – thickness P - density
Gear Ratio=Grpm/Rrpm	Grpm-Generator rpm Rrpm-Rotor rpm

END OF FORMULA SHEETS

END OF PAPER