PVP 23

Code: 23EE2601

III B.Tech – II Semester - Regular Examinations – APRIL 2026

FUNDAMENTALS OF ELECTRIC VEHICLES

(Common for ALL BRANCHES)

Duration: 3 hours Max. Marks: 70

Note: 1. This question paper contains two Parts A and B.
2. Part-A contains 10 short answer questions. Each Question carries 2 Marks.
3. Part-B contains 5 essay questions with an internal choice from each unit. Each Question carries 10 marks.
4. All parts of Question paper must be answered in one place.

BL – Blooms Level CO – Course Outcome

PART – A

		BL	CO
1.a)	Why there is a need for electric vehicles?	L2	CO1
b)	What are the main factors affecting EV market growth?	L1	CO1
c)	What is the function of an inverter in EVs?	L1	CO2
d)	List the main components of an electric vehicle.	L1	CO2
e)	List any two advantages of induction motors in EVs.	L1	CO1
f)	What are the requirements of electric machines for electric vehicles?	L1	CO2
g)	What is the function of the internal combustion engine in HEVs?	L2	CO2
h)	What is regenerative braking in hybrid electric vehicles?	L1	CO2
i)	What is the basic principle of a fuel cell?	L1	CO1
j)	List the advantages of lead–acid batteries.	L1	CO1

PART – B

			BL	CO	Max. Marks
		UNIT-I			
2	a)	Discuss in detail the types of Electric Vehicles with block diagrams.	L2	CO2	5 M
	b)	Compare Electric Vehicles and Conventional Vehicles.	L3	CO2	5 M
		OR			
3	a)	Explain the fundamentals of vehicles and vehicle dynamics.	L2	CO1	5 M
	b)	Mention the limitations and drawbacks of conventional ICE vehicles.	L1	CO1	5 M
		UNIT-II			
4	a)	Articulate the operation of bidirectional DC–DC converters in EV battery systems.	L3	CO3	5 M
	b)	Explain the role of the controller in electric vehicle operation.	L2	CO2	5 M
		OR			
5	a)	Explain the power flow in electric vehicles during motoring and regenerative braking modes.	L2	CO2	5 M
	b)	Compare different power converters used in EVs.	L3	CO3	5 M

UNIT-III					
6	a)	Explain the characteristics of traction drives used in electric vehicles.	L2	CO3	5 M
	b)	Mention the advantages and limitations of induction motors in electric vehicles.	L2	CO3	5 M
OR					
7	Discuss the working principle and advantages of Brushless DC motors in EV applications.		L2	CO3	10 M
UNIT-IV					
8	a)	Compare Series, Parallel and Complex Hybrid Electric Vehicles.	L3	CO4	5 M
	b)	Discuss the advantages and disadvantages of Hybrid Electric Vehicles.	L2	CO4	5 M
OR					
9	Illustrate the operation of the Hybrid Electric Vehicle architecture in detail.		L4	CO4	10 M
UNIT-V					
10	Analyze the working and importance of a Battery Management System (BMS).		L5	CO5	10 M
OR					
11	Explain the construction and working of hydrogen fuel cells used in EVs.		L2	CO5	10 M

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FUNDAMENTALS OF ELECTRIC VEHICLES

(ELECTRICAL & ELECTRONICS ENGINEERING)

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SCHEME OF EVALUATION

PART-A

1. **a) 2M**

b) 2M

c) 2M

d) 2M

e) 2M

f) 2M

g) 2M

h) 2M

i) 2M

j) 2M

PART - B

UNIT-I

2 a) Types 2M
Block Diagram 3M
b) Comparison 5M

OR

3 a) Explanation 5M
b) Limitations 3M
Drawbacks: 2M

UNIT-II

4. a) Circuit Diagram 3M
Explanation 2M
b) Explanation 5M

OR

5. a) Explanation 3M
Diagram 2M
b) Comparison 5M

UNIT-III

6. a) Characteristics 5M
b) Advantages 3M
Limitations 2M

OR

7.a) Working Principle 3M
Diagram 4M
Advantages 3M

UNIT-IV

8. a) Comparison 5M
b) Advantages 3M
Disadvantages 2M

OR

9. Operation 3M
Architecture 4M
Explanation 3M

UNIT-V

10. Working 5M
Importance 5M

OR

11.Construction 3M
Diagram 4M
Working 3M

PART A (2 marks each)

a) Why there is a need for electric vehicles?

- To reduce **air pollution and greenhouse gas emissions**
- To decrease dependence on **fossil fuels** and improve energy efficiency

b) Main factors affecting EV market growth

- Government policies & subsidies
- Charging infrastructure availability
- Battery cost and technology
- Consumer awareness and fuel prices

c) Function of an inverter in EVs

- Converts **DC from battery into AC** to drive the motor
- Controls motor speed and torque

d) Main components of an electric vehicle

- Battery pack
- Electric motor
- Inverter/controller
- DC/DC converter

e) Two advantages of induction motors in EVs

- Rugged and low maintenance (no brushes)
- High reliability and good efficiency

f) Requirements of electric machines for EVs

- High efficiency and power density
- Wide speed range and good torque characteristics

g) Function of ICE in HEVs

- Provides additional power to drive wheels
- Charges battery through generator

h) What is regenerative braking?

- A process where the motor acts as a **generator during braking**
- Converts kinetic energy into electrical energy and stores it in battery

i) Basic principle of a fuel cell

- Converts **chemical energy ($H_2 + O_2$)** directly into electrical energy
- Produces water and heat as by-products

j) Advantages of lead-acid batteries

- Low cost and widely available
- Simple technology and reliable

UNIT – I

Q2(a): Discuss in detail the types of Electric Vehicles with block diagrams. [L2, CO2,5M]

Answer:

Definition of Electric Vehicle (EV):

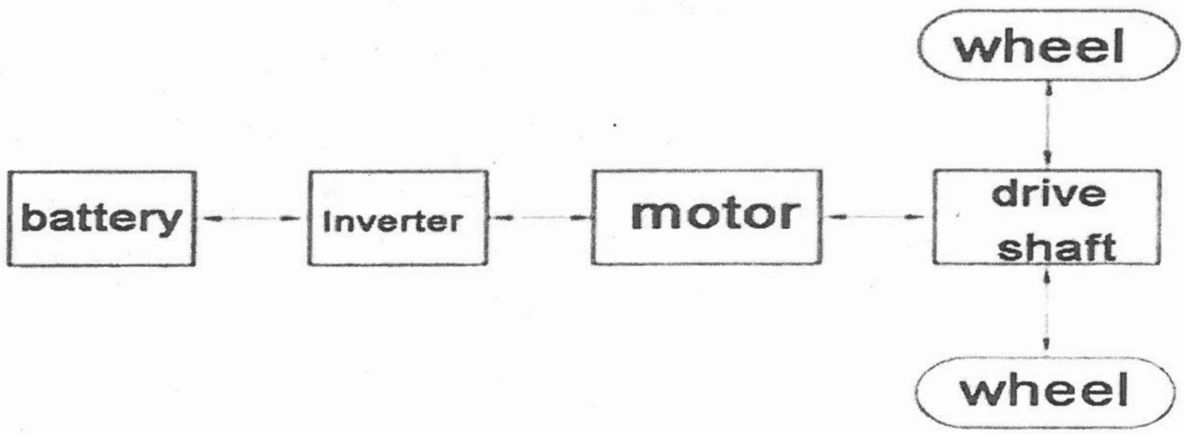
An Electric Vehicle (EV) is a vehicle in which: (i) the energy source is portable and electrochemical or electromechanical in nature, and (ii) traction effort is supplied solely by an electric motor. The EV powertrain converts stored electrical energy into mechanical energy to drive the wheels.

Types of Electric Vehicles:

1. **Battery Electric Vehicle (BEV)**
2. **Hybrid Electric Vehicle (HEV)**
3. **Plug-in Hybrid Electric Vehicle (PHEV)**
4. **Fuel Cell Electric Vehicle (FCEV)**

Battery Electric Vehicle (BEV): Powered entirely by an on-board rechargeable battery pack. No IC engine. Zero tail-pipe emissions. Example: Tesla Model 3, Nissan Leaf.

1. Battery supplies **DC power**
2. Inverter converts it to **AC power**
3. Motor converts electrical → mechanical energy
4. Wheels rotate → vehicle moves
5. During braking → energy flows back to battery (regeneration)



2. Hybrid Electric Vehicle (HEV): Combines IC engine + electric motor. Engine charges battery via regenerative braking. No external charging needed. Example: Toyota Prius, Honda Civic Hybrid.

