The Shirpur Education Society's
R. C. Patel College of Engineering and Polytechnic, Shirpur
Department of Electrical Engineering

NOTES

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Course Abbr.: EVT

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Subject Teacher :- Ms. H.A.Badgujar

UNIT-03 – (16 MARKS)

BATTERIES AND ENERGY STORAGE SYSTEMS

CO Coverage: - Test the performance of batteries and energy storage systems used for EV applications.

Content (Syllabus)

3.1 Energy storage technology: EV Batteries, Super capacitors, flywheel energy storage. Battery Parameters: Cell and Battery Voltages, Charge (or Amp hour) Capacity, Energy Stored, Specific Energy, Energy Density, Specific Power, Amp hour (or Charge) Efficiency, Energy Efficiency, Self-discharge Rates, Battery Geometry, Battery Temperature, Heating and Cooling Needs, Battery Life and Number of Deep Cycles.

3.2 Batteries: Lead-acid, NiMH (Nickel-Metal Hydride), Li-Ion (Lithium-Ion), Ni-Zn (Nickel-Zinc), Ni-Cd (Nickel-Cadmium), Aluminum–Ion batteries (Al–Ion batteries), Aluminum–air batteries (Al–air batteries)- their basic construction components, life time (cycles), efficiency, advantages and disadvantages. Comparison of various batteries. Factors influencing the operation of battery, and selection of battery. Series and Parallel connection of Batteries, Calculation of battery capacity.

3.3 Battery Management Systems (BMS): Need of BMS, Block diagram of BMS, function of each block, Battery Condition Monitoring, "3R" (Reduce, Reuse, Recycle) process for battery.

3.4 Fuel Cell: Difference between fuel cell and batteries, Fuel Cell Terminology: Anode, Cathode, Electrolyte, Catalyst, Reformer, Direct Fuel Cell, Working principle of fuel cell. Types of Fuel Cells used in EVs: Alkaline Fuel Cell (AFC), Polymer Electrolyte Membrane Fuel Cell (PEMFC), Phosphoric Acid Fuel Cell (PAFC), Molten Carbonate Fuel Cell (MCFC), Solid Oxide Fuel cell (SOFC), Their comparison on the basis of Electrolyte type, Cell voltage, Operating temperature, System output (kW), Efficiency (%) and Applications.

3.1 Energy storage technology :-

* EV Batteries :- Energy storage technology in electric vehicles is essential for storing and supplying power to the electric motor, ensuring smooth and efficient vehicle operation. The performance, driving range, and reliability of an EV largely depends on how efficiently energy is stored and managed.

Three types of energy storage technologies are commonly used in EV's:

1) Batteries
2) Super Capacitors.
3) Flywheel Energy storage system.

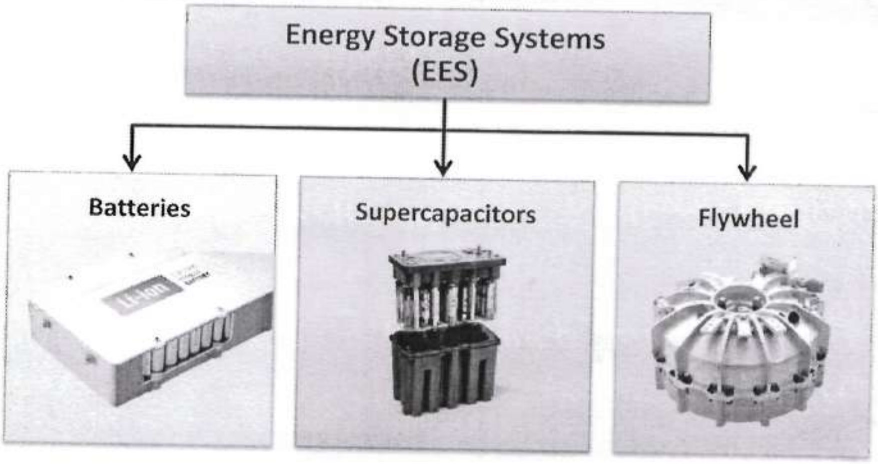

Fig. No. 3.1.1 Energy Storage Technology

* EV Batteries :-> EV batteries store energy in the form of chemical energy and convert it into electrical energy to power the electric motor.

→ During charging or regenerative braking, the batteries absorb electrical energy and store it again as chemical energy for future use.

→ There types of EV batteries :-

1) Lithium Ion Batteries
2) Nickel-metal Hydride
3) Lead Acid Batteries
4) Aluminium Air
5) Aluminium Ion.

→ Advantages :-

1) High energy storage capacity for long driving range.
2) Rechargeable and Reliable.

3) Produces less noise.

* Disadvantages :

1) Requires long charging time.
2) High temperatures reduce battery performance.
3) Battery replacement is expensive.

* Applications :- Primary power source for electric cars, motor cycles, buses and trucks.

* Super Capacitors *

→ Super Capacitors or Ultra Capacitors are large capacitors which can be used as energy stores.
→ Super Capacitors store energy through electric fields rather than chemical reactions.
→ In EV's, they can rapidly deliver or absorb energy during acceleration and braking, making them ideal for high power applications.

* Types :- 1) Electrochemical double layer capacitors (EDLC's)
2) Hybrid capacitors.

* Advantages :- 1) Fast charging and discharging.
2) Long service life
3) Ideal for rapid & instant power demand.

* Disadvantages :- 1) Low energy storage capacity.
2) Can not be used alone to power an EV over long driving distances.

* Applications :- 1) Regenerative braking system.
2) Supporting the battery during sudden acceleration.
3) Handling short-term high power loads, thereby extending battery life.

* Flywheel Energy Storage *

→ Flywheel Energy Storage systems store energy by spinning a rotor at very high speeds.
→ In EV's, the stored kinetic energy is rapidly released whenever the vehicle requires a sudden increase in power

such as during acceleration.

* Types :- 1) Mechanical flywheels.
  2) Advanced flywheels with magnetic bearings.

* Advantages :- 1) Rapid Energy delivery for high power applications.
  2) Long operational life with low maintenance requirement.
  3) Suitable for short duration, high power demands.

* Disadvantages :- 1) Large and heavy, making them unsuitable for small EV's
  2) High Cost and safety Concerns due to operation at very high rotational speeds.

* Applications :- 1) Used in High performance and hybrid electric vehicles.
  2) Energy recovery during regenerative braking.
  3) Power assistance during rapid acceleration.

3.1.1 Battery Parameters :-

1) Cell Voltage :- Cell voltage is the electric potential difference between the positive and negative terminals of a battery cell. For lithium ion cells, the typical cell voltage range from 3.6 to 3.7 V, which is commonly used in electric vehicles.

2) Battery Voltage :- Battery voltage is a total voltage of an EV-battery pack, obtained by connecting multiple battery cells in series. In most electric vehicles, the battery pack voltage typically ranges from 300V to 400V.

3) Charge Capacity (Ampere-Ah) :- Charge capacity is also known as Ampere-hour (Ah) capacity, indicates the amount of electric charge a battery can deliver over a period of time. It is measured in Ampere-hours (Ah). A battery with a higher charge capacity can provide a longer driving range on a single charge.

