

Electric Vehicle Technology (315335)

Model Question Paper — Set B · Model Answers

Q.1

a) Main goal of EV30@30.

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).

(Goal with target 2 M)

b) Motors used in EVs.

2 M

- Brushless DC (BLDC) motor
- Permanent magnet synchronous motor (PMSM)
- Induction motor (IM)
- Switched reluctance motor (SRM)
- Synchronous reluctance motor (SynRM) / PM-assisted SynRM
- Brushed DC motor (series / separately excited) — older EVs
- Axial flux permanent magnet motor

(Any four, ½ M each)

c) Meaning of 'deep cycle'.

2 M

A **deep cycle** means discharging a battery to a large depth of discharge (usually 80 % DOD or more) and then fully recharging it. Deep-cycle batteries (e.g. EV traction batteries) are designed to withstand many such cycles; their life is given as the number of deep cycles before the capacity drops to 80 % of rated value.

(Meaning 2 M)

d) Battery pack capacity ranges.

2 M

Vehicle segment	Typical battery pack capacity
Electric 2-wheeler	≈ 1.5 – 5 kWh
Electric 3-wheeler (e-rickshaw / e-auto)	≈ 3 – 12 kWh
Electric car	≈ 25 – 100 kWh
Electric bus (city, 9–12 m)	≈ 150 – 450 kWh
Electric truck	≈ 100 kWh (light) to 600 kWh or more (heavy)

Approximate ranges; exact values depend on model and manufacturer.

(Each 1 M)

e) Objectives of Maharashtra EV Policy 2021.

2 M

- Make BEVs **10 % of all new vehicle registrations** in Maharashtra by 2025.
- Achieve **25 % electrification of public transport and last-mile delivery vehicles** in six urban agglomerations — Mumbai, Pune, Nagpur, Nashik, Aurangabad and Amravati — by 2025.
- Convert **15 % of MSRTC's existing bus fleet** to electric.
- Set up about **2,500 public charging stations** in seven urban agglomerations (the above six cities and Solapur) and on four highway corridors (Mumbai–Pune, Mumbai–Nashik, Mumbai–Nagpur, Pune–Nashik).
- All new government vehicles to be electric from 1 April 2022.
- Make Maharashtra the top state in India for BEV manufacturing capacity; set up at least one giga-scale Advanced Chemistry Cell (battery) plant.
- Promote R&D, skilling and innovation in the EV sector.

*(Any two, 1 M each)***f) Meaning of V2X.**

2 M

V2X (Vehicle-to-Everything) is a bidirectional charging concept in which the EV battery can supply energy back (and exchange information) to the grid (V2G), a home (V2H), a building (V2B) or loads (V2L) through a bidirectional charger. The EV acts as a mobile energy storage unit for the smart grid.

*(Meaning 2 M)***g) Precautions while charging.**

2 M

- Use only certified chargers / EVSE and the cable supplied by the manufacturer; never use extension boards or damaged cables.
- Ensure proper earthing, RCD / RCCB protection and correctly rated wiring and socket.
- Do not charge in rain on open sockets, near water or near flammable materials; keep the area ventilated.
- Do not charge a battery that is swollen, damaged, very hot or leaking.

*(Any two, 1 M each)***Q.2****a) Advantages and disadvantages of EVs.**

4 M

Advantages:

- Zero tailpipe emission — reduces urban air pollution and greenhouse gases.
- High efficiency ($\approx 80\text{--}90\%$) compared with IC engine ($\approx 20\text{--}35\%$).
- Low running cost and low maintenance (fewer moving parts, no engine oil).
- Silent and vibration-free operation; full torque from zero speed.

Disadvantages:

- High initial (capital) cost, mainly due to battery.
- Limited driving range per charge — "range anxiety".
- Long charging time compared with refuelling.

- Charging infrastructure still limited (especially highways / rural).

(Advantages 2 M, disadvantages 2 M)

b) BEV architecture.