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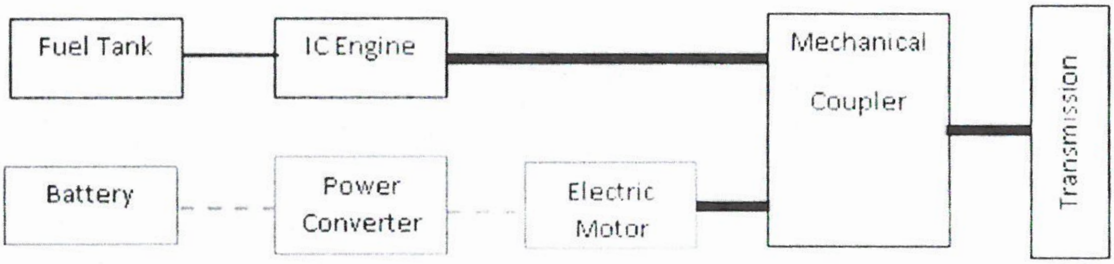
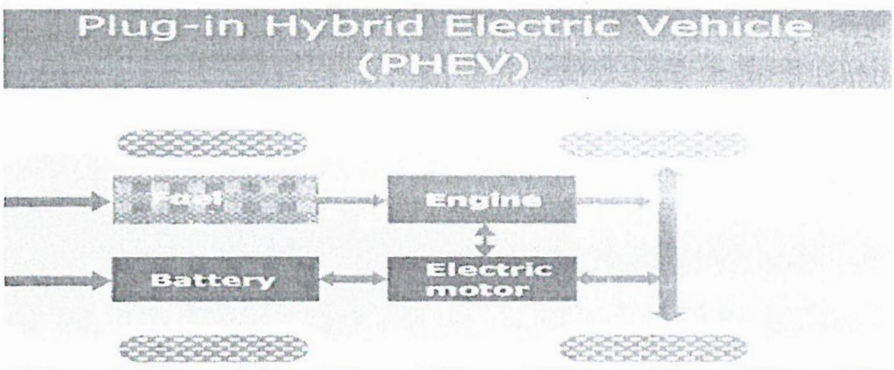
HEV operates by intelligently combining power from an internal combustion engine and an electric motor to drive the vehicle efficiently under different conditions. At low speeds or during light load conditions, the vehicle typically runs on electric power alone, where the battery supplies energy to the motor, enabling silent and fuel-free operation. As the speed increases or when higher power is required—such as during acceleration or climbing—the engine automatically starts and works together with the electric motor to provide additional torque, ensuring better performance and fuel efficiency. During steady cruising at higher speeds, the engine may take over as the primary power source, sometimes simultaneously charging the battery through a generator. When the vehicle slows down or brakes, the electric motor reverses its function and acts as a generator, converting the vehicle's kinetic energy into electrical energy and storing it back in the battery through regenerative braking. Throughout this entire process, an electronic control unit continuously monitors parameters like speed, load, and battery charge to seamlessly switch between modes or combine power sources, ensuring optimal energy utilization, reduced fuel consumption, and lower emissions without requiring external charging in conventional HEVs.



3. **Plug-in Hybrid Electric Vehicle (PHEV):** Same as HEV but battery can be charged from external grid. Larger battery enables longer electric-only range. Example: Chevrolet Volt. **(PHEV)** operates similarly to a hybrid vehicle but with a larger battery that can be charged externally through a charging port, allowing extended electric-only driving. Initially, the vehicle runs in electric mode where the battery supplies power to the motor, enabling zero-emission operation for short to moderate distances. As the battery charge depletes or when higher power is required, the internal combustion engine automatically starts and works alongside the electric motor to drive the wheels, ensuring continuous operation without range limitations. During high-speed cruising, the engine may take the dominant role while also charging the battery through a generator system.



4. Fuel Cell Vehicle (FCEV)

Uses hydrogen fuel + fuel cell to generate electricity on-board. Zero emission (only water vapor). Example: Toyota Mirai, Honda Clarity. **FCEV** generates electricity onboard using hydrogen instead of relying solely on a battery. Hydrogen gas stored in high-pressure tanks is supplied to the fuel cell stack, where it undergoes an electrochemical reaction with oxygen from the air to produce electricity, water, and heat. The generated electrical energy is then conditioned by power electronics and used to drive the electric motor, which propels the vehicle. A small battery or supercapacitor is typically included to store excess energy and assist during acceleration or transient loads. During braking, regenerative braking allows the motor to act as a generator, converting kinetic energy back into electrical energy and storing it in the battery.

H_2 Tank	→	Fuel Cell Stack	→	DC/DC Converter	→	Inverter	→	Electric Motor	→	Wheels
			↕	Battery (Buffer)						

Q2(b): Compare Electric Vehicles and Conventional Vehicles. [L3, CO2, 5M]

Answer:

The following table compares EVs and ICEVs across key parameters:

Parameter	Electric Vehicle (EV)	Conventional Vehicle (ICEV)
Energy Source	Battery / Fuel Cell	Petrol / Diesel / CNG
Emission	Zero tail-pipe emission (ZEV)	CO_2, NO_x, HC – high emission
Efficiency	~85–95% (motor + inverter)	~20–35% (thermal engine)
Fuel Cost	Low (electricity cheaper)	High (fossil fuel dependent)
Range	200–650 km per charge	500–800 km per tank
Refueling	Charging takes 20 min–8 hrs	~5 minutes at gas station
Maintenance	Very low – no oil, filters	Higher – frequent servicing
Noise	Silent operation	Significant engine noise
Regeneration	Regenerative braking available	Braking energy wasted as heat
Capital Cost	Higher (battery cost)	Lower upfront cost
Power Density	High torque at zero speed	Poor torque at low rpm

Q3(a): Explain the fundamentals of vehicles and vehicle dynamics. [L2, CO1, 5M]

6

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Answer:

Vehicle Dynamics – Fundamental Forces:

Vehicle motion is governed by Newton's Second Law. The net tractive force at wheels must overcome various resistive forces to accelerate the vehicle:

Net Tractive Force: F_net = F_TR – F_resistance

where F_TR = Traction force from motor, F_resistance = Total resistance force

Resistance Forces Acting on a Vehicle:

1. Rolling Resistance Force (F_rr):

   F_rr = $C_0 \times m \times g \times \cos(\beta)$

C_0 = rolling resistance coefficient (≈ 0.01–0.02), m = vehicle mass, β = road slope angle

2. Aerodynamic Drag Force (F_ad):

   F_ad = $\frac{1}{2} \times \rho \times C_D \times A^f \times v^2$

ρ = air density, C_D = drag coefficient, A^f = frontal area, v = vehicle velocity

3. Gradient (Hill Climbing) Force (F_g):

   F_g = $m \times g \times \sin(\beta)$

4. Acceleration Force (F_a):

   F_a = m_eq × a   (m_eq = equivalent mass including rotating inertias)

Total Tractive Force Required:

F_TR = F_rr + F_ad + F_g + F_a

   = $m \cdot g \cdot C_0 \cdot \cos(\beta) + \frac{1}{2} \cdot \rho \cdot C_D \cdot A^f \cdot v^2 + m \cdot g \cdot \sin(\beta)$ + m_eq·(dv/dt)

Vehicle Mass (m)	Road Grade (β°)	Rolling Resist. (F_rr)	Aero Drag (F_ad)	Gradient Force (F_g)

Equivalent Vehicle Mass:

m_eq = $k_m \cdot m_v + N_p \cdot m_p$

k_m = mass factor (accounts for rotating inertias of wheels, driveshaft, engine, motor)

N_p = number of passengers, m_p = average passenger mass (≈75 kg)

Q3(b): Mention the limitations and drawbacks of conventional ICE vehicles. [L1, CO1, 5M]

Answer:

Limitations and Drawbacks of Conventional ICE Vehicles:

- Low Thermal Efficiency: Only 20–35% of fuel energy converts to useful work; rest is wasted as heat.

- Poor Torque at Low Speed: IC engines have poor torque at low RPM and require multi-gear transmission.
- No Regenerative Braking: Kinetic energy during deceleration is entirely wasted as heat in brakes.
- High Maintenance: Requires regular oil changes, filter replacements, coolant, spark plugs.
- Noise and Vibration: Combustion process generates significant noise and mechanical vibrations.
- Complexity: Many moving parts (pistons, camshaft, crankshaft, valves) increase failure risk.
- Heat Engine Constraint: Efficiency is fundamentally limited by the Carnot cycle.
- Urban Air Quality: Significant contributor to smog and respiratory health problems in cities.

UNIT – II

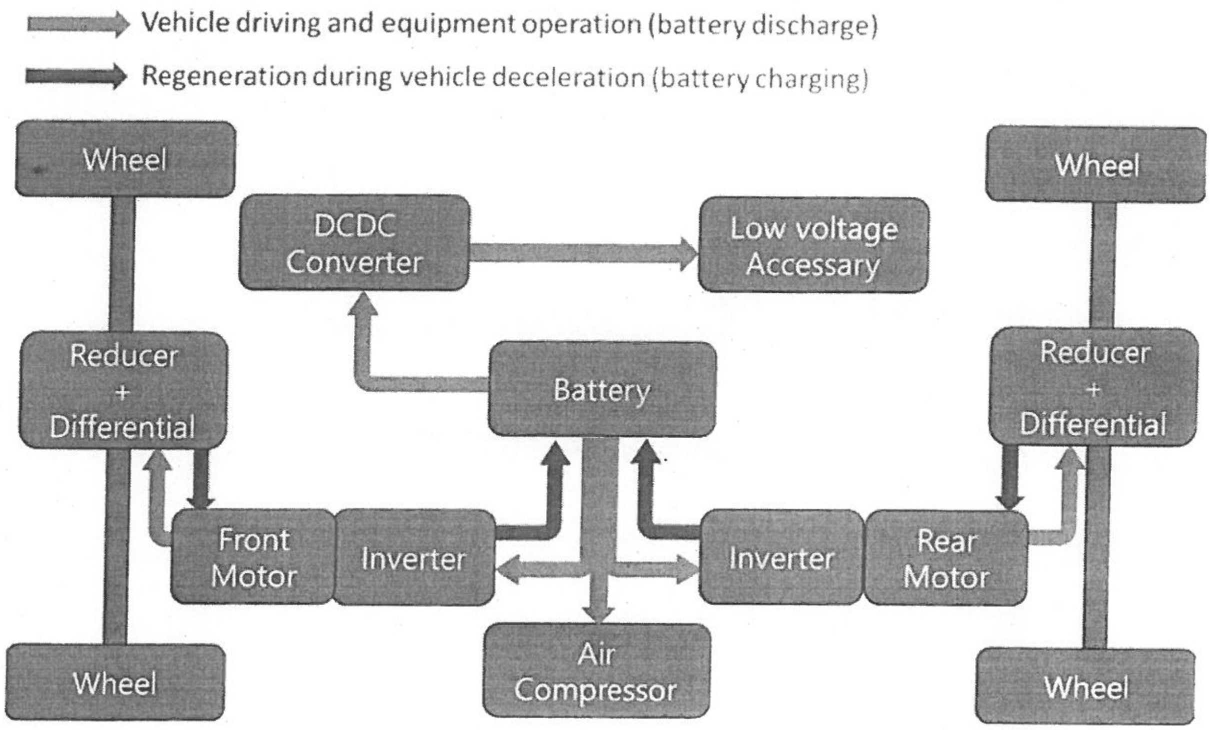
Q4(a): Articulate the operation of bidirectional DC–DC converters in EV battery systems. [L3, CO3, 5M]

