ELECTRIC VEHICLE

DIPLOMA WALLAH

EE/EEE

JHARKHAND UNIVERSITY OF TECHNOLOGY (JUT)

UNIT III: BATTERIES AND ENERGY STORAGE SYSTEMS

3.1 Energy Storage Technologies in EVs

Topic Overview:
Energy storage is fundamental for electric vehicles (EVs) to provide the power needed for propulsion and auxiliary systems. The main energy storage technologies include batteries, supercapacitors, and flywheels, each differing in how they store and release energy. Batteries store electrical energy chemically and supply it steadily over time, making them the primary storage in EVs. Supercapacitors store energy electrostatically, enabling rapid charging and discharging, which is useful for quick bursts of power such as regenerative braking. Flywheel energy storage stores kinetic energy by rotating a mass at high speed and can quickly release it when needed. Understanding the characteristics and parameters of these storage devices is essential for efficient EV design and operation.

Explanation:

- Batteries provide high energy storage capacity and smooth power output, essential for driving range.
- Supercapacitors have high power density but low energy density, ideal for transient power demands.
- Flywheels mechanically store energy, provide fast response, and have high cycle life but are bulky.
- Battery parameters such as cell voltage, ampere-hour capacity, energy stored, and specific energy determine performance.
- Energy density and specific power describe how much energy/power is stored or delivered per unit volume or weight.
- Battery temperature and thermal management affect safety and longevity.
- Self-discharge and battery life (number of deep cycles) are critical for maintenance and replacement planning.

Real-Life Examples:

- Tesla Model 3 uses lithium-ion batteries for high energy density.
- Hybrid buses use supercapacitors for efficient regenerative braking.
- Flywheel systems are tested in race cars to store braking energy.

3.2 Batteries: Types, Components, and Parameters

Topic Overview:
Several battery chemistries are employed in EVs, catering to different performance needs and costs. The main types include Lead-acid, Nickel-Metal Hydride (NiMH), Lithium-Ion (Li-ion), Nickel-Zinc (Ni-Zn), Nickel-Cadmium (Ni-Cd), Aluminium-Ion, and Aluminium-Air batteries. Each battery type has unique construction, advantages, limitations, lifespan, efficiency, and costs that influence their suitability for EV applications. Proper understanding of battery connections, operating factors, and capacity calculations is crucial for designing EV power systems.

Batteries Types:

1. **Lead-Acid Batteries:** Classic, inexpensive, and reliable but heavy with low energy density and shorter life cycles.
2. **NiMH Batteries:** Better energy density and life than lead-acid, traditionally used in early hybrid vehicles.
3. **Lithium-Ion Batteries:** High energy density, long cycle life, and currently dominant in modern EVs; includes variants like NMC and LFP.
4. **Ni-Zn Batteries:** Offer high charge rate but limited cycle life and less commercial use.
5. **Ni-Cd Batteries:** Known for robustness and good charge retention but suffer from toxicity and memory effect.
6. **Aluminium-Ion Batteries:** Emerging technology with fast charging potential and lightweight advantages.
7. **Aluminium-Air Batteries:** High theoretical energy density but challenges remain in rechargeability and commercialization.

Battery Type	Energy Density (Wh/kg)	Cycle Life (Approx.)	Charge Efficiency	Advantages	Disadvantages	Common Applications
Lead-Acid	30 - 50	300 - 500	70-85%	Low cost, mature, recyclable	Heavy, low energy	Electric rickshaws, golf carts

					density, short life	
Nickel-Metal Hydride (NiMH)	60 - 120	500 - 1000	70-90%	Better energy density, safer than Ni-Cd	Heavier, self-discharge higher than Li-ion	Early hybrid EVs
Lithium-Ion (Li-ion)	150 - 250	1000 - 3000	90-95%	High energy density, long life, light	Expensive, thermal runaway risk, needs BMS	Modern EVs (Tesla, Nissan Leaf)
Nickel-Zinc (Ni-Zn)	50 - 120	~500	80-90%	Fast charging	Limited commercial use, moderate cycle life	Niche EV applications
Nickel-Cadmium (Ni-Cd)	45 - 80	1000 - 2000	70-80%	Robust, good at low temperatures	Toxic materials, memory effect	Older EVs, power tools
Aluminium-Ion (Al-Ion)	150 - 200	1000 or more	85-95%	High energy density, fast charging	Emerging tech, expensive	Experimental, future EV use
Aluminium-Air (Al-Air)	300 - 1300 (theoretical)	Limited	N/A	Very high energy density, lightweight	Not rechargeable, expensive refuel	Experimental, niche military uses

Components:

- Batteries consist of anode, cathode, electrolyte, separator, and casing.
- Construction impacts voltage, capacity, and safety.

