UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 5 Examination in Engineering: December 2020

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) State the main characteristic of a renewable energy source.

ii) State the meaning of the term "energy mix".

iii) Name the top three renewable energy sources in terms of global installed capacity.

[1.5 Marks]

b) i) Briefly explain the greenhouse effect.

ii) Mention three adverse effects on environment due to global warming initiated by rising energy consumption.

iii) "Even though renewable energy sources are environmentally friendly alternatives, they can still contribute to greenhouse gas emissions". Discuss this statement considering solar energy as an example.

[2.0 Marks]

c) The Thambapavani wind farm located in the southern coast of Mannar island has a rated capacity of 103.5 MW and is anticipated to generate 380 GWh of clean energy to the national grid annually.

i) Calculate the anticipated capacity factor of the Thambapavani wind farm.

ii) Briefly explain why capacity factors for most of the renewable generation facilities are lower compared to nuclear power plants.

[1.5 Marks]

d) i) Name two types of concentrated solar thermal power systems.

ii) Briefly explain the two main types of scattering that happens to solar rays when passing through the earth's atmosphere.

iii) Consider a light beam having a wavelength of 450 nm falling directly to a Photovoltaic (PV) panel having an area of 8 m^2. Determine the photon flux and input power to the PV panel if 4.8×10^{21} number of photons fall to the panel each minute.

iv) Determine the Air Mass for a site with an atmospheric pressure of 0.95 atm when the zenith angle is 45^0.

v) A site located 42.5^0 N and 8^0 E has a direct horizontal irradiance of 300 Wm^{-2} and a diffuse horizontal irradiance of 220 Wm^{-2} on 21st of June at 10:00 local solar time. The solar collector uses a 2-axis solar tracking system. Take the ground reflective coefficient as 0.12. Calculate the orientation of the solar collector and the global irradiance on the tracked plane.

[5.0 Marks]

Q2 a) i) State two advantages and two disadvantages of thin film PV modules compared to crystalline silicon PV modules.

ii) Briefly explain the effect of cell temperature and solar irradiance on the I-V characteristic of a solar cell.

iii) Consider the nameplate data of a PV module given in table Q2. Calculate characteristics resistance, fill factor and efficiency of the PV module under standard test conditions (STC).

[3.0 Marks]

b) A grid-connected roof-top PV system needs to be installed without a battery storage at a site located in Hambantota (6.2° N, 81.1° E). Nameplate data of the selected PV module for the installation is given in table Q2. All the PV modules will be facing south with a tilt angle of 12^0. The minimum daily insolation on the tilted plane is measured on 23rd of December. Determine the following.

i) The daily insolation on a horizontal plane (H_0) at the site without atmospheric effects on 23rd of December.

ii) The minimum daily insolation on the tilted plane with atmospheric effects ($H_{at,min}$), if the clearness index is 0.35 and overall tilt factor is 1.2 on that day.

iii) The required number of PV modules for an average monthly energy production of 510 kWh. State any assumption you make.

iv) The actual area required on the roof for the installation.

[4.0 Marks]

c) Efficiency of a solar thermal collector is modelled by the following equation where notations have their usual meanings.

$$\eta = \eta_0 - \frac{a_1\ (T_{coll} - T_a)}{G} - \frac{a_2 (T_{coll} - T_a)^2}{G}$$

A solar thermal collector has parameters $\eta_0 = 0.82, a_1 = 2.2\ Wm^{-2}K^{-1}$ and $a_2 = 0.004\ Wm^{-2}K^{-2}$. Take the ambient temperature as 25 ^{0}C and the average collector temperature as 45 ^{0}C.

i) Explain what is denoted by η_0.

ii) Determine the required collector area to deliver a thermal output power of 1 kW under a solar irradiance level of 800 Wm^{-2}.

iii) Calculate the flow rate to be set to heat up a fluid (specific heat capacity: 3.8 $kJkg^{-1}K^{-1}$ and density: 1.1 kgl^{-1}) from inlet temperature of 35 ^{0}C to output temperature of 55 ^{0}C with 1.5 kW thermal output power.

[3.0 Marks]

Q3. a) Show that the power P of the wind with a density ρ and velocity v, incident on a horizontal axis wind turbine having a swept area A is given by;

$$P = \frac{1}{2}\rho A v^3$$

[1.0 Mark]

b) You have been asked to design a wind farm for a coastal site in the Southern Province of Sri Lanka, that can feed at least 300 GWh of energy to the national grid annually. Following information related to the selected site is available to you.