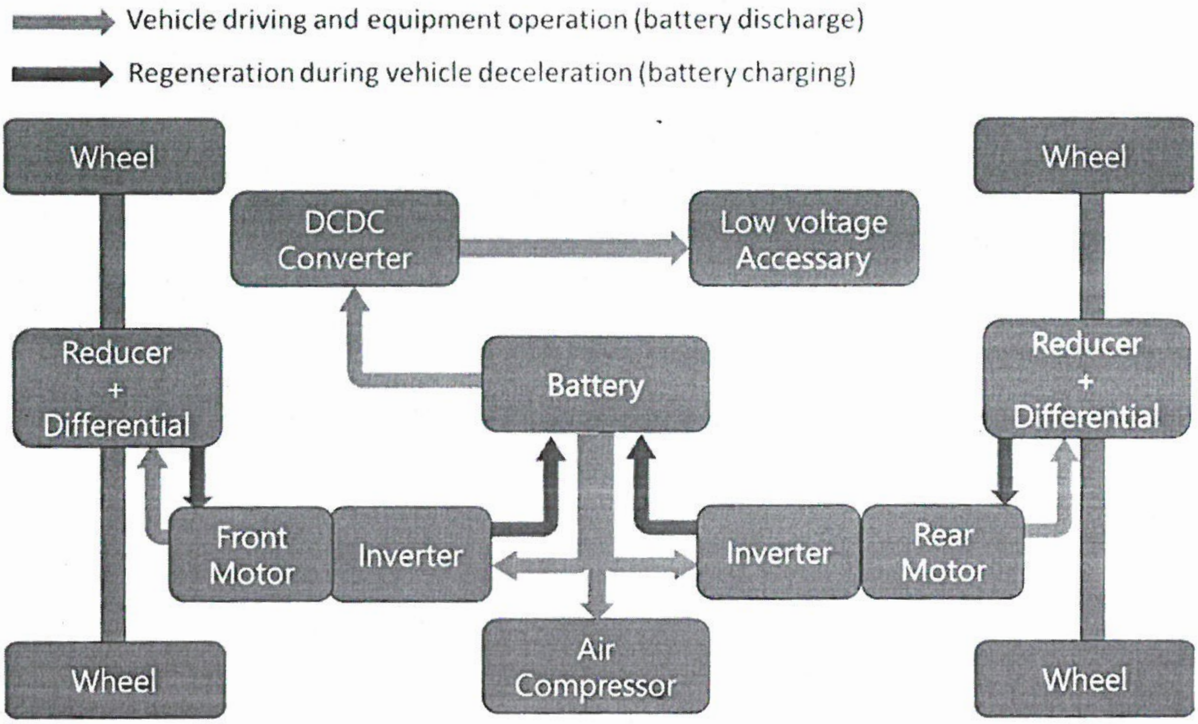
Answer:

Role of Bidirectional DC–DC Converter in EVs:

In EVs and HEVs, power must flow in both directions between the battery pack and the high-voltage DC bus. A Bidirectional DC–DC Converter (BDC) enables:

- Discharging Mode (Buck): Battery supplies power to DC bus → motor drive (propulsion)
- Charging Mode (Boost): Regenerative braking / generator charges battery from DC bus





Operating Modes

Mode 1 – Propulsion (Buck / Step-Down Mode)

In this mode, the vehicle is **moving forward** and requires power.

- The **high-voltage DC bus** supplies energy.
- The converter **steps down voltage** to a lower level.
- **Switch Q1 is ON, Q2 is OFF.**
- The **inductor stores energy** when Q1 is ON and releases it to the load.

☞ Output relation:

Vout=D×VinV_{out} = D \times V_{in}Vout=D×Vin

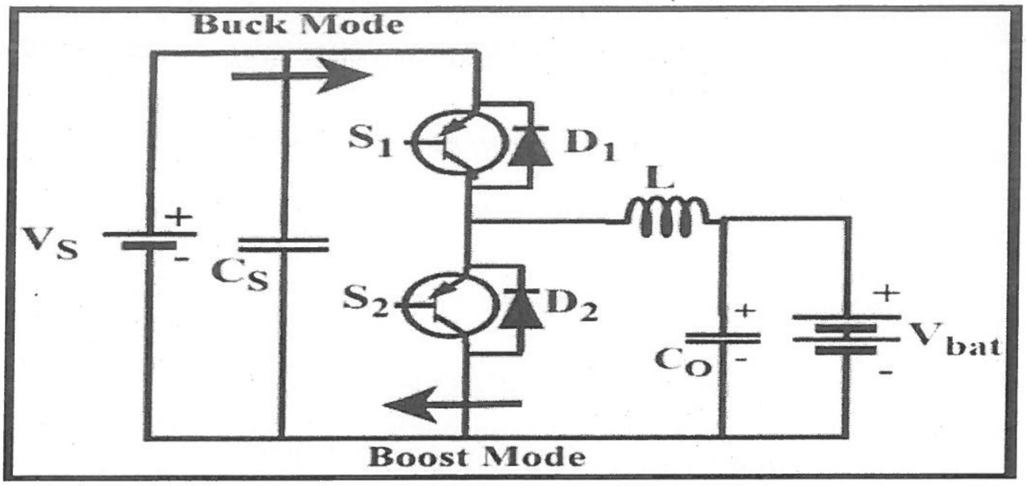
✓ Meaning:

- Output voltage is **lower than input**
- Used for **powering low-voltage systems or controlled delivery**

Mode 2 – Regenerative Braking (Boost / Step-Up Mode)

In this mode, the vehicle is **slowing down**, and energy is recovered.

- Motor acts as a **generator**
- Energy flows back toward the battery
- Converter **steps up voltage** to charge the high-voltage bus
- **Switch Q2 is ON, Q1 is OFF**



Components Explanation

- **V_HV** → High Voltage DC Bus
- **V_Bat** → Battery (Low Voltage)
- **Q1 & Q2** → Power switches (IGBTs/MOSFETs)
- **D1 & D2** → Freewheeling diodes
- **Inductor (L)** → Stores and transfers energy

The **inductor is the key element**:

- Stores energy in magnetic form
- Releases it based on switching
- Enables **buck and boost operation**

Q4(b): Explain the role of the controller in electric vehicle operation. [L2, CO2, 5M]

Answer:

Vehicle Control System Architecture:

Modern EVs use a hierarchical control structure with the Vehicle Supervisory Controller (VSC) at the top. It coordinates all subsystem controllers via CAN (Controller Area Network) protocol.

Roles of the Controller:

- Torque Control: Translates accelerator pedal input into motor torque commands via current/speed regulation.
- Regenerative Braking Control: Detects deceleration; switches motor to generator mode to recover kinetic energy.
- Energy Management: Optimizes power flow between battery, motor, and auxiliary loads for maximum efficiency.
- Battery Protection: Monitors SOC, temperature, voltage limits; prevents overcharge and over-discharge.
- Thermal Management: Controls cooling fans/pumps for battery, motor, and power electronics.

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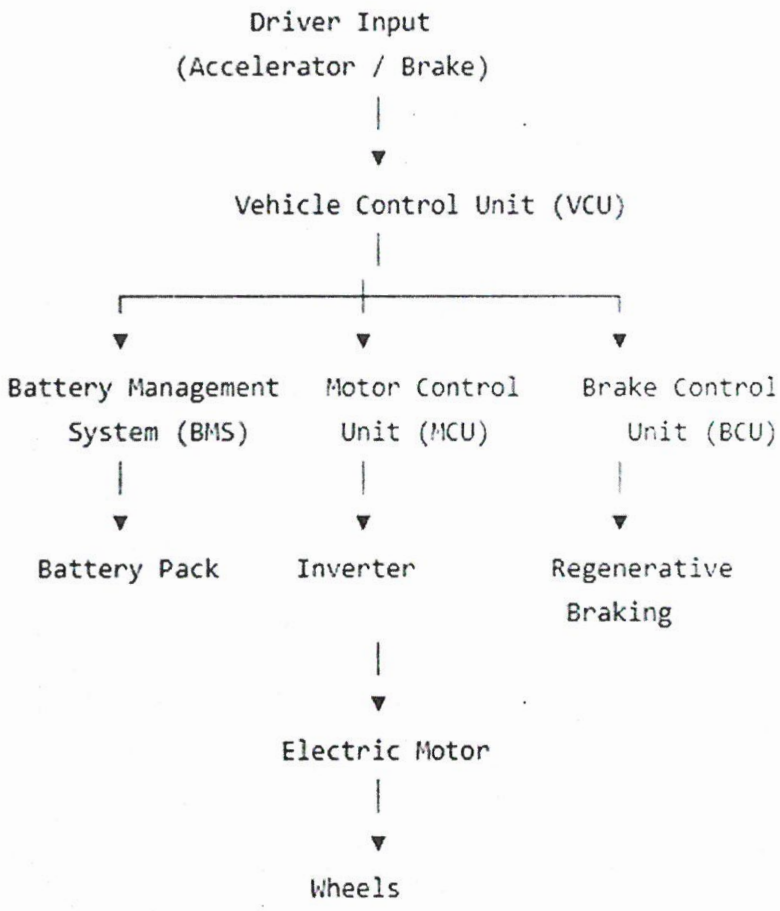
- Battery Protection: Monitors SOC, temperature, voltage limits; prevents overcharge and over-discharge.
- Thermal Management: Controls cooling fans/pumps for battery, motor, and power electronics.
- Fault Detection: Monitors sensor inputs, detects anomalies, activates safety responses.
- Communication: VSC communicates with all ECUs via CAN bus; interfaces with dashboard instruments.



