OCD009

UNIVERSITY OF BOLTON

OFF CAMPUS DIVISION

WESTERN INTERNATIONAL COLLEGE

BENG (HONS) ELECTRICAL AND ELECTRONIC ENGINEERING

SEMESTER ONE EXAMINATION 2024/25

RENEWABLE ENERGIES

MODULE NO: EEE6016

Date: Saturday, 11 January 2025 **Time: 10:00 am – 12:30 pm**

INSTRUCTIONS TO CANDIDATES:

There are FIVE (5) questions on this paper.

Answer any FOUR (4) questions.

All questions carry equal marks.

QUESTION 1

Design an off-grid photovoltaic (PV) system for a house. Ensure the system can reliably supply power for essential household appliances. Refer to the Appendix for PV panel, inverter, and battery specifications. Address the following:

a) Analyse the total daily energy consumption based on the household appliance usage given in **Table 1**.

(2 marks)

b) Evaluate the total wattage of solar panels required to meet the energy demand. Specify the number of panels and PV array configuration. Refer to the appendix for panel specifications.

(6 marks)

c) Select an appropriate inverter based on the calculated peak load and energy requirements. Refer to the appendix for inverter specifications.

(2 marks)

d) Justify the choice of battery capacity, type, and configuration using the battery specifications in the Appendix, ensuring adequate power storage and reliability.

(5 marks)

e) Determine and recommend appropriate wire sizing for the system, considering both safety and efficiency requirements.

(10 marks)

Question 1 continued over the page…

Question 1 continued…

Table 1. Load Estimation

Appliances	Quantity	Power (W)	Power Usage (hrs/day)	Energy Consumption (Wh/day)
TV	1	200	4	800
Blender	1	1200	0.1	120
Washing Machine	1	800	1	800
Lamps	15	10	4	600
Microwave	1	1000	0.25	250
Iron	1	1800	0.25	450
Refrigerator	1	350	8	2800
Vacuum Cleaner	1	1700	0.25	425
Water Heater	1	1800	1	1800
Ceiling Fan	6	150	5	4500
Air Conditioner	3	2500	2.4	18,000
Desktop Computer	2	200	5	2000
Laptop	4	100	2	800
Motor	1	500	1	500

[TOTAL 25 MARKS]

QUESTION 2

The wind conditions at a proposed site for a wind turbine installation follow a Weibull distribution with a shape parameter of 1.7 and a scale parameter of 8. A wind turbine with a rotor diameter of 35 meters and a rated power capacity of 1500 kW with an average capacity factor of 55% is planned for installation at this site, where the average wind speed at hub height 80 meters is 7.14 m/s. The turbine's power curve is shown in the **Figure Q2**, indicating that it starts generating power at a wind speed of 4 m/s, reaches its rated output at 14 m/s, and shuts down at 25 m/s.

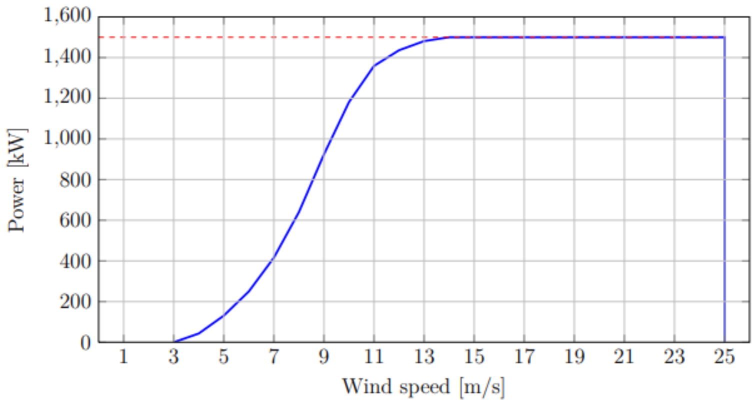

Figure Q2: Wind turbine power curve

a) Calculate how many days a year this wind turbine produces at rated power. and estimate the annual energy output in kWh.

(8 marks)

b) 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)

c) The manufacturer is releasing an upgraded wind turbine model with two main enhancements: a 1% increase in efficiency at all wind speeds and a 5% increase in blade length for improved wind capture. All other features remain the same as the previous model.

Question 2 continued over the page…

Question 2 continued…

Calculate the power curve for this new model and provide a table comparing its power output to that of the previous model across various wind speeds.

