Design Of Electric vehicle – Battery Pack

Report submitted to GITAM (Deemed to be University) as a partial fulfillment of the requirements for the award of the Degree of Bachelor of Technology in EEE

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DECLARATION

I/We declare that the project work contained in this report is original and it has been done by me under the guidance of my project guide.

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CERTIFICATE

This is to certify that Keerthi.K and Sai Kalyan bearing BU22EECE0200010 and BU22EECE0200026 has satisfactorily completed Mini Project Entitled in partial fulfillment of the requirements as prescribed by University for VIIth semester, Bachelor of Technology in “Electrical, Electronics and Communication Engineering” and submitted this report during the academic year 2025-2026.

[Signature of the Guide] [Signature of the HOD]

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Chapter 1: Introduction

Overview of the problem statement

The rapid global shift toward sustainable transportation has significantly increased the demand for **electric vehicles (EVs)**. At the core of every EV lies the **battery pack**, which serves as the primary source of energy for propulsion and auxiliary systems. Despite significant technological advancements, battery packs still face critical challenges that hinder their performance, reliability, and widespread adoption.

One of the foremost issues is the **limited energy density** of current battery chemistries, which directly affects the driving range of EVs. This limitation often leads to **range anxiety** among users, making it difficult for EVs to compete with traditional internal combustion engine vehicles in terms of travel distance per charge. Additionally, **thermal management** is a major concern, as batteries generate heat during charging and discharging cycles. Ineffective heat dissipation can result in performance degradation, reduced lifespan, and in extreme cases, safety hazards such as **thermal runaway**.

Another significant challenge lies in the **charging infrastructure and time**. Long charging durations place stress on the battery, accelerating capacity fade and limiting the vehicle's usability. Moreover, variations in **state of charge (SoC)**, **state of health (SoH)**, and uneven cell balancing can lead to premature failure or reduced overall efficiency of the battery pack.

Objectives and goals

Objective

To design and analyze a Lithium-ion battery pack that meets the required voltage, capacity, energy, range, and safety needs of an electric vehicle.

Main Goals

1. Select suitable cell chemistry (NMC / LFP).
2. Design a proper series–parallel configuration to achieve required voltage (e.g., 60V/72V).
3. Calculate total energy (kWh) and expected driving range.
4. Integrate a Battery Management System (BMS).
5. Ensure thermal safety and efficient cooling.

Additional Goals

- Cost estimation
- Comparison with commercial EV battery packs
- Environmental impact study

Chapter 2 : Literature Review

1. Overview

- A battery pack in an EV comprises many individual battery cells assembled (in series and/or parallel), modules, thermal management, protective housing, battery management system (BMS), and the enclosure/housing. The performance, safety, life, cost, and weight of the EV depend heavily on how well each part is designed. Key concerns are:
- Maintaining temperature within optimal range
- Accurately estimating state of charge (SoC) / state of health (SoH)
- Ensuring safety (avoiding thermal runaway, mechanical damage, etc.)
- Efficient architecture, cost, material use, durability
- End of life, recycling, and manufacturability
- Recent literature has particularly emphasised thermal management, SoC/SoH estimation, housing & enclosure durability, bonding/adhesives, and materials improvements.

2. Thermal Management (TMS)

Because lithium-ion batteries are very sensitive to temperature (too hot → faster degradation, safety risk; too cold → reduced performance), much of the literature focuses on battery thermal management.

Reviews of TMS:

Li et al. (2023) in *Energies* review various thermal management strategies in "new energy vehicles," discussing active vs passive cooling, modeling approaches, and trade-offs.

- Another review in *Applied Thermal Engineering* compares academic and industrial systems, noting what manufacturers use in production vs what is studied in lab settings.

