

Renewable Energy Technology (315337)

Model Question Paper — Set A · Model Answers

Q.1

a) Beam and diffuse radiation.

2 M

i) Beam (direct) radiation: Solar radiation received on the earth's surface **directly from the sun without change of direction**, i.e. without being scattered or reflected by the atmosphere. It casts a shadow and can be focused by concentrators.

ii) Diffuse radiation: Solar radiation received **after its direction has been changed** by scattering and reflection from air molecules, dust, water vapour and clouds. It comes from the whole sky and does not cast a sharp shadow.

Global (total) radiation = beam + diffuse radiation.

(Each definition 1 M)

b) Use of pyrheliometer and pyranometer.

2 M

i) Pyrheliometer: used to measure the **beam (direct normal) radiation** — it is pointed at the sun through a collimating tube so that only direct rays reach the sensor.

ii) Pyranometer: used to measure the **global (total = beam + diffuse) radiation** on a horizontal surface from the whole hemisphere of the sky. With a shading ring that blocks the sun, it measures **diffuse radiation** only.

(1 M each)

c) Fill factor of a solar cell.

2 M

Fill factor (FF) is the ratio of the maximum power actually obtained from the solar cell to the product of its open-circuit voltage and short-circuit current. It shows the 'squareness' of the I-V curve.

$$FF = P_{\max} / (V_{oc} \times I_{sc}) = (V_m \times I_m) / (V_{oc} \times I_{sc})$$

Typical value for silicon cells: 0.7 – 0.85.

(Definition 1 M, expression 1 M)

d) Cut-out wind speed and power coefficient.

2 M

i) Cut-out wind speed: The maximum wind speed (about 25 m/s) at which the turbine is **shut down** (blades feathered and brake applied) to protect the rotor, gearbox and tower from damage.

ii) Power coefficient (Cp): The ratio of the mechanical power extracted by the rotor to the total power available in the wind passing through the swept area: $C_p = P_{\text{rotor}} / (\frac{1}{2} \rho A V^3)$. Its theoretical maximum is $16/27 = 0.593$ (Betz limit).

(1 M each)

e) Methods of hydrogen production.

2 M

1. **Electrolysis of water** (alkaline / PEM electrolyser) using electricity, preferably from solar or wind.
2. **Thermochemical water splitting** (e.g. sulphur–iodine cycle) using high-temperature heat.
3. **Coal gasification** (and steam reforming of natural gas) — $C + H_2O \rightarrow CO + H_2$.
4. **Photo-electrolysis** — splitting water directly with sunlight using semiconductor electrodes.
5. Biological methods (bio-photolysis by algae, fermentation of biomass).

(Any four, ½ M each)

f) Factors affecting biogas generation.

2 M

1. **Temperature** — best 30–40 °C (mesophilic, about 35 °C); gas falls sharply below 15 °C.
2. **pH value** — should be about 6.8 – 7.5 (near neutral).
3. **Retention time** — 30 to 60 days depending on temperature.
4. **Carbon to nitrogen (C/N) ratio** — about 25–30 : 1.
5. Total solids content (about 7–10 %, dung : water $\approx$ 1 : 1), loading rate, stirring, toxic substances.

(Any four, ½ M each)

g) Advantages of small hydro power plants.

2 M

1. Renewable and pollution-free; no fuel cost and very low running cost.
2. Mostly run-of-river type — little or no submergence of land and no large-scale rehabilitation.
3. Suitable for remote and hilly areas; supplies power locally and reduces transmission losses.
4. Short gestation period, simple design, long life and high efficiency (80–90 %).
5. Quick start and stop; can be run by local people (decentralised generation).

(Any four, ½ M each)

Q.2

a) Angstrom compensation pyrhelimeter.

4 M

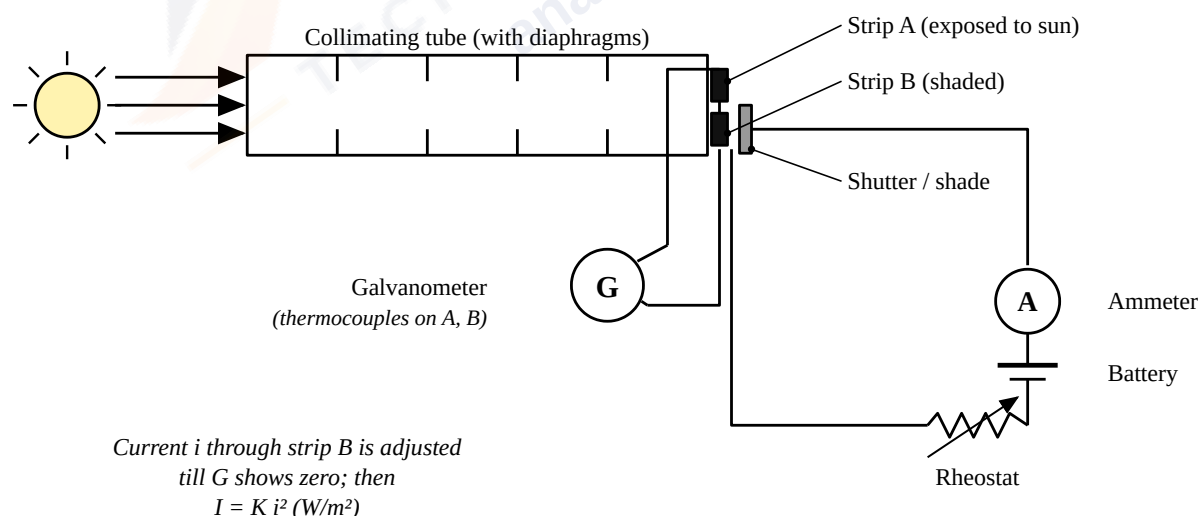


Fig.: Angstrom compensation pyrhelimeter

Construction: Two identical thin **blackened manganin strips A and B** are fixed at the base of a collimating tube which is pointed towards the sun. Strip A is exposed to the sun; strip B is shaded by a shutter. Thermocouple junctions on the back of the strips are connected to a sensitive **galvanometer**. Strip B is connected to an electric circuit having a battery, rheostat and ammeter.

Working: Strip A absorbs beam radiation and becomes hotter than B, so the galvanometer deflects. A current i is passed through the shaded strip B and adjusted with the rheostat until both strips are at the same temperature (galvanometer reads zero). Then the electrical heat supplied to B equals the solar energy absorbed by A:

$$I_b = K i^2, \text{ where } K = R/(w \alpha) \text{ is the instrument constant (} R = \text{resistance per unit length, } w = \text{width and } \alpha = \text{absorptivity of the strip}).$$

The shutter is then changed over to the other strip and the reading repeated to remove errors. It is a standard (absolute) instrument used to calibrate other pyrheliometers.

