THAPAR INSTITUTE
OF ENGINEERING & TECHNOLOGY
(Deemed to be University)

Scheme & Syllabi
M.E.
(Electric Vehicle Technology)

w.e.f. 2024

Electrical and Instrumentation Engineering Department

M.E. (Electric Vehicle Technology) *w.e.f. 2024*

First Semester

S. No.	Course No.	Course Name	L	T	P	Cr
1	PEV**	Power Converters and Control	3	0	2	4.0
2	PEV**	Special Electrical Machines	3	0	0	3.0
3	PEV**	Battery Management Systems	3	0	2	4.0
4	PEV**	EV Modeling and Simulation	3	0	2	4.0
5	PEV**	Vehicle to X Technology	3	0	0	3.0
6	PEV**	Deep Learning for Electric Vehicles	3	0	2	4.0
		Total	**18**	**0**	**8**	**22.0**

Contact hrs./ week: 26
Credits First Sem : 22.0

Second Semester

S. No.	Course No.	Course Name	L	T	P	Cr
1	PEV**	Communication Protocols for Electric Vehicles	3	0	0	3.0
2	PEV**	EV Charging Technology	3	0	2	4.0
3	PEV**	Electric Drive and Power Train	3	0	2	4.0
4	PEV**	Autonomous Vehicle Technology	3	0	2	4.0
5	PEV**	Design Project on EV	--	--	--	4.0
6	PEV**	Elective				3.0
		Total	**15/14**	**0**	**6/8**	**22.0**

Contact hrs./week: (21 or 22)
Credits Second Sem: 22.0

Third Semester

S. No.	Course No.	Course Name	L	T	P	Cr
1	PEV**	Seminar	-	-	-	4.0
2	PEV**	Project	-	-	-	4.0
3	PEV**	Dissertation (Start)	-	-	-	-
		Total	**-**	**-**	**-**	**8.0**

Credits Third Sem: 8.0

Fourth Semester

S. No.	Course No.	Course Name	L	T	P	Cr
1	PEV**	Dissertation				16.0
		Total	**-**	**-**	**-**	**16.0**

Credits Fourth Sem: 16.0

List of Electives

S. No.	Course No.	Course Name	L	T	P	Cr
1	PEV**	Smart Grid for EVs	3	0	0	3.0
2	PEV**	Embedded Systems for Automotive Applications	2	0	2	3.0
3	PEV**	Advanced Power Technologies for Electric Vehicles	2	0	2	3.0
4	PEV**	Modern Power System Operation & Control	2	0	2	3.0
5	PEV**	Protective Relaying	2	0	2	3.0

Total Credits: 68.0

PEV**: Power Converters and Control

L	T	P	Cr.
3	0	2	4.0

Course Objective: To familiarize students with the concept of diverse power conversion topologies and circuits. Additionally, it delves into the principles of power converter control and design methodologies to develop a simple DC/DC converter and DC/AC inverter.

Basic Power Electronic Devices: Diodes, Thyristors, Bipolar Junction Transistors, Metal–Oxide–Semiconductor Field Effect Transistors, Insulated Gate Bipolar Transistors, Ultracapacitors. Characteristics of power electronic switches, Driver circuits, Voltage, and current sensing mechanism, Datasheets.
Power Converters Control: Steady state converter analysis, Steady state modeling of the power converters, DC transformer model, loss modeling, Dynamic modeling of the power converters, AC modeling of converters, state-space averaging, Linearization, Designing of the close loop control of a power converter, Transfer functions and frequency domain analysis, Extra Element Theorem, Pulse Width Modulation (PWM) control of power converters SPWM, SVPWM etc., Analog and digital implementation of the controllers, Advanced analysis and control techniques applied to power electronics converters.
DC/DC Converter: Basic principle of DC–DC Converter, Step-Down (Buck) Converter, Step-Up (Boost) Converter, Buck–Boost Converter, Isolated DC–DC Converter, Four-Quadrant DC–DC Converter, Feedback control design, voltage mode and current mode control.
Rectifiers and Inverters: Single-phase and Three-phase Diode Rectifiers, Poly-phase Diode Rectifiers, Active front end rectifiers, Filtering Systems in Rectifier Circuits, High-frequency Diode Rectifier Circuits. Single-phase and Three-phase Voltage Source Inverters, Current Source Inverters, Closed-loop Operation of Inverters, Regeneration in Inverters, Multistage Inverters.
Laboratory Work: Modelling and simulation of DC-DC and AC-DC unidirectional and bidirectional converters in open loop and closed loop, PWM control techniques, Design of driver circuits etc.

Course Learning Outcomes: Upon completion of this course each student will be able to
Illustrate the basic principles of power converter control
Analyze the modeling of power converters
Design of controller loops for typical power converters
Illustrate the various power conversion topologies/circuits
Design of Power converter circuits.

Recommended Books/References

1. *Rashid M.H., Power Electronics Circuits, Devices and Applications, Prentice Hall India, Third Edition (2011).*
2. *Ali Emadi, Handbook of Automotive Power Electronics and Drives, Taylor & Francis Group, First Edition (2005).*

3.	*Bimal K Bose, Modern Power Electronics and AC Drives, Pearson Education, second Edition (2003).*
4.	*Dubey. G.K., Thyristorised power controllers, new age International (2002).*
5.	*Amirnaser Yazdani, Reza Iravani, Voltage Sourced Converters in Power Systems: Modeling, Control, and Applications, Wiley-IEEE Press (2010).*
6.	*R. W. Erickson, D. Maksimovic, Fundamentals of Power Electronics, Kluwer Academic Publishers, (2004).*
7.	*I. Batarseh, Power Electronic Circuits, Wiley, (2004).*
8.	*J. Kassakian, M. F. Schlecht, and G. C. Verghese, Principles of Power Electronics, Addison-Wesley Publishing Company (1991).*
9.	*N. Mohan, T.M. Undeland, and W.P. Robbins, Power Electronics, Converters, applications, and design, John Wiley and Sons Inc. (2007).*

PEV**: Special Electrical Machines

L	T	P	Cr.
3	0	0	3.0

Course Objective: To impart knowledge of construction, principle of operation, control and performance of stepping motors, switched reluctance motors, permanent magnet brushless D.C. motors, permanent magnet synchronous motors and other special Machines.