4 M

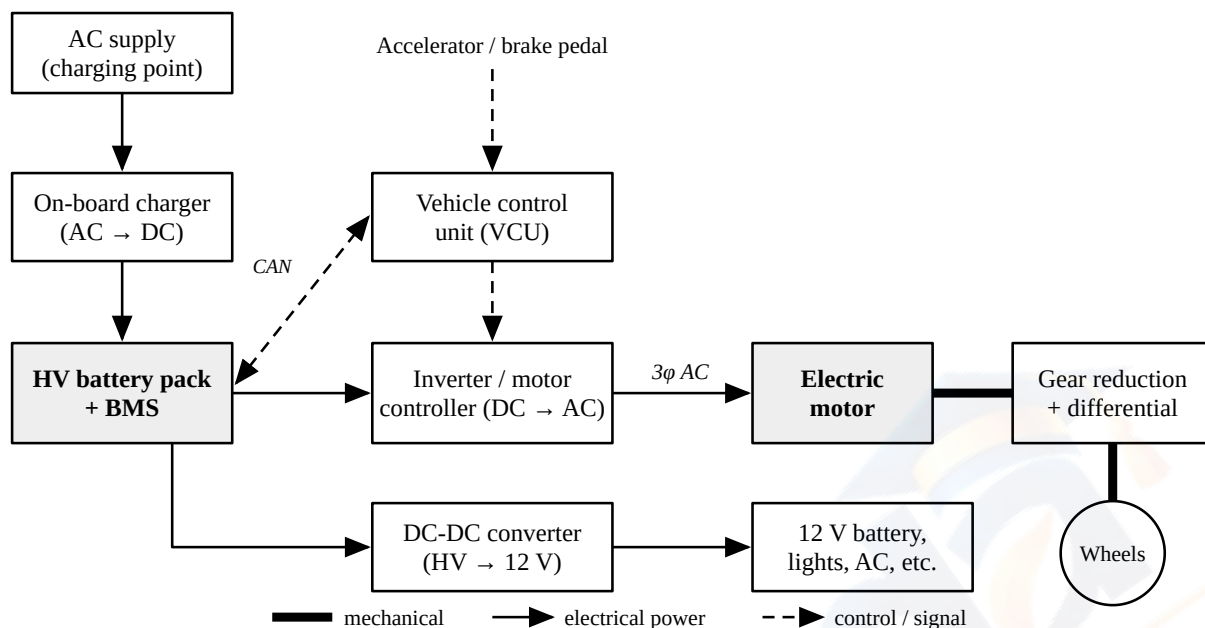


Fig.: Architecture (block diagram) of a battery electric vehicle (BEV)

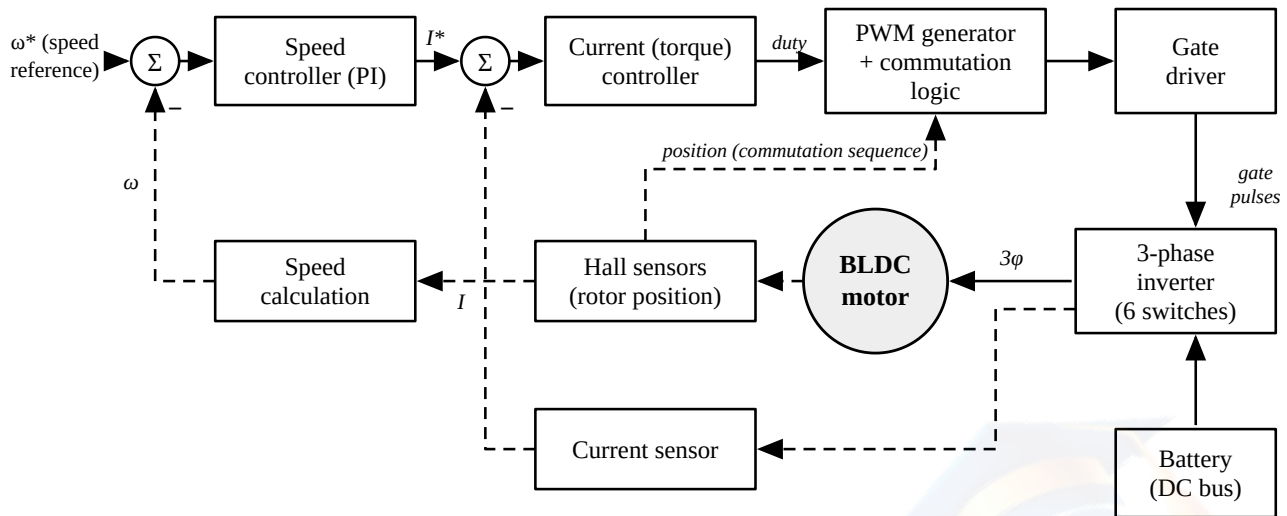
Main components:

- **Battery pack + BMS:** stores electrical energy (e.g. 300–400 V Li-ion pack); BMS monitors and protects the cells.
- **On-board charger:** converts AC supply from the charging point into DC to charge the battery.
- **Inverter / motor controller:** converts battery DC into variable-voltage, variable-frequency 3-phase AC for the motor and controls speed and torque.
- **Electric motor:** PMSM / BLDC / induction motor converts electrical energy into mechanical energy; works as generator during braking.
- **Transmission:** single-speed reduction gear and differential drive the wheels.
- **VCU:** reads accelerator / brake pedal and coordinates BMS, inverter, charger over CAN bus.
- **DC-DC converter:** steps down HV battery voltage to 12 V for lights, wipers, infotainment and control circuits.

(Diagram 2 M, components 2 M)

c) BLDC torque control block diagram.

4 M



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 $\propto$ 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.

(Diagram 2 M, explanation 2 M)

d) AC charging vs DC fast charging.