4) Energy Stored :- Energy stored is the total amount of electrical ~~power~~ energy available in a battery. It is calculated

by multiplying the battery voltage (v) by it's Ampere-hour (Ah) capacity. It is expressed in Watt-hour (wh) or kilowatt-hours (kwh).

Formula = Energy (wh) = Voltage(v) × Capacity (Ah).

5) Specific energy :- specific energy is the amount of energy stored per unit mass of a battery. It is measured in watt-hours per kilogram (wh/kg). It indicates how much energy a battery can store relative to it's weight.

→ A higher specific energy results in a lighter battery for the same ~~sen~~ energy capacity.

6) Energy Density :- Energy Density is the amount of energy stored per unit volume of a battery. It is measured in watt-hours per litre (wh/L). It determines how compact a battery can be while storing a given amount of energy.

→ Higher ~~e~~ energy density allows for smaller and more compact battery packs.

7) Specific Power :- Specific power is the rate at which a battery can deliver energy per unit mass. It is measured in watts per kilogram (w/kg). It directly affects the acceleratn, power output, and overall performance of an electrical vehicle.

→ A battery with higher specific power can supply energy more quickly, resulting in better vehicle performance.

8) Ampere-hour (or Charge) Efficiency :-

Ampere-hour efficiency is also known as charge efficiency, is the ratio of ~~of~~ the charge obtained during discharge to the charge supplied during charging.

9) Energy Efficiency :- Energy efficiency is the ratio of the output energy delivered during discharge to the input energy supplied during charging.

→ It indicates how much energy is lost, mainly as heat, during the charging-discharging cycle.

10) Self discharge rate :- Self discharge rate is the rate at which a battery gradually loses it's stored energy when it is not in use. It is usually expressed as a percentage (% per month).
→ A lower self discharge rate helps maintain the battery's charge, readiness and storage capability for long periods.

11) Battery Geometry :→ Battery geometry refers to the physical shape, size and arrangement of battery cells within a battery pack.
→ It influences space utilization, structural design, thermal management. and cooling efficiency in an electric vehicle.

12) Battery Temperature :- Battery temperature is the operating temperature of a battery during charging, discharging, and normal use.
→ maintaining an optimal operating temperature is essential for ensuring battery safety, performance, efficiency and service life.

13) Heating and Cooling Needs :→ Heating and cooling needs refer to the thermal management systems, used to maintain the battery temperature within it's optimum operating range.
→ Proper thermal management improves battery performance, efficiency, safety and lifespan, while preventing thermal damage and overheating.

14) Battery life :→ Battery life is the total operating hours or no. of charge-discharge cycles during which a battery performs effectively before it's capacity decreases significantly. Battery life directly affects the long term performance, reliability and operating cost of an electric vehicles.

15) No. of Deep Cycles :- No. of deep cycles refers to the no. of times a battery can be fully charged and deeply discharged before it's capacity begins to decline significantly.
→ It is an important parameter for evaluating the durability, reliability and service life of an EV battery.

3.2 - Batteries

Introduction of Batteries :- Electro chemical batteries convert electrical energy into chemical energy during charging and vice versa during discharging.

→ Comprising one or more electrochemical cells, each cells includes two electrodes (anode and cathode) and an electrolyte.

→ Battery operation relies on redox reactions; during discharge, electrons flow from the anode to the cathode, generating electric current, while ions travel through the electrolyte to maintain charge balance.

→ Charging reverses this process, coverting electrical energy back into chemical energy for storage.

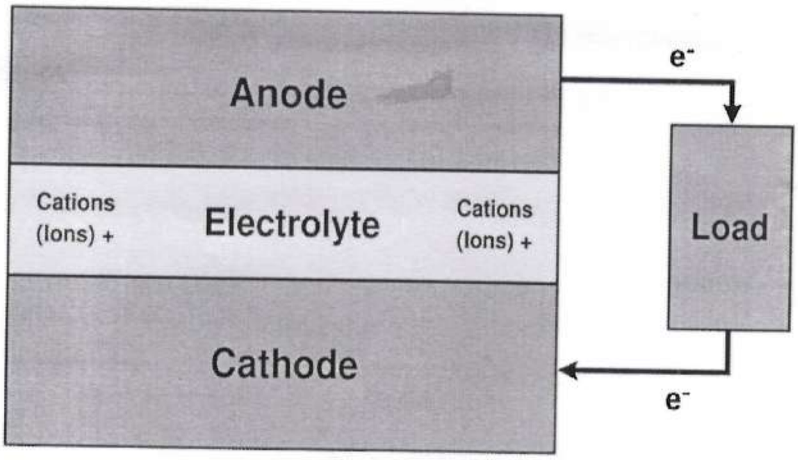

Fig. No. 3.2.1: Typical construction of a battery

3.2.1 - Lead Acid Battery :-

A lead Acid battery is one of the oldest and most widely used rechargeable battery technologies.

→ It uses lead plates and sulphuric acid as the electrolyte to store and deliver electrical energy.

→ Lead acid batteries are low cost, reliable and capable of supplying high surge currents, making them suitable for many automotive and industrial applications.

→ However, they have low energy density, are heavier, require more maintainance, and have shorter service life compared to modern battery technologies such as lithium ion batteries.

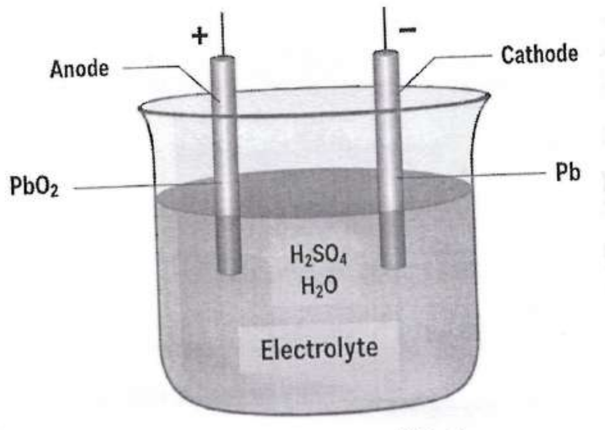

Fig. No. 3.2.2.1: Lead-Acid Battery

→ In electric vehicles (EV's), lead acid batteries are mainly used in low speed vehicles or as auxiliary power sources for operating low voltage electrical systems (such as lighting, control circuits and accesories) rather than as the main traction battery pack due to their lower energy storage capacity and higher weight.

→ Lead Acid batteries are economical, reliable and recyclable, but their low energy density, shorter lifespan (typically 300-500 cycles) and lower efficiency (70-85%) make them less suitable for modern long range EV's, where lithium ion batteries are preferred.

* Advantages :-

1) Low initial cost compared to other rechargeable batteries.
2) Simple charging system.
3) Highly recyclable, 795% material recovered.
4) Widely available and easy to replace.

* Disadvantages :-

1) Lower energy density
2) shorter cycle life.
3) Lower charging & energy efficiency.
4) Requires regular maintenance.

* Applications :- 1) Electric Rikshaws.
2) low speed electric vehicles.
3) Solar energy storage system.
4) Emergency lighting.

3.2.2 – NiMH (Nickel metal Hydride) Battery :-

→ A Nickel Metal Hydride (NiMH) battery is a rechargeable battery that uses a hydrogen-absorbing alloy as the negative electrode (~~anode~~) and nickel oxide hydroxide (NiOOH) as the positive electrode.

