UNIVERSITI TEKNOLOGI PETRONAS

FINAL EXAMINATION
SEPTEMBER 2024 SEMESTER

COURSE	**:**	**MEB4513 - RENEWABLE ENERGY I**
DATE	**:**	**28 NOVEMBER 2024 (THURSDAY)**
TIME	**:**	**9.00 AM - 12.00 NOON (3 HOURS)**

INSTRUCTIONS TO CANDIDATES

1. Answer **ALL** questions in the Answer Booklet.
2. Begin **EACH** answer on a new page in the Answer Booklet.
3. Indicate clearly answers that are cancelled, if any.
4. Where applicable, show clearly steps taken in arriving at the solutions and indicate **ALL** assumptions, if any.
5. **DO NOT** open this Question Booklet until instructed.

Note :

i. There are **FOURTEEN (14)** pages in this Question Booklet including the cover page and appendix.

ii. **DOUBLE-SIDED** Question Booklet.

1. a. **FIGURE Q1a(i)** shows a preliminary study for the wind farm, where an international group of energy companies acquired land (30 km long and 15 km wide) for generating 1000 MW of electricity. **FIGURE Q1a(ii)** shows the prevailing wind velocity, v_h, at various heights, h. Develop a proposal for 1000 MW electricity generation by indicating height, diameter, and number of wind turbines. Illustrate your concept in a schematic layout. Assume the efficiency of the turbine is 40%.

[10 marks]

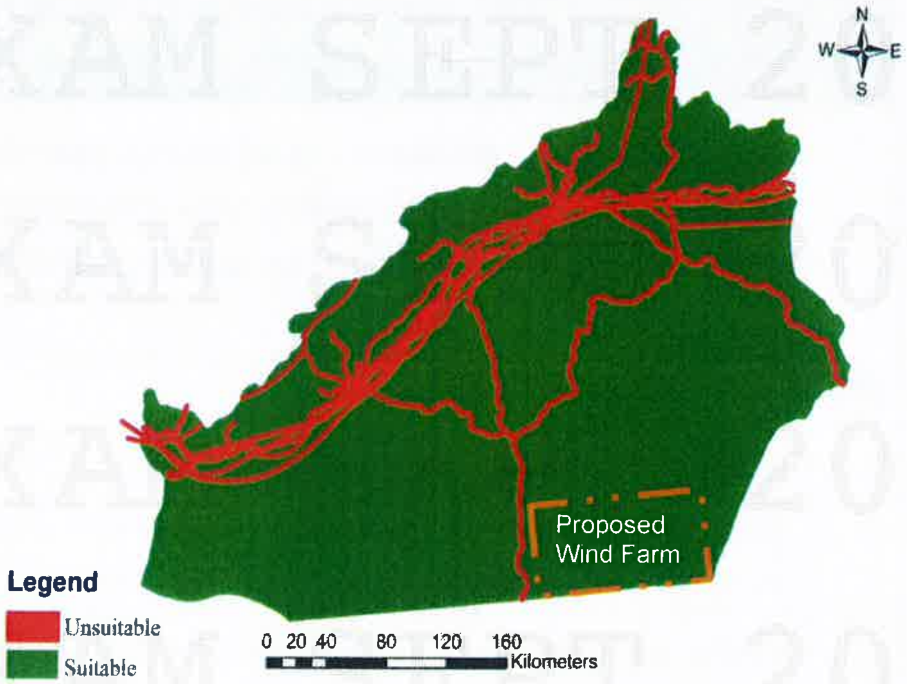


FIGURE Q1a (i)