4 M

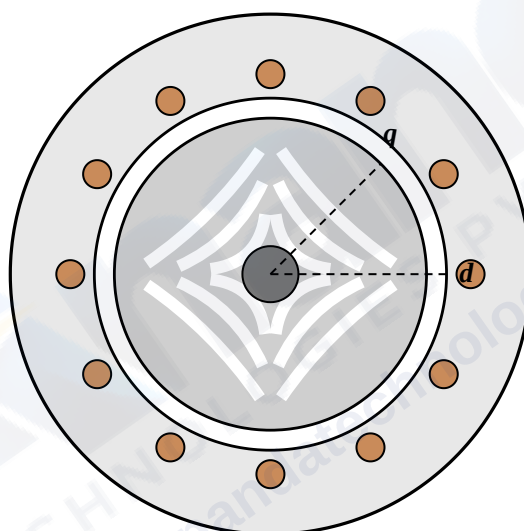
Point	AC charging	DC charging
Conversion	AC to DC conversion is done by the on-board charger inside the vehicle.	AC to DC conversion is done in the off-board charger (charging station).
Power level	Low to medium: about 2–22 kW.	High: about 25–350 kW.
Charging time	Slow — about 4 to 12 hours for a car.	Fast — about 30–60 minutes to reach 80 % SOC.
Connectors	Type 2 (AC), Bharat AC-001, 15 A socket.	CCS2, CHAdeMO, GB/T, Bharat DC-001.
Effect on battery	Gentle; better for battery life.	More heating; frequent use can speed up ageing.

(Any four points, 1 M each)

Q.3

a) Synchronous reluctance motor.

4 M



Stator (distributed 3 ϕ winding)
Rotor with flux barriers (no magnets)

Fig.: SynRM — rotor with flux barriers (d = low reluctance axis, q = high reluctance axis)

Construction: Stator is the same as an induction motor (3-phase distributed winding). The rotor has no winding and no magnets; it is made of laminations with cut-out **flux barriers** (air slots), which give a low-reluctance path along the d -axis and a high-reluctance path along the q -axis ($L_d \gg L_q$).

Operating principle: A magnetic material placed in a magnetic field tries to align itself so that the reluctance of the flux path is minimum. The 3-phase stator winding fed by an inverter produces a rotating magnetic field. The rotor d -axis (minimum reluctance) tries to align with the stator field, so a **reluctance torque** is produced and the rotor runs at synchronous speed. Torque $T = \frac{3}{2}(P/2)(L_d - L_q) i_d i_q$; larger saliency ratio L_d/L_q gives more torque.

Advantages: no magnets (low cost, no demagnetisation), no rotor copper loss (cool rotor, high efficiency), rugged, good for high speed. **Limitations:** lower power factor, torque ripple, needs inverter with position control. Adding a small amount of magnet in the barriers gives the **PM-assisted SynRM**.

(Diagram 1 M, principle 2 M, features 1 M)

b) Classification of EV batteries.

4 M

Batteries used in EVs are classified by chemistry:

- **Lead-acid batteries:** flooded, VRLA (sealed) — e-rickshaws, 12 V auxiliary batteries.
- **Nickel-based batteries:** nickel-cadmium (Ni-Cd), nickel-metal hydride (NiMH), nickel-zinc (Ni-Zn).
- **Lithium-based batteries:** Li-ion (LCO, NMC, NCA, LFP, LTO), lithium-polymer.
- **Metal-air batteries:** aluminium-air (Al-air), zinc-air — very high energy, mechanically recharged.
- **Other / emerging:** aluminium-ion (Al-ion), sodium-ion, solid-state batteries.

Battery	Cell voltage (V)	Specific energy (Wh/kg)	Cycle life	Remarks
Lead-acid	2.0	30–40	300–500	Cheap, heavy; e-rickshaws, 12 V auxiliary
Ni-Cd	1.2	40–60	1000–2000	Toxic cadmium, memory effect
NiMH	1.2	60–80	500–1000	Used in hybrid cars (Toyota Prius)
Ni-Zn	1.6	60–80	300–500	Low cost, short life
Li-ion (NMC / LFP)	3.6–3.7 / 3.2	100–250	1000–4000	Most used in modern EVs
Al-air	≈ 1.2	Very high (theoretical)	Primary	Mechanically recharged (replace Al plates)

Typical textbook ranges; values vary with manufacturer and chemistry.

(Classification 3 M, examples 1 M)

c) Bidirectional DC-DC converter.

