Curriculum and Syllabus

MTech

in

Power Systems Engineering

Department of Electrical Engineering

Indian Institute of Technology Bhubaneswar

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Curriculum

SEMESTER 1

Type	Subject Name	Subject Code	L-T-P	Credit	Contact Hour
Core	Power System Analysis and Operation	EE6L061	3-1-0	4	4
Core	Distribution Systems Engineering	EE6L062	3-1-0	4	4
Open Elective	Elective I		3-0-0/3-1-0	3/4	3/4
Dept. Elective	Elective II		3-0-0/3-1-0	3/4	3/4
Dept. Elective	Elective III		3-0-0/3-1-0	3/4	3/4
Core	Power System Analysis and Operation Laboratory	EE6P056	0-0-3	2	3
			Total	**19/22**	**20/23**

SEMESTER 2

Type	Subject Name	Code	L-T-P	Credit	Contact Hour
Core	Power System Protection	EE6L004	3-1-0	4	4
Core	Power System Stability and Control	EE6L021	3-1-0	4	4
Dept. Elective	Elective IV		3-0-0/3-1-0	3/4	3/4
Dept. Elective	Elective V		3-0-0/3-1-0	3/4	3/4
Core	Energy Systems Laboratory	EE6P002	0-0-3	2	3
Core	Computer Methods in Power System Laboratory	EE6P057	1-0-3	3	4
Core	Thesis Part-1	EE6D101	-	2	-
			Total	**21/23**	**21/23**

SEMESTER 3

Type	Subject Name	Code	L-T-P	Credit	Contact Hour
Core	Thesis Part-2	EE6D102	-	14	-
			Total	**14**	

SEMESTER 4

Type	Subject Name	Code	L-T-P	Credit	Contact Hour
Core	Thesis Part-3	EE6D103	-	14	-
			Total	**14**	

Total Credit: 68/73

Syllabus (Core Subjects)

Type	Subject Name	Subject Code	L-T-P	Credit	Contact Hour
Core	Power System Analysis and Operation	EE6L061	3-1-0	4	4
Core	Distribution Systems Engineering	EE6L062	3-1-0	4	4
Core	Power System Analysis and Operation Laboratory	EE6P056	0-0-3	2	3
Core	Power System Protection	EE6L004	3-1-0	4	4
Core	Power System Stability and Control	EE6L021	3-1-0	4	4
Core	Energy Systems Laboratory	EE6P002	0-0-3	2	3
Core	Computer Methods in Power System Laboratory	EE6P057	1-0-3	3	4

Power System Analysis and Operation

Subject Code: EE6L061	L-T-P-C: 3-1-0-4

Learning Outcome:

- Solve power system load flow using Gauss-Seidel, Newton-Raphson, and decoupled methods, including power electronics and AC-DC systems.
- Develop and analyze network models, including bus admittance and bus impedance matrices, for load flow, line flow, and loss calculations and short circuit studies.
- Apply optimal operation strategies: generator dispatch, unit commitment, hydrothermal scheduling, and security analysis (state classification, contingency, sensitivity).
- Implement state estimation methods like Least Squares, static/dynamic estimation, and tracking, focusing on computation and reliability.
- Use load forecasting and power system restructuring techniques, including time series, Kalman filters, and market-based analysis in deregulated systems.

Module 1 (Load flow analysis) (18 hours)

Load Flow Studies in power systems, Network model formulation, Bus-Admittance Matrix, Gauss-Seidel, Newton Raphson and decoupled load flow studies, Line Flow and Losses, Load flow with power electronics control, AC-DC analysis

Module 3 (Optimal system operation) (18 hours)

Optimal operation of generators on bus bar, optimal unit commitment, optimal generation scheduling, Unit commitment and Scheduling of Hydro thermal systems, Power system security: System state classification, security analysis, contingency analysis, sensitivity factors.

Module 2 (State estimation) (14 hours)

Least squares and maximum likelihood state estimators, static state estimation and tracking/dynamic state estimation of power systems, computational considerations, Reliability considerations in power system operation

Module 4 (Load forecasting) (6 hours)

Forecasting methodology, time series and Kalman filter based approach, long term load forecasting

Text Books:

1. Hadi Saadat 'Power system analysis', Tata McGraw Hill Education, 2002.

Reference Books:

1. D P Kothari, I J Nagrath 'Modern Power System Analysis', Tata McGraw-Hill Education, 2011
2. J. J. Grainmger and W. D. Stevenson 'Power System Analysis', Tata McGraw-Hill Education, 1994.
3. Loi Lei Lai, 'Power System Restructuring and Deregulation: Trading, Performance and Information Technology', John Wiley & Sons, 2001

Distribution Systems Engineering

Subject Code: EE6L062	L-T-P-C: 3-1-0-4

Learning Outcome:

- Model static and dynamic load behavior in distribution systems, incorporating voltage/frequency dependencies and estimating load parameters using real-world data.
- Evaluate substation configurations and components, layouts, grounding methods, and feeder structures, with an understanding of international system design differences.
- Perform deterministic and probabilistic load flow analysis using techniques such as backward-forward sweep, Gauss implicit Zbus, and Monte Carlo simulation, for radial and weakly meshed networks.
- Conduct short-circuit studies and fault analysis using phase-variable and direct methods, enabling effective fault detection and protection coordination in distribution systems.
- Apply analytical and numerical techniques for voltage drop and power loss estimation, load allocation, and feeder design, including uniformly and lumped loaded systems.
- Design optimal placement and sizing strategies for distributed generation and capacitors, and assess advanced topics like hosting capacity, distribution automation, and system reconfiguration for smart grid integration

Module 1 (Load modelling) (8 hours)
Static (ZIP, exponential, polynomial) and dynamic (ERL, composite) load models including voltage and frequency dependency; Load model parameter estimation; Load curve, load duration curve, various associated factors (peak load, average load, base load, load factor, diversity factor, coincidence factor, demand factor, load loss factor); Load allocation methods; Duck curve phenomenon; Load forecasting techniques

Module 2 (Basic features of distribution systems) (2 hours)
Difference between transmission and distribution systems, North American vs. European style distribution layouts; Substation components and layouts, Various feeder configurations: Radial, loop, primary or secondary selective, networked configurations; System grounding: means of grounding (resistive, reactive, resonant grounding, grounding transformer), coefficient of grounding, effective vs. non-effective grounding, Equipment grounding types: TT, IT, TN (TN-C, TN-S and TN-C-S)

Module 3 (Load flow and short-circuit analysis) (25 hours)
Modelling of distribution system components for load flow studies;
Deterministic load flow methods: Backward-forward sweep (current summation, admittance summation, power summation method), Gauss implicit Zbus, direct load flow, linear load flow techniques; Load flow for radial and weakly meshed systems; Unbalanced load flow
Probabilistic load flow: Monte-carlo simulation and its applications
Static vs. time-series load flow and application for system planning
Distribution system short-circuit analysis: Phase variable based short-circuit analysis; Direct method of short-circuit analysis

Module 4 (Approximate analytical methods of distribution system analysis) (15 hours)

Analysis of uniformly loaded feeders; K-factors and their applications; Exact lumped model; Network equivalencing and reduction; Analysis of feeders with uniform and lumped loading; Lumping loads in geometric configurations; Substation service area calculations; Voltage drop limited (VDL) vs. thermally limited (TL) feeders; Optimal placement and sizing of capacitors and DGs in distribution system: For single capacitor or DG – 2/3rd rule of optimal placement and sizing; For multiple capacitors or DGs

Module 5 (Advanced topics) (6 hours)

Hosting capacity determination of distribution systems; Distribution system planning and reconfiguration: Different approaches; Active distribution networks with the integration of Distributed Generation (DG); Distribution system automation; Reliability indices and power quality aspects; TSO-DSO interactions

Text Books:

1. W. H. Kersting, R. J. Kerestes, "Distribution system modeling and analysis – with MATLAB and WindMil", CRC Press, Taylor & Francis Group, 5th Edition, 2023.
2. Turan Gonen, "Electric power distribution system engineering", CRC Press, 2nd Edition, 2002.

Reference Books:

1. T. A. Short, "Electrical Power Distribution Handbook", CRC Press, 2004.
2. H. Lee Willis, "Power distribution planning reference book", Marcel Dekker, Inc., 2nd Edition, 2004.
3. James Northcote-Green and Robert Wilson, "Control and automation of electrical power distribution systems", CRC Press, 2007.
4. James A. Momoh, "Electric power distribution, automation, protection and control", CRC Press, 2007.
5. Richard E. Brown, "Electric Power Distribution Reliability", CRC Press, 2nd Edition, 2009.

Power System Analysis and Operation Laboratory

Subject Code: EE6P056	L-T-P-C: 0-0-3-2

Learning Outcome:

- Analyze and simulate key power system operations, including load flow, economic dispatch, and distribution network performance using MATLAB
- Apply signal processing methods to identify and interpret various power quality disturbances and perform phasor estimation using Fourier algorithms.
- Demonstrate and study hardware setup for protection schemes such as distance, overcurrent, voltage, and frequency relays for power system safety and reliability.
- Model and analyze transmission line behaviour and demonstrate it on a line simulator, including parameter estimation, voltage regulation, and the Ferranti effect.
- Demonstrate control of power flow in interconnected systems using devices like phase-shifting transformers and evaluate their impact on system stability and performance.

Experiment 1: Study of various power quality phenomena and corresponding signal processing

Experiment 2: Newton Raphson load flow

Experiment 3: Economic load dispatch/optimal power flow

Experiment 4: Distribution system load flow analysis

Experiment 5: Phasor estimation using Fourier full and half cycle algorithms

Experiment 6: Design and study of distance protection

Experiment 7: Transmission line modelling, parameter estimation, Ferranti effect and voltage regulation

Experiment 8: Numerical over/under voltage and over/under frequency relay

Experiment 9: control of active power flow in interconnected power systems using 3-ph phase shifting transformer

Experiment 10: Overcurrent protection of 3-ph transformer

Text Books:

1. Hadi Saadat 'Power system analysis', Tata McGraw Hill Education, 2002.

Reference Books:

1. D P Kothari, I J Nagrath 'Modern Power System Analysis', Tata McGraw-Hill Education, 2011

Power System Protection

Subject Code: EE6L004	L-T-P-C: 3-1-0-4

Learning Outcome:

- Perform fault analysis using symmetrical components and sequence-networks
- Design relay logics and analysing protection functions for applications including overcurrent, overvoltage, directional, differential, distance protections
- Demonstrate impact of power system phenomena (swings and loading), on distance relaying
- Design numerical relaying algorithms

Module-1 : Introduction to Relaying: (10 Hrs)

Evolution in Protection systems (electromechanical, static, numerical relaying, and wide-area protection systems); Characteristic of protective relays; Zones of protection, primary vs. backup protection; Design principles of relays – overcurrent, overvoltage, directional, differential, distance protection; Universal torque equation; overcurrent protection of radial lines, relay coordination.

