DEPARTMENT OF MECHANICAL ENGINEERING

Course Book for

M. Tech. in

Electric Vehicle Technology

For

<u>Academic Year</u>
<u>2023 - 2024</u>

Visvesvaraya National Institute of Technology,

Nagpur-440 010 (MH)

Institute Vision Statement

To contribute effectively to the National and International endeavour of producing quality human resource of world class standard by developing a sustainable technical education system to meet the changing technological needs of the Country and the World incorporating relevant social concerns and to build an environment to create and propagate innovative technologies for the economic development of the Nation.

Institute Mission Statement

The mission of VNIT is to achieve high standards of excellence in generating and propagating knowledge in engineering and allied disciplines. VNIT is committed to providing an education that combines rigorous academics with joy of discovery. The Institute encourages its community to engage in a dialogue with society to be able to effectively contribute for the betterment of humankind.

Department Vision Statement

To produce quality human resource of high standard in mechanical engineering who can contribute favorably to the technological and socio-economic development of the nation.

Department Mission Statement

To develop state of the art facilities related to mechanical engineering. To attract highly qualified faculty to the mechanical engineering department. To promote participation of industries in academics, research and consultancy. To undertake research at regional and national level.

Brief about Mechanical Department

Department of Mechanical Engineering is one of the oldest department started in 1960, currently department is offering 1 UG and 4 PG programmes. Faculty members of the department are highly motivated for teaching and conducting research in the diversified fields of mechanical engineering.

List of Faculty Members

Sr No	Faculty Name	Areas of specialization
1	Dr. A. S. Dhoble	Thermal Engineering
2	Dr. Ritesh Keshri	Electrical Engineering
3	Rahul Bagdia	Policy, Regulations & Energy
4	Vikrant Vaidya	Vehicle Integration & 1-D Simulation
5	Dr. Kamal Vora	EV Verification & Validation
6	Dr. Jose Biona (Manny)	EV Design & Prototyping
7	Hemant Padhye	Program Management
8	Vivek Sahasrabuddhey	EV Value Chain
9	Dr. Raghavendra G	Vehicle Electronics & Telematics

UG/ PG Programmes Offered by Mechanical Department:

The department offers following undergraduate and postgraduate programmes

	Program	Description
UG	B. Tech in Mechanical Engineering	Intake: 115
PG	M. Tech. in 1. Computer Aided Design & Manufacturing 2. Industrial Engineering 3. Heat Power Engineering 4. Engineering Aided Medical Science (Interdisciplinary) 5. Electric Vehicle Technology – Online (Interdisciplinary)	 Intake : 23 Intake : 23 Intake : 23 Intake : 14 Intake : 50

Credit System at VNIT:

Education at the Institute is organized around the semester-based credit system of study. The prominent features of the credit system are a process of continuous evaluation of a student's performance / progress and flexibility to allow a student to progress at an optimum pace suited to his/her ability or convenience, subject to fulfilling minimum requirements for continuation. A student's performance/progress is measured by the number of credits he/she has earned, i.e. completed satisfactorily. Based on the course credits and grades obtained by the student, grade point average is calculated. A minimum number of credits and a minimum grade point average must be acquired by a student in order to qualify for the degree.

Course credits assignment

Each course, except a few special courses, has certain number of credits assigned to it depending on lecture, tutorial and laboratory contact hours in a week.

For Lectures and Tutorials: One lecture hour per week per semester is assigned one credit and

For Practical/ Laboratory/ Studio: One hour per week per semester is assigned half credit.

Example: Course XXXXXX with (3-0-2) as (L-T-P) structure, i.e. 3 hr Lectures + 0 hr Tutorial + 2 hr Practical per week, will have (3x1 + 0x1 + 2x0.5 =) 4 credits.

Grading System

The grading reflects a student's own proficiency in the course. While relative standing of the student is clearly indicated by his/her grades, the process of awarding grades is based on fitting performance of the class to some statistical distribution. The course coordinator and associated faculty members for a course formulate appropriate procedure to award grades. These grades are reflective of the student's performance vis-à-vis instructor's expectation. If a student is declared pass in a subject, then he/she gets the credits associated with that subject.

Depending on marks scored in a subject, a student is given a Grade. Each grade has got certain grade points as follows:

Grade	Grade points	Description
AA	10	Outstanding
AB	9	Excellent
BB	8	Very good
BC	7	Good
CC	6	Average
CD	5	Below average
DD	4	Marginal (Pass Grade)
FF	0	Poor (Fail) /Unsatisfactory / Absence from end-sem exam
NP	-	Audit pass
NF	-	Audit fail
SS	-	Satisfactory performance in zero credit core course
ZZ	-	Unsatisfactory performance in zero credit core course
W	-	Insufficient attendance

Performance Evaluation

The performance of a student is evaluated in terms of two indices, viz, the Semester Grade Point Average (SGPA) which is the Grade Point Average for a semester and Cumulative Grade Point Average (CGPA) which is the Grade Point Average for all the completed semesters at any point in time. CGPA is rounded up to second decimal.

The Earned Credits (ECR) are defined as the sum of course credits for courses in which students have been awarded grades between AA to DD. Grades obtained in the audit courses are not counted for computation of grade point average.

Earned Grade Points in a semester (EGP) = **Σ** (Course credits x Grade point) for courses in which AA- DD grade has been obtained

SGPA = EGP / Σ (Course credits) for courses registered in a semester in which AA- FF grades are awarded

CGPA= EGP / Σ(Course credits) for courses passed in all completed semesters in which AA-DD grades are awarded

Overall Credits Requirement for Award of Degree of M.Tech in Electric Vehicle Technology

SN	Category of Course	Symbol	Credit Requirement M. Tech. (Electric Vehicle Technology) (2 Year)
	Program Core		
4	Departmental core	DC	**36**
	Program Elective		
3	Departmental Elective	DE	**16** (Minimum)
Total requirement : DC+ DE =			**52**
Minimum Cumulative Grade Point Average required for the award of degree			**6.00**

Attendance Rules

1. All students must attend every class and 100% attendance is expected from the students. However, in consideration of the constraints/ unavoidable circumstances, the attendance can be relaxed by course coordinator only to the extent of not more than 25%. Every student must attend minimum of 75% of the classes actually held for that course.
2. A student with less than 75% attendance in a course during the semester, will be awarded W grade. Such a student will not be eligible to appear for the end semester and re-examination of that course. Even if such a student happens to appear for these examinations, then, answer books of such students will not be evaluated.
3. A student with W grade is not eligible to appear for end semester examination, reexamination & summer term.

Program Outcomes for M. Tech (Common to all PG programmes):

a. PO1 → An ability to apply Systems Engineering principles to Electric Vehicle design, development and integration using Virtual Model-based Development.
b. PO2 → An ability to write and present a substantial technical report/document.
c. PO3 → Students should be able to demonstrate a degree of mastery over the area as per the specialization of the program. The mastery should be at a level higher than the requirements in the appropriate bachelor program.

Scheme for M. Tech EV Technology

(July – 2021 onwards)

List of core courses (DC)

Sr. No.	Course code	Course Name	Structure L-T-P-Cr	Conducted in sem (1/2/3/4)	Pre-requisite(s) and / or any other condition for registration	
					Course code	Course name
1	EVT001	Energy Sources and Powertrain Electrification - Hybrid, BEV, Fuel Cell	3-0-0-3	1		
2	EVT010	Control Systems as applied to Electric Powertrains	3-0-0-3	1		
3	EVT002	EV Systems Engineering: Design and Integration	3-0-2-4	1		
4	EVT005	EV Design Verification & Validation Planning	3-0-0-3	2		
5	EVT012	Advanced Energy Storage & Battery Systems in e-Mobility New Batteries, Ultracapacitors, Fuel Cells	3-0-0-3	2		
6	EVT011	Motors, Generators & Power Converters: Design for EVs	3-0-2-4	2		
7	EVT003	EV Modeling and Simulation for Product Development	2-2-0-4	3	EVT002	EV Systems Engineering: Design and Integration
8	EVP001	Project Phase 1	0-0-12-6	3	26 credits	
9	EVP002	Project Phase 2	0-0-12-6	4	39 credits + Project Phase 1	

List of Elective Courses (DE)

Sr. No.	Course code	Course Name	Structure L-T-P-Cr	Conducted in sem (1/2/3/4)	Pre-requisite(s) and / or any other condition for registration	
					Course code	Course name
1	MEL432	Automobile Engineering	3-0-0-3	1		
2	ESC101	Basic Electrical Engineering (Theory Only)	3-0-0-3	1		
3	EVT007	EV Thermal Management: Batteries & Motors	3-0-0-3	2		
4	EVT013	Charging & Energy Infrastructure	3-0-0-3	2		
5	EVT006	Smart Mobility: ADAS, Autonomous, Connected	3-0-0-3	3		
6	EVT014	EV Fleet Planning & Optimization	3-0-0-3	3		
7	EVT008	EV Range Extension Technologies: Hydrogen Fuel Cell & Runtime Charging	3-0-0-3	4		
8	EVT015	EV Maintenance, Safety, Salvage and Recycling	3-0-2-4	4		
9	EVT016	EV Value Chain and Circular Economy	3-0-0-3	4		
10	EVT004	EV Diagnostics and Prognostics: Leveraging IoT, Data Analytics	3-0-2-4	4		

Credits for semester wise registration of a student.
(Typical values to be mentioned, actual credits may vary from student to student).

