

Renewable Energy Technology (315337)

Model Question Paper — Set B · Model Answers

Q.1**a) Solar constant and insolation.**

2 M

i) Solar constant (G_{sc}): The rate at which solar energy is received on a unit area perpendicular to the sun's rays at the mean earth–sun distance, **outside the earth's atmosphere**. Its accepted value is **1367 W/m²** (≈ 1.367 kW/m²).

ii) Insolation: The total solar radiation energy actually received on a given (usually horizontal) surface on the earth per unit area in a given time, e.g. kWh/m²/day. In most of India it is about 4–7 kWh/m²/day.

*(1 M each)***b) Applications of concentrating collectors.**

2 M

1. Solar thermal power generation (parabolic trough, power tower, dish–Stirling).
2. Industrial process heat and steam generation (dairy, textile, food processing).
3. Solar cooking (Scheffler dish, community kitchens) and solar furnaces.
4. Solar air-conditioning / refrigeration (absorption chillers) and desalination.

*(Any four, ½ M each)***c) Materials used for solar cells.**

2 M

1. Monocrystalline silicon
2. Polycrystalline (multicrystalline) silicon
3. Amorphous silicon (a-Si, thin film)
4. Cadmium telluride (CdTe)
5. Copper indium gallium selenide (CIGS)
6. Gallium arsenide (GaAs) — space applications

*(Any four, ½ M each)***d) Generators used in wind power generation.**

2 M

1. **Permanent magnet DC (PMDC) generator** — small battery-charging wind turbines.
2. **Synchronous generator** (wound-rotor or permanent-magnet synchronous generator, PMSG — used in gearless turbines).
3. **Squirrel cage induction generator (SCIG)** — constant speed turbines.
4. **Doubly fed induction generator (DFIG)** — variable speed turbines.

*(½ M each)***e) Polarization in fuel cell and its types.**

2 M

Polarization: The decrease of the actual terminal voltage of a fuel cell below its ideal (open-circuit, reversible) voltage when current is drawn from it, due to irreversible losses.

Types: 1) Activation polarization 2) Resistance (ohmic) polarization 3) Concentration (mass transport) polarization.

(Definition 1 M, types 1 M)

f) Feedstock for biogas.

2 M

1. Cattle dung (cow / buffalo dung)
2. Poultry droppings, pig and human excreta (night soil)
3. Agricultural residues — crop stalks, leaves, straw
4. Kitchen and food waste, vegetable market waste
5. Aquatic weeds (water hyacinth), press mud, distillery waste

(Any four, ½ M each)

g) OTEC and minimum temperature difference.

2 M

OTEC (Ocean Thermal Energy Conversion) is a method of generating electricity using the temperature difference between the warm surface water of tropical oceans and the cold deep water (from about 1000 m depth) to run a heat engine (closed, open or hybrid cycle).

A minimum temperature difference of about **20 °C** is required for practical working.

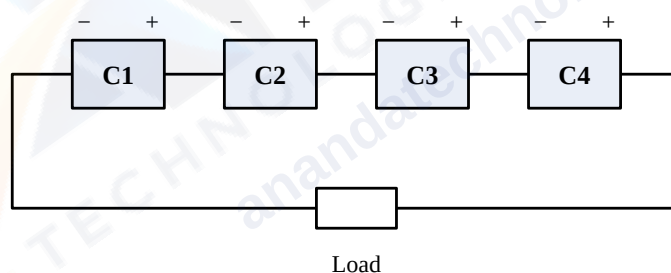
(Definition 1 M, ΔT 1 M)

Q.2

a) Series and parallel connection of solar cells.

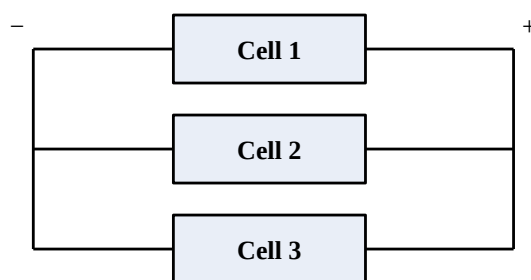
4 M

A single silicon cell gives only about 0.5–0.6 V and a few amperes, so cells are connected in series and parallel to form **modules**, and modules to form **arrays**.



$$V = V_1 + V_2 + \dots + V_4 ; I = I(\text{cell})$$

Fig.: 4 solar cells connected in series



$$I = I_1 + I_2 + \dots + I_3 ; V = V(\text{cell})$$

Fig.: 3 solar cells connected in parallel

Series connection: the positive terminal of one cell is joined to the negative of the next. The **voltages add** while the current is the same as that of one cell: $V = V_1 + V_2 + \dots$; $I = I_{\text{cell}}$.

Advantage: required system voltage (12/24 V or higher) is obtained; lower current reduces I^2R loss and cable size. (A 36-cell module gives $V_{oc} \approx 21$ V for charging a 12 V battery.)

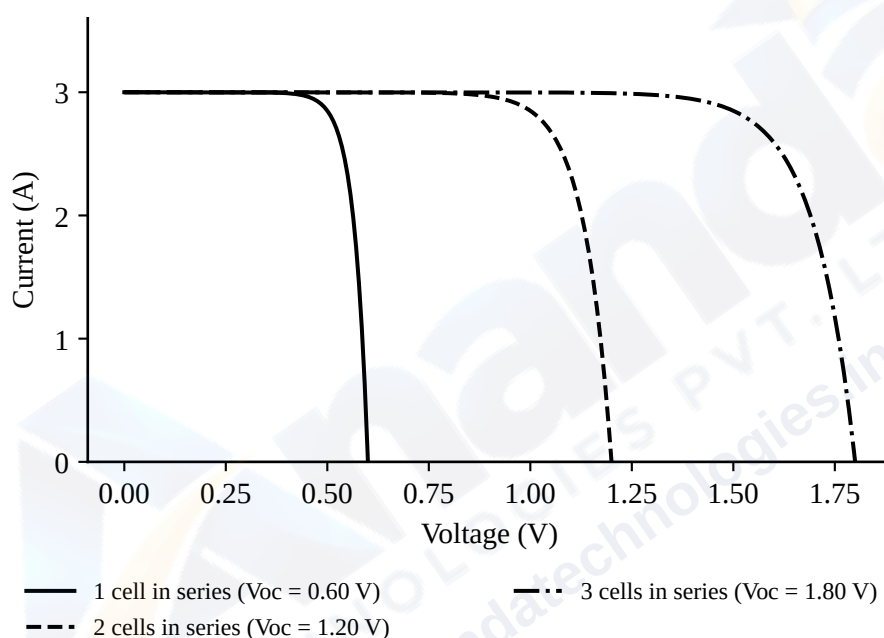


Fig.: I-V curves of cells connected in series (same current, voltages add)