(Sketch 2 M, explanation 2 M)

b) Equivalent circuit and I-V characteristics of solar cell.

4 M

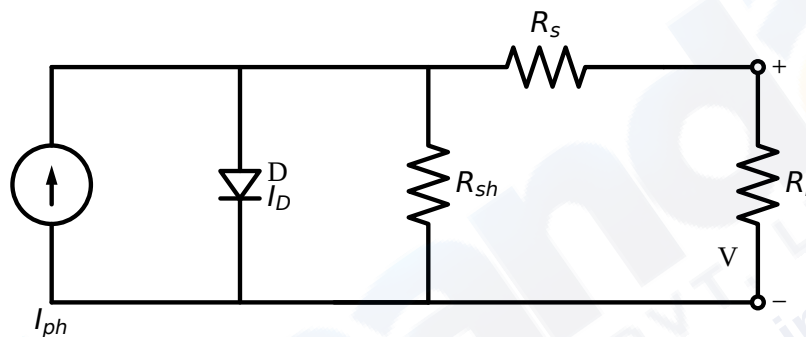


Fig.: Equivalent circuit of a solar cell (single-diode model)

Equivalent circuit: A solar cell is represented by a **current source I_{ph}** (photo-current, proportional to irradiance) in parallel with a **diode D** (the p-n junction), a **shunt resistance R_{sh}** (leakage paths) and a **series resistance R_s** (resistance of semiconductor, contacts and grid).

$$I = I_{ph} - I_0 [e^{q(V + IR_s)/nkT} - 1] - (V + IR_s)/R_{sh}$$

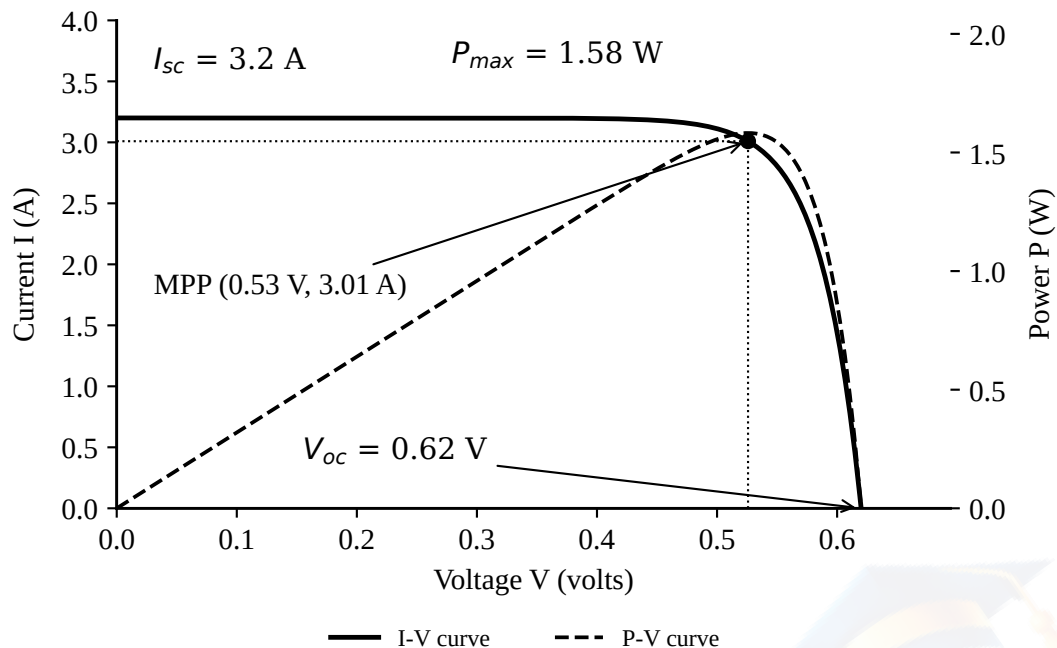


Fig.: I-V and P-V characteristics of a solar cell

I-V characteristics (drawn for a cell with $I_{sc} = 3.2 \text{ A}$, $V_{oc} = 0.62 \text{ V}$):

- **Short-circuit current I_{sc} :** current when terminals are shorted ($V = 0$); it is the maximum current and is proportional to irradiance.
- **Open-circuit voltage V_{oc} :** voltage when no current flows ($I = 0$); $\approx 0.6 \text{ V}$ for a silicon cell.
- As voltage increases from zero the current stays nearly constant, then falls sharply near V_{oc} (the "knee").
- **Maximum power point (MPP):** the point on the knee where $V \times I$ is maximum (here $V_m = 0.53 \text{ V}$, $I_m = 3.01 \text{ A}$, $P_m = 1.58 \text{ W}$, $FF = 0.80$). An MPPT controller keeps the cell working at this point.

(Equivalent circuit 1 M, I-V curve 2 M, explanation 1 M)

c) Power available in wind and Betz limit.

4 M

Consider air of density ρ moving with velocity V through the swept area A of the rotor.

Kinetic energy of mass m of air: $KE = \frac{1}{2} m V^2$

Mass of air flowing through area A per second (mass flow rate): $\dot{m} = \rho \times (\text{volume per second}) = \rho A V$

Power = kinetic energy per second = $\frac{1}{2} \dot{m} V^2 = \frac{1}{2} (\rho A V) V^2$

$P = \frac{1}{2} \rho A V^3$ watts, where $A = \pi D^2/4$ for a rotor of diameter D .

Hence power in the wind is proportional to (i) air density, (ii) swept area (D^2) and (iii) **cube of wind speed** — doubling the wind speed gives 8 times the power.

Betz limit: A turbine cannot extract all this power because the air must keep moving away after the rotor. Betz showed that the maximum fraction is obtained when the downstream speed is one-third of the upstream speed, giving **$C_{p,max} = 16/27 = 0.593$** . Thus no wind turbine can extract more than **59.3 %** of the power in the wind; practical turbines achieve $C_p \approx 0.35 - 0.45$.

Power extracted $P_T = C_p \times \frac{1}{2} \rho A V^3$

(Derivation 3 M, Betz limit 1 M)

d) Hydrogen–oxygen fuel cell.