Stepper Motors: Constructional features, Principle of operation, Types, Torque predictions, Linear Analysis, Characteristics, Drive circuits, Closed loop control, Concept of lead angle, Applications.

Switched Reluctance Motors (SRM): Constructional features, Principle of operation, Torque prediction, Characteristics, Steady-state performance prediction, Analytical Method, Power controllers, Control of SRM drive, Sensor less operation of SRM, Applications.

Permanent Magnet Brushless D.C. Motors: Fundamentals of Permanent Magnets, Types, Principle of operation, Magnetic circuit analysis, EMF and Torque equations, Power Converter Circuits and their controllers, Characteristics and control, Applications.

Permanent Magnet Synchronous Motors (PMSM): Constructional features, Principle of operation, EMF and Torque equations, Sine wave motor with practical windings, Phasor diagram, Power controllers, Performance characteristics, Digital controllers, Applications.

Other Special Machines: Constructional features, Principle of operation and Characteristics of Hysteresis motor, Synchronous Reluctance Motor, Linear Induction motor, Repulsion motor, Super conducting machines, Written pole machines, Micro-motors, PCB motors, Applications of these special machines.

Course Learning Outcomes: Upon completion of this course each student will be able to
Acquire the knowledge on construction and operation of special electrical machines.
Analyse and design controllers for special electrical machines.
Select a special electrical machine for a particular application.

Recommended Books/References

1. *K. Venkataratnam, Special Electrical Machines, Universities Press (India) Private Limited (2008).*
2. *T. Kenjo, Stepping Motors and Their Microprocessor Controls, Clarendon Press London (1984).*
3. *E.G. Janardanan, Special electrical machines, PHI learning Private Limited, Delhi, (2014).*
4. *R. Krishnan, Switched Reluctance Motor Drives – Modeling, Simulation, Analysis, Design and Application', CRC Press, New York, (2001).*
5. *Kenjo, T., Nagamori, S. Permanent Magnet and Brushless DC Motors. Clarendon Press, London (1988).*

6. *Miller, T.J.E. Brushless Permanent-Magnet and Reluctance Motor Drives. Oxford University Press (1989).*
7. Srinivasan, R. Special Electrical Machines. *Lakshmi Publications (2013).*

PEV**: Battery Management Systems

L	T	P	Cr.
3	0	2	4.0

Course Objective: This course delves into the significance of a Battery Management System (BMS) across diverse battery technologies, exploring various potential configurations. Additionally, it delves into the sophisticated functionalities of the BMS, enriching insights into the battery system's status and ensuring its optimal utilization.

Battery Basics: Introduction of battery, Types of batteries; Lithium-ion: Lithium Nickel Cobalt Oxide (NCA) or lithium cobalt oxide (LCO), batteries of the cylindrical, prismatic, and pouch varieties, Sodium ion batteries.
Need of Battery-Management-System : Functionality of BMS, Battery pack sensing: current, voltage and temperature, isolation and thermal control, protection, and interface, SoC, energy and power estimation requirement.
Modelling of Battery Packs: Equivalent-circuit models, physics-based models, equations of vehicle dynamics, vehicle range calculations.
State and Health Estimation of Battery: Estimation of SoC and SoH, Implementation of EKF Derivation and visualization of Kalman Filter and Extended Kalman Filter (EKF). Implementation of EKF on ESC model. Problems with EKF, improved with sigma-point methods, The SPKF steps, Implementing SPKF on ESC model, Implementing SPKF on ESC model, Real-world issues pertaining to sensors, initialization, Real-world issues: Speed, solved by “bar-delta” filtering, Bar-delta filtering using the ESC cell model. A Kalman filter framework for estimating parameters, EKF for parameter estimation, Simultaneous state and parameter estimation, Robustness, and speed, problem with least-squares capacity estimates, weighted ordinary least squares, weighted total least squares, Goodness of the model fit and confidence intervals.
Cell Balancing: Causes (and not causes) of imbalance, Design choices when implementing balancing, Circuits for balancing (1): Passive (2): Active, capacitive (3): Active, inductive and dc-dc.
Laboratory Work: Modelling and simulation of battery packs, State Estimation of Battery, Battery Health Estimation, Active and Passive Cell Balancing etc.

Course Learning Outcomes: Upon completion of this course each student will be able to
Illustrate the basics of BMS and its Modelling.
Illustrate Various techniques for state estimation and health estimation of battery.
Apply various cell balancing methods
Acquire the knowledge of battery choice for EV applications.

Recommended Books/References
1. *Gregory Plett,* Battery Management Systems, Volume II: Equivalent-Circuit Methods, *Artech (2015).*
2. *Phil Weicker, A Systems Approach to Lithium-Ion Battery Management (Power Engineering), Artech (2013).*
3. *Gregory L Plett, Battery Modeling Volume I: Battery Modeling (Power Engineering) (2015).*
4. *Handbook on Battery Energy Storage System, Asian Development Bank (2018).*

PEV**: EV Modeling and Simulation

L	T	P	Cr.
3	0	2	4.0

Course Objective: This course is designed to provide students with the knowledge and skills necessary to model and simulate Electric Vehicles (EVs), analysis various electromagnetic signals, and optimize the performance of electric vehicles.

