Electric Vehicle Technology (315335)

Model Question Paper — Set A · Model Answers

Q.1

a) Types of electric vehicles. 2 M

1. **Battery Electric Vehicle (BEV):** runs only on a rechargeable battery and electric motor (e.g. e-scooters, Tata Nexon EV).
2. **Hybrid Electric Vehicle (HEV):** IC engine + electric motor with a small battery charged by engine and regenerative braking.
3. **Plug-in Hybrid Electric Vehicle (PHEV):** hybrid with a larger battery that can also be charged from the grid.
4. **Fuel Cell Electric Vehicle (FCEV):** electricity is produced on board by a hydrogen fuel cell.

(Any four types ½ M each)

b) Goal of EV30@30 campaign. 2 M

The **EV30@30 campaign** was launched in 2017 by the Electric Vehicles Initiative (EVI) of the Clean Energy Ministerial (CEM). Its goal is to reach a **30 % sales share of electric vehicles** (battery electric, plug-in hybrid and fuel cell) in passenger cars, light commercial vehicles, buses and trucks **by the year 2030** in the participating countries (India is a participant).

(Correct goal 2 M)

c) Specific energy and energy density. 2 M

- **Specific energy:** Energy stored per unit mass of the battery, in Wh/kg. It decides the range for a given battery weight.
- **Energy density:** Energy stored per unit volume of the battery, in Wh/L. It decides the space needed for the battery.

Example: a 50 kg battery storing 7.5 kWh has specific energy 7500/50 = 150 Wh/kg.

(Each definition 1 M)

d) Need of BMS. 2 M

- Protects cells from over-voltage, under-voltage, over-current and over-temperature (prevents fire / thermal runaway).
- Estimates SOC (fuel gauge) and SOH of the battery.
- Balances cells so that all cells have equal charge — uses full capacity and increases life.
- Controls charging (communicates with charger) and thermal management; reports faults to VCU / driver.

(Any two needs, 1 M each)

e) Battery swapping. 2 M

Battery swapping is the method of quickly removing the discharged battery of an EV at a swapping station and replacing it with a fully charged battery (in 2–5 minutes), instead of charging the battery inside the vehicle. The removed batteries are charged at the station and used again. It is popular for e-2W and e-3W fleets ('Battery-as-a-Service').

(Definition 2 M)

f) Classification of EV drives. 2 M

- **DC motor drives:** separately excited, shunt, series and permanent magnet (PMDC) brushed DC motors; Brushless DC (BLDC) motor — electronically commutated, fed from DC through an inverter.
- **AC motor drives:** induction motor (squirrel cage), permanent magnet synchronous motor (PMSM), synchronous reluctance motor (SynRM), PM-assisted SynRM, switched reluctance motor (SRM), axial flux PM motor.

(DC drives 1 M, AC drives 1 M)

g) Barriers to adoption of e-mobility. 2 M

- High upfront cost of EVs (mainly battery cost).
- Inadequate charging infrastructure; range anxiety.
- Long charging time.
- Import dependence for lithium-ion cells and critical minerals.
- Limited choice of models; uncertain resale value.

(Any two, 1 M each)

Q.2

a) EV vs IC engine vehicle. 4 M

Point	Electric vehicle (EV)	IC engine vehicle
Environmental impact	Zero tailpipe emission; low noise pollution.	Emits CO_2, CO, NO_x, HC and particulate matter.
Power source	Electric energy stored in battery (or fuel cell).	Petrol / diesel / CNG burnt in the engine.
Maintenance	Low — few moving parts, no oil change, clutch, spark plugs or exhaust system.	High — engine oil, filters, clutch, exhaust, timing belt etc.
Running cost	Very low — roughly ₹1–2 per km for cars on electricity.	High — roughly ₹6–10 per km for cars on petrol/diesel.

Running cost per km is approximate and depends on electricity tariff and fuel price.

(Each point 1 M)

b) Block diagram of EV subsystems. 4 M

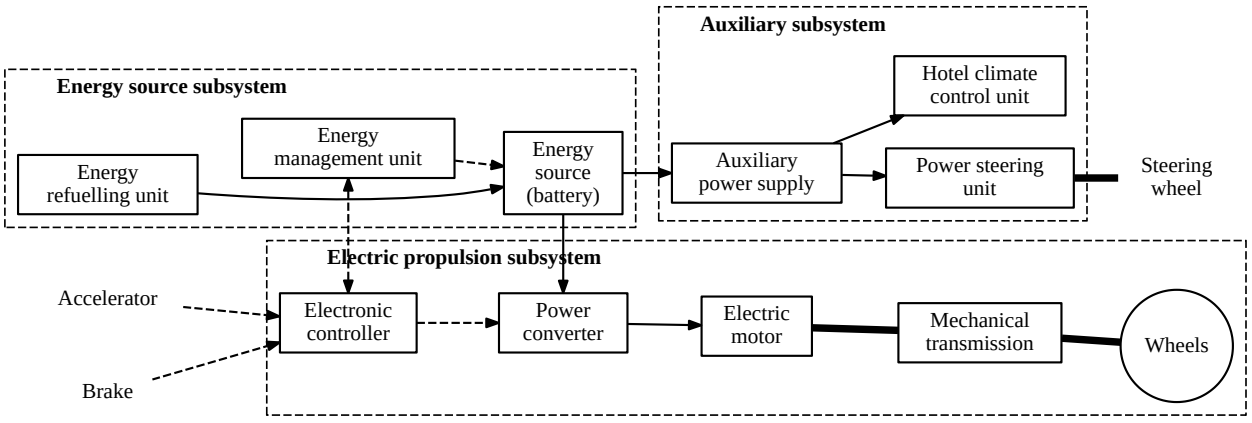


Fig.: Block diagram of EV subsystems (energy source, propulsion and auxiliary)