Cooling methods:

- **Air cooling**: simpler, lower cost, lower complexity, but relatively poor thermal uniformity and limited cooling capacity.
- **Liquid cooling**: more effective; better power & temperature control; higher complexity and cost.
- **Phase Change Materials (PCMs)**: used for passive thermal buffer, smoothing temperature spikes. Some recent works use PCM combined with active cooling.
- **Hybrid systems**: combining active cooling (liquid, microchannels) + passive components (PCM, foams) to improve uniformity and reduce max temperature
- **Modeling & Experimental Studies**:
- Detailed experimental thermal characterization of a 48V Li-ion pack under charge/discharge to understand internal gradients and module-level differences
- Study of an EV battery module's cooling performance, focusing on thermal interface material (TIM) compression ratio and its effect on heat transfer.
- Use of machine learning (especially physics-informed ML) to predict temperature fields or temperature distribution in pack, given that full detailed finite-element analysis (FEA) is computationally heavy. Physics-informed models help reduce data needs and still enforce physical constraints.

Challenges:

- Ensuring uniform temperature across cells/modules to avoid differential aging.
- Balancing effectiveness vs weight, volume, and cost (coolant, channels, PCM add mass or complexity).
- Dealing with extreme ambient temperatures (cold starts, high ambient heat).
- Fast charging increases thermal load.

2. State of Health (SoH) and State of Charge (SoC) Estimation; BMS

- Accurate estimation of SoC and SoH is crucial, not just for user display but to manage battery life and safety. Poor estimation can lead to overcharging, under-discharging, or misuse.

- A systematic review (2023) examines methods for SoC and SoH estimation in EV battery applications. Techniques include empirical models, equivalent circuit models, data-driven (machine learning), and hybrid models. Trade-offs are between complexity, accuracy, data required, and computational load.

- Example: "Battery Pack State of Health Prediction Based on the Electric Vehicle Management Platform Data" uses ambient temperature, charging/discharging behavior, optimized model (double polynomial + particle swarm optimization) to predict pack SoH, achieving error less than ~1.5%.

- Cell balancing (passive vs active balancing) is repeatedly mentioned: needed to ensure cells in series/parallel age similarly and maintain capacity. Also, voltage monitoring, over/under volting, overcurrent, overtemperature protections are integral functions of BMS.

Chapter 3: Strategic Analysis and Problem Definition

3.1 SWOT Analysis

Strengths (S):

1. **High Energy Efficiency** – Battery packs offer >90% round-trip efficiency compared to internal combustion energy storage.
2. **Environmental Benefits** – Zero tailpipe emissions reduce greenhouse gases and urban pollution.
3. **Instant Power Delivery** – Lithium-ion packs provide high torque and fast acceleration.

Weaknesses (W):

1. **High Initial Cost** – Battery packs contribute 30–40% of EV cost due to expensive raw materials (Lithium, Cobalt, Nickel).
2. **Limited Energy Density** – Current Li-ion packs (200–300 Wh/kg) are lower than gasoline (~12,000 Wh/kg).
3. **Degradation Over Time** – Capacity fades after ~1,000–1,500 cycles, reducing vehicle range.

Opportunities (O):

1. **Government Incentives** – Subsidies and policies encourage EV adoption and battery R&D.
2. **Recycling & Second-Life Use** – Used EV batteries can be repurposed for stationary energy storage.
3. **Technological Innovations** – Emerging solid-state, lithium-sulfur, and sodium-ion batteries promise higher safety and density.