Mathematical Model and Characteristics Analysis of the Electric Motors: The basic structure of the electric motors (IM, BLDC, and SRM), the importance of modelling of electric motors, modelling of a three-phase stator winding of electric motors (IM, BLDC, and SRM), modelling of the electromagnetic circuit of motors, ABC and DQ modelling, ABC to DQ and DQ to ABC conversion, analysis of speed-torque characteristics of BLDC motor.
Mathematical Modelling of EVs Powertrain: The basic architecture of EVs, general description of EVs moment, vehicle resistance: Rolling resistance, Aerodynamic drag, Grading resistance, force calculation of EVs, dynamic equation of EVs, calculate mechanical power with and without gears, mathematical modelling of braking operation: Braking force, braking distribution on the front and rear axles, analysis of braking performance.
Control of EVs: Major components of EVs and their uses, analysis of the speed-torque characteristic of EVs with various loading conditions, speed and torque control methods of electric motors (BLDCM, IM, SRM), analysis of braking and motoring operation of various electric motors and analyzing EVs performance, range, and efficiency.
Design and Optimization of Electric Motors Used for Light EVs: Electromagnetic design of the PMSM, SRM and IM, Numerical validation of the designed motors, Optimization of the designed motors, and Optimization methods.
Analysis of Acoustic Noise and Vibration of EVs: Various sources of Acoustic Noise and Vibration (ANV) in EVs, torque ripples, effects of torque ripples on ANV, the relationship between ANV, speed and torque of electric motors, and reduction techniques of ANV.
Condition Monitoring and Fault Diagnosis of Electric Motors: Introduction of condition monitoring and fault diagnosis of electric motors, types of faults, thermal analysis of electric motors, mathematical modelling of a faulty and healthy system of electric drives, and analysis of healthy and faulty electric drives.
Laboratory Work: Designing, Modelling, and Simulating electric vehicle systems.

Course Learning Outcomes: Upon completion of this course each student will be able to
Develop mathematical modelling of electrical motors
Simulate the EVs with consideration of various load conditions
Modelling and Simulation of High-Performance EVs Powertrains
Conduct sensitive analysis of various signals like vibration, acoustic noise, faults, torque-speed characteristics, etc.

Recommended Books/References

1.	*Dubey, G.K., Fundamentals of Electric Drives, Narosa Publications (2001).*
2.	*Dubey, G.K., Power Semiconductor Controlled Drives, Prentice Hall Inc. (1989).*
3.	*Rama Krishnan, Electric motor drives: modelling, analysis, and control, Pearson Education India; 1st ed. (2015).*
4.	*A. E. Fitzgerald, Charles Kingsley, Stephen D. Umans Electric Machinery, TMH, 6th ed. (2017).*
5.	*Bose, B.K., Modern Power Electronics and AC Drives, Prentice-Hall of India Private Limited (2006).*
6.	*Mehrdad Ehsani, Yimin Gao, Ali Emadi, Modern Electric, Hybrid Electric, and Fuel Cell Vehicles: Fundamentals, CRC Press, (2010).*

PEV**: Vehicle to X Technology

L	T	P	Cr.
3	0	0	3.0

Course Objective: To comprehend the fundamentals of Vehicle-to-Grid (V2G) and Vehicle-to-Home (V2H) technologies, while analysing their integration into the electrical grid and assessing the technical aspects, feasibility, and challenges of V2V charging systems.

Introduction to Vehicle-to-Grid (V2G) Technology: Overview of V2G technology and its significance, Evolution of electric vehicle (EV) integration into the grid, Applications and potential benefits of V2G systems, Types of EVs and their suitability for V2G applications
Grid Integration of Electric Vehicles: Grid infrastructure and smart grid concepts, Challenges and opportunities of integrating EVs into the grid, Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) communication, V2G Communication Protocols and Standards, V2G communication architectures and protocols, Interoperability and compatibility considerations
V2G System Components and Technologies: V2G system architecture and components, Power electronics and bidirectional charging technology; Vehicle-grid integration controllers (VGICs) and software platforms.
V2G Control Strategies and Grid Services: Grid services provided by V2G systems (ancillary services, peak shaving, frequency regulation), V2G control algorithms and optimization techniques; Economic incentives.
Introduction to Vehicle-to-Home (V2H) Technology: Overview of V2H technology and its significance in residential energy management, V2H System Architecture and Components: Components of a V2H system: EVs, bidirectional chargers, and home energy management systems.
Benefits and Challenges of V2H Integration: Economic benefits of V2H, peak shaving, load balancing, and electricity cost optimization; Challenges in V2H implementation: interoperability, grid compatibility, and battery degradation.
Introduction to V2V Charging in EVs: Overview of V2V charging technology and its significance, Importance of V2V charging in extending the driving range of EVs, Principles of V2V Charging; Power transfer mechanisms in V2V charging systems, V2V Charging Infrastructure, Design considerations for V2V charging stations. Deployment strategies and challenges in establishing V2V charging networks, Applications of V2V Charging.

Course Learning Outcomes: Upon completion of this course each student will be able to
Demonstrate comprehensive understanding of V2G technology, elucidating its core principles and operational mechanisms.
Analyse the intricacies of electric vehicle integration into the electrical grid, discerning the impact on grid stability and energy management
Apply knowledge of the principles and diverse applications of V2H technology in optimizing energy usage and residential power distribution
Analyse the technical intricacies, feasibility considerations, and potential challenges inherent in the implementation of V2V charging systems.

Recommended Books/References

1. *Junwei Lu and Jahangir Hossain, Vehicle-to-Grid: Linking electric vehicles to the smart grid (Energy Engineering), IET (2015).*
2. *Sekyung Han and Moses Amoasi Acquah, Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) Technologies, MDPI (2021).*
3. *Lou Shrinkle, Modular Battery Swap: How We Can Get Everybody Driving an Electric Car Paperback, Waterside Productions (2022).*
4. *Kevin A. Wilson, The Electric Vehicle Revolution: The Past, Present, and Future of EVs, Motorbooks (2023).*

PEV**: Deep Learning for Electric Vehicles

L	T	P	Cr.
3	0	2	4.0

Course Objective: To explain the concepts and facilitate discussion on deep learning approaches, and their applications to electric vehicles.

