OCD19

UNIVERSITY OF BOLTON

OFF CAMPUS DIVISION

WESTERN INTERNATIONAL COLLEGE

BENG(HONS) ELECTRICAL AND ELECTRONIC ENGINEERING

SEMESTER ONE EXAMINATION 2023/24

RENEWABLE ENERGIES

MODULE NO: EEE6016

Date: Saturday 13 January 2024 **Time: 10:00 AM – 12:30 PM**

INSTRUCTIONS TO CANDIDATES:

There are FIVE questions on this paper.

Answer ANY FOUR questions.

All questions carry equal marks.

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Off Campus Division, Western International College
BEng(Hons) Electrical & Electronic Engineering
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Renewable energies
Module No. EEE6016

Question 1

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 1 - Thermodynamic data

	Enthalpy of formation $\overline{\Delta h_f \Delta h_f}$ **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,

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

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

Please turn the page

Question 2

A hydrogen/Oxygen fuel cell has a V-J characteristic (at RTP) given by

$$V_L = 0.98 - 10^{-3} J.$$

The active area of its electrodes is 0.44m^2. The water is exhausted from the cell in gaseous form.

i. Evaluate rate of heat production when the cell is open circuited?

(2 marks)

ii. Assess the rate of heat production when the cell is short circuited?

(6 marks)

iii. Analyse the heat production when the cell is connected to a load that maximizes the power output?

(5 marks)

iv. Calculate the efficiencies of the cell under the 3 conditions above?

(3 marks)

v. Analyse the efficiency of the cell if it delivers half of the maximum power.

(9 marks)

Total 25 marks

Question 3

The electrical load for a residential building situated in the UAE is given in Table 2. Given, Peak sun hours= 5.84; Battery depth of discharge = 80%;

Question 3 continued over…

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Question 3 continued…

Table 2 - Electrical load of appliances

Loads	Quantity	Watts	hrs
TV	1	200	8
Blender	1	1200	0.8
Washing machine	1	800	1.5
Lamps	15	10	6
Microwave	1	1000	0.5
Iron	1	1800	0.5
Refrigerator	1	350	4
Vacuum cleaner	1	1700	0.5
Water heater	4	1800	1
Ceiling Fan	6	150	10
Air conditioner	3	2500	8
Desktop Computer	2	200	10
Laptop	4	100	3
Motor	1	500	2

Design a roof-top off-grid Solar PV System for the given load. The specifications are provided in appendix.

Total 25 marks

Question 4

A Nordex 55-m diameter wind turbine having a rated power of 1MW is installed at a hub height wind speed of 14m/s. It has a cut-in speed of 4m/s and a cut-out speed of 25m/s. Assume that this machine is located at a site where the mean wind speed is 10m/s and that a Rayleigh wind speed distribution can be used. Calculate the following

Question 4 continued over…

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Question 4 continued…

i. Determine number of hours per year that the wind turbine is below the cut-in speed and the number of hours when the machine will be shut down due to wind speeds above the cut-out velocity.

(5 marks)

ii. Calculate the annual energy production (in kWh) when the Nordex 60 m diameter wind turbine operates at its rated power.

(5 marks)

iii. Evaluate the overall average efficiency of the turbine and assess its productivity in terms of kWh/year delivered per square meter of swept area.

(7 marks)

iv. Assess the capacity factor of the wind turbine based on the given information.

(3 marks)

v. Discuss the major components of a Horizontal axis wind turbine and explain why each part is important for the turbine to function effectively.

(5 marks)

(Total 25 marks)

Question 5

A 40m diameter, three bladed Horizontal axis wind turbine produces 700KW at a wind speed of 14m/s at a height of 20m.The air density is 1.225kg/m^3.

Question 5 continued over…

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Question 5 continued…

i. Evaluate tip speed ratio for an HAWT with a 50 rpm rotor speed. Determine the gear ratio needed to sync with an 1800 rpm generator. Compare calculated tip speed ratio to optimal values and analyse the potential implications on the wind turbine's operation.

(8 marks)

ii. Analyse the efficiency of the given wind turbine system?

(3 marks)

iii. Determine the wind speed if the wind turbine is kept at a height of 40m over surface terrain with a few trees (Surface roughness length for the given terrain is 100mm) using both Logarithm Wind profile and Power law wind profile estimation methods. Assume power law exponent as 0.142.

(5 marks)

iv. Evaluate the ratio of available power in the wind at the highest point the rotor reaches to its lowest point. (2 marks)

v. Determine the maximum axial thrust, centrifugal force acting on the blade root, and the torque coefficient of the turbine based on the provided HAWT specifications. (7 marks)

Total 25 marks

END OF QUESTIONS
Please turn over for equations sheet

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) , $\lambda\lambda$ = $\frac{Tip\ speed\ of\ rotor\ blade}{Wind\ speed}$

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.

Capacity Factor(C.F) = $\frac{Actual\ Energy\ Delivered}{Rated\ Power * 8760}$

Maximum Axial Thrust,

$$F = \left(\frac{\pi}{9}\right) \rho D^2 V^2$$

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 = $\frac{\lambda V_u}{R}$

Please turn the page

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

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=$1925.3Ah * 1.21925.3Ah * 1.2$ (to compensate for battery charge/discharge losses.)

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

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

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

Please turn the page

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

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

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

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

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

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

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

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

Panel specification

LG400N2W-V5 | 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℃
Voltage at end of Discharge	57.6V
Working Voltage	44.8-57.6V
Discharge Temperature	-4 to 140 ºF (-20 to 60 ºC)
Charge Temperature	32 to 113 ºF (0 to 45 ºC)
Storage Temperature	23 to 95 ºF (-5 to 35 ºC)
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

FUEL CELL:

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

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

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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 $\Delta H \Delta H$ is enthalpy of formation,$\Delta S \Delta S$ 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:

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

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

$P_L = I \times V_L$

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

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

Please turn the page

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

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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