4 M

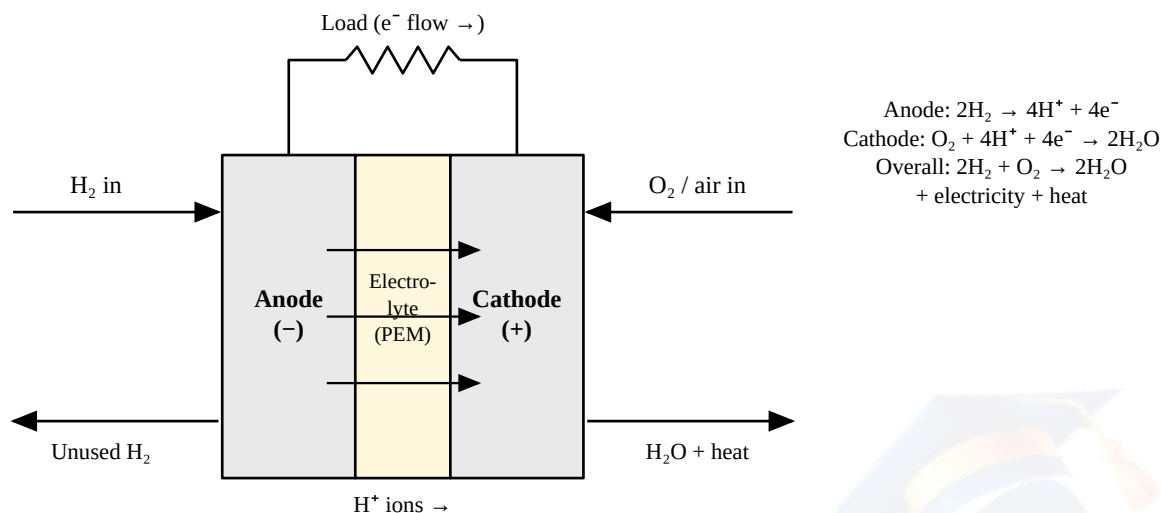


Fig.: Hydrogen–oxygen fuel cell (PEM type)

Construction: A fuel cell has two porous electrodes — **anode** (fuel electrode) and **cathode** (oxidant electrode) — coated with catalyst (platinum), separated by an **electrolyte** (proton exchange membrane, KOH or phosphoric acid). Hydrogen is supplied to the anode and oxygen (or air) to the cathode. The electrodes are connected through an external load.

Working:

1. At the anode, H_2 molecules split into hydrogen ions and electrons with the help of the catalyst:
 $2H_2 \rightarrow 4H^+ + 4e^-$.
2. The H^+ ions pass through the electrolyte to the cathode; electrons cannot pass through the electrolyte, so they flow through the external circuit — this is the **DC electric current**.
3. At the cathode, oxygen combines with H^+ ions and electrons to form water: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$.
4. Overall reaction: $2H_2 + O_2 \rightarrow 2H_2O + \text{electricity} + \text{heat}$. Ideal voltage ≈ 1.23 V per cell (practically 0.6–0.8 V); cells are stacked in series for higher voltage.

(Diagram 2 M, working 2 M)

Q.3

a) Stand-alone PV system block diagram.

4 M

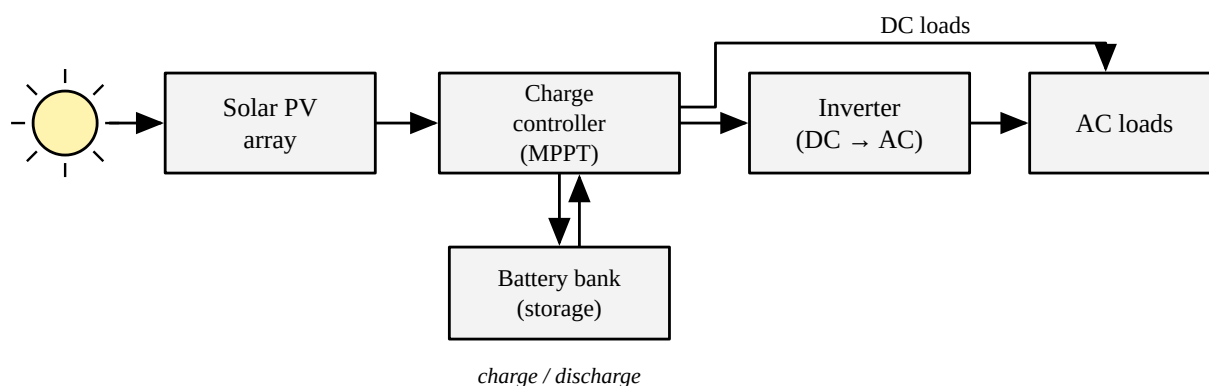


Fig.: Block diagram of a basic (stand-alone / off-grid) PV power system

- **Solar PV array:** modules connected in series-parallel convert sunlight directly into DC electricity.
- **Charge controller (MPPT/PWM):** regulates the array output to charge the battery correctly; prevents over-charging and deep discharge; MPPT type extracts maximum power.
- **Battery bank:** stores surplus energy during the day and supplies the load at night and on cloudy days.
- **Inverter:** converts DC from battery/array into 230 V, 50 Hz AC for AC appliances.
- **Loads:** DC loads (LED lights, DC fans) can be fed directly from the controller; AC loads from the inverter.

Such systems are used where the grid is not available — remote homes, street lights, telecom towers, water pumping.

(Block diagram 2 M, function of blocks 2 M)

b) Metal hydride storage of hydrogen.

4 M

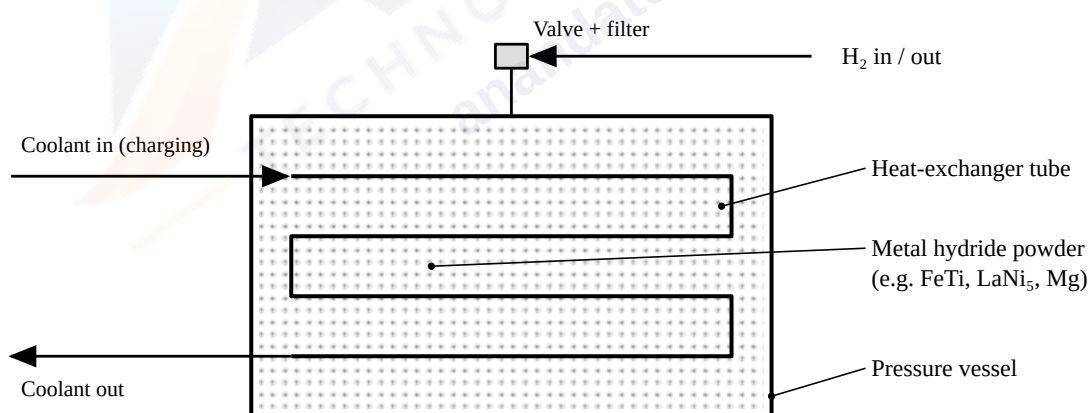
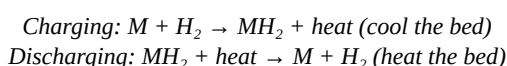
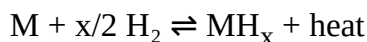


Fig.: Metal hydride hydrogen storage vessel

Principle: Certain metals and alloys (FeTi, LaNi₅, Mg, Mg₂Ni) absorb hydrogen into their crystal lattice and form **metal hydrides**. The reaction is reversible:



- **Charging:** hydrogen is supplied under moderate pressure; heat is released, so the bed is cooled by coolant flowing in the heat-exchanger tubes.
- **Discharging:** heat is supplied (hot water / engine exhaust) and the pressure is lowered; hydrogen is released from the hydride.

