

Executive M. Tech Programme

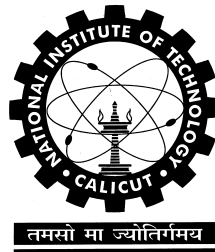
(for Working Professionals)

IN

SUSTAINABLE ELECTRICAL ENERGY

Curriculum and Syllabi

(With effect from Academic Year 2025-2026)



Department of Electrical Engineering
National Institute of Technology Calicut
Kozhikode – 673 601, Kerala, India

The Program Educational Objectives (PEOs) of Executive M. Tech programme in Sustainable Electrical Energy

PEO1	Enable working professionals to apply advanced knowledge and skills in sustainable electrical energy systems to excel in their careers across the renewable energy sector, power utilities, energy system consulting and energy project management.
PEO2	Equip professionals with the ability to design and implement innovative, energy-efficient, and sustainable solutions for real-world challenges in electrical energy systems that align with industry demands, economic feasibility, and environmental responsibility.
PEO3	Foster professionalism, ethical responsibility, effective communication, leadership, and collaborative skills, empowering professionals to take on leadership roles and drive sustainable energy initiatives in their respective domains.

Programme Outcomes (POs) of Executive M. Tech programme in Sustainable Electrical Energy

PO1	Ability to independently conduct research, investigations, and development work to address practical challenges in sustainable electrical energy systems.
PO2	Ability to effectively write, document, and present substantial technical reports and research findings relevant to sustainable energy technologies
PO3	Demonstrate mastery of sustainable electrical energy principles, technologies, and applications at a level higher than that required in an undergraduate program, with a focus on real-world implementation.
PO4	Ability to apply acquired knowledge in managing projects, optimizing energy systems, and addressing administrative challenges in the renewable energy and power sector while maintaining a commitment to continuous learning.
PO5	Strong commitment to professional ethics, environmental responsibility, and social values while developing and implementing sustainable energy solutions as an engineer, researcher, or decision-maker.

CURRICULUM

Total credits for completing the **Executive M. Tech programme in Sustainable Electrical Energy** is **75**.

COURSE CATEGORIES AND CREDIT REQUIREMENTS:

The structure of executive M. Tech programme shall have the following Course Categories:

Sl. No.	Course Category	Minimum Credits
1.	Program Core (PC)	23
2.	Program Electives (PE)	12
3.	Project (CP)	40

The effort to be put in by the student is indicated in the tables below as follows:

L: Lecture (One unit is of 50-minute duration)

T: Tutorial (One unit is of 50-minute duration)

P: Practical (One unit is of 1-hour duration)

O: Outside the class effort / self-study (One unit is of one-hour duration)

PROGRAMME STRUCTURE

Semester I

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Category
1.	EE6701E	Electrical Energy System Analysis	3	0	2	7	4	PC
2.	EE6702E	Electrical Energy System Operation and Control	3	0	2	7	4	PC
3.	EE6703E	Power Electronics for Renewable Energy Integration	3	0	2	7	4	PC
Total			9	0	6	21	12	-

Semester II

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Category
1.	EE6711E	Electrical Energy System Economics	3	0	2	7	4	PC
2.	EE6712E	Computational Intelligence for Electrical Energy Systems	3	0	2	7	4	PC
3.	EE6713E	Computer Aided Power System Protection	3	0	0	6	3	PC
Total			9	0	4	20	11	-

Semester III

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Category
1.		Elective I	3	0	0	6	3	PE
2.		Elective II	3	0	0	6	3	PE
3.		Elective III	3	0	0	6	3	PE
4.		Elective IV	3	0	0	6	3	PE
Total			12	0	0	24	12	--

Semester IV

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Category
1.	EE7791E	Project I	0	0	26	13	13	CP
Total			0	0	26	13	13	-

Semester V

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Category
1.	EE7792E	Project II	0	0	26	13	13	CP
Total			0	0	26	13	13	--

Semester VI

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Category
1.	EE7793E	Project III	0	0	28	14	14	CP
Total			0	0	28	14	14	-