(10 marks)

[TOTAL 25 MARKS]

QUESTION 3

A coastal town is evaluating the feasibility of installing a wind turbine to help meet its energy needs sustainably. They plan to install a 50-meter diameter, three-bladed horizontal-axis wind turbine (HAWT) with a rated power of 1200 kW at a wind speed of 15 m/s, measured at a height of 25 meters. The air density at the site averages 1.18 kg/m³ due to the humid coastal climate.

The turbine will be connected to the town's power grid, which operates with an induction generator running at 2000 rpm.

a) To maximize energy capture, calculate the tip speed ratio if the turbine's rotor speed is set to 55 rpm, and determine the necessary gear ratio to synchronize the turbine with a 2000 rpm generator. Compare the calculated tip speed ratio to ideal values for similar coastal wind turbines and discuss how any differences might affect the turbine's efficiency and performance under coastal wind conditions. **(8 marks)**

b) Evaluate the efficiency of this wind turbine system. **(3 marks)**

c) Calculate the maximum axial thrust that could occur due to high wind conditions. Also, determine the centrifugal force acting on each blade root and the turbine's torque coefficient. **(6 marks)**

Question 3 continued over the page…

Question 3 continued…

d) If the turbine is elevated to a hub height of 45 meters for better wind capture, estimate the wind speed at this new height using both the logarithmic wind profile and the power law wind profile. Assume a coastal terrain with sparse vegetation, with a surface roughness length of 0.1 meters and a power law exponent of 0.12. Also assess the ratio of available wind power between the highest and lowest points of the rotor's sweep.

(8 marks)

[TOTAL 25 MARKS]

QUESTION 4

A fuel cell system is designed to operate under specific thermodynamic and electrical conditions.

a) Consider a fuel cell employing the reaction

$$A + B \rightarrow AB$$

At STP, the thermodynamic data for this reaction are:

	$\Delta\overline{h}_f^\circ$ MJ/kmole	$\overline{s}$ kJ/(K kmole)
A(g)	0	100
B(g)	0	150
AB(g)	-200	200

Determine the reversible voltage of the fuel cell for this reaction, given that 2 electrons circulate per molecule of AB. **(8 marks)**

b) A fuel cell battery is intended for a satellite power supply. It must deliver a steady 2 kW at 24 V for 1 week.

The fuel cell manufacturer has a design with the following characteristics:

Open-circuit voltage: 1.10 V

Internal resistivity: 92×10^{-6} ohm m^2

Cell mass: 15 kg per m^2 of active electrode area.

Question 4 continued over the page…

Question 4 continued…

There is a linear relationship between V_L and I_L.

i. Determine the number of cells required in series to achieve a 24 V output. **(8 marks)**

ii. Calculate the total mass of the fuel cells in the battery, assuming the minimum mass required. **(4 marks)**

iii. If the hydrogen is stored at 500 atmospheres, determine the storage volume needed at 298 K. **(5 marks)**

[TOTAL 25 MARKS]

QUESTION 5

The open circuit voltage of a hydrogen/oxygen fuel cell operating at RTP is 0.96 V and its internal resistance is 1.2 mΩ. The activation voltage drop is given by

$$V_{act} = 0.031 + 0.015 \ln I,$$

where I is in amperes.

From thermodynamic data, the reversible voltage, Vrev, is known to be 1.185 V.

200 of the above cells are connected in series forming a battery that feeds a resistive load rated at 2.5 kW at 100 V.

a) Calculate the actual load voltage of the battery. **(10 marks)**

b) Determine the amount of heat generated internally by the battery, assuming the water is exhausted in vapor form. **(15 marks)**

[TOTAL 25 MARKS]

END OF QUESTIONS

PLEASE TURN THE PAGE FOR EQUATION SHEET

University of Bolton
Off Campus Division - Western International College
BEng (Hons) Electrical & Electronic Engineering
Semester One Examination 2024/25
Renewable Energies
Module No: EEE6016

EQUATION SHEET

PV Array Sizing Formula:

$$\text{Required PV Array Size (kW)} = \frac{\text{Energy Demand (kWh/day)}}{\text{Peak Sun Hours (hours/day)} \times \text{System Efficiency}}$$

Cable Sizing Formula:

$$A = \frac{p \times L \times I \times 2}{V_d}$$

The current for a three-phase system is calculated as:

$$I_{phase} = \frac{P_{inverter}}{V_{out} \times \sqrt{3} \times \text{Power Factor}}$$

$$\text{Battery Capacity (Ah)} = \frac{\text{Energy Demand (kWh/day)} \times \text{Autonomy (days)}}{\text{Nominal Voltage (V)} \times \text{DoD} \times \text{Battery Efficiency}}$$