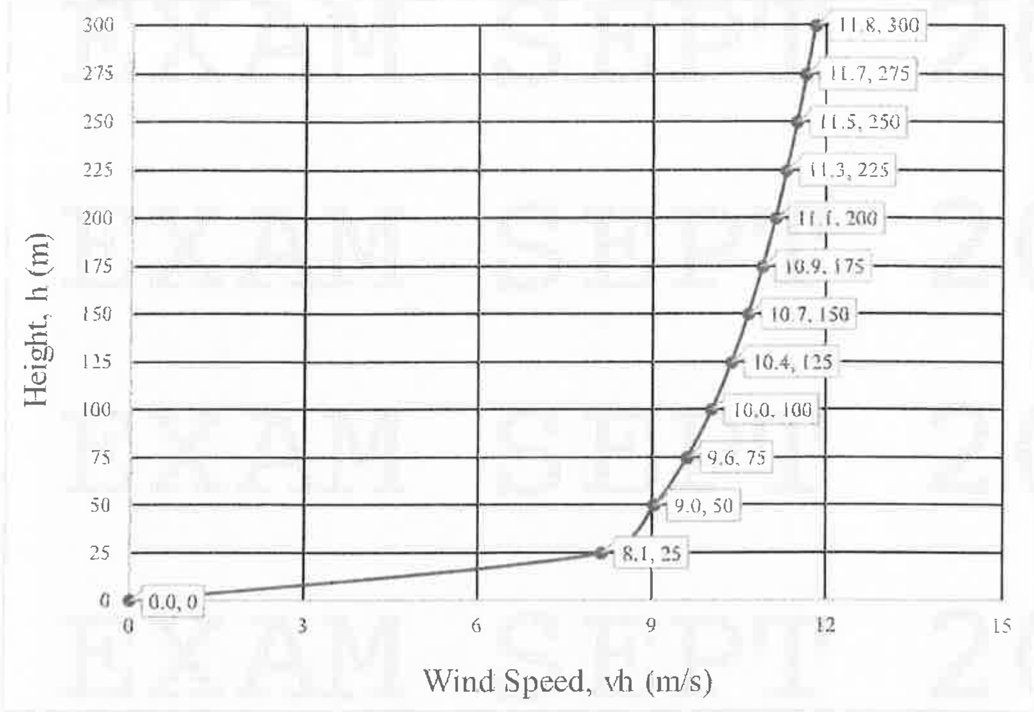


FIGURE Q1a (ii)

b. **FIGURE Q1b** shows a wind turbine's front and side elevation; the rotor diameter is 70 m, and the hub height is 100 m. The turbine is installed at the prevailing wind speed of 70 km/h. At the proposed location at 50 m height, the recommended wind speed is 12.5 m/s, whereas the air density is 1.2 kg/m^3. Estimate:

i. *rpm* of the rotor, the turbine will operate at a *TSR* (tip speed ratio) of 5, and the tip speed of the rotor,

[7 marks]

ii. the gear ratio required to match the rotor speed to the generator speed, which is proposed as 2200 rpm, and

[4 marks]

iii. the efficiency of the turbine when the output of the generator is 750 kW.

[4 marks]

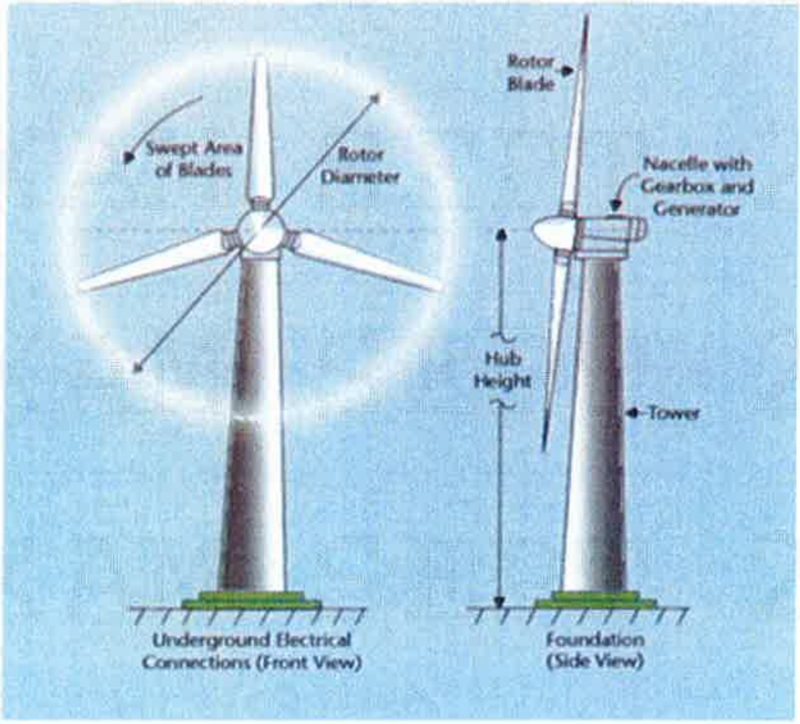

Rotor Blade
Swept Area of Blades
Rotor Diameter
Nacelle with Gearbox and Generator
Hub Height
Tower
Underground Electrical Connections (Front View)
Foundation (Side View)

FIGURE Q1b

2. a. **FIGURE Q2a** shows the watershed area in a highland region connecting to a natural reservoir of about 5000 hectares. The preliminary assessment shows that the location can generate 200 MW of electricity. Develop a concept of a hydropower plant and illustrate the project's main components using sketches.