Parallel connection: all positive terminals are joined together and all negative terminals together. The **currents add** while the voltage is that of one cell: $I = I_1 + I_2 + \dots$; $V = V_{\text{cell}}$. Advantage: higher current/power at the same voltage, and if one cell/string is shaded or fails the others continue to supply power.

(Series 2 M, parallel 2 M)

b) Liquid flat plate collector.

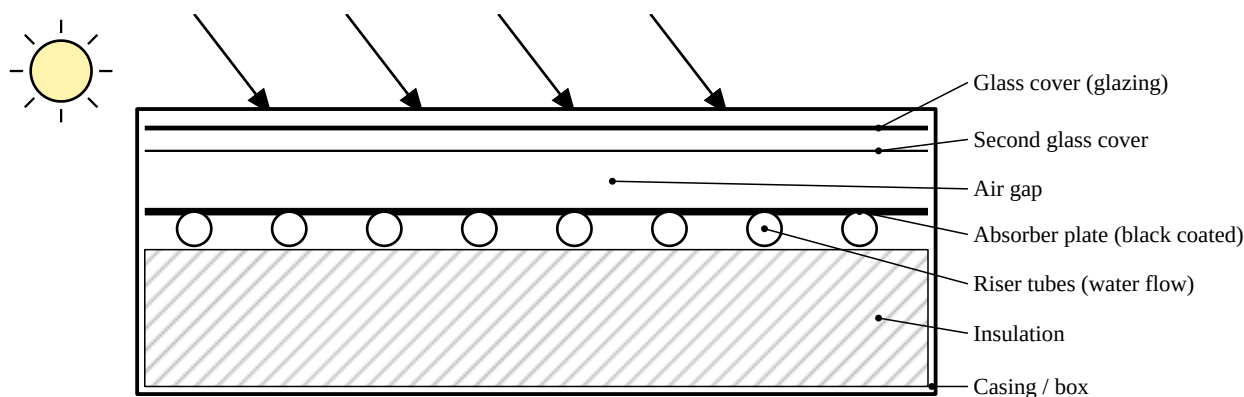


Fig.: Cross-section of a liquid flat plate collector

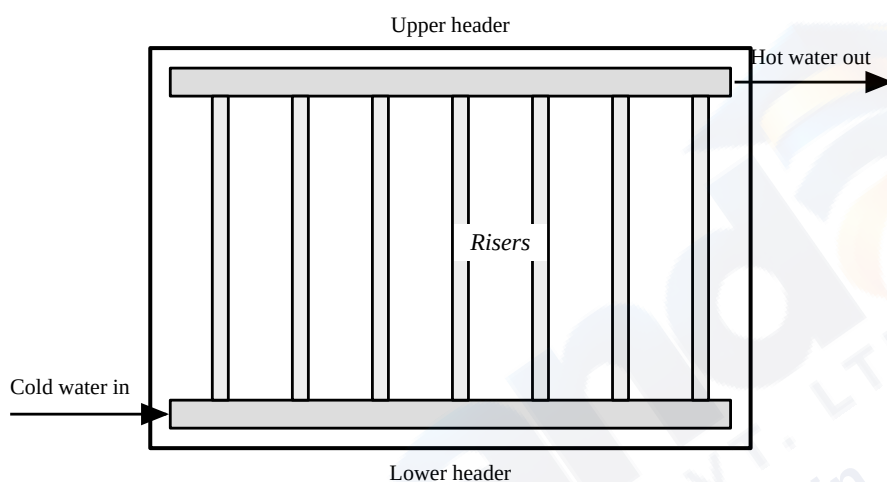


Fig.: Header and riser arrangement (front view)

Construction: 1) **Glazing** — one or two toughened glass covers that pass solar radiation but reduce convection and radiation losses (greenhouse effect). 2) **Absorber plate** — copper/aluminium sheet with black (selective) coating that absorbs radiation. 3) **Riser tubes** bonded to the plate, connected to upper and lower **headers**. 4) **Insulation** (glass wool) at back and sides. 5) **Casing** — weatherproof box.

Working: Radiation passes through the glass and is absorbed by the black plate; heat is conducted to the water flowing in the risers. Cold water enters the lower header and hot water leaves from the upper header to a storage tank (by thermosiphon or pump). Temperatures up to about 80–100 °C are obtained.

Applications: domestic and hotel/hostel water heating, space heating, pre-heating of boiler feed water, swimming-pool heating.

(Sketch 2 M, explanation 1 M, applications 1 M)

c) Lift and drag forces on wind turbine blade.