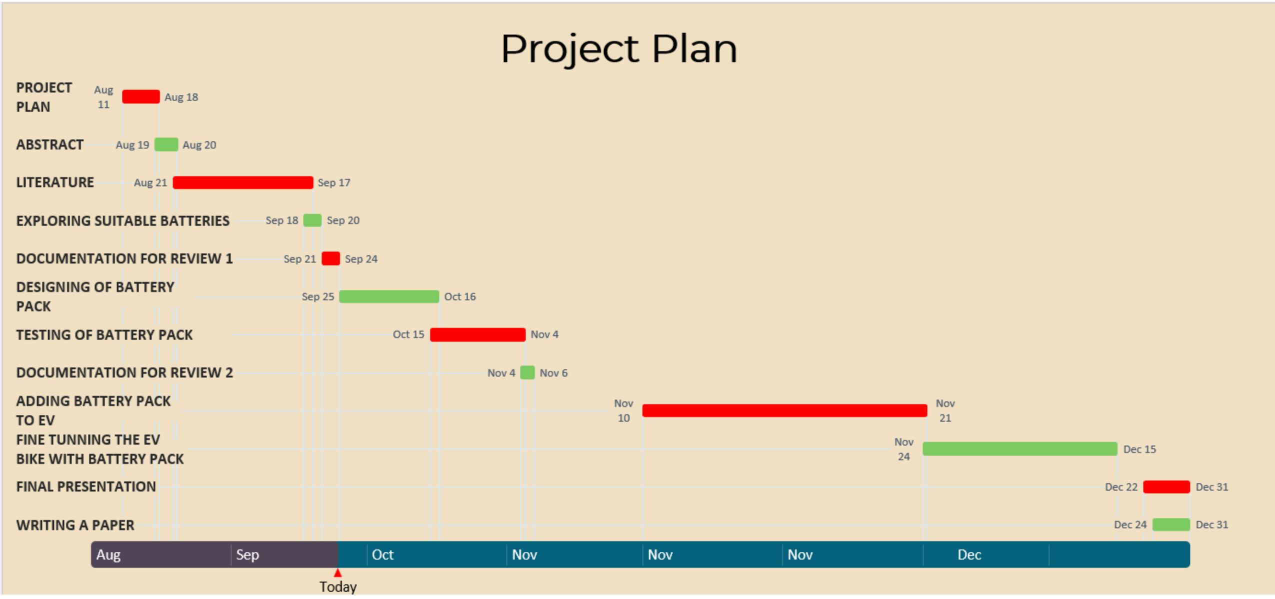
Threats (T):

1. **Raw Material Dependency** – Global supply of lithium, cobalt, and nickel is limited and politically sensitive.
2. **Safety Risks** – Fire hazards due to short circuits, overcharging, or crashes pose challenges.
3. **Competition from Alternatives** – Hydrogen fuel cells and advanced

biofuels may compete with battery-powered EVs.

4. **Recycling Challenges** – Large-scale safe recycling systems are still under development.

3.2 Project Plan



3.3 Problem statement

The transition from conventional internal combustion engine (ICE) vehicles to electric vehicles (EVs) is primarily driven by the urgent need to reduce greenhouse gas emissions, dependence on fossil fuels, and rising environmental concerns. At the core of EV technology lies the **battery pack**, which acts as the main energy storage and power delivery unit. Despite significant advancements in lithium-ion and emerging battery technologies, several critical challenges remain unresolved.

Chapter 4: Methodology

The approach adopted in this project focuses on understanding, analyzing, and optimizing the design and performance of battery packs used in electric vehicles (EVs). A systematic methodology was followed, starting from theoretical analysis to practical considerations, to ensure that the study addresses both academic and industrial perspectives.

1.Requirement Analysis

The first step was identifying the performance requirements of an EV battery pack, such as energy density, power output, lifecycle, charging time, safety, and cost. These requirements were based on current EV market trends and consumer expectations.

Battery Chemistry Evaluation

Various chemistries, such as Lithium-ion (Li-ion), Lithium-Polymer (Li-Po), Lithium-Iron-Phosphate ($LiFePO_4$), and next-generation Lithium-Sulfur (Li-S), were reviewed. Their energy densities, voltage ranges, cycle lives, and safety characteristics were compared to select the most suitable chemistry for EV application.

Pack Architecture Design

A modular design approach was considered, where cells are grouped into modules, and modules are integrated into the full battery pack. This modularity allows easy scalability, improved cooling, and simplified fault isolation. Both series and parallel configurations were evaluated to achieve the desired pack voltage and capacity.

Tools and techniques utilized

Computer-Aided Design (CAD) Tools

1.Software such as *AutoCAD* and *SolidWorks* was used for modeling the physical structure of the battery pack, including cell arrangement, cooling channels, and module casing.

2.CAD helped visualize compact and efficient designs, while also considering thermal management and mechanical strength.

Simulation and Analysis Software

1.MATLAB/Simulink was used to simulate charge–discharge cycles, state of charge (SOC), and state of health (SOH).

2.ANSYS and COMSOL Multiphysics were applied for **thermal simulations**, predicting heat generation and validating cooling mechanisms.

3.These simulations ensured that the battery operated within safe limits and provided reliable performance predictions.