[10 marks]

FIGURE Q2a

b. **FIGURE Q2b** shows the details of a Pelton wheel proposed for a hydropower project. For the design of the Pelton wheel, the following requirements are given:

- Power to be delivered, P = 50,000 KW
- Net Head, H = 300 m
- Speed = 400 rpm
- The ratio of jet to wheel diameter = 1/15
- Hydraulic efficiency = 0.89
- C_v = 0.95
- Speed ratio, f = 0.50

Estimate:

i. the number of jets and their diameter, d,

[8 marks]

ii. the diameter of the wheel, D, and,

[4 marks]

iii. the water flow rate, Q.

[3 marks]

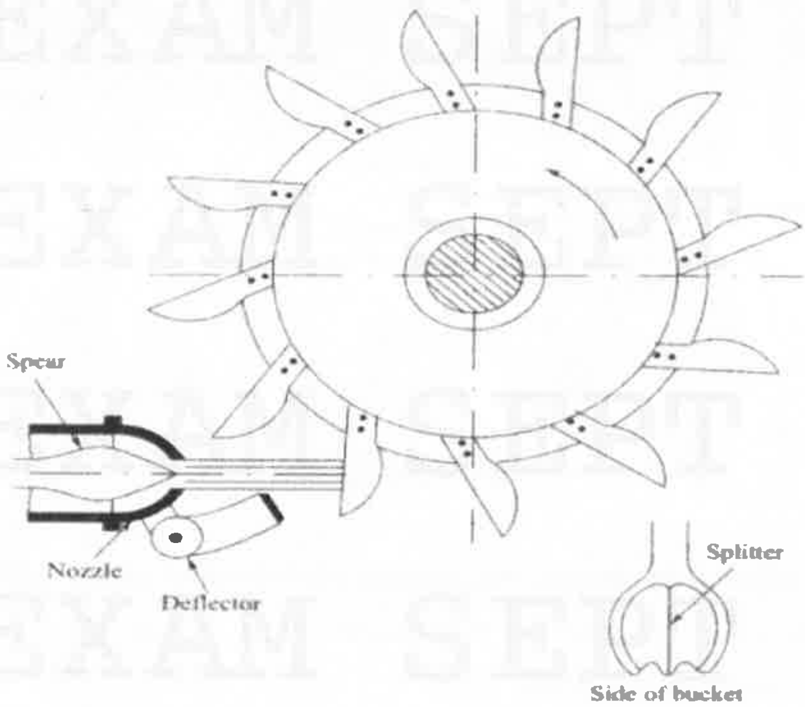


FIGURE Q2b

3. a. As a consultant, you are tasked with designing a standalone solar PV system for a remote cabin located in a wood area, far from the electrical grid. The cabin is used all year-round and requires a reliable source of electricity for basic lighting, appliances, and occasional use of power tools. The collected information for the design is as follow:

- The system will be powered by 12 Vdc, 100 Wp with 3.75 A short circuit current (I_{sc}) PV module.
- The appliances are listed in **TABLE Q3.**
- The wiring, connection and losses in the battery are 35 %.
- The Panel Generation Factor (PGF) for that location is 4.7.
- Autonomy day is 3 days.
- The inverter safety margin is taken as 30%.
- Battery loss and depth of discharge factors are 0.85 and 0.6 respectively.
- The safety margin factor for solar charge controller is 1.3.

TABLE Q3

No.	Appliance	Unit	Total Power (Watt)	Hours per day (Hour)
1.	Water Heater	1	1500	1
2.	Kettle	1	1000	2
4.	Ceiling fan	1	200	7
5.	TV	1	200	7
6.	Light bulb	3	500 (total for bulbs)	7 (for all bulbs)
7	Plug point	3	500	10

i. With the aid of diagram, explain and justify the solar PV configuration suitable for the system.

[8 marks]

ii. Based on the information, calculate the sizing of all components in the standalone solar PV system to meet the cabin's needs.

[12 marks]

b. Describe the working principals of a solar PV system in detail. Start by explaining the process that occurs within a solar panel when it is exposed to sunlight. Then, outline how the generated DC (direct current) electricity is converted into usable AC (alternating current) electricity for powering homes and businesses. Finally, discuss any key components and technologies used in this process. Provide a clear and comprehensive explanation.

[5 marks]

4. a. Differentiate between the flat plate and evacuated tube solar collectors. Under the Malaysian local weather conditions, which one is more suitable and why?

[5 marks]

b. A hotel manager decided to use solar energy for hot water supply to the hotel rooms and kitchen. There are 160 rooms in the hotel. Each room is proposed to accommodate an average of 2 persons, assuming full occupation over the year. Each one person in the room requires 100 litres of water/day. The kitchen needs 2560 litres/day. Both, the kitchen and the rooms are requiring hot water at 45°C. **TABLE Q4** shows the technical characteristics of the solar water heater (SWH).

