Program Structure and Course Contents

M.Tech in Electrical Engineering (Electric Vehicle Technology)

Approved in 6^{th} BoS Meeting

Department of Electrical Engineering

Islamic University of Science and Technology, Awantipora

December 24, 2025

Contents

Approved Course Structure

M.Tech in Electrical Engineering
(Electric Vehicle Technology)

(For Batches admitted in 2026 and onwards)

Semester I (21 Credits)

S. No	Course Title	Course Code	L	T	P	S	Credits
1.	Fundamentals & Dynamics of EVs	MEC511C	3	1	0	0	4
2.	Electric Vehicle Engineering Fundamentals	ELE501C	3	0	0	0	3
3.	Design and Control of Power Converters	ELE505C	3	1	0	0	4
4.	Charging Infrastructure for EVs	ELE503C	3	1	0	0	4
5.	Elective -I (Generic)	-	3	0	0	0	3
6.	EV System Design and Analysis	ELE504C	2	0	2	0	3
							Total Credits 21

Semester II (23 Credits)

S.No	Course Title	Code	L	T	P	S	Credits
1	Battery Management System	ELE550C	3	1	0	0	4
2	Advanced Motor Drives	ELE551C	3	1	0	0	4
3	Advanced Control Systems	ELE552C	3	1	0	0	4
4	Embedded System Design for EVs	ELE553C	2	0	2	0	3
5	Scientific Research Methods and Practices	ELE556C	3	0	0	0	3
6	Electric Vehicle Systems Laboratory	ELE554C	0	0	2	0	1
7	Industrial Internship	ELE555C	-	-	-	-	2
8	Open Elective I	-	2	0	0	0	2
							Total Credits 23

Semester III (15 Credits)

S.No	Course Title	Code	L	T	P	S	Credits
1	Elective -II (Discipline-Centric)	-	3	0	0	0	3
2	Elective -III (Discipline-Centric)	-	3	0	0	0	3
3	Elective -IV (Generic)	-	3	0	0	0	3
4	Open Elective II	-	2	0	0	0	2
5	Pre-Dissertation	ELE601C	0	0	8	0	4
						Total Credits	**15**

Semester IV (12 Credits)

S.No	Course Title	Code	L	T	P	S	Credits
1	Dissertation	ELE650C	0	0	24	0	12
						Total Credits	**12**
						Total Credits all semesters	**71**

A. Discipline-Centric Electives[1]

S.No	Course Title	Code
1	Sensors and Instrumentation for EVs	ELE501E
2	EV Motor Design and Thermal Analysis	ELE502E
3	Safety and Regulations of EVs	ELE503E
4	Data Analytics and Digital Twins for EVs	ELE504E
5	Cybersecurity in EVs and Charging Networks	ELE505E
6	Power Quality in EV Systems	ELE506E
7	Innovation and Entrepreneurship in EVs	ELE507E
8	EVs: Economics, Policy and Social Embedding	ELE508E
9	EVs and Smart Grids	ELE509E
10	Reliability Engineering for EVs	ELE510E
11	Restructured Power Systems	ELE511E
12	Solar EV Charging Infrastructure Design	ELE512E
13	Retrofitting and Intelligent Transportation System	ELE513E
14	Renewable Energy and Sustainable Systems	ELE514E

B. Generic Electives [2]

S.No	Course Title	Code
1	Hydrogen and Fuel Cell Technologies	ELE501G
2	Optimization for Engineering Design	ELE452G
3	Carbon Audit and Net Zero Energy Buildings	ELE454G
4	Bio Conversion and Processing of Waste	ELE502G
5	Renewable Energy Resource Assessment and Forecasting	ELE503G
6	Nonlinear Control Systems	ELE455G
7	Optimal Control Methods	ELE456G
8	Principles of System Identification	ELE457G
9	Soft Computing and Intelligent Systems	ELE504G

[1] These electives are open only for students of the program M.Tech(EVT)
[2] These electives are open for the students of any other M.Tech program in EE, ECE, ME, CSE etc.

Approved Course Contents

Core Courses

MEC511C - Fundamentals and Dynamics of EVs

Type of Course: Core **Semester:** I

L	T	P	Contact Hrs/Week	Credits
3	1	0	4	4

Course Objectives: Understand the dynamics of vehicle ride under different riding conditions. Present a problem-oriented in-depth knowledge of vehicle dynamics and the underlying concepts and methods. Calculate and refer to the loads and forces associated with vehicles and analyze their behavior under acceleration, ride, and braking.

Course Outcomes:

1. Analyze the dynamics of vehicles under various riding conditions.
2. Evaluate acceleration and braking performance in electric vehicles.
3. Articulate road loads and tyre dynamics in EVs.
4. Interpret comfort, vibrations, cornering, and rollover behaviors.
5. Infer suspension kinematics and controllable suspension systems in EVs.

Module I: Basics of Vehicle Dynamics

History, vehicle classifications, fundamental approaches to vehicle dynamics, vehicle axis systems, forces and moments acting on a vehicle, earth-fixed coordinate system, dynamic axle loads, equations of motion, transmission characteristics, vehicle performance, brake proportioning, and braking efficiency.

Module II: Acceleration and Braking Performance

Powertrain components, power and traction-limited acceleration, transverse weight shift, drive configurations (FWD, RWD, AWD), braking force analysis, brake design, federal regulations, ABS, tire/road friction, safety, and maintenance.

Module III: Road Loads and Tire Dynamics

Wind drag and car body design, rolling resistance, total road loads, gas mileage and driving style analysis, aerodynamics, tire specifications and constructions, tire force and motion analysis, vibration and contact stress analysis, and tire modeling.

Module IV: Ride and Cornering/Steering

Ride comfort and vibration perception, sources and transmission of vibration, low/high-speed cornering, bicycle model, rollover analysis: quasi-static rigid and suspended vehicles, transient rollover.

Module V: Chassis and Suspension Systems

Suspension kinematics and types, solid axles, independent suspension, anti-squat, anti-pitch, and anti-dive geometries, roll center analysis, suspension dynamics, body/wheel hop, controllable suspension (active/semi-active), spring rate selection, and calculation.

Books Recommended

Textbooks:

1. Thomas Gillespie, *Fundamentals of Vehicle Dynamics*, SAE Publications.
2. Mike Blundell and Damian Harty, *The Multibody Systems Approach to Vehicle Dynamics*, Elsevier, 2004.
3. Iqbal Hussein, *Electric and Hybrid Vehicles: Design Fundamentals*, CRC Press, 2003.

Reference Books:

1. Reimpell, Stoll, and Betzler, *The Automotive Chassis: Engineering Principles*.
2. Hans Pacejka, *Tire and Vehicle Dynamics*, Elsevier, 2012.
3. R.V. Dukkipati, *Vehicle Dynamics*, Narsova Publications.

ELE501C - Electric Vehicle Engineering Fundamentals

Type of Course: Core **Semester:** I

L	T	P	Contact Hrs/Week	Credits
3	0	0	3	3

Course Objectives: To provide students with a comprehensive understanding of EV power circuits, electromechanical energy conversion, electric motor fundamentals, power electronic converters, and control systems essential for modern electric vehicle propulsion.

Course Outcomes:

1. Analyze EV power circuits using electrical laws, network theorems, and AC/DC circuit fundamentals.
2. Understand the principles of electromechanical energy conversion and evaluate force, torque, and transformer operation.
3. Compare and assess various EV traction motors, their characteristics, and performance parameters.
4. Demonstrate knowledge of power electronic devices and converter topologies used in electric vehicle applications.
5. Model, analyze, and design basic control systems, including PID controllers, for EV propulsion and motor control.

Module I: EV Power Circuit Fundamentals

Network theorems: Thevenin's, Norton's, Superposition; Mesh and nodal analysis of EV power circuits; Transient response analysis of RLC circuits; AC circuit fundamentals; Real, Reactive, and Apparent power; Power factor; Three-phase system configurations and Power calculations

Module II: Electromechanical Energy Conversion

Fundamentals of magnetic circuits, magnetic flux, magnetomotive force, and the properties of magnetic materials, including the B–H curve. Principles of electromagnetic induction and induced EMF. Analysis and calculation of force and torque in translational and rotational electromechanical systems. Introduction to transformers and their operating principles.

Module III:EV Motor Fundamentals

Induction Motor fundamentals and torque-speed characteristics, Permanent Magnet Synchronous Motors (PMSM): Construction, Operating principle, Advantages, Applications; Brushless DC (BLDC) motor: Comparison with conventional dc motors, Torque-speed Characteristics, Applications; Performance parameters for EV traction motors.

Module IV: Power Electronics for EV

Review of power semiconductor switching devices, Thyristors, MOSFET, IGBT, and modern devices, characteristics and applications, Introduction to Turn-On/Turn-Off mechanism of switching devices, Review of power converter topologies: rectifiers, inverters; DC-DC converters

Module V: Control Systems for EV Propulsion

Control system fundamentals: open-loop and closed-loop systems; Mathematical modeling of electrical and mechanical components; Transfer functions and system response analysis; Stability analysis: Routh-Hurwitz, root locus; Frequency response techniques: Bode and Nyquist plots; Design and tuning of PID controllers for EV motor control; Sensors for EV control.

Books Recommended

Textbooks:

1. C.K. Alexander, M.N.O. Sadiku, *Fundamentals of Electric Circuits*, McGraw-Hill.
2. William H. Hayt, Jack E. Kemmerly, and Steven M. Durbin, *Engineering Circuit Analysis*, McGraw-Hill, Latest Edition.
3. A. E. Fitzgerald, Charles Kingsley Jr., and Stephen D. Umans, *Electric Machinery*, McGraw-Hill, Latest Edition.
4. K. Ogata, *Modern Control Engineering*, Prentice Hall.

Reference Books:

1. P. C. Sen, *Principles of Electric Machines and Power Electronics*, Wiley, Latest Edition.
2. Katsuhiko Ogata, *Modern Control Engineering*, Pearson, Latest Edition.
3. M. Ehsani, Y. Gao, S. E. Gay, and A. Emadi, *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles: Fundamentals, Theory, and Design*, CRC Press, Latest Edition.

ELE505C - Design and Control of Power Converters

Type of Course: Core **Semester:** I

L	T	P	Contact Hrs/Week	Credits
3	1	0	4	4

Course Objectives: To provide students with a comprehensive understanding of modern power electronic devices, converter topologies, control techniques, and design methodologies essential for electric vehicle (EV) powertrain, charging, and energy management applications.

Course Outcomes:

1. Analyze the characteristics of power semiconductor devices and design appropriate isolation, gate-driver, snubber, and thermal management circuits for reliable converter operation.
2. Perform steady-state analysis, component selection, and magnetics design for non-isolated and isolated DC–DC converters used in EV power conversion
3. Evaluate AC–DC rectifier operation, identify power quality issues, and apply suitable PFC and PWM rectification techniques for on-board charger (OBC) applications.
4. Design and control single-phase and three-phase voltage source inverters using PWM and SVPWM techniques for EV traction and auxiliary systems.
5. Explain the operation of bidirectional converter topologies such as Dual Active Bridge and 4-switch buck–boost converters, and analyze their control strategies for EV charging and backup power flow management.

Module I: Power Semiconductor Devices and Drive Circuit Design

MOSFET and IGBT characteristics Isolation Circuits: Pulse Transformer, Optocoupler; Gate Driver Circuits: Low side and High side Drivers; Design of Snubbers; Heat Sink: Selection and Types; Commercial Gate driver boards, Intelligent Power Modules, Wideband semiconductor devices and their driver boards.

Module II: DC to DC Switch Mode Power Converters and Their Design

Steady-state analysis of non-isolated (Buck, Boost and Buck boost) and isolated DC-DC converters (Flyback and Bridge converter) in continuous/discontinuous modes, component selection, Magnetics design, and PWM techniques.

Module III: AC–DC Conversion, Power Quality, and PFC Techniques for On-Board Chargers

Uncontrolled and controlled rectifiers, Power Quality Issues in AC–DC Converters, Power Factor Correction (PFC) Techniques, Introduction to PWM Rectifiers, Operation and Control of PWM Rectifiers, On-board charger (OBC) PFC stages.

Module IV: Design of Switch Mode DC-AC Inverters

Single-phase inverter operation and control, Unipolar and Bipolar PWM technique for single phase VSI, Three-phase voltage source inverter operation, Sine PWM and Space vector pulse width modulation (SVPWM) technique for three phase VSI, Applications, and component selection for inverter design.

Module V:Bidirectional Converter Architectures for EV Charging and Backup Power

Fundamentals of Bidirectional Isolated DC–DC Converters, Operating Principle of the Dual Active Bridge (DAB) Converter, Power Flow Direction and Bidirectional Control in DAB, Operating Principle of 4-Switch Buck–Boost Bidirectional DC–DC Converter, Transition Between Charging and Backup Modes in 4-Switch Buck–Boost Converter.

Books Recommended

Textbooks:

1. L. Ashok Kumar, S. Albert Alexander, *Power Converters for Electric Vehicles*, CRC Press, Taylor & Francis Group, 2021.
2. Mohan N., Undeland T., Robbins, *Power Electronics: Converters, Applications, and Design*, Wiley, 3rd ed., 2002.
3. Iqbal Hussein, *Electric and Hybrid Vehicles: Design Fundamentals*, CRC Press, 2003.

Reference Books:

1. Christophe Basso, *Switch Mode Power Supplies: SPICE Simulations and Practical Designs*, McGraw-Hill, 2008.
2. Daniel M. Mitchell, *DC-DC Switching Regulator Analysis*.
3. B. Jayant Baliga, *Power Semiconductor Devices*, International Thompson Computer Press, 1995.

ELE503C - Charging Infrastructure for EVs

Type of Course: Core **Semester:** I

L	T	P	Contact Hrs/Week	Credits
3	1	0	4	4

Course Objectives: To understand electric vehicle operation and battery fundamentals, EV battery charging methods, fast charging behavior, renewable energy-based charging station design, and charger specifications.

Course Outcomes:

1. Analyze the impact of EV charging on the power grid.
2. Design and analyze various charging infrastructures, their selection, and their sizing.
3. Design renewable energy-based electric vehicle charging stations.
4. Evaluate charging methodologies and analyze their performance.
5. Design charger specifications and select communication protocols.

Module I: Introduction to EV Charging

Introduction to Vehicle Electrification, Electric Vehicle Supply Equipment (EVSE): Components, Classifications, PEV Battery Systems, Smart Charging, Demand Identification, Challenges in Electric Vehicle Charging.

Module II: Charging Types and Standards

Charger Classifications; On-board and Off-board Charging, Inductive and Conductive Charging, Battery swapping stations, move-and-charge zones, AC and DC charging, Power electronic converter configurations for EV charging, Challenges of Fast Charging Stations, EV/PHEV (Plug-in Hybrid Vehicles), Charging Standards, Charging Time Estimation.

Module III: Advancements in Charging

Inductive and Resonant Wireless Charging, EVs as Distributed Storage Resources: Grid to Vehicle (G2V) and Vehicle to Grid (V2G), V2X Concept, Integration of Charging Station with Renewable Sources and its Impact on the Grid, Renewable-based charging in EVs.