Module 2 (Symmetrical and Unsymmetrical Fault analysis) (16 hours)

Types Faults, Short Circuit KVA Calculation, Symmetrical Fault and fault current distribution calculation in larger network, Sequence component analysis, Unsymmetrical Fault Calculation, Fault Current Calculation and sequence networks, Open conductor (one and two open) fault calculation, Simultaneous fault fault analysis.

Module 3 (Transmission line protection: Distance Relaying) (12 hours)

Principles of Simple Impedance Relaying, 3-stepped distance relaying and zones of protection, Reactance relay, MHO relay, Impedance calculation and sequence networks for phase-phase and phase-earth faults, Distance relaying in multi-terminal lines, parallel lines, Effect of compensation on distance relaying, loadability of distance relays, Power system phenomena and relaying considerations, apparent impedance during power swing, Impact of Power swing on performance of distance relays. Power swing Blocking and Out of step protection and blinders for distance relaying.

Module 4 (Transformer Protection) (6 hours)

Over current, differential and percentage bias differential protection of transformer, Concept of magnetising inrush phenomena and harmonic restraint relays, computation of differential current for three phase transformers and relay setting, multi-winding transformer protection.

Module 5 (Numerical/digital relaying) (12 hours)

Basic elements of Digital protection, signal conditioning and conversion, Fourier analysis and least square based techniques, Differential equation based techniques for transmission line applications, Fundamentals of travelling wave based techniques, Digital differential protection of transformers and transmission systems. Intelligent protection using ANN and Fuzzy systems, Application of advanced DSP in numerical relaying.

Text Books:

1. A G Phadke and J. Thorp, "Computer Relaying for Power Systems", Wiley, 2009
2. S. H. Horowitz, A. G. Phadke, "Power system relaying", John Wiley & Sons Ltd., 3rd edition, 2008.

Reference Books:

1. P. M. Anderson, "Power System Protection", Wiley-IEEE Press, 1999
2. P. M. Anderson, "Analysis of faulted power systems", IEEE Press, 1995
3. B. A. Oza, N-K C Nair, R P Mehta, V H makwana, "Power system protection & switchgear", Tata McGrow Hill Education Pvt. Ltd., 2010.
4. J. Lewis Blackburn, Thomas J. Domin, "Protective Relaying Principles and Applications", CRC

Power System Stability and Control

Subject Code: EE6L021	L-T-P-C: 3-1-0-4

Learning Outcome:

- Develop mathematical models and state-space representations of synchronous machines, excitation controls, governors, and control equipment.
- Analyze various types of power system stability phenomenon using analytical and numerical methods
- Evaluate subsynchronous oscillations and resonance phenomena, including torsional interactions and mitigation techniques.
- Design and assess load frequency control schemes, including automatic generation control (AGC) and tie-line bias control for maintaining system balance during normal and emergency conditions.
- Implement and assess control strategies for reactive power flow and system reliability, using devices such as AVR, OLTC transformers, FACTS, and static VAR compensators

Module 1 (Modelling of power system components) (14 hours)
Basic Ideas of Modeling of Synchronous machines, excitation systems and Governors, State space formulation of single and multi-machine models with control equipments. Damping effects of FACTS devices.

Module 2 (Power system stability) (12 hours)
Classification of power system stability – steady-state, dynamic and transient stability; rotor-angle stability, frequency stability, voltage stability, converter driven stability and resonance stability; small-signal vs. large-signal stability; Application of numerical techniques to multi-machine dynamic and transient stability studies.

Module 3 (Subsynchronous oscillations) (10 hours)
Subsynchronous oscillations, subsynchronous resonance, Modal Analysis, Torsional Oscillations, induction generator effect, Torsional interaction effect, countermeasure.

Module 4 (Load frequency and automatic generation control) (12 hours)
Generation/Frequency Characteristics and load frequency characteristics, tie-line bias control, Automatic Generation Control, Alert and emergency system operation control

Module 5 (Reactive power flow and system control) (8 hours)
Control of reactive power flow: AVR, OLTC Transformers, FACTS, Static var compensators, system loss minimization, Emergency control, Reliability and security, Protective relaying

Text Books:

1. P. Kundur, "Power system stability and control", McGrow-Hill, Edition, Year.

Reference Books:

1. P. M. Anderson, A. A. Fouad, "Power system control and stability", Wiley-IEEE Press, 2nd Edition, 2003.
2. P. Sauer, M. A. Pai, "Power system dynamics and stability", Prentice Hall, 1998.
3. K. R. Padiyar *'Power System Dynamics: Stability and Control'*, B P B Publications, 2002

4. Olle I. Elgerd ‘Electric Energy Systems Theory: An Introduction’, Tata McGraw Hill, 2001.

Energy Systems Laboratory

Subject Code: EE6P002	L-T-P-C: 0-0-3-2

Learning Outcome:

- Develop proficiency in MATLAB/Simulink for modeling and simulation of renewable energy systems, including photovoltaic (PV) cells, arrays, and DC-DC converter integration.
- Analyze the electrical characteristics (I-V and P-V curves) of PV cells and arrays under varying conditions, including uniform insolation, partial shading, and different series/parallel configurations.
- Evaluate and compare the performance of DC-DC converter topologies and MPPT algorithms for maximizing energy extraction in PV systems under dynamic environmental conditions.
- Gain practical experience with hardware-based testing and performance analysis of PV and fuel cell systems, interpreting real-time data under different loading and environmental scenarios.

Experiment 1: Study of an equivalent model of a PV cell and its I-V and P-V characteristics under uniform operating conditions.

Experiment 2: Simulation Study of I-V and P-V characteristics of a PV array under non-uniform operating conditions.

Experiment 3: Simulation Study of different DC-DC converters application for a photovoltaic system

Experiment 4: Simulation Study of different maximum power point tracking (MPPT) algorithms.

Experiment 5: Hardware Experimental study of fuel cell system characteristics under different operating conditions.

Experiment 6: Hardware Experimental Study of I-V and P-V characteristic of a PV array under uniform and partial shading conditions.

Experiment 7: Hardware Experimental Study of MPPT tracking of PV array driving DC load.

Experiment 8: Hardware Experimental Study of MPPT tracking of PV array driving AC load.

Experiment 9: Hardware Experimental Study of Power Flow in Type 3 (DFIG) WECS.

Experiment 10: Hardware Experimental Study of PV based Microgrid system.

Text Books:

1. M. Godoy Simões, Felix A. Farret, “Modeling Power electronics and interfacing energy conversion systems”, Wiley-IEEE Press, 2017.

2. Math J. Bollen, Fainan Hassan 'Integration of Distributed Generation in the Power System', IEEE Press, 2011

Reference Books:

1. Randall Shaffer, "Fundamentals of Power Electronics with MATLAB", Charles River Media, Thomson Learning Inc., 2007.

Computer Methods in Power System Laboratory

Subject Code: EE6P057	L-T-P-C: 1-0-3-3

Learning Outcome:

- Formulate and compute elemental power system matrices (Ybus and Zbus) using sparse matrix techniques, with an emphasis on storage efficiency and numerical stability.
- Apply advanced sparse matrix methods, including L-U factorization, optimal ordering, and matrix inversion lemma, to efficiently solve large-scale power system load flow problems.
- Analyze and compare nonlinear power flow solvers, including Gauss, Gauss-Seidel, and Newton-Raphson methods, focusing on their convergence characteristics and suitability for different power system conditions.
- Perform contingency and security analysis using linear sensitivity factors
- Develop short to long term forecasting models for load and renewable generation, employing time-series analysis techniques to capture trends, seasonality, and uncertainty
- Integrate data analytics and AI/ML techniques for intelligent decision support in power system operations, including fault detection, demand prediction, and system optimization

Experiment 1: Computation of elemental matrices for power system analysis viz. Ybus and Zbus

Experiment 2: Power flow solution using Gauss-Seidel method

Experiment 3: Sparse matrix methods and their application to load flow analysis

Experiment 4: Newton Raphson load flow in polar and rectangular coordinates

Experiment 5: Fast decoupled and DC load flow analysis

Experiment 6: State estimation and bad data detection

Experiment 7: Contingency analysis using linear sensitivity factors

Experiment 8: Load forecasting

Experiment 9: Short-circuit studies in phase and sequence domains

Experiment 10: Data analytics and AI/ML application to power systems

Text Books:

1. Arrillaga J. and Watson N.R., “Computer Modelling of Electrical Power Systems, John Wiley & Sons, 2003.

Reference Books:

1. Ramasamy Natarajan, “Computer-Aided Power System Analysis”, CRC Press, 2002.
2. Nasser Tleis, “Power Systems Modelling and Fault Analysis: Theory and Practice”, Academic Press, 2019.

3. Abur A. and Exposito A. G., Power System State Estimation: Theory & Implementation, Marcel Dekkar, 2004.

Syllabus (Electives)

Type	Subject Name	Subject Code	L-T-P	Credit	Contact Hour
Elective	Electric Power Quality	EE6L002	3-0-0	3	3
Elective	High Voltage Engineering	EE6L009	3-0-0	3	3
Elective	Grid Integration of Renewable Energy Systems	EE6L013	3-0-0	3	3
Elective	Smart Grid Technology	EE6L014	3-0-0	3	3
Elective	Power System Modelling and Simulation	EE6L019	2-0-2	3	4
Elective	Design and Analysis of Electric Machines	EE6L020	3-0-0	3	3
Elective	Resonant Power Converters	EE6L060	3-0-0	3	3
Elective	High-Frequency Wave Phenomena in Power System	EE6L022	3-0-0	3	3
Elective	Wide Area Monitoring Systems	EE6L023	3-0-0	3	3
Elective	Renewable Energy Systems	EE6L024	3-0-0	3	3
Elective	Control Methods in Power Engineering	EE6L025	3-0-0	3	3
Elective	High Voltage Pulsed Power Engineering	EE6L026	3-0-0	3	3
Elective	HVDC Transmission Systems	EE6L063	3-0-0	3	3
Elective	Flexible AC Transmission System (FACTS)	EE6L064	3-0-0	3	3
Elective	High Frequency Magnetics	EE6L065	2-0-2	3	4
Elective	Automotive Electronics and Drivetrains	EE6L066	3-0-0	3	3
Elective	Advanced EV Charging Technologies	EE6L067	3-0-0	3	3
Elective	Power Management Circuits for Consumer Electronic Applications	EE6L068	3-0-0	3	3
Elective	Switched Mode Power Conversion	EE6L051	3-1-0	4	4
Elective	Analysis of Electric Drives	EE6L057	3-1-0	4	4
Elective	Analysis and Design of Power Converters	EE6L058	3-0-0	3	3
Elective	Advanced Electric Drives	EE6L059	3-0-0	3	3

Electric Power Quality

Subject Code: EE6L002	L-T-P-C: 3-0-0-3

Learning Outcome:

- Describe sources, impacts, monitoring methods and mitigation strategies for various power quality events
- Perform power quality checks of supply voltages as per various international standards
- Explain and apply principles of passive and active power quality filters
- Design and develop control strategies for power quality filters

Module 1 (Introduction) (3 hours)
Definition of power and its quality, Various power quality events, source of generation of power quality problems, their impacts on equipment and systems, need of monitoring, international power quality standards.