→ NiMH batteries provide higher energy density and longer service life than lead acid batteries.

→ They are also more durable and safer than Lithium-ion (Li-ion) batteries.

→ Hoever, they are heavier and have a higher self discharge rate compared to li-ion batteries.

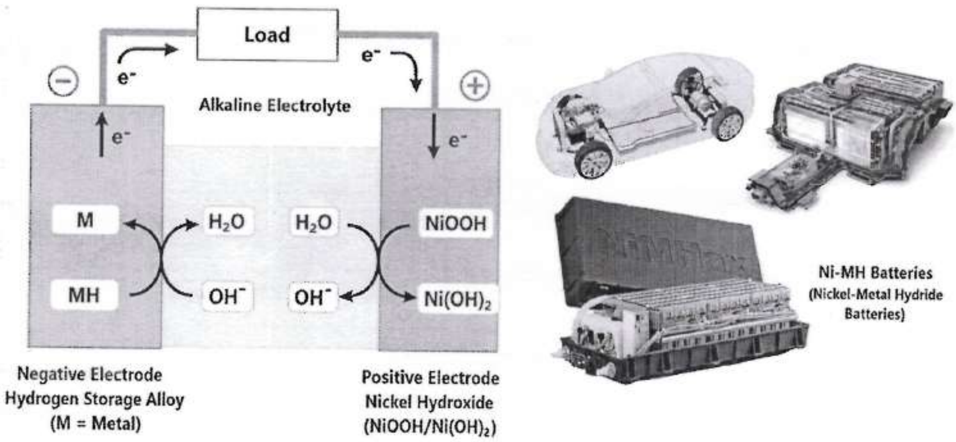

Fig. No. 3.2.2.2 Nickel-Metal Hydride (NiMH) battery

→ NiMH batteries are commonly used in Hybrid electric vehicles, such as Toyota Prius, due to their reliability, safety and long cycle life.

* Advantages :-

1) Higher energy density than lead acid battery
2) Longer cycle life and better durability.
3) Safer than lithium ion batteries
4) Good high current performance.
5) Reliable & proven technology.

* Disadvantage :-

1) Lower energy density than lithium ion batteries.
2) Higher self discharge rate.
3) Generate more heat during charging and discharging.
4) More expensive than lead acid batteries.

→ NiMH batteries have good life cycle (500-1000 cycles) and charge efficiency is 80-90%.

* Applications :- 1) Hybrid Electric Vehicles i.e Toyota Prius.
2) Cordless power tools.
3) Digital Cameras.
4) Medical devices.

3.2.3 - Lithium-Ion (Li-ion) Battery :→

→ Lithium ion batteries are the most widely used batteries in modern electric vehicles, because they have high energy density, lightweight design, and long life cycle.

→ These batteries use lithium compounds as the electrolyte and provide efficient charging, low self discharge and good performance

→ However they are sensitive to temperature and require a battery management system (BMS) for safe operation.

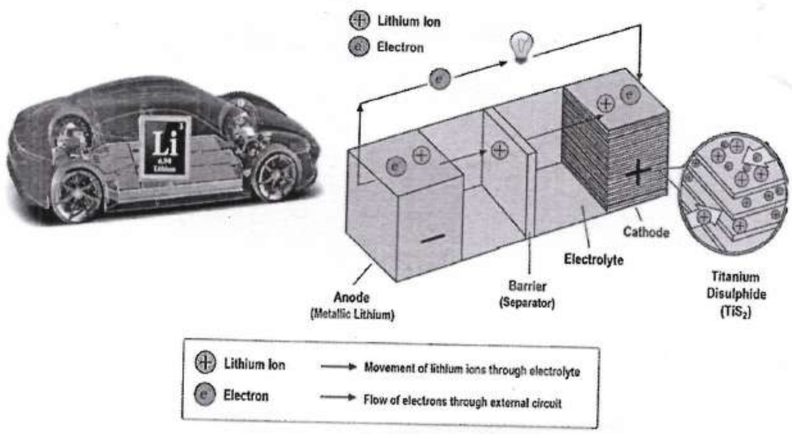

Fig. No. 3.2.2.3: Lithium-ion (Li-ion) battery

→ Tesla, BYD and most other EV manufacturer rely on Li-ion battery technology.

→ Typical lifecycle - 1000 - 3000 charge discharge cycle. (depending on battery chemistry and operating conditions.

→ charging efficiency is 95-99%.

* Advantages :-

1) High energy density, allowing more energy storage in a compact size.
2) Light weight compared to Lead Acid and NiMH batteries.
3) Long cycle life with proper battery management.
4) fast charging capability.

* Disadvantages :

1) Higher initial cost than Lead-Acid batteries.
2) Requires BMS for safe operation.
3) Recycling is complex than Lead-Acid.

* Applications :-

1) Battery Electric Vehicles (BEV's)
2) Plug in hybrid Electric Vehicles (PHEV)
3) Electric bycycles and scooters.
4) Energy storage systems.

3.2.4 Nickel-Zinc (Ni-Zn) battery :-

→ Nickel zinc batteries use a zinc electrode as the negative electrode and Nickel oxide as the active material for the +ve electrode

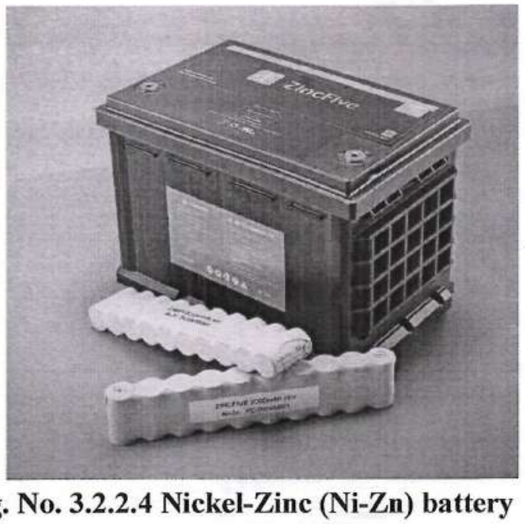

Fig. No. 3.2.2.4 Nickel-Zinc (Ni-Zn) battery

→ These batteries offer higher energy density and higher power density than Nickel-Metal Hydride (NiMH) batteries and are considered safer than lithium Ion (Li-ion) batteries.
→ They are also non-toxic and environmentally friendly.
→ However, due to limitations in cycle life and stability, Ni-Zn

batteries are still under developement and are not yet widely used in large scale in ~~ev~~ ~~a~~ ev applications.

→ Typical life cycle is 300-800 charge-discharge cycles (depending on depth of discharge and operating conditions)

→ Charging efficiency is 85-90%..

* Advantages :-

1) Higher energy density than Nickel Cadmium and Nickel metal Hydride, batteries.
2) Higher cell voltage.
3) Fast charging capability.
4) Good safety characteristics
5) Lower cost than many lithium-ion batteries system.

* Disadvantages :-

1) Shorter life cycle.
2) Higher self discharge rate.
3) Limited commercial availability.
4) Performance degrades under deep discharge conditions.

* Applications :-

1) Electric scooters.
2) Power tools.
3) medical devices.
4) military and industrial portable equipments.

3.2.5 - Nickel Cadmium battery (Ni-cd) :→

→ Nickel cadmium batteries use Nickel oxide hydroxide as the positive electrode and metalic cadmium as negative electrode.