4 M

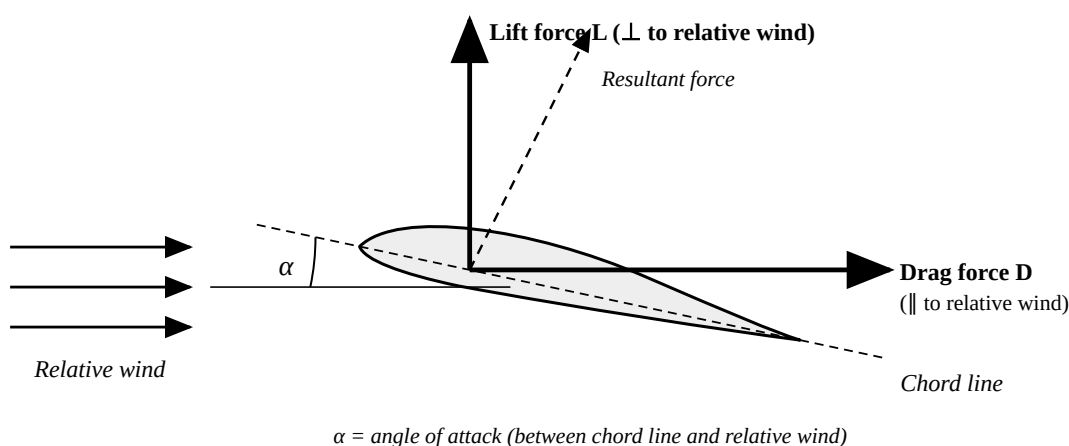


Fig.: Lift and drag forces on a wind turbine blade section (aerofoil)

When air flows over an aerofoil-shaped blade, the air on the curved upper surface travels faster than on the lower surface, so the pressure on the upper surface is lower (Bernoulli's principle). The resultant aerodynamic force is resolved into two components:

- **Lift force (L):** perpendicular to the direction of the relative wind. It is the main force that produces the useful **torque** to rotate modern (lift-type) turbine rotors.
- **Drag force (D):** parallel to the direction of the relative wind; it opposes motion of the blade and adds thrust on the tower. Drag-type rotors (Savonius, cup anemometer) use drag, but have low efficiency.
- **Angle of attack (α):** the angle between the chord line and the relative wind. Lift increases with α up to about 10–15°; beyond this the flow separates and the blade **stalls** (lift falls, drag rises).
- The lift-to-drag ratio (L/D) should be high for good efficiency; this is controlled by blade shape and pitch angle.

(Sketch 2 M, explanation 2 M)

d) Compressed gas and liquid hydrogen storage.

4 M

1) Compressed gas storage: Hydrogen is compressed to high pressure (200–350 bar; up to 700 bar for vehicles) and stored in high-strength steel or carbon-fibre composite cylinders. Large quantities may be stored in underground caverns or depleted gas fields.

- Simple and widely used; fast filling and discharge.
- Low storage density by volume even at high pressure; energy is needed for compression; heavy cylinders; leakage and burst hazards.

2) Liquid hydrogen (cryogenic) storage: Hydrogen is cooled and liquefied at -253°C (20 K) and stored in double-walled, vacuum-insulated (Dewar type) tanks.

- Much higher density than compressed gas ($\approx 71 \text{ kg/m}^3$); used in space rockets and for bulk transport by tankers.
- Liquefaction consumes about 30 % of the energy content; boil-off losses occur; cryogenic handling is difficult and costly.

(Each method 2 M)

Q.3

a) PV plant in a cloudy region.

4 M

i) Dominating radiation: In cloudy weather most of the beam radiation is scattered by clouds, so **diffuse radiation** dominates (on an overcast day almost all radiation reaching the panel is diffuse).

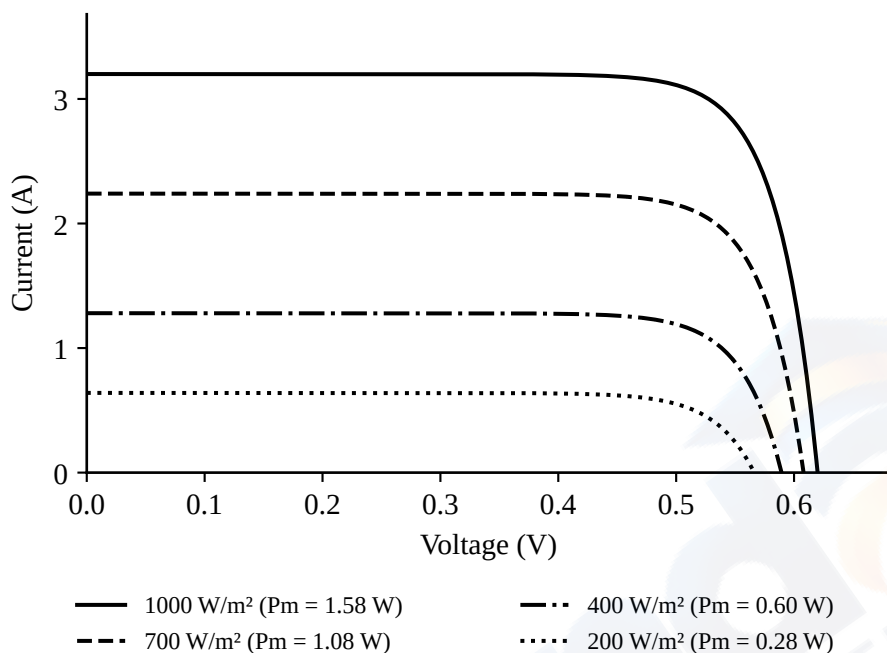


Fig.: Effect of irradiance on I-V curve (25 °C)

ii) Effect on output: Total irradiance falls (from about $1000 W/m^2$ to $100\text{--}400 W/m^2$). The short-circuit current, and hence the power, falls almost in proportion to irradiance, while V_{oc} falls only slightly (see figure). Concentrating collectors and trackers become useless as they use only beam radiation; partial shading by moving clouds causes mismatch and hot spots.

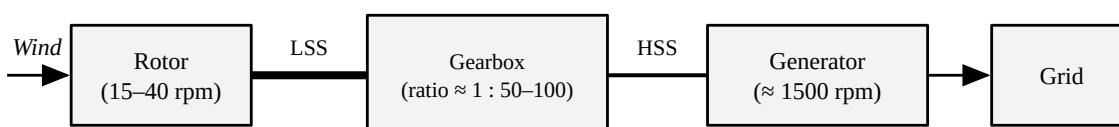
Measures to minimise loss:

- Use modules with good low-light response (e.g. thin-film / high-efficiency mono-PERC cells) and fixed tilt (no concentration).
- Use **MPPT** charge controllers / inverters to track the changing maximum power point.
- Use bypass diodes and string/micro-inverters to reduce mismatch losses.
- Over-size the array and battery bank (more days of autonomy); keep panels clean; consider hybrid with wind/grid.