Module 2 (Power quality monitoring) (8 hours)
Power quality meters and monitoring techniques, required signal processing techniques and their applications, various power quality indices

Module 3 (Passive filters) (10 hours)
Control of harmonics using passive L-C filters, tuned and detuned filters, their design criterion and implementation

Module 4 (Active power filters - Introduction) (10 hours)
Power factor improvement, reactive power compensation, mitigation of harmonics and voltage sag compensation using active power filters. Study of various active power filters viz., static shunt compensators (STATCOM), dynamic voltage restorer (DVR), unified power quality conditioner (UPQC), etc.

Module 5 (Active power filters - Design & control) (11 hours)
Suitability of type of active filters for mitigation of various power quality problems, Design of active power filters, various topologies and control schemes

Text Books:

1. M. H. Bollen *'Understanding Power Quality Problems: Voltage Sags and Interruptions'*, Wiley-IEEE Press, 1999

Reference Books:

1. S. Santoso, H. W. Beaty, R. C. Dugan, and M. F. McGranaghan, *'Electrical Power Systems Quality'*, McGraw-Hill Professional, 2002
2. A. Ghosh and Gerard Ledwich *'Power Quality Enhancement Using Custom Power Devices (Power Electronics and Power Systems)'*, Springer; 2002.
3. Math. H. J. Bollen, Irene Y. H. Gyu, "Signal processing of power quality disturbances", IEEE Press, John Wiley & Sons, 2006.
4. Paulo Fernando Ribeiro, Carlos Augusto Duque, Paulo Márcio da Silveira, Augusto Santiago Cerqueira, "Power systems signal processing for smart grid", Wiley, 1st edition, 2014.

High Voltage Engineering

Subject Code: EE6L009	L-T-P-C: 3-0-0-3

Learning Outcome:

- Design of HVDC power source for a specified voltage level, load, and ripple.
- Design a stable & resilient HVAC voltage source for a specified voltage level, harmonics content, and peak voltage for continuous power or testing purposes.
- Design an impulse voltage and impulse current source for both lightning and switching impulse-testing purposes.
- Develop/design an optimized & cost-effective voltage and current measurement system for a given power supply (HVAC, HVDC, impulse) and test subject.
- Identify electric stress accumulation under different geometries, materials, and power supplies. And design appropriate insulation as per requirements.

Module 1 (Introduction) (2 hrs)
Origin, Importance, Danger, and Application of High Voltages.

Module 2 (Generation of High Voltages and Currents) (11 hrs)
Importance and Different Methods to Generate High DC & AC Voltages, Mechanism of Spark-Gap, Generation of Impulse Voltages, Generation of Impulse Currents, Operation, Design, and Control of Impulse Generators.

Module 3 (Measurement of High Voltages and Currents) (8 hrs)
Measurement of High DC and AC Voltages, Measurement of Peak Voltages, Methods for Impulse Voltage & Impulse Current Measurements, Oscilloscope for Impulse Voltage and Current Measurements.

Module 4 (Breakdown in Dielectrics) (10 hrs)
Electrical Field Distribution and Breakdown Strength of Insulating Materials with - i) Uniform Field, ii) Rod-Gap, ii) Rod-Plane Gap, Fields in Homogeneous, Isotropic Materials Under Different Practical Geometry,
Intrinsic Breakdown, Electromechanical Breakdown, Thermal Breakdown, Breakdown of Solid Dielectrics in Practice, Breakdown in Composite Dielectrics, and Solid Dielectrics Used in Practice.
Gases as Insulating Media, Collision Process, Ionization Process, Townsend's Criteria of Breakdown in Gases, Paschen's Law. Liquid as Insulator, Pure and Commercial Liquids, Breakdown in Pure and Commercial Liquids.

Module 5 (Testing of High Voltage Apparatus) (11 hrs)
Testing of Insulators and Bushings, Testing of Isolators and Circuit Breakers, Testing of Cables, Testing of Transformers, Testing of Surge Arresters. Assessing the Health of Typical Power Apparatus. Applying High Voltages in Real Life & Current High Voltage Trends.

Textbooks:

1. C. L. Wadhwa, "*High Voltage Engineering*," 4th Edition, New Age, 2020.
2. E. Kuffel and W. S. Zaengl, J. Kuffel, "*High Voltage Engineering: Fundamentals*," CBS Publishers, 2005.

3. Naidu, Kamaraju, "*High-Voltage Engineering*", 6th Edition, McGraw-Hill.

Reference Books:

1. W. Peek, and F. W. Peek *"Dielectric Phenomena in High Voltage Engineering"*, Rough Draft Printing, 2008.
2. Dieter Kind, Kurt Feser, and Y. Narayana *Rao, "High-Voltage Test Techniques",* Newnes, 2001.
3. Research publications that will be suggested during the course.

Grid Integration of Renewable Energy Systems

Subject Code: EE6L013	L-T-P-C: 3-0-0-3

Learning Outcome:

After completing the course, students will be able to:

- Identify the challenges in the integration of Renewable Energy Sources (RES), storages with the grid, and the rest of the network. Envisage the probable solutions to the identified challenges
- Understand, design and develop the controllers for grid-connected and stand-alone mode of operations of RES/Microgrid systems
- Identify the limitations of state-of-the-art linear controllers and develop the nonlinear controllers for grid-connected and islanded mode of RES/Microgrid Systems
- Design Controllers for voltage and frequency regulation, thereby power dispatches in distributed generators/RES/Microgrids for different modes of operations
- Adapt/design and develop the controllers to eliminate Power Quality Problems
- Develop algorithmic steps for optimal capacity sizing of RES based Microgrids
- Explore all the aforementioned issues in the context of large-scale integration of RES with grid while understanding the flexibility of conventional generating sources.

Module 1 (Introduction) (5 hours)

Understanding of Global Energy Scenario, Indian context, Targets, and achievements in renewable energy sector as a Country. Conventional grid versus Microgrid systems, advantages and limitations, Understanding the concept of distributed generation, terminologies, and their adaptability necessities. Introduction to Grid integration of Renewable Energy Sources, Challenges in integration and Control of Renewable Energy Sources

Module 2 (Control of Distributed Generators) (12 hours)

Understanding of linear controllers for grid-connected and stand-alone mode of operations of RES, Control of frequency and voltage of distributed generation in Stand-alone and Grid-connected modes, design and development of nonlinear controllers for grid-connected and islanded modes

Module 3 (Energy Storages and their Control) (5 hours)

Use of energy storage and power electronics interfaces for the connection to grid and loads.

Module 4 (Microgrid and its Control) (10 hours)

Concept of microgrid, operation of microgrid in grid-connected as well as in isolated mode, Design and optimization of size of renewable sources and storages, power quality problems and control solutions

Module 5 (Integration of large capacity renewable sources to the grid.) (10 hours)

Operation and control, present trends, challenges, future technological needs, improved flexibility in conventional generation, transmission technology

Text Books/Reference Books:

1. Math J. Bollen, Fainan Hassan 'Integration of Distributed Generation in the Power System', IEEE Press, 2011
2. Gilbert M. Masters, Renewable and Efficient Electric Power Systems John Wiley & Sons, Inc., 2004
3. Different research articles/papers/reports

Smart Grid Technology

Subject Code: EE6L014	L-T-P-C: 3-0-0-3

Learning Outcome:

- Describe the fundamental components of traditional and modern electrical power systems, and explain the key characteristics and technologies enabling smart grid functionality.
- Analyze the role of digital communication protocols and network architectures in smart grid communication, and evaluate challenges related to interoperability and demand-side management.
- Design of grid-forming and grid-following converters for the integration of various renewable energy sources and energy storage systems in grid operations.
- Explain the functions of SCADA, PMUs, and sensor networks, and evaluate their impact on observability and performance in wide area monitoring systems, considering communication delays.
- Identify potential cybersecurity threats and privacy challenges in smart grids, and corresponding defense mechanisms to ensure secure and reliable grid operation.

Module 1 (Introduction) (4 hours)
Review of basic elements of electrical power systems, desirable traits of a modern grid, principal characteristics of the smart grid, key technology areas.

Module 2 (Smart Grid Communication) (10 hours)
Digital communication protocols, interoperability issues, network architectures, IP-based systems, Power line communications, advanced metering infrastructure, demand side management.

Module 3 (Grid Operation with Renewables and Energy Storage:) (12 hours)
Grid operation with grid forming and grid following converters (energy storage, solar energy, wind energy, biomass, hydropower, geothermal, and electric vehicles (EVs).

Module 4 (Wide Area Measurement:) (8 hours)
Sensor Networks, SCADA, Phasor Measurement Units, Communications Infrastructure, Time delays in communication channels, Observability

Module 5 (Security and Privacy:) (8 hours)
Cyber Security Challenges in Smart Grid, Defense Mechanism, Privacy Challenges.

Text Books:

1. James Momoh *‘Smart Grid: Fundamentals of Design and Analysis’* Wiley-IEEE Press, 2012.

Reference Books:

1. A. Keyhani, “Smart Power Grid Renewable Energy Systems,” Wiley 2011.

Power System Modelling and Simulation

Subject Code: EE6L019	L-T-P-C: 2-0-2-3

Learning Outcome:

- Given a practical power system study or problem statement, to pick-up an appropriate modelling methodology with appropriate level of details and to choose a computationally efficient solution strategy
- To derive continuous and discretized differential algebraic equations for various power system components
- To design and simulate Inverter-based Resources' (IBR's) electromagnetic transient (EMT) generic and real-code models for normal and fault cases
- To develop and analyze frequency domain models and relate it to EMT models

To distinguish and identify need for various testing and validation benchmark developments for given problem statement

Module 1 (Fundamentals) (5 hours)

Time-scales and corresponding modelling requirements in power systems Modelling Principles: Time domain vs. phasor domain vs. frequency domain models; linearized vs. Nonlinear models

Module 2 (Electromagnetic transient (EMT) Modeling) (8 hours)

Dommel's representation of power system components; Switching model vs. average model Modelling Thevenin equivalents of grid for EMT simulation; Relation between EMT and Phasor domain models; Obtaining EMT equivalents of Phasor domain models and vice-versa; EMT models of inverter-based resources (IBRS) – grid-following and grid-forming controls, real-code vs. generic models, fault models

Module 3 (EMT simulations) (6 hours)

Discretization and numerical solution of ordinary differential equations; Various solvers for ordinary differential equations (ODEs) and differential algebraic equations (DAE); Stiff vs. non-stiff solvers; Stability of solvers/numerical methods.