4 M

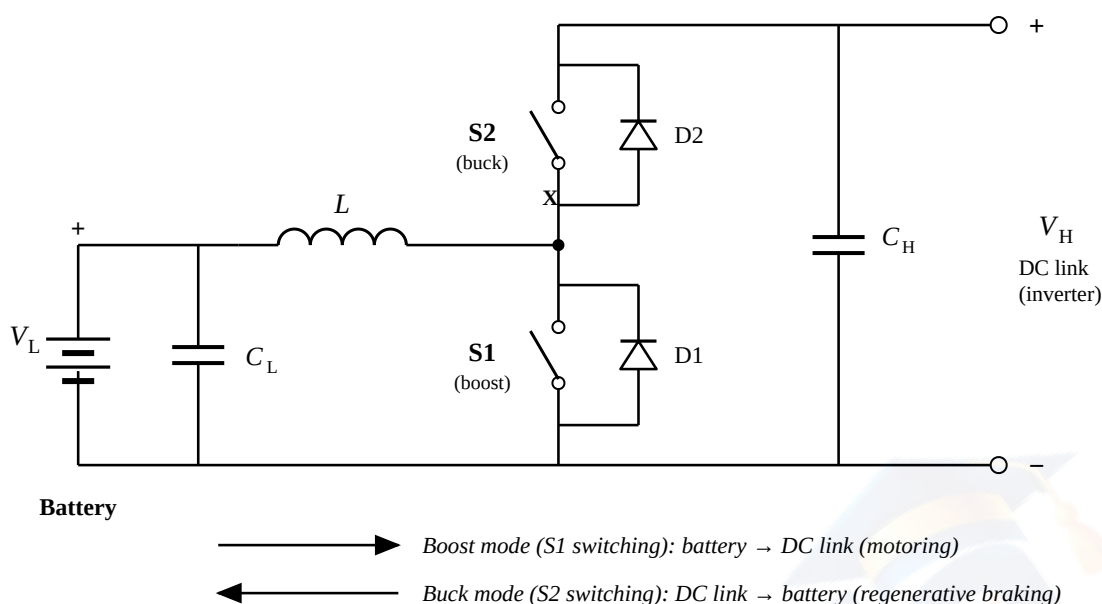


Fig.: Bidirectional (half-bridge buck-boost) DC-DC converter between battery and DC link

A **bidirectional DC-DC converter** connects the battery (low voltage V_L) with the high-voltage DC link (V_H) of the inverter and allows power flow in both directions.

- **Boost mode (motoring):** S1 is switched with PWM, S2 is OFF. When S1 is ON, the inductor stores energy; when S1 is OFF, the inductor voltage adds to battery voltage and current flows through D2 to the DC link — battery voltage is stepped up ($V_H = V_L / (1 - D)$).
- **Buck mode (regenerative braking / charging):** S2 is switched, S1 is OFF. Energy from the DC link (motor working as generator) is stepped down and fed back to charge the battery; D1 freewheels.
- Allows a smaller, lower-voltage battery while the motor works at a higher, constant DC link voltage — better motor and inverter efficiency.
- Controls battery current, protects battery and helps in efficient recovery of braking energy. Also used between fuel cell / supercapacitor and DC bus, and in V2G chargers.

(Diagram 2 M, function 2 M)

d) Demand and scrappage incentives (Maharashtra EV Policy 2021).

4 M

Basic demand incentive (given per kWh of battery capacity, up to the vehicle-count limit, in addition to central incentives):

Vehicle segment	Basic demand incentive	Maximum per vehicle	No. of vehicles
e-2W	₹5,000 per kWh of battery	₹10,000	1,00,000
e-3W (passenger, L5M)	₹5,000 per kWh	₹30,000	15,000
e-3W (goods, L5N)	₹5,000 per kWh	₹30,000	10,000
e-4W (car, M1)	₹5,000 per kWh	₹1,50,000	10,000
e-4W goods (N1)	₹5,000 per kWh	₹1,00,000	10,000
e-bus	10 % of vehicle cost	₹20,00,000	1,000

Early-bird incentives were also offered for vehicles bought before 31 December 2021.

Scrappage incentive — for buyers who scrap an old vehicle and buy an EV (on scrapping certificate):

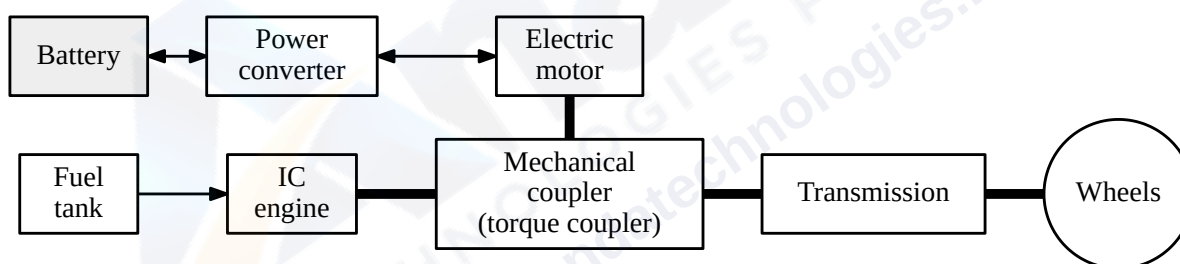
Vehicle segment	Scrappage incentive (up to)
e-2W	₹7,000
e-3W	₹15,000
e-4W	₹25,000

Figures are from Maharashtra EV Policy 2021 (GR dated 23 July 2021). Policies change — check the latest GR.
(Demand incentives 2 M, scrappage incentives 2 M)

Q.4

a) Parallel hybrid electric vehicle.

4 M



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

Fig.: Parallel hybrid electric vehicle — engine and motor both drive the wheels through a mechanical coupler

Working: Both the IC engine and the electric motor are mechanically coupled to the wheels through a torque coupler, so they can drive the vehicle alone or together. At low load the motor alone drives; at high load (acceleration, hill) both engine and motor supply torque; during braking the motor works as generator and charges the battery.