Advantages: very safe (hydrogen is chemically bound, released slowly; low leakage risk); high volumetric storage density — more than liquid hydrogen; low operating pressure; no cryogenic cooling; long cycle life.

Limitation: heavy (low weight % of H_2 — about 1.5–7 %), costly alloys, heat management needed.

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

c) KVIC floating drum biogas plant.

4 M

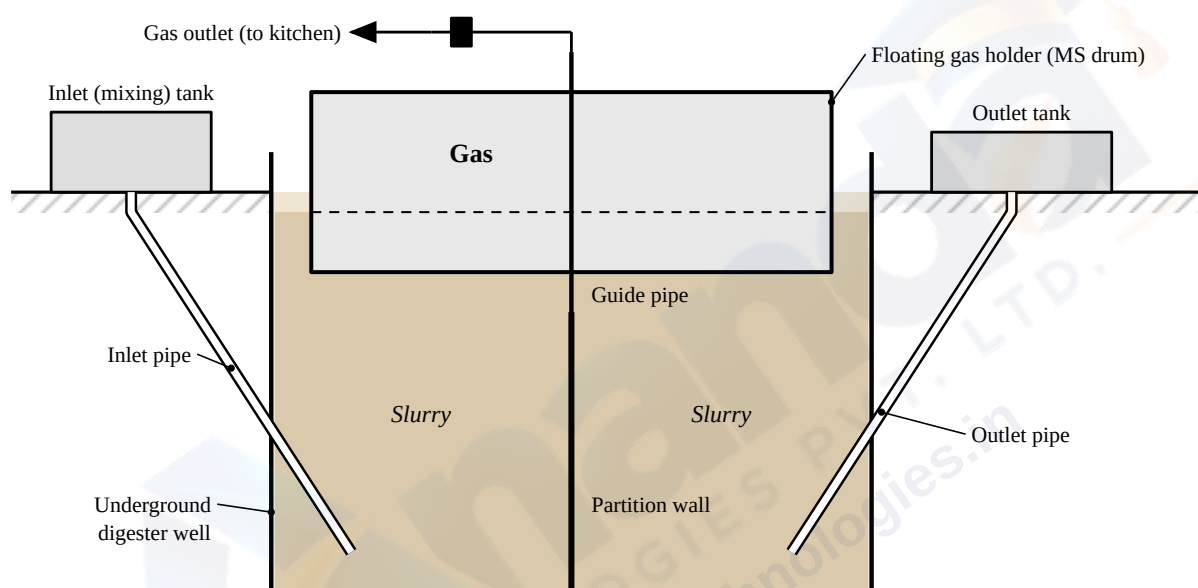


Fig.: KVIC floating drum type biogas plant

Construction:

- **Digester:** underground cylindrical well of brick masonry, divided by a **partition wall** into two chambers for proper fermentation.
- **Gas holder:** mild-steel drum (inverted) which floats on the slurry and moves up and down along a **central guide pipe**.
- **Inlet tank and pipe:** dung and water are mixed (1 : 1) and fed to the bottom of the digester.
- **Outlet tank and pipe:** digested slurry overflows to the outlet tank and is used as manure.
- **Gas outlet pipe** with valve on the top of the drum.

Working: The slurry is fermented by anaerobic bacteria and produces biogas (CH_4 55–65 %, CO_2 30–40 %). The gas collects in the drum, which rises as gas accumulates. The weight of the drum keeps the gas at a **constant pressure** (about 8–10 cm water column). When gas is used, the drum moves down. Fresh slurry added daily pushes the same volume of spent slurry out through the outlet.

(Diagram 2 M, construction and working 2 M)

d) Closed cycle OTEC system.

4 M

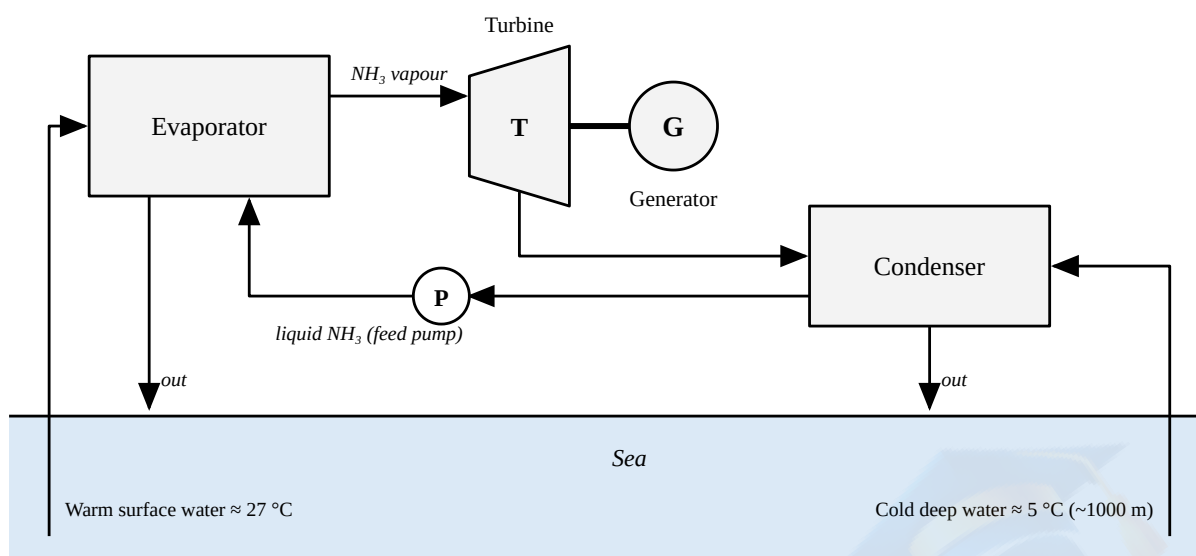


Fig.: Closed cycle (Anderson) OTEC system

Principle: OTEC uses the temperature difference (about 20–25 °C) between warm surface sea water ($\approx 27\text{ }^{\circ}\text{C}$) and cold deep sea water ($\approx 5\text{ }^{\circ}\text{C}$ from $\sim 1000\text{ m}$ depth) to run a heat engine.