List of Electives**

Sl. No.	Course Code	Course Title	L	T	P	O	Credits
1.	EE6721E	Electrical Energy System Automation	3	0	0	6	3
2.	EE6722E	Distributed Energy Generation	3	0	0	6	3
3.	EE6723E	Smart Grid	3	0	0	6	3
4.	EE6724E	Power Quality	3	0	0	6	3
5.	EE6725E	Distribution Systems	3	0	0	6	3
6.	EE6726E	Energy System Optimisation	3	0	0	6	3
7.	EE6727E	Industrial Energy Audit	3	0	0	6	3
8	EE6728E	Sustainable Energy Policy and Economics	3	0	0	6	3
9.	EE6729E	Python Programming	3	0	0	6	3
10.	EE6730E	Energy Storage Systems and Applications	3	0	0	6	3
11.	EE6731E	Electrical Energy System Reliability	3	0	0	6	3

**** List of Electives offered in each semester will be announced by the Department.**

EE6701E Electrical Energy System Analysis

Pre-requisites: **NIL**

L	T	P	O	C
3	0	2	7	4

Total Lecture Sessions: 39

Course Outcomes:

CO1: Using digital techniques to compute load flow and short circuit analysis on large-scale AC, DC, and AC-DC power systems.

CO2: Choose appropriate load flow methods for distribution systems

CO3: Develop mathematical models for State Estimation and Contingency analysis

CO4: Recommend appropriate security enhancements and stability management strategies based on the analysis of power system operating conditions

Load Flow Studies

Power Flow Analysis: Review of Gauss-Seidel, Newton-Raphson, Decoupled and Fast Decoupled Methods, DC Power Flow, AC-DC Load Flow Analysis, Load Flow under Power Electronic Control

Fault Analysis

Fault Analysis: Review of Sequence Matrices- Review of Symmetrical and Unsymmetrical Short-Circuit Analysis of Large Power Systems - Phase Shift in Sequence Quantities Due to Transformers - digital simulation

Distribution System Analysis

Load flow analysis of balanced and unbalanced radial distribution system – Load flow analysis of weakly meshed system – Backward/forward sweep - Direct approach - Direct approach for weakly meshed systems - Gauss Implicit Z-matrix Method - Short-circuit analysis: Sequence-components vs. phase-variable - LG, LLG, LLLG, and LL Faults - Weakly meshed system - Applications of distribution system analysis

Power System Stability and Security

Power System Stability studies – Steady state and transient stability– Swing equation - Equal area criterion – Multi-machine stability analysis- Voltage stability problem: causes and improvement methods - Introduction to power system security - Contingency analysis - adding and removing multiple lines, Analysis of single and multiple contingencies, Contingency Analysis by DC model, System reduction for contingency and fault studies – linear sensitivity factors – State estimation – least square and weighted least square estimation methods for linear and non-linear systems.

Note: The laboratory sessions involve simulation or hardware experiments based on the theoretical concepts covered in the course.

References:

1. John J. Grainger and William D. Stevenson, *Power System Analysis*, Tata McGraw-Hill, 2003
2. Haadi A. Sadat, *Power System Analysis*, McGraw Hill Co. Ltd., India, 2000.
3. George L. Kusic, *Computer Aided Power System Analysis*, Prentice Hall of India (P) Ltd., New Delhi, 1989.
4. J. Arrilaga, C.P. Arnold, B.J. Harker, *Computer modelling of Electric Power Systems*, Wiley, New York, 1983.
5. A.K. Mahajanabis, D.P. Kothari, S.I. Ahson, *Computer Aided Power System Analysis & Control*,
6. Tata McGraw Hill, New Delhi, 1988.
7. O.I. Elgard, *Electric Energy System Theory: An Introduction*, 2nd ed., McGraw Hill, New York, 1982.
8. Mariesa L. Crow, *Computational Methods for Electric Power Systems*, CRC Press, 2010.
9. Arthur R. Bergen, Vijay Vittal, *Power Systems Analysis*, Pearson Education, 2009.
10. Allen J. Wood, Bruce Wollenberg and Gerald B. Sheble, '*Power Generation, Operation and Control*', 3rd Edition. John Wiley and Sons, 2013.
11. B.Das, *Power Distribution Automation.*, [Volume 2 of Energy Engineering](#), [Volume 75 of IET power and energy series](#), Institution of Engineering and Technology, 2016.