Module IV: Public charging infrastructure

Location, Planning and Implementation of Public Charging Stations; Components; Selection and Sizing - HT/LT Equipment & Cables; Protection; Safety Standards: Policy and Regulatory Aspects; EV Charging Station and their Business Models; Economic Aspects; Major Challenges

Module V: EV charger communications protocols

Open Charge Point Protocol (OCPP); Open System Interconnection Layer Model (OSI); Adapted PWM Signal based Low-level Communication; PLC based High-level Communication; CAN Communication; Billing and Authentication

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Books Recommended

Textbooks:

1. Sandeep Dhameja, *Electric Vehicle Battery Systems*, Newnes Publishing, 2002.
2. Emadi, A. (Ed.), Miller, J., Ehsani, M., *Vehicular Electric Power Systems*, CRC Press, 2003.
3. Sheldon S. Williamson, *Energy Management Strategies for Electric and Plug-in Hybrid Electric Vehicles*, Springer, 2013.
4. M. S. Alam, R. K. Pillai, and N. Murugesan (Eds.), *Developing Charging Infrastructure and Technologies for Electric Vehicles*, IGI Global, 2022.

Reference Books:

1. Jerry Sergent and Al Krum, *Thermal Management Handbook: For Electronic Assemblies*, McGraw-Hill, 1998.
2. I. Husain, *Electric and Hybrid Vehicles*, CRC Press, 2010.
3. James Larminie and John Lowry, *Electric Vehicle Technology Explained*, Wiley, 2012.
4. Tariq Muneer and Irene Illescas García, *The Automobile, in Electric Vehicles: Prospects and Challenges*, Elsevier, 2017.

ELE504C - EV System Design and Analysis

Type of Course: Core **Semester:** I

L	T	P	Contact Hrs/Week	Credits
2	0	2	4	3

Course Objectives: To understand the performance parameters of electric vehicles. This course aims to describe drivetrain characteristics, concepts of energy management systems, and vehicle dynamics and simulations.

Course Outcomes:

1. Understand the modelling of vehicle performance parameters.
2. Model battery electric vehicles.
3. Describe the drivetrain characteristics.
4. Apply the dynamic model to simulate the EV.
5. Design the MATLAB models of EVs.

Module I: Introduction

Intro EV Historical Background, Benefits of Using EVs, Overview of types of EVs and its Challenges, Motor Drive Technologies, EV Energy Source Technologies, EV Battery Charging Technologies, EV Vehicle to Grid.

Module II: EV Configurations

EV Subsystems and Configurations: Components of EV system, Typical BEV configuration, Hybridization of Energy Sources, HEV Subsystems and Configurations, HEV Subsystems and Modes of Operation: Starting, acceleration and deceleration, normal driving, regenerative braking, charging, axle balancing.

Module III: Vehicle Dynamics

Vehicle System, Vehicle Design, Modelling of Vehicle Dynamics: longitudinal, lateral dynamics; tractive effort, aerodynamic drag, rolling resistance, gradient and hill climbing, gradability, angular acceleration, regenerative force.

Module IV: Dynamic Equations of EVs

Dynamic equation: propulsion system with power and energy balance, constant tractive effort, variable tractive effort, Velocity equation and its solution, instantaneous tractive power, energy required

Module V: Simulation of Traction and Dynamics

Simulating the tractive effort as: gradient force, aerodynamic force, rolling resistance force, vehicle velocity on these forces and the power variation. Simulating the dynamic equation with constant tractive effort, Examples for case study.

List of Experiments:

1. MATLAB programming basics.
2. Simulations of basic control design for EVs.
3. Simulations of Power electronic converters for EVs.
4. Simulating the vehicle tractive forces.
5. Simulating the dynamic equations of EVs.
6. Series HEV simulation to study parameter variation.
7. Parallel HEV simulation with parameter impact analysis.
8. Complete system-level electric vehicle simulation.

Books Recommended

Textbooks:

1. Amir Khajepour, Saber Fallah, and Avesta Goodarzi, *Electric and Hybrid Vehicles: Technologies, Modelling and Control*, John Wiley & Sons, 2014.
2. James Larminie, John Lowry, *Electric Vehicle Technology Explained*, John Wiley & Sons, 2003.
3. Iqbal Hussein, *Electric and Hybrid Vehicles: Design Fundamentals*, CRC Press, 2003.

Reference Books:

1. Antoni Szumanowski, *Hybrid Electric Powertrain Engineering and Technology: Modelling, Control, and Simulation*, IGI Global, 2013.
2. Mehrdad Ehsani, Yimin Gao, and Ali Emadi, *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles*, 2nd ed., CRC Press, 2010.
3. B. Jayant Baliga, *Power Semiconductor Devices*, 1st ed., International Thompson Computer Press, 1995.

ELE550C - Battery Management System

Type of Course: Core **Semester:** II

L	T	P	Contact Hrs/Week	Credits
3	1	0	4	4

Course Objectives: This course aims to provide a comprehensive understanding of electric vehicle (EV) batteries, their characteristics, modelling techniques, management systems, and charging control strategies. It equips students with the knowledge required to analyse battery performance, ensure safety through BMS algorithms, and apply modern diagnostic and estimation methods for efficient EV energy management.

Course Outcomes:

1. Explain the construction, characteristics, and architecture of EV battery systems including cell chemistry, performance parameters, and pack configurations.
2. Demonstrate the need, functions, and standards of Battery Management Systems (BMS) for ensuring safe, reliable, and efficient battery operation.
3. Apply battery modelling, testing, and characterization methods to evaluate capacity, cycle life, thermal behaviour, and performance under different operating conditions.
4. Analyze and implement state estimation techniques using classical and advanced estimation methods while identifying sources of estimation errors.
5. Evaluate charging strategies, control methods, and safety mechanisms to design and assess stable, fault-tolerant BMS and charging systems for electric vehicles.

Module I: EV Batteries – Technology, Characteristics & Management

Introduction to Electric Vehicle (EV) battery systems, Types of EV batteries: Lead–acid, Lithium-ion, Lithium phosphate (LiFePO4) battery, Solid-state batteries, Key characteristics: energy density, power density, C-rate, voltage/capacity ratings, thermal behavior, EV battery pack architecture: cells, modules, pack configuration, series–parallel arrangements

Module II: Introduction to Battery Management Systems (BMS

General introduction to battery management system, Need for BMS, BMS for making storage systems efficient, safe, and dependable, Basic functions of a BMS, Energy control management, Customized battery management systems, Standards for BMS development

Module III: Battery Modelling, Testing and Characterization

Purpose of battery modelling, non-circuit models, Equivalent circuit models, Schemes of battery testing, Standardization of characteristic tests. Capacity tests, Charge and discharge rate tests, Battery cycle tests, Fixed-rate cycle test method, Thermal management in EV batteries: air cooling, liquid cooling, refrigerant-based cooling, phase-change materials.

Module IV: State Estimation Methods

SoC, SoP, and SoE: definitions and relationships, Classical SoC estimation methods, Open-circuit voltage (OCV) method, Challenges in SoC estimation, Complex estimation methods, Estimation errors and their sources

Module V: Charging Control & BMS Safety

Charge control methods, Effect of charge control on battery performance, Charging circuits and characteristics, Key indicators of charging behavior, Constant-current and constant-voltage (CC–CV) charging, Fast and ultra-fast charging, Design of battery parameter measurement systems, Safety control in BMS, Stability of BMS, Battery fault diagnosis

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Books Recommended

Textbooks:

1. Xiong, Rui, and Weixiang Shen, *Advanced battery management technologies for electric vehicles*, John Wiley & Sons, 2019.

2. Dhameja, Sandeep, *Electric vehicle battery systems*, Elsevier, 2001.

3. Dincer, Ibrahim, Halil S. Hamut, and Nader Javani, *Thermal management of electric vehicle battery systems*, John Wiley & Sons, 2016.

Reference Books:

1. Dincer, Ibrahim, Halil S. Hamut, and Nader Javani. *Thermal management of electric vehicle battery systems.* John Wiley & Sons, 2016.

2. Xiong, Rui. *Battery management algorithm for electric vehicles.* (2020): 978-981.

ELE551C - Advanced Motor Drives

Type of Course: Core **Semester:** II

L	T	P	Contact Hrs/Week	Credits
3	1	0	4	4

Course Objectives: This course aims to provide a comprehensive understanding of electric vehicle motor technologies and their control strategies, covering DC, Induction, BLDC, PMSM, and Switched Reluctance Motor drives. It equips learners with the knowledge of dynamic modelling, converter design, and advanced control techniques required for efficient and reliable electric drive systems in modern electric vehicles.

Course Outcomes:

1. Able to analyze and model electric drive systems and hybrid electric drive trains, including load characteristics, torque–speed relationships and multi-quadrant operation
2. Analyze torque–speed characteristics and dynamic models of DC, BLDC, Induction, and Permanent Magnet Synchronous Motors.
3. Design and evaluate electric drive trains, including series and parallel hybrid configurations with appropriate power and torque coupling considerations.
4. Apply vector control, field-oriented control, direct torque control, and sensorless techniques for high-performance operation of AC motor drives.
5. Select and configure suitable power converter topologies and control strategies for SRM, BLDC, Induction, and PMSM drives to meet electric vehicle performance requirements.

Module I: Fundamentals of Electric Drives

Components of Electric drives, Types of Loads, Components of load toques, Fundamental torque equations, Equivalent value of drive parameters for loads with rotational and translational motion. Steady state stability, Multi quadrant operation of drives.

Module II: DC and BLDC Motor Drives

Torque speed characteristics, DC Motor dynamics, Field Weakening Control, Four quadrant operation of DC motor drives, DC Motor Dynamics & Control, Brushless DC Motor Drives: Control Principles; Back EMF Zero Crossing Point Computation; Current Sensing; Sensorless Rotor Position Techniques.

Module III: Induction Motor Drives

Closed loop induction motor drives – Review of dynamic modelling of induction machine, space phasor model, Closed loop induction motor drives – V/f control, need for vector control, Field oriented control.

Module IV: Permanent Magnet Synchronous Motor Drives

Closed loop synchronous motor drives – Review of dynamic modelling of synchronous machine, Basic Scheme for Field Orient Control: Parameter Adaptation, Field Weakening; Current Sensing and Scaling; Speed Regulation; Sensorless Rotor Position Technique.

Module V: Switched Reluctance Motor Drives

Inductance Profile; Detection of Initial Rotor Position; Commutation Strategies; Speed Control in Different Operating Regions; Power Converter Topologies and its Basic Design; Dynamic Modelling for E-vehicle Requirements; Case Studies for Hub and Frame Configurations.

Books Recommended

Textbooks:

1. Austin Hughes and Bill Drury, *Electric Motors and Drives: Fundamentals, Types and Applications* , 5th edition, Newnes publications

2. Krishnan, R., 2001. *Electric motor drives: modeling, analysis, and control.* Prentice Hall.

3. Ali Emadi *Energy efficient electric motors*, 3rd Edition, revised and expanded, Marcel Dekker, 2005

Reference Books:

1. K Wang Hee Nam, *AC Motor Control & Electrical Vehicle Application*, CRC Press, Taylor & Francis Group, 2019

2. C.C Chan, K.T Chau, *Modern Electric Vehicle Technology*, Oxford University Press Inc., New York 2001.

3. Haitham Abu-Rub, AtifIqbal, J. Guzinski, *High Performance Control of AC Drives with Matlab/Simulink*, Wiley, 2nd Edition

ELE552C - Advanced Control Systems

Type of Course: Core **Semester:** II

L	T	P	Contact Hrs/Week	Credits
3	1	0	4	4

Course Objectives: This course aims to develop a solid foundation in state-space modelling, stability analysis, optimal state-feedback control, and state estimation, and to apply these methods to control-oriented models of electric vehicle subsystems. It introduces constrained optimal control and basic adaptive control strategies to address practical limitations such as actuator constraints and parametric uncertainty, enabling students to analyze and design modern control systems for motor and battery applications within an EV framework.

Course Outcomes: Upon successful completion of the course, students will be able to:

1. Formulate state-space models of electrical and electromechanical systems and analyze their stability, controllability, and observability.
2. Design optimal state-feedback controllers and state estimators, including LQR and Kalman filtering techniques.
3. Develop control-oriented models of electric vehicle subsystems, including motor and battery dynamics, suitable for controller design.
4. Formulate and apply constrained optimal control strategies, including Model Predictive Control, for torque regulation and energy management.
5. Design basic adaptive control schemes to address parametric uncertainty in motor and battery systems and evaluate their performance relative to fixed-gain controllers.

Module I: State-Space Modelling and Stability

LTI system representation using transfer function and state-space models; state-space modelling of electrical and electromechanical systems; solution of state equations and state transition matrix; internal stability and Lyapunov stability (direct method); controllability and observability concepts and tests; stabilizability.

Module II: Optimal Control and State Estimation

State-feedback control and pole placement; limitations of pole placement; Linear Quadratic Regulator (LQR) formulation and solution; introduction to state observers; Kalman filter formulation and algorithm; application to battery State-of-Charge (SOC) estimation.

Module III: Control-Oriented Modelling of EV Subsystems

Hierarchical EV control structure and time-scale separation; PMSM modelling in the dq-reference frame including electrical and mechanical dynamics; state-space representation and linearization about operating equilibrium; first-order Thevenin battery equivalent circuit model; state-space formulation with State-of-Charge (SOC) as augmented state; parameter variation and uncertainty in motor and battery models relevant to control design.

Module IV: Constrained Optimal Control for EV Systems

Limitations of unconstrained optimal control in the presence of actuator saturation and state/input constraints; formulation of finite-horizon optimal control problems with quadratic cost and constraints; receding horizon principle; Model Predictive Control (MPC) structure including prediction model and constrained optimization framework; application to torque regulation and energy management in EV subsystems.

Module V: Adaptive Control for EV Systems

Control under parametric uncertainty and limitations of fixed-gain controllers; Model Reference Adaptive Control (MRAC) including reference model selection, control law structure, parameter adaptation using the MIT rule, and tracking error dynamics; conceptual stability reasoning for adaptive systems; application to motor parameter variation and adaptive estimation in battery systems; comparison between optimal and adaptive control strategies in terms of robustness and performance trade-offs.

Books Recommended

Reference Books:

1. Hui Zhang, Dongpu Cao, Haiping Du (Editors), *Modeling, Dynamics and Control of Electrified Vehicles*, Elsevier.

2. Rajesh Rajamani, *Vehicle Dynamics and Control*, Springer.

3. K. J. Åström and B. Wittenmark, *Adaptive Control*, Prentice Hall.

4. R. T. Stefani et al., *Design of Feedback Control Systems*, Oxford University Press.

5. Ashish Tewari, *Modern Control Design: With MATLAB and SIMULINK*, Wiley.

6. K. Ogata, *Modern Control Engineering*, Prentice Hall.

7. M. Gopal, *Control Systems: Principles and Design*, McGraw-Hill, 2012

ELE553C -Embedded System Design for EVs

Type of Course: Core **Semester:** II

L	T	P	Contact Hrs/Week	Credits
2	0	2	4	3

Course Objectives: To equip students with the knowledge and hands-on skills required to design, program, interface, and implement embedded systems and IoT-enabled applications using ARM-based microcontrollers, sensors, actuators, and wireless communication modules.