TABLE Q4

Area	2.4 m^2
Overall heat loss coefficient	6 W/m^2-K
Collector heat removal factor	0.85
The transmittance of glass cover	0.85
Absorber plate absorptance	0.9
The mean inlet temperature from the supply tank	30°C

i. As a consultant, suggest the required number of collectors be installed to meet the hotel's demand for hot water. Assume the mean daily solar irradiance to be 500 W/m^2 and the mean ambient temperature is 25°C.

[10 marks]

ii. The operational life of the proposed SWH is 10 years. The cost of each collector is RM8,000. The tanks, pumps and the piping system cost RM80,000. The annual maintenance of the system is RM5000. The installation and commissioning cost is RM200,000. Estimate the capital cost and express your opinion on the project's feasibility. Take the mean cost of electricity RM0.45/kWh.

[10 marks]

- END OF PAPER –

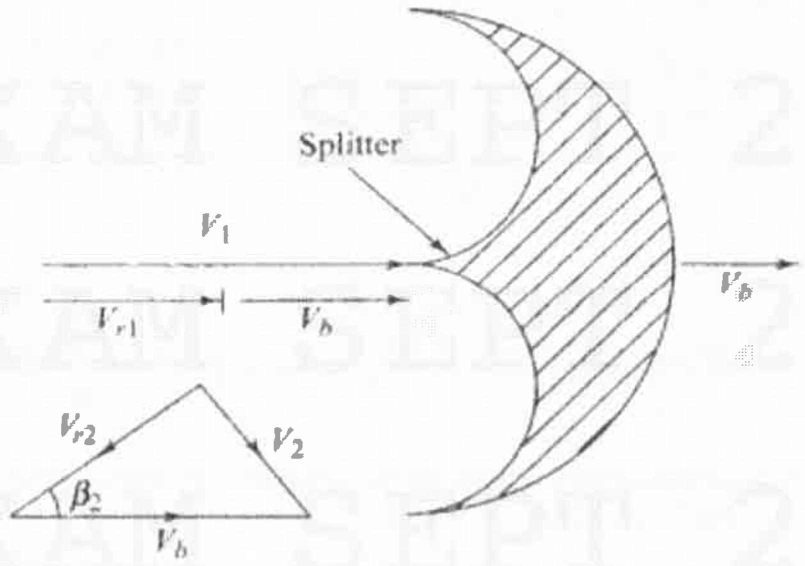
Appendix

SOLAR THERMAL

Electrical Power (kWh) = (4.2 x Volume (water) x Temp. difference)/3600

For water, C_p = 4200 J/kg·°C and ρ = 1000 kg/m^3

HYDROPOWER



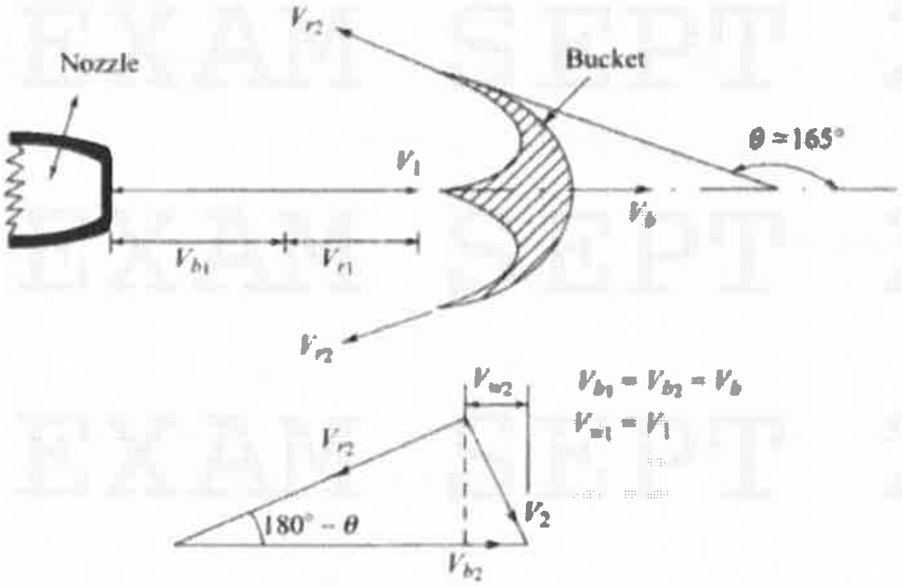
$$V = \omega r = \frac{\pi D N}{60} \qquad N_{S_{MJ}} = \sqrt{n}\, N_{S_{SJ}}$$

where r and D are the bucket circle radius and diameter respectively and ω is the angular velocity given by $\frac{2\pi N}{60}$, N being the rpm.