An EV is divided into three subsystems:

1. **Electric propulsion subsystem:** electronic (vehicle) controller, power converter, electric motor, mechanical transmission and wheels. The controller receives accelerator and brake pedal signals and commands the power converter, which feeds the motor; the motor drives the wheels through the transmission. During braking the motor works as a generator (regenerative braking).
2. **Energy source subsystem:** energy source (battery / fuel cell / ultracapacitor), energy management unit and energy refuelling (charging) unit. The energy management unit works with the vehicle controller to control charging, regenerative energy recovery and to monitor the source.
3. **Auxiliary subsystem:** auxiliary power supply (DC-DC converter, 12 V), power steering unit and hotel climate control unit (air-conditioning, heating), lights, wipers, infotainment.

(Diagram 2 M, explanation 2 M)

c) Battery capacity of e-scooter. 4 M

Given: Range = 90 km, energy consumption = 35 Wh/km, battery pack efficiency η = 85 %, system voltage V = 60 V

Step 1 – Energy required at the wheels side (from battery output):

E_{req} = range × consumption = 90 × 35 = **3,150 Wh = 3.15 kWh**

Step 2 – Battery capacity (energy) considering η:

$E_{batt} = E_{req} / \eta$ = 3,150 / 0.85 = **3,705.88 Wh ≈ 3.71 kWh**

Step 3 – Capacity in ampere-hour:

Ah = E_{batt} / V = 3,705.88 / 60 = **61.76 Ah**

Answer: Required battery capacity ≈ **3.71 kWh** and ≈ **61.8 Ah** at 60 V (a standard 60 V, 62–65 Ah pack would be selected).

(Energy 1 M, kWh 1 M, Ah 1 M, answer with units 1 M)

d) Maharashtra EV Policy 2021 — charging infrastructure incentives. 4 M

- **Slow chargers** (on private / residential / office premises): capital subsidy of 60 % of charger cost, up to ₹10,000 per charger, for the first 15,000 chargers.
- **Moderate / fast chargers** (public charging stations): 50 % of cost, up to ₹5 lakh per charger, for the first 500 chargers.
- Incentive is given only after the charging station starts operation; target of about 2,500 public charging stations in 7 cities and 4 highway corridors.
- Urban local bodies are encouraged to give property-tax rebate to residential owners who install private chargers.
- Charging stations are supplied at a separate EV tariff of the DISCOM (as approved by MERC).

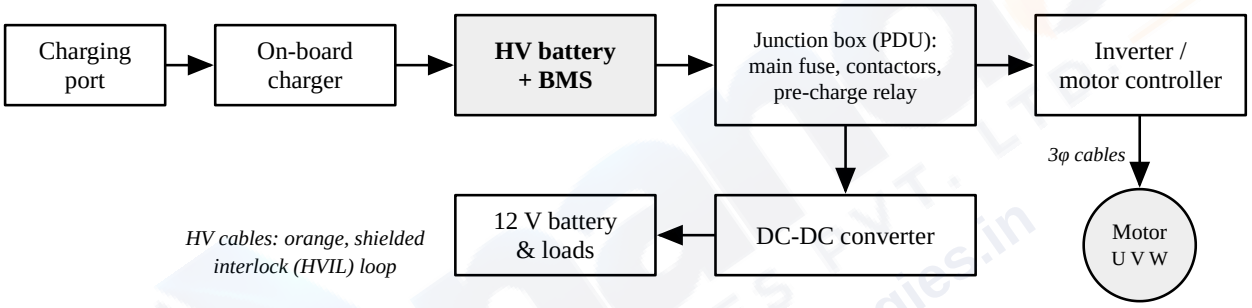
Figures are from Maharashtra EV Policy 2021 (GR dated 23 July 2021). Policies change — check the latest GR.

(Any four points, 1 M each)

Q.3

a) Mechanical and electrical connections of motor. 4 M

(a) Electrical connections



(b) Mechanical connections (central motor)

Hub (in-wheel) motor: motor is fitted inside the wheel — no gearbox, differential or drive shafts

Fig.: Electrical and mechanical connections of the motor in an EV

Mechanical connections:

- The motor shaft is coupled to a **single-speed reduction gear** (ratio about 7:1 to 10:1) since the motor runs at high speed (up to 12,000–16,000 rpm).
- The gear output drives the **differential**, which allows the left and right wheels to rotate at different speeds on turns.
- **Drive shafts with CV joints** transfer torque to the wheels; motor is held on rubber mounts to absorb vibration.
- In hub motors the motor is directly inside the wheel, so no gear, differential or shafts are needed; in 2W mid-drive motors a belt / chain is used.

Electrical connections:

- HV battery → junction box / PDU (main fuse, main contactors, pre-charge relay) → inverter (motor controller) → 3-phase cables U, V, W → motor.
- Charging port → on-board charger → battery; DC fast charging is connected directly to battery through DC contactors.
- DC-DC converter supplies the 12 V system (lights, ECU, wipers) from the HV battery.
- Signal connections: position / speed sensor (Hall / resolver) and temperature sensor from motor to controller; CAN bus between VCU, BMS, controller.
- Orange shielded HV cables, proper earthing and HV interlock loop are used for safety.