Advantages: only two propulsion devices; smaller engine and motor can be used; high efficiency on highway because engine drives wheels directly.

Disadvantages: engine speed is linked to vehicle speed so it cannot always run at its best point; control and mechanical coupling are more complex.

(Diagram 2 M, working 2 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.
Cost	High — platinum catalyst, hydrogen storage and production.	Lower (Li-ion pack cost falling every year).
Weight	Light for long range (hydrogen has very high specific energy); tank + stack are bulky.	Heavy for long range (≈ 150 – 250 Wh/kg).
Efficiency	About 40–60 % (hydrogen to electricity).	High, about 85–95 % (charge-discharge).

(Each point 1 M)

c) Battery capacity and number of cells for e-car.

4 M

Given: Range = 150 km, energy consumption = 140 Wh/km, efficiency $\eta = 90\%$, system voltage $V = 350$ V

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

$$E_{\text{req}} = \text{range} \times \text{consumption} = 150 \times 140 = \mathbf{21,000 \text{ Wh} = 21 \text{ kWh}}$$

Step 2 – Battery capacity (energy) considering η :

$$E_{\text{batt}} = E_{\text{req}} / \eta = 21,000 / 0.9 = \mathbf{23,333.33 \text{ Wh} \approx 23.33 \text{ kWh}}$$

Step 3 – Capacity in ampere-hour:

$$\text{Ah} = E_{\text{batt}} / V = 23,333.33 / 350 = \mathbf{66.67 \text{ Ah}}$$

Step 4 – Number of cells in series: $N_s = V / V_{\text{cell}} = 350 / 3.7 = 94.59 \rightarrow \mathbf{95 \text{ cells}}$ (pack voltage = $95 \times 3.7 = 351.5$ V)

Step 5 – Number of parallel strings: $N_p = \text{Ah} / \text{Ah}_{\text{cell}} = 66.67 / 35 = 1.9 \rightarrow \mathbf{2 \text{ strings}}$ (pack capacity = $2 \times 35 = 70$ Ah)

Step 6 – Total cells = $N_s \times N_p = 95 \times 2 = \mathbf{190 \text{ cells}}$ (95S2P). Actual pack energy = $351.5 \text{ V} \times 70 \text{ Ah} = \mathbf{24.61 \text{ kWh}}$ ($\geq$ required 23.33 kWh ✓)

95 cells in series per string $\times$ 2 strings in parallel (95S2P)

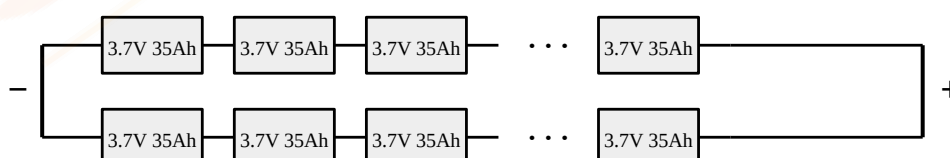


Fig.: Battery pack arrangement

Answer: 23.33 kWh, 66.67 Ah; 95 cells in series $\times$ 2 in parallel = 190 cells.

(kWh 1 M, Ah 1 M, series cells 1 M, parallel strings 1 M)

d) Battery swapping.

4 M

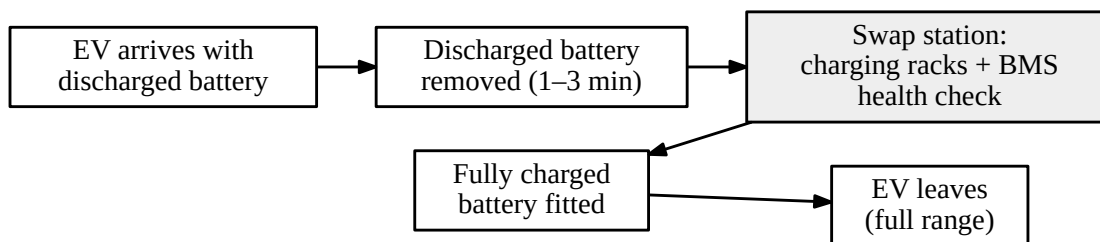


Fig.: Battery swapping process

Battery swapping is a method in which a discharged battery of an EV is removed and replaced by a fully charged battery at a swapping station within a few minutes, instead of charging the battery in the vehicle.

Advantages: very short 'refuelling' time (2–5 min); vehicle cost reduces if battery is leased ('Battery-as-a-Service'); batteries are charged slowly and under control at the station — longer life; useful for e-2W, e-3W and fleet vehicles.

Limitations: needs standard battery size, connectors and BMS across manufacturers; high investment in spare batteries and stations; ownership, quality and safety of shared batteries; not practical for large car battery packs. (NITI Aayog released a draft battery swapping policy in 2022.)

(Concept 2 M, advantages 1 M, limitations 1 M)

e) Location of motor and battery in 2W and 4W EV.