Module 4 (Phasor and frequency domain modeling) (6 hours)

Phasor-domain or RMS models; multi-frequency representation of power system components; Network impedance loci, application to filter design; Harmonic load flow; Harmonic state-estimation; Basics of modal analysis; Introduction to extended/dynamic harmonic domain; Introduction to time-frequency decomposition & multi-rate signal processing

Module 5 (Methods of verification, validation and testing) (3 hours)

Offline and real-time simulation, Co-simulation, Emulation, Software-in-loop (SIL) simulation, Controller hardware-in-loop (CHIL), Rapid Control Prototyping (RCP), Power hardware-in-loop (PHIL), Interface methods, impact of interfacing delays, their stability assessments

Experiment 1 (2 hours): Demonstrate nonlinear (large-signal) switching model, nonlinear average model, linearized (small-signal) average model, and equivalent small signal average circuit model of a power electronic circuit (e.g. boost converter)

Experiment 2 (2 hours): Numerical solutions of ODEs and DAEs

Experiment 3 (4 hours): Electromagnetic transient simulation of a DC microgrid

Experiment 4 (6 hours): Electromechanical (phasor-domain/RMS) dynamic simulation of a multimachine power system

Experiment 5 (2 hours): Frequency-dependent dynamic equivalents of large-scale power systems

Experiment 6 (6 hours): EMT simulation of grid-following inverter-based resource

Experiment 7 (4 hours): Small-signal and modal analysis

Experiment 8 (2 hours): Imittance modelling of inverter-based resource interfaced power system

Text Books:

1. N. Watson, and J. Arrillaga, "Power Systems Electromagnetic Transients Simulation", IET, 2003.
2. L. Fan, and Z. Miao, "Modeling and stability analysis of inverter based resources", CRC Press, 2024.

Reference Books:

1. Babak Badrzadeh, Zia Emin, "Power System Dynamic Modelling and Analysis in Evolving Networks", CIGRE Green Books, Springer Nature, 2024.
2. CIGRE TB 766, WG C4/B4.38, "Network modelling for harmonic studies", CIGRE, 2019
3. Jason R. Miller, Istvan Novak, "Frequency-Domain Characterization of Power Distribution Networks", Artech House, 2007.

Design and Analysis of Electric Machines

Subject Code: EE6L020	L-T-P-C:3-0-0-3

Learning Outcome:

- Understand the importance of various electric machine design aspects, such as electromagnetic, thermal, and structural.
- Determine key transformer design parameters like no or turns, yoke thickness, and cooling requirements.
- Determine important design parameters for rotary machines like, number of poles, number of slots, winding type, and number of turns.
- Perform sizing calculations for electrical machines based on application requirements.
- Knowledge of various materials used in electrical machines and the choice of appropriate materials as per the application.
- Validate the design using Finite Element Analysis (FEA) tools.

Module 1 (2 Hours):
Review of magnetic circuits: MMF calculation, Energy conversion, Determination of Force and torque, flux and flux density, magnetic saturation.

Module 2 (2 Hours):
Materials used for electric machines: Soft and Hard magnetic materials, Types of steel - properties and standards, Insulation materials.

Module 3 (3 Hours):
Types of cooling and thermal modelling of machines: Natural and forced cooling (Air, liquid), 1-D thermal modelling.

Module 4 (6 Hours):
Design of transformer: Sizing considerations, Core and yoke design, output equation, effect of cooling methods.

Module 5 (3 Hours):
Introduction to Finite Element Analysis (FEA) for electrical machines: Maxwell's equation, numerical methods, Mesh types.

Module 6 (3 Hours):
Winding for rotating electrical machines: Pitch and Distribution factor, concentrated and distributed winding, Fractional pitch winding.

Module 7 (3 Hours):
Sizing of motors: Sizing considerations, Magnetic and electric loading, output equation, effect of cooling methods.

Module 8 (2 Hours):

Choice of pole slot combinations.

Module 9 (4 Hours):

Design of Induction motor: Stator and rotor design, effect of rotor slot shape, magnetizing current.

Module 10 (2 Hours):

Performance analysis of induction motor: Torque speed characteristics, magnetic saturation.

Module 11 (4 Hours):

Design of permanent magnet motors (BLDC and PMSM): Winding selection, SPM and IPM designs, demagnetization effects.

Module 12 (2 Hours):

Performance analysis of BLDC/PMSM motor: Torque speed characteristics, magnetic saturation.

Module 13 (6 Hours):

Simulation of electric machines using FEA: Design validation of transformer, induction and BLDC/PMSM motor.

Text Books:

1. A course in Electric Machine Design by A. K. Sawhney, Dhanpat Raj and Co, 2014
2. Design and testing of Electrical machines by M. V. Deshpande, PHI Learning, 2010
3. Design of rotating electrical machines by Juha Pyrhonen, Tapani Jokinen, Valeria Hrabovcov, Wiley, 2008

Reference Books:

1. Introduction to AC machine design by Thomas A. Lipo, Wiley 2017
2. Design of Brushless Permanent Magnet Machines by J. R. Hendershot and T. J. E. Miller, Magna Physics Publishing, 2010
3. The Performance and Design of Alternating Current Machines by M. G. Say, Pitman & Sons, 2002

Resonant Power Converters

Subject Code: EE6L060	L-T-P-C:3-0-0-3

- Operating principle of resonant converters: Students can analyzer the operation of power rectifiers, resonant inverters, and resonant DC-DC converters.
- Classify different types of resonant Converters: Students can classify different types of resonant converters and explain their applications.
- Derive the steady state and small signal models of the resonant converters: Students can derive steady-state models of the most common resonant converters and derive analytical expressions that describe the relation between circuit components, the input power source, the output load, and the operating frequency. Students can derive small-signal models of a resonant power converter.
- Identify and Calculate Losses in Resonant Converters: Students can identify and calculate the resonant converter losses.
- Design of resonant converters Power Circuits: Students can design practical resonant rectifiers, inverters, and converters adhering to typical application requirements and practical constraints.
- Design of closed loop controller for Resonant Converter: Students can design a phase-shift controller and frequency controller for a resonant power converter.

Module 1 (2 Hours):
Introduction to Resonant Power Conversion: Course planning and the syllabus overview; Why do today's power electronic technologies need resonant power conversion?

Module 2 (2 hours):
Resonant Power Converters – classification and overview

Module 3 (2 hours):
Semiconductor switches for resonant converters – an overview; Hard-switching vs. ZVS and ZCS switching

Module 4 (2 hours):
Loss modelling in resonant converters; Understanding non-idealises and nonlinear phenomena in reactive elements and switches

Module 5 (3 hours):
High-Frequency Rectifiers: Class D Current Driven Rectifiers

Module 6 (2 Hours):
Class D Voltage-Driven Rectifiers

Module 7 (2 Hours):
Class E low dv/dt Rectifiers

Module 8 (3 Hours):
Resonant Power Converters: Class D Series Resonant Converter

Module 9 (3 Hours):
LLC resonant converter; the principle of operation of quasi-resonant DC-DC converters (a Buck ZVS quasi-resonant converter)

Module 10 (2 Hours):
Resonant Power Inverters; Resonant Inverters – introduction

Module 11 (3 Hours):
Class D Series Resonant Inverter; Class D Parallel Resonant Inverter

Module 12 (3 Hours):
Class E ZVS Resonant Inverter; Phase controlled voltage- and current-source inverters

Module 13 (3 Hours):
Resonant Power Converters Modelling and Control: Resonant power converter modelling – modelling principles

Module 14 (4 Hours):
Extended Describing Function (EDF) and D-Q modelling of a resonant converter

Module 15 (3 Hours):
Design and implementation of frequency and phase-shift controllers

Module 16 (3 Hours):
Selected Case Studies

Text Books:

1. Marian K. Kazimierczuk; Dariusz Czarkowski, "Resonant Power Converters", Willy, 2011

Reference Books:

1. Robert W. Erickson, Dr. Maksimović, "Fundamentals of Power Electronics", Springer, 2020
2. Xinbo Ruan, "Soft-Switching PWM Full-Bridge Converters: Topologies, Control, and Design", Willy, 2014.
3. Peter Renz, Bernhard Wicht, "Integrated Hybrid Resonant DC-DC Converters", Springer 2021.
4. Application Report, Texas Instruments, 2004

High-Frequency Wave Phenomena in Power System

Subject Code: EE6L022	L-T-P-C: 3-0-0-3

Learning Outcome:

- Classify and analyze different types of transients—impulse, oscillatory, slow-front, fast-front, and very fast-front—arising from switching operations, faults, and lightning events.
- Evaluate transient phenomena associated with power system events, such as line energization, current chopping, trapped charges, and short-line faults, considering their impact on equipment and system stability.
- Model power system components for transient studies using Bergeron and frequency-dependent line models, nonlinear transformer models, and machine dynamics under transient conditions.
- Simulate and interpret traveling wave behavior in multi-conductor systems and assess the influence of tower footing resistance and surge propagation on system protection.
- Apply insulation coordination principles to design and evaluate surge protection schemes using circuit breakers, lightning arresters, and overvoltage limiting devices.
- Use advanced simulation tools (e.g., EMTP/PSCAD) to conduct transient analysis and assess mitigation strategies for modern systems with power electronic interfaces and renewable energy integration

Module 1 (Introduction) (5 hours)

Origin and nature of transients and surges, classification of transients – impulse and oscillatory, lightning and switching transients, slow-front, fast-front and very fast-front transients

Module 2 (Power System Phenomenon associated with Transients) (10 hours)

Line energization and de-energization transients, current chopping, short-line faults, trapped charge effects, effect of source, capacitor and reactor switching, Lightening, effect of tower footing resistance, travelling waves

Module 3 (Modelling of power system components for transient studies) (15 hours)

Multi-conductor Transmission Lines and Cables: Bergeron Model and Frequency-Dependent Models. Transformers and Electrical Machines; Modelling of Saturation Power Electronic Switches and controls; Interpolation Techniques to improve accuracy.