(Diagram 1 M, mechanical 1½ M, electrical 1½ M)

b) Fuel cell vs battery. 4 M

Point	Fuel cell	Battery
Energy source	Fuel (hydrogen) supplied continuously from an external tank.	Energy stored inside the battery chemicals.
Working	Energy converter — works as long as fuel and oxygen are supplied.	Energy storage device — must be recharged after discharge.
Recharging / refuelling	Refuelled with hydrogen in 3–5 minutes.	Recharged from electric supply in 30 min to several hours.
Efficiency	About 40–60 % (hydrogen to electricity).	High, about 85–95 % (charge-discharge).
By-product / emission	Water and heat only.	No emission during use.

(Any four points, 1 M each)

c) Working principle of PMSM. 4 M

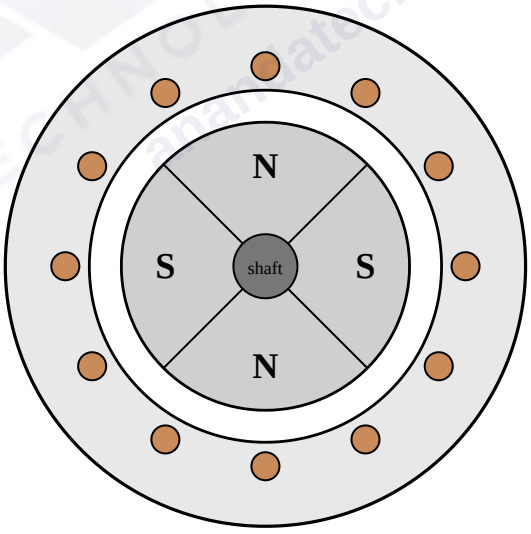


Fig.: Cross-section of PMSM (distributed winding, PM rotor)

Construction: Stator carries a 3-phase distributed winding (like an induction motor); rotor has permanent magnets (surface-mounted or interior / buried). An inverter supplies sinusoidal currents.

Working principle: When the 3-phase stator winding is fed with balanced 3-phase sinusoidal current, a rotating magnetic field is produced at synchronous speed $N_s = 120\ f / P$. The PM rotor poles lock with the rotating field poles (magnetic locking) and the rotor rotates at the same synchronous speed. Speed is controlled by changing the inverter frequency; torque is controlled by field oriented control (FOC) using a rotor position sensor (resolver / encoder).

Features / advantages:

- Highest efficiency (no rotor copper loss) and high power density — compact and light.
- Smooth torque (sinusoidal back-EMF and currents), low noise.
- High torque at low speed and wide speed range with field weakening.
- Good regenerative braking; low maintenance (no brushes).

(Principle 2 M, any two advantages 2 M)

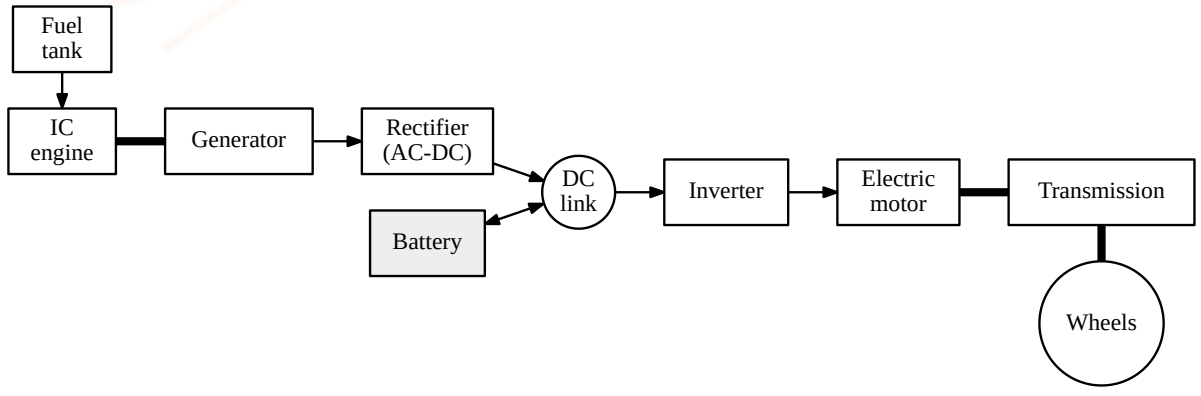
d) AC charging vs DC charging. 4 M

Point	AC charging	DC charging
Conversion	AC to DC conversion is done by the on-board charger inside the vehicle.	AC to DC conversion is done in the off-board charger (charging station).
Power level	Low to medium: about 2–22 kW.	High: about 25–350 kW.
Charging time	Slow — about 4 to 12 hours for a car.	Fast — about 30–60 minutes to reach 80 % SOC.
Cost of charger	Low; simple wall box; easy home installation.	High; large equipment, needs dedicated transformer / supply.
Location	Homes, offices, parking places (overnight).	Highways, public fast-charging stations, fleets.

(Any four points, 1 M each)

Q.4

a) Series hybrid electric vehicle. 4 M



Legend: ━ mechanical link ——▶ electrical (power) link - - ▶ control / signal

Fig.: Series hybrid electric vehicle — engine only drives the generator; only the motor drives the wheels

Working: The IC engine is not connected to the wheels. It drives a generator; the generated AC is rectified and fed to the DC link. The battery is also connected to the DC link. The inverter takes power from the DC link and drives the traction motor, which alone drives the wheels. During braking the motor recharges the battery.

Advantages: engine runs at its most efficient speed (decoupled from wheels); simple drivetrain, no clutch / multi-speed gearbox; good for stop-go city driving (city buses).