Battery Management System (BMS) Tools

- BMS design involved microcontroller-based platforms such as *Arduino* and *Raspberry Pi* for prototyping.
- Tools like *CAN Bus analyzers* were used to test communication between modules.
- Algorithms for cell balancing, SOC estimation, and fault detection were implemented and validated.

Testing and Measurement Instruments

- *Battery cyclers* and *programmable power supplies* were employed to test charge/discharge profiles.
- Instruments like *digital multimeters*, *oscilloscopes*, and *temperature sensors* monitored electrical and thermal parameters.
- Electrochemical Impedance Spectroscopy (EIS) was used to evaluate internal resistance and battery health.

Design considerations

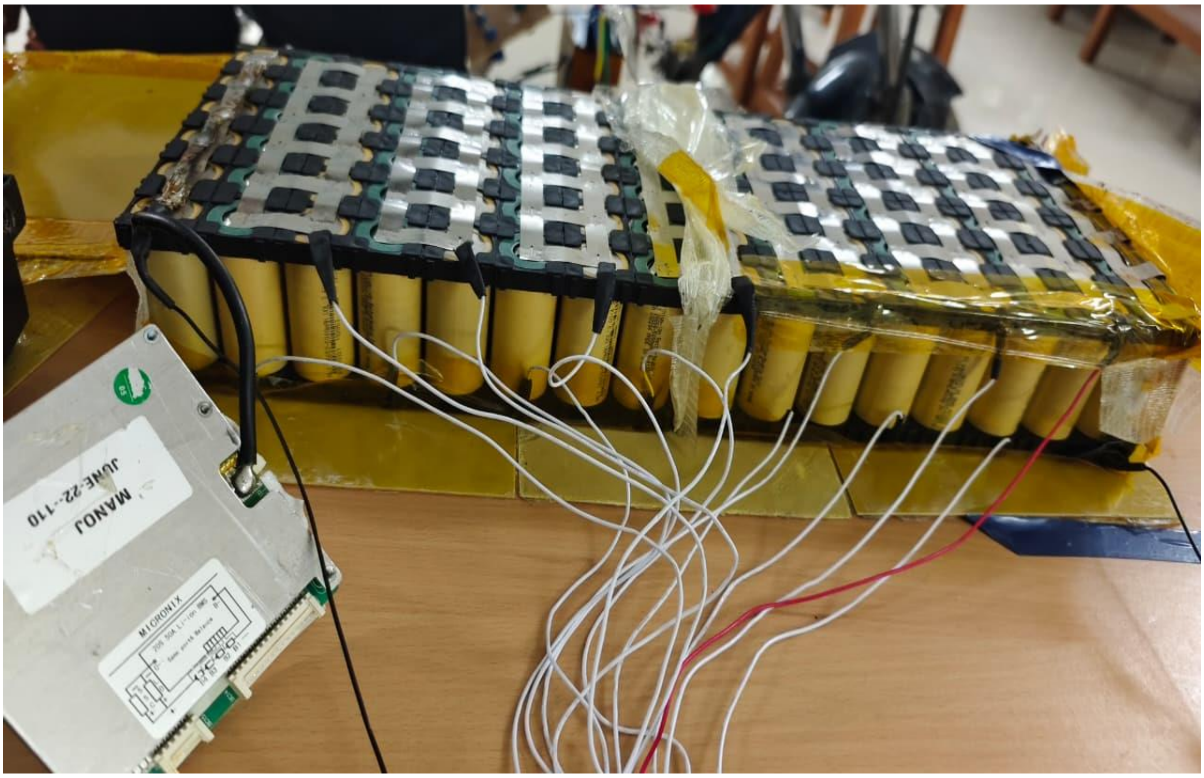
The design of a battery pack in an electric vehicle (EV) requires careful integration of multiple factors to ensure performance, safety, cost-effectiveness, and durability. Unlike standalone battery cells, a battery pack is a complete system consisting of modules, bus bars, sensors, cooling systems, a Battery Management System (BMS), and protective housing. The following considerations play a crucial role in the design process:

1.Energy Density and Power Requirements
- High gravimetric (Wh/kg) and volumetric (Wh/L) energy density is critical to maximize driving range without significantly increasing vehicle weight.
- Power density must be sufficient to deliver high acceleration and support regenerative braking.