Course Outcomes:

1. Understand the fundamentals of embedded systems, ARM architecture, and Cortex-M core features, including microcontroller components, design considerations, and the differences between microprocessors and microcontrollers.
2. Apply ARM instruction set programming and configure on-chip peripherals such as GPIO, timers, PWM, ADC, DAC, and interrupts on STM32F401 microcontroller platforms.
3. Interface sensors, actuators, and peripheral modules (LCD, 7-segment display, serial communication devices) using STM32F401 and Arduino development boards, and develop basic embedded applications.
4. Design and implement embedded control applications such as temperature sensing, light sensing, motor control, relay-based load control, and multi-sensor integration using microcontroller-based systems.
5. Develop IoT-enabled embedded systems using wireless communication modules such as GSM/Bluetooth and integrate sensors (accelerometer, gas sensor) for smart and real-time monitoring applications.

Module I: Introduction to Embedded Systems & ARM Architecture

Introduction to Embedded Systems, Embedded system components & design considerations, Microprocessors vs Microcontrollers, Overview of ARM architecture, ARM Cortex-M core features, ARM architecture

Module II: ARM Instruction Set & On-Chip Peripherals

ARM Instruction Set, STM32F401 Nucleo board architecture, GPIO architecture and programming, Timers, PWM generation, interrupts, Digital-to-Analog Converter (DAC), Analog-to-Digital Converter (ADC) – operation, sampling, resolution.

Module III: Sensors, Actuators & Interfacing Techniques

Output devices, sensors & actuators, Microcontroller development boards, MBED programming environment, Interfacing with STM32F401 board, Interfacing with Arduino Uno, 7-segment and LCD display interfacing, Serial communication (CoolTerm)

Module IV: Embedded System Applications & Control

Temperature sensing system design, Light sensing using LDR, Speaker and microphone interface, Basics of control system design using microcontrollers, Relay interfacing and load control, DC motor interfacing and speed control, multi-sensor control applications.

Module V: IoT, Wireless Communication & Advanced Applications

Introduction to Internet of Things (IoT), GSM and Bluetooth modules, Wireless communication protocols, Touch sensor–based alarm system, Accelerometer: working & interfacing, Gas sensor interfacing.

List of Experiments:

1. GPIO Programming & LED Blinking on ARM Board
2. PWM Generation using ARM Timers
3. ADC-Based Temperature Measurement
4. Light Detection using LDR with ADC
5. DAC-Based Analog Signal Generation
6. LCD/7-Segment Display Interfacing
7. Relay Interfacing & Control of Electrical Loads
8. DC Motor Speed Control Using PWM
9. Bluetooth-Based Control of Devices
10. IoT Sensor Node with Gas/Temperature Sensor

Books Recommended

Textbooks:

1. Jonathan W. Valvano, *Embedded Systems: Real-Time Interfacing to ARM Cortex-M Microcontrollers*, 5th Edition, 2022, CreateSpace Publishing.
2. Joseph Yiu, T*he Definitive Guide to ARM Cortex-M3 and Cortex-M4 Processors*, 3rd Edition, 2014, Newnes/Elsevier.
3. Muhammad Ali Mazidi, Sarmad Naimi & Sepehr Naimi, *ARM Assembly Language Programming & Architecture*, 1st Edition, 2017, Micro Digital Ed.

Reference Books:

1. Shibu K. V., *Introduction to Embedded Systems*, 2nd Edition, 2017, McGraw-Hill Education.
2. Andrew N. Sloss, Dominic Symes, Chris Wright, *ARM System Developer's Guide: Designing and Optimizing System Software*, 1st Edition, 2004, Morgan Kaufmann.

Online Resources:

1. NPTEL Course: Embedded System Design, IIT Kharagpur https://nptel.ac.in/courses/106105159

ELE556C - Scientific Research Methods and Practices

Type of Course: Core **Semester:** II

L	T	P	Contact Hrs/Week	Credits
3	0	0	3	3

Course Objectives: To develop an understanding of the fundamentals of scientific research, knowledge systems, and epistemology. To equip students with statistical and analytical tools for data-driven research. To train students in effective scientific writing, communication, and presentation. To enable students to prepare technical documents using LaTeX. To introduce modelling, simulation, and data-driven analysis using Python and MATLAB.

Course Outcomes:

1. Understand the foundations of scientific reasoning and the evolution of scientific ideas.
2. Apply descriptive and inferential statistical techniques in research problems.
3. Conduct data analysis using Python and visualize findings.
4. Prepare scientific manuscripts, reports, and presentations following standard conventions.
5. Use LaTeX for documentation and MATLAB for modelling and simulation.

Module I: Foundations of Scientific Research

Knowledge and epistemology; kinds of knowledge. Deductive and inductive inference; Popper's falsifiability. History of scientific ideas: Greek science; Islamic science; Scientific Revolution. Overview of 20th-century scientific developments.

Module II: Statistical Analysis and Experimental Design

Data and statistics; types of data; levels of measurement. Measures of central tendency and variation. Correlation, regression, and model fitting. Hypothesis testing: t-test, F-test, ANOVA; parametric vs non-parametric tests. Python labs: Jupyter Notebook, data loading, visualization, descriptive statistics, variance/standard deviation, simple linear regression.

Module III: Scientific Writing and Communication

Principles of research; identifying research gaps. IMRaD structure; abstracts, introductions, methods transparency. Referencing styles; bibliographies; plagiarism; reference managers. Scientific presentations: narrative structure, visual hierarchy. Peer-review process; common pitfalls in writing.

Module IV: Documentation Using LaTeX

LaTeX essentials: document structure, packages. Cross-references, floats, tables, equations. Figures, complex mathematics, and graphs. Building a complete article using Overleaf. BibTeX and bibliography management. Beamer for scientific presentations.

Module V: Modeling, Simulation and Data Visualization

Role of modelling in research. MATLAB essentials: data types, scripts, functions, plotting. First-principle / physics-based modelling. Solving ODEs; deterministic model simulation. Data-driven modelling: regression, curve fitting. System modelling and simulation using Simulink.

Books Recommended

Textbooks:

1. R.C. Kothari, *Research Methodology: Methods and Techniques*, 2nd ed., New Age International, 2009.
2. David V. Thiel, *Research Methods for Engineers*, Cambridge University Press.
3. Ranjit Kumar, *Research Methodology: A Step-by-Step Guide for Beginners*, 2nd ed., SAGE, 2005.

Reference Books:

1. Stephen J. Chapman, *MATLAB Programming for Engineers*, Cengage Learning.
2. William M. Trochim, *The Research Methods Knowledge Base*, 2nd ed.
3. Thomas Hill, Paul Lewicki, *Statistical Methods and Applications*, StatSoft Inc., 2013.
4. Jake VanderPlas, *Python Data Science Handbook*, O'Reilly.
5. Leslie Lamport, *LaTeX: A Document Preparation System*, Addison-Wesley.

Additional Resources:

1. `https://michaelnielsen.org/blog/principles-of-effective-research/`
2. `https://www2.isical.ac.in/~palash/research-methodology.html`
3. `https://goelsan.wordpress.com/2013/04/10/research-method-for-engineering-research-students-iv-an-incomplete-course-for-phd-scholars/`

ELE554C - Electric Vehicle Systems Laboratory

Type of Course: Core **Semester:** II

L	T	P	Contact Hrs/Week	Credits
0	0	2	2	1

Course Objectives: To provide hands-on experience with EV battery systems, power electronic converters, motor drive hardware, and integrated powertrain testing for practical electric vehicle applications.

Course Outcomes:

1. Analyze and test EV battery cells, battery packs, and BMS hardware to evaluate performance, safety, and state-management functions.
2. Implement and assess DC–DC converters, inverters, and gate-driver circuits used in EV power conversion and motor-drive systems.
3. Operate and evaluate induction motor, BLDC motor, and hub-motor drive hardware for speed control and powertrain performance assessment.

List of Experiments:

1. Charge–discharge cycling of Li-ion and $LiFePO_4$ cells using a battery analyser
2. Testing and diagnosis of EV battery pack modules
3. Implementation and testing of a basic Battery Management System (BMS)
4. Design and development of battery pack with spot-welding process
5. Hardware implementation of DC–DC converters (Buck/Boost) for EV subsystems
6. Hardware implementation of DC–AC inverter for motor-drive applications
7. Gate-driver circuit development and testing using IPM modules
8. Implementation of V/f control for induction motor drive
9. Speed control and performance evaluation of BLDC motor drive
10. Testing and characterization of EV powertrain using BLDC hub motor

Approved Course Contents

Discipline-Centric Electives

ELE501E - Sensors and Instrumentation for EVs

Type of Course: Discipline-Centric Elective

L	T	P	Contact Hrs/Week	Credits
3	0	0	3	3

Course Objectives: To introduce students to the principles and applications of sensors and instrumentation systems in electric vehicles. The course covers sensor technologies, signal conditioning, data acquisition, communication protocols, and integration with EV subsystems such as batteries, motors, power electronics, and vehicle dynamics.

Course Outcomes:

1. Understand and select appropriate sensors for EV subsystems.
2. Design instrumentation and data acquisition systems for EV monitoring and control.
3. Apply communication protocols (CAN, LIN, IoT) for real-time data transfer.
4. Integrate sensor systems with control and digital twin frameworks for EV optimization.

Module I: Introduction to Sensors & Instrumentation

Overview of EV subsystems; importance of measurement and monitoring, classification of sensors, Static vs dynamic properties of transducers, Transfer functions, Ideal and realistic transducer models, Resolution, linearization, dynamic range, detection threshold, Selectivity and sensitivity, Calibration, Errors of the experimental measurements, Noise.

Module II: Temperature, Pressure, and Chemical Sensors

Temperature sensors for battery packs, inverters, and motor windings (thermistors, RTDs, thermocouples); pressure sensors for pneumatic or hydraulic systems; gas sensors for EV safety (CO, O2, H2 sensors); chemical sensors for battery health monitoring; thermal management instrumentation.

Module III: Battery, BMS & Safety Instrumentation

Voltage, current, and temperature sensing for Li-ion cells and modules. SoC/SoH/SoP estimation, Gas pressure sensors, thermal runaway detection sensors, integration of sensors in BMS circuits, isolation and safety requirements.

Module IV: Data Acquisition and Communication

Data acquisition systems, ADCs, multiplexers, filtering, calibration, noise reduction; communication protocols including CAN, LIN, Modbus, and IoT-enabled cloud monitoring; real-time data logging and time-series analysis; integration with BMS and motor controllers.

Module V:EV Instrumentation Applications and Case Studies

Integration of sensors for battery management, motor drives, vehicle dynamics (speed, acceleration, braking), simulation-based case studies; examples from Tesla, BYD, Tata EVs.

Books Recommended

Text Books:

1. Jacob Fradan, *Handbook of Modern Sensors*, 5th Edition, Springer.
2. Patranabis, D., *Sensors and Transducers*, PHI, 2021.
3. Patranabis, D., *Principles of Industrial Instrumentation*, McGraw Hill, 2017.
4. Morris, A.S., Langari, R., *Measurement and Instrumentation*, Academic Press, 2015.

Reference Books

1. Michael Stanley and Jongmin Lee, *Sensor Analysis for the Internet of Things*, 2018.
2. Randy Frank, *Understanding Smart Sensors*, Artech House, 2000.
3. Bela Lipták, *Instrument Engineers' Handbook*, CRC Press, 2012.
4. K. Krishnaswamy, S. Vijayachitra, *Industrial Instrumentation*, 2011.
5. Müller et al., *Microsensors*, IEEE Press, 1991.
6. Aurélien Géron, *Hands-On Machine Learning*, O'Reilly.

ELE502E - EV Motor Design and Thermal Analysis

Type of Course: Discipline-Centric Elective

L	T	P	Contact Hrs/Week	Credits
3	0	0	3	3

Course Objectives: Upon completion of the course, students will have a solid foundation in electrical machine design, capable of analyzing, selecting dimensions, and designing various components for induction motors, Switched Reluctance Machines (SRM), BLDC (Brushless DC) motors, and PMMC (Permanent Magnet DC) motors. Students will apply their knowledge to design different motors for Electric Vehicle applications, considering efficiency, performance and specific requirements of EVs.

Course Outcomes:

1. Understand the foundational electromagnetic laws and behavior of magnetic materials, including BH curves, and their application in automotive technologies.
2. Perform design and analysis of electromagnetic systems, including the principles governing electromechanical energy conversion.
3. Design electrical machine windings, focusing on direct current (DC) and alternating current (AC) machines.
4. Analyze the design parameters and calculations involved in the design of induction motors with a particular focus on Electric Vehicles (EVs).
5. Design SRM motors, BLDC motors and PMMC motors for Electric Vehicle (EV) applications.

Module I: EV motor fundamentals

EV propulsion requirements, DC motor drives, induction motors, and basic performance metrics like torque-speed curves for two-wheeler applications. Introduces configuration, control strategies, and losses in DC/induction machines operating as motors or generators. Ties to vehicle dynamics

Module II: Electromechanical Energy Conversion

Electromechanical energy conversion and force in electromagnetic systems; design and analysis of the electromagnetic system with an example; considerations in electrical machine design;

design factors; calculation of total MMF for the air gap; effect of saliency; total electrical and magnetic loadings; specific electrical and magnetic loadings.

Module III: Electrical Machine Winding Design

Relation between winding parameters, MMF and flux distribution of armature winding (full pitch coil and distributed winding); phase spread; EMF in a full pitch concentrated winding; production of EMF in a distributed winding; DC machine windings; AC machine windings; winding design for variable speed machines; importance, design factors and standards of electrical machines.

Module IV: Motor Design

Induction motor (IM) design; output equation of AC machines; main dimensions; stator core design of IM; stator winding, stator conductors, shape and number of stator slots, stator core, length of air gap; rotor core design of IM; volume and density of IM; IM parameter calculation; IM design for EV application. Design of special machines; Switched Reluctance Machine (SRM) sizing equations; stator and rotor design of SRM; machine parameters and calculations of SRM; design of BLDC and PMMC motors

Module V: Thermal Analysis

Thermal issues in machines, limits and heat transfer techniques; cooling methods and design; thermal equivalent circuits; thermal design of electrical machines. Introduces finite element methods (FEM/ANSYS) for coupled electromagnetic-thermal design, demagnetization risks, and hotspots.

Books Recommended

Textbooks:

1. A.K. Sawhney, *Electric Machine Design.*
2. R.K. Agarwal, *Electrical Machine Design.*
3. Thomas A. Lipo, *Introduction to AC Machine Design*, IEEE Press, John Wiley & Sons, Inc., NJ, USA.
4. Alexander Gray, *Electrical Machine Design - The Design and Specification of Direct and Alternating Current Machinery*, McGraw Hill, NY, USA.
5. R. Krishnan, *Switched Reluctance Motor Drives: Modeling, Simulation, Analysis, Design, and Applications*, CRC Press, USA.