Disadvantages: energy is converted many times (mechanical → electrical → mechanical) so overall efficiency is lower on highway; three full-size machines (engine, generator, motor) are needed.

(Diagram 2 M, working 2 M)

b) Battery terms. 4 M

- **Self-discharge rate:** Loss of stored charge when the battery is kept idle (not connected to any load), expressed in % per month. It increases with temperature (Li-ion ≈ 2–3 %/month, NiMH much higher).
- **Deep cycle / number of deep cycles:** A deep cycle is a discharge of the battery to a large depth (typically 80 % DOD or more) followed by full recharge. Battery life is expressed as the number of such deep cycles before capacity falls to 80 % of rated value.
- **Specific power:** Power the battery can deliver per unit mass, in W/kg. It decides acceleration capability.
- **Battery life:** Number of charge-discharge cycles (cycle life) or years (calendar life) after which capacity falls to about 80 % of the rated capacity.

(Each definition 1 M)

c) Charging time of 40 kWh battery. 4 M

Given: Battery capacity = 40 kWh, SOC 25 % → 90 %, charger power P = 7.2 kW, η = 90 %

Step 1 – Energy to be supplied to the battery:
$E = \text{capacity} \times (SOC_{final} - SOC_{initial}) = 40 \times (0.9 - 0.25) = 40 \times 0.65 =$ **26 kWh**

Step 2 – Effective charging power:
$P_{eff} = P \times \eta = 7.2 \times 0.9 =$ **6.48 kW**

Step 3 – Charging time:
$t = E / P_{eff} = 26 / 6.48 =$ **4.012 h ≈ 4 h 1 min**

Answer: Charging time ≈ **4.01 h (4 h 1 min)**.

(Energy 1 M, effective power 1 M, time 2 M)

d) V2X technology and smart grid. 4 M

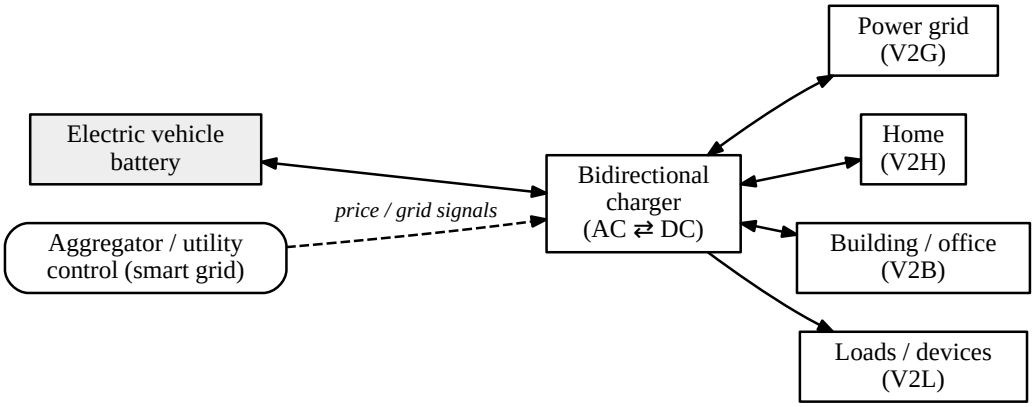


Fig.: Vehicle-to-Everything (V2X): energy can flow from the EV battery back to grid, home, building or loads

V2X (Vehicle-to-Everything) means the EV battery, through a **bidirectional charger**, can not only take energy but also **supply energy back** to the grid (V2G), a home (V2H), a building (V2B) or loads / devices (V2L). It also includes communication of the vehicle with grid, infrastructure and other vehicles.

Significance in smart grid:

- **Peak shaving / load levelling:** EVs charge at off-peak hours and give energy back at peak hours — reduces peak demand on the grid.
- **Grid support services:** frequency regulation, voltage support and spinning reserve, as thousands of EVs act as a virtual power plant.
- **Renewable integration:** EV batteries store surplus solar / wind energy and release it when generation is low.
- **Back-up power** to homes and buildings during outage; owner can earn by selling energy at high tariff (time-of-day tariff).
- **Requirements:** bidirectional charger, smart meter, communication standard (e.g. ISO 15118), aggregator; battery degradation must be considered.

(Meaning 1 M, diagram 1 M, significance 2 M)

e) Scrappage incentives. 4 M

Role of scrappage incentives:

- A scrappage incentive is an extra amount given to a buyer who scraps an old (usually polluting, end-of-life) vehicle and buys a new EV.
- It reduces the effective purchase price of the EV, so more people switch to EVs.
- Old petrol / diesel vehicles, which cause the most pollution, are removed from the road — direct reduction in urban air pollution.
- Encourages organised scrapping and recycling of materials; supports EV demand and manufacturing.

Scrappage incentives in Maharashtra EV Policy 2021 (in addition to the demand incentive, on producing a scrapping certificate):

Vehicle segment	Scrappage incentive (up to)
e-2W	₹7,000
e-3W	₹15,000
e-4W	₹25,000

Figures are from Maharashtra EV Policy 2021 (GR dated 23 July 2021). Policies change — check the latest GR.