Introduction : Perceptron, Multi-layer Perceptron, Backpropagation, gradient descent and variants, regularization in neural network
Convolutional Neural Networks (CNNs): CNN architectures, learning in CNN and-evolution of CNN architectures; transfer learning models; Visualization of Kernels, Deconvolution Methods; Class attribution map methods and advancements; Applications of CNNs for Object detection, segmentation, Recognition and Verification
RNNs and Attention Models: Introduction to RNNs; Backpropagation through time, LSTM and GRU models; Introduction to Attention Models, transformers and spatial transformers networks
Deep Generative Models: Generative adversarial networks (GANs), autoencoders (AEs); Deep Generative Models, self-supervised learning
Deep Learning Applications to Electric Vehicle : Deep learning applications to areas such as EV design and modeling; automotive and grid scale applications; EV scheduling for charging and discharging; vehicle life cycle assessment; autonomous vehicle, EV in microgrids, fault detection, load forecasting etc.
Laboratory Work: Implement deep learning models using python and open source libraries namely Tensorflow, Keras, OpevCV using standard repositories.

Course Learning Outcomes: Upon completion of this course each student will be able to
Comprehend the advancements in learning techniques.
Compare and explain various deep learning models / algorithms
Demonstrate the applications of deep learning in various fields of EV Technology

Recommended Books/References

1. *Bengio, Y.; Goodfellow, I.; Courville, A. Deep Learning; MIT Press: Massachusetts (2017).*
2. *Richard Szeliski, Computer Vision: Algorithms and Applications. Springer, (2010).*
3. *Benjamin Planche, Eliot Andres, Hands-On Computer Vision with Tensor Flow, Packt Publishing (2019).*

PEV**: Communication Protocols for Electric Vehicles

L	T	P	Cr.
3	0	0	3.0

Course Objective: This course provides an in-depth exploration of communication protocols relevant to EVs. It covers the fundamental principles, standards, and protocols governing communication within EV systems, including V2G, V2V, V2I, and internal vehicle communication. Students will gain practical knowledge of protocols such as CAN, OCPP, ISO 15118, and others, along with emerging technologies and trends in EV communication.

Introduction to Electric Vehicles and Communication Protocols: Overview of electric vehicle architecture, Importance of communication protocols in EVs, Evolution of EV communication standards.
Fundamentals of CAN Bus: Understanding Controller Area Network (CAN), CAN protocol layers and message structure, Diagnostics and error handling in CAN.
EV Charging Communication Protocols: Introduction to EV charging infrastructure, OCPP (Open Charge Point Protocol), ISO 15118 (Plug and Charge), Vehicle-to-Grid (V2G) Communication: Concept and significance of V2G communication, Standards and protocols for V2G communication, Applications and challenges of V2G integration.
Vehicle-to-Vehicle (V2V) Vehicle-to-Infrastructure (V2I) Communication: Overview of V2V communication in electric vehicles, IEEE 802.11p (Wireless Access for Vehicular, Environments - WAVE), Safety and cooperative driving applications of V2V, Role of V2I communication in smart mobility, DSRC (Dedicated Short Range Communication), Integration of V2I with traffic management systems.
Security and Privacy in EV Communication: Threats and vulnerabilities in EV communication, Security protocols and measures for protecting EV systems, Privacy concerns and data protection regulations.
Emerging Technologies and Future Trends: Latest advancements in EV communication protocols, Wireless charging and bidirectional power flow, Standardization efforts and industry developments.
Case Studies and Practical Applications: Analysis of real-world implementations of EV communication protocols, Case studies of successful EV communication deployments, Hands-on exercises and demonstrations.

Course Learning Outcomes: Upon completion of this course each student will be able to
Illustrate the importance of communication protocols in electric vehicles.
Familiarize students with the fundamentals of CAN bus architecture.
Explore the standards and protocols for EV charging communication.
Examine V2G, V2V, and V2I communication protocols and their applications.
Analyze case studies and real-world implementations of EV communication protocols.
Evaluate emerging technologies and future trends in EV communication.

Recommended Books/References

1.	*Neaimeh, M., Andersen, P.B. Mind the gap- open communication protocols for vehicle grid integration. Energy Inform 3, 1 (2020)*
2.	*Sumedha Rajakaruna and Nick Jenkins, Electric Vehicle Integration into Modern Power Networks, Springer (2013).*
3.	*Das, Himadry & Rahman, Mohammad & Li, S. & Tan, C.W.. (2019). Electric vehicles standards, charging infrastructure, and impact on grid integration: A technological review. Renewable and Sustainable Energy Reviews.*
4.	*Emanuele Crisostomi, Robert Shorten, Sonja Stüdli, Fabian Wirth, Electric and Plug-In Hybrid Vehicle Networks: Optimization and Control, CRC Press (2020).*
5.	*Junwei Lu and Jahangir Hossain, Vehicle-to-Grid: Linking electric vehicles to the smart grid (Energy Engineering), IET (2015).*

PEV**: EV Charging Technology

L	T	P	Cr.
3	0	2	4.0

Course Objective: To impart the knowledge of EV traction-battery chargers, electric vehicle supply equipment (EVSE),their main components, and charging protocols.

Classification of EV chargers and standards: classification of chargers based on charging levels, modes, plug types; architecture and specifications of Bharat AC001 and DC001 chargers; standards related to: connectors, communication, supply equipment, EMI/EMC.
PFC Converters: Role of front-end power-factor-correction (PFC) converters in EV chargers; types of AC-DC converters; working principles, modulation, design, and closed loop control of PFC converters such as: Boost type PFC, Totem-pole PFC, active front-end converter, three-phase PFCs; working principles, modulation, design, and closed loop control of single-stage AC-DC PFC converters; G2V, V2X modes of operation.
DC-DC converters in EV chargers: Types of DC-DC converter used for EV chargers; working principles, modulation, design, modelling and closed loop control of: dual active bridge (DAB), LLC converter, buck-boost converter; high frequency magnetics; soft-switching criteria.
Protocols and Communication: 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; testing methodology for EV battery chargers and EVSE.
EMI/EMC considerations: sources of EMI in battery chargers; differential mode noise; common mode noise; LISN; measuring of EMI/EMC spectrum; design of DM filters and CM filters.
Laboratory Work: Study of PFC rectifier comprising a diode-bridge and boost converter; PFC rectifier based on active full-bridge; CC/CV based battery charging using buck-boost converter; CC/CV based battery charging using a dual active bridge (DAB); Bidirectional power flow in EV charging system; CAN communication for automotive applications and EV charging; Measurement of EMI/EMC, design of CM and DM filters.