EE6702E Electrical Energy System Operation and Control

Pre-requisites: **NIL**

L	T	P	O	C
3	0	2	7	4

Total Lecture Sessions: 39

Course Outcomes:

CO1: Explain the principles of economic and secure power system operation.

CO2: Apply optimization techniques to unit commitment, dispatch, and scheduling.

CO3: Analyse voltage, frequency, and reactive power control mechanisms.

CO4: Assess the impact of energy storage, advanced distribution systems, and EV integration.

Economic Operation and Unit Commitment

Introduction to system operation objectives and constraints; formulation of economic dispatch with and without losses; incremental cost and penalty factor methods; optimization preliminaries and dynamic programming; numerical methods for dispatch; hydrothermal coordination and pumped storage; unit commitment formulation—priority list, dynamic programming, and Lagrange relaxation; production cost modeling and reliability considerations; inter-utility energy interchange, power pooling, and banking.

System Control, Security, and Optimization

Automatic voltage regulator (AVR) and automatic generation control (AGC); single- and multi-area load–frequency control; reactive power and voltage control using capacitors, SVCs, STATCOMs, and OLTC transformers; ancillary services and Indian Grid Code; contingency analysis and system security assessment; formulation and solution of optimal power flow (AC/DC and security-constrained); reliability indices and reserve evaluation; simulation-based case studies using MATLAB and PowerFactory.

Advanced Operation and Emerging Technologies

Integration of SCADA/WAMS for real-time monitoring; advanced distribution system management—volt–VAR control, demand response, feeder reconfiguration, and DER integration; modeling and control of energy storage systems for load leveling and frequency regulation; EV charging coordination, vehicle-to-grid operation, and grid impact assessment in the Indian context; optimization-based scheduling and case studies using Python and PowerFactory.

Note: *The laboratory sessions involve simulation or hardware experiments based on the theoretical concepts covered in the course.*

References:

1. A. J. Wood, B. F. Wollenberg, and G. B. Sheble, *Power Generation, Operation, and Control*, 3rd ed., Wiley, 2013.
2. P. Kundur, *Power System Stability and Control*, McGraw-Hill, 1994.
3. O. I. Elgerd, *Electric Energy Systems Theory: An Introduction*, 2nd ed., McGraw-Hill, 1982.
4. A. Monticelli, *State Estimation in Electric Power Systems*, Springer, 1999.
5. D. P. Kothari and I. J. Nagrath, *Modern Power System Analysis*, 4th ed., Tata McGraw-Hill, 2011.
6. N. P. Padhy, *Unit Commitment in Power Systems*, Alpha Science, 2008.
7. J. Wood and B. Wollenberg, "Economic dispatch and unit commitment in modern power systems," *IEEE Trans. Power Syst.*, vol. 19, no. 2, pp. 643–652, May 2004.
8. IEEE PES Task Force, "Integration of Electric Vehicles and Energy Storage in Smart Grids," *IEEE Trans. Smart Grid*, vol. 14, no. 3, pp. 2105–2118, Mar. 2023.
9. A. Abur and A. G. Exposito, *Power System State Estimation: Theory and Implementation*, CRC Press, 2004.

EE6703E Power Electronics for Renewable Energy Integration

Pre-requisites: **NIL**

L	T	P	O	C
3	0	2	7	4

Total Lecture Sessions: 39

Course Outcomes:

- CO1: Interpret and demonstrate the synchronization techniques of single-phase power converters with the utility grid.
- CO2: Analyse and implement synchronization methods for three-phase power converters connected to the grid.
- CO3: Design and evaluate filters with appropriate damping characteristics for effective grid synchronization of power converters.
- CO4: Explain and analyse various islanding detection techniques used in grid-connected systems.
- CO5: Implement and assess control strategies for grid-interfacing power converters under various operating conditions.