Fig. No. 3.2.2.5: Nickel-Cadmium (Ni-Cd

→ The batteries are rugged, can withstand high temperatures, and tolerate deep discharge.

→ However, they suffer from memory effect, have low energy density and contain toxic cadmium, which raise environmental concerns.

→ Due to these drawbacks, Nickel-Cadmium batteries are rarely used in modern electric vehicles.

→ Typical lif cycle is 1000-2000 charge-discharge cycles.

→ Charging efficiency is 70-90%.

* Advantages :-

1) Long Life and excellent durability.
2) High power output.
3) fast charging capability
4) Rugged and reliable for demanding industrial applications.

* Disadvantages :-

1) Contains toxic cadmium, making disposal and recycling challenging.
2) Higher self discharge rate than lithium-ion batteries.
3) Use is restricted in many Countries.
4) Heavier than lithium ion batteries.

* Applications :-

1) Emergency Lighting system.
2) Railway Signaling system.
3) medical Equipment.
4) military Communication equipment.

3.2.6 → Aluminium - Ion Battery :-

→ Aluminium-Ion Batteries use aluminium as the anode and graphite or carbon based materials as the cathode.

→ These batteries offer fast charging capabilities, high safety, and are more environmentally friendly than li-ion batteries.

→ Although Al-ion batteries are still in the research and developement stage, their high conductivity and long cycle life make them a promising technology for future electric vehicle applications.

→ Typical life cycle is 5000-10000+ Charge discharge cycles.

→ Charging efficiency is 90-98%.

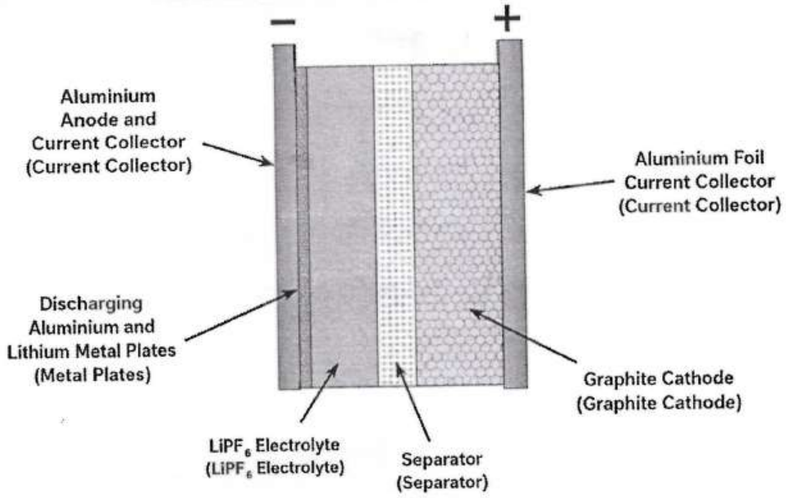

Fig. No. 3.2.2.6: Aluminium-ion (Al-Ion) battery

* Advantages :-

1) Very long life cycles as compared to other rechargeable batteries.
2) Fast charging capability.
3) Better safety with a lower risk of thermal runaway.
4) Environment friendly and easier to recycle than many lithium based batteries.
5) Good thermal stability and reduced fire risk.

* Disadvantages :-

1) Still under research and not widely available commercially.
2) Lower operating voltage than Lithium-Ion batteries.
3) Limited commercial manufacturing.

* Applications :-

1) Electric vehicles (future Applications)
2) Portable electronics.
3) Renewable energy storage.
4) Aerospace and defence system.

3.2.7 :-> Aluminium Air battery :->

→ Aluminium air batteries generate electrical energy through the electrochemical reaction between aluminium and oxygen from the air.

→ These batteries are light weight and offer very high energy density, enabling electric vehicles (EVs) to achieve long driving ranges.
→ However, they are not conventionally rechargeable and requires ~~the~~ the replacement of aluminium plates after use.
→ Therefore, Aluminium - Air batteries are more suitable for range extension rather than serving as the primary battery in electric vehicles.

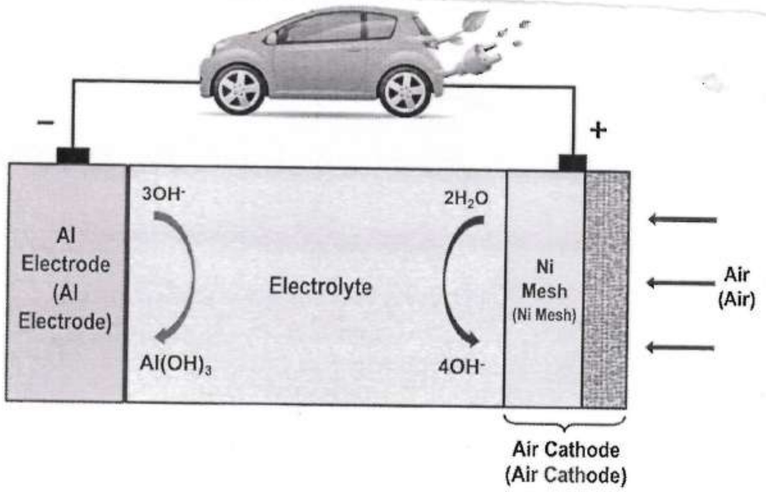

Fig. No. 3.2.2.7: Aluminium-air (Al-Air) Battery

* Advantages :- 1) Lightweight due use of atmospheric oxygen.
2) Aluminium is abundant, inexepensive and reccyclable.
3) Suitable for long range applications.
4) Low risk of fire and thermal runaway.

* Disadvantage :-
1) Non rechargeable by conventional electrical charging.
2) Electrolyte maintenance or replacement is required.
3) Limited commercial vailability.

* Applications :- 1) Long range electric vehicles.
2) Emergency backup power system.
3) military defence equipments.
4) marine and underwater applications.

→ No cycle life (Non rechargeable battery) operates untill the aluminium anode is completely consumed.
→ Electrical efficiency is 50-70%.

Table 3.2.3: Summary of Comparison of Different Types of Batteries Used for Electric Vehicles

Battery Type	Basic Construction	Lifetime (Cycles)	Efficiency (%)	Advantages	Disadvantages
Lead-Acid	**Negative active material:** Spongy lead (Pb) **Positive active material:** Lead oxide (PbO_2) **Electrolyte:** Dilute sulphuric acid (H_2SO_4)	300–500	70–80	Low cost, reliable, recyclable	Heavy, low energy density, short life
Ni-MH (Nickel-Metal Hydride)	**Electrolyte:** Alkaline solution **Positive electrode:** Nickel oxyhydroxide (NiOOH) **Negative electrode:** Hydrogen-absorbing alloy (nickel, titanium, vanadium and other metals)	500–1000	65–70	Safer than Li-ion, durable, tolerant to overcharging	Heavy, high self-discharge, memory effect
Li-Ion (Lithium-Ion)	**Positive electrode:** Lithium metal oxide (commonly lithium cobalt oxide or similar materials) **Negative electrode:** Graphite (carbon) **Electrolyte:** Lithium salt solution in an organic solvent	1000–2000+	90–95	High energy density, lightweight, long life	Expensive, temperature sensitive, requires Battery Management System (BMS)
Ni-Zn (Nickel-Zinc)	**Positive electrode:** Nickel oxyhydroxide **Negative electrode:** Zinc **Aqueous electrolyte**	500–1000 (developing)	80–85	Non-toxic, higher voltage, eco-friendly	Limited commercial use, shorter cycle life under load
Ni-Cd (Nickel-Cadmium)	**Positive electrode:** Nickel oxyhydroxide **Negative electrode:** Cadmium **Electrolyte:** Alkaline electrolyte	1000+	70–80	Durable, performs well under extreme conditions	Toxic (cadmium), memory effect, not eco-friendly
Al-Air (Aluminium-Air)	**Anode:** Aluminium **Cathode:** Ambient air (oxygen) **Electrolyte:** Water-based electrolyte	Single use	50–60	Very high energy density, lightweight	Not rechargeable, requires metal replacement
Al-Graphite	**Anode:** Aluminium **Cathode:** Graphite (carbon) **Electrolyte:** Ionic liquid electrolyte	1000–7000 (estimated)	85–95	High safety, potentially low cost, fast charging	Still under research, lower energy density than Li-ion