Reference Books:

1. M. G. Sen, *Electrical Machine Design.*
2. Rajiv Nagaranjan, *Electrical Machine Design.*

3. Mittle and Mittla, *Design of Electrical Machines*.

Online Resources:

1. *Design of Electric Motors*, Prof. Prathap Reddy, IISc Bangalore, NPTEL Online Course.

ELE503E - Safety & Regulations of EVs

Type of Course: Discipline-Centric Elective

L	T	P	Contact Hrs/Week	Credits
3	0	0	3	3

Course Objectives: This course aims to provide students with a comprehensive understanding of safety requirements in electric vehicles by focusing on regulatory standards, high-voltage protection, battery safety, charging system integrity, and post-crash emergency measures. It enables learners to analyze safety challenges through hazard assessment techniques and equips them to ensure compliance with national and international EV safety regulations for the development of reliable and secure electric mobility systems

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Course Outcomes:

1. Interpret key national and international standards and regulations governing EV safety.
2. Analyze high-voltage system risks and implement appropriate electric shock protection strategies.
3. Evaluate battery safety issues, including thermal management and abuse testing measures.
4. Assess the safety requirements, communication protocols, and cybersecurity in EV charging infrastructure.
5. Apply safety analysis techniques to ensure crashworthiness, fire mitigation, and emergency response in EV systems.

Module I: Introduction to EV Safety & Standards

Automotive Safety-Active and passive safety, Driver assistance systems in automobiles,definitions and terminology.Overview of EV safety challenges & requirements. Classification of EVs: HEV – Hybrid Electric Vehicle, PHEV – Plug-in Hybrid Electric Vehicle, BEV – Battery Electric Vehicle, FCEV – Fuel Cell Electric Vehicle .Global safety standards & regulatory bodies like ISO, IEC, SAE, AIS, FMVSS, UNECE. EV homologation processes.

Module II: High Voltage System Safety of EVs

High-Voltage architecture and components. Protection against electric shock.Insulation monitoring, isolation resistance.Safety interlocks, HV disconnects, grounding, earthing.Short circuit & arc-flash hazards.Safety in battery pack design & integration.Safety requirements: ISO 6469, IEC 60664. Risk assessment and safety planning.

Module III: Battery Safety, Thermal Management & Regulations

Battery chemistry (Li-ion, LFP, NMC, solid-state safety aspects). Failure modes: Thermal runaway, venting, fire propagation. Battery Management Systems (BMS) functional safety. Abuse testing: Mechanical, thermal, electrical. Battery recycling & hazardous waste handling. Standards: ISO 12405, UL 2580, AIS-048/AIS-156, IEC 62660

Module IV: Charging System Safety & Communication Protocols

Charging infrastructure (AC/DC, Wireless charging). EVSE safety requirements & grid interaction.Fault detection: Overcurrent, ground faults, overvoltage.Charging communication & cybersecurity.Interoperability and safe plug design.Standard references: IEC 61851, UL 2231

Module V: Crashworthiness, Fire Safety & Emergency Responses

EV crash regulations: UNECE R100, R94, R95.Structural safety for battery enclosure.Post-crash electrical safety & occupant protection.Fire suppression technologies and materials. Emergency shutdown systems & first-respond protocols. Reliability, failure analysis & safety case documentation.

Text Books:

1. Gianfranco Pistoia & Boryann Liaw (Eds.) (2018). Behaviour of Lithium-Ion Batteries in Electric Vehicles: Battery Health, Performance, Safety and Cost. Springer International Publishing. ISBN 978-3-319-69950-9.
2. Advanced Battery Management Technologies for Electric Vehicle by Rui xhiong.
3. Standards & Regulations Collection — e.g., ISO 6469 (Safety specs for EVs), IEC 61851 (EV charging systems), ISO 26262 (Functional safety of road vehicles) etc.

Reference Books:

1. Crash Safety of High-Voltage Power train Based Electric Vehicles Author: C. Gong
2. Wired for Safety: Your Essential Guide for Electric Vehicle Safety .ISBN: 979-8394555220
3. Electric and hybrid vehicle. (Design and fundamentals) by Iqbal Hussain.
4. SAE International Information Report: SAE J2344 "Guidelines for Electric Vehicle Safety" – specifically addresses high-voltage safety in EVs.

ELE504E - Data Analytics and Digital Twins for EVs

Type of Course: Discipline-Centric Elective

L	T	P	Contact Hrs/Week	Credits
3	0	0	3	3

Course Objectives: The objective of this course is to provide theoretical foundations and practical frameworks for Digital Twin (DT) technologies with emphasis on modelling, data analytics, and applications in electric vehicles (EVs). Students will learn hybrid modelling (physics-informed + data-driven), real-time data engineering, subsystem-level digital twins (battery, motor-drive, thermal), and system-level implementations for charging and fleet optimisation.

Course Outcomes:

1. Explain Digital Twin concepts, dimensions, architectures, standards, and enabling technologies.
2. Design hybrid (physics-based and data-driven) models and data pipelines required for DT development.
3. Develop and validate Digital Twins for EV battery systems (SOC, SOH, RUL estimation).
4. Build Digital Twins for motor-drive systems and thermal/charging subsystems.
5. Integrate subsystem twins into fleet/charging-level Digital Twins and evaluate performance, safety, and cybersecurity implications.

Module I: Digital Twin Concepts, Architectures, Standards

Definition and evolution of Digital Twins; canonical five-dimension view; Digital Twin taxonomy, Enabling technologies: IoT, edge/cloud computing, co-simulation, FMI/FMU standards, OPC-UA; Data considerations: real-time streaming, metadata,synchronisation; Industry standards and reference architectures.

Module II: Modelling & Data Engineering for DTs

Physics-based, data-driven, and hybrid modelling for cyber-physical systems; State estimation: EKF/UKF, particle filtering, uncertainty quantification; Data engineering workflows: preprocessing, sensor fusion, feature engineering, data governance, versioning, cybersecurity.

Module III: Battery Digital Twin for EVs

Battery modelling: electrochemical models, equivalent circuit models (ECM); SOC/SOH/RUL estimation: hybrid ML–model methods, thermal coupling, degradation modelling; Parameter identification, calibration, validation strategies; Applications in BMS, predictive maintenance, and fast-charging optimisation.

Module IV: Motor/Drive Digital Twins

Electrical machine and inverter models, loss modelling, switching behaviour; Signal-based fault signatures, anomaly detection, hybrid ML–physics diagnostics; DTs for efficiency optimisation, thermal stress analysis, and health monitoring.

Module V: Thermal Systems, Charging Infrastructure & Fleet Digital Twins

Thermal management Digital Twins: coolant loops, HVAC interactions, thermal-energy modelling; Charging-station and grid-interaction models; Fleet-level DTs: telematics integration, distributed optimisation, charging scheduling; Safety, privacy, and cybersecurity considerations.

Books Recommended

Text Books:

1. **Digital Twin Technology for Smart Grid**, S. Choobkar and S. M. Hashemi, Springer, 2025.
2. **The Engineering of Digital Twins**, J. Fitzgerald, C. Gomes, and P. G. Larsen, Springer, 2024.
3. **Digital Twin – Architectures, Networks, and Applications**, Y. Zhang, SpringerBriefs, 2024.
4. **Digital Twin Operation and Maintenance for Traction Power Supply System of High-Speed Train**, K. Liu and G. Wu, Springer, 2025.
5. **Digital Twin Driven Intelligent Systems and Emerging Metaverse**, E. Karaarslan, Ö. Aydin, Ü. Cali, and M. Challenger, Springer, 2023.

References (Papers & Surveys)

1. Liu, M. et al., "A Review of Digital Twin: Concepts, Technologies, and Applications," 2021.
2. Yao, J. F. et al., "Systematic Review of Digital Twin Technology and Applications," 2023.
3. Naseri, F. et al., "Digital Twin of Electric Vehicle Battery Systems," 2023.
4. Issa, R. et al., "A Data-Driven Digital Twin of Electric Vehicle Li-Ion Battery," MDPI Batteries, 2023.

ELE505E - Cybersecurity in EVs and Charging Networks

Type of Course: Discipline-Centric Elective

L	T	P	Contact Hrs/Week	Credits
3	0	0	3	3

Course Objectives: This course aims to provide foundational and applied knowledge of cybersecurity for electric vehicles and charging networks through cryptography, embedded security, secure communication protocols, charging-network protection, firmware resiliency, intrusion detection, and standard-driven cybersecurity architectures to ensure safe and cyber-resilient EV deployment.

Course Outcomes:

1. Explain cybersecurity fundamentals, cryptographic algorithms and cyber–physical attack surfaces in EV ecosystems.
2. Analyze vulnerabilities in EV embedded systems, automotive networks, ECUs, cloud platforms and charging infrastructure.
3. Apply authentication, encryption and secure key management to protect EV–charger and in-vehicle communication.
4. Implement cybersecurity standards and secure-boot firmware-resiliency strategies for EV hardware and V2G platforms.
5. Recommend cybersecurity architectures, monitoring frameworks and incident-response strategies for EV fleets and charging networks.

Module I: Cryptography Foundations of Cybersecurity (EV Focus)

Introduction to cybersecurity, security goals (CIA Triad), OSI security architecture, cybersecurity for EVs, block and stream ciphers, symmetric and asymmetric cryptosystems (DES, RSA), key management (Diffie-Hellman), introduction to hash functions.

Module II: In-Vehicle Network & Embedded System Security

Embedded security requirements for automotive systems, automotive CAN, LIN, FlexRay, automotive Ethernet vulnerabilities, OBD-II attack vectors (bus spoofing, replay, flooding attacks), security of ECUs and telematics units, firmware vulnerabilities in automotive environments, resource-constrained nature of modern EV ECUs, lightweight cryptography, secure CAN/CAN-FD authentication.

Module III: Cybersecurity in EV Charging Infrastructure

Cyber-attacks on EVSE, device-level threats, communication protocol-level attacks, application/cloud backend threats, physical tampering and debug-port exploitation, OCPP cybersecurity, IP protection in cloud-connected systems, secure code isolation, encryption for charge-session management, roaming authentication challenges, trust-domain management for charging networks.

Module IV: Secure Communication & Smart-Grid Cybersecurity

Secure communication requirements for EVs and charging networks, ISO 15118, OCPP 2.0.1, TLS/PKI-based authentication, encryption and certificate lifecycle management, secure boot, authenticated updates, rollback-protection, hardware root of trust (HRoT), cybersecurity challenges in vehicle-to-grid (V2G) and grid-interactive EVs, smart-grid security for plug-in electric vehicles (PEVs).

Module V: Cybersecurity Monitoring, Incident Response & Case Studies

Cyber intrusion detection and anomaly analytics for EV fleets, real-time event logging and forensic frameworks, UN R155 cybersecurity management system (CSMS), ISO/SAE 21434 cybersecurity lifecycle compliance, cyber incident-response planning for EV ecosystems.

Books Recommended

Textbooks:

1. Behrouz A. Forouzan, *Cryptography and Network Security.*
2. Bruce Schneier, *Applied Cryptography*, John Wiley & Sons Inc.
3. Jean-Charles Grégoire, *Cybersecurity for Connected and Autonomous Vehicles.*
4. J. Miller, *The Hackers Handbook for Automotive Systems.*
5. S. Samani, *Securing Electric Vehicles and Charging Infrastructure.*
6. S. Jeschke and A. Brecher, *Security and Privacy in Electric Vehicles*, Springer.

Reference Books:

1. ISO 15118, *Road Vehicles – Secure Communication for EV Charging.*
2. ISO/SAE 21434, *Road Vehicle Cybersecurity.*
3. UN R155, *Cybersecurity Management System for Vehicles.*
4. NIST IR 8219, *Electric Vehicle Supply Equipment Security Guidelines.*
5. IEEE/SAE papers on EV cybersecurity and V2G digital-security architectures.

ELE506E - Power Quality in EV Systems

Type of Course: Discipline-Centric Elective

L	T	P	Contact Hrs/Week	Credits
3	0	0	3	3

Course Objectives: To provide students with a fundamental understanding of power quality issues in electric vehicle systems and charging infrastructure. It covers the sources, effects, measurement, and mitigation of PQ problems, with a focus on EV drives, chargers, and smart grid integration.

Course Outcomes:

1. Identify and analyze common power quality issues in electric vehicles and charging systems.
2. Apply PQ measurement techniques and interpret data using relevant standards.
3. Design basic mitigation strategies for harmonics, voltage sags, swells, and power factor correction in EV systems.
4. To analyze power quality issues arising from various EV charging methods, assess the impact of fast charging on distribution network performance, interpret EV load profiles, and propose effective strategies to improve PQ at charging infrastructures.
5. Evaluate advanced PQ solutions in smart EV grids, including V2G/G2V integration and renewable energy interfacing.

Module I: Basics of Power Quality

Power quality phenomenon:Sources and effects of power quality problems, Need for concern of Power quality, types of power quality disturbances,Transients: classification and origin, Short duration voltage variation: interruption, sag, swell, Long duration voltage variation, voltage unbalance, waveform distortion: notching, harmonics and voltage flicker.

Module II: PQ Measurement, Monitoring and standards

Overview of power quality standards: IEEE 519, IEEE 1433 and IEC 61000, PQ indices, Power quality Monitoring: Objectives and measurement issues, different monitoring instruments – Power quality analyzer, harmonic spectrum analyzer, flicker meters.

Module III: PQ mitigation techniques in EVs

Harmonic Mitigation: passive and active filters for EV chargers; Voltage Sag/Swell Compensation: methods suitable for EV charging systems; Power Factor Improvement: techniques for single-phase and three-phase EV chargers, sag and swell correction using Dynamic Voltage Restorer, DVR for EV infrastructure, DSTATCOM in EV charging systems, UPQC in charging grids.

Module IV: EV Charging Systems and PQ

AC vs DC Charging: PQ challenges in different charging types; Fast Charging Impact: effects on distribution networks and voltage stability; EV Load Profiles: analysis of typical EV charging patterns; PQ Improvement Strategies: practical methods to maintain PQ at charging stations.

Module V: Smart EV Grids and Advanced PQ Solutions

Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) Concepts: bidirectional energy flow and PQ impact, PQ Challenges in Smart EV Networks: voltage fluctuations, harmonics, and reactive power, Integration with Renewables: maintaining PQ with distributed energy resources, Case Studies: examples of PQ improvement in smart EV grids.

Books Recommended

Reference Books:

1. Bhim Singh, *Power Quality Problems and Solutions*, 3rd Edition, 2015.
2. IEEE Std 1159-2019, *Recommended Practice for Monitoring Electric Power Quality.*
3. IEEE Std 2030.1.1, *Smart Grid Interoperability for Electric Vehicles.*
4. M. H. Rashid, *Power Electronics Handbook*, 4th Edition.
5. *IEEE Transactions on Smart Grid* focusing on EV–grid integration and power quality.