Factors Influencing Operation:

- Temperature impacts performance and degradation.
- Depth of discharge influences battery lifespan.
- Charging and discharging rates affect efficiency.

Connections:

- Batteries connected in series increase voltage.
- Batteries connected in parallel increase capacity.

Calculation of Battery Capacity for Electric Vehicles

Battery capacity calculation is vital to determine how much energy storage is needed to operate an electric vehicle (EV) for a desired range and performance. The capacity is typically expressed in ampere-hours (Ah) or kilowatt-hours (kWh).

Key Parameters and Definitions:

- **Battery Voltage (V):** The total voltage of the battery pack; sum of voltages of series-connected cells.
- **Battery Capacity (Ah):** The amount of charge the battery can deliver over time.
- **Energy Stored (Wh or kWh):** Product of voltage and capacity; Energy (Wh) = Voltage (V) × Capacity (Ah).
- **Efficiency:** Charging and discharging losses must be considered (typically 85-95% for Li-ion).
- **Power Consumption:** Power used by the motor and auxiliary systems in watts.

Stepwise Calculation:

1. **Determine Required Energy (E):**
   Calculate required energy for driving using power demand and driving time or distance.
2. **Adjust for Battery Efficiency:**
   Because of charging and discharging inefficiencies, divide calculated energy by efficiency factor (e.g., 0.85).
3. **Consider Motor Efficiency:**
   Further divide by motor efficiency to account for powertrain losses.
4. **Calculate Battery Capacity in kWh:**

$$\text{Battery Capacity (kWh)} = \frac{\text{Power Demand (kW)} \times \text{Operating Time (h)}}{\text{Battery Efficiency} \times \text{Motor Efficiency}}$$

5. **Convert to Ampere-Hours (Ah):**

$$\text{Capacity (Ah)} = \frac{\text{Battery Capacity (Wh)}}{\text{Battery Voltage (V)}}$$

where Battery Capacity (Wh) = Battery Capacity (kWh) × 1000.

Example:

For an EV requiring 4.2 kW of power, running for 1 hour at 48 V battery system, with battery efficiency 85% and motor efficiency 85%:

- Adjusted energy demand:

$$\frac{4.2\ \text{kW}}{0.85 \times 0.85} \approx 5.81\ \text{kWh}$$

- Battery capacity in Wh = 5.81 × 1000 = 5810 Wh.
- Battery capacity in Ah:

$$\frac{5810\ \text{Wh}}{48\ \text{V}} \approx 121\ \text{Ah}$$

Thus, a battery pack of 48 V and 121 Ah capacity is required.

Additional Formulas:

- **Number of cells in series (for desired voltage):**

$$N_{\text{series}} = \frac{\text{Battery Pack Voltage}}{\text{Cell Voltage}}$$

- **Number of parallel strings (for desired capacity):**

$$N_{\text{parallel}} = \frac{\text{Battery Pack Capacity (Ah)}}{\text{Cell Capacity (Ah)}}$$

- **Total Number of Cells:**

$$N_{\text{total}} = N_{\text{series}} \times N_{\text{parallel}}$$

Summary:

To calculate the battery capacity for an EV, first estimate total energy requirements using power and time/distance, adjust for efficiency losses, convert energy to ampere-hours using nominal battery voltage, and break down the pack into series and parallel cell configurations. This ensures the battery can deliver the required voltage and capacity for EV operation.

Diagram Suggestion to Draw:

- **Battery Pack Configuration:** Series and parallel connection layout showing number of cells, voltage adds in series, capacity adds in parallel.

Capacity Calculation:

- Total voltage is product of series-connected cell voltages.
- Total capacity is sum of parallel cell capacities.