Grid Synchronization of Single-Phase Power Converters

Single Phase Two-Level VSC: Sinusoidal Pulse Width Modulation (SPWM) for Single Phase full-bridge VSC, Bipolar versus Unipolar SPWM, Harmonics and filtering, Leakage current issue in SPWM. Single Phase Inverters derived from H-Bridge topology - The H5 Inverter, HERIC Inverter, REFU Inverter, Full-Bridge Inverter with DC Bypass – FB-DCBP, Full-Bridge Zero Voltage Rectifier – FB-ZVR

Grid Synchronization Techniques: Grid Synchronization Using the Fourier Analysis and Phase-Locked Loop, Phase Detection Based on In-Quadrature Signals - PLL Based on a T/4 Transport Delay, PLL Based on the Hilbert Transform, PLL Based on the Inverse Park Transform. PLLs Based on Adaptive Filtering - The Enhanced PLL, Second-Order Adaptive Filter, Second-Order Generalized Integrator, The SOGI-PLL - Analysis of the SOGI-FLL

Grid Synchronization in Three-Phase Power Converters

Three Phase Two-Level VSC: SPWM for 2-Level three-phase VSC, Motivation for SVM for Three-phase Two-Level VSC, Switching States, Space Vectors, Dwell Time calculation, Modulation Index, Switching Sequence, Spectrum Analysis.

Three-Phase grid synchronization techniques: Unbalanced Grid Voltages during a Grid Fault, Transient Grid Faults, the Voltage Sags (Dips), Propagation of Voltage Sags. Synchronous Reference Frame PLL – SRF PLL under Unbalanced and Distorted Grid Conditions. The Decoupled Double Synchronous Reference Frame PLL (DDSRF-PLL) - The Double Synchronous Reference Frame, The Decoupling Network, Analysis of the DDSRF, Structure and Response of the DDSRF-PLL. The Double Second-Order Generalized Integrator FLL (DSOGI-FLL) - Structure of the DSOGI, Relationship between the DSOGI and the DDSRF, The FLL for the DSOGI, Response of the DSOGI-FLL.

Filter Design & Islanding Detection

Grid filter design: Filter Topologies, Design Considerations, Resonance Problem and Damping Solutions - Instability of the Undamped Current Control Loop, Passive Damping of the Current Control Loop, Active Damping of the Current Control Loop. Nonlinear Behaviour of the Filter

Islanding detection: Overview of Islanding Detection Methods, Passive Islanding Detection Methods - OUF–OUV Detection, Phase Jump Detection (PJD), Harmonic Detection (HD), Passive Method Evaluation. Active Islanding Detection Methods - Frequency Drift Methods, Voltage Drift Methods, Grid Impedance Estimation, PLL-Based Islanding Detection, Comparison of Active Islanding Detection Methods

Control of Grid Interfacing Converter

Model of the Converter: Mathematical Model of the L-Filter Inverter, Mathematical Model of the LCL-Filter Inverter

AC Voltage and DC Voltage Control: Management of the DC Link Voltage, Cascaded Control of the DC Voltage through the AC Current, Tuning Procedure of the PI Controller.

Voltage Oriented Control and Direct Power Control: Synchronous Frame VOC – Open loop & Closed loop. Stationary Frame VOC - Open loop & Closed loop. Virtual-Flux-Based Control. Direct power control.

Stand-alone, Micro-grid, Droop Control and Grid Supporting: Grid-Connected/Stand-Alone Operation without Load Sharing, Micro-Grid Operation with Controlled Storage, Droop Control.

Note: The laboratory sessions involve simulation or hardware experiments based on the theoretical concepts covered in the course.