ELE507E - Innovation and Entrepreneurship in EVs

Type of Course: Discipline-Centric Elective

L	T	P	Contact Hrs/Week	Credits
3	0	0	3	3

Course Objectives: This course aims to cultivate an entrepreneurial mindset and innovation competencies specific to the EV sector, this course equips students with practical expertise. It focuses on identifying market opportunities, designing robust business models, and launching startup ventures within electric vehicle ecosystems.

Course Outcomes:

1. Identify and evaluate market opportunities and unmet needs in the e-mobility sector.
2. Develop comprehensive business plans and viable business models for e-mobility startups.
3. Assess technological innovations and their commercial feasibility in e-mobility applications.
4. Design customer-centric solutions addressing sustainability and operational challenges.
5. Articulate funding strategies, investor pitches, and financial projections for e-mobility ventures.

Module I: E-Mobility Landscape and Market Opportunities

Overview of global and Indian e-mobility markets, market segmentation (personal EVs, commercial vehicles, micro-mobility), regulatory environment and government incentives, technological trends (battery technology, autonomous driving, connected vehicles), competitive analysis, market size and growth projections, identification of unmet customer needs, gap analysis, and emerging niches in e-mobility.

Module II: Innovation and Technology Assessment

Fundamentals of innovation and disruption, technology assessment frameworks, EV powertrain innovations (battery management systems, motor technologies), charging infrastructure innovations (wireless charging, fast charging), vehicle-to-grid (V2G) and grid-to-vehicle (G2V) technologies, autonomous mobility solutions, smart fleet management systems, sustainability metrics and environmental impact analysis, and intellectual property considerations.

Module III: Business Model Development and Strategy

Business model canvas for e-mobility ventures, revenue streams and pricing strategies, value proposition design, customer segmentation and targeting, competitive positioning, strategic partnerships and ecosystems, supply chain considerations for EVs, scaling strategies, and market entry approaches (direct launch, partnerships, licensing).

Module IV: Entrepreneurship and Venture Creation

Startup ecosystem and stakeholders, ideation and concept validation, lean startup methodology, MVP (Minimum Viable Product) development, customer discovery and validation, pivot strategies, team building and organizational structure, leadership in early-stage ventures, ethical and responsible innovation, and risk management.

Module V: Funding, Finance, and Implementation

Sources of funding (angel investors, venture capital, government grants, crowdfunding), business financial modeling and projections, investment pitch development and presentation, due diligence process, term sheets and valuation, go-to-market strategies, performance metrics and KPIs, scaling operations, and case studies of successful e-mobility startups.

Books Recommended

Textbooks:

1. Steve Blank and Bob Dorf, The Startup Owner's Manual: The Step-by-Step Guide for Building a Great Company, K&M Peters, 2012.

2. Alexander Osterwalder , Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers, John Wiley & Sons, 2010.

3. Ashok Leyland, Electric Vehicles and the Changing Automotive Landscape, Elsevier, 2023.

Reference Books:

1. Eric Ries, The Lean Startup: How Today's Entrepreneurs Use Continuous Innovation to Create Radically Successful Businesses, Crown Business, 2011.

2. Christoph M. Reinhardt, E-Mobility Technology and Trends, Springer , 2022.

3. Clayton M. Christensen, The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail, Harvard Business School Press, 1997.

ELE508E - EVs: Economics, Policy and Social Embedding

Type of Course: Discipline-Centric Elective

L	T	P	Contact Hrs/Week	Credits
3	0	0	3	3

Course Objectives: This course aims to cultivate an understanding of electric mobility's economic foundations and their effects on energy systems, markets, and society, equipping students with essential expertise. It focuses on EV policies, regulations, institutions, cost-benefit analyses, business models, investments, and public-private partnerships across consumer, firm, and system viewpoints.

Course Outcomes:

1. Explain key concepts in transport and energy economics and apply them to EV adoption and diffusion.
2. Evaluate the total cost of ownership and externalities of EVs versus conventional vehicles.
3. Interpret and compare major EV policy instruments such as subsidies, tax incentives, mandates, and standards.
4. Analyse interactions of EVs with electricity markets, grids, and renewable energy integration, including basic V2G concepts.
5. Assess social acceptance, distributive impacts, and behavioural drivers of EV transitions across different user groups.

Module I: Fundamentals of EV Economics

Introduction to transport and energy economics; demand for mobility and generalized cost of travel; private vs. social costs; technology diffusion and learning curves; total cost of ownership (TCO) of EVs vs. ICE vehicles; lifecycle costing and externalities (emissions, noise, congestion).

Module II: Markets, Business Models and Investment

EV value chains and market structure; charging infrastructure ownership and business models (public, private, PPP); fleet economics (buses, taxis, logistics); financing EV projects, risk and uncertainty; role of utilities and aggregators; innovative tariffs, battery leasing and mobility-as-a-service concepts.

Module III: Policy Instruments and Regulation

Rationale for policy intervention; overview of global and national EV roadmaps and targets; fiscal incentives (subsidies, tax rebates, feebates), non-fiscal measures (ZEV mandates, CAFÉ standards, access regulations); fuel economy and emission standards; regulatory issues in charging infrastructure, interoperability, and grid codes.

Module IV: Social Embedding and Governance of EVs

Socio-technical transitions and mobility justice; patterns of EV adoption across income, gender, urban–rural and regional divides; public perception, risk communication and misinformation; labour, skills and industrial restructuring; urban planning, land use and charging access; role of cities, utilities, civil society and user communities in EV governance.

Module V:Case Studies and Scenario Analysis

International case studies (e.g., EU, China, USA) and national/state initiatives; comparative assessment of EV policy mixes; simple EV uptake and emissions scenarios under alternative price and policy assumptions; group project: design of a context-specific EV policy package integrating economic, regulatory and social dimensions.

Books Recommended

Textbooks:

1. M. A. Delucchi and D. Sperling, Transport Policy and the Environment, Oxford University Press, 2011.
2. T. Turrentine et al., Electric Vehicle Adoption: Behaviour, Policy and Markets, Springer, 2022.
3. R. Garcia-Valle and J. A. Peças Lopes (eds.), Electric Vehicle Integration into Modern Power Networks, Woodhead Publishing, 2019.

Reference Books:

1. International Energy Agency (IEA), Global EV Outlook, Annual Reports 2023-2025.
2. World Bank, E-Mobility Economics and Policy: A Global Synthesis, Transport and ICT Global Practice, 2023.
3. UNEP, Global Outlook on Electric Vehicle Transitions, 2023.

ELE509E - EVs and Smart Grids

Type of Course: Discipline-Centric Elective

L	T	P	Contact Hrs/Week	Credits
3	0	0	3	3

Course Objectives: This course aims to provide comprehensive knowledge of Smart Grid concepts, architectures, and technologies with emphasis on distributed generation, communication systems, and EV integration. It enables learners to understand, analyze, and manage power quality and operational challenges in modern intelligent power systems.

Course Outcomes:

1. Explain the fundamental concepts, need, regulatory aspects, and national initiatives related to smart grids.
2. Describe smart grid architectures, standards, control layers, and automation technologies in transmission and distribution systems.
3. Apply distributed generation, renewable energy, storage, electric vehicle, and communication technologies in smart grid applications.
4. Analyze PMU, WAMS, and IoT-based data for monitoring, control, and decision-making in smart grids.
5. Evaluate power quality issues due to renewable and EV integration and propose appropriate mitigation and monitoring solutions.

Module I: Introduction to Smart Grid

Basics of conventional power systems and their limitations; definition and evolution of smart grids; need for smart grid; smart grid domain and enablers; smart grid priority areas; regulatory challenges; smart-grid activities in India.

Module II: Smart Grid Architecture

Smart grid architecture and standards-policies; smart-grid control layer and elements; network architectures including IP-based systems and power line communications; supervisory control and data acquisition system; advanced metering infrastructure.

Module III: Integration of EVs and Distributed Generation in Smart Grids

Concept and importance of distributed generation (DG); impact of DGs and EVs on generation, transmission and distribution grids; EV load characteristics and charging infrastructure planning; coordinated and uncoordinated charging; vehicle-to-grid (V2G), vehicle-to-home (V2H) and vehicle-to-building (V2B) concepts; energy management strategies; EVs as distributed storage; role of renewable energy in EV charging; microgrids with EV integration.

Module IV: Communication Technologies in Smart Grid

Introduction to communication technology and two-way digital communications paradigm; Synchro-Phasor Measurement Units (PMUs) and Wide Area Measurement Systems (WAMS); introduction to Internet of Things (IoT); applications of IoT in smart grids.

Module V: EV Power Quality Management in Smart Grid

Power quality issues introduced by EV charging infrastructure and power electronic converters; impact of fast and ultra-fast EV chargers on smart distribution networks; power quality challenges due to distributed generations and inverter-based resources; interaction effects of simultaneous EV–DG integration in smart grids; smart-grid-based mitigation techniques including active filtering, smart inverter control, FACTS devices, real-time monitoring and coordinated control strategies.

Books Recommended

Textbooks:

1. S. Borlase, *Smart Grids, Infrastructure, Technology and Solutions*, CRC Press, 2013, 1st Edition.
2. G. Masters, *Renewable and Efficient Electric Power System*, Wiley–IEEE Press, 2013, 2nd Edition.
3. Ali Keyhani, *Design of smart power grid renewable energy systems*, Wiley IEEE, 3rd Edition, 2019.

Reference Books:

1. J. A. Momoh, *Smart Grid: Fundamentals of Design and Analysis*, Wiley-IEEE Press, 1st Edition, March 2012.
2. A. G. Phadke and J. S. Thorp, *Synchronized Phasor Measurements and their Applications*, Springer, 2nd Edition, 2017.

ELE510E - Reliability Engineering for EVs

Type of Course: Discipline-Centric Elective

L	T	P	Contact Hrs/Week	Credits
3	0	0	3	3

Course Objectives: To introduce reliability engineering principles for electric vehicles, covering failure mechanisms, reliability modelling, testing methods, and PHM-based maintenance strategies to enhance EV system durability and lifecycle performance.

Course Outcomes:

1. Explain basic reliability concepts, metrics and distributions used in EV systems.
2. Analyze EV reliability data using Weibull, FMEA, FTA and physics-of-failure methods.
3. Evaluate failure mechanisms of major EV components such as batteries, power electronics, motors, sensors and charging systems.
4. Apply ALT, HALT/HASS and IEC environmental tests to assess EV component reliability.
5. Recommend reliability improvements using PHM, derating and reliability-centered maintenance strategies.

Module I: Fundamentals of Reliability Engineering

Reliability definitions and metrics including failure rate, MTTF, MTBF and MTTR; hazard and survival functions; probability distributions such as Weibull, exponential and log-normal; repairable and non-repairable systems; reliability block diagrams; bathtub curve; lifecycle reliability considerations for EV systems.

Module II: Failure Modelling & Reliability Data Analysis

Failure data classification: complete, censored and interval data; Weibull analysis and parameter estimation; FMEA and Fault Tree Analysis for EV systems; physics-of-failure models for automotive components; Monte-Carlo simulation for reliability prediction.

Module III: Reliability of Electric Vehicle Components

Battery ageing mechanisms, thermal runaway risks and SoH degradation; power electronics reliability including thermal fatigue, switching stress and SiC/GaN device issues; motor reliability covering bearing failures, insulation degradation, overheating and cooling system issues; sensor drift, communication failures and BMS hardware concerns; charging system reliability including connectors, cables and environmental stresses.

Module IV: Reliability Testing & Evaluation Methods

Accelerated Life Testing (ALT) using thermal, mechanical and vibration stresses; HALT/HASS methodologies for design robustness; IEC 60068 environmental tests covering humidity, dust, shock and vibration; Reliability Demonstration Testing (RDT); EV safety and reliability compliance standards including AIS-156, ISO 6469, IEC 62619 and SAE-J.

Module V: Reliability Improvement, Diagnostics & Case Studies

Design for Reliability (DfR) and derating principles; redundancy and fault-tolerant design approaches; condition monitoring and prognostics health management (PHM); reliability-centered maintenance for EV fleets; selected case studies on batteries, inverters, motors and analysis of field failure datasets.

Books Recommended

Textbooks:

1. Frede Blaabjerg, *Reliability of Power Electronic Converter Systems*, Wiley-IEEE.
2. Charles E. Ebeling, *An Introduction to Reliability and Maintainability Engineering.*
3. E. A. Elsayed, *Reliability Engineering.*
4. Davide Andrea, *Battery Management Systems for Large Lithium-Ion Battery Packs.*
5. K. K. Aggarwal and Yogesh Singh, *Essentials of Reliability Engineering.*

References:

1. Modarres M., *Reliability Engineering and Risk Analysis.*
2. Wayne Nelson, *Applied Life Data Analysis.*
3. ReliaSoft, *Weibull Analysis Handbook.*
4. Rashid M. H., *Power Electronics: Devices, Circuits and Applications.*
5. IEEE/SAE/IEC Standards for EV reliability and environmental testing.

Research Paper References:

1. Blaabjerg, F. et al., "Mission profile-based reliability design and assessment of power electronic systems," *IEEE Industrial Electronics Magazine*, 2021.
2. Yang, X. et al., "Lithium-ion battery fast-charging behaviour, ageing and degradation mechanisms," *Nature Energy*, 2022.

3. Haines, J. C. et al., ”Prognostics and health management of PMSM traction motors in electric vehicles,” *IEEE Transactions on Industrial Electronics*, 2021.

4. Khan, A. et al., ”Reliability assessment and thermo-mechanical ageing of high-power EV fast-charging connectors,” *Energy Reports*, 2023.

5. Schaltz, E. et al., ”Fleet-level reliability analysis and real-world failure data of electric vehicles: A comprehensive review,” *IEEE Transactions on Transportation Electrification*, 2023.

ELE511E - Restructured Power Systems

Type of Course: Discipline-Centric Elective

L	T	P	Contact Hrs/Week	Credits
3	0	0	3	3

Course Objectives: The course aims to develop a thorough understanding of deregulated power systems by explaining the structural changes in the power industry, the operation of competitive electricity markets, transmission pricing mechanisms, congestion management techniques, and the role of ancillary services in ensuring reliable and economic operation of modern power networks.

Course Outcomes:

1. Demonstrate a clear understanding of power-sector restructuring, deregulation principles, and their implications for transmission and distribution systems with DG and EV integration.
2. Explain power market reforms, ISO functions, smart grid trading arrangements, and open-access frameworks used in competitive electricity markets.
3. Analyze and compare different electricity pricing and transmission cost-allocation methods under deregulated market conditions.
4. Assess congestion issues in power systems and evaluate appropriate congestion management techniques using transfer capability concepts.
5. Apply ancillary service concepts for load–generation balancing, voltage and reactive power control, and system restoration in deregulated and smart grid–enabled power systems.

Module I: Restructuring of Power Industry

Introduction to power industry restructuring; reasons for deregulation; fundamentals and motivation for restructuring; restructuring process including unbundling and privatization; restructuring models; components of restructured systems; impact of distributed generations and electric vehicles on restructured power systems; technical and regulatory issues in deregulated distribution networks.