(Radiation 1 M, effect 1 M, measures 2 M)

b) Need of gearbox in wind turbine.

4 M



LSS = low-speed shaft (high torque) · HSS = high-speed shaft (low torque)

Fig.: Gearbox (speed increaser) between rotor and generator

Need:

- Large wind turbine rotors turn slowly (about 15–40 rpm) because the tip speed must be limited (tip speed ratio $\approx 6-8$) for efficiency, noise and blade stress.
- Standard 4-pole generators need about 1500 rpm (synchronous speed for 50 Hz). A generator for low speed would need very many poles — large, heavy and costly.
- The **gearbox (speed increaser)** raises the speed from the low-speed shaft to the high-speed shaft (ratio about 1 : 50 to 1 : 100) and reduces torque correspondingly, so a small, cheap, standard generator can be used.
- Usually a multi-stage planetary + helical gearbox is used.

Alternative (gearless / direct drive): a low-speed, multi-pole **permanent magnet synchronous generator** coupled directly to the rotor with a full-rated power converter — avoids gearbox losses, noise and maintenance.

(Block diagram 2 M, need 2 M)

c) Chinese fixed dome biogas plant.

4 M

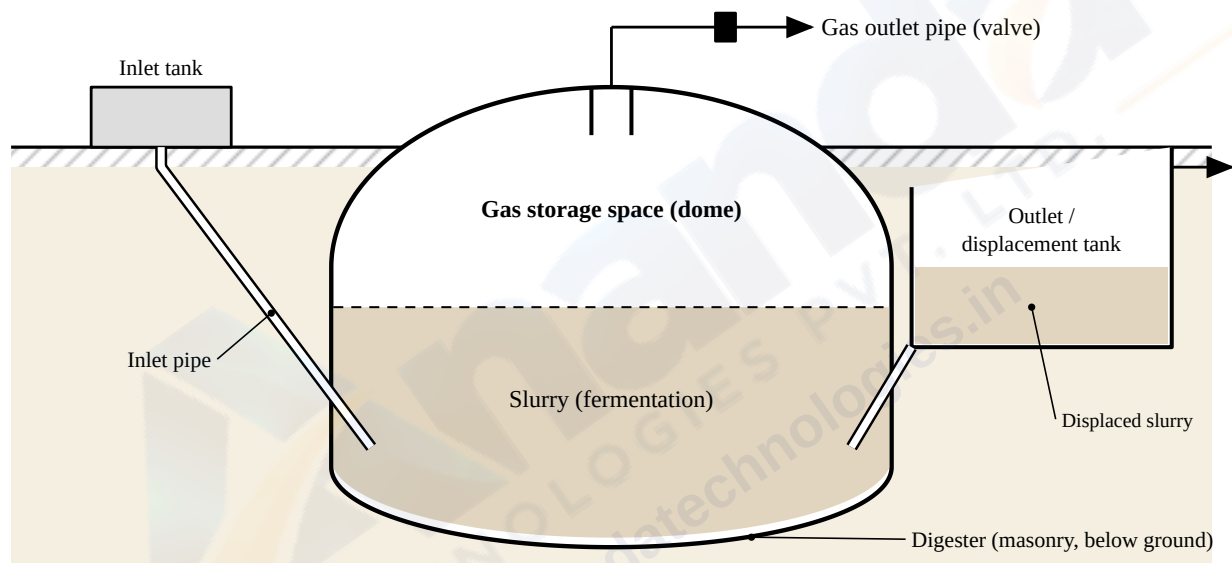


Fig.: Chinese fixed dome type biogas plant

Working:

1. Cattle dung mixed with water (1 : 1) is fed through the inlet tank and inlet pipe into the underground digester.
2. Anaerobic bacteria ferment the slurry and produce biogas, which collects in the **fixed dome** at the top.
3. As gas accumulates its pressure increases and pushes the slurry from the digester into the **outlet (displacement) tank**; the level difference gives the gas pressure.
4. When the gas valve is opened, slurry flows back from the displacement tank into the digester and pushes the gas out; digested slurry overflows from the outlet tank as manure.

(Sketch 2 M, working 2 M)

d) Tidal energy vs wave energy.

4 M

Point	Tidal energy	Wave energy
Cause	Gravitational pull of moon and sun on ocean water.	Wind blowing over the sea surface (indirectly solar energy).
Predictability	Highly predictable — tides occur twice a day on a fixed schedule.	Less predictable; depends on weather and wind.
Energy form	Potential energy of water head between sea and basin (or kinetic energy of tidal currents).	Kinetic and potential energy of moving waves (up-and-down motion).
Site	Estuaries/bays with high tidal range (> 5 m), e.g. Gulf of Kutch, Gulf of Khambhat.	Coastlines exposed to strong waves; offshore or shoreline.
Devices	Barrage with bulb turbines and sluices, tidal stream turbines.	Oscillating water column, floats/buoys, Pelamis, Salter duck.
Development	Commercial plants exist (La Rance, France 240 MW).	Mostly pilot plants (e.g. Vizhinjam OWC, Kerala).

(Any four points, 1 M each)

Q.4

a) Campbell–Stokes sunshine recorder.