References:

1. Remus Teodorescu, Marco Liserre, Pedro Rodriguez, “Grid Converters for Photovoltaic and Wind Power Systems” Wiley-IEEE Press, January 2011.
2. Suleiman M. Sharkh, Mohammad A. Abu-Sara, Georgios I. Orfanoudakis, Babar Hussain, “Power Electronic Converters for Microgrids” Wiley-IEEE Press, April 2014.
3. Fang Lin Luo, Hong Ye, “Advanced DC/AC Inverters: Applications in Renewable Energy” CRC Press.
4. Sudipta Chakraborty, Marcelo G. Simões, William E. Kramer, “Power Electronics for Renewable and Distributed Energy Systems” Springer 2013.
5. Amirnaser Yazdani & Reza Iravani, *Voltage-Sourced Converters in Power Systems*, IEEE Press, John Wiley & Sons, 2010

EE6711E Electrical Energy System Economics

Pre-requisite: **NIL**

L	T	P	O	C
3	0	2	7	4

Total Lecture Sessions: 39

Course Outcomes

- CO1: Understand the principle and operation of deregulated power system.
- CO2: Illustrate how electricity is priced in deregulated power markets.
- CO3: Explain the working of various electricity markets around the world.
- CO4: Understand the concepts of development and evaluation of power projects.

Introduction to Deregulation

Why deregulate? – What to deregulate – Pricing power, energy, and capacity - Power supply and demand – Market structure and architecture – Spot market – Day ahead market – Real-time market – Reserve market – Ancillary services - US and European market evolution - Reforms in Indian power sector

Energy and Derivative Markets

Concept of marginal cost - Market equilibrium – Market clearing price – Congestion pricing fundamentals – Locational marginal pricing – Operating reserve pricing – Value-of-lost-load pricing – Pricing losses on lines - Pricing losses at nodes - Derivative markets – Hedging risk – Contract for difference - Forwards - Futures – Options – Swaps

Power Generation and Transmission Investments and Economics

Cost of Power Generation – Levelized Cost of Energy – Generation Planning – Investment Analysis– Time Value of Money – Net Present Value – Benefit/cost Ratio – Payback Period - Profit/investment Ratio – Business Economic Feasibility Study – Power Purchase Agreements – Transmission Investments – Supply and Demand Functions

Distribution System and Microgrid Economics

Tariff and Energy Bills – Net Metering – Net Feed-in - Rooftop Solar PV Business models - Customer Savings Analysis – Grid Parity – Utility and DSO economics - Local energy markets – Virtual power plant and microgrids – Microgrid prosumer consortium – Role of DSO – Business models

Note: The laboratory sessions involve simulation or hardware experiments based on the theoretical concepts covered in the course.

References:

1. Daniel S. Kirschen, Goran Strbac, 'Fundamentals of Power System Economics, Wiley, 2018.
2. Darryl R. Biggar, Mohammad Reza Hesamzadeh, 'Economics of Electricity Markets', Wiley-IEEE press, 2014.

3. *Mohammad Shahidehpour, Muwaffaq Alomoush, 'Restructured Electrical Power Systems: Operation: Trading, and Volatility', Marcel Dekker Inc., 2001.*
4. *Steven Stoft, 'Power System Economics: Designing Markets for Electricity', Wiley-IEEE Press, May 2002.*
5. *Anna Creti, Fulvio Fontini, 'Economics of Electricity', Cambridge University Press, May 2019.*
6. *Loi Lei Lai, 'Power System Restructuring and Deregulation', Wiley, 2001.*
7. *Jin Zhong, 'Power System Economic and Market Operations', CRC Press, 2018.*
8. *Kankar Bhattacharya, Math H. J. Bollen, Jaap E. Daalder, 'Operation of Restructured Power System', Springer, 200*

EE6712E Computational Intelligence for Electrical Energy Systems

Pre-requisite: **NIL**

L	T	P	O	C
3	0	2	7	4

Total Lecture sessions: 39

Course Outcomes:

CO1: Apply the concepts of linear algebra, optimization, and statistics to analyze power system and other related problems.

CO2: Apply data-driven approaches to analyze dynamical systems including power systems.

CO3: Apply computational data analysis tools to learn data-driven modelling of dynamical systems including power systems.

CO4: Apply concepts of machine learning algorithms to address power system problems.

Introduction to Linear Algebra, Optimization & Statistics:

Vectors, matrices, product of matrix & vector, rank, null space, distance, projections, eigenvalue decomposition. Introduction to Optimization, Algorithms for Constrained and Unconstrained Optimization. Conditional Probability and Bayes' Theorem in Machine Learning Context.