(Role 2 M, incentives 2 M)

Q.5

a) BLDC motor — principle, working and torque control. 6 M

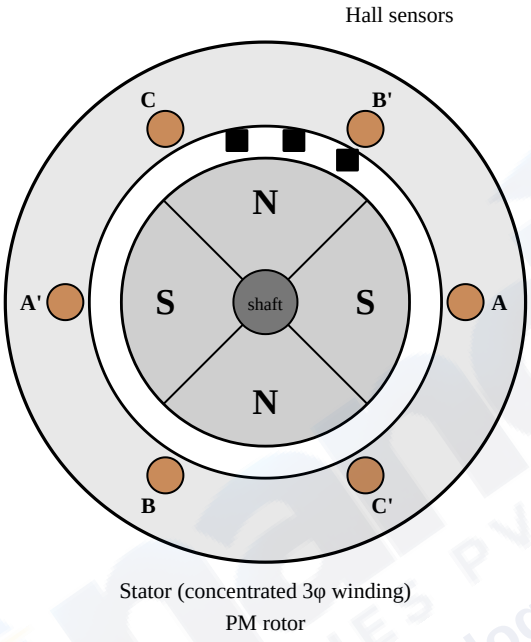
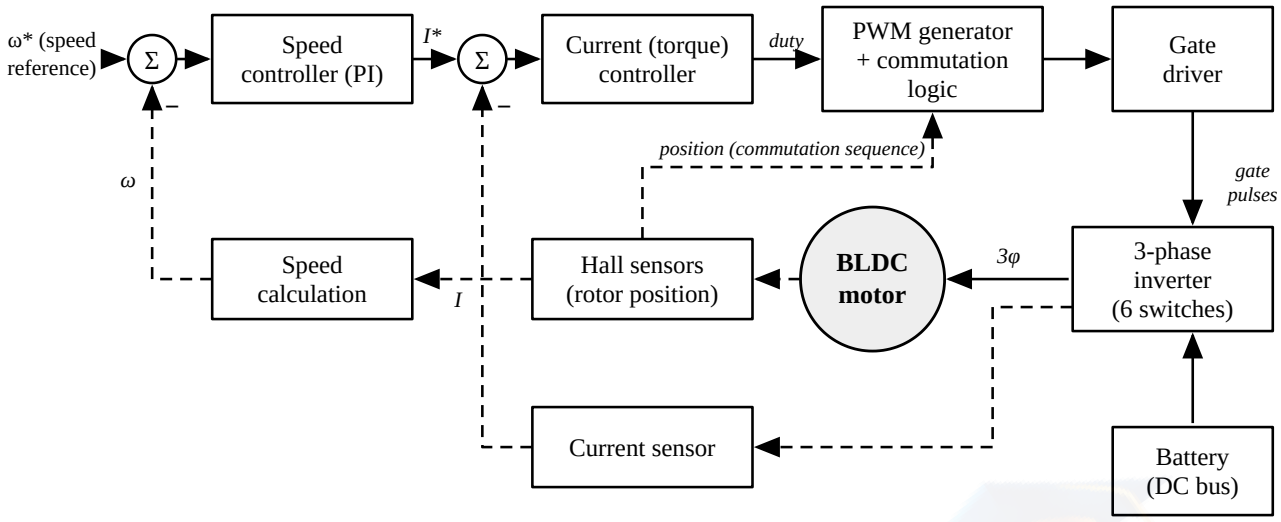


Fig.: Cross-section of a 4-pole BLDC motor (Hall sensors sense rotor position)

Principle: A BLDC motor works on the same principle as a DC motor — force on a current-carrying conductor in a magnetic field (here the reaction torque acts on the PM rotor). The mechanical commutator of the DC motor is replaced by an **electronic commutator** (inverter). The stator field is switched in steps so that it always stays about 90° ahead of the rotor magnet field; the rotor magnet follows it and produces continuous torque.

Working:

1. Stator has a 3-phase winding; rotor has permanent magnets.
2. Three Hall sensors (120° apart) detect the rotor position and give a 3-bit code.
3. The controller uses this code to switch ON the proper two inverter switches, so two phases conduct at a time (six-step / 120° conduction).
4. The resulting stator field attracts the rotor; as the rotor turns, the next Hall code switches the next pair — the field rotates in 6 steps per electrical cycle.
5. Speed is controlled by varying the average voltage (PWM duty) and torque by controlling the current.



Outer loop: speed control · Inner loop: current (torque) control · Hall sensors decide which two phases conduct

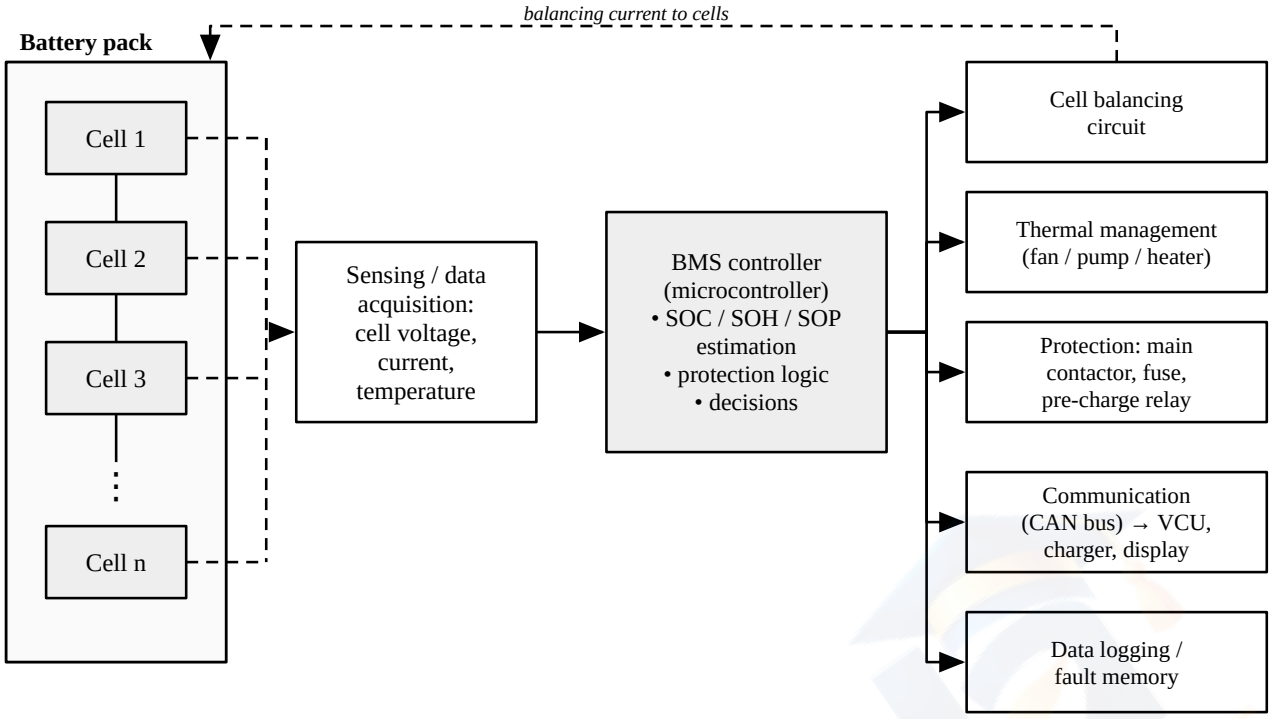
Fig.: Block diagram of torque (current) control of a BLDC motor drive