* Factors infuencing the operation of battery :-

1) Temperature :- The efficiency and lifespan of a battery depend on temperature.

2) Discharge rate :- A high discharge rate increases heat generation and reduces the usable battery capacity, which can shorten the battery's overall lifespan.

3) Charge rate :- High speed charging without proper battery management can accelerate battery degradation, whereas slow and controlled charging helps maintain battery health and extends it's service life.

4) Depth of Discharge (DoD) :- Frequently discharging a battery to very low levels reduces it's overall cycle life.

5) Cycle Life :- The no. of complete charge-discharge cycles that a battery can withstand directly determines it's usable service life.

6) Internal Resistance :- Higher internal resistance causes energy loss in the form of heat, reducing battery efficiency and increasing thermal stress.

7) state of charge :- keeping the battery within a moderate state of charge (SOC) range (e.g. 20% - 80%) reduces stress on the battery and helps extend it's useful life.

8) Vibration and mechanical stress :- Physical shocks and vibrations experienced by vehicles can damage battery cells or electrical connections.

9) Age and usage patterns :- Battery performance gradually degrades with age. It's lifespan also depends on how frequently it is used and the charging & discharging patterns followed over time.

* Selection of battery :-

Following technical and application specific factors should be considered while selecting a battery :-

1) Batteries with high energy density (such as Lithium-Ion batteries) are preferred for EV's.

2) Power density affects the acceleration and overall performance of the vehicle. Batteries with high power density can deliver energy rapidly.

3) Cycle life :- Batteries with a long cycle life can withstand a greater no. of charge - discharge cycles, resulting in a longer service life and reduced replacement costs.

4) Fast charging capability improves user convenience.

5) Battery should operate efficiently under different environment conditions.

6) Lightweight and compact batteries improve the efficiency & performance of EV's.

7) Safety features such as thermal stability, low risk of fire or explosion and resistance to overcharging.

8) Cost :- Battery is the most expensive components of an EV.

9) Recycling and proper disposal should also be considered during battery selection.

10) Application type → low capacity Battery - for small EV's.
→ High capacity Battery - for High performance EV's.

* Series and parallel Connection of batteries :-

1) Series Connection :- In series connection, the positive terminal of one battery is connected to the negative terminal of next battery.

→ The total voltage is equal to the sum of the individual voltages of all connected batteries.

→ The total capacity remains same as that of a single battery.

→ Total voltage $(V_T) = V_1 + V_2 + V_3 \ldots V_n$.

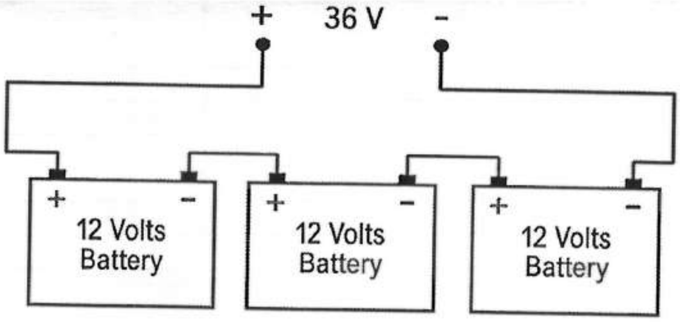

Fig. No. 3.2.6.1: Example of Series connection of batteries

As shown above, three 12 V, 10 Ah, batteries are connected in series.

$$\therefore V_T = V_1 + V_2 + V_3 = 12 + 12 + 12 = 36\ V$$

batteries are connected in series, the resulting o/p is 36V, 10Ah.

(2) Parallel Connection :- In parallel connection, all the positive terminals are connected together, and all the negative terminals are connected together.

→ The voltage remains same as that of a single battery.

→ The total capacity is equal to the sum of the capacities (Ah) of all the connected batteries.

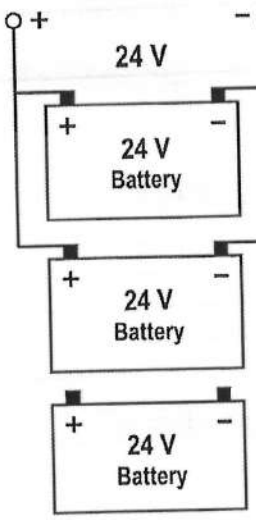

Fig. No. 3.2.6.1 Example of Parallel connection of batteries

→ From the above diagram :-

Total Capacity = (24 V, 200 Ah) + (24V, 200Ah) + (24V, 200 Ah)

= (24V, 600Ah)

3) Series parallel Connection :- In a series parallel connection, batteries are first connected in series ~~and~~ to increase voltage and then connected in parallel to increase ~~voltage~~ capacity.

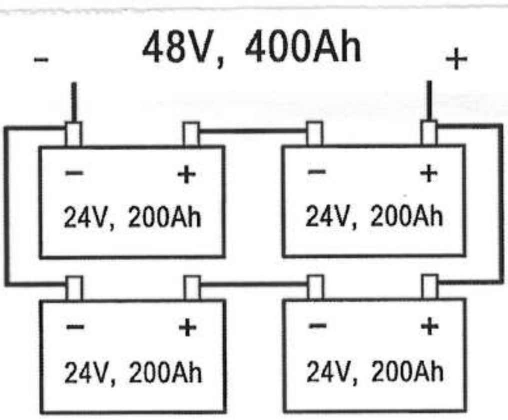

Fig. No. 3.2.6.1 Example of Series-Parallel connection of batteries

→ Both voltage and capacity are increased

→ The total voltage is equal to the sum of the voltage of the batteries connected in each series group.

→ The total capacity is equal to sum of the capacities (Ah) of the parallel connected groups.

NUMERICALS ON BATTERY CAPACITY

Basic Battery Capacity Calculations

1. **Current & Time Formula:**

   Capacity (Ah) = Current (A) × Time (h)

2. **Energy & Voltage Formula:**

   Capacity (Ah) = Energy (Wh) / Voltage (V)

1) **A 100 Ah battery is discharged at a constant current of 10 A. How long will it take to fully discharge the battery?**

   Solution:

   Time = Battery Capacity / Current

   Time = 100 Ah / 10 A = 10 hours.