Working (Anderson / closed Rankine cycle):

1. Warm surface water is pumped through the **evaporator**, where a low boiling point working fluid (**ammonia** or propane) evaporates.
2. The high-pressure vapour expands in a **turbine** which drives a **generator**.
3. The exhaust vapour is condensed in a **condenser** cooled by cold water pumped from the deep ocean.
4. The liquid ammonia is pumped back to the evaporator by the **feed pump**, completing the closed cycle.

Since ΔT is small, the efficiency is low (Carnot $\approx 7\%$, actual $\approx 2\text{--}3\%$) and large water flows are needed.

(Sketch 2 M, explanation 2 M)

Q.4

a) Focusing vs non-focusing collectors.

4 M

Point	Focusing (concentrating) collector	Non-focusing collector
Principle	Reflects / refracts the beam radiation onto a small receiver (concentration ratio > 1).	Absorbs radiation on the same area as it intercepts (no concentration, ratio ≈ 1).
Radiation used	Uses only beam radiation.	Uses both beam and diffuse radiation.
Tracking	Needs one- or two-axis sun tracking.	Fixed; no tracking needed.
Temperature	High: $150\text{ }^{\circ}\text{C}$ to above $500\text{ }^{\circ}\text{C}$.	Low: up to about $100\text{ }^{\circ}\text{C}$.

Examples	Parabolic trough, parabolic dish, central receiver (heliostat), Fresnel lens.	Flat plate collector, evacuated tube collector, solar air heater.
Use	Power generation, industrial process heat, steam.	Water heating, space heating, drying.

(Any four points, 1 M each)

b) Site selection for wind farm.

4 M

- 1. High annual average wind speed:** since $P \propto V^3$, the site should have a high and steady wind speed (preferably above 6–7 m/s at hub height); wind data of at least one year should be studied.
- 2. Availability of open land:** large, cheap land free from obstacles (buildings, trees); turbines spaced 5–9 rotor diameters apart.
- 3. Nearness to grid / load centre:** reduces transmission line cost and losses.
- 4. Nature of ground and foundation:** strong soil to carry the tower; hill tops, ridges and coastal areas give good wind due to height and low roughness.
- 5. Accessibility:** good roads for transporting large blades and cranes.
- 6. Environmental aspects:** away from bird routes, airports and residential areas (noise, shadow flicker); low turbulence.

(Any four, 1 M each)

c) Hazards of hydrogen and preventive measures.

4 M

Hazards: Hydrogen has a very wide flammability range (4–75 % by volume in air) and very low ignition energy (≈ 0.02 mJ), so it ignites easily; it burns with an almost **invisible flame**; it is colourless and odourless so leaks are not noticed; being the smallest molecule it leaks easily through joints; it causes **hydrogen embrittlement** of metals; liquid hydrogen (-253 °C) causes cold burns.

Preventive measures:

1. Use leak-proof, embrittlement-resistant materials (stainless steel, special alloys) and properly welded joints; test regularly for leaks.
2. Install **hydrogen leak detectors** and alarms; provide good **ventilation** at roof level since hydrogen rises.
3. Remove ignition sources — no smoking or open flames, use flame-proof electrical fittings, earth all equipment to avoid static sparks.
4. Provide pressure relief valves, flame arrestors and flame (UV/IR) detectors; store cylinders upright, away from heat.
5. Train personnel; use protective gloves and face shields while handling liquid hydrogen.

(Hazards 1 M, measures 3 M)

d) Small hydro power output and turbine selection.

4 M

Given: discharge $Q = 1.8$ m³/s, net head $H = 9$ m, overall efficiency $\eta_o = 0.82$, $\rho = 1000$ kg/m³, $g = 9.81$ m/s².

Hydraulic (water) power $P_w = \rho g Q H = 1000 \times 9.81 \times 1.8 \times 9 = 158,922$ W = 158.9 kW

Electrical output $P = \eta_o \times \rho g Q H = 0.82 \times 158.9 = \mathbf{130.3 \text{ kW}}$

Recommended turbine: Kaplan (or propeller / bulb / tubular) turbine.

- The head of 9 m is a **low head** (below about 30 m) with a relatively large discharge — reaction turbines of axial flow type are best suited.
- Kaplan turbine has adjustable runner blades, so it maintains high efficiency even when river flow varies.
- It has high specific speed, so it can run at reasonable speed under low head; a cross-flow turbine may also be used for very small (micro) schemes.

(Calculation 2 M, turbine with justification 2 M)

e) Stages of anaerobic digestion.

4 M

Anaerobic digestion is the decomposition of organic matter by bacteria **in the absence of oxygen**, producing biogas (mainly CH_4 and CO_2) and digested slurry. It takes place in three stages:

1. **Hydrolysis (enzymatic stage):** complex organic compounds (cellulose, proteins, fats) are broken down by enzymes of fermentative bacteria into simple soluble compounds — sugars, amino acids, fatty acids.
2. **Acid formation (acidogenesis):** acid-forming bacteria convert these simple compounds into volatile organic acids (mainly acetic acid), CO_2 and H_2 . The pH tends to fall in this stage.
3. **Methane formation (methanogenesis):** methanogenic bacteria (strictly anaerobic) convert acetic acid, CO_2 and H_2 into methane: $\text{CH}_3\text{COOH} \rightarrow \text{CH}_4 + \text{CO}_2$ and $\text{CO}_2 + 4\text{H}_2 \rightarrow \text{CH}_4 + 2\text{H}_2\text{O}$. These bacteria are sensitive to temperature and pH (6.8–7.5).

(Introduction 1 M, three stages 3 M)

Q.5

a) VSCF scheme of wind energy conversion.

6 M

In a **variable speed constant frequency (VSCF)** scheme the rotor is allowed to run at a speed that changes with wind speed (to keep the tip speed ratio at its optimum value and obtain maximum C_p), while the electrical output supplied to the grid is kept at **constant frequency (50 Hz)** by power electronic converters.

