UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 5 Examination in Engineering: March 2022

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

[Three Hours]

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

All notations have their usual meanings. Equations and data you may require are given in page 6.

Q1. a) i) What is meant by a renewable energy source?

ii) What are the main characteristics of renewable energy sources?

iii) State five major types of renewable energy sources that are used to generate electricity.

iv) What are the technical challenges pose by renewable energy sources in electricity generation?

v) How does the fossil fuel based electricity generation affect the global warming?

[5.0 Marks]

b) i) State three impacts of earth's atmosphere on solar radiation.

ii) Briefly explain the power generation process in a concentrated solar power (CSP) plant.

iii) A light beam having a total power density of 6 Wm^{-2} is falling directly to a photovoltaic (PV) panel having an area of 9.5 m^2. Determine the photon flux, the wavelength of the beam and input power to the PV panel if 4.5×10^{23} photons fall to the panel each hour.

iv) A site located at Perth (31.7^0 S, 115.2^0 E) has a global horizontal irradiance of 250 Wm^{-2} (direct: 100 Wm^{-2}, diffuse 150 Wm^{-2}) on 3rd of September at 14:30 local solar time. Taking the ground reflective coefficient as 0.12, calculate the global irradiance on a plane tilted by 30^0 facing north.

[5.0 Marks]

Q2. a) i) Briefly discuss three advantages of a micro-inverter based PV system compared to a central inverter-based PV system.

ii) Briefly explain the purpose of using bypass diodes and blocking diodes in PV modules.

iii) Illustrate what is meant by the fill factor and the characteristic resistance using a typical I-V characteristic of a PV module.

iv) A solar thermal collector with an area of 12 m^2 has a zero-loss coefficient of 0.8 and a heat loss coefficient of 3.6 $Wm^{-2}K^{-1}$. The inlet and the outlet temperatures are 40 ^0C and 70 ^0C respectively. Determine the mass flow rate, if the specific heat capacity of the fluid is 4.2 $kJkg^{-1}K^{-1}$. Take the ambient temperature as 25 ^0C and the solar irradiance as 650 Wm^{-2}.

[4.5 Marks]

b) An off-grid PV system needs to be installed with a battery storage for a commercial building located in Ampara (7.3° N, 81.8° E). All the PV modules will be facing south with a tilt angle of 10^0. The minimum daily insolation on the tilted plane is measured on 14th of December. Following data are provided for the design.

- **Average daily demand of the building**: AC loads consume 4.5 kWh during day time and 1.5 kWh during night time, DC loads consume 1 kWh during day time and 2 kWh during night time
- **Battery storage:** efficiency = 72%, Depth of discharge = 50%, Nominal voltage = 24 V
- **PV module**: Efficiency = 18%, Rated output power = 250 W, Area = 1.65 m^2
- **Inverter**: Efficiency = 98%
- Days of autonomy = 1 day, Days of recharge = 3 days

Determine the following. State any assumption you make.

i) The minimum daily insolation on the tilted plane with atmospheric effects ($H_{at,min}$), if the clearness index is 0.28 and overall tilt factor is 1.3 on 14th of December.

ii) The required PV array size and the actual area required for the installation.

iii) The required capacity of the battery storage.

[5.5 Marks]

Q3. a) i) Name two types of periodic winds.

ii) Briefly discuss the factors to be considered when selecting the tip speed ratio for wind turbine operation.

iii) Draw a schematic diagram of variable speed wind turbine system with partial-scale power converter and state its main characteristics.

iv) Starting from first principles, show that the theoretical maximum power coefficient of a wind turbine is approximately equal to 0.5926.