4 M

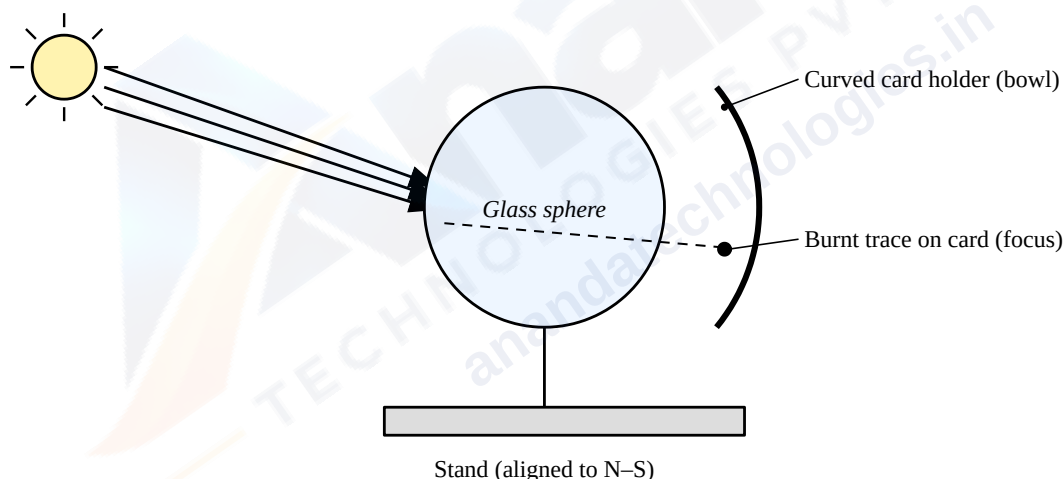


Fig.: Campbell–Stokes sunshine recorder

Use: It measures the **duration of bright sunshine** (number of sunshine hours) in a day.

Construction: A solid **glass sphere** (about 10 cm diameter) acts as a lens and is mounted concentrically in a spherical bowl (card holder). A calibrated **card** marked in hours is placed in grooves of the bowl at the focus of the sphere. The instrument is mounted on a stand aligned in the north–south direction and adjusted for latitude.

Working: Whenever the sun shines brightly, the sphere focuses the sun's rays to a point on the card and **burns a trace** on it. As the sun moves across the sky, the focus moves along the card. When clouds cover the sun, the burning stops. At the end of the day the total length of the burnt trace,

read against the hour scale, gives the hours of bright sunshine. Different cards are used for summer, winter and equinox seasons.

(Sketch 2 M, explanation 2 M)

b) Hydrogen production by electrolysis.

4 M

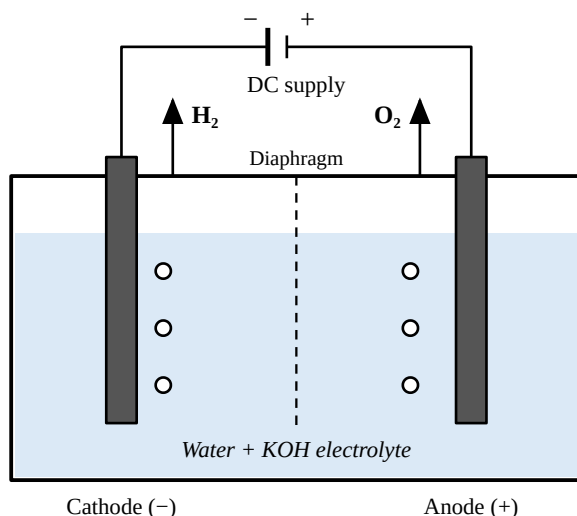
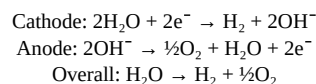


Fig.: Alkaline water electrolyser for hydrogen production

Principle: When direct current is passed through water (made conductive by adding KOH or NaOH), water decomposes into hydrogen and oxygen.

- The electrolyser has two electrodes (nickel-plated steel) dipped in the electrolyte and separated by a porous **diaphragm** that allows ions to pass but keeps the gases apart.
- Hydrogen is liberated at the **cathode (-)** and oxygen at the **anode (+)**; they are collected separately.
- About 1.23 V is the theoretical minimum; practical cells operate at 1.8–2.2 V, using about 4.5–5 kWh per m³ of hydrogen.
- Hydrogen of very high purity is obtained; if the electricity comes from solar/wind, the hydrogen is fully "green". Alternatives: PEM and solid-oxide electrolyzers.

(Sketch 2 M, explanation 2 M)

c) Hydrogen fuel cell vehicle vs battery electric vehicle.

4 M

Point	Hydrogen fuel cell vehicle (FCEV)	Battery electric vehicle (BEV)
i) Refuelling / charging time	Refuelling with compressed H ₂ takes about 3–5 minutes, like petrol.	Charging takes 30–60 min (fast DC) to 6–10 h (AC home charging).
ii) Driving range	Long range, about 500–650 km per fill; little loss in cold weather.	Typically 200–500 km; reduced in cold weather and with heavy loads.
iii) Infrastructure	Very few hydrogen stations; production, storage and transport of H ₂ are costly.	Charging points are growing fast; can charge at home from the existing grid.
iv) Environmental impact	Only water vapour at the tailpipe; overall impact depends on how H ₂ is produced	Zero tailpipe emission; overall impact depends on grid electricity

(green H₂ is clean, grey H₂ from natural gas emits CO₂).

mix; battery mining and disposal issues.

(1 M each)

d) Topography and river characteristics in SHP site selection.