4 M

Two-wheeler: motor is either a **hub motor** inside the rear wheel (e.g. TVS iQube) or a **mid-drive motor** on the frame driving the rear wheel by belt / chain (e.g. Ather 450 series). Battery is placed under the floorboard or under the seat; controller near the battery.

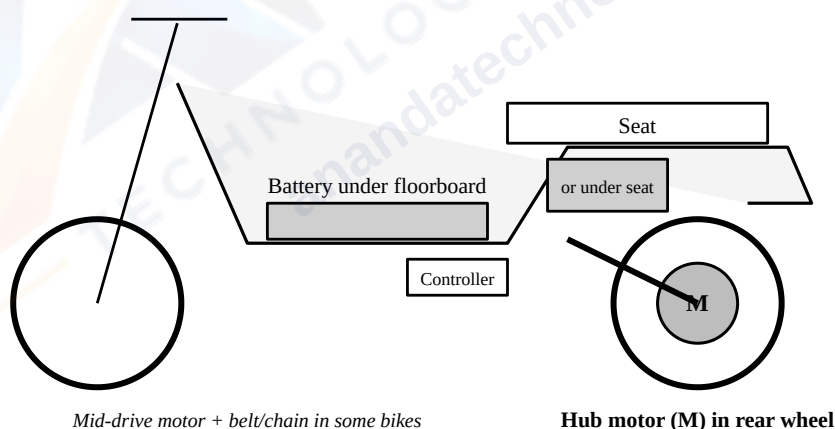


Fig.: Location of motor and battery in an electric two-wheeler (side view)

Four-wheeler: motor with reduction gear and differential on the **front axle** (front-wheel drive, e.g. Tata Nexon EV), on the **rear axle** (rear-wheel drive) or on both axles (dual-motor AWD). Battery is a flat pack **under the floor between the axles** — low centre of gravity, better stability and more cabin space.

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).

Limitations: costly rare-earth magnets (NdFeB), risk of demagnetisation at high temperature, needs position sensor and complex controller.

Use: most electric cars and many e-2W (e.g. Tata Nexon EV uses a PMSM).

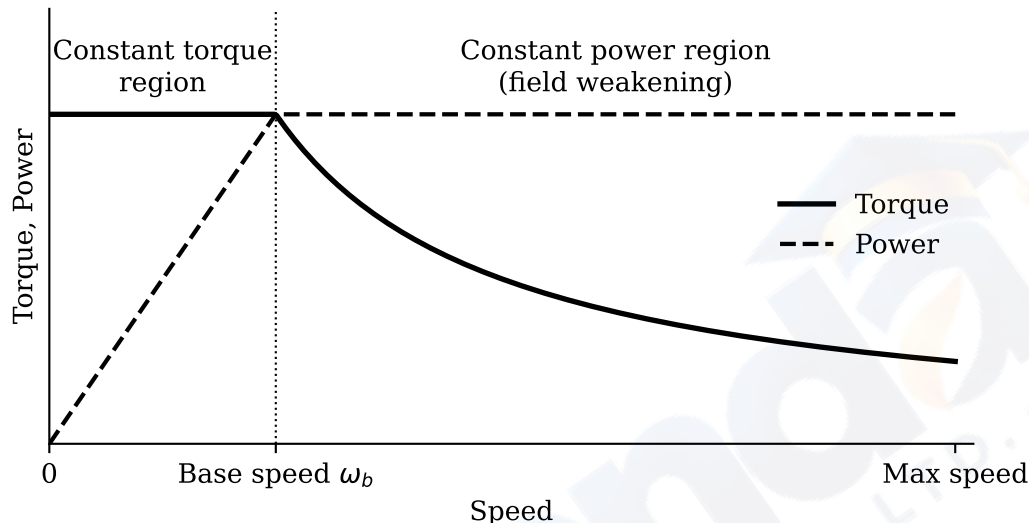


Fig.: Torque-speed characteristic of PMSM (constant torque up to base speed, then field weakening)

