UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 5 Examination in Engineering: May 2023

Module Number: EE5208 **Module Name: Renewable Energy**

[Three Hours]

[Answer **all questions**, each question carries 10 marks]

Q1. a) i) Define the term renewable energy and list six most common types of renewable energy sources.

ii) What are the main advantages of using renewable energy? Elaborate your answer by giving two facts.

iii) List four technical challenges of using renewable energy-based power generation in the utility grid.

[5 Marks]

b) Voltage drop due to the shading of photovoltaic (PV) cells is a major problem in PV systems.

i) By using the diagram shown in Figure Q1, derive an equation for the voltage drop in a PV array due to the shading of a single PV cell.

ii) Explain a solution that can be used to minimize the effect of shading of PV cells with the use of suitable diagrams.

[5 Marks]

Q2. A photovoltaic (PV) system with a rated capacity of 500 kW needs to be designed. This PV system will be connected to a three-phase ac grid with a line-line rms voltage of 460 V and frequency of 60 Hz. Answer the following. You may use the Table Q2a equations for your calculations, where the symbols have the usual meanings. Specifications of the PV module to be used are given in Table Q2b.

i) Assume the inverter operates at 0.9 modulation index and 5 kHz switching frequency. Calculate the dc side voltage and the current rating of the inverter.

ii) Calculate the number of modules in a string and the number of strings in the PV array. The dc voltage of the PV array should be less than 1000 V. A boost converter will be used to step-up the PV array voltage.

iii) Calculate the minimum sizes of the filter capacitor and the inductor required for the boost converter.

iv) Draw the single-line diagram of the PV system. [10 Marks]

Q3. a) i) Sketch the power characteristic curve (mechanical power vs wind speed) of a wind turbine by highlighting the main regions in the curve.

ii) Identify two design trade-offs in wind energy power plants and elaborate on them by using examples.

[3 Marks]

b) A 600 kW wind turbine's rotor tip speed is 56 ms^{-1}. Wind speed is 14 m/s and air density is 1.225 kg/m^3.

i) Calculate the tip speed ratio of the wind turbine rotor.

ii) Calculate the efficiency of the wind turbine if the radius of the turbine blades is 14 m?

[4 Marks]

c) A 60 Hz fixed-speed squirrel cage induction generator whose rated power with 3 MW is used in a wind energy conversion system. The input impedance of this generator is $2.68 \angle 153.3^0 \ \Omega$.

The system is connected to the primary side of a three-phase transformer with primary side line-line voltage of 3 kV, 60 Hz. Assume the generator is operating at its rated condition.

Calculate the stator active, reactive, and apparent power of the induction generator.

[3 Marks]

Q4. a) i) What are the two main reasons for moving from constructing large hydropower plants to micro hydropower plants?

ii) 75 kW micro hydropower project is proposed to build, and its parameters are as follows.

Turbine Efficiency (η_t)	= 0.9
Generator Efficiency (η_g)	= 0.97
Transformer Efficiency (η_{tr})	= 0.96
Efficiency of Penstock (η_p)	= 0.98
Density of Water (ρ)	= 1,000 kg/m^3
Acceleration due to gravity (g)	= 9.81 m/s^2
Design flow (Q) (For one Turbine)	= 0.55 m^3/s

Check the capability of constructing the 75 kW power plant with the above parameters by taking the net head as 15 m.

iii) Based on the knowledge of the efficiencies of turbines, select the most appropriate turbine for the above Q4 a) application between Francis and Crossflow by giving a reason. [6 Marks]

b) i) A rectangular-shaped canal was proposed for the above micro hydro project and the parameters to calculate the slope of the canal are shown in Table Q4.

Calculate the slope of the concrete canal using Manning's formula and calculate the values of the depth and width of the rectangular-shaped canal. Take the hydraulic radius (r) as 0.367 m and the velocity of water (v) as 1.1 ms^{-1}.

Manning's formula

$$slope = \frac{n * v}{r^{2/3}}$$

where n is the Roughness coefficient and

Roughness coefficient for neat cement plaster	= 0.01
Roughness coefficient for concrete	= 0.015

ii) State the purpose of the overflow canal.

