UNIVERSITY OF BOLTON

WESTERN INTERNATIONAL COLLEGE FZE

BEng (Hons) ELECTRICAL AND ELECTRONIC ENGINEERING

SEMESTER ONE EXAMINATION 2018/2019

RENEWABLE ENERGIES

MODULE NO: EEE6016

Date: Thursday 17th January 2019 **Time: 10:00am - 12:30pm**

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.

Western International College FZE
BEng (Hons) Electrical & Electronic Engineering
Semester 1 Examinations 2018/19
RENEWABLE ENERGIES
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Q1.

Design a residential PV system for a residential building situated in the UAE. The electrical load 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	120	4
Washing machine	1	500	0.5
Lamps	10	10W	5
microwave	1	1200W	1
Iron	1	1000W	0.5
Refrigerator	1	180W	24
Vacuum cleaner	1	200W	1
water heater	4	4000W	3
fan	4	75W	3
Air conditioner	4	1000W	8
Laptop	2	50W	5
Motor	1	750W	1

i) Determine

a) PV array sizing, number of PV modules, area required and modes of connections, connection.

(10 marks)

b) Charge controller and Battery sizing.

(8 marks)

Q1 continued over the page

Please turn the page

Q1 continued.

c) Inverter sizing

(2 marks)

ii) Critically evaluate the environmental & sustainability limitations relevant to PV systems.

(5 marks)

Total 25 marks

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	**$\overline{s}$ 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

Please turn the page

Q2 continued.

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

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

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

Q3.

The EV1 was an exceedingly well designed automobile, having excellent aerodynamics and, all over, low losses. With an energy supply of 14 kWh, it had range of over 100 km. A 100 kW motor is used to get a good acceleration. The problem was that, no matter how good a battery it used, it took a long time to recharge it. If instead of a battery, it had used fuel cells, then refueling would take only minutes versus hours for recharging.

Imagine that you want to replace the NiMH batteries by a fuel cell battery which must supply 100 kW of power.

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

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

The maximum internal heat dissipation capability is 300 W.

Product water exits the cell in vapor form.

Q3 continued over the page

Please turn the page

Q3 continued.

The fuel cells deliver their energy to a power conditioning unit (inverter) that changes its dc input into ac power .The efficiency of this unit can be taken as 100%.

Analyse the following

a) The voltage that the fuel cell battery (at 100 kW), must deliver 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 110 km/h needs only 20 kW, estimate in kilogram the amount of hydrogen required to cover a range of 800 km.

(10 marks)

d) If the hydrogen is stored at 500 atmospheres, how much volume does it occupy at 298 K?

(3 marks)

Total 25 marks

Q4.

i) Analyse the significance of “angle of attack” in the design of wind turbines with the aid of appropriate diagrams.

(6 marks)

ii) A wind turbine with rotor diameter of 5 m is located over a terrain with surface roughness length of 100 mm and hub height of 40 m. Speed over the terrain at a height of 10 m is found to be 9 m/s. Determine wind speed at the given hub height and also torque available at the rotor shaft if the speed of rotor is 130 rpm. Assume air density is 1.24 kg/m^3 and power coefficient of turbine is 0.35.

(5 marks)

Q4 continued over the page

Please turn the page

Q4 continued.

iii) Suppose a 1300 kW wind turbine with 60 m rotor diameter is mounted at a hub height of 50 m tower with an the average wind speed of 20 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 30% turbine efficiency for both 15^0C and -5^0C.

(2 marks)

iv) A wind turbine with a rotor diameter of 55 m is rated at 1 MW at a hub height wind speed of 14 m/s. It has a cut-in speed of 4 m/s and cut-out speed of 25 m/s. Assume that this machine is located at a site where the mean wind speed is 10 m/s and that a Rayleigh wind speed distribution can be used. Determine and analyse the following:

a) The number of hours per year that the wind is below the cut-in speed.

(2 marks)

b) The number of hours per year that the machine will be shut down due to wind speeds above the cut-out velocity.

(2 marks)

c) The Energy production (MWh/year) when the wind turbine is running at rated power.

(2 marks)

d) The ideal power curve for the turbine and calculate energy produced in one day if wind blows continuously between 15 and 20 m/s all day.