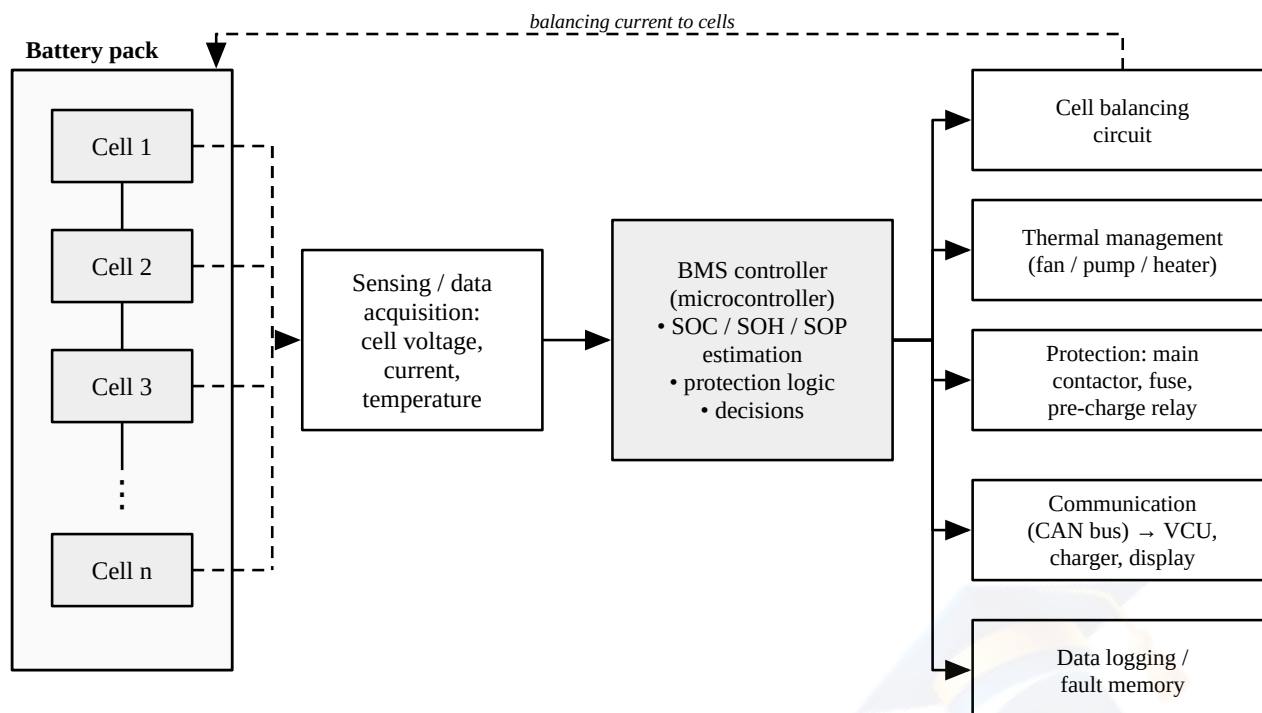
(Construction 1 M, working 2 M, advantages 1 M, limitations 1 M, applications 1 M)

b) BMS — need, block diagram, functions.

6 M

Need of BMS:

- 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.



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.

(Need 1 M, diagram 2 M, functions 3 M)

c) E-bus SOC and charging time.

6 M

Given: Battery capacity = 300 kWh (100 % SOC at start), distance = 180 km, consumption = 1.1 kWh/km, charger 60 kW and 120 kW, $\eta = 95\%$

i) Energy used = $180 \times 1.1 = 198 \text{ kWh}$

Energy left = $300 - 198 = 102 \text{ kWh}$

SOC at end of day = $102 / 300 \times 100 = 34\%$

ii) With 60 kW DC charger:

Step 1 – Energy to be supplied to the battery:

$$E = \text{capacity} \times (\text{SOC}_{\text{final}} - \text{SOC}_{\text{initial}}) = 300 \times (1 - 0.34) = 300 \times 0.66 = \mathbf{198 \text{ kWh}}$$

Step 2 – Effective charging power:

$$P_{\text{eff}} = P \times \eta = 60 \times 0.95 = \mathbf{57 \text{ kW}}$$

Step 3 – Charging time:

$$t = E / P_{\text{eff}} = 198 / 57 = \mathbf{3.474 \text{ h} \approx 3 \text{ h } 28 \text{ min}}$$

iii) With 120 kW DC charger:

Step 1 – Energy to be supplied to the battery:

$$E = \text{capacity} \times (\text{SOC}_{\text{final}} - \text{SOC}_{\text{initial}}) = 300 \times (1 - 0.34) = 300 \times 0.66 = \mathbf{198 \text{ kWh}}$$

Step 2 – Effective charging power:

$$P_{\text{eff}} = P \times \eta = 120 \times 0.95 = \mathbf{114 \text{ kW}}$$

Step 3 – Charging time:

$$t = E / P_{\text{eff}} = 198 / 114 = \mathbf{1.737 \text{ h} \approx 1 \text{ h } 44 \text{ min}}$$

Answer: SOC = 34 %; charging time $\approx 3.47 \text{ h}$ (3 h 28 min) with 60 kW and $\approx 1.74 \text{ h}$ (1 h 44 min) with 120 kW. (In practice DC chargers reduce power above about 80 % SOC, so actual time is somewhat longer.)

(SOC 2 M, time with 60 kW 2 M, time with 120 kW 2 M)

Q.6

a) Induction motor vs BLDC motor.