3.3 Battery Management Systems (BMS)

Topic Overview:
The BMS is essential for monitoring and managing battery health, safety, and performance in EVs. It collects real-time data from sensors on voltage, current, and temperature, balances cell charges to avoid mismatch, and protects the battery pack against unsafe conditions such as overcharging or overheating. Additionally, BMS communicates battery status to vehicle systems, enabling optimized energy management and safety protocols.

Core Functions:

- Measurement of cell parameters and battery pack status.
- Cell balancing to ensure uniform charge levels and prevent damage.
- Overcharge, overdischarge, and thermal protection.
- State of charge (SOC) and state of health (SOH) estimations.
- Fault detection and alerts.
- Communication with vehicle control units for coordinated operation.

Block Diagram Elements:

- Sensors for voltage, current, and temperature.
- Control unit for data processing and decision making.
- Balancing circuits for charge equalization.
- Communication interface to vehicle ECU.

Battery Condition Monitoring:
Continuous monitoring improves reliability and extends battery life.

3R Process:

- **Reduce:** Minimize battery material consumption.
- **Reuse:** Extend battery life for second-life applications.
- **Recycle:** Recover and process battery materials sustainably.

3.4 Fuel Cells in Electric Vehicles

Topic Overview:
Fuel cells convert chemical energy from hydrogen and oxygen into electricity with water as the only emission. Unlike batteries, fuel cells do not store energy but continuously generate it when fuel is supplied. This makes them promising for long-range EVs. Several types of fuel cells exist, distinguished by electrolyte type, voltage output, operating temperature, and efficiency.

Difference Between Batteries and Fuel Cells:

- Batteries store and release chemical energy; fuel cells produce electricity continuously from supplied fuel.

Terminologies:

- **Anode:** Where fuel oxidation occurs.
- **Cathode:** Where reduction reaction occurs.
- **Electrolyte:** Ion conductor separating anode and cathode.
- **Catalyst:** Speeds up reactions.
- **Reformer:** Converts hydrocarbons into hydrogen.
- **Direct Fuel Cell:** Uses pure hydrogen fuel without reforming.

Working Principle:
Hydrogen splits into protons and electrons at anode; protons cross electrolyte; electrons flow external circuit; oxygen combines with protons and electrons at cathode to form water; electricity and heat generated.

Fuel Cell Types in EVs:

Type	Electrolyte	Cell Voltage (V)	Operating Temp (°C)	Output (kW)	Efficiency (%)	Applications

AFC	Alkaline	0.9 - 1.2	60 - 90	Up to 250	40 - 60	Spacecraft, backup
PEMFC	Polymer Membrane	0.6 - 0.7	50 - 100	50 - 200	40 - 60	Automobiles (e.g., Toyota Mirai)
PAFC	Phosphoric Acid	0.6 - 0.7	150 - 200	200 - 400	40 - 50	Stationary power plants
MCFC	Molten Carbonate	0.7	600 - 700	1000+	45 - 60	Large scale power generation
SOFC	Ceramic Oxide	0.7 - 1.0	800 - 1000	1000+	50 - 60	Stationary and auxiliary power