4 M

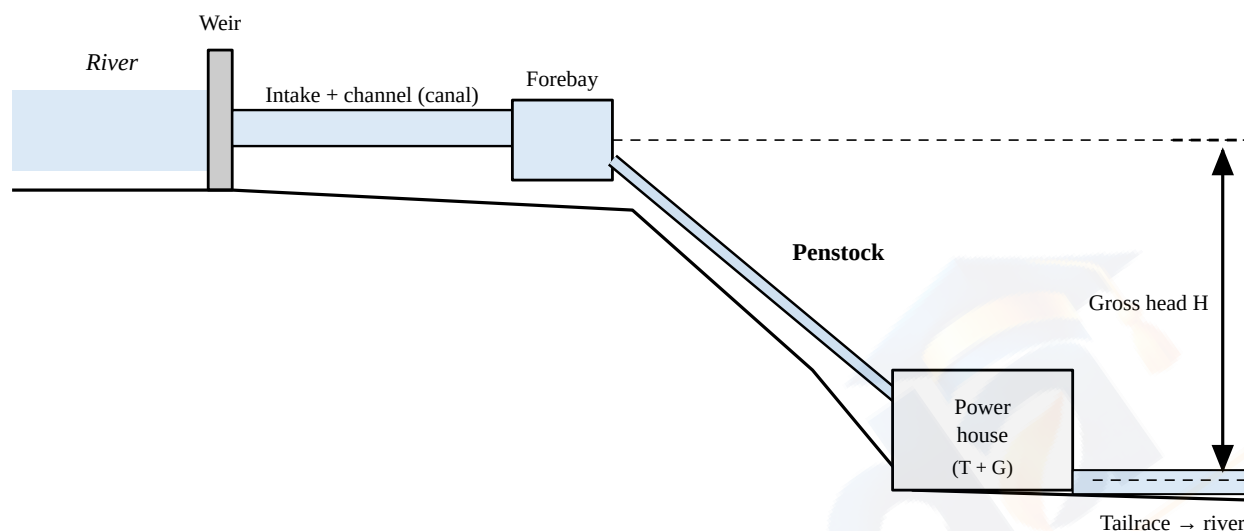


Fig.: General arrangement of a small hydroelectric power plant (run-of-river)

Role of topography:

- Steep slopes, waterfalls or river bends give a large **head** in a short length of channel/penstock, reducing cost ($P = \rho g Q H$).
- Suitable stable ground for the diversion weir, forebay, penstock and powerhouse; land above flood level for the powerhouse.
- Accessibility for construction and nearness to load centre/grid.

Role of river characteristics:

- **Discharge (flow) and its variation** — perennial river with reliable minimum flow (flow-duration data) is needed; this fixes the plant capacity.
- **Silt load** — high silt needs a desilting tank and causes turbine wear.
- **Flood levels** — weir and powerhouse must be safe during floods.
- Water rights, irrigation needs and environmental (minimum) flow must be respected.

(Topography 2 M, river characteristics 2 M)

e) Site selection for a biogas plant.

4 M

1. **Distance:** close to the cattle shed (source of dung) and to the kitchen/point of use, to reduce labour and gas-pipe length.
2. **Water availability:** sufficient water nearby for mixing with dung (about 1 : 1).
3. **Sunny and open place:** warmth improves digestion; avoid shade of trees whose roots can damage the plant.
4. **Safety of drinking water:** at least 10–15 m away from wells and water sources to avoid contamination.

5. **Soil and water table:** firm level ground with low water table so that the digester does not float or leak.

6. **Space** for inlet/outlet tanks and compost (slurry) pits; easy access for maintenance.

(Any four, 1 M each)

Q.5

a) Constant vs variable speed turbines; DFIG system.

6 M

Point	Constant speed wind turbine	Variable speed wind turbine
Rotor speed	Fixed ($\pm 1-2\%$), set by grid frequency.	Varies with wind speed.
Generator	Squirrel cage induction generator connected directly to grid.	DFIG, PMSG or SCIG with power converter.
Energy capture	Optimum C_p only at one wind speed — less energy.	Optimum tip speed ratio maintained — 10–20 % more energy.
Mechanical stress	Gusts cause torque pulsations and gearbox stress.	Gusts absorbed as rotor speed changes — less stress.
Power quality	Power fluctuations; draws reactive power.	Smooth power; reactive power can be controlled.
Cost / complexity	Simple, cheap, robust.	Costly power electronics, complex control.

ii) DFIG based variable speed system:

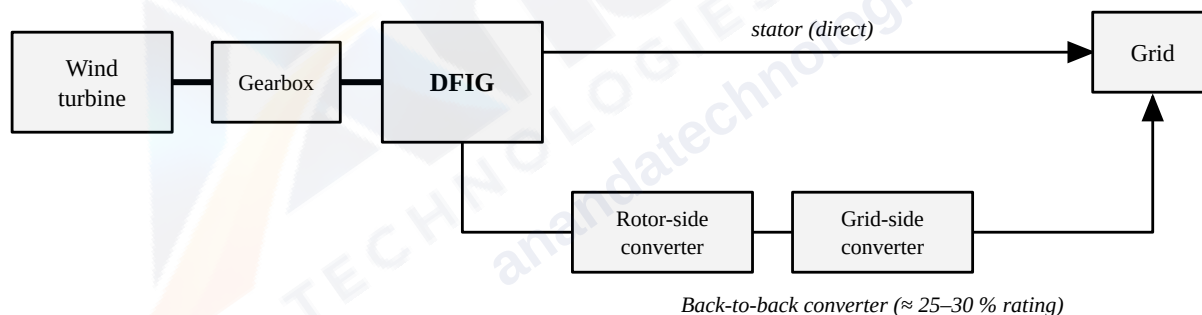


Fig.: DFIG based variable speed wind turbine (stator to grid, rotor through converter)

- The wound-rotor induction generator has its **stator connected directly to the grid** and its **rotor connected through a back-to-back converter** (rotor-side and grid-side converters with a DC link).
- The converter injects rotor current of variable frequency $f_r = s \cdot f$, so the stator output stays at 50 Hz while the rotor speed varies about $\pm 30\%$ around synchronous speed.
- Below synchronous speed power flows from grid into the rotor; above synchronous speed the rotor also delivers power to the grid.
- The converter handles only slip power ($\approx 25-30\%$ of rating), so it is cheaper than a full converter; it also controls active and reactive power.

(Comparison 3 M, DFIG diagram and explanation 3 M)

b) Safety precautions for hydrogen.

6 M

Hydrogen is colourless, odourless, has a wide flammability range (4–75 %), very low ignition energy, an invisible flame, very high diffusivity and causes embrittlement of metals. Hence:

A) Storage:

- Use certified cylinders/tanks of embrittlement-resistant material with pressure relief valves and burst discs.
- Store in well-ventilated, open or roof-vented areas, away from heat, oxidisers and ignition sources; keep cylinders upright and secured.
- Install hydrogen leak sensors and alarms; display "No smoking / No open flame" signs.