6 M

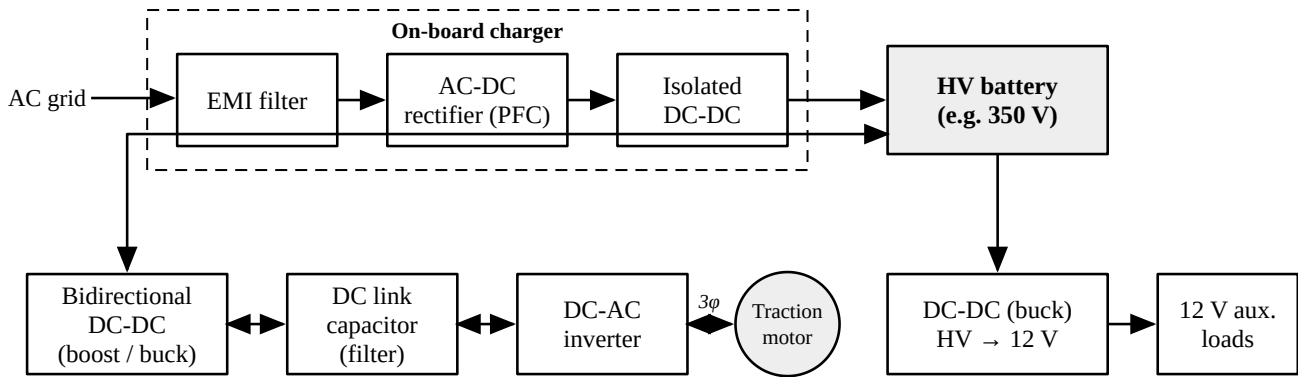
Point	Induction motor (IM)	BLDC motor
Power-to-weight ratio	Medium	High
Torque-speed characteristic	Wide speed range with field weakening; constant power region 3–4× base speed	High starting torque; limited constant-power (field weakening) range
Cost of controller	High (vector control inverter)	Low–medium (six-step inverter + Hall sensors)
Cost of motor	Low (rugged, no magnets)	High (rare-earth magnets)
Efficiency	Medium–high (≈ 85 – 92 %)	High (≈ 90 – 95 %)
Maintenance	Very low	Very low

Efficiency values are typical ranges from textbooks; actual values depend on design and rating.

(Each point 1 M)

b) Power electronic converters in EV.

6 M



Double-headed arrows: power flows both ways (motoring and regenerative braking)

Fig.: Power electronic converters in a typical EV

Description and functions:

- **AC to DC converter (rectifier):** in the on-board charger it converts grid AC into DC; with power factor correction (PFC) it draws sinusoidal current at near unity power factor. Also used to convert generator AC to DC in hybrids.
- **DC to DC converter:** (i) isolated DC-DC in the charger regulates charging voltage / current; (ii) bidirectional boost-buck converter steps up battery voltage to DC link voltage and returns regenerative energy; (iii) buck converter gives 12 V for auxiliaries.
- **DC to AC converter (inverter):** converts battery DC to variable-voltage, variable-frequency 3-phase AC using PWM to control motor speed and torque; works as rectifier during regenerative braking.
- **Filters:** EMI filter at the input reduces conducted noise; DC link capacitor smooths ripple voltage; LC filters reduce harmonics on the AC side.

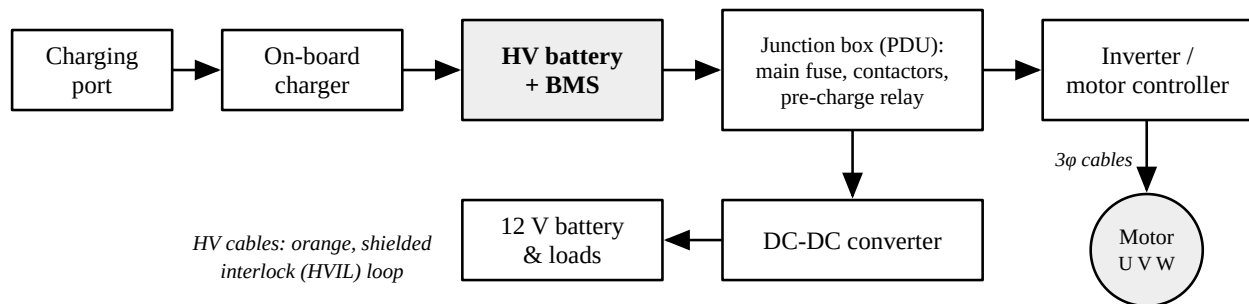
(Diagram 2 M, four functions 1 M each)

c) Connections and selection criteria of EV motors.

6 M

i) Mechanical and electrical connections

(a) Electrical connections



(b) Mechanical connections (central motor)

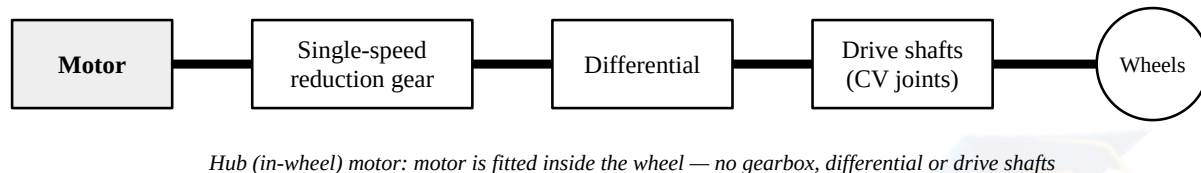


Fig.: Electrical and mechanical connections of the motor in an EV

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.

ii) Selection criteria (any four):

- **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.

(Connections 4 M, criteria 2 M)

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