2) **A battery is rated at 7.4 Wh with a voltage of 3.7 V. What is its capacity in Ah?**

- **Solution:**

  Capacity = Energy / Voltage

  Capacity = 7.4 Wh / 3.7 V = 2 Ah.

3) **A battery is 25% charged and has a total capacity of 200 Ah. How many more Ah will it charge if it receives 10 A for 4 hours?**

- **Solution:**

  Initial Ah = 25% of 200 Ah = 50 Ah.

  Charge in 4 hours = 10 A × 4 h = 40 Ah.

  Total Ah = 50 Ah + 40 Ah = 90 Ah.

4) **If a Battery allows a current of 7 amperes to go through it for 8 hours, calculate its storage capacity in amp-hour (Ah).**

- **Solution:**

  By using the formula:

  Battery Capacity (in Ah) = (Current × Time)

  Battery Capacity = (7 A × 8 h)

  Battery Capacity = 56 Ah

5) **A battery has a storage capacity of 70 ampere-hours (Ah) and gives a constant current of 4 amperes. How long will the battery last?**

- **Solution:**

  Using the rearranged formula:

  Time (in hours) = (Battery Capacity) / Current

  ⇒ Time = (70 Ah) / 4 A

⇒ Time = 17.5 hours

6) **There is a battery with a storage capacity of 60 watt-hours (Wh) and a constant current of 20 amperes with 1 volt. Find how long will the battery last.**

- **Solution:**

As we know, P = VI = 20 × 1 = 20 Watts

Thus, Time (in hours) = Battery Capacity (in Wh) / Power (in watts)

⇒ Time = 60 Wh / 20 watts

⇒ Time = 3 hours

7) **A battery has a storage capacity of 80 ampere-hours (Ah) allowing a current of 4 amperes for 6 hours. Calculate the total amount of charge transferred during the given time.**

- **Solution:**

Using the formula:

Charge (in coulombs) = Current × Time × 3,600

⇒ Charge = 4 A × 6 h × 3,600

⇒ Charge = 86,400 coulombs

8) **A battery with a storage capacity of 100 ampere-hours (Ah) and it is discharged with a constant current of 10 amperes. How long will it take to fully discharge the battery?**

- **Solution:**

Using the rearranged formula:

Time (in hours) = Battery Capacity (in Ah) / Current

⇒ Time = 100 Ah / 10 A

⇒ Time = 10 hours

9) **The capacity of a battery is 60 Ah. For how long can the current of 5 ampere be drawn from this battery 12 hours.**

The capacity of battery = 60 Ah

Current delivered = 5 A

Duration of time (T) will now be:

T=60 Ah/5 A = 12 hr = 12 × 60 min OR 720 mins

3.3 Battery Management System (BMS) :-

3.3.1 Need of BMS :-

1) BMS ensures that the battery operates within safe voltage, current and temperature limits.
2) BMS continuously monitors the voltage of each battery cell as well as entire battery to detect any imbalance or abnormal condition.
3) The BMS continuously measures the battery temperature and activates the cooling or heating system whenever required.
4) State of charge (SoC) Estimation :- BMS Estimates the Actual state of charge of battery using voltage, current and temperature data.
5) BMS monitors changes in capacity, internal resistance, and charge-discharge cycles, so battery age can be evaluated.
6) Cell balancing :- The BMS performs active or passive cell balancing to equalize the voltage of all cells, thereby improving battery performance.
7) Communication with vehicle system
8) Energy efficiency optimization.
9) Battery life Extension.
10) Data logging & diagnostics.

3.3.2 :- Block diagram of BMS and function of Each block :-

Fig. below shows the block diagram of BMS system :-

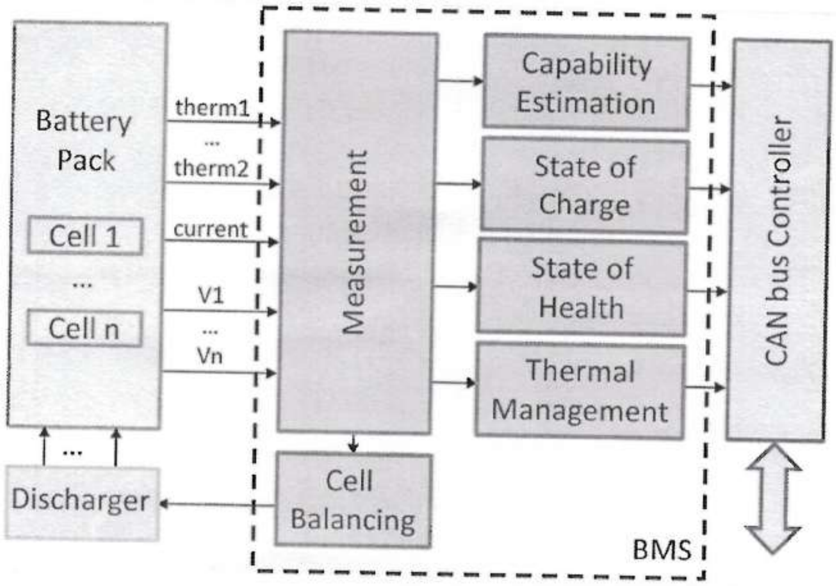

Fig. No. 3.3.2.1 Block diagram of Battery Management System (BMS)

1) Battery Pack (Cell 1 to Cell n) :-
→ The battery pack consists of multiple individual cells connected in series, parallel or a combination of both.
→ It serves as the primary electrical energy source for the EV and stores the energy required to power the vehicle.

2) Measurement :- This block collects important electrical and thermal data.

3) Capability Estimation :- This block estimates the batteries available capacity and power delivery capability.

4) State of charge (SoC) :- Monitors the remaining charge in a battery as a percentage.

5) State of Health :- This block monitors the overall condition and degradation of the battery, over time.

6) Thermal Management :- This block maintains the battery pack within a safe operating temperature.

7) Cell balancing :- This block maintains ~~the battery~~ equal voltage across battery cells.

8) Discharger :- During cell balancing process, the discharger is used to reduce voltage of cells that have a higher charge level.

9) CAN Bus Controller :- The CAN (Controller Area Network) Bus controller enables communication between the Battery Management System (BMS) and other electronic Control Units (ECUs) in the vehicle.

3.3.3 :- Battery Condition Monitoring :→

→ Battery Condition monitoring is a continuous process in which the condition and performance of batteries used in Electric vehicles are measured, monitored and analyzed.
→ This process assess critical electrical and physical parameters to evaluate the batteries's current functionality and detect potential faults or degradation early.
→ The main goal is to enable preventive measures before significant issues arise.

* Need of battery Condition monitoring :-

1) Safety :- The battery may overheat or become damaged, which can lead to serious issues such as fire or explosion. Continuous monitoring helps to detect these issues.

2) Reliability :- The risk of unexpected breakdowns caused by battery failure can be minimized, thereby improving the overall reliability of the electric vehicles

3) Performance :- Overtime, the batteries ability to store charge and deliver energy gradually decreases. BMS ensures optimal battery utilization, allowing the vehicle to maintain consistent performance

4) Battery Life :- Early detection of battery related issues enables timely maintenance, which helps extend the overall battery life and reduces the cost of battery replacement.

5) Range Prediction :- Accurate information about the battery's SOC helps estimate the vehicles remaining driving range, providing a more convenient driving experience and reducing range anxiety.

