COURSE NAME:	EV Battery Management System
TOTAL DURATION:	45 Hrs
MODE OF DELIVERY	PHYSICAL CLASSROOM TRAINING AT RESPECTIVE COLLEGES
TRAINER TO STUDENT RATIO:	1:50
TOTAL MARKS:	75

Table 1	
OVERALL COURSE OBJECTIVE:	1. **Analyze Battery Technologies and Chemistry**: Evaluate the principles of lithium-ion and alternative battery chemistries, and deconstruct the structural and operational characteristics of cells, modules, and battery packs to identify performance implications in EV applications. 2. **Design and Optimize BMS Architectures**: Develop and apply advanced concepts of centralized, modular, and distributed BMS architectures, and synthesize strategies for implementing critical BMS functions such as monitoring, protection, balancing, and communication. 3. **Implement Advanced Battery State Estimation Techniques**: Design and execute State of Charge (SoC), State of Health (SoH), and State of Power (SoP) estimation models to enhance battery diagnostics and predictive capabilities. 4. **Evaluate Thermal Management Systems**: Design and critically assess thermal management solutions to optimize battery safety and performance, integrating advanced methods for efficient heat dissipation and temperature regulation in EV batteries. 5. **Integrate Cell Balancing for Enhanced Performance**: Formulate and implement cell balancing methodologies that ensure uniform charge distribution, extend battery life, and maintain consistent energy output under varying operational conditions.

LEARNING OUTCOME:	1. **Demonstrate Battery Technologies**: Demonstrate the ability to critically evaluate and differentiate between various battery chemistries and configurations, assessing their suitability for specific EV applications. 2. **Design Robust BMS Systems**: Create and optimize battery management system (BMS) architectures by integrating monitoring, protection, balancing, and communication functions to meet industry standards and safety requirements. 3. **Develop and Validate State Estimation Models**: Construct and validate accurate State of Charge (SoC), State of Health (SoH), and State of Power (SoP) estimation models, leveraging advanced analytical and computational techniques for improved battery management. 4. **Optimize Thermal Management Strategies**: Design and implement innovative thermal management systems, applying engineering principles to enhance battery safety, efficiency, and performance under diverse operating conditions. 5. **Apply Advanced Cell Balancing Techniques**: Devise and execute cell balancing strategies that improve energy consistency and longevity in battery systems, demonstrating proficiency in addressing real-world challenges in battery pack operations.

TABLE 2: MODULE-WISE COURSE CONTENT AND OUTCOME				
SL. NO	**MODULE NAME**	**MODULE CONTENT**	**MODULE LEARNING OUTCOME**	**DURATION (HRS)**
1	Fundamentals of Lithium-Ion Batteries and Performance Factors	1. Lithium-Ion Battery Chemistry 2. Battery Parameters 3. Battery Performance	1. **Analyze** the chemical composition and properties of lithium-ion batteries to determine their suitability for EV	8 Hrs

		Factors 4. Thermal Behavior of Li-Ion Cells	applications. 2. **Evaluate** key battery parameters such as capacity, voltage, and energy density, and correlate them with performance outcomes. 3. **Assess** the factors influencing battery efficiency and longevity, including charge-discharge cycles and thermal behavior. 4. **Design** basic strategies to mitigate performance degradation under varying operational conditions.	
2	Battery Cell Balancing and Thermal Manageme nt	1. Importance of Cell Balancing 2. Types of Balancing 3. Cell Balancing Algorithms 4. Balancing Circuit Design 5. Thermal Management Strategies	1. **Design** effective cell balancing techniques, including passive and active balancing, to optimize battery performance. 2. **Develop** algorithms and circuit designs for efficient cell balancing in multi-cell battery	9 Hrs