Sr. No.	Type	I Sem	II Sem	III Sem	IV Sem	Total
1	DC	10	10	10	6	36
2	DE/OC/HM	3	3	3	7	16
	Total (per sem)	13	13	13	13	52

Odd Semester

MEL432 Automobile Engineering

3 credits (3-0-0)

Pre-requisites: Nil

Overlaps with: Nil

Course Outcomes/ Objectives:

At the end of this course students will demonstrate the ability to,

1. Understand the broad classifications of automotive vehicles.
2. Understand the function of various vehicle sub-systems.
3. Understand the various vehicle functional attributes and performance metrics.
4. Identify & analyze various on-board energy sources of a vehicle.

Mapping with POs:

POs → / COs ↓	PO1	PO2	PO3
CO1	M	M	M
CO2	H	M	M
CO3	H	H	M
CO4	M	M	M
Overall	H	M	M

Content:

Module 1: Automobiles Classification & Segmentation

Types of automobiles, vehicle construction and layouts, chassis, frame and body, vehicle aerodynamics, etc.

Module 2: IC Engines

IC engines- components, function and materials, variable valve timing (VVT). Engine auxiliary systems, electronic injection for SI and CI engines, unit injector system, rotary distributor type and common rail direct injection system, transistor-based coil ignition & capacitive discharge ignition systems, turbo chargers (WGT, VGT), engine emission control by 3-way catalytic converter system, Emission norms (Euro & BS)

Module 3: Transmissions & Drivetrain

Transmission systems, clutch types & construction, gear boxes- manual and automatic gear shift mechanisms, Over drive, transfer box, flywheel, torque converter, propeller shaft, slip joints, universal joints, differential and rear axle, Hotchkiss drive and Torque tube drive.

Module 4: Suspension, Steering, Chassis & Body

Steering geometry and types of steering gear box, power steering, types of front axle, types of suspension systems, pneumatic and hydraulic braking systems, antilock braking system (ABS), electronic brake force distribution (EBD) and traction control.

Module 5: Energy

Alternative energy sources, natural gas, LPG, biodiesel, bio-ethanol, gasohol and hydrogen fuels in automobiles, modifications needed, performance, combustion & emission characteristics of alternative fuels in SI and CI engines, Electric and Hybrid vehicles, application of Fuel Cells

Text/References:

William Crouse and Donald Anglin, Automotive Mechanics, McGraw Hill Education; 10th edition (1 July 2017)

Kirpal Singh, Automobile Engineering, 7th ed., Standard Publishers, New Delhi, 1997.

Jain K.K. and Asthana R.B., Automobile Engineering, Tata McGraw Hill, New Delhi, 2002.

Heitner J., Automotive Mechanics, 2nd ed., East-West Press, 1999.

1. Heisler H., Advanced Engine Technology, SAE International Publ., USA, 1998.

ESC101 Basic Electrical Engineering (Theory only)

3 credits (3-0-0)

Pre-requisites: Nil

Overlaps with: Nil

Course Outcomes/ Objectives:

At the end of this course students will demonstrate the ability to,

1. Understand and analyze basic electric and magnetic circuits.
2. Study the working principles of electrical machines and power converters.
3. Understand the components of low voltage electrical installations.

Mapping with POs:

POs → COs ↓	PO1	PO2	PO3
CO1	M	L	L
CO2	H	M	M
CO3	H	M	L
Overall	H	M	L

Content:

Module 1: DC Circuits

Electrical circuit elements (R, L and C), voltage and current sources, Kirchoff current and voltage laws, analysis of simple circuits with dc excitation. Superposition, Thevenin and Norton Theorems. Time-domain analysis of first-order RL and RC circuits.

Module 2: AC Circuits

Representation of sinusoidal waveforms, peak and rms values, phasor representation, real power, reactive power, apparent power, power factor. Analysis of single-phase ac circuits consisting of R, L, C, RL, RC, RLC combinations (series and parallel), resonance. Three phase balanced circuits, voltage and current relations in star and delta connections

Module 3: Transformers

Magnetic materials, BH characteristics, ideal and practical transformer, equivalent circuit, losses in transformers, regulation and efficiency. Auto-transformer and three-phase transformer connections.

Module 4: Electrical Machines

Generation of rotating magnetic fields, Construction and working of a three-phase induction motor, Significance of torque-slip characteristic. Loss components and efficiency, starting and speed control of induction motor. Single-phase induction motor. Construction, working, torque-speed characteristic and speed control of separately excited dc motor. Construction and working of synchronous generators..

Module 5: Power Converters
DC-DC buck and boost converters, duty ratio control. Single-phase and three-phase voltage source inverters; sinusoidal modulation.

Module 6: Electrical Installations
Components of LT Switchgear: Switch Fuse Unit (SFU), MCB, ELCB, MCCB, Types of Wires and Cables, Earthing. Types of Batteries, Important Characteristics for Batteries. Elementary calculations for energy consumption, power factor improvement and battery backup.

Text/References:
D. P. Kothari and I. J. Nagrath, “Basic Electrical Engineering”, Tata McGraw Hill, 2010.
D. C. Kulshreshtha, “Basic Electrical Engineering”, McGraw Hill, 2009.
L. S. Bobrow, “Fundamentals of Electrical Engineering”, Oxford University Press, 2011.
E. Hughes, “Electrical and Electronics Technology”, Pearson, 2010.
1. V. D. Toro, “Electrical Engineering Fundamentals”, Prentice Hall India, 1989..

EVT001 Energy Sources and Powertrain Electrification - Hybrid, BEV, Fuel Cell
3 credit (3-0-0)
Pre-requisites: Nil
Overlaps with: Nil
Course Outcomes/ Objectives:
At the end of this course students will demonstrate the ability to,

1. Understand the various automotive powertrain layouts and architectures.
2. Analyze and evaluate various automotive powertrain architectures against vehicle propulsion requirements.
3. Analyze and evaluate various energy sources and on-board energy storage along with their conversion devices.
4. Analyze the tank to wheel efficiency for various powertrain architectures and on-board energy storage mix.

Mapping with POs:

POs → COs ↓	PO1	PO2	PO3
CO1	M	M	M
CO2	H	M	H
CO3	H	M	H
CO4	H	H	H
Overall	H	M	H

Content:
Module 1: Basics and Evolution of ICE Powertrains
ICE basics (processes, cycles, combustion, volumetric efficiency, IP,BP & FP, etc.)

Evolution of ICE past to present by displacement, by air-induction, by other technologies
Evolution by fuels Petrol, Diesel, Blended Fuels (Ethenol, Biodiesel, etc.), CNG/LNG, Hydrogen IC engine
Evolution of emission regulations and exhaust aftertreatment technologies

Module 2: Electrification of Automotive Powertrains
ICE --> start-stop systems, Microhybrids (BAS & BAS+), Strong Hybrids (HEV), Plug-in Hybrids (PHEV)
Extended Range Electric Vehicles (EREVs), Battery Electric Vehicles (BEVs) and Fuel Cell Electric Vehicles (FCEVs)
ICE layout connstraints v/s options with motor (mid motor, eAxles, hub motors - independent wheel drive, etc.)
Need of clutch/torque converter/n-speed gearbox/differential in ICE v/s BEV
Prime-mover and driveline efficiencies (ICE v/s motor - mid, axle & hub)
Key performance attributes (starting from rest & initial vehicle movement, acceleration & deceleration, energy efficiency, energy density & range, etc.) and accessory drive
Energy Management & HEV Mode Selection Strategies (fuel consumption based cost function, etc.), Gasoline Gallon Equivalent & equivalent fuel economy (e.g. EPA MPGge)

Module 3: On-board Energy Devices
Basics of battery (electrochemistry, unit cells, modules and packs)
Future of batteries
Basics of ultracapacitors (dielectric properties, capacitor banks v/s large capacitors, etc.)
Basics of fuel cells, why PEM fuel cells
FC stacking, sizing fuel cell stacks and hydrogen tank
System efficiencies - Fossil fuel ICE v/s Hydrogen ICE v/s BEVs v/s FCEVs
Hybrid energy storage solutions