Module II: Power Market Reforms

Reforms in Indian power sector; Independent System Operator (ISO): functions and responsibilities; smart grid trading arrangements including pool, bilateral and multilateral models; open access transmission systems; Open Access Same Time Information System (OASIS).

Module III: Transmission Pricing

Introduction to electricity pricing; marginal pricing of electricity; nodal pricing and zonal pricing; embedded cost method; postage stamp method; contract path method; boundary flow method; MW-mile method; MVA-mile method; comparison of different transmission pricing methods.

Module IV: Congestion Management

Definition of congestion and reasons for transfer capability limitation; importance and features of congestion management; congestion management in normal operation; calculation of total transfer capability (TTC), available transfer capability (ATC), and capacity benefit margin (CBM); non-market congestion management methods.

Module V: Ancillary Service Management

Introduction to ancillary services; types and classification of ancillary services; load-generation balancing related services; voltage control and reactive power support devices; black start capability service; ancillary service markets and management strategies.

Books Recommended

Textbooks:

1. L. L. Lai, *Power System Restructuring and Deregulation*, John Wiley & Sons Ltd., 2012, 1st Edition.
2. K. Bhattacharya, J. E. Daadler, and Math H. J. Bollen, *Operation of Restructured Power Systems*, Kluwer Academic Pub., 2012, 1st Edition (Reprint).
3. D. Kirschen and G. Strbac, *Fundamentals of Power System Economics*, John Wiley & Sons Ltd., 2019, 2nd Edition.

Reference Books:

1. Philipson Lorrin and Willis H. Lee, *Understanding Electric Utilities and De-regulation*, Marcel Dekker Pub.
2. Ilic M., *Power Systems Restructuring - Engineering and Economics*, Kluwer Int. Series.
3. Mohammad Shahidehpour and Muwaffaq Alomoush, *Restructured Electrical Power Systems: Operation, Trading, and Volatility*, CRC Press.

ELE512E - Solar EV Charging Infrastructure Design

Type of Course: Discipline-Centric Elective

L	T	P	Contact Hrs/Week	Credits
2	0	2	4	3

Course Objective: To impart fundamental and applied knowledge required to design, assess, and implement solar photovoltaic–based electric vehicle (EV) charging systems, covering solar resource evaluation, PV system components, system design for various EV charging applications, and economic viability.

Course Outcomes:

1. Explain the global and Indian scenarios of solar-based EV charging systems and assess their role in future clean mobility transitions.
2. Analyze solar photovoltaic specifications, resource assessment parameters, and evaluate PV module performance for EV charging applications.
3. Identify and select appropriate balance-of-system (BoS) components, inverters, batteries, cabling, protection devices, and mechanical structures for reliable solar PV installations.
4. Design solar PV charging systems for different applications, including single-point, petrol-pump–based, multi-point commercial, off-grid, and two-wheeler charging stations.
5. Conduct cost estimation and economic analysis of solar EV charging systems, including component pricing, tariffs, and financial viability for charging station owners.

Module I: Introduction to Solar-Based EV Charging

General aspects of solar-based EV charging energy systems; global and Indian EV charging energy scenario; solar PV demand forecast for EV charging infrastructure up to 2040; role of solar PV in achieving net-zero CO_2 emissions by 2050; India's rooftop solar market for EV charging applications; state energy policies relevant to solar-powered EV charging stations.

Module II: SPV Specifications & Resource Assessment

Solar cell basics, parameters and efficiency; PV modules ratings, parameters and measurement; series/parallel module connections; PV power estimation and module selection; IV–PV characteristics; solar irradiance, insolation, radiation and PSI; sun path; solar and tilt angles (altitude, azimuth, optimum tilt); solar energy estimation on flat and tilted surfaces; PV energy conversion.

Module III: Solar PV Plant BoS and Accessories

Overview and selection criteria for types of photovoltaic systems, solar inverters, batteries and charge controllers; solar PV balance of system: AC cables, AC distribution boards, AC isolators, array junction boxes (AJB), batteries (optional), connectors, DC cables, DC distribution boards, disconnects/switches, earthing kits, fuses, lightning protection, meters, surge protection devices and transformers; electrical installation design; wires and cables; mechanical structure design.

Module IV: Design of Solar Plant for EV Charging Infrastructure

Design for single-point charging for individual shops; design for petrol station-based charging systems; design for multiple-point commercial charging stations; design of off-grid charging stations; charging for two-wheelers with multiple points.

Module V: Costing and Economics of Solar PV Charging Systems

Costing of solar components; per-unit costing of panels, batteries, structures, wires and electronics; total system costing; different charging tariffs; economic analysis and benefits for charging station owners.

Lab Experiments:

1. To plot the different characteristics of solar PV panel.
2. Series and parallel connection of solar panel for enhancing the voltage and current rating of the PV array.
3. To measure the effects of temperature and irradiance on the solar PV panel output parameters like current, voltage and power.
4. To measure the effects of shading on the solar PV panel output parameters like current, voltage and power.
5. To estimate the solar radiation on the horizontal and tilted plane and also estimate the seasonal effects through simulation.
6. To estimate the solar energy generation on the horizontal and tilted plane and also estimate the seasonal effects through simulation.
7. To understand the main components and balance of system of a solar plant.
8. To understand the different configuration and types of solar plants.
9. To design the on-grid solar plant for EV charging infrastructure using simulation software like PVSyst/PVSol etc. along with the economic analysis.
10. To design the off-grid solar plant for EV charging infrastructure using simulation software like PVSyst/PVSol etc. along with the economic analysis.

Books Recommended

Textbooks:

1. C. S. Solanki, *Solar Photovoltaics – Fundamentals, Technologies and Applications*, 2nd ed., PHI Learning, 2011.

2. B. H. Khan, *Non-Conventional Energy Resources*, 3rd Edition, McGraw Hill Education India, 2017.

3. M. A. Hannan, Faisal M. S. Hussein, Saad Mekhilef, *Electric Vehicle Charging Infrastructure: Smart Grid and Renewable Energy Integration*, 1st Edition, CRC Press, 2021.

Reference Books:

1. A. Luque and S. Hegedus (eds.), *Handbook of Photovoltaic Science and Engineering*, John Wiley and Sons, 2010.

2. V. V. N. Kishore (ed.), *Renewable Energy Engineering and Technology – A Knowledge Compendium*, TERI Press, 2008.

3. R. A. Messenger and A. Abtahi, *Photovoltaic System Engineering*, 3rd ed., CRC Press, 2010.

4. GSES, *Grid Connected PV Systems Design and Installation*, GSES India Sustainable Energy, 2013.

5. Gilbert M. Masters, *Grid-Connected Solar Electric Systems*, 2nd Edition, Wiley, 2017.

6. Subhes C. Bhattacharyya, *Energy Economics: Concepts, Issues, Markets and Governance*, 1st Edition, Springer, 2011.

Online Resources:

1. Design of Photovoltaic Systems, Prof. L. Umanand, IISc Bangalore (NPTEL): `https://onlinecourses.nptel.ac.in/noc22_ee71/preview`

ELE513E - Retrofitting and Intelligent Transportation System

Type of Course: Discipline-Centric Elective

L	T	P	Contact Hrs/Week	Credits
3	0	0	3	3

Course Objectives: To develop competency in vehicle retrofitting (with emphasis on electric vehicle conversion and safety upgrades) and Intelligent Transportation Systems (ITS). The course covers retrofit feasibility, design and integration of key subsystems, safety/compliance and testing, and ITS technologies (sensing, communication, vehicle-to-everything connectivity, and traffic management) for safer and more efficient mobility.

Course Outcomes:

1. Perform retrofit feasibility assessment using packaging, energy/range, performance, safety, cost, and lifecycle considerations.
2. Design a retrofit architecture for electric vehicle conversion including motor, inverter, battery pack, battery management system, charger, auxiliaries, wiring, and protections.
3. Formulate validation and compliance plans covering high-voltage safety, functional checks, electromagnetic compatibility basics, and documentation required for approval.
4. Explain Intelligent Transportation Systems architecture and technologies (sensing, connectivity, vehicle-to-everything) and map them to mobility and safety use-cases.
5. Evaluate deployment performance using key performance indicators, data analytics basics, cybersecurity, and privacy fundamentals.

Module I: Retrofitting and Intelligent Transportation Systems Foundations

Need and scope of retrofitting; retrofit categories (powertrain conversion, emissions/efficiency upgrades, safety and advanced driver-assistance retrofits); baseline vehicle assessment (gross vehicle weight, duty cycle, constraints); overview of Intelligent Transportation Systems, stakeholders, architecture concept, and performance measures (safety, delay, emissions, throughput).

Module II: Electric Vehicle Conversion Retrofit Design

Selection of conversion approach; motor and drivetrain matching; inverter and controls overview; battery chemistry selection and sizing; state-of-charge and state-of-health concepts; battery management system functions; charging basics (alternating-current/direct-current charging, on-board charger); connector/interface overview; direct-current to direct-current converter and low-voltage network; thermal management; braking and regenerative braking integration; wiring harnessing, fusing, contactors, and pre-charge; electromagnetic compatibility and electromagnetic interference considerations; diagnostics and maintainability.

Module III: Safety, Standards, Testing, and Approval

High-voltage safety (isolation, interlocks, protections) and workshop practices; hazard identification and risk assessment; verification and validation planning (functional checks, insulation and continuity, thermal tests, road tests); documentation and traceability; reliability, serviceability, and quality assurance; overview of compliance and homologation workflow and inspection lifecycle.

Module IV: Intelligent Transportation Systems Technologies and Applications

Traffic sensing (inductive loop detectors, cameras, radar, light detection and ranging) and data quality; positioning and timing using Global Navigation Satellite System; communication overview (cellular communication, Dedicated Short-Range Communications and cellular vehicle-to-everything concepts); vehicle-to-everything use-cases (collision warning, hazard alerts, signal priority); adaptive signal control and corridor management; public transport Intelligent Transportation Systems (automatic vehicle location, passenger information systems); parking and electronic tolling overview; basics of edge computing versus cloud computing in Intelligent Transportation Systems.

Module V: Deployment, Analytics, Cybersecurity, and Case Studies

Intelligent Transportation Systems project lifecycle (planning, procurement, integration, operations and maintenance); interoperability concepts and application programming interfaces; key performance indicators (travel time, reliability, queue length, safety indicators); basic analytics for traffic and incident prediction; cybersecurity basics for connected vehicles and roadside units, privacy and data governance; retrofit program case studies (buses, light commercial vehicles, campus fleets).

Books Recommended

Textbooks:

1. John G. Hayes and G. Abas Goodarzi, *Electric Powertrain: Energy Systems, Power Electronics and Drives for Hybrid, Electric and Fuel Cell Vehicles*, Wiley, 2018.
2. Mehrdad Ehsani, Yimin Gao, Sebastien E. Gay, and Ali Emadi, *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles: Fundamentals, Theory, and Design*, CRC Press, 2005 (or later edition).
3. James D. Halderman, *Automotive Electricity and Electronics*, Pearson, latest edition.

Reference Books (Retrofitting-leaning + Intelligent Transportation Systems):

1. Ali Emadi (ed.), *Handbook of Automotive Power Electronics and Motor Drives*, CRC Press, 2017.
2. Rajesh Rajamani, *Vehicle Dynamics and Control*, Springer, 2012.
3. Mashrur A. Chowdhury and Adel Sadek, *Fundamentals of Intelligent Transportation Systems Planning*, Artech House, 2003.

ELE514E - Renewable Energy and Sustainable Systems

Type of Course: Discipline-Centric Elective

L	T	P	Contact Hrs/Week	Credits
3	0	0	3	3

Course Objectives: To provide comprehensive knowledge of renewable energy technologies—including hydro, solar, wind, biomass, and green hydrogen—and enable students to analyze, design, and evaluate sustainable and carbon-neutral energy systems for modern power applications.

Course Outcomes (COs): After successfully finishing the course, students should possess the capability to:

1. Analyze the global energy scenario and evaluate the role of hydro power and solar-based EV charging systems in sustainable energy development.
2. Explain the working principles of solar photovoltaic systems and design basic SPV applications for power generation and water pumping.
3. Analyze wind energy characteristics and design basic wind energy conversion systems considering technical and economic aspects.
4. Evaluate biomass conversion technologies and assess their role in biofuel production and carbon-negative energy systems.
5. Explain green hydrogen production, storage, and fuel cell technologies and assess their integration in hybrid renewable energy systems.

Module I: Introduction

Introduction to General Energy and its Requirement, effect of conventional sources on climate change, climate change scenario, role of energy in economic development, role of renewable energy sources in sustainable development. Hydro power: small scale hydro power, benefits of small hydro power over large hydro power plants, future of micro-hydro power, recent advancement in run-off small hydro plants (vortex flow).

Module II: Solar Photovoltaic Technology

Introduction, SWOT analysis of solar photovoltaic systems, present status of solar photovoltaic technology, efficiency of solar cells, design of solar photovoltaic systems, role of solar photovoltaics in sustainable development, design of solar PV technology for sustainable applications.

Module III: Wind Energy

Introduction, Beaufort wind scale, wind energy and its characteristics, design of wind energy system, wind energy conversion systems, classifications of wind generators, wind energy devices, uses of wind energy systems, economics of wind power, environmental concerns.

Module IV: Biomass Energy

Introduction to biomass, classification, and characteristics; biomass production and harvesting techniques; biomass processing for fuel use, Bioenergy with carbon capture and storage (BECCS), future prospects of carbon-negative technologies, carbon-negative biofuels, biofuel conversion technologies, and CO_2 capture and storage technologies.

Module V: Green Hydrogen Fundamentals

Introduction to types of hydrogen, hydrogen production, hydrogen storage, fuel cells, hydrogen safety, hydrogen vehicles, hybrid energy systems, future of hydrogen, harnessing renewable energy for green hydrogen production, economics of hydrogen production.

Books Recommended

Textbooks:

1. N. S. Rathore and N. L. Panwar, *Fundamental of Renewable Energy Systems*, CRC Press, New India Publishing Agency, New Delhi-110 034.

2. C. S. Solanki, *Solar Photovoltaics – Fundamentals, Technologies and Applications*, 2nd ed., PHI Learning, 2011.

3. B. H. Khan, *Non-Conventional Energy Resources*, 3rd ed., McGraw Hill Education India Private Limited, 1 July 2017.

4. Mohammad G. Rasul, Abul Kalam Azad, and Subhash C. Sharma (eds.), *Clean Energy For Sustainable Development*, Academic Press (Elsevier), ISBN: 978-0-12-805423-9.

5. Rohit Srivastava, Jayeeta Chattopadhyay, and Diogo M. F. Santos (eds.), *Solar-Driven Green Hydrogen Generation and Storage*, Elsevier, 2023.