		6. Heat Generation and Dissipation	packs. 3. **Evaluate** the impact of thermal management strategies on the safety, performance, and lifespan of lithium-ion batteries. 4. **Integrate** thermal behavior modeling with heat dissipation techniques to improve system reliability under extreme conditions.	
3.	Battery Management Systems and Architecture	1. Overview of Battery Technology in EVs 2. Role and Importance of a BMS 3. BMS Components 4. Types of BMS Architectures 5. BMS Topology in EVs 6. Battery Pack Design and Integration	1. **Design** a comprehensive battery management system (BMS) incorporating components like sensors, controllers, and communication modules. 2. **Analyze** different BMS architectures (centralized, modular, and distributed) and determine their application-specific advantages. 3. **Synthesize** battery pack designs with	10 Hrs

			appropriate integration of BMS components to meet safety and performance standards. 4. **Critically evaluate** BMS topologies for their adaptability and scalability in electric vehicle systems.	
4	State Estimation Techniques and Diagnostics	1. State of Charge (SoC) Estimation 2. State of Health (SoH) Estimation 3. State of Power (SoP) Estimation 4. Diagnostics and Fault Detection Data Acquisition and Signal Processing	1. **Develop** and validate accurate models for State of Charge (SoC), State of Health (SoH), and State of Power (SoP) estimation using computational tools. 2. **Apply** diagnostic techniques to identify and predict faults within battery systems, ensuring proactive maintenance. 3. **Evaluate** data acquisition and signal processing methods for precise monitoring of battery voltage, temperature, and current. 4. **Create** fault-detection	10 Hrs

			algorithms that enhance battery reliability and performance under diverse operating conditions.	
5.	Advanced Monitoring and Circuit Design	1. Voltage, Temperature, and Current Sensing 2. Electrical Circuit Design for BMS 3. Thermal Modeling	1. **Design** advanced electrical circuits for battery monitoring systems, ensuring compatibility with real-time sensing technologies. 2. **Integrate** voltage, temperature, and current sensing mechanisms with BMS for accurate performance tracking. 3. **Construct** thermal models that predict and mitigate overheating risks in complex battery systems. 4. **Optimize** the interaction between sensing and control units to improve overall battery performance and efficiency.	8 Hrs

TABLE 3: OVERALL COURSE LEARNING OUTCOME ASSESSMENT CRITERIA AND USE CASES			
LEARNING OUTCOME	**ASSESSMENT CRITERIA**	**PERFORMANCE CRITERIA**	**USE CASES**
1. Working principle of lithium-ion cells (anode, cathode, electrolyte, separator). 2. Characteristics of Li-ion batteries (energy density, thermal stability, cycle life) 3. Voltage, current, state of charge (SoC), state of health (SoH), depth of discharge (DoD), and temperature 4. Impact of temperature, charging rate, and discharge cycles on battery performance	Demonstrates the ability to use BMS data to analyze battery health and identify early signs of degradation. 1.Data Analysis: Interprets SoC and cycle life data to assess battery usage patterns and schedule timely maintenance. 2.Predictive Modeling: Creates predictive maintenance schedules using analytical tools based on degradation patterns and usage cycles. 3.Implementation Strategy: Proposes actionable maintenance plans aligned with fleet operational demands.	1.Monitoring Accuracy: Accurately monitors and records SoC, voltage, and temperature data from the BMS of a fleet vehicle over a defined period. 2.Fault Prediction: Successfully predicts potential battery degradation issues based on historical and real-time usage data. 3.Maintenance Scheduling: Develops a well-structured maintenance plan incorporating predictive analysis, demonstrating a reduction in downtime. 4.Optimization Impact: Evaluates the effectiveness of the predictive maintenance strategy by	**Fleet Management and Predictive Maintenance** BMS plays a critical role in monitoring battery health, state of charge (SoC), and cycle life in fleet vehicles. Through predictive maintenance, BMS can analyze battery degradation patterns and usage cycles to schedule maintenance before issues arise