Explanation of blocks:

- **Speed reference & speed controller (PI):** compares reference speed ω* with actual speed ω; the error gives the required torque, i.e. current reference I* (torque ∝ current in BLDC).
- **Current (torque) controller:** compares I* with actual current measured by the current sensor and sets the PWM duty cycle, so motor torque follows the command.
- **PWM generator + commutation logic:** using Hall sensor signals it selects which two phases conduct (six-step sequence) and applies PWM to them.
- **Gate driver & 3-phase inverter:** amplify gate pulses and switch the battery DC to the motor windings.
- **Hall sensors / speed calculation:** give rotor position for commutation and frequency of Hall signals gives speed feedback.
- **Current sensor:** gives current feedback for torque control and over-current protection.

(Principle & working 3 M, block diagram 2 M, explanation 1 M)

b) Block diagram of BMS. 6 M



SOC = state of charge · SOH = state of health · SOP = state of power

Fig.: Block diagram of a Battery Management System (BMS)

Function of each block:

- **Battery pack:** many cells connected in series and parallel to get required voltage and capacity.
- **Sensing / data acquisition:** measures each cell voltage, pack current (shunt / Hall sensor) and temperatures at many points; converts them to digital form (ADC) for the controller.
- **BMS controller (MCU):** brain of BMS — estimates SOC (coulomb counting, OCV method), SOH and available power (SOP); compares values with safe limits and takes decisions.
- **Cell balancing circuit:** equalises cell charges — passive (bleeding extra charge through resistors) or active (transferring charge from higher to lower cells).
- **Thermal management:** controls cooling fan / liquid pump / heater to keep cells within the safe temperature range.
- **Protection (contactor control):** opens main contactors on over-voltage, under-voltage, over-current, short-circuit, over-temperature or insulation fault; pre-charge relay limits inrush current.
- **Communication (CAN):** sends SOC, limits and faults to VCU, charger and dashboard; tells charger how much current to give.
- **Data logging:** stores history and fault codes for diagnosis and warranty.

Architectures: *Centralised* (one board wired to all cells — cheap, many wires), *Modular / distributed* (a slave board per module with one master — scalable, used in EVs).

(Diagram 3 M, functions 3 M)

c) Comparison of EV motors. 6 M

Point	Brushed DC motor	Induction motor (IM)	BLDC motor	PMSM	SRM
Power-to-weight ratio	Low	Medium	High	Very high	Medium
Torque-speed characteristic	Good starting torque; high speed limited by commutator	Wide speed range with field weakening; constant power region 3–4× base speed	High starting torque; limited constant-power (field weakening) range	High torque; wide speed range with field weakening; smooth torque	Very wide speed range; high torque ripple and noise
Cost of controller	Low (simple DC chopper)	High (vector control inverter)	Low–medium (six-step inverter + Hall sensors)	High (FOC inverter + position sensor)	Medium (special asymmetric converter)
Cost of motor	Medium (brush / commutator)	Low (rugged, no magnets)	High (rare-earth magnets)	High (rare-earth magnets)	Low (no magnets, no winding on rotor)

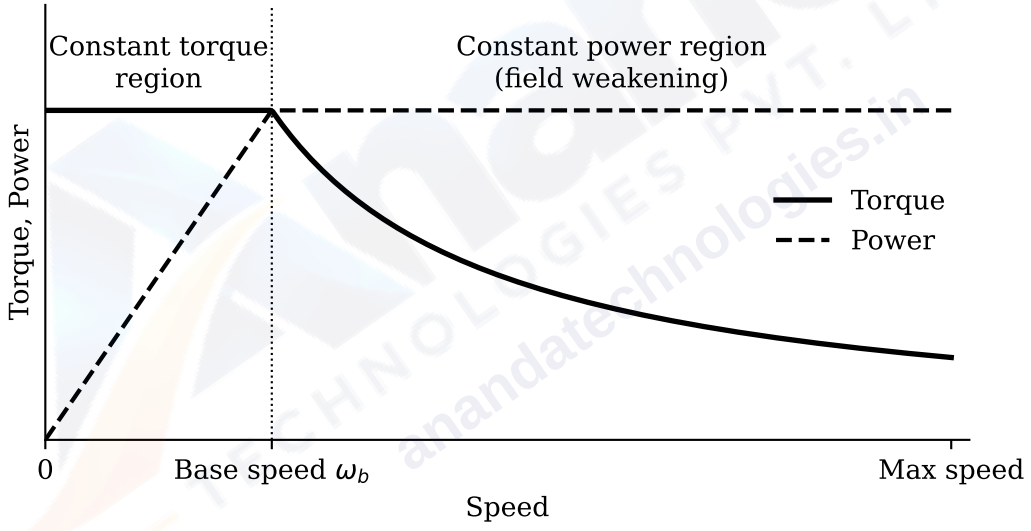


Fig.: Typical torque-speed and power-speed characteristic of an EV traction motor