Dimensionality reduction and transforms

Dimensionality Reduction: Singular Value Decomposition, Principal and Independent Component Analysis - Dynamic Mode Decomposition - Equation Free Modelling. Fourier Series and Transforms, Discrete and Fast FFT, Wavelets.

Machine Learning & Data Analytics

Regression & ANOVA, Nonlinear Regression and Gradient Descent, Over- and Under-Determined Systems, Model Selection.

Clustering & Classification: Feature Selection and Data Mining, Supervised & Unsupervised Learning. k-means Clustering, Support Vector Machines (SVM), Classification Trees and Random Forest.

Neural Networks: Multi-layer Networks and Activation Functions.

Data-Driven Dynamical Systems

Neural Networks for Dynamical Systems, Koopman Operator Theory & Analysis, Mode Decomposition. Power System Case Studies.

Note: The laboratory sessions involve simulation or hardware experiments based on the theoretical concepts covered in the course.

Reference

1. Gilbert Strang. Differential Equations and Linear Algebra. Wellesley-Cambridge Press, 2015.
2. J. Nathan Kutz & Steve L. Brunton. Data Driven Science and Engineering. Cambridge University Press, 2019.
3. Ali Tajer, Samir M. Perlaza, & H. Vincent Poor. Advanced Data Analytics for Power Systems. Cambridge University Press, 2021.
4. Nino Boccara. Modelling Complex System. Springer Publications, 2010.
5. H. Steven Strogatz. Nonlinear Dynamics and Chaos. Westview Press, 2015.
6. J. Nathan Kutz. Data-Driven Modeling & Scientific Computation: Methods for Complex Systems & Big Data. Oxford University press, 2013.

EE6713E Computer Aided Power System Protection

Pre-requisites: **NIL**

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

- CO1: Analyse various relaying strategies and standards used
- CO2: Determine relays settings for various scenarios
- CO3: Interpret protection schemes for various power system elements
- CO4: Recognize the advantages of digital relays over conventional relay
- CO5: Apply the suitable signal processing techniques for protection

Art of relaying

Protective Relaying - Qualities of relaying - Definitions - Codes- Standards; Characteristic Functions; Classification – analog - digital- numerical; schemes and design-factors affecting performance –zones and degree of protection. Instrument transformers for protection -Current Transformer- Capacitor Voltage Transformer- Fiber Optic Sensors

Numerical Relaying

Faults in Power System - Elements and Features of Protection Scheme - Fault Analysis Review - Sequence Components - Numerical Relaying Concept - Discrete Fourier Transform - Recursive and Half Cycle DFT and Cosine Filter - Least Square Technique - Frequency Response of Phasor Estimation techniques - In the Presence of Decaying DC.

Overcurrent and Directional Protection

Overcurrent Relay Characteristics - Overcurrent Relay Coordination -Relay Coordination with Fuse. Introduction to Directional Relaying - Positive Sequence Directional Relay - Negative and Zero Sequence Directional Relay- Superimposed Component Based Directional Relaying.

Introduction to Distance Relay - Fault Classification - Apparent Impedance Calculation - Distance Relay Implementation - Application to Double Circuit Line –Multi terminal Lines - "Protection of series compensated lines- Effect of Fault Resistance- Load Encroachment - Power Swing - Power Swing Detection Techniques- Adaptive Distance Relaying- Communication Assisted Relaying Scheme

Apparatus Protection

Introduction to Transformer Protection- Differential Relay- Steps in Differential Relay Processing - Inrush Detection- C T Saturation, Negative Sequence Differential and Restricted Earth Fault Relay. Line Differential - Busbar Protection

Modern Protection Schemes

Fault Characteristics of Renewable Sources - Protection Challenges of Distribution Systems with Renewables. Traveling Wave Basics - Protection using Travelling Waves- Fault Location using Travelling Wave. Wide Area Measurement Basics - Wide Area Measurement for Protection

References:

1. A.G.Phadke, James S.Thorp, '*Computer Relaying for Power Systems*', 2nd EJohn-Wiley and sons, 2009.
2. Waldemar Rebizant , Janusz Szafran, and Andrzej Wiszniewski. "*Digital Signal Processing in Power System Protection and Control*", Springer Publication, 2011.
3. A.T.Johns and S.K.Salman, '*Digital Protection for Power Systems*', IEEE Power Series, 1997
4. Stanley H. Horowitz, Arun G. Phadke, and Charles F. Henville. '*Power System Relaying*', 5th Edition, John Wiley & Sons 2022
5. D N Vishwakarma, Badri Ram, and Soumya R Mohanty. '*Power System Protection and Switchgear*', 3rd Edition. McGraw Hill, 2022
6. Latest IEEE Transactions papers on recent advancements in digital and adaptive relays
7. Latest Digital relay manuals of ABB, Siemens etc.

EE7791E Project –I

Pre-requisites: **NIL**

L	T	P	O	C
0	0	26	13	13

Course Outcomes:

- CO1: Develop comprehensive solution to issues identified and to meet the requirements as stated in project proposal.
- CO2: Attain the results of the detailed analytical studies conducted, lay down validity and design criteria, for application to the power system problems.
- CO3: Analyse the results critically, interpret the results and justify the achievement of the stated objectives.
- CO4: Report the concept and detailed design solution and to effectively communicate the research contributions

Faculty members propose projects /broad area of work and student will be asked to meet the faculty member who is offering the project of interest for guidance. Student can also select the topic for the interdisciplinary project too after discussions with guide. Students can carry out their projects in R&D organizations/ industries including their companies/organisation which have facility in the proposed area with an officer from there as external guide and with internal guide from Department. Students are required to undertake detailed technical work in the chosen area using one or more of the following: (i) Analytical models (ii) Computer simulations (iii) Hardware implementation. The assessment of the project will be done at the end of the semester by a committee. Atleast two evaluations are mandatory in a semester. The students will present their project work before the committee. The complete project report is expected at the end this semester. A 60–70 page typed concise report based on the work done will have to be submitted by the students to the assessing committee.

Students should complete the work planned in the fourth semester, attaining all the objectives, and should prepare the project report of the complete work done in the fourth semester.

EE7792E Project –II

Pre-requisites: **NIL**

L	T	P	O	C
0	0	26	13	13

Course Outcomes:

- CO1: Develop comprehensive solution to issues identified and to meet the requirements as stated in project proposal.
- CO2: Attain the results of the detailed analytical studies conducted, lay down validity and design criteria, for application to the power system problems.
- CO3: Analyse the results critically, interpret the results and justify the achievement of the stated objectives.
- CO4: Report the concept and detailed design solution and to effectively communicate the research contributions and publish in reputed journals/conference

EE7792E Project – II shall be a continuation of EE7791E Project – I in the fourth semester. Students should complete the work planned in the fifth semester, attaining all the objectives, and should prepare the project report of the complete work done in the fifth semester. They are expected to communicate their research contributions in reputed conferences and/or journals.

EE77943E Project –III

Pre-requisites: **NIL**

L	T	P	O	C
0	0	28	14	14

Course Outcomes:

- CO1: Develop comprehensive solution to issues identified and to meet the requirements as stated in project proposal.
- CO2: Attain the results of the detailed analytical studies conducted, lay down validity and design criteria, for application to the power system problems.
- CO3: Analyse the results critically, interpret the results and justify the achievement of the stated objectives.
- CO4: Report the concept and detailed design solution and to effectively communicate the research contributions and publish in reputed journals/conference

EE7793E Project – III shall be a continuation of EE7792E Project – II in the fifth semester. Students should complete the work planned in the sixth semester, attaining all the objectives, and should prepare the project report of the complete work done in the sixth semester. They are expected to communicate their research contributions in reputed conferences and/or journals.