Module 4: Various Fuels
Fossil fuels: Petrol / gasoline, diesel, LPG / autogas. Properties & specifications for automotive use (RON/PON/MON, RVP, heating value, composition, etc.)
Fossil fuels extraction & refinement processes, composition of outputs of 1 barrel of crude oil
Fossil fuel storage & distribution, global reserves, supply chains and self sufficiency challenges
CNG & LNG: Properties & specifications for automotive use
Sources of CNG & reforming
CNG storage, compression + refrigeration and distribution
CNG & LNG: Tailpipe emissions & their impact v/s fossil fuels
Methanol / Ethanol / biodiesel / blended fuels. Properties & specifications for automotive use
Biofuels sources (competition with food products), storage & distribution
Biofuels: Tailpipe emissions v/s fossil fuels & CNG, impact of source on carbon capture before harvest
Hydrogen properties & specifications for automotive use

Hydrogen sources and colour coding, production (electrolysis, etc.), storage, distribution, dealing with corrosion
Hydrogen on-board storage - compression & cryo-refrigeration

Module 5: Electricity - Generation, Transmission & Distribution
Sources of electricity in fixed generation - non-renewable: Coal, Gas, Diesel, Nuclear Fission, Large Hydroelectric and Geo-thermal
Sources of electricity in fixed generation - renewable: Solar, Wind, Small Hydroelectric, Flex-fuel fuel cells (Solid Oxide Fuel Cells) and Nuclear Fusion
Transmission, Distribution & Charging: Intermittency in generation v/s demand, Base load - Peak load - Load balancing, fixed battery energy storage systems, Transmission infrastructure, distribution infrastructure, Micro-grid & off-grid systems
EV charging and supply infrastructure, Charger ratings and charging rates
Emerging on-board energy technologies - Metal-air cells, higher efficiency IC Engines (Rotary, 6-stroke??), micro-jet engines, Co-generation with ICE & fuel cells.

Module 6: Lifecycle Energy and Hybrid Energy Solutions
Introduction to Lifecycle Energy Analysis
Technology assessment based on lifecycle energy
Total energy efficiency approach
Opportunities to mix various energy sources
Optimization for minimum losses / emissions

Text/References:
1. M. Ehsani, Y. Gao and A. Emadi, “Modern Electric, Hybrid Electric and Fuel cell vehicles: Fundamentals, theory and design,” second edition, CRC Press, Taylor and Francis, 2010.
2. Energy Studies (3rd Edition) by William Shepherd (Author), David William Shepherd, 2014.
3. Special issue, “State of Art Electric Vehicle Technologies,” Proceedings of IEEE, vol. 95, no. 4, Sept 2007.

EVT010 Control Systems as applied to Electric Powertrains
3 credit (3-0-0)
Pre-requisites: Nil
Overlaps with: Nil
Course Outcomes/ Objectives:
At the end of this course students will demonstrate the ability to,
1. Understand automotive controller development process.
2. Understand various controller design specifications.
3. Design controllers to satisfy the desired design specifications using simple controller structures (P, PI, PID, compensators).
4. Design controllers using the state-space approach.

Mapping with POs:

POs → COs ↓	PO1	PO2	PO3
CO1	H	M	H
CO2	H	M	H
CO3	M	M	M
CO4	H	M	M
Overall	H	M	H

Content:

Module 1: Introduction to EV Control and Design Specifications

Various EV controllers - BMS, MCU, VCU, etc. Control strategy selection criteria. Sensors & actuators with EV examples. Virtual sensors. Automotive controller development process - model-based development, MiL, SiL, HiL. Introduction to design problem and philosophy. Introduction to time domain and frequency domain design specification and its physical relevance. Effect of gain on transient and steady state response. Effect of addition of pole on system performance. Effect of addition of zero on system response.

Module 2: Design of Classical Control System in the time domain

Introduction to compensator. Design of Lag, lead lag-lead compensator in time domain. Feedback and Feed forward compensator design. Feedback compensation. Realization of compensators. EV example for classical control system in time domain.

Module 3: Design of Classical Control System in frequency domain

Compensator design in frequency domain to improve steady state and transient response. Feedback and Feed forward compensator design using bode diagram. EV example for classical control system in frequency domain.

Module 4: Design of PID controllers

Design of P, PI, PD and PID controllers in time domain and frequency domain for first, second and third order systems. Control loop with auxiliary feedback – Feed forward control. EV example for PID controller.

Module 5: Control System Design in state space

Review of state space representation. Concept of controllability & observability, effect of pole zero cancellation on the controllability & observability of the system, pole placement design through state feedback. Ackerman’s Formula for feedback gain design. Design of Observer. Reduced order observer. Separation Principle.

Module 6: Nonlinearities and its effect on system performance

Various types of non-linearities. Effect of various non-linearities on system performance. Singular points. Phase plot analysis.

Text/References:

1. M. Gopal, “Control Systems: Principles and Design”, McGraw Hill Education, 1997. Text Book
2. B. C. Kuo, “Automatic Control System”, Prentice Hall, 1995.
3. K. Ogata, “Modern Control Engineering”, Prentice Hall, 1991.
4. I. J. Nagrath and M. Gopal, “Control Systems Engineering”, New Age International, 2009.

EVT002 EV Systems Engineering: Design and Integration

4 credits (3-0-1)

Pre-requisites: Nil

Overlaps with: Nil

Course Outcomes/ Objectives:

At the end of this course students will demonstrate the ability to,

1. Understand the need of an electric vehicle, components of the subsystems and dynamics.
2. Understand and use the control strategies for vehicle control, battery management and the required communication link.
3. Model the batteries, motor and other auxiliary loads and integration for component-wise and system level performance.
4. Analyze the use pattern and dependency on the charging infrastructure.

Mapping with POs:

POs → COs ↓	PO1	PO2	PO3
CO1	M	M	M
CO2	H	M	H
CO3	H	M	M
CO4	H	M	M
Overall	H	M	M

Content

Module 1: EV Technologies and Integration Aspects

Need of Electrical Vehicles; Traction Motors; Batteries; Regeneration; Power electronics; Vehicle systems & dynamics, ePowertrain architectures

Module 2: Energy Management & Control

Basics of control systems; Types of control strategies; Battery Management System; Motor Controllers, Vehicle Controllers; System Functional Safety.

Module 3: System Engineering Tools

Introduction to systems engineering as applied to EVs, Virtual Model Based Development; Introduction to system modelling techniques; Root Cause Analysis, & Failure Mode Effect Analysis

Module 4: Application Engineering

Legacy ICE vehicles Users v/s First time EV buyers; Individual Users v/s Fleets Vehicle Performance Attributes; Introduction to APQP; Mapping customer expectations; Data collection & analysis; Vehicle Requirements to Technical Specifications; Vehicle Performance Integration;

Module 5: Supply Chains & Supplier Qualification

ePowertrain System, Sub-System & Component Level value chains, Introduction to Global Supply Chains, Supplier Evaluation & Qualification Processes, Introduction to Supplier Quality Management

Module 6: Infrastructure Dependencies

Charging & grid liability; Charging protocols & safety; Telematics & connected vehicles; Renewable energy; EV Policies & Regulations, Introduction to EV Safety.

Laboratory 1: EV Technology Familiriazation

EV vs ICE vehicle system comparison, EV vs ICE vehicle dirving feel comparison, EV sub-systems identification on vehicle, ePowertrain physical integration aspects (packaging, cooling & ventilattion, cables, electrical connectors, controller, etc.)

Laboratory 2: ePowertrain Subsystems Familiarization

ePowertrain disassembly to sub-system level (motor, gearbox, battery, power converter, controllers - BMS, motor drive, and on-board charger), ePowertrain sub-Systems high-level characterization, EV sub-Systems reassembly

Laboratory 3: Data Acquisition on vehicles

Data collection on electric vehicle using loggers, data analysis for driver behaviour, data analysis for operating conditions, use-case creation for various functional validation

Text/References: "

1. Iqbal Husain, "Electric and Hybrid Vehicles: Design Fundamentals," CRC Press, Taylor and Francis, 2005.
2. R. Rajamani, "Vehicle dynamics and Control," second edition, Springer, 2012.
3. M. Ehsani, Y. Gao and A. Emadi, "Modern Electric, Hybrid Electric and Fuel cell vehicles: Fundamentals, theory and design," second edition, CRC Press, Taylor and Francis, 2010.

EVT003 EV Modeling and Simulation for Product Development
4 credits (2-2-0)
Pre-requisites: EVT002 EV Systems Engineering: Design and Integration
Overlaps with: Nil

Course Outcomes/ Objectives:
At the end of this course, students will demonstrate the ability to,
1. Understand the modelling of linear-time-invariant systems using transfer function and state-space representations.
2. Understand the concept of stability and its assessment for linear-time invariant systems.
3. Design simple feedback controllers.

Mapping with POs:

POs → COs ↓	PO1	PO2	PO3
CO1	H	L	H
CO2	H	L	H
CO3	M	M	M
Overall	H	L	H

Content:

Module 1: Introduction to 1-D System Model based product development.