(2 marks)

Total 25 marks

Please turn the page

Q5.

i) Analyse wind turbine power curve with the aid of necessary diagrams and over speed protection mechanisms used in wind turbines. (6 marks)

ii) A multibladed wind turbine operates at a wind speed of 36 kmph to pump water using a motor at a rate of 8 m^3/h with a lift of 10 m. The efficiency of the water pump is 50%, efficiency of the motor connected to pump is 80%, power co-efficient of turbine is 0.3 and tip speed ratio is 1. Given water density is 1000 kg/m^3, g=9.81 m/s^2 and air density is 1.225 kg/m^3. Design rotor radius of the turbine and evaluate the angular velocity of the rotor. (6 marks)

iii) Design a wind turbine with an electrical generator rated at 200 kW output. The low speed shafts rotates 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 0.94 and generator efficiency is 0.93.

a) Determine the necessary shaft diameters (5 marks)

b) Evaluate area moment of inertia and mass moment of inertia of low speed shaft of length 0.8 m. Assume volume density of steel is 7800 kg/m^3. (3 marks)

iv) A 120 kW Darrieus wind turbine has the following specifications.

Moment of inertia = 51,800 kg.m^2

Rated torque =23,900 N.m/rad.

Rated rotor speed = 52 rpm.

Q5 continued over the page

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Q5 continued.

A steel clutch plate is to be used for starting the turbine with specific heat capacity of 527 J/kg· ^{0}C and the allowable temperature rise of 100^{0}C. The density of steel is ρ = 7800 kg/m^3. The clutch plate is to be circular with a thickness L = 25.4 mm. Assuming rated torque is applied and that there is no help from the wind, Evaluate the time required to accelerate the rotor to rated speed and minimum radius of the plate.

(5 marks)

Total 25 marks

END OF QUESTIONS

Please turn the page for the Equation Sheets

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BEng (Hons) Electrical & Electronic Engineering
Semester 1 Examinations 2018/19
RENEWABLE ENERGIES
Module No. EEE6016

EQUATION SHEET

PV Module Sizing

Typical percentages of the losses in a PV System are:

90% for temperature loss
85% for battery losses
97% for wiring losses

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

Final PV Module =$\frac{\text{PV Module Size}}{\text{Total Losses}}$

Battery sizing

$\text{Battery Capacity} = \frac{\text{Daily Load Battery}}{\text{Effificiency}}$ Watt Hrs

Multiplying by 3 (number of sun days) Battery Capacity
Multiplying by 80% depth of discharge

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

Inverter Sizing

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

The size of the inverter current =1.3 x the panel current

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Please turn the page for the Appendix

Western International College FZE
BEng (Hons) Electrical & Electronic Engineering
Semester 1 Examinations 2018/19
RENEWABLE ENERGIES
Module No. EEE6016

Appendix 1

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)

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)

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)

Wind Energy

Equations	Variables
U(Z)/U(ZR) =[ln (Z/Zo)]/ [ln (ZR /Zo)]	U(Z) - unknown velocity (m/s) at height Z in m. U(ZR) - velocity (m/s) at reference height ZR in m Zo - surface roughness length in m.

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Module No. EEE6016

Tip speed ratio, λ = ωR/V = 4π/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
Cp/CT= λ	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
$\rho_{z,t} = \frac{353.1}{273.15+t} exp(-0.0342 * \frac{z}{273.15+t})$	ρz,t - air density z - hub height in m t - temperature in 0C
$P_{avg\ in\ W/m^2} = 1.91 * \frac{1}{2}\rho v^3$ (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
$F\ (V \le v)\Big\|_{Rayleigh} = 1 - e^{-\left[\frac{\pi}{4}\left(\frac{v}{\bar{v}}\right)^2\right]}$	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	ts – time reuired by rotor to accelerate ω – angular veloctity

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U = I ω2/2 m = U/ Cp ΔT V = m/ρ r0 = √ (V/πL)	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

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 :

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

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

$N_0=6.023 \times 10^{23}$

Hydrogen production rate:

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

1 H_2 is equal to 202 x 10^{-3} Kg/mol

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

$$P_L = I \times V_L$$

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

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

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

END OF PAPER