Module 4 (Switchgear for control of transients) (12 hours)

Insulation coordination, circuit breaker duty, surge arresters, lightning arresters, overvoltage limiting devices

Text Books:

1. Allen Greenwood, "Electrical transients in power systems", John Wiley & Sons, 2nd Edition, 1991.
2. Gevork Gharehpetian, Atousa Yazdani, Behrooz Zaker, "Power System Transients: Modelling Simulation and Applications", CRC Press, 2023.

Reference Books:

1. Lou van der Sluis, “Transients in power systems”, John Wiley & Sons, 2001.
2. Marek Michalik, Eugeniusz Rosołowski, “Simulation and Analysis of Power System Transients”, Wroclaw University of Technology, 2010.
3. Fabian M. Uriarte, “Multicore simulation of power system transients”, IET, 2013.
4. Filipe Faria da Silva, Claus Leth Bak, “Electromagnetic Transients in Power Cables”, Springer, 2013

Wide Area Monitoring Systems

Subject Code: EE6L023	L-T-P-C: 3-0-0-3

Learning Outcome:

- Describe the architecture and components of Wide Area Monitoring Systems (WAMS), including PMUs and Phasor Data Concentrators.
- Apply state estimation techniques, including legacy and PMU-based methods, for real-time system visualization and monitoring.
- Analyze real-time power system stability using synchronized measurements for voltage, angle, and oscillation monitoring.
- Design and evaluate wide-area control strategies using generator models, damping controllers, and power system stabilizers.
- Develop and assess protection schemes using PMU data, including AI-based frameworks for wide-area system protection

Module 1 (Introduction) (4 hours)

Background of WAMS, Synchronized Measurement Devices, Standalone PMUs, PMU-Enabled IEDs, Time Synchronization Options, Phasor Data Concentrators, Synchronized Measurement Networks, Phasor and frequency estimation.

Module 2 (State Estimation and Visualization) (8 hours)

The Energy Management System, Real Time Operational Requirements, SCADA System, System Network Configurator, Legacy State Estimation Algorithms, PMU-Based LSE, Dynamic State Estimation.

Module 3 (Real-time stability monitoring) (10 hours)

Real Time Stability Monitoring: Stability Phenomena in Power Systems, Real Time Voltage Stability Monitoring, Real Time Oscillation Monitoring, Real Time Angle Stability Monitoring

Module 4 (Wide area power system control) (10 hours)

Basics of synchronous generator modelling, Wide area damping controllers and power system stabilizers

Module 5 (Wide area power system protection) (10 hours)

Fault Detection and Classification; Protection Schemes using PMU Data; Intelligent/AI-based Protection Frameworks

Text Books:

1. M. Kezunovic, S. Meliopoulos, V. Venkatasubramanian, and V. Vittal, “Application of Time-Synchronized Measurements in Power System Transmission Netowrks”, . Springer International Publishing, 2014.

Reference Books:

1. A. G. Phadke and J. S. Thorp, Synchronized Phasor Measurements and their Applications, Springer, 2008.
2. P. W. Sauer, M. A. Pai, and J. H. Chow, Power system dynamics and stability: with synchrophasor measurement and power system toolbox. John Wiley & Sons, 2017
3. P. Kundur, Power System Stability and Control, McGraw-Hill, 1995.

Renewable Energy Systems

Subject Code: EE6L024	L-T-P-C: 3-0-0-3

Learning Outcomes:

After completing the course, it is intended that students will be able to:

- Estimate the energy availability and the power that can be tapped for a given wind profile with the help of probability density functions, thereby able to calculate the productivity, capacity factor and the overall efficiency
- Estimate the insolation levels on different surfaces at different locations on different days, there by the power, hence the energy output of a PV system can be estimated.
- Develop the equivalent electrical model for PV arrays, thereby able to derive the necessary mathematical relations for electrical parameters, such as voltage, current and power
- Design and develop maximum power point tracking mechanisms and associated controllers for different types of generators, adapting them as per the practical considerations

Module 1 (Introduction) (5 Hours)

Brief idea on renewable and distributed sources, their usefulness and advantages.

Module 2 (Wind Energy Conversion Systems) (12 Hours)

Estimates of wind energy potential, wind maps, instrumentation for wind velocity measurements, aerodynamic and mechanical aspects of wind machine design, conversion to electrical energy, aspects of location of wind farms, types of wind energy conversion systems.

Module 3 (Solar Energy Conversion Systems) (12 Hours)

Present and new technological developments in photovoltaic, estimation of solar irradiance, and components of solar energy systems, equivalent circuit of a PV cell, P-V and I-V Characteristics under uniform and non-uniform irradiations.

Module 4 (Control of Renewable Energy Systems) (10 Hours)

Control of Wind Energy System, Control of solar energy conversion systems, Maximum power tracking, Hierarchical and Distributed control of Renewable Energy systems

Module 5 (Hybrid Energy Systems) (3 Hours)

Requirements of hybrid/combined use of different renewable and distributed sources, and energy storages.

Text Books/Reference Books:

1. Math J. Bollen, Fainan Hassan 'Integration of Distributed Generation in the Power System', IEEE Press, 2011

2. Gilbert M. Masters, Renewable and Efficient Electric Power Systems John Wiley & Sons, Inc., 2004
3. D. Yogi Goswami, Frank Kreith and Jan F. Kreider 'Principles of Solar Engineering', Taylor & Francis 2000
4. Different research articles/papers/reports

Control Methods in Power Engineering

Subject Code: EE6L025	L-T-P-C: 3-0-0-3

Learning Outcome:

- Develop and analyze mathematical models of power systems and components.
- Apply advanced linear control techniques and design controllers for LTI and LTV systems in power applications.
- Design and implement centralized, decentralized, and distributed control strategies for networked power systems, using graph-theoretic principles and consensus algorithms.
- Analyze and control nonlinear systems using passivity-based control, back-stepping, sliding mode control, and model predictive control methods in real-world power system scenarios.
- Apply model order reduction techniques to simplify large-scale power systems for control design and system analysis.

Module 1 (Review of Basic Control Systems) (8 Hrs.)
Introduction to transfer functions and state-space modeling, system stability, and transient response. Evaluation of control performance metrics. Application-focused modeling of converters, motors, and basic power systems.

Module 2 (Linear Dynamical Systems) (10 Hrs.)
Linear algebra foundations, controllability and observability, Kalman decomposition. State-space based control design with optimal control techniques including LQR and LQG. Introductory analysis of linear time-varying and time-periodic systems. Relevant power engineering case studies.

Module 3 (Networked & Multi-agent Control Systems) (10 Hrs.)
Explore centralized, decentralized, and distributed control architectures. Essentials of graph theory; Consensus-based control using state and output feedback control protocols. Applications: Coordinated control of DC microgrids and power electronic converters.

Module 4 (Nonlinear System Analysis and Control) (10 Hrs.)
Properties of nonlinear systems, Autonomous and non-autonomous systems, Barbalat's lemma, LaSalle's invariance principle, Lyapunov stability, Passivity. Control Techniques: Backstepping, Sliding Mode and Model Predictive Control. Introductory Adaptive Control. Relevant case studies: Applications to Power Electronic Converters and Power systems.

Module 5 (Model Order Reduction for Large-Scale Systems) (4 Hrs.)
Singular perturbation method, aggregation method, modal analysis, and frequency/ norm-based methods to simplify complex dynamic models. Emphasis on applications in large-scale power systems.

Text Books:

1. Power Electronics: Essentials and Applications, L Umanand, Wiley 2009.

2. Guo, Fanghong, Changyun Wen, and Yong-Duan Song. "Distributed control and optimization technologies in smart grid systems". CRC Press, 2017.
3. Blaabjerg, Frede, ed. *Control of Power Electronic Converters and Systems: Volume 2*. Vol. 2. Academic Press, 2018.

Reference Books:

1. Bidram, A., Nasirian, V., Davoudi, A., & Lewis, F. L., "*Cooperative synchronization in distributed microgrid control"*. Springer, 2017.
2. Chow, Joe H., ed. *Power system coherency and model reduction*. Vol. 84. New York: Springer, 2013.
3. Pai, M. Anantha. *Energy function analysis for power system stability*. Springer Science & Business Media, 1989.
4. Lu, Qiang, Yuanzhang Sun, and Shengwei Mei. *Nonlinear control systems and power system dynamics*. Vol. 10. Springer Science & Business Media, 2013.

High Voltage Pulsed Power Engineering

Subject Code: EE6L026	L-T-P-C: 3-0-0-3

Learning Outcome:

- Analyze various pulsed power energy storage devices, pulse modulators, pulse transformers, Marx circuits, magnetic pulse compression circuits, and flux compression generators (FCGs) to understand their operational characteristics and selection criteria.
- Design pulsed power generators and power conditioning systems by selecting appropriate switching devices, insulation schemes, and circuit topologies to achieve desired performance in high-voltage and high-current environments.
- Design and optimize insulation systems and magnetic materials under pulsed voltage stresses to enhance system reliability and safety.
- Design and implement accurate measurement techniques for pulsed power parameters to ensure precise diagnostics and system validation.
- Evaluate and recommend pulsed power system configurations for advanced practical applications.

Module 1 (Overview of Pulsed Power Engineering) (2 hrs)
Introduction, Importance, National Importance, Application, Current Trend, Interdisciplinary Application

Module 2 (Storage Devices) (4 hrs)
Working Principles and Selection of Energy Storage Devices: Capacitors, Inductors, Batteries, Flywheels;

Module 3 (Switching Devices) (3 hrs)
Fast Switching Devices—Characteristics and Stress Handling, Power Conditioning Systems: Charging Supplies, Solid-State Modulators, Series-Parallel Configurations, Snubber and Protection for Switching.

Module 4 (Insulation) (3 hrs)
Insulation requirements for pulsed power systems- gaseous, liquid, solid, and magnetic insulation and their behaviour under pulsed voltages.

Module 5 (Pulse Circuits & Generator) (10 hrs)
Pulsed circuits, pulsed-powered generators, Marx Generators, Pulse Modulators, Magnetic Pulse Compression Circuits, Flux Compression Generators, PFN schemes, FCG, Explosively driven FCGs, Homopolar generators. Pulsed power generators. Pulse transformers, Modular power system design.

Module 6 (Pulse Measurement) (9 hrs)
Measurement techniques of pulsed power parameters-Voltage, Current, Rise Time, Pulse Width, Energy. Rogowski Coils, Voltage Dividers.