Need of virtual system model-based development, application in EV development - requirement to vehicle specifications, competitive benchmarking studies, vehicle technical specifications to ePowertrain technical specifications, inputs required for technology selection & first sub-system sizing, sub-system and vehicle level validations, generating design and validation load cases for sub-system and components, and systems engineering dependencies

Module 2: System Modeling Basics

Approaches to system modeling - physics-based (first principle) modeling, data (math) based modeling, hybrid physics & data based modeling, static models, kinematic models, dynamic models, time-domain analysis, state-space modeling technique, parametrized models, model accuracy vs inputs required vs resources vs reusability tradeoffs

Module 3: Data Based Models in ePowertrain

Simple electric motor model from characterization data in specification sheet, battery charge capacity correction model for temperature, c-rate and State-of-Health (SoH), battery internal resistance modeling for c-rate, State-of-Charge (SoC) and SoH, Open Circuit Voltage (OCV) characteristics for temperature & SoC, road profiling and duty cycle from real-world measurements

Module 4: Physics Based Models in ePowertrain

Simple battery SoC & cell voltage model with data based correction factors, battery pack-level modeling techniques - cell imbalance, charge neutralization, impact of one bad cell, etc., motor efficiency model based on various losses - copper loss, core loss & mechanical loss estimation, vehicle longitudinal dynamics 1 & 2 wheel models, driveline modeling with finite stiffness.

Module 5: Hybrid Physics & Data Based Models in ePowertrain

Integration of battery model - physics based SoC & cell voltage models with data based corrections & compensations, vehicle road load coefficient derivation from coast down test data, various driver behaviour models from test data, integration of full vehicle model - vehicle, driver, motor, battery, road profile, duty cycle, regeneration, accessories, etc.

Module 6: Setting Up Simulations, Post-processing & Decision-making

Setting up system simulations - parametrized models for vehicles, load cases and drivers, selecting solvers & setting up solver parameters, live visualizations & data logging, post-processing results, cascading vehicle-level loads to sub-system & component level, making product decisions based on simulation results.

EVT014 EV Fleet Planning & Optimization
3 credits (3-0-0)
Pre-requisites: Nil
Overlaps with: Nil
Course Outcomes/ Objectives:
At the end of this course students will demonstrate the ability to,

1. Understand elements of EV fleets ecosystem and their interlinkages.
2. Understand how EV key elements (battery, eDrive & charging) technology & sizing affect technical feasibility.
3. Analyze and evaluate various overall fleet requirements planning, and economics.
4. Do real time problem solving and building future scenarios for desired EV operations.

Mapping with POs:

POs → COs ↓	PO1	PO2	PO3
CO1	M	L	M
CO2	H	M	H
CO3	H	M	H
CO4	H	M	H
Overall	H	M	H

Content:
Module 1: Basics of EV Fleets

Electric vehicle basics, personal shared mobility fleets, e-commerce delivery fleets, public & private bus fleets, individual subscribed to fleets, data collection on fleet vehicle using tracking systems or mobile phone GPS logging, data analysis for route characterization, data analysis for driver behaviour & operating conditions.

Module 2: Fleet Modeling

Introduction to fleet modelling & tools, vehicle energy modeling, route planning, 1-Bus 1-Route scheduling, battery technology selection & pack sizing, 1-Route fleet scheduling, charger selection & scheduling, charging & energy infrastructure sizing.

Module 3: EV Fleet Disruptions

Vehicle disruptions, route disruptions, power disruptions, technological disruptions, change in regulations & policies, modeling vehicle & route disruptions, modeling power and technological disruptions.

Module 4: EV Adoption in Existing Fleets

Electric vs ICE vehicles, vehicle specs from requirements, new EVs vs ICE vehicle conversion, mixed fleet dynamics, modeling mixed fleet operations.

Module 5: Cost Analysis

Various fleet revenue models, capital expenses, operating expenses, Total Cost of Ownership (TCO), financing models, introduction to cost analysis tools – revenues, expenses, etc., TCO modeling for various types of fleets and vehicle segments.

Text/References:

Schenzen City public transport fleet electrification study report SBG

EV fleet deployment study reports by pManifold in Pacific islands, Philippines, India,

Kazakhstan, Ghana, Zimbabwe, Turkey, etc.

Trans-Jakarta public transport fleet electrification study report by ITDP.

EVT006 Smart Mobility: ADAS, Autonomous, Connected
3 credits (3-0-0)
Pre-requisites: Nil
Overlaps with: Nil
Course Outcomes/ Objectives:
At the end of this course students will demonstrate the ability to

1. Identify and analyze effectiveness of various Advanced Driver Assist Systems (ADAS) functions.
2. Understanding basics concepts of automation such as AI, DL, ML, etc. as applied to autonomous driving.
3. Map various individual ADAS functions to specific requirements of autonomous driving and perform system-level integration.
4. Understand the functional risks and legal challenges around autonomous driving and their possible mitigation.

Mapping with POs:

POs → COs ↓	PO1	PO2	PO3
CO1	M	M	H

CO2	M	M	M
CO3	H	M	H
CO4	H	M	H
Overall	H	M	H

Content:

Module 1: Introduction to Autonomous Driving

Understanding Driver Functions: Basic automotive driver controls (steering, accelerator, brake, clutch and gearshift, indication systems, etc.), co-ordination of various driver controls, impact of automation of individual functions already achieved in road vehicles (auto-gearshift, traction control, brake and steering correction, etc.)

Safety critical aspects of driving - collision prevention, adaptation to abnormal road adhesion, critical indicators to others on the road, manual power off in case of emergencies, etc.

Module 2: Advanced Driver Assist Systems (ADAS)

Evolution of ADAS, major ADAS modules - Alerts and Warnings, Crash Mitigation, Driving Task Assistance, Visual and Environmental Monitoring - and their individual functionalities, interactions and synergies between various ADAS functionalities, integration challenges and current ADAS deployments

Driver preferences and self-tuning functions, impact of self-tuning systems on ADAS integration and functional safety.

Module 3: Basics of Driver Automation and Mapping ADAS Functions

Introduction to Artificial Intelligence (AI), Deep Learning (DL) and Machine Learning (ML), Clustering, Reinforcement Learning, Logical Reasoning, PAC Learning, etc. as applied to Autonomous Driving

Intelligent Decision-Making and Motion Planning

ADAS Vision System

3D plans to Visual Odometry

Environmental modeling: lights, shadows, materials and textures

Object Detection, Tracking and Trajectory Prediction

Lane Detection, Prediction, and Path Planning

Artificial Detection and Ranging Methods (LIDAR, RADAR, GNSS, etc.)

Multi-agent Systems

Decision Arbitration Techniques - Cost Functions, safety-related overrides, etc.

Module 4: Autonomous Vehicles - Policies and Regulations

ADAS and AV Legal Issues and Liabilities: Human Factors of Automated Driving Systems, Legal Issues Surrounding Cyber Security and Privacy on Automated Vehicle

Cooperative Intelligent Transport Systems (C-ITS) Standards, Localized Vehicle

Communications (V2X), ADAS standards and regulations, etc.
Legal framework and experiments: The notion of the "driver", ""Custodian"", ""Autonomy"" and ""Liability"", Self-driving vehicle insurance, need for uniform regulation.

Text/References:

1. Abdelaziz Bensrhair and Thierry Bapin, "From AI to Autonomous and Connected Vehicles: Advanced Driver-Assistance Systems (ADAS)", Wiley-ISTE, September 2021
2. Amit Kumar Mondal & Lentin Joseph ""Autonomous Driving and Advanced Driver-Assistance Systems (ADAS): Applications, Development, Legal Issues, and Testing"", CRC Press; 1st edition (16 December 2021)
3. Yan Li & Hualiang Shi, ""Advanced Driver Assistance Systems and Autonomous Vehicles: From Fundamentals to Applications"", Kindle Edition

EVP001 Project Phase – I: Problem Definition and Approach & Methodology
6 credits
Pre-requisites: 26 credits
Overlaps with: Nil
Course Outcomes/ Objectives:

1. To identify product development decision or operational problem.
2. To review literature for best practices.
3. To present research report.
4. To present approach and methodology to enable the decision or solve the problem.

Mapping with POs:

POs → COs ↓	PO1	PO2	PO3
CO1	M	L	L
CO2	L	H	H
CO3	M	H	H
CO4	M	H	H
Overall	M	H	H

Even Semester

EVT005 EV Design, Verification & Validation Planning

3 credits (3-0-0)

Pre-requisites: Nil

Overlaps with: Nil

Course Outcomes/ Objectives:

At the end of this course students will demonstrate the ability to

1. Understand the industry followed processes and practices for vehicle development and validation.
2. Understand various types of verification and validation testing including virtual validation techniques.
3. Collect and analyze real-world usage data and extract design and validation load cases.
4. Design a complete validation & verification plan and align it with vehicle development process.

Mapping with POs:

POs → COs ↓	PO1	PO2	PO3
CO1	H	L	H
CO2	M	M	H
CO3	H	M	H
CO4	H	M	H
Overall	H	M	H

Content:

Module 1: Introduction to Vehicle Development Process

Vehicle development process, ePowertrain development process, APQP (Advanced Product Quality Planning), PPAP (Production Part Approval Process), Program Management, Product Development Processes, etc.