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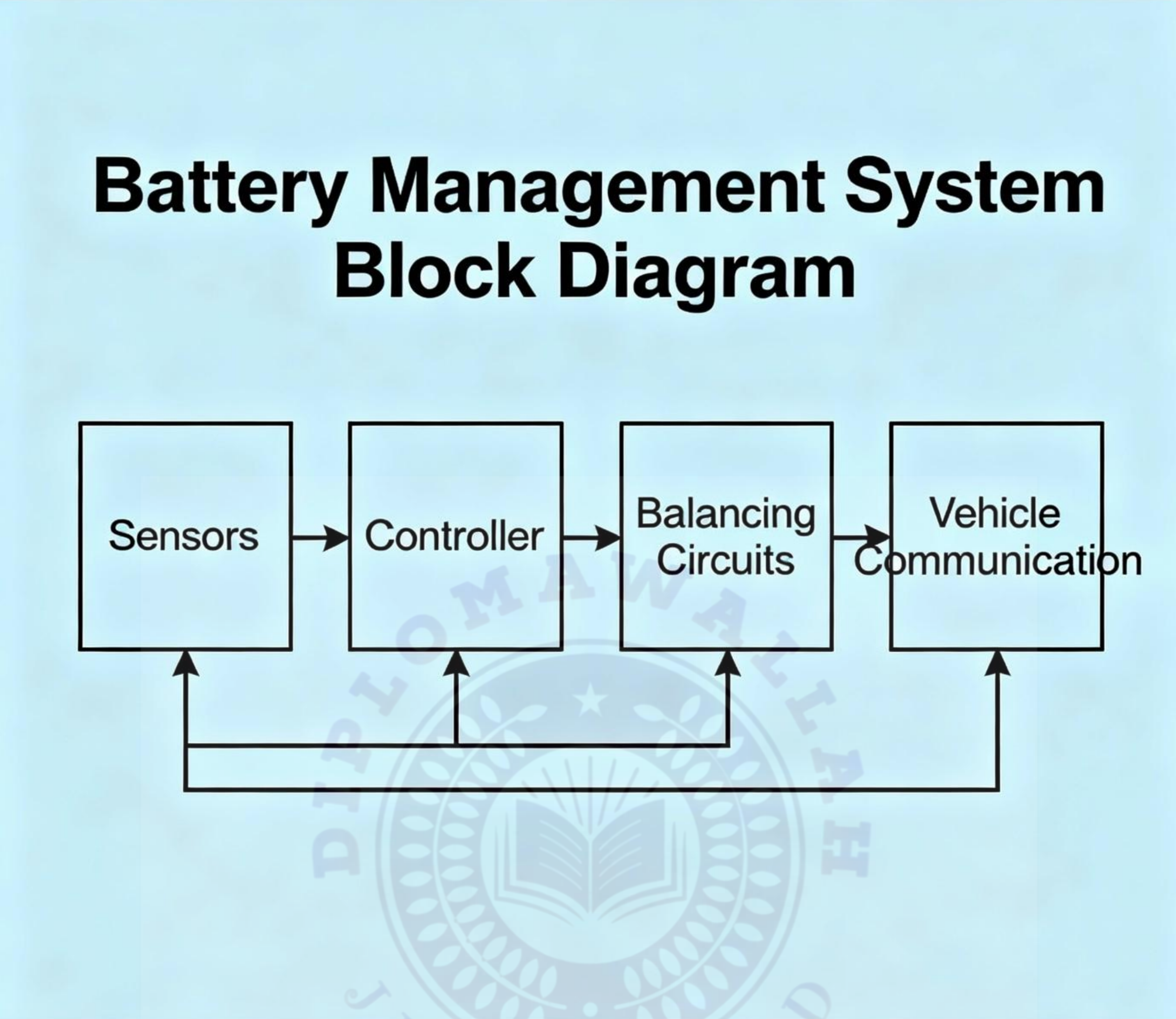
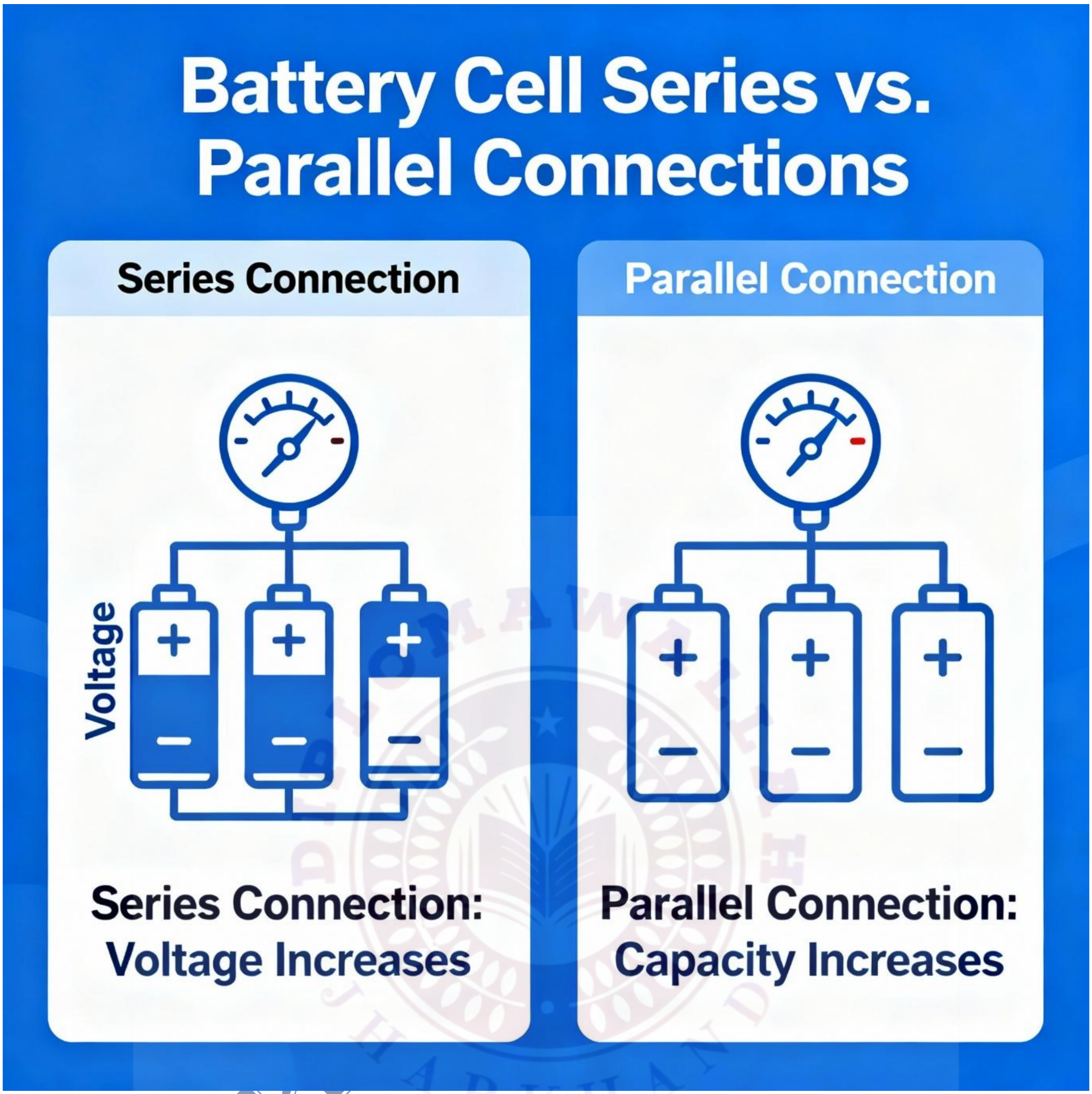
Suggested Diagrams to Draw:

- *Battery connection diagram showing series and parallel wiring.*
- *Block diagram of Battery Management System with sensors, controller, balancing circuit, and communication.*
- *Working schematic of a Polymer Electrolyte Membrane Fuel Cell (PEMFC) illustrating flow of hydrogen, oxygen, ions, electrons, and water formation.*
- *Comparative table for battery types illustrating capacity, cycle life, advantages, and disadvantages.*


Battery Management System
Block Diagram
Sensors
Controller
Balancing
Circuits
Vehicle
Communication


Battery Cell Series vs. Parallel Connections
Series Connection
Voltage
Series Connection: Voltage Increases
Parallel Connection
Parallel Connection: Capacity Increases

Battery Type	Advantages	Disadvantages	Cycle Life	Energy Density
Lithium-Ion (Li-Ion)	High energy density, mature technology, wide temperature range	Risk of thermal runaway, limited resource availability	1000-2000 cycles	150-250 Wh/kg
Lithium Polymer (Li-Polymer)	Risk of form factor, lightweight, high eiergy density	Higher cost, slower charging speed	500-1000 cycles	150-250 Wh/kg
Lithium Polymer (Li-Polymer)	Flexible form factor, lightweight, high enrgy density	Higher cost, slower charging speed	500-1000 cycles	200-300 Wh/kg
Solid-State	High safety, longer cycle life, high energy density	High production cost, low ion conductivity at low temps	2000-5000 cycles	300-400 Wh/kg
Lead-Acid	Low cost, reliable performance	Low energy density, heavy weight, short cycle life	300-500 cycles	30-50 Wh/kg

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