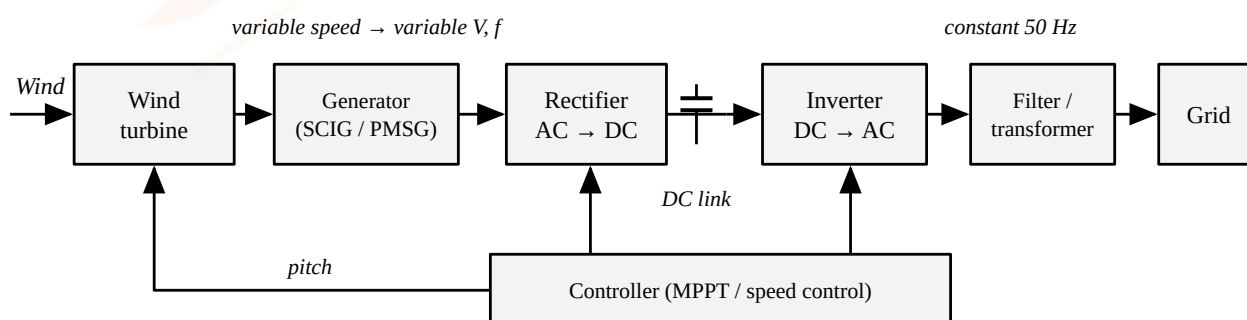


Fig.: Variable speed constant frequency (VSCF) scheme using AC–DC–AC link

1. The wind turbine drives a generator (SCIG or permanent-magnet synchronous generator) at variable speed; its output voltage and frequency vary with speed.

2. A **rectifier** converts this variable-frequency AC into DC; a capacitor in the **DC link** smooths the voltage.
3. An **inverter** (PWM, IGBT based) converts DC into AC at constant voltage and 50 Hz, synchronised with the grid; a filter/transformer improves the waveform and steps up voltage.
4. The controller tracks maximum power (MPPT) and controls pitch above rated speed. Another common VSCF arrangement is the **DFIG**, where only rotor power passes through a partly rated converter.

Advantages over constant speed scheme:

- More energy capture (about 10–20 %) because the rotor operates at optimum tip speed ratio over a wide range of wind speeds.
- Reduced mechanical stress, torque pulsations and gearbox wear (gusts are absorbed as speed changes).
- Smoother output power, better power quality and reactive power control; easier grid synchronisation.
- Lower noise at low wind speeds.

(Concept 1 M, block diagram 2 M, explanation 1 M, advantages 2 M)

b) Chinese fixed dome biogas plant.

6 M

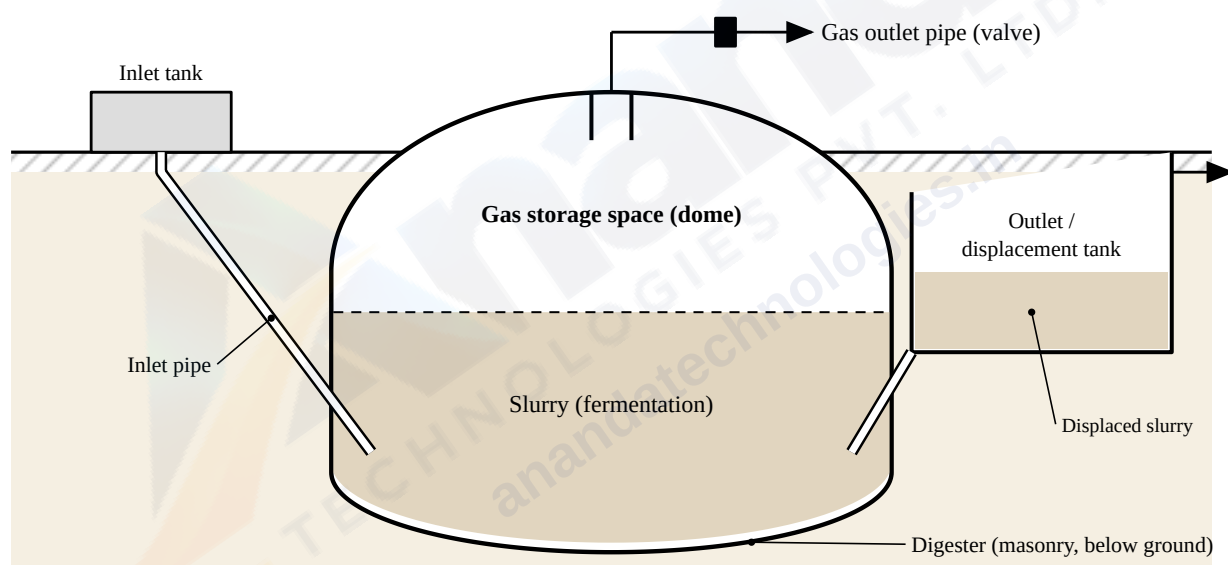


Fig.: Chinese fixed dome type biogas plant

Construction: The digester is an underground masonry chamber with a **fixed, dome-shaped roof** (no moving parts). The upper part of the dome is the gas storage space. An inlet pipe from the mixing (inlet) tank enters the digester; an outlet pipe connects it to an **outlet (displacement) tank**. A gas outlet pipe with valve is fitted at the top of the dome.

Working: The dung–water slurry ferments anaerobically and the biogas collects under the dome. As gas accumulates, its pressure pushes the slurry down in the digester and up into the outlet (displacement) tank. When gas is drawn, the slurry flows back into the digester. Hence the gas pressure is **variable** (rises as more gas is stored). Daily feeding through the inlet displaces digested slurry out through the outlet as manure.

Advantages:

- Low construction cost — no steel gas holder, so no rusting and no painting; long life (20+ years).
- Fully underground — saves space and the slurry stays warm in winter, giving steady gas production.
- No moving parts; low maintenance; uses local materials and labour.

Limitations:

- Gas pressure is not constant, so appliances may not work at best efficiency.
- Requires skilled masons; the dome must be absolutely gas-tight — cracks cause gas leakage.
- Difficult to repair once built; gas quantity cannot be seen directly.

(Sketch 2 M, construction and working 2 M, advantages and limitations 2 M)

c) Binary cycle geothermal power plant.