		comparing performance metrics before and after implementation.	
1.Prevent overcharging and undercharging, improving lifespan, and ensuring uniform performance. 2. Passive balancing vs. active balancing. 3. Algorithms for efficient balancing based on cell voltages and SoC. 4. Design and implementation of circuits for cell balancing in EV battery packs	1.Thermal Behavior Analysis: Demonstrates the ability to analyze thermal behavior in high-performance EV batteries during rapid discharge scenarios. 2.System Design: Designs a thermal management strategy leveraging BMS to regulate temperature effectively during high-speed operations. 3.Integration of Thermal Models: Develops and applies thermal models to predict heat generation and dissipation accurately under dynamic conditions. 4.Safety and Performance Evaluation: Evaluates the impact of implemented thermal management strategies on	1.Temperature Monitoring: Accurately monitors and records temperature variations in EV batteries during high-power discharges using BMS data. 2.Heat Dissipation Strategies: Designs and implements cooling or heat dissipation systems that maintain the battery within safe operational temperature limits. 3.Thermal Model Accuracy: Creates thermal models that successfully predict temperature fluctuations under varying load conditions, validated against experimental data. 4.Performance Improvement: Demonstrates an improvement in	**Thermal Management in High-Performance Evs** High-performance EVs generate significant heat due to the rapid discharge of power. BMS monitors and regulates battery temperature using thermal management systems to ensure safe operating conditions, improving performance during high-speed driving

	battery safety and performance metrics.	battery safety and sustained performance during high-speed driving through effective thermal management. 5.Operational Safety: Ensures the system operates within industry safety standards, mitigating risks of overheating and thermal runaway	
1. Types of batteries used in EVs (Lithium-Ion, Solid-State, etc.). 2. Basics of battery chemistry, cell structure, and charging/discharging processes. 3. Functions of a BMS: protection, monitoring, and balancing. 4. Safety and reliability factors in EV batteries. 5.Learning on sensors, microcontrollers, communication interfaces, and power management circuits	1. Battery Types: Demonstrates the ability to differentiate between lithium-ion, solid-state, and other battery types, identifying their applications in EVs. 2. Battery Chemistry: Analyze the basics of battery chemistry, including cell structure and charging/discharging processes. 3.BMS Functions: Identifies and explains the functions of a BMS, such as protection, monitoring, and balancing.	1.Battery Type Identification: Accurately identifies battery types and evaluates their advantages and limitations for specific EV applications. 2.Battery Chemistry Application: Examine the impact of cell chemistry and structure on battery performance and efficiency in EVs. 3.BMS Functions Evaluation: Demonstrates the ability to design or simulate a simple BMS system incorporating	

	4.Application of Safety Concepts: Demonstrates safety and reliability considerations in EV batteries, including sensor and circuit integration.	protection, monitoring, and balancing features. 4.Sensor and Circuit: Integrates sensors, microcontrollers, and communication interfaces into a basic power management circuit for battery monitoring.	
1. Techniques for SoC estimation: coulomb counting, open-circuit voltage, and model-based estimation. 2. Methods to monitor battery degradation and predict end-of-life. 3. Parameters affecting SoH: capacity fade, impedance growth. 4. Estimating power availability based on battery conditions and application needs.	1.SoC Estimation Techniques: Applies coulomb counting, open-circuit voltage, and model-based methods for estimating SoC. 2.Battery Degradation Monitoring: Demonstrates techniques to monitor battery degradation and predict end-of-life accurately. 3.Analysis of SoH Parameters: Evaluates capacity fade and impedance growth to determine battery health. 4.Power Availability Estimation: Estimates	1.SoC Calculation: Correctly implements SoC estimation techniques in simulated or real-world scenarios. 2.Degradation Tracking: Analyzes degradation patterns using BMS data and proposes maintenance schedules based on end-of-life predictions. 3.Health Parameter Evaluation: Correlates capacity fade and impedance growth to operational performance and proposes	