Motor

Speed/Torque Control Loop:

```
+-------------------+
|  Speed Reference  |
+-------------------+
          |
          v
      +-------+
      |   Σ   |<-----------------------------+
      +-------+                              |
          |                                  |
          v                                  |
+-------------------+                        |
|   PI Controller   |                        |
+-------------------+                        |
          |                                  |
          v                                  |
+-------------------+                        |
|        PWM        |                        |
+-------------------+                        |
          |                                  |
          v                                  |
+-------------------+                        |
|     Inverter      |                        |
+-------------------+                        |
          |                                  |
          v                                  |
+-------------------+                        |
|       Motor       |                        |
+-------------------+                        |
          |                                  |
          v                                  |
+-------------------+                        |
|      Encoder      |------------------------+
+-------------------+
          |
          v
    Speed Feedback
```

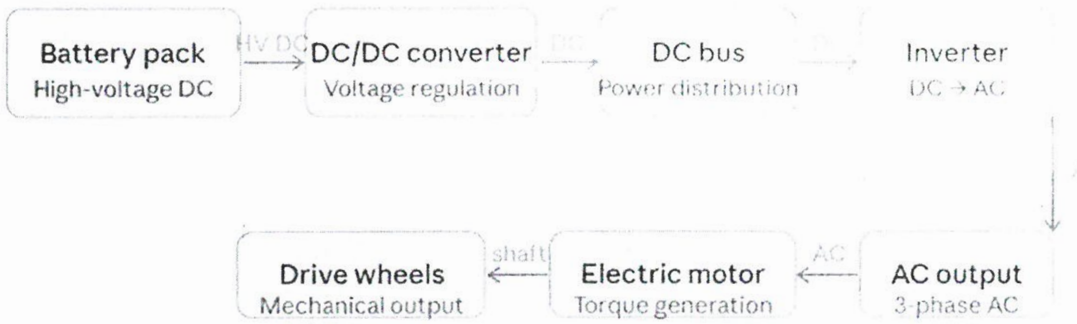
5Q(a): Explain the power flow in electric vehicles during motoring and regenerative braking modes. [L2, CO2, 5M]

Answer:

<u>Motoring Mode (Driving):</u>

During motoring, stored chemical energy in the battery is converted to mechanical energy.

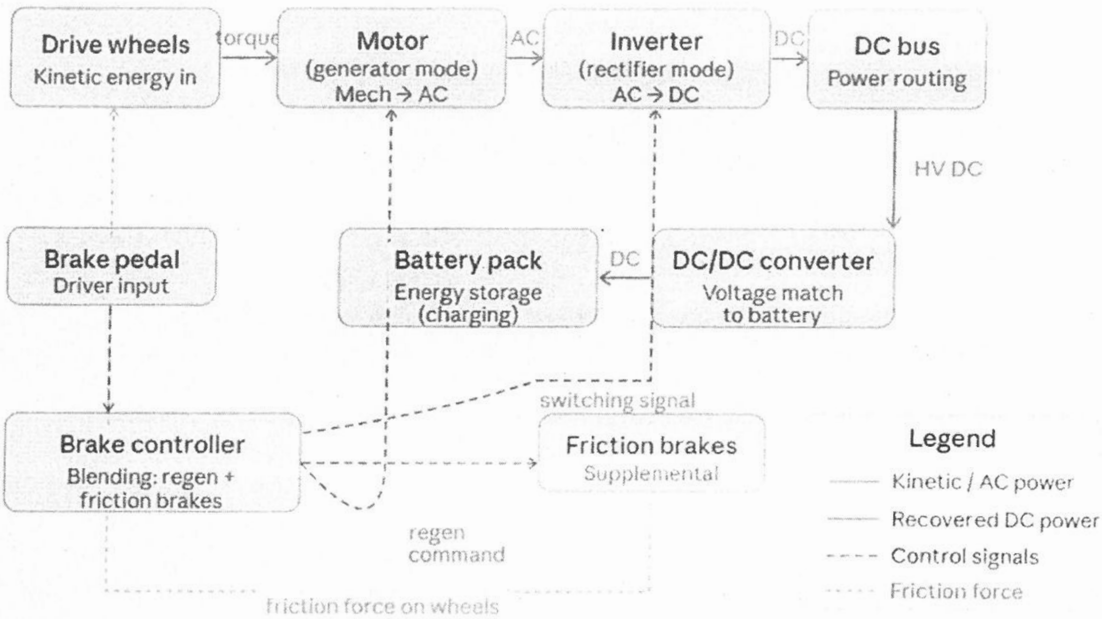
- Battery stores **chemical energy** and supplies **DC power**
- DC/DC converter regulates voltage
- Inverter converts **DC → AC** with variable frequency
- Traction motor converts electrical energy into **mechanical torque**
- Wheels rotate → vehicle moves



<u>Regenerative Braking Mode:</u>

When the driver releases the throttle or applies brakes, the motor operates as a generator.

- When braking, wheels drive the motor
- Motor acts as a **generator**
- Converts kinetic energy → electrical energy
- Inverter converts **AC → DC**
- Battery gets charged



5Q(b): Compare different power converters used in EVs. [L3, CO3, 5M]

Answer:

Converter Type	Function	Configuration	Typical Application	Key Feature
DC/DC Buck	Step-down voltage	Single switch + L, C	Battery to low-voltage loads	High efficiency
DC/DC Boost	Step-up voltage	Single switch + L, C	Fuel cell interface	Simple control
Bidirectional DC/DC	Both up/down	Two switches + inductor	Battery-motor interface	Regen braking
DC/AC Inverter (VSI)	DC → 3-phase AC	6-switch bridge (IGBT)	Drives AC traction motor	PWM control
AC/DC Rectifier	AC → DC	Diode / IGBT bridge	On-board charger	PFC capability
Isolated DC/DC	Galvanic isolation	H-bridge + transformer	OBC, battery charger	Safety isolation

UNIT – III

Q6(a): Explain the characteristics of traction drives used in electric vehicles. [L2, CO3, 5M]

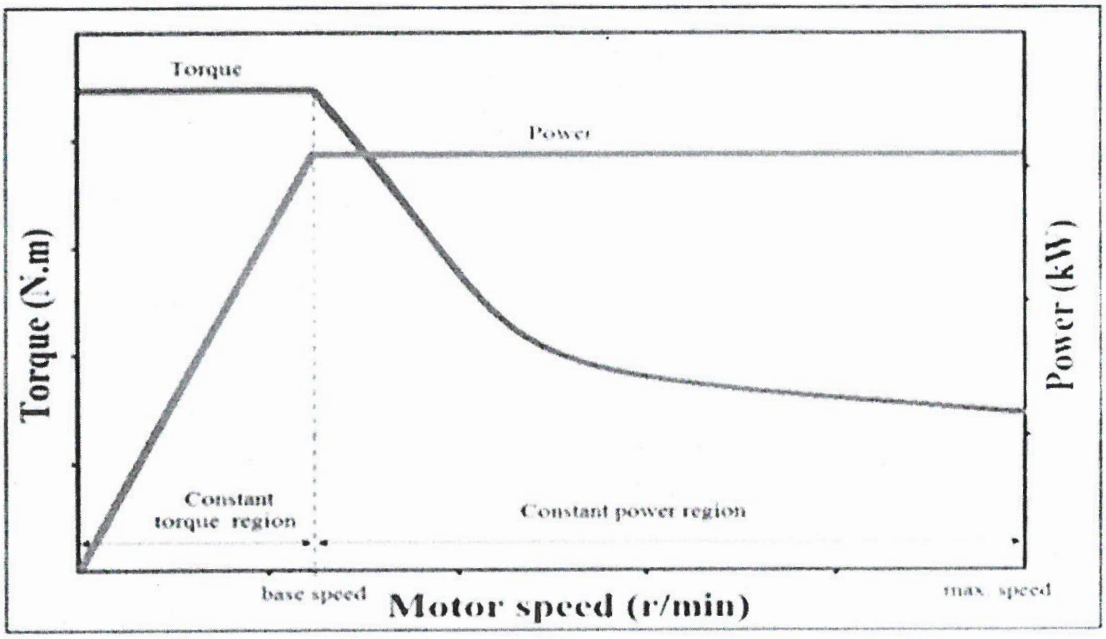
Answer:

Requirements of EV Traction Drive System:

A traction drive system consists of the electric motor, power converter (inverter), and electronic controller. Together they must satisfy demanding EV performance requirements:

- High torque at zero/low speed for starting and hill climbing
- Wide speed range with constant power capability for highway cruising
- High efficiency over entire torque-speed range
- Fast dynamic response for rapid acceleration
- Bidirectional power flow for regenerative braking
- High power density and compact size for vehicle integration
- Reliability and robustness under harsh automotive conditions

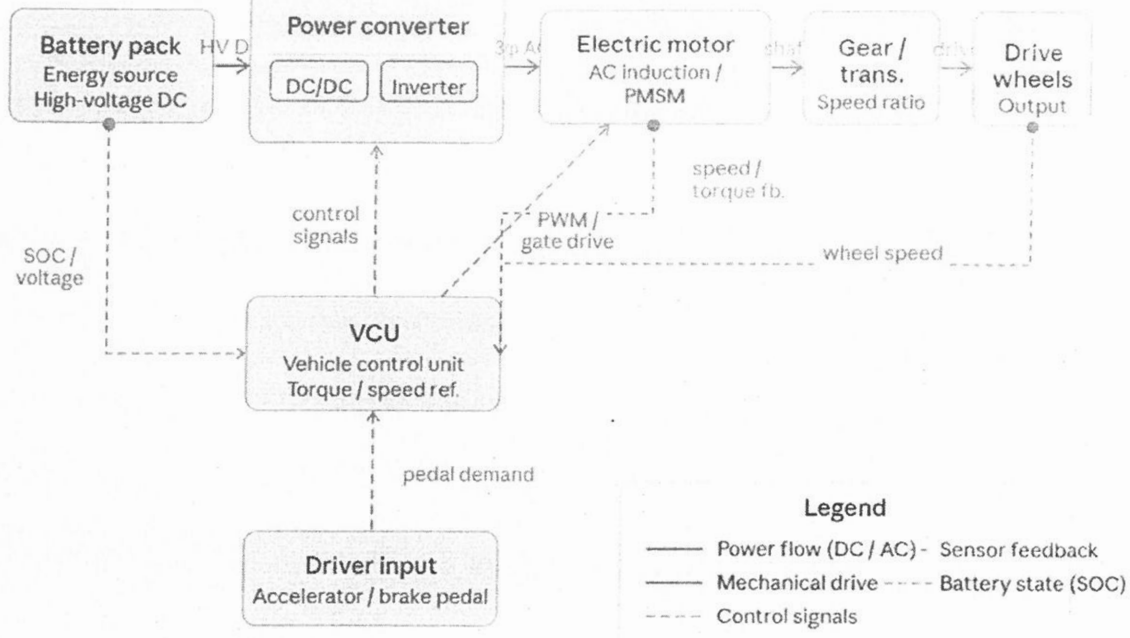
Traction Motor Torque–Speed Characteristics:



The motor operates in:

- Constant Torque Region (0 → Base speed ωb): Current limited; maximum torque maintained
- Constant Power Region (ωb → ωmax): Voltage limited; torque decreases as speed increases
- Power: $P = T \times \omega$ = constant in the second region

Key Traction Drive Components:



<u>**Types of Traction Motors Used:**</u>

- Induction Motor (IM): Robust, low cost, used by Tesla Model S; vector control for high performance
- Permanent Magnet Synchronous Motor (PMSM): High power density, high efficiency; used in Nissan Leaf, Toyota Prius
- PM Brushless DC (BLDC): Trapezoidal back-EMF, simpler control; used in smaller EVs
- Switched Reluctance Motor (SRM): Simple rotor, wide constant power range; acoustic noise is a drawback

Q6(b): Mention the advantages and limitations of induction motors in electric vehicles. [L2, CO3, 5M]

Answer:

<u>**Advantages of Induction Motors in EVs:**</u>

- Robust and Reliable: Simple squirrel-cage rotor with no brushes, slip rings or permanent magnets.
- Low Cost: No rare-earth materials required; lower manufacturing cost than PM motors.
- Maintenance-Free: No commutator, no brushes → no periodic maintenance needed.
- Wide Availability: Mature technology with well-established manufacturing supply chain.
- High Speed Capability: Can operate at very high speeds suitable for direct drive applications.

- Field Weakening: Easily achieves wide constant power range by reducing stator flux.
- Fault Tolerance: Can continue limited operation even with one phase failure.
- No Demagnetization Risk: Unlike PM motors, induction motors cannot be demagnetized.

Limitations / Drawbacks of Induction Motors in EVs:

- Lower Power Density: Larger and heavier than equivalent PM motors; requires more space.
- Lower Efficiency: Copper losses in rotor cage and magnetizing current losses reduce efficiency.
- Complex Control: Requires vector control (Field Oriented Control) for good dynamic performance — computationally intensive.
- Magnetizing Current: Always draws reactive (magnetizing) current, reducing power factor.
- Heat Generation: Rotor heat is difficult to remove, limiting continuous power ratings.
- Reduced Efficiency at Light Load: Motor is less efficient at partial load conditions.
- Torque Ripple: Can exhibit torque ripple at low speeds affecting ride comfort.

7Q: Discuss the working principle and advantages of Brushless DC (BLDC) motors in EV applications. [L2, CO3, 10M]

Answer:

Brushless DC (BLDC) Motor – Construction:

The BLDC motor is a permanent magnet AC machine with trapezoidal back-EMF waveforms. Unlike conventional DC motors, electronic commutation replaces mechanical brushes:

- Stator: Three-phase concentrated windings (similar to induction motor stator)
- Rotor: Permanent magnets (surface mounted or inset); no windings or brushes
- Position Sensor: Hall-effect sensors or encoder detect rotor position for commutation
- Power Electronics: Three-phase inverter (6 IGBTs) provides electronic commutation

Working Principle:

The BLDC motor uses electronic commutation based on rotor position feedback:

- Step 1: Hall sensors continuously detect rotor position (every 60° electrical)
- Step 2: Controller decodes Hall signals → determines which two phases to energize
- Step 3: Inverter switches ON the corresponding IGBTs → current flows in two stator phases
- Step 4: Current-carrying stator windings create magnetic field → interacts with rotor PM field
- Step 5: Lorentz force produces electromagnetic torque → rotor rotates

- Step 6: As rotor moves 60°, Hall sensors change → next phase pair is energized (commutation)

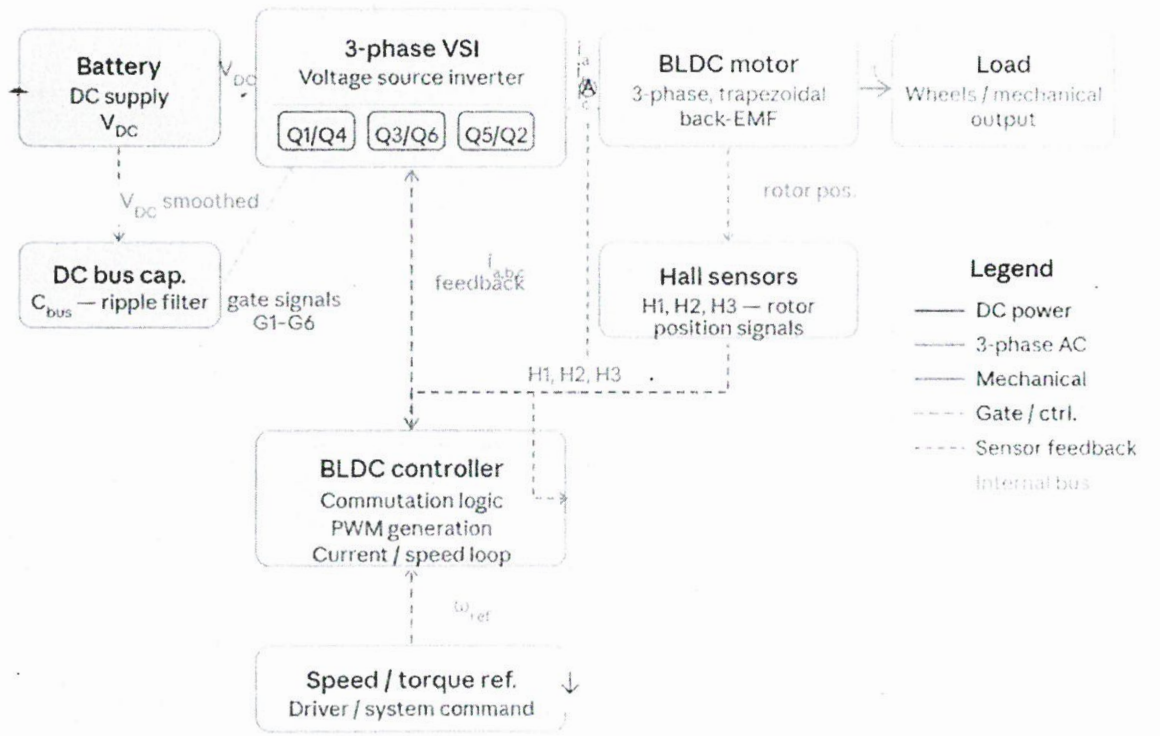
The trapezoidal back-EMF waveform aligns with the square-wave phase currents for maximum torque production. The electromagnetic torque is:

$$T_{em} = \frac{e_a i_a + e_b i_b + e_c i_c}{\omega_r}$$

Where:

- T_{em} = Electromagnetic torque
- e_a, e_b, e_c = Back EMF of phases a, b, c
- i_a, i_b, i_c = Phase currents
- ω_r = Rotor angular speed (rad/s)

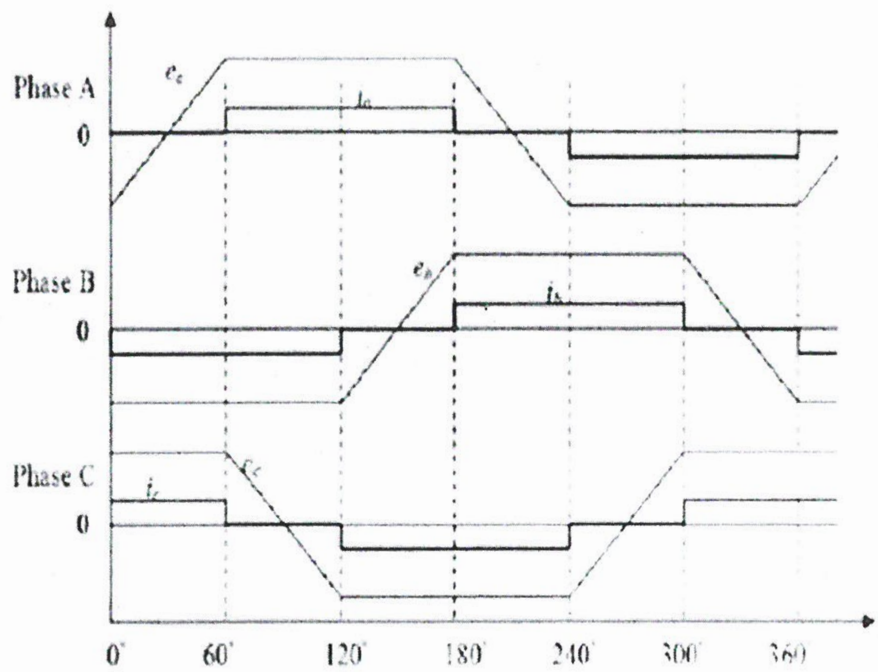
BLDC motor drive — block diagram



<u>Back-EMF and Phase Current Waveforms:</u>

BLDC Trapezoidal Back-EMF and Ideal Phase Currents

Phase A: Back-EMF	Trapezoidal waveform: Flat top for 120°, transitions at 60° boundaries	Period: 360° electrical
Phase A: Current	Square wave aligned with flat top of back-EMF for max torque (120° ON, 60° OFF)	Amplitude = I_DC



Advantages of BLDC Motors in EV Applications:

- High Efficiency: No brush friction losses; PM rotor has no copper losses → 90–95% efficiency
- High Power Density: Rare-earth PM rotor provides high torque-to-weight ratio
- Low Maintenance: No brushes or commutator → minimal wear and maintenance
- Good Speed Control: Wide speed range from zero to high speed with precise electronic control
- Compact Size: Smaller and lighter than equivalent induction or DC motors
- Low Noise: Quieter than brushed DC motors; no commutator sparking
- Long Life: No mechanical commutation wear → extended operational life
- Better Heat Dissipation: Heat generated mainly in stator (easily cooled) rather than rotor
- Regenerative Braking: Easily operates as generator for energy recovery
- Suitable for Hub Motor Design: Can be integrated directly into wheel hub

Limitations:

- Cost: Rare-earth magnets (NdFeB) are expensive, increasing motor cost
- Limited Field Weakening: PM field cannot be reduced easily → limited constant power range
- Torque Ripple: Square-wave current commutation causes torque ripple at low speeds
- Demagnetization Risk: High temperatures or fault currents can demagnetize rotor magnets
- Position Sensor Required: Hall sensors or encoder needed for commutation (adds cost/complexity.

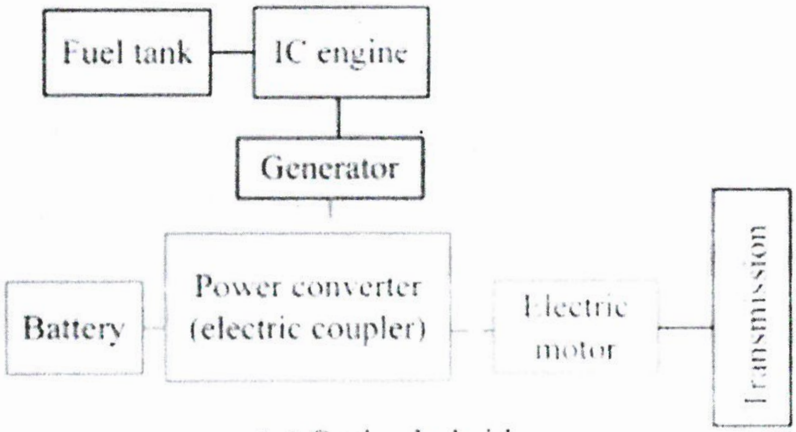
UNIT – IV

Q8(a): Compare Series, Parallel and Complex Hybrid Electric Vehicles. [L3, CO4, 5M]

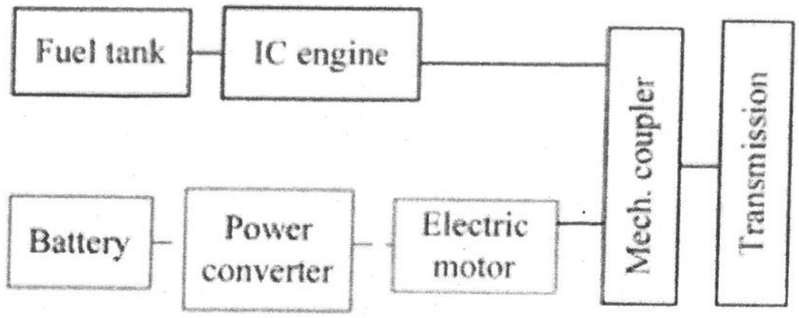
Answer:

Parameter	Series HEV	Parallel HEV	Series-Parallel (Complex) HEV
Power to wheels	Only from electric motor	Engine + Motor jointly	Both paths possible
Engine coupling	Not mechanically linked to wheels	Directly linked via transmission	Linked + electrical path
No. of propulsion	3 (Engine, Generator,	2 (Engine + Motor/Gen)	3+ with powersplit

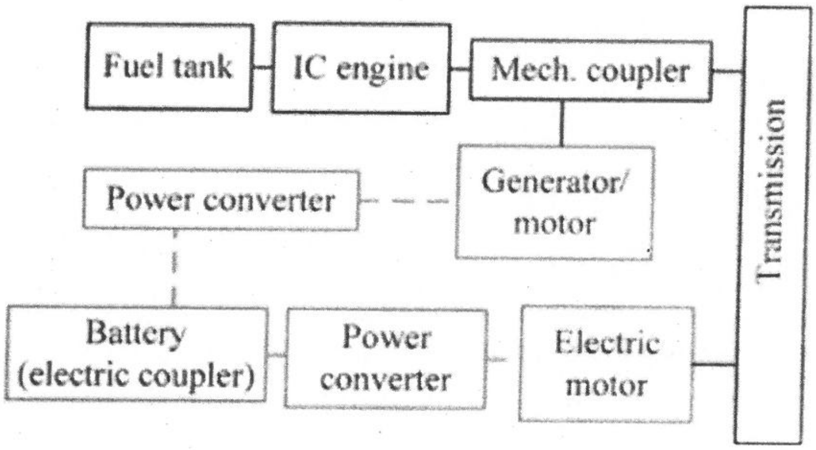
devices	Motor)		
Engine efficiency	Always at optimal point	Varies with road load	Optimal via control
Motor size	Large (full vehicle power)	Smaller (partial power)	Medium
Battery size	Larger	Smaller	Medium
Best for	City driving, stop-go	Highway/mixed driving	All conditions
Example	Chevy Volt (Range Extender)	Honda Accord Hybrid	Toyota Prius (THS)
Fuel Efficiency	Good for city	Good for highway	Excellent overall
Control complexity	Moderate	High (torque blending)	Very high



(a) Series hybrid



(b) Parallel hybridD



(d) Complex hybrid

Q8(b): Discuss the advantages and disadvantages of Hybrid Electric Vehicles. [L2, CO4, 5M]

Answer:

Advantages of Hybrid Electric Vehicles (HEVs):

- Improved Fuel Economy: IC engine operates at its most efficient operating point; electric motor handles peaks → 30–50% better mileage than ICEV.
- Reduced Emissions: Downsized engine + electric assist → significantly lower CO_2, NO_x and HC emissions.
- Regenerative Braking: Recovers kinetic energy during deceleration to recharge battery → further efficiency gain.
- No Range Anxiety: IC engine provides unlimited range; battery acts as a buffer — no charging infrastructure needed (for non-PHEV).

- Engine Downsizing: Smaller engine (lower displacement) needed, reducing cost and emissions.
- Auto Stop-Start: Engine shuts off at idle (traffic lights) → zero idle consumption.
- Better Torque: Electric motor supplements IC engine torque → improved acceleration and performance.
- Grid Independence: Charge-sustaining HEVs do not require external charging infrastructure.
- Reduced Brake Wear: Regenerative braking reduces mechanical brake usage → longer brake life.