Introduction to DVVP & vehicle validation planning and Failure Mode Effect Analysis (FMEA)

Module 2: Types of Verification and Validation

Vehicle Level: Functional integration tests, regulatory compliance tests, on-road durability tests, hot & cold climate tests, endurance tests, reliability tests, etc.

Sub-system Level: Functional integration tests, regulatory compliance tests, bench durability tests, endurance tests, reliability tests, etc.

Component Level: Materiel tests, rig durability tests, endurance tests, reliability tests, etc.

Controllers: Compliance, Hardware tests - HiL (Hardware-in-Loop), sensors and actuators reliability & robustness, Software tests - SiL (Software-in-Loop) & MiL (Model-in-Loop), Unit functionality testing, FTA & System FMEA, etc.

Module 3: Mapping Representative Usage Patterns

Data Acquisition: Different types of RLDA (Road Load Data Acquisition) systems, on-board sensors, add-on sensors and instrumentation, calibration of sensors, need of real-world usage data, ways to collect real world usage data, etc.
Basics of Statistical Analysis: Terms and definitions, probability distrubution function, binning, confidence level, error margins, sample sizing for finite and infinite population, etc.
Data Clean-up and post processing: Channel synchronization, identifying data errors, data clean up, introduction to data filtration and analysis

Module 4: Design of Validation Tests

Usage pattern Analysis: Using real-world usage data to profile driving patterns, operating conditions like terrain, water, dust, road surface, ambient temperature, humidity, etc. Working out percentile patterns and selection of representative percentiles for each profile.
Sub-system Characterization: Motor, battery, power converters, etc. characterization tests, verification of technical specifications, validation against sub-system compliance requirements, incorporating standards and best practices into validation tests
Sub-system & Component Loads: Cascading selected percentile vehicle usage patterns to motor, transmission, battery and power converter requirements, using sub-system loads derived from vehicle usage patterns to create component design loads & duty cycles. Finalizing high & low cycle fatigue loads, abuse loads, cycles accumulation rates with respect to vehicle distance accumulation
Failure Mode Based & Accelerated Validation: Analyzing influence of different loads and cycles on various failure modes, designing failure mode-specific validation tests and test segments, identifying high impact and high probability loads and incorporating them into the validation tests, establishing equivalence of vehicle distance covered in accelerated validation test to real-world vehicle distance accumulation.

Module 5: Complete DVVP Plan, Key Milestones and Result Interpretation

Assembling the complete DVVP plans - vehicle level, sub-system level and component level, aligning it with the Product Development Plans, leveraging virtual validation tools and techniques for right design of experiments, virtual validation plans, choice of appropriate product build (prototype) maturity for specific physical validation tests, key linkages to compliance and certifications tests, captive validation fleet optimization.
Design of appropriate monitoring, defining key decision milestones - design kick-off, tooling kick-off, process kick-off, certification test planning, production kick-off, launch readiness and in-service milestones.
Failure detection and Resolution System: Replication of failure modes, root cause analysis and issue resolution process, incorporating new failure modes into validation tests and plans."

Module 6: Long-term Validation Fleet Monitoring Systems

Introduction to telematics and remote data acquisition systems, dos & don'ts while operating prototypes and validation vehicles, safety and other compliance requirements for on-road validation fleet vehicles, designing appropriate frequency of data analysis, reviews and course corrections and other operational best practices.

Text/References:

1. Risk Management and System Safety by Leonam Dos Santos Guimarães Frontier India (25 November 2016) ISBN-13 : 978-9385699108

2. VEHICLE TESTING AND HOMOLOGATION by by K.V.FADADU & B.H.KADIYA BOOKS INDIA PUBLICATIONS; 1st edition (1 January 2016)

3. Verification of Automotive ECUs using HIL technique: Overview of Hardware-In-Loop setup by Vinay Kumar Vishwanath Kindle Edition

EVT012 Advanced Energy Storage & Battery Systems in e-Mobility

New Batteries, Ultracapacitors, Fuel Cells

3 credit (3-0-0)

Pre-requisites: Nil

Overlaps with: Nil

Course Outcomes/ Objectives:

At the end of this course students will demonstrate the ability to

1. Understand the basic concepts of electrochemistry applicable to batteries and fuel cells.
2. Analyze and evaluate various considerations for chemistry selection, battery pack sizing and BMS tuning for EVs.
3. Understanding other energy storage options - on-board electric vehicles and off-board stationary storage.
4. Understand the various EV battery solutions, regulatory and standards framework governing EV batteries.

Mapping with POs:

POs → COs ↓	PO1	PO2	PO3
CO1	M	L	H
CO2	H	H	H
CO3	M	M	M
CO4	H	M	M
Overall	H	M	H

Content:

Module 1: Basics of Electrochemistry & Electric Circuits

Electrochemistry - Nernst Equation, charging & discharging at half-cell level, Standard cell potentials, Electrochemical half-cell and cell, unit cell chemistries, unit specifications, Ragone plots, electric circuits, Kirchhoff's laws and series-parallel configurations.

Module 2: Electric Vehicle Application

EV battery pack specifications, battery manufacturing, assembly & packaging, vehicle energy consumption estimation, battery chemistry selection, energy v/s power batteries, pack sizing, charging and charger sizing, thermal & ageing aspects.

Module 3: Battery Management Systems

Basics of control systems, cell balancing - need and methods, operational sensitivities - ambient temperature, ingress protection, power and energy draw - continuous & peak, charging - slow & fast, Battery Management System functions - SoC estimation, SoH estimation, compensations & corrections, current thresholds, voltage thresholds, cell balancing control, communication and diagnostics, cooling systems, and charge control

Module 4: Energy Storage System Options

Li-Ion battery advancements (Solid State, Graphene, etc.), new battery chemistries (Na-Ion, Al-Air, Redox batteries, etc.), ultracapacitors & hybrid energy solutions, hydrogen (ICE, Microturbine, Fuel Cells, etc.), other energy storage options (flywheel, phase-change, pumped water, compressed air, etc.)

Module 5: Energy Storage - Support Systems

EV Charging & battery swapping systems, energy infrastructure requirements & power quality, battery secondary use, repurposing and recycling, regulations – batteries & chargers.

Text/References:

1. Helena Berg, "Batteries for Electric Vehicles: Materials and Electrochemistry", Cambridge University Press (20 August 2015)

2.Sandeep Dhameja, "Electric Vehicle Battery System", Yesdeen, 2012.

3. Hrvoje Pandzic, "Integration of Electric Vehicles and Battery Storage Systems", Mdpi AG (22 April 2021)

EVT011 Motors, Generators & Power Converters: Design for EVs
4 credits (3-0-1)
Pre-requisites: Nil
Overlaps with: Nil

Course Outcomes/ Objectives:

At the end of this course students will demonstrate the ability to:

1. Understand various power converter components and their operations inside the power converter.
2. Understand various power converters and their applications in an electric vehicle.
3. Understand various types of electric machines, their modes of operations and applications in an electric vehicle.
4. Analyze various electric machine technologies, select appropriate technology for a particular EV application and match the characteristics to requirements.

Mapping with POs:

POs → COs ↓	PO1	PO2	PO3
CO1	M	L	M
CO2	H	M	M
CO3	H	M	M
CO4	H	M	H
Overall	H	M	M

Content:

Module 1: Power switching devices

Diode, Thyristor, MOSFET, IGBT: I-V Characteristics; Firing circuit for thyristor; Voltage and current commutation of a thyristor; Gate drive circuits for MOSFET and IGBT.

Module 2: Rectifiers

Single-phase half-wave and full-wave rectifiers, Single-phase full-bridge thyristor rectifier with R-load and highly inductive load; Three-phase full-bridge thyristor rectifier with R-load and highly inductive load; Input current wave shape and power factor.
Application to EV chargers: Voltage step-up, step down, and current control

Module 3: DC-DC Buck & Boost converters

Elementary chopper with an active switch and diode, concepts of duty ratio and average voltage, power circuit of a buck converter, analysis and waveforms at steady state, duty ratio control of output voltage.
Power circuit of a boost converter, analysis and waveforms at steady state, relation between duty ratio and average output voltage.
Application to EV: Low voltage DC converters for accessories, high voltage DC-DC conversion for battery to DC Bus

Module 4: Single and Three Phase Inverters

Power circuit of single-phase voltage source inverter, switch states and instantaneous output voltage, square wave operation of the inverter, concept of average voltage over a switching cycle, bipolar sinusoidal modulation and unipolar sinusoidal modulation, modulation index and output voltage
Power circuit of a three-phase voltage source inverter, switch states, instantaneous output voltages, average output voltages over a sub-cycle, three-phase sinusoidal modulation
Application to motor drives: Waveform, frequency & speed, current & torque

Module 5: Electric Machines - Basics, Classification and Design Considerations

Basics: Rotation, magnetic circuits, torque, power, efficiency & losses, back emf, constant voltage operation, motor & generator modes, asynchronous & synchronous motors, and other general properties.
Motor Classification: Overall types DC & AC motors, motors for traction application - ACIM, BLDC, PMSM, SRM, etc.
Design Considerations: EV traction application - power and torque characteristics, maximum speed, drive charcteristics, other considerations like EMI/EMC, ingress protection, etc., non-traction motors on EV.