2. Cell Chemistry Selection
- Lithium-ion chemistries such as NMC (Nickel Manganese Cobalt), LFP (Lithium Iron Phosphate), and NCA (Nickel Cobalt Aluminum) are most common.
- Choice depends on trade-offs between cost, cycle life, safety, and energy density.

3. Thermal Management
- Effective cooling or heating systems are essential to maintain optimal operating temperature (20–40 °C).
- Air cooling, liquid cooling, or phase-change materials may be employed to prevent thermal runaway and ensure uniform temperature distribution.

4. Battery Management System (BMS)
- The BMS monitors voltage, current, temperature, and state of charge (SOC).
- It balances cells, prevents overcharging/discharging, and ensures safety protocols are followed.



Fig(1) Battery

Figure: Lithium-Ion Battery Pack (16 Series × 6 Parallel = 96Cells) Battery capacity(30Ah)

Shown above is a custom EV battery pack constructed using cylindrical 3.7V,5000mAh Li-ioncells.

The pack uses a 16S6P configuration, where six cells are connected in parallel to form a 30 Ah group, and sixteen such groups are connected in series to achieve the required operating voltage.

The nominal pack voltage is 59.2 V, with a fully charged voltage of approximately 67.2 V.

Individual balancing and temperature-monitoring leads are connected to the Battery Management System (BMS) to ensure safe charging, discharging, and cell health monitoring.

The pack is reinforced with insulation layers, cell holders, and protective tape for mechanical stability and safety.

Chapter 5 : Implementation

5.1 Description of how the project was executed

Phase 1 – Problem Identification and Literature Survey:
The execution began with the identification of key challenges faced by electric vehicle battery packs, such as limited energy density, high cost, thermal management, and safety concerns. A detailed literature review was carried out to study existing research papers, industrial reports, and technical articles related to lithium-ion, lithium-sulfur, and emerging solid-state battery technologies. This phase helped in setting a strong theoretical foundation.

Phase 2 – Requirement Analysis and Data Collection:
Technical specifications of modern EVs (such as Tesla Model 3, Tata Nexon EV, and Nissan Leaf) were analyzed to understand real-world battery pack configurations. Data on cell chemistries, voltage ranges, energy capacity, and thermal management systems were collected from industry standards, manufacturers’ datasheets, and academic sources.