	available power based on battery conditions and application needs.	corrective actions. 4.Power Prediction Accuracy: Uses analytical tools to accurately predict power availability under various operational conditions.	
1. How temperature affects battery performance and safety. 2. Passive cooling, active cooling (liquid, air), and phase-change materials. 3. Use of thermal models to predict and manage cell temperatures. 4. Design considerations for heat generation during charge/discharge cycles.	1.Impact of Temperature: Explains how temperature variations affect battery performance and safety. 2.Cooling Techniques: Compares passive cooling, active cooling (liquid and air), and phase-change materials for thermal management. 3.Thermal Model Usage: Develops and applies thermal models to predict cell temperature during charge/discharge cycles. 4.Heat Generation Design: Designs strategies to manage heat generation	1.Temperature Analysis: Accurately assesses the effects of temperature on battery performance using case studies or real-time data. 2.Cooling Strategy Selection: Selects and justifies the most suitable cooling technique for a given EV application scenario. 3.Thermal Model Implementation: Creates and validates thermal models to predict temperature changes under varying operating conditions. 4.Heat Mitigation Design: Designs an efficient	

	during battery operation.	thermal management system that minimizes heat-related performance issues during operation.	
1. Importance of precise sensing and monitoring for safe operation. 2. Methods for measuring voltage, current, and temperature. 3. How BMS collects and processes data from sensors. 4. Methods for detecting common faults (over-voltage, under-voltage, overheating). 5. Algorithms for fault detection and error reporting.	Compatibility Assessment: Demonstrates the ability to use BMS data to verify the compatibility of battery packs with different EV models and swapping stations. SoC Analysis: Accurately evaluates the State of Charge (SoC) of individual battery packs to ensure readiness for deployment. Health Monitoring: Analyzes battery health parameters (State of Health, temperature, cycle count) to determine the suitability of batteries for reuse or replacement. Modular Integration: Designs a system for managing	Battery Health Evaluation: Monitors and identifies battery packs with suboptimal health or potential faults, ensuring only functional batteries are deployed. SoC Compatibility: Confirms that swapped battery packs have sufficient charge levels to meet immediate operational needs without overloading or underutilizing resources. Swapping Process Automation: Demonstrates the use of BMS for automating battery compatibility checks, reducing swapping time, and minimizing manual intervention. System Scalability: Designs and	**Battery Swapping and Modular Battery Management** In EV battery swapping stations, BMS is used to monitor the health, SoC, and compatibility of individual battery packs. It ensures that only fu

	modular battery packs in real-time to support seamless swapping operations. Operational Efficiency Evaluation: Assesses the efficiency and reliability of battery swapping processes based on BMS integration and usage data.	tests a modular BMS system that can efficiently manage multiple battery packs across various vehicle types and swapping stations. Safety Assurance: Ensures swapped batteries meet safety and thermal standards during installation, transport, and operation.	

TABLE 4: LIST OF FINAL PROJECTS THAT COMPREHENSIVELY COVER ALL THE LEARNING OUTCOME		
SL. NO	**FINAL PROJECT**	
1.	Battery Cell Balancing Circuit Design	1. Design effective cell balancing techniques, including passive and active balancing, to optimize battery performance. 2. Create fault-detection algorithms that enhance battery reliability and performance under diverse operating conditions. 3. Design advanced electrical circuits for battery monitoring systems, ensuring compatibility with real-time sensing technologies.
2.	State of Charge (SoC) Estimation Model	1. Develop and validate accurate models for State of Charge (SoC), State of Health (SoH), and State of Power (SoP)

		estimation using computational tools. 2. Evaluate data acquisition and signal processing methods for precise monitoring of battery voltage, temperature, and current. 3. Integrate voltage, temperature, and current sensing mechanisms with BMS for accurate performance tracking.
3.	Thermal Management System Prototype	1. Evaluate the impact of thermal management strategies on the safety, performance, and lifespan of lithium-ion batteries. 2. Integrate thermal behavior modeling with heat dissipation techniques to improve system reliability under extreme conditions. 3. Construct thermal models that predict and mitigate overheating risks in complex battery systems.
4.	Battery Fault Detection System	1. Apply diagnostic techniques to identify and predict faults within battery systems, ensuring proactive maintenance. 2. Create fault-detection algorithms that enhance battery reliability and performance under diverse operating conditions. 3. Design advanced electrical circuits for battery monitoring systems, ensuring