[5.0 Marks]

b) According to the data collected from an anemometer, a potential wind site has an annual average wind speed of 5.2 ms^{-1} at a height of 8 m above the ground level. And the wind speed distribution can be modelled as a Weibull distribution having a shape factor of 2.0. The site is in open terrain with surface roughness length of 0.5 m. The power curve of the selected wind turbine is shown in Figure Q3. It will be installed with a hub height of 50 m and a blade swept area of 3850 m^2. Relationship between the power coefficient C_P and the tip speed ratio λ of the wind turbine can be approximated by the following equation where R is the radius of the turbine blades in meters.

$$C_P = \lambda\,(0.16 - 0.01\,\lambda\,) - \frac{8}{R}$$

Calculate the following.

i) The maximum power coefficient, $C_{P,MAX}$ of the wind turbine.
ii) The annual energy output of the wind turbine.
iii) The power coefficient and the rotor speed when the wind speed is 20 ms^{-1}.

[5.0 Marks]

Q4. a) i) What are the three forms of energy available in the flowing water?
ii) What are the factors affect the pipe loss in a micro-hydro scheme?
iii) Show that for optimum power output, the pipe loss should be equal to one third of the gross head. State any assumptions you make.

[4.0 Marks]

b) Fore bay tank of a hypothetical run off the river type micro-hydro power plant is located at 550 m above mean sea level and the power house is located 430 m above the mean sea level. Suppose that the water is taken from the tank and delivered through a 320 m long 8 cm diameter polyethylene pipe to a turbine at the power house. Friction Head Loss in m of head per 100 m of pipe for different flow rates in liters per minute for the given 8 cm diameter Polyethylene pipe is given in Figure Q4. The efficiency of the turbine/generator system is 50%. Take gravitational acceleration as 9.81 ms^{-2}. State any assumptions you make. (1000 liters of water = 1 m^3 of water).

i) Using the Friction Head Loss chart, estimate the total pipe loss for a flow rate of 10 liters per second.
ii) How much power will be delivered by the turbine/generator system for the flow rate mention in part (i) above?
iii) How much electric energy would be generated in a 30 day month for the operating condition mentioned in part (ii) above?
iv) Using the Friction Head Loss chart, estimate the flow rate for optimum power output from the turbine/generator system.

v) How much power will be delivered by the turbine/generator system for the flow rate estimated in part (iv) above?

vi) If the flow rate is increased to 20 liters per second, will it increase power output more than what you calculated in part (v) above? Explain the reasons for your answer.

[6.0 Marks]

Q5. a) i) Briefly discuss why Hydrogen (H_2) is considered to be one of the ideal fuels.

ii) Draw the polarization curve of a fuel cell and explain its characteristics.

iii) State the role of an electrolyte in a fuel cell and name three materials used as electrolytes.

iv) A fuel cell stack consists of 50 cells and each cell operates at a voltage of 0.452 V. Overall redox reaction of the fuel cell is shown below.

$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O + Energy$$

Molar masses of H_2 and O_2 are 2.02 $gmol^{-1}$ and 32 $gmol^{-1}$ respectively. Densities of H_2 and O_2 are 0.085 gl^{-1} and 1.4 gl^{-1} respectively. The power output of the stack is 210 W when the H_2 and O_2 flow rates are 3.65 $lmin^{-1}$ and 1.8 $lmin^{-1}$ respectively. Determine the H_2 and O_2 utilization factors.

[6.0 Marks]

b) i) State the three major markets associated with bio-energy and a leading country in each market at the present.

ii) State the three thermochemical bio-energy conversion processes with their corresponding outputs.

iii) Briefly discuss why Gliricidia Sepium is commonly used as the fuel for dendro power plants in Sri Lanka

iv) 'Bio-energy is the best alternative for fossil fuels.' Do you agree with this statement? Give reasons for your answer.