* Methods of Condition monitoring :-

Battery Condition monitoring is carried out through the combined use of hardware and software, which is usually housed within the BMS (Battery Management System). It includes the following components:-

1) Sensors :- Sensors measure key parameters like voltage, current, Temperature, SOC, SOH ... etc.

2) Data Processing :- BMS collects data received from the sensors, analyzes it, and detects any abnormalities or sign of wear & tear caused by usage.

3) Decision making :- Based on the processing data, the BMS controls the charging/discharging process, notifies the driver about potential issues, or isolates faulty cells to prevent damage.

4) Communication :- The BMS sends the battery's status to the vehicles control unit and dashboard, providing real-time updates to the driver.

3.3.4 – 3R – Reduce, Reuse, Recycle process for battery :–

Electric Vehicle (EV) batteries contain valuable and limited natural resources such as lithium, cobalt, nickel and graphite. Managing these batteries effectively at every stage of their lifecycle minimizes environmental impact, lowers costs, and promotes sustainable devevelopement. The 3R approach - Reduce, Reuse, Recycle - plays a crucial role in this process.

~~1) Reused~~ :–

1) Reduce :- To minimize the use of raw materials and energy required for battery production, andtoprevent waste generation throughout the battery's entire lifecycle.

→ Efficient design :- Designing batteries with reduced usage of rare materials like lithium, cobalt and Nickel.

→ Longer Lifespan :- Extending battery life using a BMS, thereby reducing the need for frequent replacement.

→ Energy efficiency :- Utilizing fast charging batteries, that experience lower energy loss.

→ Smart usage :- Preventing damage and improving efficiency through habits like avoiding overcharging.

2) Reuse :- To give second life to battery that are no longer suitable for use in EV's but still retain functional capacity.

→ second life applications :- Batteries no longer fit for EV's can be repurposed for - i) Domestic or industrial energy storage.
ii) solar backup systems.
iii) Charging stations for small devices.

→ Battery Refurbishment :- Replacing or repairing damaged / weak battery modules to make them suitable for alternative uses.

3) Recycle :- To extract valuable materials from unsable batteries and process them into reusable form.

→ material Recovery : Extracting metals such as lithium, cobalt, nickel and copper to manufacture new batteries.

→ Ecofriendly Disposal :- Safely processing batteries to prevent toxic chemicals leaks instead of letting them end up in landfills.

→ Recycling technologies :- Developing advanced chemical and mechanical processes for high efficiency battery recycling.

→ Closed loop system :- Using recycled battery components to create new batteries, thereby reducing the demand for virgin raw materials.

3.4 Fuel Cell

3.4.1 Difference between fuel cell and batteries :

Sr. No.	Point of Comparison	Fuel Cell	Battery
1	**Energy Source**	Uses external hydrogen fuel which is converted into chemical energy.	Stores chemical energy internally.
2	**Operation**	Generates electricity continuously as long as hydrogen is supplied.	Stores energy and supplies electricity when needed. Requires recharging.
3	**Refueling/Charging**	Refueling is quick. Hydrogen refueling takes only a few minutes.	Charging takes longer, typically from 30 minutes to several hours.
4	**Byproducts**	Produces only water and heat (environmentally friendly).	Produces byproducts during production and disposal that can be harmful.
5	**Use in EVs**	Suitable for long-range and heavy-duty EVs.	Commonly used in light-duty and short- to medium-range EVs.
6	**Energy Storage**	Does not store energy; generates it as needed.	Stores energy and releases it when required.
7	**Efficiency**	Moderate efficiency, depends on operating conditions.	High efficiency for most applications.
8	**Maintenance**	Requires complex systems and advanced components, leading to higher maintenance.	Simple and low maintenance requirements.

3.4.2 Fuel Cell terminology :-

1) Anode :- Anode is the negative electrode of a fuel cell where hydrogen gas (H_2) is supplied. At the anode, hydrogen molecules are split into protons (H^+) and electrons (e^-) through an electrochemical reaction.

2) Cathode :- The cathode is the positive electrode of a fuel cell where oxygen (O_2) is supplied. At the cathode, oxygen reacts with photons (H^+) and electrons (e^-) to produce water (H_2O).

3) Electrolyte :- The electrolyte is a medium that allows only photons (H^+) to pass from the anode to the cathode, while

blocking the flow of electrons (e^-)

4) Catalyst :- A catalyst is a substance, typically platinum (Pt), that speeds up the electrochemical reactions occuring at the electrodes without being consumed during the process.

5) ~~Catalyst :- Catalyst is a substance, typically~~

5) Reformer :- A reformer is a device that extracts hydrogen from hydrocarbon fuels, such as natural gas or methanol, for use in a fuel cell.

6) Direct Fuel Cell :- A direct fuel cell is a type of fuel cell that uses liquid fuels, such as methanol, directly without first converting them into hydrogen. An example is the Direct methanol Fuel Cell (DMFC).

3.4.3 Working Principle of Fuel Cells :-

→ A fuel cell is an electrochemical energy conversion device that uses hydrogen (H_2) and oxygen (O_2) to generate electricity, heat and water.

→ Hydrogen atoms (H_2) enter the anode of the fuel cell.

→ At the anode, hydrogen molecules are split into protons (H^+) and electrons (e^-) through an electrochemical reaction.

→ The positively charged protons (H^+) pass through the electrolyte membrane to the cathode, while the negatively charged electrons (e^-) flow through an external electrical circuits, generating electric Current (electricity

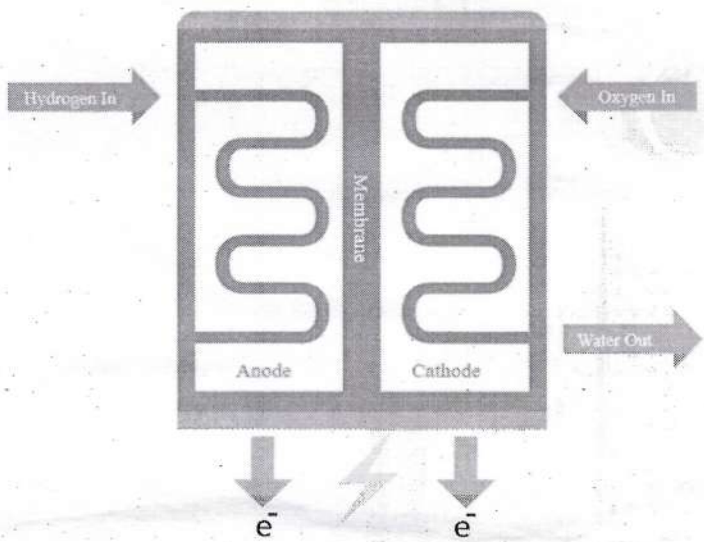

Fig. Fuel Cell basic block diagram.

→ After passing through the external circuit, the electrons (e^-) combine with protons (H^+) and oxygen (O_2) at the cathode to produce the by products of the fuel cell: water (H_2O) and heat.

→ The rate of the electrochemical reactions is relatively slow. This limitation is overcome by using catalysts such as platinum (P_t) or palladium (Pd), which accelerate the reaction. To increase the effective surface area, the catalysts is finely divided into microscopic particles and uniformly coated onto the electrodes, thereby improving the overall performance and efficiency of the fuel cell.