Disadvantages of Hybrid Electric Vehicles:

- Higher Initial Cost: Additional components (motor, inverter, battery, generator) increase vehicle price by 15–30%.
- Complex Powertrain: Two separate power systems (electrical + mechanical) increase design and manufacturing complexity.
- Heavier Weight: Extra battery, motor, and power electronics add significant mass (50–150 kg), affecting handling.
- Battery Replacement Cost: Hybrid batteries have limited life (8–10 years) and replacement is expensive.
- Not Zero Emission: Still uses IC engine; cannot achieve zero emission like pure BEVs.
- Limited Electric Range: Non-PHEVs have small batteries → cannot run long distances on electricity alone.
- Complex Control Algorithms: Supervisory control must coordinate two power sources optimally — complex software needed.
- Maintenance: Though electric parts need less maintenance, the IC engine still requires regular servicing.

9Q: Illustrate the operation of the Hybrid Electric Vehicle architecture in detail. [L4, CO4, 10M]

Answer:

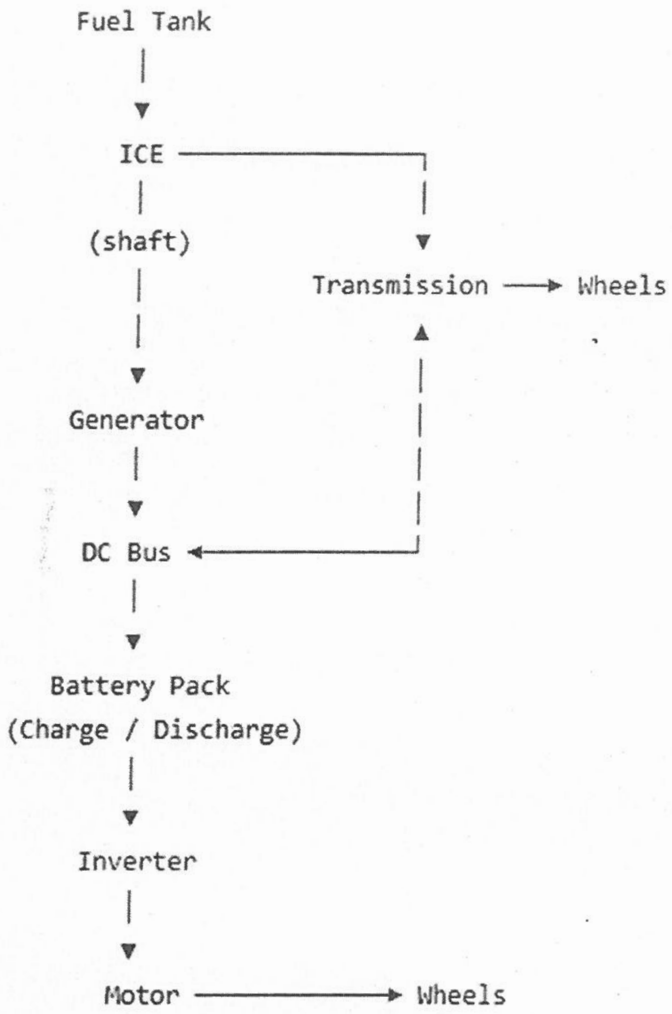
A **Hybrid Electric Vehicle (HEV)** combines an **Internal Combustion Engine (ICE)** with an **electric propulsion system** to improve fuel efficiency and reduce emissions. The system intelligently switches between or combines both power sources.

Operation of HEV

1. Start / Low-Speed Operation (Electric Mode)

- ICE is OFF
- Battery supplies power to motor
- Motor drives the wheels
- Zero fuel consumption and emissions

Basic HEV Architecture



2. Normal Driving (Hybrid Mode)

- Both **ICE and motor** operate together
- ICE provides main power
- Motor assists during acceleration
- Improves efficiency and performance

3. High-Speed Operation (Engine Mode)

- ICE alone drives the vehicle
- Motor may remain OFF or assist slightly
- Suitable for highways

4. Acceleration Mode

- Both engine and motor provide torque

- Gives **high power output**
- Reduces load on engine

5. Regenerative Braking Mode

- Motor acts as **generator**
- Converts kinetic energy → electrical energy
- Charges the battery

6. Battery Charging Mode

- Generator converts mechanical energy from ICE → electrical energy
- Charges battery while driving

Types of HEV Architectures

- **Series HEV:** Engine → Generator → Motor → Wheels
- **Parallel HEV:** Engine + Motor → Wheels
- **Series-Parallel (Complex):** Combination of both

Advantages of HEV

- Improved fuel efficiency
- Reduced emissions
- Energy recovery (regenerative braking)
- Better performance

UNIT – V

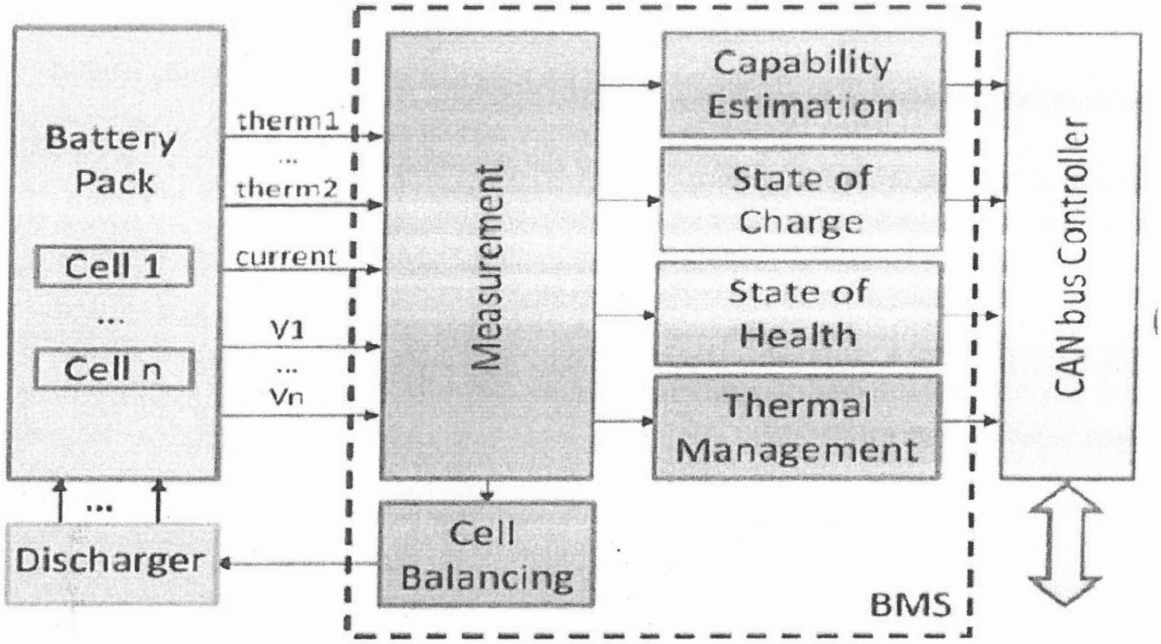
10Q: Analyze the working and importance of a Battery Management System (BMS). [L5, CO5, 10M]

Answer:

Introduction to Battery Management System (BMS):

The Battery Management System (BMS) is a critical electronic system in EVs and HEVs that monitors, controls, and protects the battery pack. It ensures safe, efficient, and reliable operation of the energy storage system throughout its service life.

BMS Architecture Block Diagram:



BMS block diagram STATE OF CHARGE ESTIMATION:

BMS Operational Flow:

Fig. 10.2 – BMS Operational Cycle

Key ON Initialization (Self-discharge check)	→	**Sample: Cell V, T Ch/Disch I**	→	**Estimate SoC & Update SoH**	→	**Calculate Power Limits & Equal. Commands**	→	**Report to VSC Store Data**

Key Functions of BMS:

1. State of Charge (SoC) Estimation:

- SoC = (Available capacity / Rated capacity) × 100%
- Methods: Voltage-based, Coulomb counting (current integration), Kalman Filter observer-based
- SoC guides powertrain control — avoids deep discharge and overcharge

2. State of Health (SoH) Monitoring:

- SoH compares current capacity/resistance to original specification
- Detects cell aging, capacity fade, and abnormal self-discharge
- Alerts VSC when battery needs replacement or reconditioning

3. Temperature Management:

- Monitors individual cell temperatures; detects thermal hotspots
- Controls cooling fans, liquid cooling pumps to prevent thermal runaway
- Temperature imbalance causes SoC imbalance — must be minimized

4. Charge/Discharge Power Control:

- Sets maximum charge power (P_chg_max) and discharge power (P_dchg_max) limits
- Reported to VSC for motor torque limiting and regenerative braking control

5. Cell Equalization (Balancing):

- Detects voltage mismatch between cells in series string
- Active balancing: Energy transferred from high SoC cells to low SoC cells
- Passive balancing: Excess energy dissipated as heat through shunt resistors

6. Data Logging:

- Records V, I, T, SoC, cycle count as function of time
- Used for diagnostics, warranty claims, and SoH trend analysis

7. Protection Functions:

- Over-voltage protection: Disconnects circuit if cell V > V_max
- Under-voltage protection: Prevents discharge below V_min
- Over-current protection: Opens contactors on short circuit / overcurrent
- Over-temperature protection: Triggers cooling or load reduction

Levels of Battery Management:

- Pack Level Management: Monitors overall pack voltage and SoC — basic protection only
- Module Level Management: Monitors groups of cells — better equalization capability
- Cell Level Management: Monitors individual cells — most complete protection, highest cost

Importance of BMS in EVs:

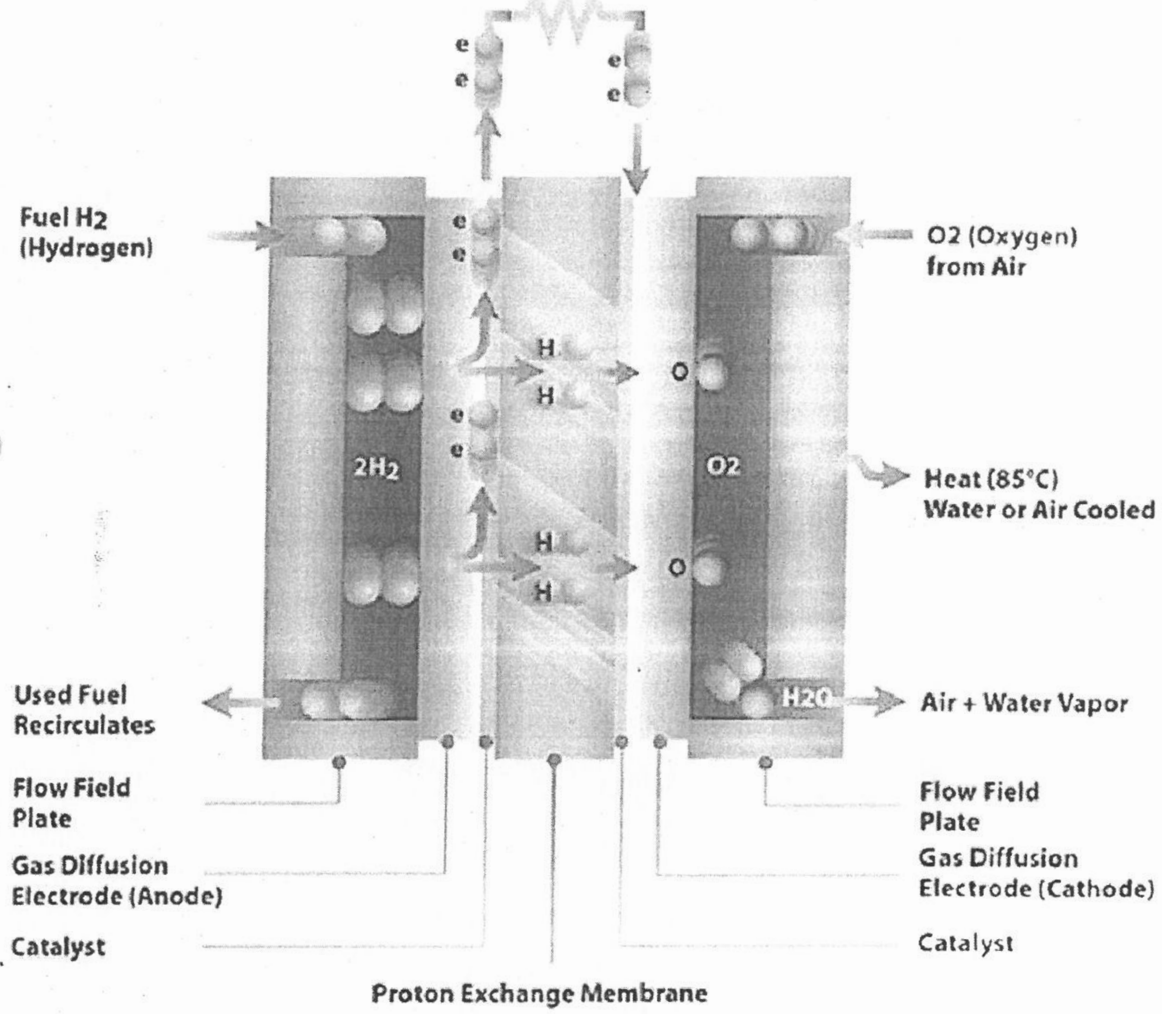
- Safety: Prevents catastrophic failures like thermal runaway (Li-ion battery fire)
- Range Optimization: Accurate SoC enables full usable capacity without damage
- Battery Longevity: Prevents abuse conditions → extends battery life from 5 to 10+ years
- Performance: Delivers maximum power when needed; protects during sustained operation
- Cost Reduction: Early detection of cell failures avoids costly complete battery replacement

11Q: Explain the construction and working of hydrogen fuel cells used in EVs. [L2, CO5, 10M]

Answer:

A fuel cell is an electrochemical energy converter that directly converts chemical energy of hydrogen fuel into electrical energy without combustion. It operates like a battery but is continuously refueled. The Proton Exchange Membrane (PEM) fuel cell is the type used in electric vehicles.

PEM Fuel Cell – Construction:



Key Components of PEM Fuel Cell:

- Membrane Electrode Assembly (MEA): Core component — Nafion® polymer membrane sandwiched between two catalyst-coated electrodes
- Anode Electrode: Platinum catalyst coated on carbon paper; H_2 oxidation occurs here
- Cathode Electrode: Platinum catalyst; O_2 reduction and water formation occur here
- Gas Diffusion Layer (GDL): Porous carbon fiber layer distributes fuel and air uniformly to catalyst
- Bipolar Plates: Graphite/stainless steel plates with flow channels for fuel and coolant; current collectors
- Cooling System: Water/glycol coolant circulates between plates to maintain ~80°C operating temperature

Chemical Reactions in PEM Fuel Cell:

Anode reaction (Oxidation):

$H_2 \rightarrow 2H^+ + 2e^-$

Cathode reaction (Reduction):

$\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O$

Overall cell reaction:

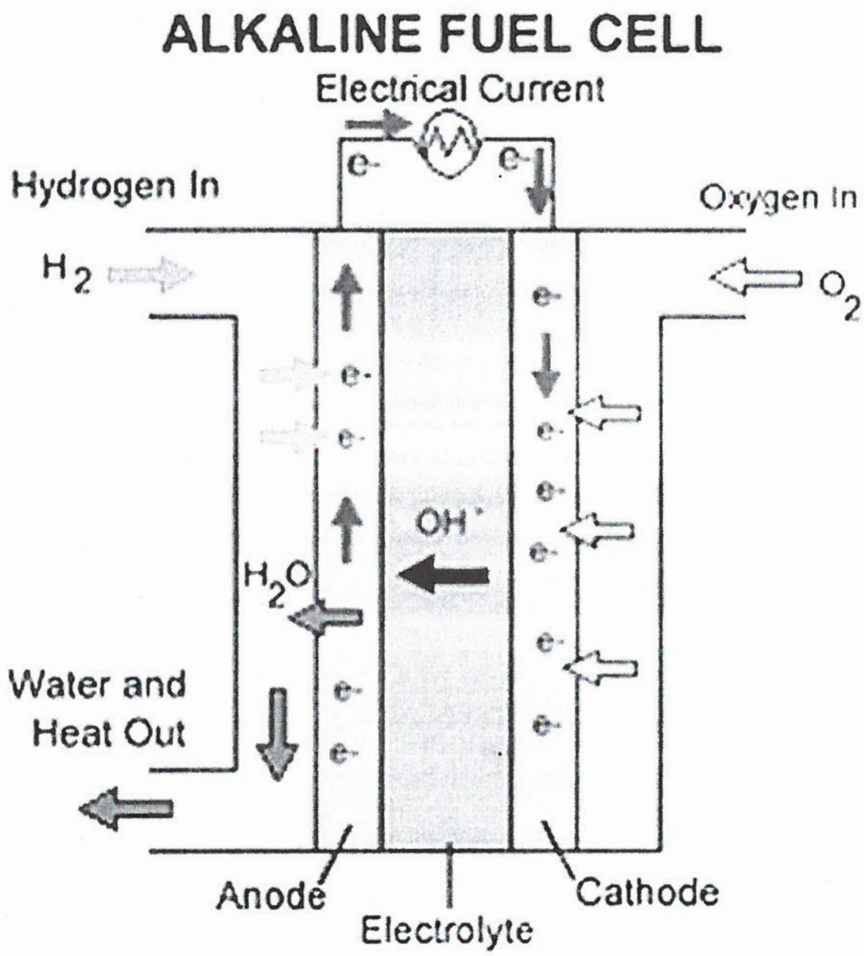
$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$ + Electrical Energy + Heat

Theoretical open-circuit voltage: $E_0 = 1.23$ V (at standard conditions)

Practical cell voltage: 0.6 – 0.8 V (due to activation, ohmic, and concentration losses)

Alkaline Fuel Cell (AFC)

An **Alkaline Fuel Cell (AFC)** is a type of fuel cell that uses an **alkaline electrolyte** (usually potassium hydroxide – KOH) to convert **hydrogen and oxygen into electricity**, with **water and heat** as by-products.



Main Components:

1. Anode (–)

- Hydrogen gas (H_2) is supplied
- Oxidation reaction occurs

2. Cathode (+)

- Oxygen (O_2) or air is supplied
- Reduction reaction occurs

3. Electrolyte

- **Potassium Hydroxide (KOH) solution**
- Conducts **hydroxyl ions (OH^-)**

4. Catalyst

- Usually nickel or platinum
- Speeds up chemical reactions

5. External Circuit

- Electrons flow through this → produces electricity

3. Working Principle

At Anode (Oxidation):

$$H_2 + 2OH^- \rightarrow 2H_2O + 2e^-$$

- Hydrogen reacts with hydroxyl ions
- Produces water and electrons

At Cathode (Reduction):

$$\frac{1}{2}O_2 + H_2O + 2e^- \rightarrow 2OH^-$$

- Oxygen reacts with water and electrons
- Produces hydroxyl ions

Overall Reaction:

$$2H_2 + O_2 \rightarrow 2H_2O + Energy$$