Module 7 (Case Studies) (11 hrs)

Applications of pulsed power systems, pulsed power systems for high-power lasers, HPM, UWB, IRA, Railgun, ETC, NEMP, and ESD simulators. Pulsed power systems for biological and pollution control applications

Text Books:

1. Jane Lehr, Pralhad Ron, “Foundations of Pulsed Power Technology,” Wiley-IEEE Press, 2017
2. P. W. Smith, “Transient Electronics: Pulsed Circuit Technology,” John Wiley and Sons, 2002
3. H. Bluhm, “Pulsed Power Systems: Principles and Applications,” Springer, 2006

Reference Books:

1. S. T. Pai and Qi Zhang, “Introduction to High Power Pulse Technology,” World Scientific, 1995
2. G. A. Mesyats, “Pulsed Power,” Springer, 2005

HVDC Transmission Systems

Subject Code: EE6L063	L-T-P-C: 3-0-0-0

Learning Outcome:

- Explain the principles, benefits, and challenges of HVDC transmission systems compared to HVAC systems. Describe and differentiate various HVDC system configurations (monopolar, bipolar, back-to-back, multi-terminal) and their applications.
- Analyse the operation, waveforms and characteristics of Line Commutated Converters (LCC) and Voltage Source Converters (VSC) with source impedance used in HVDC systems.
- Analyse converter topologies, commutation processes, and harmonics.
- Evaluate control strategies/hierarchy for HVDC systems (e.g., current control, power control) and analyse protection schemes used in HVDC networks
- Explain the operation of Modular Multilevel converters.
- Learn about the interaction between AC and DC systems, including issues like harmonic instability and the role of FACTS devices

Module 1: Introduction (3 Hours)
Evolution of HVDC Transmission, Comparison of HVAC and HVDC systems, Type of HVDC Transmission systems, Components of HVDC transmission systems.

Module 2: Analysis of HVDC Converters (9 Hours)
Analysis of simple rectifier circuit and its features for HVDC transmission, different modes of converter operation, pulse number- analysis with and without overlap- converter bridge characteristics, output voltage waveforms, thyrisor voltage and DC voltage in rectification and inverter operation, Equivalent electrical circuit.

Module 3: Control of HVDC systems (6 Hours)
HVDC system control feature, control modes, control schemes and comparison.

Module 4: Failure analysis and protection of HVDC converters (6 Hours)
Converter mal-operations, commutation failure, starting and shutting down the converter bridge, converter protection.

Module-5: Design and analysis of HVDC components (6 Hours)
Smoothing reactor and DC Lines, Reactive power requirements, Harmonic analysis, filter design for HVDC systems.

Module-6: Interaction between AC DC Systems (6 Hours)
Component Models for the Analysis of AC DC Systems, Power flow analysis of AC-DC systems, Transient stability analysis, and Dynamic stability analysis.

Module 7: Modular multilevel converters applications to HVDC (3 hours)
Advances in HVDC transmission – Application of MMC and its control.

Module-8: Multi terminal HVDC systems and Applications (3 Hours)

Multi-terminal HVDC system, HVDC system application in wind power generation.

Text Books:

1. KR Padiyar, “HVDC Power Transmission Systems”, Willey Eastern Limited, Second edition.
2. J Arrillaga, “High Voltage Direct current Transmission”, Peter Peregrinus Ltd, UK.

Reference Books:

1. SN Singh, “Electric Power Generation, Transmission and Distribution, PHI, New Delhi 2 nd edition, 2008.
2. High power converters and AC Drives– Bin Wu, Willey IEEE Press Publications.

Flexible AC Transmission System (FACTS)

Subject Code: EE6L064	L-T-P-C: 3-0-0-3

Learning Outcomes:

- Explain the limitations of conventional AC transmission systems and the need for FACTS controllers to enhance power transfer capability and system stability.
- Evaluate the characteristics and suitability of various power semiconductor devices (e.g., Thyristors, GTOs, and IGBTs) used in FACTS applications.
- Analyze the working principles and control strategies of shunt compensators such as SVC and STATCOM, and compare their performance characteristics.
- Explain the function, control schemes, and power flow enhancement capabilities of series compensators like GCSC, TSSC, TCSC, and SSSC.
- Describe the objectives and operating principles of static voltage and phase angle regulators including TCVRs, TCPARs, and converter-based alternatives.
- Explore the structure, operation, and coordinated control of combined FACTS controllers such as UPFC and IPFC.

Module 1: Introduction to FACTS (6 Hours)

Power flow in an AC System – parallel paths and meshed system, loading capability of transmission lines and dynamic stability criterion, concept of FACTS, introduction to various FACTS controllers – shunt, series and combined. Characteristics of power semiconductor devices – power diodes, thyristors, GTO and IGBTs, three level voltage source converter.

Module 2: Static shunt compensators (10 Hours)

Objectives of shunt compensation, methods of controllable var generation, switching converter type var generators - SVC & STATCOM - basic operating principle and control approaches, comparison between STATCOM and SVC.

Module 3: Static series compensators (10 Hours)

Objectives of series compensator, variable impedance type series compensators - GCSC, TSSC & TCSC - basic operation and control schemes, operation of switching converter type series compensator - SSSC - power angle characteristics- control range and VA rating – internal and external control.

Module 4: Static voltage and phase angle regulators (8 Hours)

Objectives of voltage and phase angle regulators, introduction to Thyristor-Controlled Voltage Regulators (TCVRs) and Thyristor - Controlled Phase Angle Regulators (TCPARs), basic operation of switching converter based voltage and phase angle regulators.

Module 5: Combined compensators (8 Hours)

Basic operating principle of Unified Power Flow Controller (UPFC), Comparison of UPFC to Series Compensators and Phase Angle Regulators, Basic Control System for P and Q

Control, introduction to Interline Power Flow Controller (IPFC), applications of FACTS controllers.

Text Books:

1. N.G Hingorani, and L. Gyugyi 'Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems', IEEE Press Book, Standard Publishers and Distributors, Delhi. 2001
2. K. R. Pediyar, 'FACTS Controllers in Power Transmission & Distribution', Anshan Ltd. 2009

Reference Books:

1. Flexible AC Transmission Systems: Modelling and Control, Xiao – Ping Zhang, Christian Rehtanz, Bikash Pal, Springer. 2012
2. T. J. E Miller, 'Reactive Power Control in Electric Systems', John Wiley & Sons. 2010
3. K.S. Sureshkumar, and S. Ashok, 'FACTS Controllers & Applications', E-book edition, Nalanda Digital Library, NIT Calicut. 2003

High Frequency Magnetics

Subject Code: EE6L065	L-T-P-C: 2-0-2-4

Learning Outcome:

- To understand the theory, application and design of magnetic devices (inductors and transformers) used in high frequency power applications such as electric vehicle chargers, grid-connected converters and other power supplies.
- To understand different loss mechanisms in magnetics devices, evaluation of these losses and methods to reduce them
- To familiarize the students with Ansys software for magnetics modeling and simulation
- To provide hands-on experience in the design of magnetics for power converters
- To help students build efficient power converters for different applications

Module 1: Review (2 hrs)

Review of magnetic relationships and EM laws, Maxwell's equations, EM induction, Magnetic circuits, Review of magnetic materials, magnetic susceptibility and permeability,

Module 2: Magnetic Core and Inductance (6 hrs)

Commercial core geometries, Hysteresis loss and eddy current core loss under different excitation conditions, Steinmetz empirical equation, Core losses for non-sinusoidal current, cooling of magnetic cores, Core saturation, Air-gap in magnetic cores and its effects, Laminated core loss, Definition of Inductance, Estimation of inductance for symmetrical geometries, Magnetic energy in gapped and ungapped core, Self-resonant frequency, Quality factor, Classification of power losses in magnetic components

Module 3: Skin and Proximity Effects (8 hrs)

Skin depth, AC-to-DC winding resistance ratio, Skin effect in long single round conductor and single rectangular plate, Proximity effect in parallel round conductors, coaxial cable, two parallel plates and multiple layer inductor, Construction of MMF diagrams, Foil Conductors, Power loss in foil conductor, Optimum thickness of individual foil layers, Dowell's equation, winding power loss with harmonic currents, Litz Wire: Model of Litz wire and multi-strand wire windings, Litz wire winding resistance, Optimum strand diameter at fixed porosity factor

Module 4: Design of Inductors (6 hrs)

Review of necessary power converters, Area Product (Ap) and Kg methods of Inductor Design, Filter inductor design, Optimization using Lagrange multipliers, Coupled inductor design, Optimal design of AC inductor to minimize core and copper loss, Design examples with different power converters in CCM and DCM

Module 5: Design of Transformers (6 hrs)

Review of necessary power converters, Area Product (Ap) and Kg methods of transformer design, Partially interleaved windings, Optimum flux density to minimize total power loss, Optimized window area allocation, Design examples with different power converters in CCM and DCM

Laboratory Experiments:

1. Familiarization of Ansys electronics suit (3 hrs)
2. Skin effect and AC resistance in various conductors at different frequencies (3 hrs)
3. Proximity effects in conductors (solid and foil) (4 hrs)
4. Fields, current distributions and losses in stranded conductors (4 hrs)
5. Losses and temperature of core for inductor (3 hrs)
6. Inductance for symmetric geometry (3 hrs)
7. Inductor design for buck converter in CCM and DCM (4 hrs)
8. Transformer design for flyback converter in CCM and DCM (4 hrs)

Text Books:

1. Fundamentals of Power Electronics -- Robert W. Erickson, Dr. Maksimović, Springer 2020
2. Transformers and Inductors for Power Electronics – W. G. Hurley, W.H. Wolfle 2013
3. High Frequency Magnetic Components – Marian K. Kazimierczuk 2013

Automotive Electronics and Drivetrains

Subject Code: EE6L066	L-T-P-C: 3-0-0-3

Learning Outcomes:

- Understand the architecture and key components of EV powertrains, including the challenges involved and the critical role of power electronics in enhancing performance and efficiency.
- Analyze and design power electronic converters for EV applications, covering converter topologies, modulation techniques, power loss and thermal modeling, switch selection, and subsystem integration.
- Explain the operation and control of electric machines used in EVs, such as BLDC, PMSM, and switched reluctance machines, including advanced control techniques like Field-Oriented Control (FOC) and Direct Torque Control (DTC).
- Evaluate and implement battery management systems (BMS) for EVs, including battery technologies, BMS architecture, power electronics integration, state estimation (SoC and SoH), balancing techniques, and thermal management.