[4 Marks]

Q5. a) i) List five types of biomasses available in Sri Lanka.

ii) State the technological route for biodiesel and biogas starting from biomass feedstock.

iii) State three reasons for voltage drop when current increases in a fuel cell and briefly describe each reason.

[3 Marks]

b) O_2 and H_2 flow rates for a hydrogen fuel cell are x $mols^{-1}$ and y $mols^{-1}$ respectively. The utilization factor of O_2 is p% and for H_2 is q%.

i) Show that y = 2x if p and q are equal. Calculate the fuel cell power in terms of x and p. Assume the cell voltage is 0.7 V. Faraday's Constant is 96485.332 C mol^{-1}.

ii) Predict O_2 and H_2 flow rates in a hydrogen fuel cell in terms of x and y to generate 1000 W if the number of fuel cells increases evenly. Elaborate your answer by using equations with usual notations. Assume cell voltage as E.

[7 Marks]

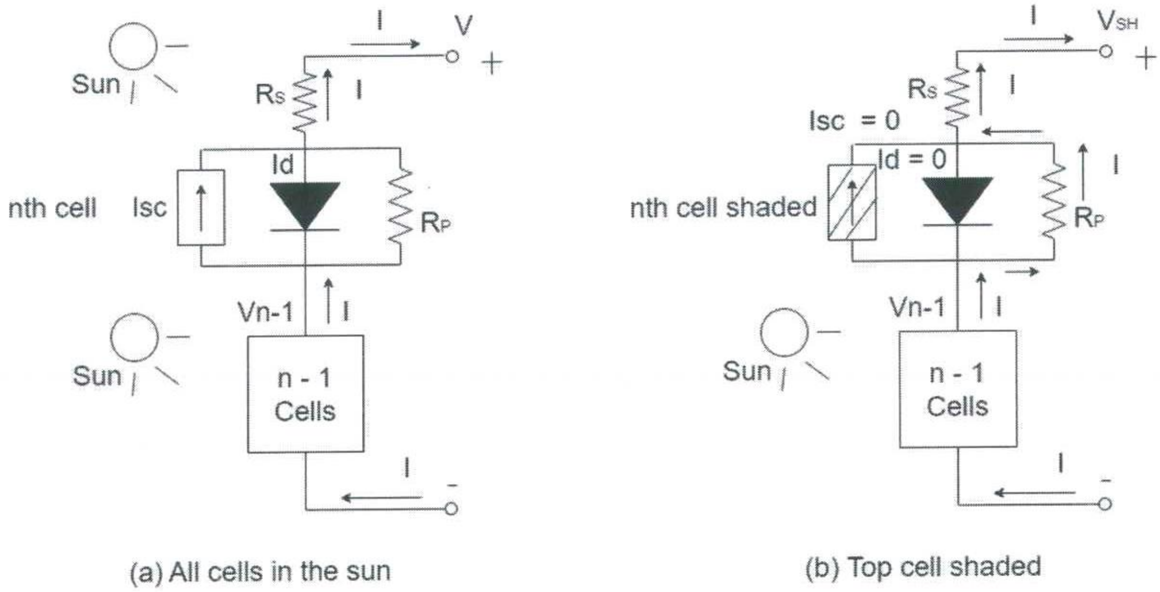

Figure Q1: PV array

Table Q2a: Boost converter equations

$\frac{V_o}{V_{in}} = \frac{1}{(1-D)}$
$R_{eq} = \frac{V_{o,dc}^2}{P}$
$L = \frac{D(1-D)^2 R_{eq}}{2f_s}$
$C = \frac{D}{f_s R_{eq}(\frac{\Delta V_o}{V})}$; Where $\left(\frac{\Delta V_o}{V}\right) = 1\%$

Table Q2b: Specifications of the PV module.

Power (max)	300 W
Voltage at maximum power point	50.6 V
Current at maximum power point	5.9 A
Open circuit voltage	63.2 V
Short-circuit current	6.5 A

Table Q4: Dimensions for different canal profiles.

Canal Profile	Suggested Dimensions
Semi circular	Diameter (d) = 4r
Rectangular	Depth (d) = 2r Width (w) = 4r
Trapezoidal	Depth(d) = 2r Width (w) = 4r / sin (μ)