6 M

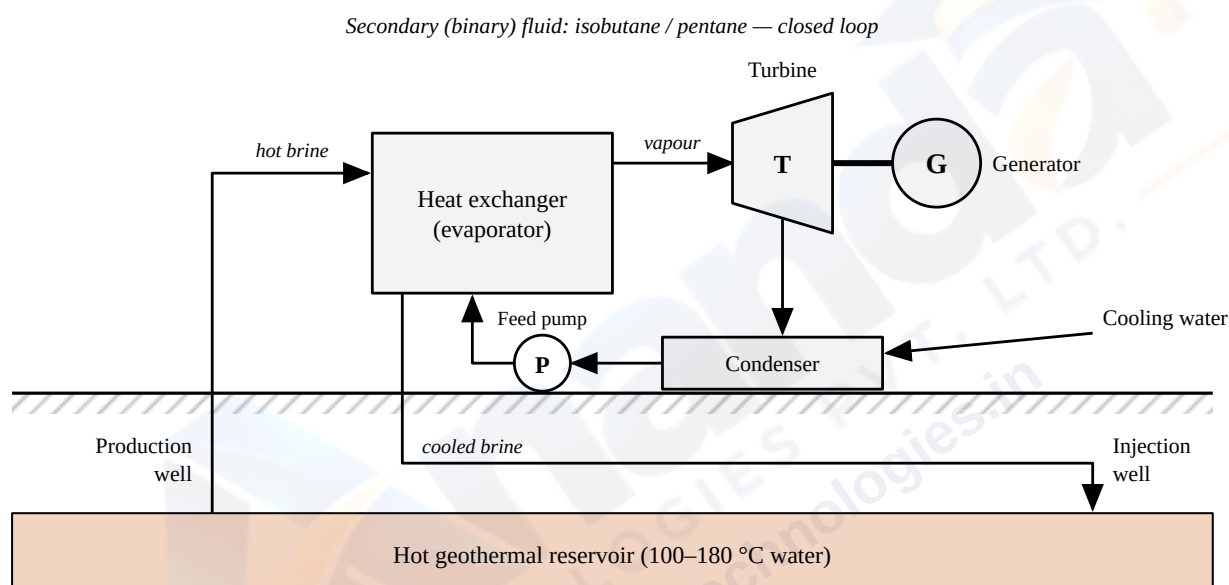


Fig.: Binary cycle geothermal power plant

Working:

1. Hot geothermal water (brine) at about 100–180 °C is pumped from the **production well** to a **heat exchanger**.
2. In the heat exchanger it transfers heat to a **secondary (binary) working fluid** — an organic fluid such as isobutane or pentane — which has a much lower boiling point than water, so it vaporises.
3. The vapour drives the **turbine** coupled to the **generator** (organic Rankine cycle).
4. The exhaust vapour is condensed in the **condenser** (air or water cooled) and pumped back to the heat exchanger by the **feed pump**, forming a closed loop.
5. The cooled brine is returned to the reservoir through the **injection well**; it never touches the turbine or atmosphere.

Why preferred for low / moderate temperature resources: Water at 100–180 °C cannot produce enough steam to run a steam turbine efficiently, but the organic working fluid boils at a low

temperature, so useful vapour is produced even from moderately hot water. As both loops are closed, there are almost no emissions, no scaling or corrosion of the turbine, and the reservoir is preserved by re-injection. Most of the world's geothermal resources are of this low/medium temperature type.

(Diagram 2 M, working 2 M, justification 2 M)

Q.6

a) Solar angles at Pune on 21 April, 11:00 AM.

6 M

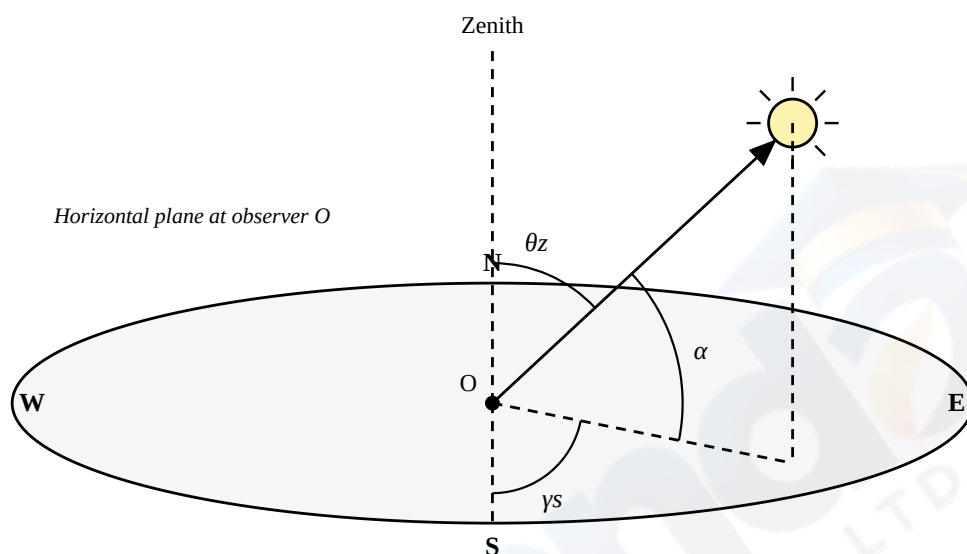


Fig.: Solar angles — zenith θ_z , altitude α and azimuth γ_s

Given: latitude $\phi = 18.5^\circ$ N, date: 21 April, solar time = 11:00 AM (11 h), collector tilt $\beta = 15^\circ$, facing due south ($\gamma = 0^\circ$).

Step 1 – Day number: $n = 90$ (days before April) + 21 = **111**

Step 2 – Declination (Cooper's equation): $\delta = 23.45^\circ \times \sin[(360/365)(284 + n)] = 23.45 \times \sin(389.59^\circ) = 23.45 \times (0.4938) = \mathbf{11.58^\circ}$

Step 3 – Hour angle: $\omega = 15^\circ \times (\text{solar time} - 12) = 15 \times (11 - 12) = \mathbf{-15^\circ}$ (negative before noon)

Step 4 – Zenith angle: $\cos \theta_z = \cos \phi \cos \delta \cos \omega + \sin \phi \sin \delta$
 $= \cos 18.5^\circ \times \cos(11.58^\circ) \times \cos(-15^\circ) + \sin 18.5^\circ \times \sin(11.58^\circ)$
 $= (0.9483)(0.9796)(0.9659) + (0.3173)(0.2007) = 0.8974 + (0.0637) = \mathbf{0.9611}$
 $\theta_z = \cos^{-1}(0.9611) = \mathbf{16.04^\circ}$; solar altitude $\alpha = 90^\circ - \theta_z = \mathbf{73.96^\circ}$

Step 5 – Angle of incidence on the south-facing tilted collector:

$\cos \theta = \cos(\phi - \beta) \cos \delta \cos \omega + \sin(\phi - \beta) \sin \delta$
 $\phi - \beta = 18.5 - 15 = 3.5^\circ$
 $\cos \theta = (0.9981)(0.9796)(0.9659) + (0.0610)(0.2007) = \mathbf{0.9568} \rightarrow \theta = \mathbf{16.91^\circ}$

Answers: i) $\delta = 11.58^\circ$ ii) $\omega = -15^\circ$ iii) $\theta_z = 16.04^\circ$, $\alpha = 73.96^\circ$ iv) $\theta = 16.91^\circ$

(δ 1 M, ω 1 M, θ_z and α 2 M, θ 2 M)

b) Wind turbine power calculation.

Given: rotor diameter $D = 60$ m, wind speed $V = 9$ m/s, air density $\rho = 1.225$ kg/m³, power coefficient $C_p = 0.42$, combined gearbox–generator efficiency $\eta = 0.9$.