Module 6: Electric Machine Technology Selection and Design Process

Technology selection process: Comparison of various motor technologies for EV traction application, typical motor characteristics and integration challenges, control challenges, cost comparison, robustness and serviceability comparisons, efficiency comparisons, maximum speed comparison and challenges, mapping vehicle requirements to motor characteristics, prioritizing vehicle requirements from motor and subsequent technology selection process.
ACIM: Rotating field, slip and torque, operation at 60 Hz supply, variable frequency operations, inverter-fed motors, various control strategies.
Permanent magnet motors: Rotating field using permanent magnet, synchronous operations, variable frequency operation, axial and radial flux designs, various control strategies
Switched reluctance motors: Rotating field, steady-state operations, transient operations, torque ripples, synchronous operations, permanent magnet assist, various control strategies

Laboratory 1: Power Switching Devices & Power Converter Familiarization

Verification of functioning of PE components (capacitors, resistors, inductors, diodes, Thyristors, MOSFET, IGBT, etc.) comparison of characteristics of components, making basic PE circuits, studying PE circuit characteristics
Study functioning of single-phase rectifier, three-phase rectifier, DC-DC buck converter, DC-DC boost converter, single-phase voltage inverters, three-phase voltage source inverters through various relevant measurements"

Laboratory 2: Electric Machines - ACIM, BLDC, PMSM, SRM Familiarization

Disassembly and reassembly of 2-3 types of motors, basic characterization of motors on bench, developing motor technical specifications from characterization tests.

Text/References:

1. M. H. Rashid, “Power electronics: circuits, devices, and applications”, Pearson Education India, 2009.
2. N. Mohan and T. M. Undeland, “Power Electronics: Converters, Applications and Design”, John Wiley & Sons, 2007.
3. R. W. Erickson and D. Maksimovic, “Fundamentals of Power Electronics”, Springer Science & Business Media, 2007.
4. L. Umanand, “Power Electronics: Essentials and Applications”, Wiley India, 2009.
1. 5. Electric Motors and Drives: Fundamentals, Types and Applications by Austin Hughes & Bill Drury ISBN-13 : 978-9351071525.

EVT013 Charging & Energy Infrastructure
3 credit (3-0-0)
Pre-requisites: Nil
Overlaps with: Nil
Course Outcomes/ Objectives:
At the end of this course students will demonstrate the ability to:

1. Understand the concepts of power systems.
2. Understand the various power system components.
3. Analyze and evaluate various EV charging systems and their suitability for application.
4. Understand the regulatory and standard framework governing EV charging systems.

Mapping with POs:

POs → COs ↓	PO1	PO2	PO3
CO1	M	L	L
CO2	H	L	L
CO3	:H	H	H
CO4	H	M	H
Overall	H	M	M

Module 1: Basics of Power Generation & Distribution

Generation: Conventional and Renewable Energy Sources. Distributed Energy Resources. Energy Storage.
Transmission and Distribution Systems: Line diagrams, transmission and distribution voltage levels and topologies (meshed and radial systems). Synchronous Grids and Asynchronous (DC) interconnections.
Review of Three-phase systems. Analysis of simple three-phase circuits. Power Transfer in AC circuits and Reactive Power.

Module 2: Power System Components

Transmission Lines: Short, medium and long lines. Power Transfer, Voltage profile and Reactive Power. Characteristics of transmission lines.
Transformers: Transformer Parameters. Voltage step-up/step-down. Multi-stage transformers. Single phase equivalent of three-phase transformers.
Generation of Over-voltages: Lightning and Switching Surges. Protection against Overvoltage, Insulation Coordination. Representation of generators, lines and transformers in sequence networks. Computation of Fault Currents. Neutral Grounding.
Energy meters: Concepts of FTM (Front of The Meter), BTM (Behind The Meter) infrastructure and efficiencies. Usage-based tariffs, ToD (Time of Day) and ToU (Time of Usage) tariffs.

Module 3: Charging Systems: Operations and Control

Introduction to EVSE (Electric Vehicle Supply Equipment) or charging systems, types of chargers, modes of chargers, levels of chargers, various charging standards and communication protocols, public charging systems.
Charging control, CCCV (Constant-Current-Constant-Voltage) charging, Pulse-Burp charging, charger thermal considerations
Battery Swapping Stations, CMS (Charger Management Systems), charging load balancing and current throttling, charger utilization and charging scheduling, impact of fast charging, safety systems and best operational practices for charging systems.
Charger Economics: Charger sharing - power v/s energy demand, battery swap economics, runtime charger economics, and overall cost optimization.

Module 4: DC Loads and Power Quality

Introduction to Power Quality, Grid Dynamics, Power Factor Correction, Voltage Regulation, Frequency Regulation, Harmonic Distortion, Peak and Base Load Management.

Module 5: Charging Regulatory Framework

Introduction to charger regulatory framework, various design (IEEE, BIS, etc.) and compliance (IEC/ISO, AIS, OCPP, etc.) standards, Indian standards for public charging stations, PESO (Petroleum and Explosives Safety Organization) guidelines for charging at fuel stations.

Text/References: No Text Book
1. O. I. Elgerd, “Electric Energy Systems Theory”, McGraw Hill Education, 1995.
2. D. P. Kothari and I. J. Nagrath, “Modern Power System Analysis”, McGraw Hill Education, 2003.

3. B. M. Weedy, B. J. Cory, N. Jenkins, J. Ekanayake and G. Strbac, “Electric Power Systems”, Wiley, 2012.

EVT007 EV Thermal Management: Batteries & Motors
3 credits (3-0-0)
Pre-requisites: Nil
Overlaps with: Nil
Course Outcomes/ Objectives:
At the end of this course students will demonstrate the ability to

1. Estimate heat generation in batteries & motors through physics-based methods and/or characterization data.
2. Formulate and analyze a heat transfer problem involving any of the three modes of heat transfer.
3. Analyze the temperature variation using various estimation methods (analytical, approximations & empirical correlations) to evaluate the rate of heat transfer.
4. Select and size devices such as heat exchangers using fluids, phase change materials, etc..

Mapping with POs:

POs → COs ↓	PO1	PO2	PO3
CO1	M	M	M
CO2	H	M	M
CO3	M	H	M
CO4	H	H	H
Overall	H	M	M

Content:
Module 1: Need of Thermal Management in Electric Vehicles

Heat generation in EV batteries - internal resistance, cell balancing, DC bus losses, thermal runaway, Li-Ion sub-chemistry thermal runaway temperature
Heat generation in Motors - various motor losses - copper losses, iron losses, frictional losses, brake resistor for regenerative braking, etc., heat production and impact on magnetic flux, impact on motor performance for various traction motor technologies - induction motors, permanent magnet motors and switch reluctance motors
Heat generation in chargers, charging ports and power converters.

Module 2: Basics of Thermal Management

Definition of heat, temperature, temperature scales, modes of heat transfer - conduction, convection & radiation, definition of thermal equilibrium and Zeroth law, First Law of Thermodynamics- concepts of internal energy, specific heat
capacities & enthalpy.

Energy balance for closed and open systems, energy balance for steady & unsteady flow systems.
Thermodynamic properties of pure substances in solid, liquid and vapour phases and phase rule.

Module 3: Passive and Active Cooling Systems

Introduction to passive and active cooling, considerations for selection and sizing of cooling systems.
Types of heat exchangers - fins, radiators, heat tubes, phase change material, etc.
Analysis and design of heat exchangers applying specific cooling requirements of electric vehicles battery packs, motors, and power converters.
Coolant properties and specifications, coolant ageing and replacement,
Design of cooling system control, activation & deactivation, hysteresis, redundancies.

Module 4: Other Thermal Management Methods in Electric Vehicles

Thermal monitoring systems, progressive battery load management systems & thermal cut-offs, motor load management systems, switching between peak and continuous power operations, charger thermal management & current throttling, thermal event detection, warning and control.
Design of air vents and ducts and their impact on vehicle aerodynamics
Safety systems: Breathers and pressure release valves, fire retardants and their use
Fire Extinguishing Methods: Dealing with electrical fires, dealing with battery fires, classes of extinguishers and their applicability.