[4.0 Marks]

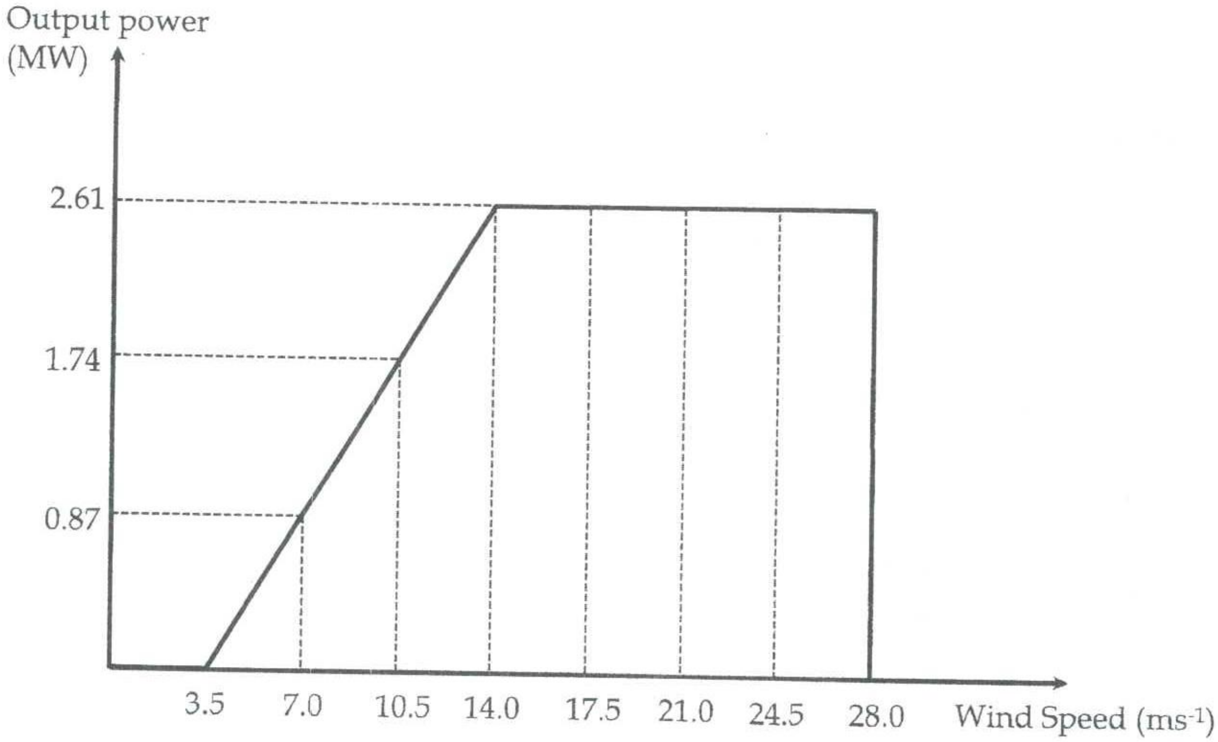

Figure Q3: Power Curve of the Wind Turbine

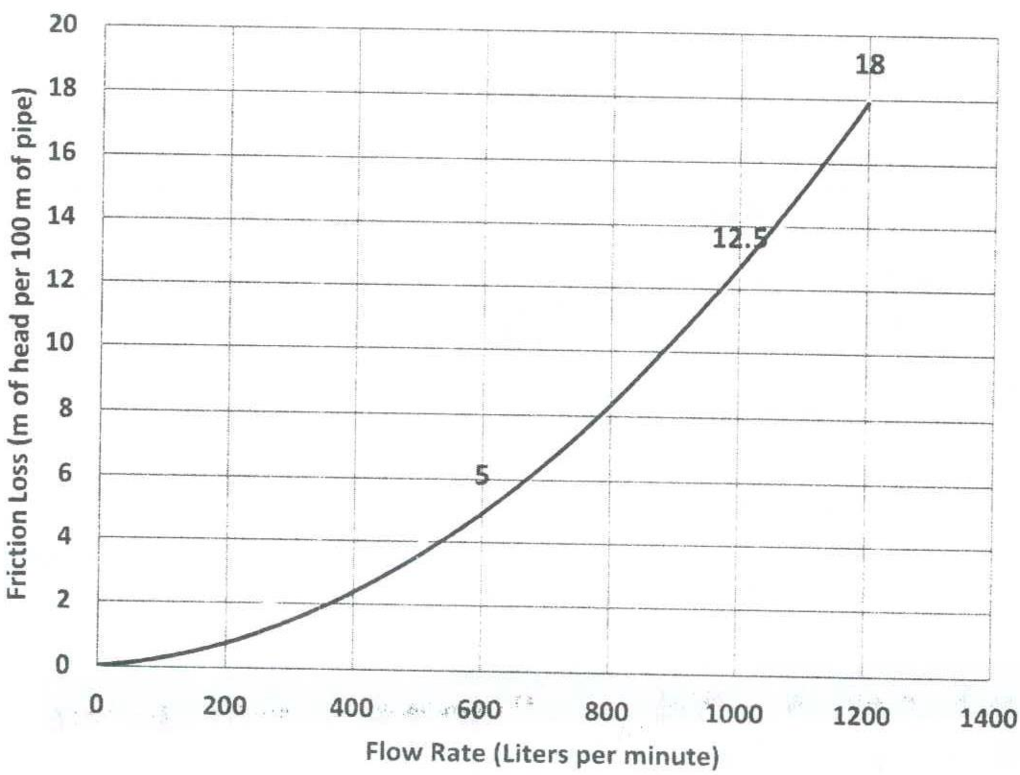

Figure Q4: Friction Head Loss Chart

Equations and Data

All the symbols and notations have their usual meanings.

Wind Energy

Typical air density (ρ) = 1.2 kgm^{-3}

$$w(u) = \frac{k}{a}\left[\frac{u}{a}\right]^{k-1} exp\left(-\left[\frac{u}{a}\right]^{k}\right)$$

$$u(z) = \frac{u^*}{K} ln\left(\frac{z-d}{z_0}\right)$$

$$a = \frac{2\bar{u}}{\sqrt{\pi}}$$

$$\Phi_{U>V} = exp\left[-\left(\frac{V}{a}\right)^{k}\right]$$

Solar Energy

Plank's constant (h) = 6.63×10^{-34} Js
Faraday's constant (F) = 96485.34 $Cmol^{-1}$
Speed of light (c) = 3×10^{8} ms^{-1}

$$AM = \frac{\left(P/P_0\right)}{Cos(\theta_z) + 0.50572(96.07995 - \theta_z)^{-1.6364}}$$

$$\delta = 23.45^0 \sin\left(\frac{360(284+n)}{365}\right)$$