- Wind speed distribution can be modelled as a Weibull distribution having a shape factor of 2.2
- Mean wind speed at the wind turbine's hub height is 7.5 ms^{-1}

You have decided to use variable-speed pitch-controlled wind turbines having the parameters given in table Q3-1 in your design. Simplified power curve characteristics of the turbine is shown in table Q3-2. Relationship between the power coefficient C_p and the tip speed ratio λ can be approximated by the quadratic equation eq. Q3-1

$$C_p = -0.01\lambda^2 + 0.18\lambda - 0.41 \quad \text{------ eq. Q3-1}$$

i) Considering the data given in table Q3-1, draw the power curve for the selected wind turbine and indicate the special points on it.

ii) Using the simplified power curve characteristics given in table Q3-2, calculate the expected annual energy output of a wind turbine installed in this site.

iii) Calculate the number of wind turbines that should be installed in this site to achieve the expected annual energy production target. State any assumptions you make.

iv) By differentiating eq. Q3-1 obtain,

A. the optimum tip speed ratio for the turbine λ_{opt} (i.e., the value of λ that maximizes C_p)

B. the maximum value of the power coefficient, $C_{p,max}$

v) Calculate the shaft speed, shaft power and torque at a wind speed of 10 ms^{-1} assuming that the turbine operates at its optimum tip speed ratio.

[7.0 Marks]

c) i) Comment with reasons on the annual energy output of the wind farm in Q3.b, if the same number of 4 MW fixed speed wind turbines are used.

ii) Suggest a solution for potential threat on the birds migrating through the wind farm.

iii) State two possible negative impacts on the environment due to this wind farm except the threat on birds.

[2.0 Marks]

Q4 a) i) Sketch the arrangement of a run-of-the river type micro-hydro power plant indicating the main components.

ii) What are the two types of turbines used in micro-hydro power plants? Give two examples for each category.

iii) Show that for maximum power, the pipe loss should be equal to one third of the gross head. State any assumptions you make.

[4.0 Marks]

b) Forebay tank of a hypothetical run-of-the river type micro-hydro power plant is located at 425 m above the mean sea level and the power house is located 350 m above the mean sea level. The slope of the ground in the area has an inclined angle of 45^0. A 12 cm diameter polyethylene pipe has been used as the penstock. A four jet Pelton wheel with 0.5 m diameter has been used in the turbine. At the rated water flow rate, the diameter of each jet of water is 3 cm and the head loss due to pipe friction is 30% of the gross head. The efficiency of the turbine at the rated speed of 625 rpm is 80%. Take gravitational acceleration as 9.81 ms^{-2}. Determine;

i) the speed of the water jet,
ii) the rated water flow rate,
iii) the run-away speed of the turbine,
iv) the mechanical power output of the turbine,
v) the rated torque of the turbine.

[6.0 Marks]

Q5 a) i) State three differences between a battery and a fuel cell.

ii) State the main applications of Alkaline fuel cells, Direct methanol fuel cells and Solid oxide fuel cells.

iii) Explain the operation of a polymer electrolyte membrane fuel cell (PEMFC).

iv) A PEMFC stack consists of 100 cells and each cell operates at a voltage of 0.48 V. Overall redox reaction of a PEMFC 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. Calculate the required H_2 and O_2 flow rates in liters per minute to get a power output of 540 W. Assume H_2 and O_2 utilization factors as 92%.

[6.0 Marks]

b) i) Briefly discuss how bioenergy industry contributes to the sustainable development of a country.

ii) State three factors considered in selecting a plant as the fuel source for biomass dendro power generation.

iii) Illustrate the technological routes for bio-energy production and final products of each route using a diagram.

[4.0 Marks]

Table Q2

Parameter	**Value**
Maximum power	250 W
Maximum power voltage	33.2 V
Open circuit voltage	37.4 V
Short circuit current	9.4 A
Maximum system voltage	1500 V_{DC}
Dimension	1450×960×40 (mm)

Table Q3-1

Parameter	**Value**
Rated power	4 MW
Cut-in wind speed	3 ms^{-1}
Cut-out wind speed	25 ms^{-1}
Rated wind speed	12 ms^{-1}
Swept area	14527 m^2
Hub height	73 m

Table Q3-2

Wind speed range (ms^{-1})	**Turbine output power (kW)**
<3	0
3 to 6	550
6 to 9	2250
9 to 12	3750
12 to 25	4000

Equations and Data

All the symbols and notations have their usual meanings.

Wind Energy

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

The Weibull distribution:

$$\varphi_u = \left(\frac{k}{C}\right)\left(\frac{U}{C}\right)^{k-1} e^{-\left(\frac{U}{C}\right)^k}$$

where $C = 2\bar{U}/\sqrt{\pi}$

The probability of the wind speed U being greater than a particular speed, V, can be found from:

$$\varphi_{u>v} = e^{-\left(\frac{V}{C}\right)^k}$$

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}

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

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

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

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

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

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

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

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

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

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

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

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

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
# of days	31	28	31	30	31	30	31	31	30	31	30	31