Text/References:
1. Ibrahim Dinçer, Halil S. Hamut, Nader Javani, "Thermal Management of Electric Vehicle Battery Systems", John Wiley & Sons Inc; 1st edition (17 March 2017)
2. J.P.Holman, Heat Transfer, Eighth Edition, McGraw Hill, 1997.
3. JILING LI & ZHEN ZHU, "Battery Thermal Management Systems of Electric Vehicles", CHALMERS UNIVERSITY OF TECHNOLOGY Göteborg, Sweden 2014

EVT008 EV Range Extension Technologies: Hydrogen Fuel Cell & Runtime Charging
3 credit (3-0-0)
Pre-requisite: Nil
Overlaps with: Nil
Course Outcome/Objectives:
At the end of this course students will demonstrate the ability to…
1. Identify and analyze various electric vehicle range extension technologies.
2. Understanding basic concepts of battery & vehicle swapping technology and its application.
3. Understanding basic concepts of run-time charging - overhead wires &

wireless, and its application.

4. Understanding basic concepts of various hydrogen powered electric vehicles and hydrogen infrastructure.

Mapping with POs:

POs → COs ↓	PO1	PO2	PO3
CO1	H	M	M
CO2	H	L	L
CO3	H	M	M
CO4	H	H	H
Overall	H	M	M

Content:

Module 1: Long Distance Vehicles and their Electrification Challenges

Personal mobility: Cruiser motorbikes, cars & utility vehicles, recreational vehicles - caravans, campers and motor homes
Passenger transport vehicles: Intercity & interstate buses - public & private transport and intercity cabs
Goods transport vehicles: Parcel & eCommerce, industrial inbound and outbound, construction material, market load & Fast Moving Commercial Goods (FMCG), perishable loads, drayage, bulkers and tankers.

Module 2: Battery and Vehicle Swapping

Introduction, basic working principle, variants, etc.
Advantages: Similar to ICE vehicle refuelling, battery or vehicle is as-a-service, usage of non-rechargeable batteries, etc.
Challenges: Large investment per unit usage - more batteries or vehicles, interoperability, etc.
Infrastructure requirements: Swapping stations, charging infrastructure, asset tracking and monitoring, etc.
Pilots & deployments:
Typical business model:

Module 3: Flash and Runtime Charging

Flash Charging
Introduction, basic working principle, variants, etc.
Advantages: Similar to ICE vehicle refuelling, etc.
Challenges: Large investment in infrastructure, battery thermals, etc.
Infrastructure requirements: Pantographs or multigun chargers, amenities to keep drivers & occupants engaged, etc.
Pilots & deployments:
Typical business model:

Runtime Charging
Introduction, basic working principle, variants, etc.
Advantages: Better than ICE vehicle refuelling due to no stoppages, smaller batteries, etc.
Challenges: Large investment in infrastructure, payment for energy, etc.
Infrastructure requirements: Overhead lines or wireless chargers beneath road surface, etc.
Pilots & deployments:
Typical business model:

Module 4: Hydrogen Fuel Cell, Microturbine & ICE based Series Hybrids

Hydrogen as on-board energy storage
Advantages: Similar to ICE vehicle refuelling, etc.
Challenges: On-board hydrogen storage, cost, etc.
Fuel Cells
Introduction, basic working principle, variants, etc.
Pilots & deployments:
Hydrogen ICE based series hybrid
Introduction, basic working principle, variants, etc.
Pilots & deployments:
Hydrogen microturbine based series hybrid
Introduction, basic working principle, variants, etc.
Pilots & deployments:
Hydrogen infrastructure: Sources of hydrogen and their colour coding, storage and transport, filling stations, etc.

Text/References:
1. Mehrdad Ehsani, Yimin Gao and Ali Emadi, ""Modern Electric, Hybrid Electric, and Fuel Cell Vehicles"", Standardsmedia (1 January 2009)
2. Geoffrey Hancock, "Inductive Charging as a Range Extender for Battery Electric Vehicles", Grin Verlag (19 April 2016)

EVT015 EV Maintenance, Safety, Salvage and Recycling
4 credits (3-0-1)
Pre-requisites: Nil
Overlaps with: Nil
Course Outcomes/ Objectives:
At the end of this course students will demonstrate the ability to…
1. Perform first-level diagnostics of issues, classification of issues and creating appropriate records.
2. Understand service, maintenance, liabilities, valuation of electric vehicles they their comparison with equivalent ICE vehicles.
3. Understand vehicle end-of-life activities, repurposing and recycling opportunities and key safety aspects.

Mapping with POs:

POs →	PO1	PO2	PO3

COs ↓			
CO1	M	L	M
CO2	M	L	L
CO3	H	M	H
Overall	M	L	M

Content:

Module 1: Introduction to After-sales Services

Defects & failures, serviceability and maintainability, initial quality, reliability & dependability, service quality.
Need for periodic maintenance, how service schedules and evolved, introduction to design for serviceability and annual maintenance contract designs for vehicles.
Consumables in service (Oils, coolants, brake pads, tires, etc.): Neither covered under warranty, nor under insurance.
Sacrificials in service (Mud flaps, bumpers, wheel covers, etc): Neither covered under warranty, nor under insurance or even most service packages.
Other spares in service (all components & subsystems other than consumables & sacrificials): Covered under warranty and insurance.
Vehicle diagnostics - hardware and electronics, spares inventory management, warranty logging systems, field service logging systems, etc.
Key differences between service of ICE & Electric Vehicles

Module 2: Introduction to Vehicle Valuation and Liability

Introduction to vehicle value depreciation, pre-owned vehicle costs - acquisition, refurbishment, transfer of ownership and margin.
Basics of motor insurance - comprehensive, third-party liability coverage and driver accident insurance, depreciation and IDV, salvage value, total loss, risk assessment, premium estimation and quotes
Claims processing - accident vehicle survey, differences between warranty coverage and insurance coverage and standard terms and conditions for insurance disbursement.
Usage data collection, vehicle ownership history and pay-as-you-drive insurance premium.
Key differences between salvage and insurance value of ICE & Electric Vehicles.

Module 3: In-service Vehicle Safety

Key differences between safety aspects of ICE & Electric Vehicles.
High voltage safety: Identification of high-voltage cables and ratings, short and open circuit hazards, insulation grades, de-energizing procedures for EV HV circuits, use of safety devices and overalls, PESO guidelines for proximity of HV devices and inflammables like ICE fuels in common vehicle service setups for ICE and electric vehicles.
Battery safety: Differences between high-voltage and low-voltage batteries, identification of battery pack safety critical components, procedure for disconnecting battery terminals, difference between lead-acid and lithium-ion batteries.
EV safety inspection setup, safety checklist, safety compliance requirements for electric vehicles.

Module 4: Recycling and Repurposing of EV Sub-systems

Introduction to vehicle End of Life (EoL), policies and guidelines for vehicle recyclability and scrappage
EV Sub-system Repurposing Ability and Recyclability: Battery - repurposing (fixed energy storage, power quality management, etc.) and recycling (various processes and material recovery), Motor - repurposing (non-automotive / non-traction usage, etc.) and recycling (various processes and material recovery) and power converters (solid state devices, other electrical components, etc.)

Module 5: EV Charging Station and Energy Infrastructure Maintenance

Charging Station Design: Sizing chargers, charging ports and protocols, standards and compliance requirements, charging station layout, traffic management, etc.
Charging Station Operations: Charging station standard operating procedures, Charging Management System (CMS) operations, protocols for information exchange & payments, best practices for optimizing charger utilization, safety and security.
Charging Station Maintenance: Periodic maintenance schedules, standard maintenance procedures, daily/weekly/periodic inspection and checklists, breakdown maintenance and safety during maintenance.
Energy Infrastructure Sizing & Maintenance: Energy consumption and sanctioned load capacity estimation, distribution transformer installation, commissioning and periodic maintenance, energy metering systems, safety switches, etc.

Laboratory 1: After-sales Service Vehicle Evaluation

Vehicle inspection and evaluation, preparation of job cards, identification of consumables, sacrificial and warranty parts, standardization of technician jobs and effort estimation, preparation of Standard Operating Procedures (SOP) and service manuals, service cost estimation, annual maintenance contract designs for vehicles.

Laboratory 2: Vehicle Evaluation for Salvage & Insurance Claims

Electric Vehicle valuation for second use: HV & LV battery State of Health (SoH), traction motor(s) evaluation, condition of consumables, roadworthiness, HV cables condition, switches & power converters, overall inspection checklist, performing mock evaluation, building up the selling price.
Accident EV Survey for Insurance: Damage estimation for HV & LV battery, traction motor(s), condition of consumables, assessment of restoration to roadworthiness, HV cables condition, switches & power converters, overall inspection checklist, performing mock evaluation, list of replacements and spares, insurance coverage for each replacement and spare item, building up the total disbursement.

Laboratory 3: Safety Audit - EV Service & Charging Station

EV Service Workshop Safety Audit: Safety checklist, Service Manuals and Standard Operating Procedures with key safety aspects highlighted, technician safety - protection (insulated gloves and footwear, hard hats, masks, etc.), ramps and pits safety related fool proofing, fire extinguishers with clear instructions and applicability, emergency evacuation plan.
EV Service Charging Station Safety Audit: Safety checklist, Operating Manuals and Standard

Operating Procedures with key safety aspects highlighted, technician safety - protection (insulated gloves and footwear, hard hats, masks, etc.), parking slot safety related fool proofing, vehicle throughfare management, fire extinguishers with clear instructions and applicability, emergency evacuation plan.