3.4.4 Types of fuel cells used in EVs :-

1) Alkaline fuel cell (AFC)
2) Polymer Electrolyte membrane fuel cell (PEMFC)
3) Phosphoric Acid Fuel cell (PAFC)
4) molten Carbonate Fuel cell (MCFC)
5) Solid oxide fuel cell (SOFC)

3.4.4.1 Alkaline fuel cell :-

→ An alkaline fuel cell (AFC) utilizes an alkaline electrolyte, usually pottasium Hydroxide (KOH)

→ The AFC operates by facilitating the movement of hydroxide ions (OH^-) from the cathode to anode.

→ At the anode, hydrogen fuel reacts with hydroxide ions, producing water (H_2O), electrons (e^-) and heat.

→ The generated electrons travel through an external circuit to produce electricity.

→ At the cathode, oxygen (O_2) reacts with water and electrons to regenerate hydroxide ions which move back to the anode.

→ AFCs exibit high efficiency and rapid electrochemical reaction rates.

→ These cells are sensitive to carbon dioxide (CO_2) contamination, which can diminish performance and efficiency.

→ They are prominent in space missions due to their reliable performance and efficiency.

→ Potential applications for AFCs include stationary power generations and transportations.

3.4.4.2 Polymer Electrolyte membrane Fuel cell (PEMFC) :-

→ The polymer Electrolyte membrane fuel cell uses a solid polymer membrane as the electrolite.

→ This membrane permits protons (H^+) to pass from the anode to the cathode while preventing electron flow (e^-)

→ At the anode, hydrogen (H_2) is split into protons and electrons, protons traverse the membrane, while electrons create an external electric current.

→ At the cathode, oxygen (O_2) reacts with protons and electrons to produce water (H_2O) as a byproduct.

→ PEMFCS operate at low temperatures (60-80°c) and are characterized by compact design and High power density.

→ Their quick startup capability makes PEMFC's suitable for applicat^ns that require rapid response, such as automotive and portable power devices.

3.4.4.3 - Phosphoric acid Fuel cell :-

→ Phosphoric Acid Fuel Cell (PAFC) is a type of fuel cell that uses liquid phosphoric acid (H_3PO_4) as the electrolyte. The electrolyte conducts protons (H^+) From the anode to the cathode.

→ In a phosphoric Acid fuel Cell (PAFC), hydrogen gas is converted at the anode into protons and electrons.

→ Protons travel through the phosphoric acid electrolyte to the cathode, while electrons generate electric current in an external circuit.

→ At the anode, oxygen reacts with protons and electrons to form water and heat.

→ PAFCs function at 150-200°c and are more tolerant to impurities, particularly carbon monoxide, making them effective with reformed fuels.

→ They are mainly used for stationary power generation in settings like hospitals and hotels but are too large and heavy for mobile applications.

3.4.4.4 - Molten Carbonate Fuel cell (MCFC) :-

→ The molten carborate fuel cell (MCFC) operates at high temperatures of 600-700°C.

→ It uses a molten carborate electrolyte, typically lithium, Sodium or pottasium Carbonate.
→ Hydrogen or carbon monoxide is utilized at the anode to generate water, Carbon dioxide, and electrons for electric power.
→ At the cathode, oxygen, oxygen combines with carbon dioxide and electrons to regeneeate carbonate ions, completing the cycle.
→ MCFCs can use various fuels, including natural gas and biogas, making them suitable for large-scale power generation and combined Heat and power systems.
→ Advantages include high efficiency and fuel flexibity.
→ Challenges include increased complexity and cost due to high operating temperatures and corrosive environments.

3.4.4.5 – Solid Oxide fuel cell-(SOFC) :-

→ Solid Oxide Fuel Cell (SOFC) Utilizes a solid ceramic electrolyte, mainly Yttria stabilizes Zirconia (YSZ), Conducting Oxide ions (O^{2-}).
→ Operates at high temperature (700-1000°C), allowing for a diverse range of fuels :- hydrogen (H_2), natural gas, biogas & liquid hydrocarbons.
→ Oxygen (O_2) at the cathode is reduced to oxide ions, which travel to the anode, reacting with fuel to generate electrons (e^-), water (H_2O), Carbon dioxide (CO_2) and heat.
→ Electric power is produced as electrons flow through an external Circuit and return to the cathode.
→ known for high efficiency, excellent fuel ~~efficiency~~ flexibility & effective waste heat recovery, making SOFCs ideal for Combined heat and power (CHP) systems.
→ Primarily applied in stationary power generation for industrial, residential and military uses.
→ Challenges include material degradation, slow start-up times, and complex system design, leading to increased costs and maintenance.

* 3.4.4.6 – Comparison of different types of fuel cells used in EVs :

COMPARISON CHART OF DIFFERENT TYPES OF FUEL CELLS USED IN EVs

Sr. No.	Fuel Cell Type	Electrolyte Type	Cell Voltage (V)	Operating Temperature (°C)	System Output (kW)	Efficiency (%)	Applications
1	Alkaline Fuel Cell (AFC)	Potassium hydroxide (KOH)	~0.9 V	60 – 90 °C	Up to 100+	60 – 70% (electrical)	Spacecraft, Military, Buses (limited EVs)
2	Polymer Electrolyte Membrane Fuel Cell (PEMFC)	Solid polymer membrane	~0.7 V	60 – 80 °C	1 – 250+	40 – 60%	Automobiles, Buses, Portable Systems
3	Phosphoric Acid Fuel Cell (PAFC)	Liquid phosphoric acid	~0.7 V	150 – 200 °C	50 – 400	35 – 45%	Stationary Power, CHP (Combined Heat and Power), Backup Systems
4	Molten Carbonate Fuel Cell (MCFC)	Molten carbonate salts (Li, Na, K)	~0.8 V	600 – 700 °C	100 – 1000+	45 – 55% (up to 85% with CHP)	Utility-scale Power, Industrial Plants
5	Solid Oxide Fuel Cell (SOFC)	Solid ceramic (e.g., Yttria-stabilized Zirconia)	~1.0 V	700 – 1000 °C	100 – 2000+	50 – 65% (up to 90% with CHP)	Large Stationary Power, CHP, Military

13-08-2026

QUESTION BANK/ASSIGNMENT -03

Course & Code: EE-5K
Name of Subject: Electric Vehicle Technology

Semester: Third
Subject Code: 315335

Que. No.	Unit 3 Controlled Converters (22 Marks)
1	Define specific energy and specific power in the context of batteries
2	List any two advantages and two disadvantages of Lithium-Ion batteries
3	Differentiate between EV batteries, super capacitors, and flywheel energy storage systems in terms of energy storage mechanism and typical applications
4	Draw and explain a basic block diagram of a Battery Management System (BMS), mentioning the function of each block
5	Compare the following battery types based on construction, cycle life, efficiency, and typical applications: Lead-Acid, NiMH, and Li-Ion
6	Discuss the factors influencing battery selection for electric vehicles. Include aspects like energy density, cost, temperature range, and safety
7	Explain the working principle of a Fuel Cell. Also explain how does it differ from a conventional battery.
8	Compare the following fuel cells used in EVs: PEMFC, SOFC, and MCFC based on electrolyte type, operating temperature, efficiency, and application.
9	
10	

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