Course Learning Outcomes: Upon completion of this course each student will be able to
Analyze charging modes of traction battery and their impact on the state-of-charge
Evaluate the roles of PFC converter and DC-DC converter in EV charging system
Study various communication systems and protocols related to EV charging equipment
Design and evaluate appropriate filters for EMI reduction in battery chargers

Recommended Books/References

1. *Per Enge, Nick Enge and Stephen Zoepf , Electric Vehicle Engineering, Mc Graw Hill (2020).*
2. *Iqbal Husain, Electric and Hybrid Vehicles: Design*

	Fundamentals, CRC Press (2021).
3.	*Robert W. Erickson, and Dragan Maksimovic Fundamentals of Power Electronics, 3rd Ed., Springer (2020).*
4.	*Christoph Marscholik and Peter Subke, Road Vehicles - Diagnostic Communication, University Science Press (2009).*
5.	*Wolfhard Lawrenz, CAN System Engineering: From Theory to Practical Applications, Springer (2013).*
6.	*Mohan N., Underland T.M. and Robbins W.P., Power Electronics–Converters, Applications and Design, 3rd Ed., Wiley India (2008).*

PEV**: Electric Drive and Power Train

L	T	P	Cr.
3	0	2	4.0

Course Objective: To familiarize students with the concept of electric vehicles, power train for electricvehicles and electric drives used in electric vehicles and their control

Review of Drive Concept: Representation of electric drive, Different machines, and load characteristics, Four quadrant operation, Equilibrium and steady state stability, Thermal and overload consideration of electric drives under continuous, Short, and intermittent duty cycle. tractive effort; vehicular dynamics; drive cycle and vehicle control unit.
Components of Power Train: Components of conventional vehicle and propulsion load; power train of HEV and EV; efficiency considerations for conventional vehicle, HEV and EV; multi-motor in-wheel EVs; impact and benefits of EV on utility grid
Induction Motor Drives: Basics of induction motor; open-loop v/f control; basic pulse width modulation techniques; vector control of IM drives of IM drives for different applications, VSI and CSI fed IM drives, vector controlled permanent magnet induction machines, slip recovery and stator emf injection method, vector control of wound rotor Induction machines.
SRM, BLDC and PMSM Drives: Basics of switched reluctance motor, BLDC motor and PMSM motors; Basics modelling of SRM, BLDC and PMSM drives, Field oriented control and direct torque control of these drives.
High-power and High-speed EVs: Applications of High-power induction motor drives; special PWM techniques for high-power applications; field-oriented control of high-power IM drives; applications of high-speed PMSM drives; field-oriented control of high-speed PMSM drives.
Laboratory Work: Vector control of PMSM and IM drives over complete drive cycle of EV; Characterization of power, torque and efficiency for EV over drive cycle; Power flow in EV power train during charging, V2G feeding, motoring and braking; Forward & backward motoring and regenerative braking of EV consisting of multiple motor- drives; Synchronized PWM techniques for high-power and high-speed IM drives

Course Learning Outcomes: Upon completion of this course each student will be able to
Gain familiarity with the propulsion architecture of various members of the EV family viz. BEV, HEV, PHEV, FCEV etc.
Develop mathematical models and control algorithms for EV traction drives based on induction motor, PMSM and SRM
Model power electronics converters for EV traction drives
Acquire the knowledge of selection of drives for various EV applications

Recommended Books/References
1. *Ali Emadi, Advanced Electric Drive Vehicles, CRC Press (2015)*

2.	*Iqbal Husain, Electric and Hybrid Vehicles – DesignFundamentals, Second Edition, CRC Press (2011).*
3.	*W. Leonard, Control of Electric Drives, Springer Press (2007).*
4.	*R Krishnan, Permanent Magnet Synchronous and BrushlessDC Motor Drives", CRC Press (2010).*
5.	*Berker B., James W. J. & A. Emadi, Switched ReluctanceMotor Drives, CRC Press (2019).*
6.	*Bin Wu, High-Power Converters and Ac Drives, IEEE WILEY Press (2017).*
7.	*Bimal K. Bose, Modern Power Electronics and AC Drives,Prentice Hall PTR (2001).*

PEV**: Autonomous Vehicle Technology

L	T	P	Cr.
3	0	2	4.0

Course Objective: The course aims to provide students with a comprehensive understanding of autonomous vehicle technology and its applications, emphasizing safety, efficiency, and societal impact.

Introduction to Autonomous Vehicles and Electric Mobility: Overview of autonomous vehicle technology; Evolution and current state of autonomous driving; Introduction to electric vehicles (EVs) and their significance in autonomous driving; Comparison between conventional vehicles and electric vehicles; Environmental and economic benefits of electric mobility.

Electric Vehicle Architecture and Components: Fundamentals of electric vehicle architecture and drivetrain; Types of electric vehicles (battery electric vehicles, plug-in hybrid electric vehicles, etc.); Components of electric vehicles (battery packs, electric motors, power electronics, etc.); Integration of autonomous technology with electric vehicle architecture; Case studies on popular electric vehicle models and their autonomous capabilities.

Autonomous Vehicle Sensors and Perception Systems: Sensors used in autonomous vehicles (LiDAR, radar, cameras, ultrasonic sensors, etc.); Principles of operation and applications of each sensor type; Sensor fusion techniques for combining data from multiple sensors; Perception algorithms for object detection, classification, and tracking in electric autonomous vehicles; Challenges and solutions in sensor integration for electric vehicles.

Autonomous Driving Algorithms and Control Systems for Electric Vehicles: Overview of autonomous driving algorithms (path planning, decision-making, localization, etc.); Control systems for autonomous electric vehicles, including adaptive cruise control, lane-keeping, and automated parking; Integration of machine learning and artificial intelligence in autonomous electric vehicle control; Safety considerations and fail-safe mechanisms in autonomous electric vehicle systems.