Text/References:

1. Electric Vehicle Service Manuals - 2-3 different vehicles
2. ""Code of Practice for Electric Vehicle Charging Equipment Installation (IET Codes and Guidance)"" by Institution of Engineering and Technology; 4th edition (12 May 2020)
3. Chris Hadfield, ""Automotive Service Job Sheets for NATEF Task Mastery"", Delmar Cengage Learning; 2nd edition (1 September 2011)

EVT016 EV Value Chain and Circular Economy

3 credits (3-0-0)

Pre-requisites: Nil

Overlaps with: Nil

Course Outcomes/ Objectives:

At the end of this course students will demonstrate the ability to

1. Understand the various automotive sub-systems & components value chains.
2. Analyze and evaluate various sourcing strategies.
3. Analyze and evaluate Bill of Material (BoM) costs for sourced EV sub-systems.
4. Understand recycling, repurposing and Restriction of Hazardous Substances (RoHS) & other compliance requirements.

Mapping with POs:

POs → COs ↓	PO1	PO2	PO3
CO1	M	M	H
CO2	M	H	M
CO3	M	H	H
CO4	H	H	H
Overall	M	H	H

Content:

Module 1: Automotive Sub-systems & Components Value Chains (10 Hours)

Vehicle sub-system Bill of Material (BoM), Tier system of suppliers, EV-specific sub-system & component (battery system, motor & motor drive, power converters, charging system, etc.) BoM, value chains & global supply chains. Key shifts in sourcing from ICE vehicles to electric vehicles

Module 2: Sourcing Strategies & Supplier Development (15 Hours)

Popular automotive industry sourcing strategies, demand aggregation strategies for economies of scale, supplier identification & evaluation process, supply risk management, logistics & inventory management, introduction to global taxation & duty policy frameworks, warranty and other liabilities, Problems per Hundred Vehicles (PPH) and Cost per Vehicle (CPV) target setting, supplier historic performance data analysis, data sharing terms and conditions.

Module 3: Bill of Material (BoM) Costs for Sourced EV Sub-systems (8 Hours)

Sub-system BoM cost make-up for battery system, motor & motor drive, power converters, charging system, etc. introduction to cost engineering, development budgets vs piece-costs, production scalability metrics

Module 4: Recycling, Repurposing Liability & Other Compliances (12 Hours)

Introduction to recycling & circular economy for EV-specific sub-system & component (battery system, motor & motor drive, power converters, charging system, etc.). Regulatory compliance framework for EV and supplier responsibilities, Restriction of Hazardous Substances (RoHS) compliance requirements, environmental compliance requirements, other legal compliances.

Text/References:

Wilson Kia Onn Wong "Automotive Global Value Chain - The Rise of Mega Suppliers", Routledge, 2019

John Humphrey & Olga Memedovic "THE GLOBAL AUTOMOTIVE INDUSTRY VALUE CHAIN: What Prospects for Upgrading by Developing Countries" UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

Advantech iService Business Group – "Supply Chain Management in the Automotive Industry", 2018

Deloitte – "2021 Global Automotive Supplier Study"

EVT004 EV Diagnostics and Prognostics: Leveraging IoT, Data Analytics

4 credits (3-0-1)

Pre-requisites: Nil

Overlaps with: Nil

Course Outcomes/ Objectives:

At the end of this course students will demonstrate the ability to…

1. Understand and perform key diagnostics processes like Root Cause Analysis, Fault Tree Analysis, etc. and the various relevant tools
2. Understand various diagnostic equipment and their high-level usage in particular scenario.
3. Understand vehicle health monitoring & management systems and their integration with cloud-based data analytics.

Mapping with POs:

POs → COs ↓	PO1	PO2	PO3
CO1	H	L	M
CO2	M	L	M
CO3	H	L	H
Overall	H	L	M

Content:

Module 1: Introduction to Automotive Diagnostic Systems

Need of diagnostic systems, evolution of diagnostics, policy and regulatory frameworks around vehicle diagnostics, On-Board Diagnostics (OBD), industry standards and voluntary diagnostics by vehicle manufacturers, and interdependencies between diagnostics and vehicle safety systems.

Module 2: Basics of Vehicle Diagnostics

Defects & failures, Root Cause Analysis (RCA) and its tools, Failure Mode Effect Analysis (FMEA) and its tools, Fault Tree Analysis (FTA), diagnostics in electronics controllers and embedded software, Diagnostic Trouble Codes (DTC), vehicle communication networks, fault indicators and driver alert systems, fault classification, reduced functionality modes and complete shutdown, clearing faults - key-in/key-out cycles, diagnostic tools and scanners.

Module 3: Introduction to Electronic Controller Functional Safety

Reliability Engineering, System Functional Safety, Systematic & Random Hardware Failures, concept of self-diagnostics in a controller, impact of ISO26262 requirements, Automotive Safety Integrity Levels (ASIL), Operational System Safety Levels, diagnostics requirements from ISO 26262 compliance perspective

Module 4: Introduction to Diagnostic Calibration & Validation

Introduction to various diagnostic layers - controller functions (ensuring specific system functionalities), monitoring & fault detection (ensuring 100% detection and preventing false detection) and system redundancies and action (system response to faults detected and system safety).

Calibration of primary functions for normal operation thresholds, calibration of monitoring systems to trigger faults whenever primary function registers interruption or erroneous behaviour and calibration of response systems to trigger driver alerts, system redundancies, reduced functionality modes and system shutdown as required.

Calibration validation techniques - physical fault insertion units (short circuits, open circuits, etc.), virtual fault insertion functions, Hardware-in-Loop (HiL), Software-in-Loop (SiL) and on-vehicle validations.

Module 5: Basics of Diagnostic Data Acquisition and Analytics

Concept of freeze frames and compressed time histories, live channels mandatory on OBD port, communication technologies - wired OBD connectors, Bluetooth and wireless connectors, data on navigation and infotainment systems, user mobile apps, direct cloud data links, data collection rates, data channel synchronization, postprocessing and filtration as required. Introduction to failure mode based and objective based data analytics.

Module 6: Vehicle Health Management Systems and Infrastructure

Introduction to Vehicle Health Management (VHM) systems, evolution of in-service vehicle health management, live vehicle health monitoring, employing in-service diagnostics to failure mode anticipation functions, piloting VHM functions on captive fleets, VHM OTA updates and driver alerts, using individual vehicle data to optimize vehicle service, preventing vehicle breakdowns using VHM.

Laboratory 1: On-Board Diagnostic Hardware Familiarization

Location of various ECU on-board vehicles, identification of various diagnostic ports and locating them on vehicles, identifying OBD ports against regulations (OBD-1 & OBD-2) and types (electricals, emission systems, HV safety, etc.), visually identifying various sensors, actuators, cables, can bus, power flow from battery, temperature sensors and their locations, speed sensors and their location, possibility of ingress of dust, water, etc.

Laboratory 2: Diagnostic Tools Familiarization

Various types of diagnostic tools and their uses, OEM diagnostics tool sample (hardware and software), third-party generic tool sample (hardware and software), OBD dongles, cables and splitters (hardware and software), exercises with diagnostics codes, messages and classifications, exercises of using diagnostic codes to support root case analysis.

Laboratory 3: OBD Data Collection, Analysis and Setting-up Simple VHM

Data collection on vehicle using OBD loggers, data clean-up and postprocessing, comparison with reference data like GPS or external sensors, identifying limitations of OBD data, data analysis exercises for understanding signs of failure modes and setting up automated data analytics to provide alerts of anticipated failures, exercise for integrating the data analytics with integrated vehicle health management systems

Text/References:

1. Ian K Jennions, ""Integrated Vehicle Health Management: The Technology"" SAE Publications 2013-09-05 R-429

2. “On-Board Diagnostics for Light and Medium Duty Vehicles Standards Manual” SAE Publications 2009-12-11 2010 Edition HS-3000/2010.

3. Robert Schnell & Sara Cascanet, “A Guide To Vehicle Diagnostics: Understanding DTCs and Their Descriptions” Kindle Edition.

EVP002 Project Phase II – Solutions & Recommendations
6 credits
Pre-requisites: EVP001 Project Phase I
Overlaps with: Nil
Course Outcomes/ Objectives: Students will be able to

1. Analyze the root cause of the selected operational problem or risks associated with a selected product decision.
2. Provide practical solutions to the problem or provide concrete analysis-based evidence to reduce the decision risk.
3. Substantiate the solution or analysis-based evidence for its validity and success.
4. Conclude decisively the action steps to resolve the problem and validate the solution or to manage the risk associated with the decision.

Mapping with POs:

POs → / COs ↓	PO1	PO2	PO3
CO1	H	M	M
CO2	M	H	M
CO3	H	H	H
CO4	H	H	H
Overall	H	H	H