OCD029

UNIVERSITY OF BOLTON

OFF CAMPUS DIVISION

WESTERN INTERNATIONAL COLLEGE

BENG(HONS) ELECTRICAL AND ELECTRONIC ENGINEERING

SEMESTER ONE EXAMINATIONS 2022/2023

RENEWABLE ENERGIES

MODULE NO: EEE6016

Date: Saturday, 07 January 2023 **Time: 10:00 – 12:30**

INSTRUCTIONS TO CANDIDATES:

There are FIVE questions on this paper.

Answer ANY FOUR questions.

All questions carry equal marks.

Q1.

A. A Horizontal axis Wind Turbine having three blades is designed and installed at a particular location with the following measured parameters.

Speed of the wind - 9 miles per hour at 1 atm and 27°C.

Diameter of Rotor – 60m

Speed of Rotor – 40 rpm

Air density – 1.23 kg/m^3

i. Calculate the theoretical power output and power density in this wind? You hook your turbine up to multimeter and find that it is pumping out 10KW. Calculate the coefficient of power of the turbine.

[5 marks]

ii. Determine the tip-speed ratio for this turbine? How does this compare with the optimal tip-speed ratio? Also, what gear ratio is needed to match the rotor speed to the generator speed of this turbine, if the generator turns at 1600 rpm?

[7 marks]

iii. Estimate the total Energy produced by the given Horizontal axis wind Turbine after 1 year. Assuming the turbine efficiency is 0.4

[3 marks]

iv. Determine the maximum axial thrust, centrifugal force on the blade root and the torque coefficient of the turbine for the given HAWT specifications.

[5 marks]

B. Design the rotor radius for a multiblade wind turbine that operates in a wind speed of 36 kmph to pump water at a rate of 6 m^3/h with a lift of 6m. Also calculate the angular velocity of the rotor. Given: water density = 1000 kg/m^3, g= 9.8m/s, water pump efficiency = 50%, efficiency of rotor to pump = 80%, C_p= 0.3; λ= 1 and air density= 1.2 kg/m^3.

[5 marks]

Total 25 marks

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Q2.

NEG Micon 60-m diameter wind turbine having a rated power of 1000 kW is installed at a site having Rayleigh wind statistics with an average windspeed of 7 m/s at the hub height.

A. Analyse the Weibull and Rayleigh statistics used for the wind data assessment.

[5 marks]

B. Determine the total energy generated by this wind turbine for the given wind speed data in table 1.

[14 marks]

Table 1 NEG Micon 60 specification

		NEG
Manufacture		**MICON**
Rated Power(KW)		**1000**
Diameter(m)		**60**
Avg.windspeed		
v(m/s)	v(mph)	KW
0	0	0
1	2.2	0
2	4.5	0
3	6.7	0
4	8.9	33
5	11.2	86
6	13.4	150
7	15.7	248
8	17.9	385

C. From the result, find the overall average efficiency of this turbine in these winds.

[4 marks]

D. Find the productivity in terms of kWh/yr delivered per m^2 of swept area.

[2 marks]

Total 25 marks

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Q3.

The electrical load for a residential building situated in the UAE is given in Table 2.

Given,

Peak sun hours= 5.3
system losses= 0.8
Battery depth of discharge = 60%
Inverter Efficiency = 85%

Table 2 - Electrical load of appliances

Loads	**Quantity**	**Watts**	**Hours/day**
TV	1	100	4
Blender	1	500	0.5
Washing machine	1	500	1
Lamps	15	10	4
Microwave	1	700	0.5
Iron	1	300	0.5
Refrigerator	1	400	10
Vacuum cleaner	1	400	1
Water heater	4	1200	2
Ceiling Fan	6	120	3
Air conditioner	3	700	8
Desktop Computer	2	200	3
Laptop	4	200	5
Motor	1	750	1

Design a 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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Q4.

A. Using a schematic diagram discuss the working principle of Hydrogen fuel cell.

[4 marks)

B. 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 RTP

Table 3 - 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.

[8 marks)

C. Consider an electrolyser in which there are 250 series connected cells each one having the below characteristics,

$V = 1.420 + 20 \times 10^{-6} \times I$, operating at 20,000 A.

Determine the following

I. The total voltage that must be applied.

[5 marks]

II. The hydrogen production rate in kg / day.

[3 marks]

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

[3 marks]

IV. The heat power rejected.

[2 marks]

Total 25 marks

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Q5.

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 200 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 350W.

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 25 kW power, estimate in kilogram the amount of hydrogen required to cover a range of 700 km.

(11 Marks]

D. If the hydrogen is stored at 400 atmospheres, calculate the volume it occupy at 298 K?

[2 marks]

Total 25 marks

END OF QUESTIONS

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EQUATION SHEET

Wind

1 miles per hour = $\frac{1}{2.237}\ m/s$

Wind power, P = $\frac{1}{2}\ \rho A\ V^3$

Swept Area, A = $\pi r^2\ \ or\ \ \frac{\pi D^2}{4}$

Power Density = $\frac{P}{A}$

Coefficient of Power, $C_p = \frac{Wind\ power\ output\ from\ turbine}{Wind\ Power}$

Tip speed ratio [TSR] , λ = $\frac{Tip\ speed\ of\ rotor\ blade}{Wind\ speed}$

Tip speed of the rotor blade = $\frac{The\ distance\ travelled\ by\ tip}{Time\ taken\ for\ 1\ revolution}$

Distance travelled by tip = 2πr

Time taken for 1 revolution= $\frac{60}{speed\ in\ rpm}$

Optimal tip speed, $\lambda_{optimal}$ = $\frac{4\pi}{n}$

n- number of blades

Gear ratio = $\frac{Generator\ rpm}{Rotor\ rpm}$

Annual energy production = turbine efficiency x power in wind x operation hours in 1 Year.

Maximum Axial Thrust, $F_{x(max)}$ = $\frac{\pi}{8}\rho D^2 V^2$

Centrifugal Force [Torque), $T_{max} = F_{x(max)} * R$

Torque coefficient, $C_T = \frac{C_P}{\lambda}$

λ- Tip speed ratio

Angular velocity of rotor, ω = $\frac{\lambda V_u}{R}$

Rayleigh pdf, f[v)= $\frac{\pi v}{2\bar{v}^2}\ e^{\left(-\frac{\pi}{4}\left(\frac{v}{\bar{v}}\right)^2\right)}$

Total hours the wind blow in v m/s in 1 year = 8760x f[v)

Energy delivered = Power x time

Average Power, $\bar{P}$ = $\frac{6}{\pi}\ \frac{1}{2}\ \rho\ A\ \bar{v}^3$

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Average Efficiency = $\frac{Energy\ at\ average\ power}{Total\ Energy}$

Productivity = $\frac{Total\ Energy}{Swept\ area}$

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.)

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

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

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

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

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

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

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

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

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

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

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FUEL CELL:

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

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

Heat generation [Second law of thermodynamics):

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

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 x 10^{-19}

N_0=6.023 x 10^{26}

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

Enthalpy of Hydrogen Δh= 241.8 x 10^6

Hydrogen production rate:

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

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

$$P_L = I \text{ x } V_L$$

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

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

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

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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Appendix 1

Panel specification

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

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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℃
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℃~35℃, 45%RH~75%RH
	Less than 3 months: -10℃~35℃, 45%RH~75%RH
	Recommended storage environment: 15℃~35℃, 45%RH~75%RH

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