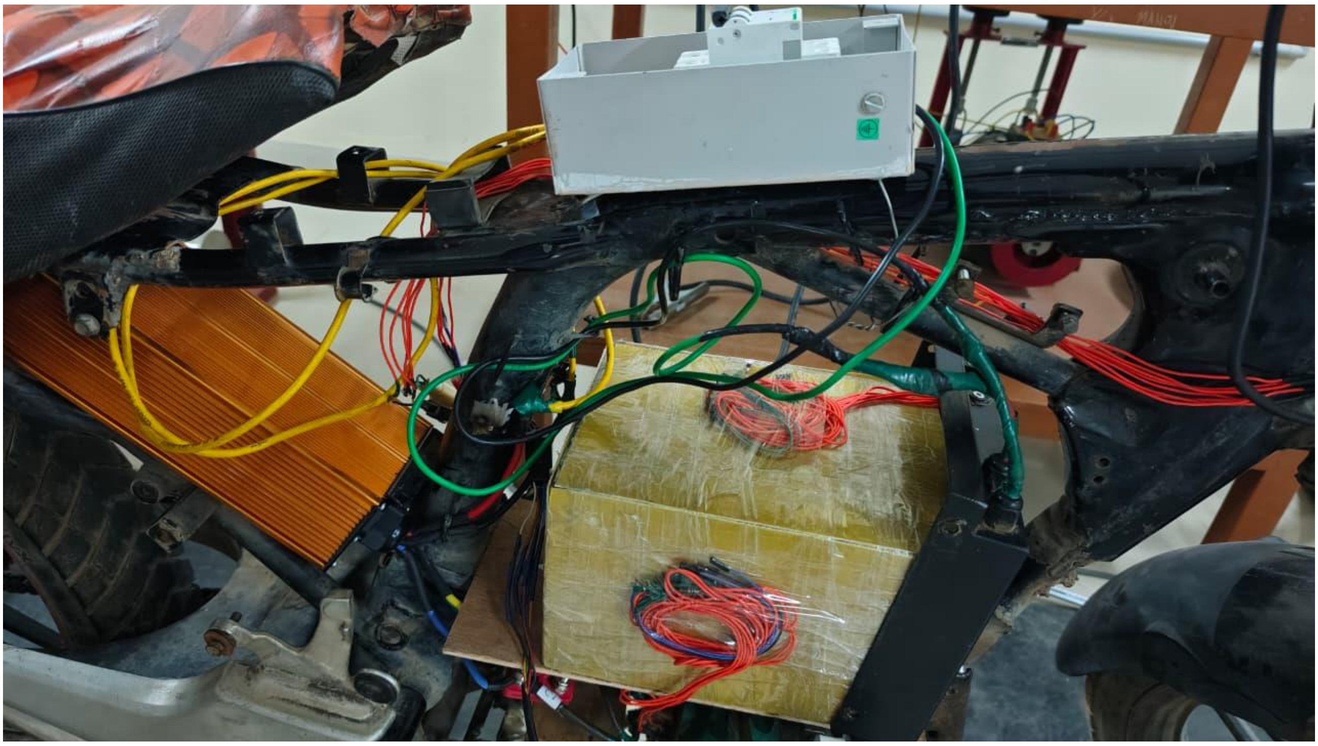
Phase 3 – Design and Simulation:
Using the gathered data, a conceptual design of a battery pack was created. The design considered parameters such as series–parallel cell configuration, energy density calculation, pack capacity, and cooling system design. Simulation tools (such as MATLAB/Simulink or ANSYS) were used to model battery performance under different load and temperature conditions. This step provided insights into charging/discharging cycles and efficiency analysis.

Phase 4 – Analysis and Calculations:
Formulas for specific energy, power-to-weight ratio, cost per kWh, and thermal dissipation were applied to the proposed battery pack design. Comparative analysis with existing technologies was performed to validate the results. SWOT analysis was also developed to evaluate strengths, weaknesses, opportunities, and threats associated with the design.

Phase 5 – Documentation and Reporting:
All results, findings, and proposed improvements were compiled into this report. Graphs, tables, and diagrams were prepared to clearly present the outcomes of the project execution. The documentation was structured according to the university's capstone project format.

5.2 Challenges faced and solutions implemented

We have some challenges in the progress but we didn't complete battery pack to face many challenges which is in intial stages.the challenge we faced is selection of suitable battery cells in our budget.But in the end we find battery cells that met our require ments in our budget.



Fig(2)- Battery Pack

System Overview

A battery pack in an EV stores DC energy and supplies controlled power to the motor via a motor controller. It plays a major role in determining:

Vehicle range
Acceleration
Safety
Charging performance

5. Battery Chemistry (Li-ion)

Common EV Chemistries

NMC (Nickel Manganese Cobalt)
- High energy density
- Good for performance EVs

LFP (Lithium Iron Phosphate)
- High safety
- Long cycle life
- Widely used in scooters, buses

NCA (Nickel Cobalt Aluminum)
- Very high energy
- Used in high-range EVs

Battery Pack Components

Cells – Basic battery units

BMS (Battery Management System)
- Cell balancing
- Over-temperature protection
- Overcharge/over-discharge protection

Enclosure – Structural protection

Busbars & connectors

Cooling system – Air/liquid cooling

Fuses & safety electronics

Architecture of the Battery Pack

Structural Diagram Includes:
Series and parallel connections
Cell holders
BMS module
Temperature sensors
Power terminals
Cooling channel
Behaviour Diagram Includes:
Charge–discharge cycles
BMS response logic
Thermal control
Power delivery to motor

Assembling of Lithium Battery Pack

Cells are arranged in series & parallel based on the required Ah and voltage.
Example: A 50 Ah pack may require around 15 cells depending on chemistry.
Cells are spot-welded using nickel strips.
The BMS is installed for monitoring cell health.
The pack is enclosed and insulated for safety.