Autonomous Electric Vehicle Infrastructure and Future Trends: Infrastructure requirements for supporting autonomous electric vehicles (charging stations, communication networks, etc.); Regulatory and policy considerations for the deployment of autonomous electric vehicles; Socio-economic impacts of autonomous electric vehicles on transportation and urban development; Emerging trends and future directions in autonomous vehicle technology and electric mobility.

Laboratory Work: Sensor Integration and Calibration, Developing Perception Algorithms for Object Detection and Tracking, Implementing Control Algorithms for Autonomous Navigation, Testing Autonomous Vehicle Systems using Simulation Tools and Hardware-in-the-Loop Setups to Evaluate Performance and Safety.

Course Learning Outcomes: Upon completion of this course each student will be able to
Illustrate the fundamental concepts and components of autonomous vehicle technology, including sensors, perception systems, and control algorithms

Demonstrate proficiency in designing and implementing autonomous vehicle algorithms for tasks such as path planning, localization, and object detection
Evaluate the challenges and limitations of autonomous vehicle systems, including sensor fusion techniques, real-time decision-making, and interaction with unpredictable environments.

Recommended Books/References
1. *Husain, I., Electric and hybrid vehicles: design fundamentals. CRC press (2021).*
2. *Sciarretta, A., & Vahidi, A., Energy-efficient driving of road vehicles. Cham, Switzerland: Springer International Publishing (2020).*
3. *Qu, Z., Cooperative control of dynamical systems: applications to autonomous vehicles. Springer Science & Business Media (2009.*
4. *Gillespie, T. (Ed.)., Fundamentals of vehicle dynamics. SAE international (2021).*
5. *Rajamani, R., Vehicle dynamics and control. Springer Science & Business Media (2011).*
6. *Anderson, J. M., Nidhi, K., Stanley, K. D., Sorensen, P., Samaras, C., & Oluwatola, O. A., Autonomous vehicle technology: A guide for policymakers. Rand Corporation (2014).*

PEV**: Smart Grid for EVs

L	T	P	Cr.
3	0	0	3.0

Course Objective: To familiarize students with the concept of influence of Evs on power system. It covers the frequency control reserves & voltage support from EVs, ICT solutions to support EV development and charging facility planning.

Introduction: Introduction, Impact of charging strategies, EV charging options and infrastructure, energy, economic and environmental considerations, Impact of EV charging on power grid, effect of EV charging on generation and load profile, Smart charging technologies, Impact on investment.
Influence of EVs on Power System: Introduction, identification of EV demand, EV penetration level for different scenarios, classification based on penetration level, EV impacts on system demand: dumb charging, multiple tariff charging, smart charging, case studies
Frequency Control Reserves & Voltage Support from EVs: Introduction, power system ancillary services, electric vehicles to support wind power integration, electric vehicle as frequency control reserves and tertiary reserves, voltage support and electric vehicle integration, properties of frequency regulation reserves, control strategies for EVs to support frequency regulation.
ICT Solutions to Support EV Deployment: Introduction, Architecture and model for smart grid & EV, ICT players in smart grid, smart metering, information & communication models, functional and logical models, technology and solution for smart grid: interoperability, communication technologies.
EV Charging Facility Planning: Energy generation scheduling, different power sources, fluctuant electricity, centralized charging schemes, decentralized charging schemes, energy storage integration into Microgrid, Design of V2G Aggregator.

Course Learning Outcomes: Upon completion of this course each student will be able to
Examine the influence of EVs on power system
Analyze the frequency control and voltage reserve from EVs.
Explore ICT solutions to support deployment
Explore about vehicle electrification and impact of charging strategies.

Recommended Books/References

1. *Crouse W.H, Anglin D.L, Automotive Transmission and Power Train construction, McGraw Hill (1971).*
2. *Harald Naunheimer, Bernd Bertsche , Joachim Ryborz , Wolfgang Novak, Automotive Transmission: Fundamentals, Selection, Design and Application, 2nd Edition, Springer (2011).*

PEV**: Embedded Systems For Automotive Applications

L	T	P	Cr.
2	0	2	3.0

Course Objective: The course aims to provide students with a comprehensive understanding of embedded system applications in automotive engineering, emphasizing the design, development, and integration of embedded solutions for vehicle control, safety, and infotainment.

Introduction to Embedded Systems in Automotive Applications: Overview of embedded systems and their role in automotive engineering; Fundamentals of microcontrollers and microprocessors used in automotive applications; Introduction to real-time operating systems (RTOS) and their importance in automotive embedded systems.
Automotive Communication Protocols: Overview of automotive communication protocols (CAN bus, LIN bus, FlexRay, etc.); Applications of embedded systems in electric vehicles and hybrid electric vehicles.
Embedded Systems for Vehicle Diagnostics and Maintenance: Introduction to onboard diagnostics (OBD) systems and standards (OBD-II, ISO 15765, etc.); Embedded systems for monitoring vehicle performance, emissions, and fault diagnosis; Implementation of diagnostic trouble code (DTC) retrieval and interpretation algorithms; Remote diagnostics and over-the-air (OTA) software updates in modern vehicles; Development of embedded diagnostic tools and maintenance systems for electric vehicles.
Automotive Infotainment and Human-Machine Interface (HMI): Introduction to automotive infotainment systems and HMI design principles, Designing and prototyping automotive infotainment systems using embedded platforms.
Embedded Systems for Vehicle Safety and Driver Assistance: Overview of advanced driver assistance systems (ADAS) and their components; Embedded systems for collision avoidance, lane departure warning, and adaptive cruise control; Case studies on real-world applications of embedded systems in vehicle safety and driver assistance.
Laboratory Work: Designing and Implementing Embedded Control Systems for Vehicle Subsystems, Programming Microcontrollers for Sensor Interfacing and Data Processing, and Testing Embedded Software on HIL Platforms to Simulate Real-World Automotive Environments.

Course Learning Outcomes: Upon completion of this course each student will be able to
Demonstrate an understanding of embedded system fundamental concepts and their relevance to automotive applications.
Develop practical skills in designing, programming, and testing embedded systems for vehicle control.
Analyze and evaluate the performance, reliability, and safety implications of embedded systems deployed in automotive environments.
Integrate knowledge from multiple domains to design embedded solutions for addressing real-world challenges in vehicle automation.