Wind

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

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

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

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

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

Tip speed ratio (TSR), λ = $\frac{\text{Tip speed of rotor blade}}{\text{Wind speed}}$

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

Distance travelled by tip = 2πr

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

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

Please turn the page

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

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

Weibull distribution, $f_2(v) = \frac{k}{A}\left(\frac{U}{A}\right)^{k-1} \exp\left(-\left(\frac{U}{A}\right)^k\right)$

Probability of the wind speed at rated speed,

$$P(\text{production} = \text{rated}) = \int_{v_{\text{rated}}}^{v_{\text{cut-out}}} f(v)dv$$

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

Energy delivered = Power x time

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

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

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

Please turn the page

Fuel Cell

$$\Delta G = \Delta H - T\Delta S$$

$$V = \frac{\Delta G}{n_e q N_0}$$

$$PV = nRT$$

$$V_{drop_{total}} = (V_{rev} - V_{oc}) + IR + Vact$$

$$\dot{N} = \frac{I_L}{q n_e N_0}$$

APPENDIX pv Panel specification

Typical Type	400W
Max Power(Pmax)	400
Max Power voltage(Vmp)	40.4
Max Power current(Imp)	9. 90
Open circuit voltage(Voc)	49.3
Short circuit current(Isc)	10.40
Module Efficiency(%)	19.68
Max system voltage	DC 1500V/DC 1000V
Maximum Series Fuse Rating	15A

Please turn the page

Inverter Specification

INVERTER OUTPUT		
Rated Output Power	8,000W	10,000W
Max. Output Power	16,000VA	20,000VA
Rated Output Voltage	120Vac, Single-Phase/240Vac, Split-Phase	
Load capacity of Motors	5HP	6HP
Rated AC Frequency	50/60Hz	
Waveform	Pure sine wave	
Output Mode	Off-grid (default) / power the load without battery	
Switch Time	10ms (typical)	
BATTERY		
Battery Type	Li-ion / Lead-acid / User-defined	
Rated Battery Voltage	48V	
Battery Volatge Range	40~60Vdc	
Max. Solar Charging Current	180A	200A
Max. Grid/Generator Charging Current	100A	120A
Max. Hybrid Charging Current	180A	200A
SOLAR INPUT		
No. Of MPPT	2	
Max. PV Array Power	5,500W+5,500W	
Max. Input Current	22A+22A	
Max. Open Circuit Voltage	500Vdc+500Vdc	
MPPT Voltage Range	125~425Vdc	
GRID/GENERATOR INPUT		
Input Voltage Range	90~140Vdc	
Input Frequency Range	50/60Hz	
Bypass Overload Current	63A	
EFFICIENCY		
MPPT Tracking Efficiency	99.9%	
Max. Efficiency	92%	

Please turn the page

Battery Specification

Electrical Characteristics	Nominal Voltage	51.2V
	Nominal Capacity	400Ah (C_5,25℃)
	Energy	20480Wh
	Internal Resistance	≤800mΩ
	Cycle Life	>2500 cycles @100% DOD; >3500 cycles @80% DOD
	Months Self Discharge	<3%
	Efficiency of Charge	100% @0.2C
	Efficiency of Discharge	96~99% @1C
Standard Charge	Charge Voltage	58.4±0.2V
	Charge Mode	0.2C to 58.4V, then 58.4,charge current 0.02C(CC/CV)
	Charger Current	≤50A*2Module(Suggested)
	Max. Charge Current	100A*2Module
	Charge Cut-off Voltage	59.2V±0.2V
Standard Discharge	Continuous Current	100A*2Module
	Max. Pulse Current	300A(<3s)
	Discharge Cut-off Voltage	40V
Environmental	Charge Temperature	0 ℃ to 45 ℃ (32F to 113F) @60±25% Relative Humidity
	Discharge Temperature	-20 ℃ to 60 ℃ (-4F to 140F) @60±25% Relative Humidity
	Storage Temperature	0 ℃ to 40 ℃ (32F to 104F) @60±25% Relative Humidity
	Water Dust Resistance	
Mechanical	Cell & Method	
	Plastic Case	6U standard case*2Module
	Dimensions (in./mm.)	600*650*800mm (482*500*280 mm*2Module)
	Weight (lbs./kg.)	260Kg
	Terminal	100A through terminal
	Protocol (optional)	RS485
	BMS	16S100A

END OF PAPER