$$G_{on} = G_{sc}\left(1 + 0.033\cos\left(\frac{360n}{365}\right)\right)$$

$$\gamma_S = \sin^{-1}\left(\frac{\cos\delta\sin\omega}{\sin\theta_Z}\right)$$

$$G_{tot} = G_{dir}\left(\frac{cos\,\theta}{cos\,\theta_Z}\right) + G_{dif}\left(\frac{1+cos(\beta)}{2}\right) + G\,\rho\left(\frac{1-cos(\beta)}{2}\right)$$

$$\omega = 15^0(12 - LST)$$

$$H_0 = \frac{24\,G_{on}}{\pi}\left[\cos\delta\cos\varphi\sin\omega_{sr} + \omega_{sr}\sin\delta\ \sin\varphi\right]$$

$$\omega_{sr} = \cos^{-1}(-\tan\varphi\ tan\delta)$$

$$\omega_{srt} = \cos^{-1}(-\tan(\varphi-\beta)\ tan\delta)$$

$$\theta_Z = \cos^{-1}\left[\cos\delta\cos\omega\cos\varphi + \sin\delta\ \sin\varphi\right]$$

$$\omega_{min} = \min\left(\omega_{sr}, \omega_{srt}\right)$$

$$\theta = \cos^{-1}\left[\cos\delta\cos\omega\cos(\varphi-\beta) + \sin\delta\ \sin(\varphi-\beta)\right]$$

	31	28	31	30	31	30	31	31	30	31	30	31