Recommended Books/References
1. *Kathiresh, M., & Neelaveni, R., Automotive Embedded Systems. Springer International Publishing (2021).*
2. *Zurawski, R., Embedded Systems Handbook: Embedded systems design and verification. CRC press (2018.*
3. *Wang, J., Real-time embedded systems. John Wiley & Sons (2017).*
4. *Zurawski, R., Embedded Systems Handbook 2-Volume Set. CRC press (2018).*
5. *Subhashini, N., Mohanaprasad, K., & Murugan, M., Intelligent embedded systems. D. Thalmann (Ed.). Springer (2018).*
6. *Nicolescu, G., & Mosterman, P. J., Model-based design for embedded systems. Crc Press. (2018).*

PEV**: Advanced Power Technologies For Electric Vehicles

L	T	P	Cr.
2	0	2	3.0

Course Objective: To impart the knowledge of high voltage architecture of EV traction, advanced battery technology and extreme fast charging systems.

High Voltage EV Powertrain: Introduction to high voltage (HV) EV traction systems; benefits and challenges of HV EV traction; analysis of benefits, challenges and future trends of 800V EV powertrain; comparison of 400V and 800V architecture of EV powertrain (mainly in terms of BMS costs, reliability, fast charging, propulsion motor, risk of partial discharge, inverter, auxiliary power units, etc.); multilevel inverters for HV EV powertrain
Multiphase Drives: Advantages and limitations of multiphase drives for EV traction; modelling of multiphase induction motor (IM) and permanent magnet synchronous motor (PMSM); five-phase and six-phase drive topologies; control methods and modulation techniques for multiphase drives.
Advanced Battery Technologies: advances in traction battery technology; advanced lithium-ion batteries; solid state batteries; sodium ion batteries; nickel cadmium batteries.
Extreme Fast Charging (XFC): Role of XFC infrastructure in increasing EV adoption; power conversion systems and standards for DC fast charging; XFC station concepts and converter topologies; role of solid-state-transformers in XFC stations; benefits and limitations of XFC stations.
Laboratory Work: Simulation study of 400V EV drivetrain, 800V EV drivetrain, multilevel inverters, five-phase and six-phase IM and PMSM drives and solid state transformer; Experimental study of multilevel inverter and multiphase drive; Study of multiphase power converters.

Course Learning Outcomes: Upon completion of this course each student will be able to
Analyse the architecture of 800V EV drivetrain
Model multiphase drive for EV drivetrain
Model power converters for XFC application

Recommended Books/References

1. *Bin Wu and Mehdi Narimani, High-Power Converters and AC Drives, IEEE Press Series on Power and Energy Systems (2017).*
2. *K.K.Gupta and P. Bhatnagar, Multilevel Inverters, Academic Press (Elsevier) (2017).*
3. I. Aghabali, J. Bauman, P. J. Kollmeyer, Y. Wang, B. Bilgin and A. Emadi, "800-V Electric Vehicle Powertrains: Review and Analysis of Benefits, Challenges, and Future Trends," in *IEEE Transactions on Transportation Electrification*, vol. 7, no. 3, pp. 927-948, 2021.

4.	Mohamed Amine Frikha et. al., Multiphase Motors and Drive Systems for Electric Vehicle Powertrains: State of the Art Analysis and Future Trends," *Energies*, vol. 16, issue 2, pp. 1-45, 2023.
5.	S. Rivera et al., "Charging Infrastructure and Grid Integration for Electromobility," in *Proceedings of the IEEE*, vol. 111, no. 4, pp. 371-396, 2023.
6.	H. Tu, H. Feng, S. Srdic and S. Lukic, "Extreme Fast Charging of Electric Vehicles: A Technology Overview," in *IEEE Transactions on Transportation Electrification*, vol. 5, no. 4, pp. 861-878, 2019.

PEV**: Modern Power System Operation & Control

L	T	P	Cr.
2	0	2	3.0

Course Objective: To impart learning about optimal generation dispatch, unit commitment, and their implementation through various classical methods. To impart knowledge about power system load-frequency and AVR control. To familiarize students with the concept of influence of EVs on the operation and control of integrated power systems.

Optimal generation dispatch: Input Output characteristics of a power generation units, Optimum generation allocation of thermal units, Reactive power dispatch, Impact of electric vehicles on power systems.
Unit Commitment: Optimal Unit commitment, Solution to unit commitment by dynamic programming, effect of start-up and shut down time/cost, Unit Commitment considering electric vehicles and renewable energy source integration
Load Frequency Control: Introduction, Modelling of Automatic load frequency control (ALFC) control loop, biased control, concept of multi-area control, tie line bias control, Mathematical models of various turbine-governor systems, Automatic generation control incorporating EVs, Plug-in Electric Vehicles participating in primary frequency control.
AVR Control: Mathematical model of automatic voltage regulator (AVR) control loop, modeling of various excitation systems, stability analysis of AVR systems, Lag-Lead compensation, cross coupling between AVR and ALFC control loops. Concept of AVR in multi-machine system, concept of reactive power and voltage dependency, voltage stability analysis of single machine infinite bus system, Voltage stability assessment of transmission system with EVs.
Laboratory Work: Implementation of Load frequency control and AVR control in single area system, Optimal generation dispatch, Unit commitment.

Course Learning Outcomes: Upon completion of this course each student will be able to
Formulate and solve economic load dispatch problems through optimization techniques.
Formulate and solve unit commitment problem through dynamic programming.
Perform load frequency control simulation on single area and multi area power systems.
Design the AVR controller for reactive power control.
Formulate and analyse the impact of EVs integration on generation scheduling and frequency control.

Recommended Books/References

1. *Wood, A.J. and Wollenberg, B.F., Power Generation, Operation and Control, John Wiley and Sons (2003)*
2. *Kothari, D.P., Dhillon J.S. Power system Optimisation, 2nd Ed., PHI, (2011).*
3. *Elgerd O.I., Electric Energy System Theory- An Introduction, McGraw-Hill (1996).*
4. *P. Kundur, Power System Stability & Control Tata McGraw Hill (2007).*

PEV**: Protective Relaying

L	T	P	Cr.
2	0	2	3.0

Course Objective: To give overview of power system protection requirements. Digital protection using different types of static relays, its application to modern power system. To familiarize with micro-grid protection scheme.