Swept area $A = \pi D^2 / 4 = \pi \times 60^2 / 4 = 2,827.43$ m²

i) Power available in wind $P = \frac{1}{2} \rho A V^3 = 0.5 \times 1.225 \times 2,827.43 \times 9^3 = 0.5 \times 1.225 \times 2,827.43 \times 729 = 1,262,484.35$ W ≈ 1262.5 kW

Power density = $P/A = \frac{1}{2} \rho V^3 = 446.5$ W/m²

ii) Maximum extractable power (Betz limit, $C_{p,max} = 16/27 = 0.593$) $= 0.593 \times 1,262,484.35 = 748.1$ kW

iii) Mechanical power at rotor $= C_p \times P = 0.42 \times 1,262,484.35 = 530.2$ kW

iv) Electrical output $= \eta \times C_p \times P = 0.9 \times 530.2 = 477.2$ kW

At $V = 12$ m/s: $P = 0.5 \times 1.225 \times 2,827.43 \times 12^3 = 2992.6$ kW. Ratio $= (12/9)^3 = 2.37$ — a 33 % rise in wind speed gives 137 % more power ($P \propto V^3$).

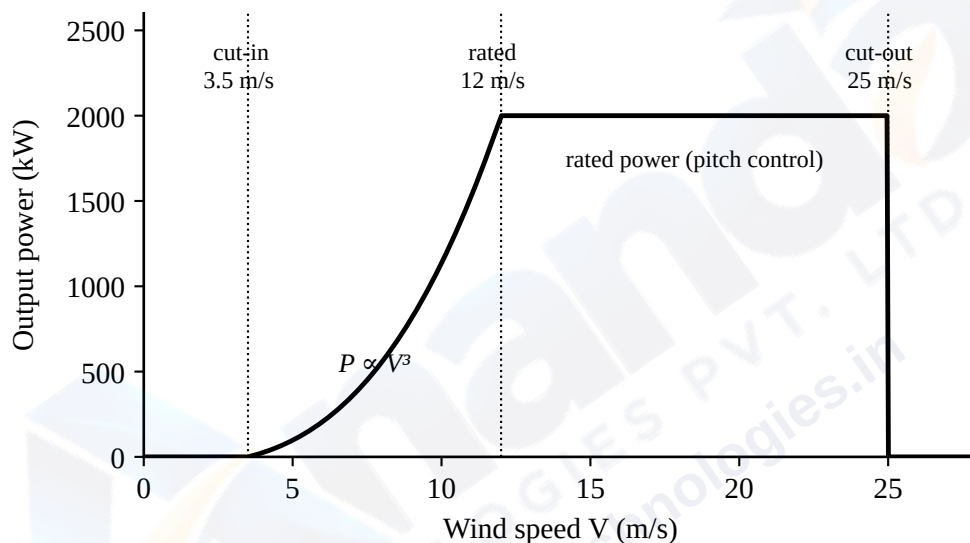


Fig.: Typical power curve — below rated speed, power rises as V^3

(Each part 1 M; effect of speed 2 M)

c) Fuel cell polarization; ideal voltage and efficiency.

6 M

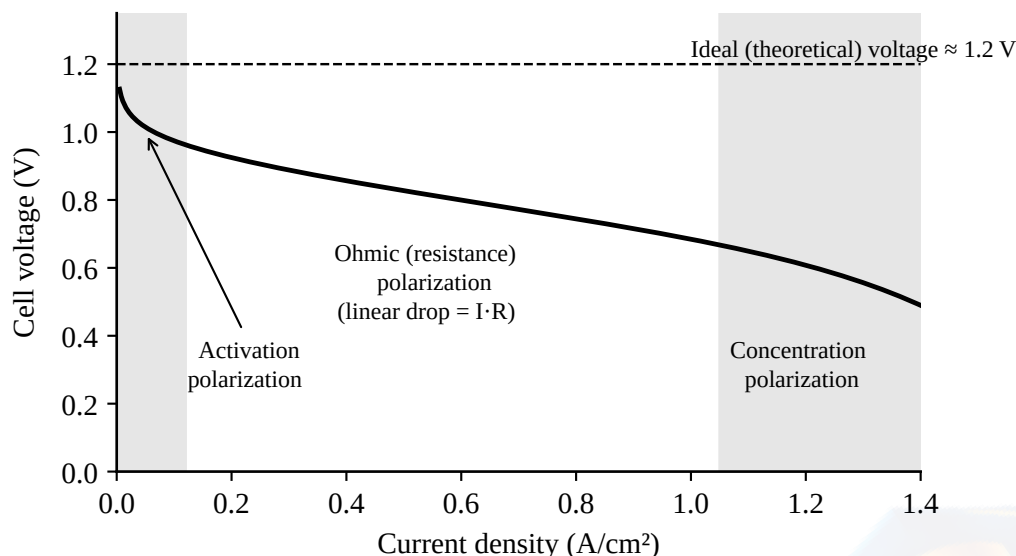


Fig.: Fuel cell polarization (V-I) curve showing three losses

i) **Polarization** is the drop of actual cell voltage below the ideal (reversible) voltage when current is drawn. Three types:

- **Activation polarization:** voltage needed to overcome the energy barrier of the electrode reactions (slow reaction rate). It causes a sharp drop at low current densities. Reduced by better catalysts (Pt), higher temperature and rough (large-area) electrodes.
- **Resistance (ohmic) polarization:** voltage drop due to the resistance of the electrolyte to ion flow and of electrodes, interconnects and contacts to electron flow; $\Delta V = I \times R_{\text{int}}$. It is linear with current (middle region). Reduced by thin, highly conductive electrolyte and good contacts.
- **Concentration polarization:** at high current the reactants cannot reach the electrode fast enough (mass transport limit), so the voltage falls steeply. Reduced by better gas diffusion and flow design.

ii) **Ideal voltage:** $E = -\Delta G / (nF)$, $n = 2$ electrons per H_2 molecule

$$E = 237.1 \times 10^3 / (2 \times 96485) = \mathbf{1.229 \text{ V}}$$

Ideal efficiency: $\eta = \Delta G / \Delta H = 237.1 / 285.8 = \mathbf{0.830 = 83.0 \%}$

(Curve 1 M, three polarizations 3 M, calculation 2 M)

Note: This is a **model question paper prepared by Ananda Technologies** only for practice and exam preparation, based on the pattern of previous MSBTE question papers and the K-scheme syllabus. It is **not an official MSBTE paper**, and it does **not** mean that these questions will come in the exam. Answers follow standard textbook points; marks shown are indicative. Free for students — anandatechnologies.in