$$V_1 = C_v\,[2gH]^{1/2}$$

where C_v is the coefficient of velocity (0.97 – 0.99).

$$V_b = \frac{\pi DN}{60}$$



$$E = (V_{w_1} V_{b_1} - V_{w_2} V_{b_2})/g = \frac{V_b}{g}\,(V_{w_1} - V_{w_2})$$

where subscript 1 represents the condition at inlet and subscript 2 the condition of water at outlet of the bucket, V_w is the velocity of whirl (tangential component) and V_b is the bucket velocity given by $V_{b1} = V_{b2} = \frac{\pi DN}{60}$

$$\eta_0 = \frac{P}{\rho Q g H} = \frac{P}{\rho \times \frac{\pi}{4} d^2 \times V \times gH}$$

WIND

$$E = \frac{1}{2}\rho u^2$$

Kinetic Energy per unit volume

$$P = E.Au = \frac{1}{2}\rho u^2.Au = \frac{1}{2}\rho.Au^3 = \frac{1}{2}\rho.(\pi r^2)u^3$$

$$(KE)_b = \frac{1}{2}\cdot \dot{m}\cdot\left(v^2 - v_d^2\right)$$

$\dot{m}$ = mass flow rate of air within stream tube $\dot{m} = \frac{dm}{dt}$

v = upwind undisturbed wind speed

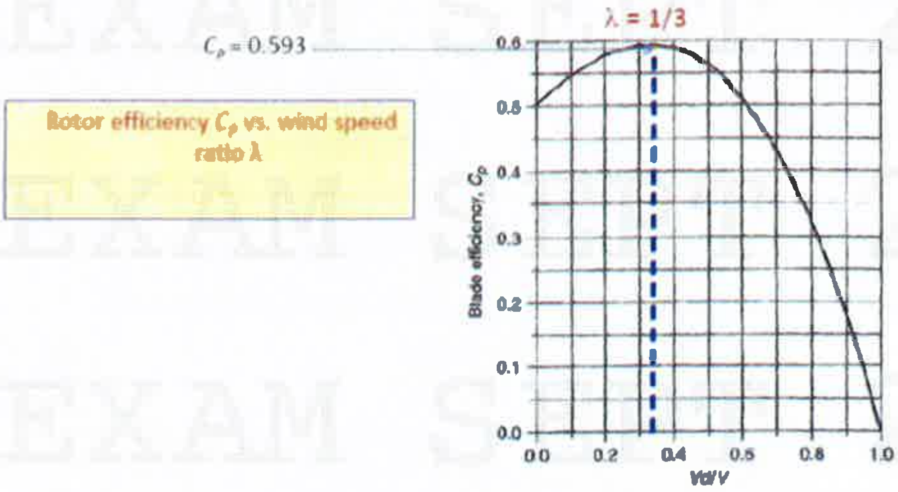
v_d = downwind wind speed

$$(KE)_b = \frac{1}{2}\cdot\rho\cdot A\cdot\left(\frac{v+v_d}{2}\right)\cdot\left(v^2 - v_d^2\right)$$

Let,

$$\lambda = Wind\ Speed\ Ratio = \frac{Downwind\ velocity}{Upwind\ velocity} = \frac{v_d}{v}$$

$$(KE)_b = \frac{1}{2}\cdot\rho\cdot A\cdot\left(\frac{v+\lambda v}{2}\right)\cdot\left(v^2 - \lambda^2 v^2\right)$$



$$\lambda = \text{Wind Speed Ratio} = \frac{\text{Downwind velocity}}{\text{Upwind velocity}} = \frac{v_d}{v}$$

Wind Speed Ratio (λ)

$$\text{Tip-Speed-Ratio (TSR)} = \frac{\text{Rotor tip speed}}{\text{Wind speed}} = \frac{\text{rpm} \times \pi D}{60v}$$

$$TSR = \frac{\left(\frac{rpm}{60}\right)\pi D}{v}$$

TSR is dimensionles.

- D = rotor diameter (m)
- v = upwind undisturbed wind speed (m/s)
- rpm = rotor speed, (revolutions/min)

$$\text{rpm} = \frac{\text{Tip-Speed-Ratio (TSR)} \cdot 60v}{\pi D}$$

$$\text{Gear Ratio} = \frac{\text{Generator rpm}}{\text{Rotor rpm}}$$

$$Ideal\ WT\ Power = \frac{1}{2}\rho A v^3 \qquad Actual\ WT\ Power = \frac{1}{2}\eta \rho A v^3$$