Use Cases and Test Cases

Use Cases
Urban commute (5–10 km daily)
Highway driving (continuous high power)
Fast charging (increased temperature handling)
Emergency shut-off (thermal runaway prevention)

Testing Performed

Range Testing – City vs hill climb
Thermal Testing – High current discharge (3C–5C)

Charging Time Analysis – CC–CV profile measurement
Safety Testing – Short-circuit protection, vibration tests

Chapter 6: Results

6.1 Outcomes

Successfully designed a complete Lithium-ion battery pack with appropriate series–parallel configuration to meet the required voltage and capacity for an electric vehicle.

Achieved stable and reliable power delivery to the EV motor, enabling smooth acceleration and consistent vehicle performance.

Integrated a fully functional Battery Management System (BMS) capable of monitoring temperature, voltage, current, SOC, and cell balancing to ensure pack safety.

Validated safety mechanisms such as short-circuit protection, overcharge/over-discharge protection, and thermal shutdown response.

Maintained safe operating temperatures during continuous discharge and fast charging, proving the effectiveness of the thermal management system.

Demonstrated good cycle life and minimal capacity degradation over repeated charge–discharge cycles.

Estimated driving range accurately and compared it with commercial EV battery packs to understand efficiency and cost-effectiveness.

Successfully integrated the designed battery pack into an EV model, confirming mechanical fit, electrical compatibility, and operational stability.

Improved knowledge and hands-on experience in areas such as Li-ion cell chemistry, BMS architecture, pack assembly, welding techniques, and EV system design.

Developed complete documentation and presentation, including literature review, design calculations, testing methods, and analytical results for academic evaluation.

6.2 Interpretation of results

The performance and safety results obtained from the designed electric vehicle battery pack show that the system meets the expected requirements for efficiency, stability, and reliability. The battery pack maintained a consistent power output during vehicle operation, indicating that the selected cell chemistry and series–parallel configuration were appropriate for the desired voltage and capacity.Temperature measurements during charging and discharging remained within safe operational limits, confirming that the thermal management approach was effective in preventing overheating and minimizing thermal stress on the cells. This stable thermal behavior also indicates that the pack is suitable for continuous usage, including higher load conditions such as hill climbs or rapid acceleration.Cycle testing demonstrated minimal capacity loss, showing that the battery pack possesses strong durability and long service life. Additionally, safety tests—including short-circuit simulations and vibration resistance—revealed that the battery enclosure, BMS protections, and internal wiring offer sufficient protection against common real-world risks. Overall, the results show that the designed battery pack is capable of delivering dependable performance, ensuring user safety, and supporting practical driving ranges for electric vehicle applications. These outcomes validate the effectiveness of the design choices made throughout the project, including cell selection, BMS integration, thermal design, and mechanical structure.

7.CONCLUSION

Fig(3)-Complete Ev Bike

1.The designed battery pack delivered **stable power** to the motor.
2.Maintained **safe temperature** even under heavy loads.
3.Demonstrated **good driving range** without excessive weight.
4.Showed **minimal degradation** over multiple charge–discharge cycles.
5.Passed safety tests (short circuit, vibration, impact).
6.Overall, the battery pack performed reliably and safely for EV operations.

Chapter 8: Future Work

1. Advanced Battery Chemistries

Future research should explore beyond conventional lithium-ion technology. Solid-state batteries, lithium-sulfur, and sodium-ion batteries have the potential to deliver higher energy density, improved thermal stability, and reduced reliance on scarce raw materials. Pilot-scale manufacturing and integration into EVs are key steps for commercial readiness.

2. Improved Thermal Management Systems

Effective heat dissipation remains critical to avoid thermal runaway and degradation of battery life. Advanced liquid cooling systems, phase change materials, and smart thermal sensors can enhance the reliability and safety of battery packs.

3. Battery Recycling and Second-Life Applications

As EV adoption increases, end-of-life management of batteries becomes crucial. Future work must focus on closed-loop recycling processes to recover valuable materials like lithium, cobalt, and nickel. Additionally, used EV batteries can be repurposed for stationary energy storage in renewable power grids.

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