B) Transportation:

- Use approved tankers/pipelines with leak-tight welded joints; regular pressure and leak testing.
- Earth/bond vehicles and hoses to prevent static discharge during filling.
- Follow speed limits, route planning and emergency response procedures; carry fire extinguishers.

C) Utilisation:

- Purge lines with nitrogen before and after use to avoid H₂–air mixtures.
- Use flame-proof electrical equipment, flame arrestors and UV/IR flame detectors (flame is invisible).
- Provide automatic shut-off valves, adequate ventilation, and trained personnel with PPE (gloves, face shield for liquid H₂).

(2 M for each part)

c) Biogas plant sizing.

6 M

Given: 8 cattle, 10 kg dung/animal/day, gas yield 0.04 m³/kg, dung : water = 1 : 1, retention time 40 days, gas holder = 60 % of daily gas.

Step 1 – Daily dung = $8 \times 10 = 80 \text{ kg/day}$

Step 2 – Daily gas production = dung $\times$ gas yield = $80 \times 0.04 = 3.20 \text{ m}^3/\text{day}$

Step 3 – Daily slurry (dung : water = 1 : 1) = $80 + 80 = 160 \text{ kg} \approx 0.16 \text{ m}^3/\text{day}$ (slurry density $\approx 1000 \text{ kg/m}^3$)

Step 4 – Digester volume = daily slurry $\times$ retention time = $0.16 \times 40 = 6.4 \text{ m}^3$

Step 5 – Gas holder volume ($\approx 60 \%$ of daily gas) = $0.6 \times 3.20 = 1.92 \text{ m}^3$

Answer: i) Gas = 3.20 m³/day ii) Digester volume = 6.4 m³ iii) Gas holder $\approx 1.92 \text{ m}^3$

Suggested plant: a family size plant of about 3 m³/day gas capacity — a **KVIC floating drum** plant (constant gas pressure, easy operation) or a **fixed dome (Deenbandhu / Chinese)** plant (lower cost, long life). A family of 5–6 needs about 2 m³/day for cooking, so this gas is sufficient.

(Each calculation 1½ M, suggestion 1½ M)

Q.6

a) Off-grid PV system design.

6 M

Step 1 – Daily energy demand:

Load	Qty	Watt	Hours/day	Energy (Wh/day)
LED lamps	6	9	6	$6 \times 9 \times 6 = 324$
Ceiling fans	2	60	8	$2 \times 60 \times 8 = 960$
LED TV	1	80	4	$1 \times 80 \times 4 = 320$
Mobile / laptop charging	1	65	3	$1 \times 65 \times 3 = 195$
Total		319 W (connected)		1799 Wh/day

Step 2 – Energy to be supplied by PV array (inverter $\eta = 0.9$, battery $\eta = 0.85$):

$$E_{PV} = 1799 / (0.9 \times 0.85) = 2352 \text{ Wh/day}$$

Step 3 – Array peak power (peak sun hours = 5.5 h, derating factor for temperature, dust and wiring = 0.8):

$$P_{array} = 2352 / (5.5 \times 0.8) = 534 \text{ Wp}$$

Step 4 – Number of modules (150 Wp, 12 V nominal each): $534 / 150 = 3.56 \rightarrow 4$ modules.

For a 24 V system, modules in series = $24/12 = 2$; parallel strings = $\lceil 4/2 \rceil = 2 \rightarrow$ total **4 modules**
(2S $\times$ 2P) = 600 Wp

Step 5 – Battery bank (2 days autonomy, depth of discharge 0.7):

$$\text{Capacity} = (\text{load} / \eta_{inv}) \times \text{days} / (V_{sys} \times \text{DoD}) = (1799/0.9) \times 2 / (24 \times 0.7) = 238 \text{ Ah at 24 V}$$

Using 12 V, 150 Ah batteries: 2 in series $\times$ 2 parallel = **4 batteries** (300 Ah at 24 V)

Step 6 – Inverter rating = $1.25 \times$ connected load = $1.25 \times 319 = 399 \text{ VA} \rightarrow$ choose **500 VA, 24 V inverter**. Charge controller: 24 V, current $\geq 1.25 \times$ array Isc.

Result: PV array 4 $\times$ 150 Wp modules (2 in series $\times$ 2 parallel strings); battery bank 4 $\times$ 12 V/150 Ah (2 series $\times$ 2 parallel); inverter about 500 VA, 24 V.

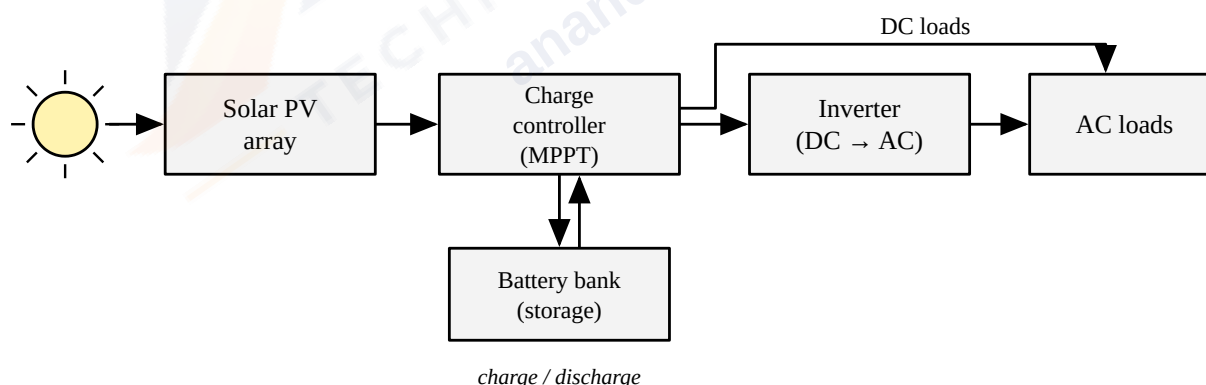


Fig.: Block diagram of a basic (stand-alone / off-grid) PV power system

(Load 1 M, array 2 M, battery 2 M, inverter 1 M)

b) Wind farm site in Maharashtra; comparison of two sites.

i) **Suggested site:** The Satara district ridges (Chalkewadi – Vankusawade plateau on the Sahyadri ranges) — also Sangli, Dhule (Brahmanvel) and Ahmednagar (Supa) belts.