Module 1: (2 hours)
Overview of EV powertrain, Architecture of EV powertrain- introduction to various subsystems, Challenges in EV powertrain, Role of power electronics in EV powertrain

Module 2: (12 hours)
Power Electronic Converters for EV Systems, Converter topologies and modulation techniques, Power loss model and thermal model converter efficiency and heatsink requirements, Switch selection: WBG vs Si and gate driver design and Subsystems design of power converter

Module 3: (7 hours)
Electric Machines for EVs, Fundamentals of machines, Permanent magnet (BLDC and PMSM), Switched reluctance machines

Module 4: (9 hours)
Control of Power Converters for EV Drive, FOC and DTC for PMSM and BLDC machines, Regenerative braking, Sensing for control: voltage, current and position/speed and PWM generation in digital control

Module 5: (12 hours)
EV Battery Management Systems, Introduction to EV Battery Technologies, Battery Management System (BMS) Architecture, Power Electronics in BMS, Battery modelling, State of Charge (SoC) and State of Health (SoH) Estimation, Battery Balancing Techniques and Thermal Management in Battery Systems

Text Books:

1. James Larminie, John Lowry “Electric Vehicle Technology Explained" Wiley, 2012
2. Ned Mohan, Tore M. Undeland, William P. Robbins "Power Electronics: Converters, Applications, and Design" Wiley, 2002

3. Austin Hughes "Electric Motors and Drives: Fundamentals, Types and Applications" Newnes, 2006
4. Seung-Ki Sul "Control of Electric Machine Drive Systems" Wiley-IEEE Press, 2011
5. H.J. Bergveld, W.S. Kruijt, P.H.L. Notten "Battery Management Systems: Design by Modelling" Springer, 2002

Reference Books:

1. Mehrdad Ehsani, Yimin Gao, Sebastian E. Gay, Ali Emadi "Modern Electric, Hybrid Electric, and Fuel Cell Vehicles: Fundamentals, Theory, and Design" CRC Press, 2018
2. Gianfranco Pistoia "Electric Vehicle Battery Systems" Elsevier, 2010

Advanced EV Charging Technologies

Subject Code: EE6L067	L-T-P-C: 3-0-0-3

Learning Outcomes:

- Explain the fundamentals of electric vehicles and the different types of EV charging systems, including Level 1, Level 2, and DC fast charging, along with their relevant electrical principles and safety standards.
- Compare and contrast on-board and off-board EV charging technologies, including fast charging techniques, battery swapping, and emerging alternative charging solutions.
- Analyze the principles and design considerations of wireless power transfer systems for EVs, including inductive and capacitive methods, compensation networks, and dynamic charging technologies.
- Evaluate the impact of EV charging on power grids, and apply concepts of demand response, load management, and Vehicle-to-Grid (V2G) interactions to optimize grid stability and energy efficiency.
- Utilize simulation tools to model and analyze EV charging systems, including wireless charging setups, to support design decisions and real-world case studies.

Module 1(6 hours)

Basics of EV Charging, Overview of Electric Vehicles and Charging Basics, Types of EV Chargers: Level 1, Level 2, and DC Fast Charging, Electrical Fundamentals Relevant to EV Charging, Standards and Protocols for EV Charging and Safety Considerations in EV Charging

Module 2 (6 hours)

EV Charging Systems and Infrastructure, Overview of EV Charging Technologies, On-board and Off-board Charging Systems, Fast Charging Techniques and Standards, Battery Swapping and Alternative Charging Technologies

Module 3-(12 hours)

Wireless Power Transfer Systems for EVs, Inductive and capacitive wireless power Transfer systems, Compensation networks and couplers, Hybrid power transfer and dynamic wireless power transfer and Energy Management and Hybrid Storage in EV Charging

Module 4 -(12 hours)

Electric Vehicles and Their Impact on Grids, Impact of EV Charging on Power Grids, Demand Response and Load Management with EVs, Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) Concepts, Impact of V2G on Grid Stability and Energy Efficiency, Impact of Autonomous Vehicles on EV Charging Infrastructure, Standards and Protocols for EV Integration

Module 5 -(6 hours)

Simulation and Modelling of EV Chargers, Simulation Tools for EV Chargers, Simulation of wireless power Charging Systems and Case Studies using Simulation Tools

Text Books:
1. Chris Mi ,‘ Hybrid Electric Vehicles: Principles and Applications With Practical Perspectives , John Wiley & Sons, New York, 2025. 2. Chun T. Rim and Chris Mi , ‘Wireless Power Transfer for Electric Vehicles and Mobile Devices, John Wiley & Sons, New York, 2017.
Reference Books:
1. James Larminie and John Lowry Electric Vehicle Charging Infrastructure Engineering, John Wiley & Sons, 2012 2. Zhen Zhang and, Hongliang Pang “Wireless Power Transfer: Principles and Applications, IEEE Press Series on Power and Energy Systems, 2022

Power Management Circuits for Consumer Electronic Applications

Subject Code: EE6L068	L-T-P-C: 3-0-0-3

Learning Outcome:

- Identify power management requirements within consumer electronic applications.
- Identify the differences between power and signal ICs in consumer electronic applications.
- Analyse the role of analog electronic components (or ICs) within consumer electronic applications.
- Design power converter interfaces for matching load requirements within consumer electronic applications.
- Able to select appropriate devices from commercially available components for developing power converter interfaces.
- Design analog electronic based feedback regulation for power management.
- Estimate the losses and efficiency for different power converter interfaces used in consumer electronic applications.
- Identify the thermal and packaging challenges for consumer electronic appliance design.
- Learn how to develop behavioral models and test the performance of power management circuits.

Module 1: Introduction to Power Management Circuits: (contact hours: 6)

Role of power management ICs in power conversion, Behavioral mode analysis and simulation of power electronic converters, Linear piecewise simulation of power electronic converters, Standards and regulations required for compliance within consumer electronic devices, Selection of power devices for consumer applications. Modeling and analysis of gate charge characteristics of mosfets, simulation of wide band gap devices.

Module 2: Analysis of power management converters for lighting applications: (contact hours: 6)

Concepts of dc-dc converters, synchronous switching and bidirectional operation in non-isolated dc-dc converters, Pulse width modulators for power management circuits, implementation of pulse width modulators using analog circuits, isolated and non-isolated gate drivers in synchronous converters, Plant modeling of converters using state space analysis, concept of frequency response analysis, case analysis of lighting control system using buck converter.

Module 3: Power Factor Correction and Regulator designs for battery chargers: (contact hours: 9)

Concept of power factor correction: Modeling and analysis, feedback methods for PFC implementation, Current programmed control of dc-dc converters, Mixed mode controller for dc-dc converters, bandgap reference and current reference selection, optimal battery charging method implementation using power converters, design and implementation of compensators using operational amplifiers, role of limiter and saturation in converter control, Battery monitor circuits, Case analysis of CC-CV charging for optimal battery charging.

Module 4: Motor controller for consumer electronic applications: (contact hours: 6)

Power management controllers for BLDC motor applications, Sensing and feedback requirements for speed control of BLDC motors, Bootstrap gate driver design for trapezoidal pulse width modulation scheme, role of noise filters using analog circuits, Role of digital controllers and its peripherals such as data conversion (analog-to-digital, digital-to-analog), encoders, timers in vehicle control, case analysis of BLDC based ceiling fans.

Module 5: Resonant converters for induction cooktop applications: (contact hours: 3)

Fundamentals of Resonant dc-dc converters, converter architectures for resonant converters, design of parameters, case analysis of induction cooktop.

Module 6: Thermal modeling and analysis of power converters: (contact hours: 6)

Overview of losses in power management units, modeling of losses within power devices, role of datasheet in loss estimation, derated operation of power converters, thermal cycling, thermal equivalent circuit of power converters, selection of heatsink for power converters, role of non-ideal elements in thermal behavior of converters, Testing and instrumentation methods for power management circuits.

Module 7: Power density and packaging: (contact hours: 6)

Concept of converter packaging, printed circuit boards and components types for enabling higher power density, planar magnetic based design of power management circuits, intelligent power modules, challenges in power device packaging, analysis of routing in printed circuit board layout.

Module 8: Reliable operation of power management circuits: (contact hours: 6)

Requirements of reliable operation of power management circuits, soft start operation, dead time circuits, protection features of power management circuits such as overvoltage lockout, under voltage lockout, overcurrent protection, thermal trip, inrush, dead time, desat protection and duty ratio limit.

Text Books:

1. Fundamentals of Power Electronics, Erickson and Maksimovic, Kluwer, 2020
2. Switch Mode Power Supplies, Basso, Tata McGrawHill, 2008

Switched-Mode Power Conversion

Subject Code: EE6L051	L-T-P-C: 3-1-0-4

Learning Outcome:

- Explain and apply appropriate principles and concepts of power electronics in isolated and non-isolated power converters in continuous and discontinuous conduction modes with suitable time analysis.
- Draw equivalent circuits for the power converters at different modes of operation and solve problems with converter steady state operating points in ideal and practical converters; apply the fundamental principles/theories to calculate voltage and current stress in the converter, efficiency of the converters
- Derive the frequency domain plant model from time domain analysis and small signal linearization; design of closed loop controller for duty ratio programmed and current programmed converters.
- Determine the topological modifications or integrations with standard configurations for achieving soft switched converters for zero-voltage switching and zero current switching configurations.
- Design of magnetic components for two or multi-winding coupled inductors and transformers for typical switched mode converters and selection of suitable core/winding for most common converters.

Module 1: Introduction (3 Hours)
About Switch Mode Power Conversion: overview of the course; linear regulators; industrial relevance of SMPC.

Module-2: Basic DC to DC power converters (8 Hours)
Basic DC-DC converters - buck, boost, buck-boost & Cuk converters - and their principles of operation; continuous and discontinuous modes of operation; SEPIC converter.

Module-3: Power semiconductor switches (5 Hours)
Recent developments in power devices for switch-mode power supplies. Drive requirements, switching performance and snubber design. Selection of devices & basic heat sink design.

Module-4: Isolated Converters (10 Hours)
Single-switch and multi-switch transformer-isolated DC-DC converters. Flyback and forward Converters; transformer isolated half-bridge, full-bridge converters. Push-pull converters. Voltage fed and current-fed converters.

Module-5: Magnetic Component Design (9 Hours)
Magnetic core materials and performance; basic inductor, coupled inductor, and transformer design for flyback, push-pull, bridge, and forward converters, Calculation of high frequency core and conduction losses in these magnetics.

Module-6: Switching Regulator Control (9 Hours)

Small-signal models for switching regulators. Performance analysis and design of closed-loop systems under different control methods and operating modes. Determination of large signal models and measurement of small signal transfer functions.

Module-7: Soft-Switched and Resonant DC-DC Power Converters (5 Hours)

Hard-switching vs. soft-switching. Introduction to resonant power converters and their characteristics. Study of soft-transition converters. Resonant converters with LC, LLC, LCLC configurations.

Module-8: Single-Phase Power-Factor Correction (5 Hours)

Problems due to harmonics in the current drawn by equipment. Basic concept of active power factor correction (PFC) techniques. Performance analysis and comparison of different PFC techniques.

Module-9: Selected Case Studies (2 Hours)

Technological trends in power electronics, including wide bandgap devices, new magnetics materials, high frequency windings, high reliability and energy density capacitors, and digital control trends.