6. Joshua Earnest and Sthuthi Rachel, *Wind Power Technology*, 3rd ed., 25 July 2019.

Reference Books:

1. A. Luque and S. Hegedus (eds.), *Handbook of Photovoltaic Science and Engineering*, John Wiley & Sons, 2010.

2. V. V. N. Kishore (ed.), *Renewable Energy Engineering and Technology – A Knowledge Compendium*, TERI Press, 2008.

3. Subhes C. Bhattacharyya, *Energy Economics: Concepts, Issues, Markets and Governance*, 1st ed., Springer, 2011. (For costing and economics module)

Approved Course Contents

Generic Electives

ELE501G - Hydrogen and Fuel Cell Technologies

Type of Course: Generic Elective

L	T	P	Contact Hrs/Week	Credits
3	0	0	3	3

Course Objectives: The objective is to provide students with the skills and knowledge needed to design, evaluate, and optimize fuel cell systems for automotive applications, considering all the technical, safety, and regulatory aspects associated with these systems.

Course Outcomes:

1. Understand the global scenario, uses, potential applications and associated challenges of hydrogen energy along with the different methods for hydrogen production.
2. Recognize the various methods of distributing and storing hydrogen, such as gas cylinders, pipelines, metal hydrides, and chemical storage.
3. Analyze the physico-chemical characteristics of hydrogen as a fuel, perform efficiency calculations and fuel consumption assessments for hydrogen-based heat engines.
4. Comprehend safety regulations, codes, and standards related to hydrogen handling and storage, evaluate the safety measures for hydrogen storage facilities and its use in vehicles through case studies.
5. Design and assess fuel cell systems for different applications, with a focus on automotive sectors.

Module I: Introduction to Hydrogen Energy

Global scenario, uses, prospects, prognosis and future scope challenges of hydrogen energy; hydrogen production from fossil and synthetic fuels; electrolysis of water using solar energy.

Module II: Transportation, Distribution and Storage

Strategic considerations for hydrogen distribution and bulk storage of gaseous hydrogen; dewars for transport applications; gas cylinders and pipelines; large-scale storage; metal hydrides; chemical and related storage including simple hydrogen-bearing chemicals, complex chemical hydrides and nano-structured materials; hydrogen storage in road vehicles; industrial scale pressurized hydrogen storage.

Module III: Hydrogen as a Fuel in Heat Engines

Hydrogen for stationary applications and powering vehicles in road transport and aviation industry; hydrogen energy and hydrogen as a fuel; liquid and gaseous fuels; physico-chemical characteristics of hydrogen; efficiency calculations and fuel consumption; internal combustion engines and aircraft; hydrogen-fuelled transportation.

Module IV: Fuel Cell (FC) Systems

Basic principles and classification of fuel cells; proton exchange membrane fuel cell and fuel cell poisoning; reversible and irreversible losses; efficiency of fuel cells; fuel crossover/internal current losses, ohmic losses, mass transport/concentration losses; system integration including power management and thermal management; fuel cell system design; application of fuel cells to automotive sectors; case study/project.

Module V: Fuel Cell Components, Types and Parts

Fuel cell stack, fuel processor, power conditioners, air compressors and humidifiers; polymer electrolyte membrane fuel cells; direct-methanol fuel cells; alkaline fuel cells; phosphoric acid fuel cells; molten carbonate fuel cells; solid oxide fuel cells; combined heat and power fuel cells; regenerative or reversible fuel cells.

Books Recommended

Textbooks:

1. Angelo Basile and Adolfo Iulianelli, *Advances in hydrogen production, storage and distribution*, Elsevier Ltd., 2014.
2. Darren P. Broom, *Hydrogen Storage Materials: The Characterisation of Their Storage Properties*, Springer, 2011.
3. Arno A. Evers, *The Hydrogen Society*, HydrogeitVerlag, 2010.
4. Vladimir Molkov, *Fundamentals of hydrogen safety engineering – I*, Bookboon.com.
5. Vladimir Molkov, *Fundamentals of hydrogen safety engineering – II*, Bookboon.com.

ELE452G - Optimization for Engineering Design

Type of Course: Generic Elective

L	T	P	Contact Hrs/Week	Credits
2	0	2	4	3

Course Objectives: This course introduces fundamental optimization principles. It covers single and multivariable unconstrained optimization, constrained optimization, and evolutionary optimization techniques such as Genetic Algorithms and Simulated Annealing. Through hands-on MATLAB lab exercises, students gain practical experience in applying these techniques to real-world engineering problems, enhancing their problem-solving abilities.

Course Outcomes:

1. State and describe the optimization problem formulation relating to engineering applications.
2. Analyze and evaluate single variable unconstrained optimization techniques.
3. Apply multivariable unconstrained optimization techniques based on optimality criteria and gradient-based methods.
4. Evaluate and solve constrained optimization problems using penalty function techniques.
5. Synthesize knowledge of evolutionary optimization techniques, including metaheuristic techniques.

Module I: Overview of Optimization

Introduction to optimization and historical development; engineering applications of optimization; optimization problem formulation; classification of optimization problems.

Lab Exercises:

- Define linear and nonlinear functions in MATLAB.
- Define single and multi-variable functions in MATLAB.
- Visualize contour plots using MATLAB's fcontour command for famous unimodal functions.

Module II: Single Variable Unconstrained Optimization

Single variable unconstrained optimization; optimization criteria; bracketing methods including exhaustive search and bounding phase methods; region elimination methods including Fibonacci search and golden section search; gradient-based methods including Newton-Raphson and bisection; root finding using optimization techniques.

Lab Exercises:

- Implement bracketing methods: bounding phase, exhaustive search, and tabulate results in MATLAB.
- Implement Fibonacci and golden section methods for region elimination in MATLAB.
- Implement Newton-Raphson for a single variable in MATLAB and tabulate results.

Module III: Multivariable Unconstrained Optimization

Multivariable unconstrained optimization and optimality criteria; unidirectional search; direct search methods including Box's evolutionary optimization and coordinate descent; Powell's conjugate direction method; gradient-based methods including Cauchy's steepest descent, Newton's method and conjugate gradient method.

Lab Exercises:

- Calculate gradient vector and Hessian matrix of functions in MATLAB.
- Implement unidirectional search methods in MATLAB and tabulate results.
- Visualize descent and ascent directions of a function in MATLAB.
- Analyze and implement descent algorithms in MATLAB.

Module IV: Constrained Optimization Techniques

Constrained optimization problem formulation; local and global minima in constrained problems; Kuhn-Tucker conditions; transformation to unconstrained problems using penalty functions; specialized methods including integer programming using penalty function method; introduction to geometric programming.

Lab Exercises:

- Familiarize with MATLAB's optimization toolbox.
- Solve constrained optimization problems in MATLAB and tabulate results.

Module V: Evolutionary Optimization Techniques

Introduction to Genetic Algorithms and differences/similarities with traditional methods; GAs for constrained optimization; introduction to Simulated Annealing.

Lab Exercises:

- Generate random numbers from standard distributions in MATLAB.
- Find global optima using GA in MATLAB.
- Compute iterations of simulated annealing method in MATLAB.

Books Recommended

Textbooks:

1. Kalyanmoy Deb, *Optimization for Engineering Design*, 2nd Edition, Prentice Hall, India, 2021.
2. Kalyanmoy Deb, *Multi-objective optimization using Evolutionary algorithms*, John Wiley.

Reference Books:

1. S. Rao, *Optimization Techniques*.

Online Resources:

1. Introduction to Optimization by Prof. A. Goswami and Prof. Debjani Chakraborty, IIT Kharagpur, NPTEL course.

ELE454G - Carbon Audit and Net Zero Energy Buildings

Type of Course: Generic Elective

L	T	P	Contact Hrs/Week	Credits
3	0	0	3	3

Course Objective: This course will give an in-depth understanding of the effects of carbon emissions on the environment and consequent challenges, skills to conduct carbon audits, different definitions of NZEBs and the different steps involved in achieving NZEB goals.

Course Outcomes:

1. Identify the effects of carbon emissions on the environment and consequent challenges.
2. Acquire necessary knowledge and skills to conduct carbon audits and life cycle analysis to identify carbon management opportunities.
3. Understand the concept of Zero Energy Building definitions, solar energy utilization in buildings and other renewable sources of power generation for buildings.
4. Analyze the transient building heat transfer and its impact on thermal comfort and energy conservation studies in building perspective.
5. Get familiar with novel materials and designs for NZEB construction and tangible strategies for reducing energy demands in different climatic zones.

Module I: Energy, Society and Carbon Emissions

Energy and society; climate change and greenhouse gases; relative contribution of various sectors to global anthropogenic greenhouse gas emissions; mitigation, adaptation and other potential strategies; energy as a major source of carbon emissions; estimation of carbon emissions from extraction, conversion, storage, transport and utilization of various energy carriers.

Module II: Carbon Management Strategies

Carbon management in new buildings and cities; carbon implications of waste reduction and recycling; strategies for carbon storage in soil and oceans; energy generation for a low carbon society; carbon credits and trading schemes; carbon economics; low carbon investments; carbon labeling; challenges and opportunities in carbon management in energy sector and energy intensive industries.

Module III: Introduction to Net Zero Energy Buildings

Introduction to Net Zero Energy Buildings (NZEBs) and concepts; different definitions of NZEBs; relevance of such systems; steps to achieve NZEBs; challenges involved in the design of such systems; sources of renewable power for NZEBs; thermal loads and energy use in buildings.

Module IV: Design Considerations in NZEBs

Building fabric/envelope, HVAC and lighting systems; integration with solar/renewable energy systems; comfort considerations in NZEBs including thermal comfort, visual comfort, acoustic comfort and indoor air quality; carbon footprint mitigation; NZEB case studies; future directions.

Module V: Building Management Systems for NZEBs

Building management systems; optimal resource dispatch (thermal and electrical); demand side management with NZEB operation including HVAC and lighting control; operation of building microgrids in grid-connected and islanded modes; provision of ancillary services or peer-to-peer sharing among various buildings.

Books Recommended

Textbooks:

1. Subramanian S. M., *The Carbon Footprint Handbook*, CRC Press, 2015.
2. Emmanuel R. and Keith B., *Carbon Management in the Built Environment*, Routledge, 2012.
3. Athienitis A. and O'Brien W., *Modeling, Design, and Optimization of Net-Zero Energy Buildings*, Ernst & Sohn, 2015.
4. Goswami D. Y., *Principles of Solar Engineering*, CRC Press Taylor & Francis Group, 2015.
5. Chwieduk D., *Solar Energy in Buildings*, Elsevier, 2014.
6. Arora C. P., *Refrigeration and Air Conditioning*, McGraw Hill Education, 2017.

Reference Books:

1. UNDP, *Carbon Handbook*, United Nations Development Programme, 2014.
2. Holman J. P., *Heat Transfer*, McGraw Hill Education, 2010.
3. Duffie J. A. and Beckman W. A., *Solar Engineering of Thermal Processes*, John Wiley & Sons, 2006.

ELE502G - Bio Conversion and Processing of Waste

Type of Course: Generic Elective

L	T	P	Contact Hrs/Week	Credits
3	0	0	3	3

Course Objective: To comprehend and understand the diverse applications of biomass and solid waste materials as energy sources, as well as their processing and utilization to extract energy and valuable products, providing valuable insights for students across different disciplines.

Course Outcomes:

1. Attain a comprehensive understanding of biomass and solid waste classification, composition, properties and production, with a focus on biomass and its role in processes like photosynthesis.

2. Demonstrate the ability to utilize waste materials for chemical feedstock through preprocessing and component separation techniques.

3. Apply thermochemical conversion methods, including pyrolysis and gasification, for solid waste utilization.

4. Analyze the process of converting various wastes into biogas, alcohols and other valuable bio-based products through bioconversion techniques.

5. Distinguish between traditional and alternative energy vehicles in the context of bio-based fuels and energy use.

Module I: Biomass and Solid Waste Fundamentals

Introduction to biomass and other solid wastes; classification of biomass and solid wastes; compositions, characteristics and properties; structural components; production of biomass and biomass wastes; photosynthesis, biomass generation and its availability; conversion processes of biomass for energy generation; waste biomass for energy applications.

Module II: Waste Utilization as Chemical Feedstock

Utilization of wastes as feedstocks for chemicals; pre-processing techniques for waste materials; separation of components for feedstock preparation; considerations for upgrading waste streams for further conversion.

Module III: Thermochemical Conversion of Wastes

Thermochemical conversion of wastes into solid, liquid and gaseous products through pyrolysis and gasification; combustion principles; appliances and systems for utilization of solid wastes for heat and power generation.

Module IV: Bioconversion and Biofuels

Bioconversion of wastes into biogas, alcohols and other products; introduction to third-generation biofuels and their applications; alcohol production from biomass; transesterification processes for biofuel production; biohydrogen: production processes and applications.

Module V: Chemical Conversion Processes and Applications

Chemical conversion processes including hydrolysis and hydrogenation; solvent extraction of hydrocarbons; fuel combustion and conversion into electricity; case studies on waste-to-energy and bio-based product pathways.

Books Recommended

Textbooks:

1. S. Samir and R. Zaborsky, *Biomass Conversion Processes for Energy and Fuels*, Plenum Press, New York, 1981.
2. H. D. Joseph, P. Joseph and H. John, *Solid Waste Management*, Van Nostrand, New York, 1973.
3. G. Tchobanoglous, H. Theisen and S. V. Samuel, *Integrated Solid Waste Management: Engineering Principles and Management Issues*, McGraw Hill, New York, 1993.

ELE503G - Renewable Energy Resource Assessment and Forecasting

Type of Course: Generic Elective

L	T	P	Contact Hrs/Week	Credits
3	0	0	3	3

Course Objectives: The course will provide students an understanding of assessment of various non-conventional energy resources such as solar energy, wind energy, biomass, geothermal, waves, tides and ocean thermal energy and its forecasting methods.

Course Outcomes:

1. Assess different energy resources, understand energy principles of meteorology and numerical weather prediction.
2. Analyze concepts of uncertainty in solar energy assessment and evaluation of solar forecasting skills.
3. Learn and implement concepts of wind energy assessment and forecasting.
4. Evaluate biomass, geothermal, ocean thermal, tidal and wave energy assessment and forecasting.
5. Learn and evaluate characterization of forecast errors and benchmarking of renewable energy forecasting.

Module I: Introduction to Renewable Energy Sources

Introduction to renewable sources: solar energy, wind energy, biomass energy, geothermal energy, ocean thermal energy, wave and tidal energy; principles of meteorology for renewable energy forecasting; observational data assimilation into numerical weather prediction (NWP) models; probabilistic forecasting; statistical models including ARMA and ARIMA; data-driven models such as AI algorithms.

Module II: Solar Energy Assessment and Forecasting

Uncertainty in solar resource assessment; means of assessment: satellite-based, land station-based, software-based (Meteonorm, SolarGIS); meteorological considerations; solar forecasting for different timescales; clear sky models and persistence forecast; evaluation of solar forecasting skills; solar radiation forecasting using machine learning, AI prediction methods, time series models, unit root tests, co-integration models and ANN models.

Module III: Wind Energy Assessment and Forecasting

Wind resource origins and measurement; wind distribution and site selection for monitoring stations; assessment techniques; wind forecasting using statistical and numerical methods; short-term prediction models; upscale models; spatio-temporal forecasting; ramp forecasting; variability forecasting and uncertainty in wind power predictions.