- The ridges of the Western Ghats face the south-west monsoon winds, giving high and steady average wind speeds, especially from May to September.
- Elevated plateaus with little obstruction (low roughness) and large open, non-agricultural land.
- Wind resource assessment has already shown good wind power density; existing wind farms, roads and grid sub-stations reduce cost.

ii) Site A (7 m/s):

Given: rotor diameter $D = 40$ m, wind speed $V = 7$ m/s, air density $\rho = 1.225$ kg/m³, power coefficient $C_p = 0.4$.

Swept area $A = \pi D^2/4 = \pi \times 40^2 / 4 = 1,256.64$ m²

Power available in wind $P = \frac{1}{2} \rho A V^3 = 0.5 \times 1.225 \times 1,256.64 \times 7^3 = 0.5 \times 1.225 \times 1,256.64 \times 343 = 264,003.74$ W ≈ 264.0 kW

Power density = $P/A = \frac{1}{2} \rho V^3 = 210.1$ W/m²

Maximum extractable power (Betz limit, $C_{p,max} = 16/27 = 0.593$) $= 0.593 \times 264,003.74 = 156.4$ kW

Mechanical power at rotor $= C_p \times P = 0.4 \times 264,003.74 = 105.6$ kW

Site B (5 m/s):

Given: rotor diameter $D = 40$ m, wind speed $V = 5$ m/s, air density $\rho = 1.225$ kg/m³, power coefficient $C_p = 0.4$.

Swept area $A = \pi D^2/4 = \pi \times 40^2 / 4 = 1,256.64$ m²

Power available in wind $P = \frac{1}{2} \rho A V^3 = 0.5 \times 1.225 \times 1,256.64 \times 5^3 = 0.5 \times 1.225 \times 1,256.64 \times 125 = 96,211.28$ W ≈ 96.2 kW

Power density = $P/A = \frac{1}{2} \rho V^3 = 76.6$ W/m²

Maximum extractable power (Betz limit, $C_{p,max} = 16/27 = 0.593$) $= 0.593 \times 96,211.28 = 57.0$ kW

Mechanical power at rotor $= C_p \times P = 0.4 \times 96,211.28 = 38.5$ kW

Justification: Power $\propto V^3$, so $(7/5)^3 = 2.74$. The turbine at the 7 m/s site develops 105.6 kW against 38.5 kW at 5 m/s — about 2.7 times more. Hence the **7 m/s site is better**; average speeds of about 6–7 m/s and above at hub height are generally considered economical, while 5 m/s is suitable only for small turbines.

(Site with justification 2 M, calculations 3 M, conclusion 1 M)

c) Effect of temperature difference in OTEC; Carnot efficiency.

Effect of temperature difference (ΔT):

- OTEC works as a heat engine between the warm surface water (T_w) and the cold deep water (T_c). The maximum (Carnot) efficiency is $\eta = (T_w - T_c)/T_w$, so it depends directly on ΔT .

- Since ΔT is only about 20–25 °C, the efficiency is very low (Carnot 6–8 %, actual 2–3 %); a large quantity of water must be pumped for each kW, and pumping power takes a big share of the gross output.
- A larger ΔT increases both efficiency and net power (net output rises roughly with ΔT^2 , because both the heat available per kg of water and the efficiency increase). With ΔT below about 20 °C the net output becomes nearly zero.
- Hence OTEC is suitable only in tropical seas (between about 20° N and 20° S latitudes) where the surface water stays warm throughout the year.

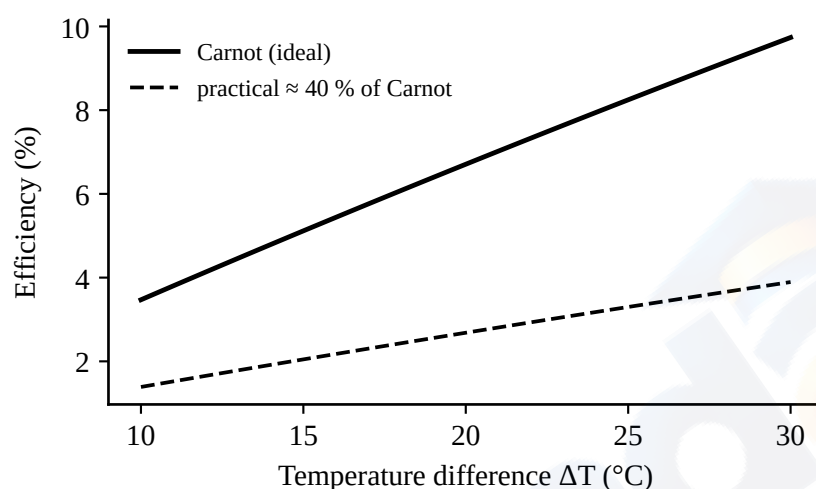


Fig.: Effect of ΔT on OTEC efficiency (cold water 5 °C)

i) $T_w = 28\text{ °C}$, $T_c = 6\text{ °C}$: $\eta_{\text{Carnot}} = (T_w - T_c)/T_w = (301.15 - 279.15) / 301.15 = 7.31\%$

ii) $T_w = 24\text{ °C}$, $T_c = 6\text{ °C}$: $\eta_{\text{Carnot}} = (T_w - T_c)/T_w = (297.15 - 279.15) / 297.15 = 6.06\%$

Comment: Reducing ΔT from 22 °C to 18 °C lowers the Carnot efficiency from 7.31 % to 6.06 % (a fall of 17 %); the actual efficiency would be only about 2–3 %. Thus OTEC plants must be located where ΔT is at least 20 °C.

(Effect 3 M, calculations 2 M, comment 1 M)

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