(Each point 1½ M)

Q.6

a) Level-1, Level-2 and Level-3 charging. 6 M

Charging levels are classified by power and type of supply (SAE J1772 terminology, widely used in India also):

Point	Level 1 (AC slow)	Level 2 (AC)	Level 3 (DC fast)
Supply	AC single-phase, household socket (120 V in USA; 230 V, 15 A in India)	AC single / three-phase, 230 V / 415 V dedicated EVSE	DC, about 200–1000 V from off-board charger
Power	≈ 1.4–3.3 kW	≈ 3.3–22 kW (commonly 7.4 kW)	≈ 25–350 kW
Charging time (car)	≈ 12–24 h or more	≈ 4–10 h	≈ 30–60 min to 80 %
Charger location	On-board charger; home	On-board charger; home, office, public parking	Off-board charger; highways, public stations
Connector	15 A plug / portable cable	Type 2, Bharat AC-001	CCS2, CHAdeMO, GB/T, Bharat DC-001
Cost	Lowest	Moderate	Highest

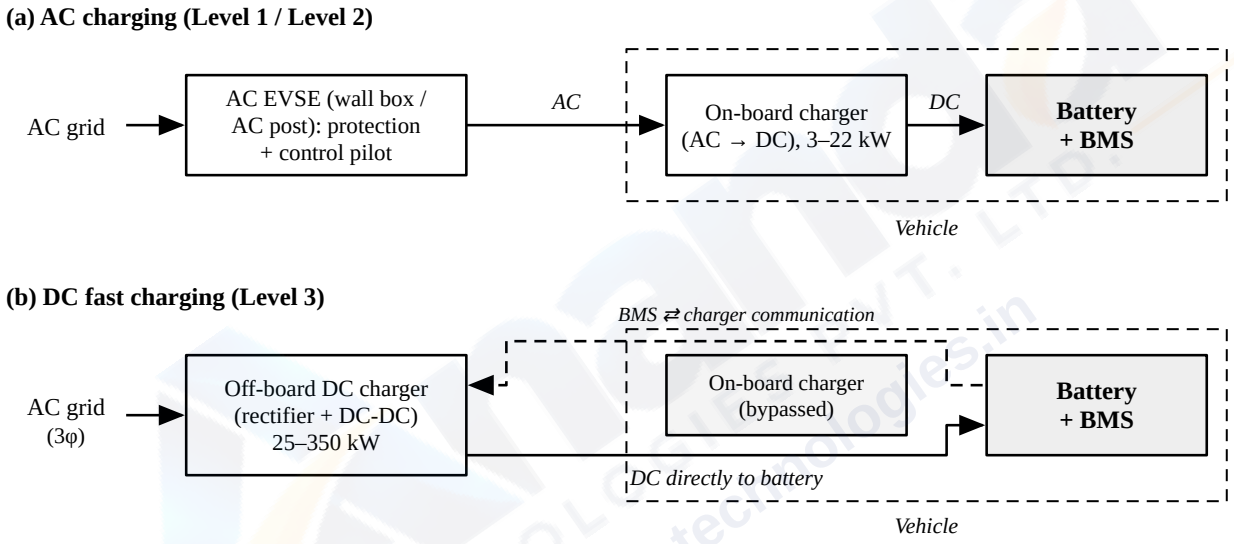


Fig.: (a) AC charging — conversion inside the vehicle; (b) DC charging — conversion in the off-board charger

Level 1 and Level 2 use the **on-board charger** of the vehicle; Level 3 uses an **off-board DC charger** that charges the battery directly.

(Table / explanation 4 M, connectors 1 M, diagram 1 M)

b) Selection criteria and location of EV motor. 6 M

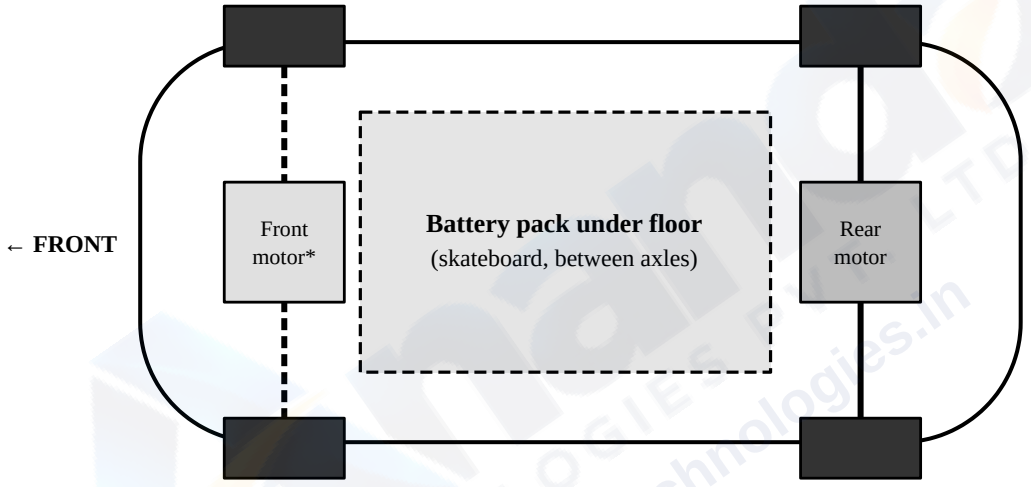
i) Selection criteria of EV motors:

- **High starting torque** for acceleration and hill climbing, and high power at cruising speed.
- **Wide speed range** — constant torque below base speed and constant power above it (field weakening up to 3–4 × base speed).
- **High efficiency** over the whole driving range — increases range per charge.
- **High power-to-weight ratio / power density** — compact and light motor.
- **Regenerative braking capability** — should work as generator efficiently.
- **Reliability and ruggedness** — vibration, dust, water, temperature; low maintenance.

- **Cost** of motor and controller; availability of magnets.
- **Low noise, low torque ripple** and good controllability; fault tolerance.

ii) Physical location of motor:

- **Front axle (front-wheel drive):** motor + reduction gear + differential mounted between front wheels (e.g. Tata Nexon EV).
- **Rear axle (rear-wheel drive):** motor mounted on the rear axle — better traction during acceleration.
- **Both axles (dual-motor AWD):** one motor on each axle for high performance / all-wheel drive.
- **In-wheel (hub) motor:** motor is inside the wheel hub — no gearbox or drive shaft (e-scooters such as TVS iQube, e-cycles).
- **Mid-drive (frame mounted):** motor fixed on the frame and drives the rear wheel by belt / chain (e.g. Ather 450 series, e-bikes).
- **Battery location:** 4W — flat pack under the floor between the axles (low centre of gravity, more cabin space); 2W — under the floorboard or under the seat.

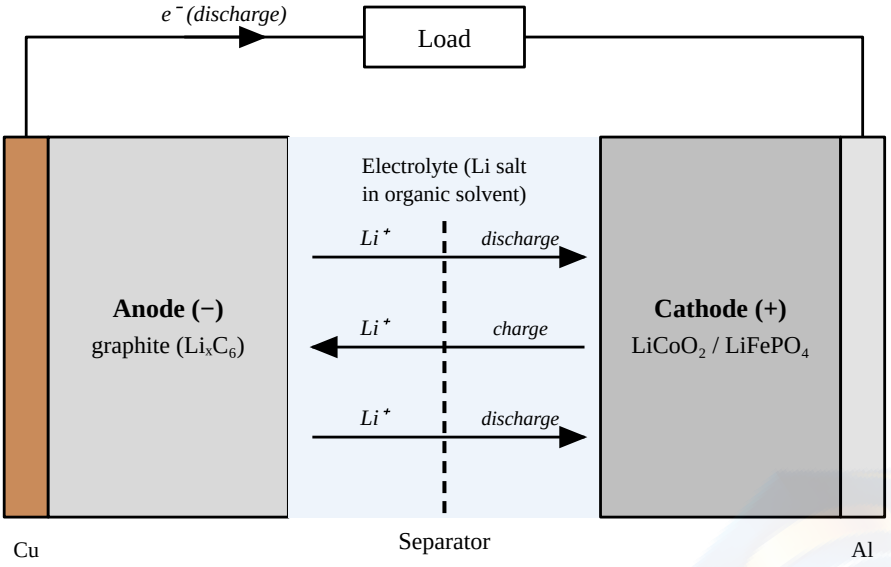


** front motor in front-wheel-drive cars; rear motor in rear-wheel-drive; both in dual-motor AWD*

Fig.: Physical location of motor and battery in a four-wheeler EV (top view)

(Criteria 3 M, location with examples 3 M)

c) Li-ion battery. 6 M



Discharge: $Li_xC_6 + Li_{1-x}CoO_2 \rightarrow C_6 + LiCoO_2$

Fig.: Construction and working of a Li-ion cell

Construction:

- **Anode (−):** graphite (carbon) coated on copper foil current collector.
- **Cathode (+):** lithium metal oxide — $LiCoO_2$, NMC (nickel-manganese-cobalt) or $LiFePO_4$ — coated on aluminium foil.
- **Electrolyte:** lithium salt ($LiPF_6$) dissolved in organic solvent; allows only Li^+ ions to move.
- **Separator:** micro-porous polymer film between electrodes — prevents short circuit, allows ions.
- Cells are made in cylindrical, prismatic or pouch form; nominal voltage ≈ 3.6–3.7 V (LFP 3.2 V).

Working: During **charging**, Li^+ ions leave the cathode, move through the electrolyte and get inserted (intercalated) between graphite layers of the anode; electrons flow through the external charger to the anode. During **discharging**, Li^+ ions move back from anode to cathode through the electrolyte while electrons flow through the external load from anode to cathode, giving current. This back-and-forth movement of ions is called the 'rocking chair' mechanism.

Advantages: high specific energy (100–250 Wh/kg) and high cell voltage; long cycle life (1000–4000 cycles); high efficiency (≈ 95 %); low self-discharge; no memory effect; fast charging possible.

Disadvantages: costly; needs BMS for protection; risk of thermal runaway / fire if over-charged, damaged or overheated; performance drops at very low temperature; ageing; recycling is complex.

(Diagram 2 M, construction & working 2 M, advantages 1 M, disadvantages 1 M)

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