		compatibility with real-time sensing technologies.
5.	Battery Pack Capacity Estimation	1. Evaluate key battery parameters such as capacity, voltage, and energy density, and correlate them with performance outcomes. 2. Synthesize battery pack designs with appropriate integration of BMS components to meet safety and performance standards. 3. Develop and validate accurate models for State of Charge (SoC), State of Health (SoH), and State of Power (SoP) estimation using computational tools.
6.	Battery Life Prediction	1. Assess the factors influencing battery efficiency and longevity, including charge-discharge cycles and thermal behavior. 2. Develop and validate accurate models for State of Charge (SoC), State of Health (SoH), and State of Power (SoP) estimation using computational tools. 3. Apply diagnostic techniques to identify and predict faults within battery systems, ensuring proactive maintenance.
7.	Integration with EV Systems	1. Design a comprehensive battery management system (BMS) incorporating components like sensors, controllers, and

		communication modules. 2. Analyze different BMS architectures (centralized, modular, and distributed) and determine their application-specific advantages. 3. Critically evaluate BMS topologies for their adaptability and scalability in electric vehicle systems.
8.	Battery Pack Modelling	1. Synthesize battery pack designs with appropriate integration of BMS components to meet safety and performance standards. 2. Construct thermal models that predict and mitigate overheating risks in complex battery systems. 3. Optimize the interaction between sensing and control units to improve overall battery performance and efficiency.
9.	Battery Pack Energy Efficiency Analysis	1. Evaluate key battery parameters such as capacity, voltage, and energy density, and correlate them with performance outcomes. 2. Assess the factors influencing battery efficiency and longevity, including charge-discharge cycles and thermal behavior. 3. Optimize the interaction between sensing and control units to improve overall battery performance and

		efficiency.
10	Overcurrent Protection System	1. Design a comprehensive battery management system (BMS) incorporating components like sensors, controllers, and communication modules. 2. Create fault-detection algorithms that enhance battery reliability and performance under diverse operating conditions. 3. Integrate voltage, temperature, and current sensing mechanisms with BMS for accurate performance tracking.

TABLE 5: COURSE ASSESSMENT RUBRICS (TOTAL MARKS: 75)				
ASSESSMENT CRITERIA	**DESCRIBE THE CRITERIA OF THE BELOW CATEGORY PERFORMANCE**			
	FAIR (1-5 Marks)	**GOOD (6-10 Marks)**	**EXCELLENT (11-15 marks)**	**Total Marks**
Demonstrate Battery Technologies	Analyze basic components and properties of lithium-ion batteries.	Illustrate the factors affecting battery efficiency with examples.	Analyze and evaluate how lithium-ion battery properties influence EV applications.	15
Design Robust BMS Systems	Exhibit basic cell balancing and thermal management concepts.	Illustrate methods for implementing basic cell balancing and temperature control strategies.	Design and optimize innovative solutions for cell balancing and thermal management in EVs.	15
Develop and Validate State	Recognize primary components	Develop a BMS architecture with proper	Evaluate and optimize a comprehensive	15

Estimation Models	of a BMS architecture.	monitoring and protection functions.	BMS architecture meeting industry standards.	
Optimize Thermal Management Strategies	Analyze definitions of SoC, SoH, and SoP estimation techniques.	Apply state estimation models for basic diagnostics and performance analysis.	Construct and validate advanced state estimation models using computational techniques.	15
Apply Advanced Cell Balancing Techniques	Develop key elements in battery circuit design	Develop a battery circuit with standard monitoring features.	Innovate and implement advanced monitoring systems with enhanced safety and efficiency features.	15