Introduction: Overview of protection systems and relaying, Types of relays, concept of digital simulation of relaying signals.
Static Relays: Mathematical theory of relay as a comparator, Operating principles and characteristics of various static relays like Overcurrent relay, Directional relay, Differential relay, Distance relays, Switched distance relay, Poly-phase relay, and Frequency relay.
Protection of Bus-bar, Transformer and Generator: High impedance and low impedance differential protection schemes, Protection schemes for busbar, transformer and generator.
Protection of Feeder and Transmission Line: Protection criteria for distribution system, Feeder Protection, Coordination of overcurrent, distance and directional relay, Distance protection scheme, Stepped time distance characteristics for distance relays, Effect of arc resistance & power surges on performance of Distance Relays, Wire Pilot protection schemes, Carrier current Protection schemes.
Numerical relaying: Numerical Relay, Data Acquisition System, Numerical Relaying Algorithms - Sample and first derivative (Mann and Morrison) algorithm, Fourier and Walsh based algorithms, Fourier Algorithm: Full cycle window algorithm, fractional cycle window algorithm, Removal of DC offset.
Micro-grid Protection: Protection schemes and their implementation challenges for different microgrid architectures, Effects of the Incorporation of Electric Vehicles on Protection Coordination in Microgrids, High Voltage Current Protection in Electric Vehicles.
Laboratory Work: Experiments on differential relay, overcurrent relay, distance relay, Protection schemes for generator, transformer and transmission lines, Simulation of different types of faults in transmission line and transformer using SIMULINK.

Course Learning Outcomes: Upon completion of this course each student will be able to
Analyze the characteristics of different types of electromagnetic and static relays.
Design the protection schemes for feeders, transmission lines, generators and transformers.
Realize different microprocessor based numerical relays and protection schemes.
Comprehend challenges with micro-grid protection.

Recommended Books/References
1. *Johns, A.T. and Salman, S.K., Digital Protection for Power Systems, IEE Power Series (1995).*
2. *Rao, T.S.M., Power System Protection: Static Relays, TMH Publishing Company (2008).*

3.	*B. Ram and D. N. Vishwakarma, Power System Protection and Switchgear, Tata McGraw Hill Education Pvt. Ltd. (2011).*
4.	*Wu, Q.H., Lu, Z., Ji, T.Y., Protective Relaying for Power Systems using Mathematical Morphology, Springer (2009).*

PEV**: Design Project on EV

L	T	P	Cr
0	0	0	4.0

Course Objectives: To facilitate the students learn and apply an engineering design process in electric vehicle technology. As a part of a team, the students will make a project, that emphasizes, hands-on experience, and integrates analytical and design skills.

Course Description: Design Project is the process of devising a system, component or process to meet desired needs. It includes both analysis and synthesis performed in an iterative cycle. As part of their design experience, students have an opportunity to define a problem, determine the problem scope and to list design objectives related to electric vehicle technology. Engineering standards and realistic constraints are critical in engineering design. The standards and constraints should be integrated into the design component of this project.

Course Learning Outcomes:

Upon completion of this course each student will be able to:

- Identify design goals and analyse possible approaches to meet given specifications with realistic engineering constraints.
- Design an electric vehicle technology project implementing an integrated design approach.
- Perform simulations and incorporate appropriate adaptations using iterative synthesis.
- Use modern engineering hardware and software tools.
- Work amicably as a member of an engineering design team.
- Improve technical documentation and presentation skills.

PEV**: Seminar

L	T	P	Cr
0	0	0	4.0

Course Objectives: To impart technical and research reading and writing skills to the students.

Course Description: The students will select a topic relevant to industry/research area. The seminar topic will challenge students to apply critical thinking skills to find the research gap. The faculty supervisor of the seminar will continuously assess the progress of the works of the assigned student. Each student will have to submit a detailed report of the seminar along with a power point presentation.

Course Learning Outcomes:
Upon completion of this course each student will be able to:

- Identify gaps for research work design goals and analyze possible approaches to meet given specifications with realistic engineering constraints.
- Illustrate modern engineering methods and tools.
- Prepare technical report.
- Deliver presentation on the research topic.

Evaluation Scheme:

S. No.	Evaluation Elements	Weightage (%)
1.	Panel of Examiner’s (within department)	50
2.	Assessment by Supervisor	50

PEV**: Project

L	T	P	Cr
0	0	0	4.0

Course Objectives: The course is designed to help the students to develop problem solving skills, which may include a thorough survey of a particular domain, finding a problem pertaining to research /industry and presenting a methodology to resolve the problem with adequate experimental results to strengthen the contribution. Students are also supposed to learn about communicating the impact of their work by different tools which includes video, poster and presentation.

Course Learning Outcomes:
Upon completion of this course each student will be able to:

- Identify, formulate and analyze of domain specific research or industrial problem.
- Propose a methodology to solve identified research or industrial problem.
- Analyze the impact/contribution of the work to the industry or research.
- Communicate and present the work to the relevant audience.

Evaluation Scheme:

S. No.	Evaluation Elements	Weightage (%)
1.	Panel of Examiner’s (within department)	100

PEV**: Dissertation

L	T	P	Cr
0	**0**	**0**	**16.0**

Course Objectives: To impart the knowledge to understand the research methodology, carry out research in thrust areas and write a comprehensive report.

Course Learning Outcomes:

Upon completion of this course each student will be able to:

- Design and implementation of identified research problem or industrial projects.
- Develop acumen for higher education and research.
- Write technical reports and publish the research work in referred journals, national and international conferences of repute.
- Foresee how their current and future work will influence/impact the economy, society and the environment.

Evaluation Scheme:

S. No.	Evaluation Elements	Weightage (%)
1.	Panel of Examiner’s (As approved by DoAA)	50
2.	Assessment by Supervisor	50