Text Books:

1. N Mohan, T M Undeland and W P Robbins, "Power Electronics: Converters, Applications and Design", Wiley, 2002.
2. Robert W. Erickson, Dr. Maksimović. “Fundamentals of Power Electronics”, Springer, 3rd Edition, 2020.

Reference Books:

3. Abraham Pressman, “Switching Power Supply Design”, 3rd Edition, The McGraw-Hill Companies, 2009.
4. L Umanand, “Power Electronics – Essentials and Applications”, 1st Edition, 2009
5. V. Ramanarayanan, “Course Materials on Switched Mode Power Converter”, IISc, Bangalore, 3rd Edition, 2007.

Analysis of Electric Drives

Subject Code: EE6L057	L-T-P-C: 3-1-0-4

Learning Outcomes:

- Explain various elements of an Electric drive.
- Analyse the operation of chopper-controlled DC motors under various conditions.
- Analyse the operation of phase-controlled rectifier-fed DC motors under various operating conditions.
- Derive the torque expression for various motors using energy conversion principles.
- Model different electric machines using the generalized theory of rotating electrical machines.

Module 1 (6 hours): Introduction to Electric Drives

Need of electric drives, basic parts, present scenario of electric drives, Mechanical Dynamics in an Electric drive—speed-torque characteristics of some common motors and loads, multi quadrant operation, equivalent values of drive parameters, stability of an electric drive, General Block Diagram of a Closed-Loop Drive System—Speed, Torque, and Position Control.

Module 2 (3 hours): Chopper Controlled DC Motor Drive

Different types of choppers and their quadrants of operations, PWM strategies for different choppers, chopper control of series DC motor.

Module 3 (6 hours): DC Motor Drive Using Phase-Controlled Rectifier

DC motor drive using half controlled and fully controlled single- phase and three- phase rectifiers, continuous and discontinuous conduction modes of operation, and 4-quadrant operation using dual converter.

Module 4 (3 hours): Closed Loop Control of DC Motor

Operating limits of a separately excited DC motor drive, dynamic model of DC motor, dynamic model of chopper and phase controlled rectifier.

Module 5 (8 hours):

Balance and unbalance operation of induction motors, braking and speed control of induction motor, control of slip ring induction motor. Introduction to synchronous motor drive, true synchronous and self-controlled mode of operation.

Module 6 (6 hours): Principles of electromagnetic energy conversion

General expression of stored magnetic energy, co-energy and force/torque, example using single and doubly excited systems. Voltage and torque equation of dc machine, three phase symmetrical induction machine and salient pole synchronous machines in phase variable form.

Module 7 (6 hours): Introduction to reference frame theory stationary and rotating reference frames, transformation relationships, examples using symmetrical three-phase passive circuits. Generalized theory of rotating electrical machine and Krons primitive machine.

Module 8 (4 hours):

Modelling of D.C. and three phase symmetrical induction and synchronous machines as per Kron's primitive machine model; voltage and torque equations.

Text Books:

1. P. C. Krause, O. Wasynczuk and S. D. Sudhoff,' Analysis of Electric Machinery and Drive Systems', John Wiley & Sons, New York, 2006.
2. G. K. Dubey, 'Fundamentals of Electrical Drives', CRC Press, 2002.

Reference Books:

1. P. S. Bimbhra 'Generalized theory of electrical machines', Khanna Publishers Delhi, 1995.
2. Chee-Mun Ong, 'Dynamic Simulation of Electric Machinery using MATLAB', Prentice Hall PTR, 1998.

Analysis and Design of Power Converters

Subject Code: EE6L058	L-T-P-C: 3-0-0-3

Learning Outcomes:

- Draw the I-V characteristics of different power semiconductor devices, explain series and parallel operation, their challenges and solutions
- Evaluate the performance of different rectifiers in terms of total harmonic distortion and power factor
- Explain working of two-level voltage source inverter (VSI), sinusoidal and space vector pulse width modulation (PWM) strategies, design control loops for VSI, design of L, LC and LCL filters for VSI
- Explain the advantages of multilevel converters, different types – cascaded H bridge, diode clamped and flying capacitor based multilevel converters, their working and PWM strategies
- Describe the operation of PWM current source rectifiers and inverters, different PWM techniques – trapezoidal modulation and selective harmonic elimination, single-bridge and dual-bridge current source rectifiers, explain power factor control and active damping control
- Analyse working of matrix converter, explain different configurations and their PWM strategies, design input filter for matrix converter
- Design of power converters using wide bandgap devices

Module 1: (3 Hours)
High-Power Semiconductor Devices: Diodes, SCR, GTO, GCT, IGBT, MOSFET. Operation of series- connected devices: main cause of unbalance, voltage equalizations.

Module 2: (6 Hours)
Multipulse Diode/SCR Rectifiers, Definition of THD and PF, THD and PF of six-pulse diode rectifier, 12, 18, 24- pulse series-type rectifiers, Effect of line and leakage inductances and Phase-Shifting Transformers, Harmonic current cancellation.

Module 3: (8 Hours)
Half bridge inverter, full bridge Inverter, sinusoidal PWM, Space Vector PWM in two-level voltage source inverters; relation between PWM rectifier and inverter operations. Filter design: L, LC,LCL. Control and design of voltage source converters.

Module 4: (4 Hours)
Three level inverter: Converter configuration, switching states, Carrier based PWM: Naturally sampled PD PWM, APOD and POD PWM; Space vector modulation: Optimized space vector sequences, modulator for selecting switching states, decomposition method.

Module 5: (6 Hours)
Multilevel inverter topologies: CHB Inverter with equal dc voltages, H-bridges with unequal dc voltages, overmodulation of cascaded H-bridges, Control of dc bus voltages of the H-bridges. Diode-Clamped Multilevel Inverters, Multilevel Flying Capacitor Inverters

Module 6: (7 Hours)
PWM Current Source Rectifiers and Inverters: Trapezoidal modulation, Selective harmonic Elimination, Space vector modulation, Single-bridge current source rectifier, Dual-bridge current source rectifier, Power factor control, Active Damping Control.

Module 7: (4 Hours)
Matrix converter: Direct and indirect converter configuration and their modulations. Design of filters for matrix converter.

Module 8: (4 Hours)
Wide band gap devices. Performance and Design of Converters using Wide Band-gap devices

Text Books:

1. L. Umanand, 'Power Electronics – Essentials and Applications', Wiley India Pvt. Ltd, 2009
2. B. Wu, 'High Power Converter and AC Drives', IEEE Press Wiley Interscience, 2006

Reference Books:

1. M. P. Kazmierkowski, R. Krishnan and F. Blaabjerg 'Control in Power Electronics - Selected Problems', Academic Press Series in Engineering, 2002

Advanced Electric Drives

Subject Code: EE6L059	L-T-P-C: 3-0-0-3

Learning Outcome:

- Design and analyze closed-loop control systems for DC motor drives and implement field weakening operation for extended speed range.
- Explain and apply field-oriented control (FOC) and direct torque control (DTC) schemes for induction motor drives.
- Explain the operation and control of Doubly Fed Induction Machines (DFIMs) including their equivalent circuit, multiple operating modes, and active/reactive power regulation.
- Explain the principles of synchronous motor drives, including vector-controlled cycloconverter-fed drives, and apply parameter estimation and sensorless control methods.
- Analyze various permanent magnet synchronous motor (PMSM) configurations, applying FOC, DTC, maximum torque per ampere control, and field weakening techniques for efficient drive operation.
- Develop dynamic model of Brushless DC Motors (BLDCMs); explain the electromagnetic characteristics and control strategies of BLDCMs.
- Model and design control schemes for switched reluctance and synchronous reluctance motor drives, addressing their unique operational characteristics.

Module 1: Closed-Loop Control Techniques for DC Motor Drives (3 Hours)

Closed loop control of DC drive, Design of a single-loop speed controller, cascaded controller design for DC motor using inner current control loop and outer speed control loop, field weakening operation.

Module 2: Field-Oriented Control of Induction Motor Drives (9 Hours)

Induction Motor Drives: Field oriented control- Direct and indirect field orientation, rotor flux estimation, stator-flux, rotor-flux and air gap-flux orientation. Flux-torque decoupling, Extended speed operation and Field weakening. Detuning operation of induction motor drive.

Module 3: Advanced Control and Operation of Induction Machines (9 Hours)

Direct torque control of Induction Motor with two- and three-level inverters, Flux and speed observers, Induction generators, Doubly Fed Induction Machines (DFIM): Different modes of operation, Equivalent circuit, Active and reactive power control, Vector control of DFIM.

Module 4: Parameter Identification and Sensorless Control of Induction Motors (4 Hours)

Identification of Induction Motor Parameters: Linear Model, Nonlinear least square identification, Parameter error indices. Speed sensor-less control: Signal injection and model based techniques, zero/low speed operation.

Module 5: Vector Control and Estimation in Synchronous Motor Drives (3 Hours)

Synchronous Motor Drives, Vector controlled Cycloconverter fed Drive, Parameter estimation and sensor-less control.

Module 6: Control Strategies for Permanent Magnet Synchronous Motors (PMSM) (5 Hours)

Introduction to PM Synchronous Motor, Various rotor configurations of PMSM, Sinusoidal Back-EMF PMSM: Field oriented control, Direct torque control. Interior PM Machine: Maximum torque per ampere control, Field weakening.

Module 7: Modeling and Control of Brushless DC Motor Drives (5 Hours)

Introduction to Brushless DC Motor: EMF and Torque of BLDC machine, Voltage Source Inverter-Fed BLDCM: Half-wave and Full-wave operation, Speed control, torque ripple minimization, and sensorless operation.

Module 8: Switched and Synchronous Reluctance Motor Drives (4 Hours)

Modeling and control of switched reluctance motor drive and synchronous reluctance motor drive.

Text Books:

1. P.C. Krause, O. Wasynczuk and S. D. Sudhoff, "Analysis of Electric Machines and Drive Systems", John Willy and Sons, New York, 2013.
2. B. K. Bose, "Modern Power Electronics and AC Drives", Pearson Education, 2005.

Reference Books:

1. W. Leonhard, "Control of Electric Drives", Springer International Edition, 2001.
2. R. Krishnan, "Electric Motor Drives – modelling, analysis and control", Pearson Education, 2015.
3. N. Mohan, "Advanced Electric Drives: Analysis, Control and Modelling using Simulink", Willy Publication, 2014.
4. Ramu Krishnan, "Permanent Magnet Synchronous and Brushless DC Motor Drives", CRC Press 2009.
5. S. K. Sul, "Control of Electric Machine Drive Systems", Willy IEEE Press, 2011.