Module IV: Small Hydro, Biomass and Geothermal Energy

Statistical analysis of data for small hydro and biomass; sources and generation mechanisms; forecasting based on statistical data; measurement of productivity; geological survey for geothermal regions; distribution of geothermal energy; types of geothermal resources; thermal gradient measurements; monitoring microseismic activity; reflection seismic; deep exploration drilling and testing with estimation.

Module V: Ocean, Wave and Tidal Energy Forecasting

Measurement and statistical analysis for assessment and forecasting of ocean thermal, wave and tidal energy; statistical and time series models; wave energy converters; characterization of forecast errors; benchmarking of renewable energy forecasting including ANEMOS and WIRE benchmarks.

Books Recommended

Textbooks:

1. G. Kariniotakis (Ed.), *Renewable Energy Forecasting: From Models to Applications*, Woodhead Publishing, 2017.

2. Jan K., *Solar Energy Forecasting and Resource Assessment*, Academic Press, 2013.

ELE455G - Nonlinear Control Systems

Type of Course: Generic Elective

L	T	P	Contact Hrs/Week	Credits
3	0	0	3	3

Course Objective: This course aims to equip students with a comprehensive understanding of nonlinear systems, enabling them to identify various nonlinearities, interpret phase portraits, analyze stability using methods like Lyapunov's direct approach, and design effective nonlinear control systems through techniques such as feedback linearization and sliding mode control.

Course Outcomes:

1. Understand nonlinear systems: describe different types of nonlinearities and recognize unique characteristics of nonlinear systems.

2. Analyze phase portraits: construct and interpret phase portraits and analyze both linear and nonlinear systems using phase plane analysis.

3. Apply describing function method: utilize the describing function method to analyze common nonlinearities.

4. Assess stability of nonlinear systems: define equilibrium points, differentiate between stable and unstable systems, apply linearization and Lyapunov's direct method for local stability analysis, and apply Lyapunov's analysis to linear time-invariant systems.

5. Design nonlinear control systems: create control designs based on Lyapunov's direct method, implement feedback linearization techniques, and grasp fundamental concepts of sliding mode control for nonlinear systems.

Module I: Introduction to Nonlinear Systems

Types of nonlinearities; peculiar properties of nonlinear systems; motivations for studying nonlinear control systems.

Module II: Phase Plane Analysis

Concept and construction of phase portraits; phase plane analysis of linear and nonlinear systems; existence of limit cycles.

Module III: Describing Function Method and Applications

Describing functions of common nonlinearities; describing function analysis of nonlinear systems.

Module IV: Stability of Nonlinear Systems

Equilibrium points; concept of stability of nonlinear systems; linearization and local stability; Lyapunov's direct method; Lyapunov's analysis of LTI systems.

Module V: Nonlinear Control System Design

Control design based on Lyapunov's direct method; feedback linearization; basic concepts of sliding mode control.

Books Recommended

Textbooks:

1. J. J. Slotine, *Applied Nonlinear Control*, Prentice Hall, 1991.

Reference Books:

1. M. Vidyasagar, *Nonlinear System Analysis*, Society for Industrial and Applied Mathematics, 2002.
2. Ashish Tewari, *Modern Control Design With Matlab And Simulation*, John Wiley, 2002.
3. H. K. Khalil, *Nonlinear Systems*, 3rd Edition, Prentice Hall, 2001.

ELE456G - Optimal Control Methods

Type of Course: Generic Elective

L	T	P	Contact Hrs/Week	Credits
3	0	0	3	3

Course Objective: The curriculum addresses optimal control principles, including classical and modern control, calculus of variations, and linear control systems. It delves into dynamic programming, emphasizing Bellman's optimality principle and the Hamilton-Jacobi-Bellman equation. The course also features optimization-based feedback for discrete systems, incorporating practices like least-square estimation, minimum energy control, and model predictive control (MPC) across diverse scenarios.

Course Outcomes:

1. Define the optimal control problem from specifications on dynamic constraints and objective formulation.
2. Explain basic concepts of calculus of variations, such as function, functional, variation, and increment.
3. Analyze and solve optimal control problems using Pontryagin's principle and Hamiltonian formalism.
4. Apply linear quadratic regulator techniques to design control systems for different performance indices and constraints.
5. Analyze and solve variational problems by deriving and solving Euler-Lagrange equations for different constraints and boundary conditions.

Module I: Introduction to Optimal Control

Classical and modern control; concept of optimization; statement of the optimal control problem; performance index; constraints and types of constraints.

Module II: Calculus of Variations and Optimal Control

Basic concepts: function and functional, increment, differential and variation; optimum of a function and functional; basic variational problem; fixed-end time and fixed-end state systems; Euler-Lagrange equation and different cases; second variation and extrema with conditions; variational approach to optimal control systems; optimal control with Hamiltonian formalism (Pontryagin principle); applications to minimum time, energy and control effort problems.

Module III: Linear Control Optimal Control Systems

Finite time linear quadratic regulator; LQR system for general performance index; analytical solution to matrix differential Riccati equation; infinite time linear quadratic regulator; finite-time linear quadratic tracking problem.

Module IV: Dynamic Programming

Bellman's principle of optimality; multistage decision processes; optimal control using dynamic programming; Hamilton-Jacobi-Bellman (HJB) equation.

Module V: Optimization-Based Feedback for Discrete Systems

Least-square estimation; minimum energy control; model predictive control (MPC).

Books Recommended

Textbooks:

1. D. S. Naidu, *Optimal Control Systems*, CRC Press, 2003.
2. D. E. Kirk, *Optimal Control Theory: An Introduction*, Dover, 2004.

Reference Books:

1. B. D. O. Anderson and J. B. Moore, *Optimal Control: Linear Quadratic Methods*, Dover Publications, 2014.
2. F. L. Lewis, D. Vrabie and V. L. Syrmos, *Optimal Control*, 3rd edition, Wiley & Sons, 2012.

Online Resources:

1. Optimal Control by Prof. G. D. Ray, IIT Kharagpur, NPTEL course.

ELE457G - Principles of System Identification

Type of Course: Generic Elective

L	T	P	Contact Hrs/Week	Credits
3	0	0	3	3

Course Objective: The course offers a thorough exploration of system identification in dynamic processes, encompassing historical developments, motivation, and models in the context of deterministic vs. stochastic models. Students delve into mathematical descriptions of processes, dynamic model identification, and techniques for identifying input-output models. The course includes the identification of state-space models, covering observability, controllability, Kalman filter, and subspace identification methods.

Course Outcomes:

1. State and describe the system identification problem.
2. Understand what class of models are suited for a given process and be equipped to handle uncertainties in data.
3. Analyze error-based control algorithms.
4. Identify parametric and non-parametric dynamical models from data.
5. Analyze system-identification tasks for obtaining state-space models.

Module I: Introduction to System Identification

Motivation and historical developments; system identification basics; quantitative and qualitative models; deterministic vs. stochastic models; non-parametric vs. parametric models; data generation and acquisition; data pre-processing and visualization; model assessment and validation; prior process knowledge; identifiability; overfitting; goodness of the model; developing state-space models.

Module II: Mathematical Descriptions of Processes

Definition of model and classification; models for identification; convolutional model; finite impulse response (FIR) model; step response model; frequency response model; difference equation form; state-space models; illustrative MATLAB examples including estimation of FIR, step-response, difference equation and state-space models.

Module III: Identification of Dynamic Models

Introduction to dynamic model identification; non-parametric and parametric descriptions; equation-error models including ARX, ARMAX and ARIMAX families; output-error family; Box-Jenkins family; selecting appropriate model structures; predictions including conditional expectation, linear predictors, one-step ahead prediction, innovations, multi-step and infinite-step ahead predictions; model and system identifiability.

Module IV: Identification of Parametric and Non-parametric Input-Output Models

Parametric time-series models: estimation of AR models, Y-W models, least squares, modified covariance methods, Burg's methods and ML estimator; estimation of MA models; non-parametric input-output models: direct impulse response estimation, regularization and prior knowledge inclusion; indirect estimation for parametric models.

Module V: Identification of State-Space Models

Mathematical essentials: observability and controllability; Kalman filter and extended Kalman filter; extended observability matrix; realization methods; subspace identification methods including MOESP and N4SID methods.

Books Recommended

Textbooks:

1. Arun K. Tangirala, *Principles of System Identification: Theory and Practice*, CRC Press, 2014.

2. Karel J. Keesman, *System Identification: An Introduction*, Springer, 2011.

Online Resources:

1. Principles of System Identification by Prof. Arun K. Tangirala, IIT Madras, NPTEL course.

ELE504G - Soft Computing and Intelligent Systems

Type of Course: Generic Elective

L	T	P	Contact Hrs/Week	Credits
3	0	0	3	3

Course Objectives: This course aims to cultivate understanding of soft computing fundamentals for complex problems with uncertainty, equipping students with essential expertise. It focuses on fuzzy logic, neural networks, evolutionary algorithms, and hybrid systems, with theory and implementations for pattern recognition, optimization, and engineering decision-making.

Course Outcomes:

1. Explain the principles of soft computing and contrast them with hard computing approaches.
2. Design and implement fuzzy logic systems for control and decision-making applications.
3. Develop neural network models for classification, regression, and pattern recognition tasks.
4. Apply evolutionary algorithms and swarm intelligence techniques for optimization problems.
5. Evaluate and compare different soft computing methodologies for real-world engineering problems.

Module I: Introduction to Soft Computing

History and evolution of soft computing; characteristics and advantages of soft computing; comparison with hard computing; uncertainty and imprecision handling; tolerance for imprecision and partial truth; synergistic combination of neural networks, fuzzy systems, and evolutionary computing; applications in engineering and intelligent systems.

Module II: Fuzzy Logic and Fuzzy Systems

Fuzzy sets and membership functions; fuzzy operations; fuzzy rules and inference systems (Mamdani and Sugeno); fuzzification and defuzzification techniques; fuzzy control systems; fuzzy decision-making; applications in process control, robotics, and diagnosis.

Module III: Artificial Neural Networks

Biological inspiration and artificial neurons; perceptron and multilayer neural networks; back-propagation algorithm and training; activation functions; network architectures (feedforward, recurrent, convolutional); learning paradigms (supervised, unsupervised, reinforcement); applications in pattern recognition, prediction, and control..

Module IV: Evolutionary Algorithms and Swarm Intelligence

Genetic algorithms: encoding, fitness evaluation, selection, crossover, mutation; evolutionary strategies and programming; particle swarm optimization (PSO); ant colony optimization (ACO); differential evolution; multi-objective optimization; applications in parameter optimization and system design.

Module V:Hybrid Intelligent Systems and Applications

Integration of fuzzy, neural, and evolutionary approaches; adaptive neuro-fuzzy inference systems (ANFIS); swarm-based neural networks; evolutionary optimization of fuzzy and neural systems; real-world case studies in robotics, power systems, renewable energy, and autonomous systems; project design and implementation.

Books Recommended

Textbooks:

1. S. N. Sivanandam and S. N. Deepa, Principles of Soft Computing, Wiley India, 2011.

2. Timothy Masters, Advanced Algorithms for Neural Networks: A C++ Sourcebook, Wiley, 1995.

3. David E. Goldberg, Genetic Algorithms in Search, Optimization and Machine Learning, Addison-Wesley, 1989.

Reference Books:

1. James A. Freeman and David M. Skapura, Neural Networks: Algorithms, Applications, and Programming Techniques, Addison-Wesley, 1991.

2. Timothy Ross, Fuzzy Logic with Engineering Applications, Wiley, 3rd Edition, 2010.

3. Xin-She Yang, Nature-Inspired Metaheuristic Algorithms, Luniver Press, 2nd Edition, 2010.

ANNEXURE-I

Approved Course Structure and Contents for Batch admitted in 2025[3]

M.Tech in Electrical Engineering (Electric Vehicle Technology)

[3] *For the M.Tech. batch admitted in 2025, the structure and curriculum for Semester I had already received approval from the Competent Authority at IUST (attached in the following pages). From Semester II and onwards, the course contents will be the same as that followed for other batches, however there are minor differences in the course structure which are given in the following pages.*

Semester I (21 Credits)

S. No	Course Title	Course Code	L	T	P	S	Credits
1.	Fundamentals & Dynamics of EVs	MEC511C	4	0	0	0	4
2.	Electrical Engineering Essentials for Electric Mobility	ELE510C	3	0	2	0	4
3.	Power Converters for EVs	ELE507C	4	0	0	0	4
4.	EV Charging Infrastructure	ELE402S	3	0	0	0	3
5.	Research Methodology: Methods and Techniques	ELE502C	3	0	0	0	3
6.	Modelling and Simulation of EVs	ELE508C	2	0	2	0	3
						Total Credits	**21**

Semester II (23 Credits)

S.No	Course Title	Code	L	T	P	S	Credits
1	Battery Management System	ELE550C	3	1	0	0	4
2	Advanced Motor Drives	ELE551C	3	1	0	0	4
3	Advanced Control Systems	ELE552C	3	1	0	0	4
4	Embedded System Design for EVs	ELE553C	2	0	2	0	3
5	Elective -I (Generic)	-	3	0	0	0	3
6	Electric Vehicle Systems Laboratory	ELE554C	0	0	2	0	1
7	Industrial Internship	ELE555C	-	-	-	-	2
8	Open Elective I	-	2	0	0	0	2
						Total Credits	**23**

Semester III (15 Credits)

S.No	Course Title	Code	L	T	P	S	Credits
1	Elective -II (Discipline-Centric)	-	3	0	0	0	3
2	Elective -III (Discipline-Centric)	-	3	0	0	0	3
3	Elective -IV (Generic)	-	3	0	0	0	3
4	Open Elective II	-	2	0	0	0	2
5	Pre-Dissertation	ELE601C	0	0	8	0	4
						Total Credits	**15**

Semester IV (12 Credits)

S.No	Course Title	Code	L	T	P	S	Credits
1	Dissertation	ELE650C	0	0	24	0	12
						Total Credits	**12**
						Total Credits all semesters	**71**

ANNEXURE-II

Approved Evaluation Mechanism for Pre-Dissertation and Dissertation

M.Tech in Electrical Engineering (Electric Vehicle Technology)

Evaluation Mechanism

A Pre-Dissertation

1. Marks to be given by concerned Project supervisor(s) – 20.
2. The following would be evaluated by a duly constituted departmental committee:
   A. Mid-term Presentation – 30 marks.
   B. Final presentation which would include:
      a. Demonstration of model/simulation (if any) – 20 marks.
      b. Final viva-voce – 20 marks.
      c. Dissertation report – 10 marks.

B Dissertation

1. Marks to be given by concerned Project supervisor(s) – 20.
2. Mid-term Presentation evaluated by a duly constituted departmental committee: – 30 marks.
3. Final presentation evaluated by the External Examiner would include:
   a. Demonstration of model/simulation (if any) – 20 marks.
   b. Final viva-voce – 20 marks.
   c. Dissertation report – 10 marks.