EE6721E Electrical Energy System Automation

Pre-requisites: **NIL**

L	T	P	O	C
3	0	0	6	3

Total Lecture sessions: 39

Course Outcomes:

- CO1: Understand the concepts of power system automation.
- CO2: Understand the components of SCADA systems.
- CO3: Comprehend the RTU, IED and other components of automation systems
- CO4: Understand the transfer of signals from the field to an operator control terminal.
- CO5: Design an interoperable powers automation system

SCADA Systems

Evolution of Automation systems, History of Power system Automation, Supervisory Control And Data Acquisition (SCADA) Systems, Components of SCADA systems, SCADA Applications, SCADA in power systems, SCADA basic functions, SCADA application functions in Generation, Transmission and Distribution

Advantages of SCADA in Power Systems, The Power system 'Field' , Types of data & signals in the Power system, Flow of Data from the field to the SCADA Control center. Building blocks of SCADA systems, Classification of SCADA systems.

Remote Terminal Unit

Remote Terminal Unit (RTU), Evolution of RTUs, Components of RTU, Communication, Logic, Termination and Test/HMI Subsystems, Power supplies, Advanced RTU Functionalities.

Intelligent Electronic Devices

Intelligent Electronic Devices (IEDs), Evolution of IEDs , IED functional block diagram, The hardware and software architecture of IED, IED Communication subsystem, IED advanced functionalities, Typical IEDs, Data Concentrators and Merging Units, SCADA Communication Systems.

Distribution Management System

Master Station, Master station software and hardware configurations, Server systems in the master station, small, medium and large master station configurations, Global Positioning Systems, Master station performance, Human Machine Interface (HMI), HMI components, Software functionalities, Situational awareness, Case studies in SCADA and IoT approach in the implementation of distributed system.

References:

1. Mini S. Thomas, John D McDonald, *Power Systems SCADA and Smart Grid*, CRC Press, Taylor and Francis.
2. John D. Mc Donald, *Electric Power Substation Engineering* CRC Press, Taylor and Francis
3. James Northcote- Green, R Wilson, *Control and Automation of Electrical Power Distribution systems*, , CRC Press, Taylor and Francis.
4. James Momoh, *Electric Power Distribution, Automation, Protection and Control*, CRC press, Taylor and Francis.
5. Related Research papers.

EE6722E Distributed Energy Generation

Pre-requisites: **NIL**

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

- CO1: Analyze the concept of distributed generation and technologies
- CO2: Investigate the technical challenges of Distributed Generation technologies
- CO3: Design the microgrid architectures and its control operation
- CO4: Explore smartgrid technologies and infrastructure

Renewable Integration to Grid

Modern Power System: Generation - Transmission - Distribution - Loads - Introduction to Distributed Generation (DG) - Technologies of DG - IEEE 1547- Solar photovoltaic generation - wind energy - Wind power plants - Microturbines - Fuel Cell - Storage Systems - batteries, fly-wheels, ultracapacitors - unit sizing of DGs - Case studies

Distributed Energy Sources

Penetration of DGs Units in Power Systems - Integration of DGs Units in Distribution Network -Modern Power Electronics for DGs Applications – multiple and single input dc-dc converters - ac-dc and dc-ac converters - Technical restrictions - Protection of DGs - Economics of DGs –Pricing and Financing framework for DG units - Optimal placement of DGs - Case studies

Microgrid

Introduction to Microgrids - AC and DC microgrids - Operational Framework of Microgrids - anti-islanding schemes - Distribution Management System (DMS) - Microgrid System Central Controller (MGCC) - Local Controllers (LC) - Economic, environmental and operational benefits of Microgrids in a distribution network - Demand Response Management in Microgrids - Business Models and Pricing Mechanism in Microgrids - Interconnection of Microgrids

Smart Grid

Introduction to Smart Grids (SG) - Factors affecting the growth of SG - The global reality in the field of smart grids and transition into future grids - Smart Agents - Electronics and communications infrastructure in SG - ICT Technologies - smart meters - metering infrastructures - metering equipment - communication of metering equipment - communication protocols - Metering Data Management Systems (MDMS) - Application of SGs - Interconnections issues between SGs

References:

1. N. Hatziaargyriou, *Microgrids: Architectures and Control*, Wiley-IEEE Press, 1st Edition, 2014
2. J. N. Twidell & A. D. Weir, *Renewable Energy Sources*, University press, Cambridge, 2001
3. James Larminie , Andrew Dicks , *Fuel Cell Systems*, John Wiley & Sons Ltd, 2000
4. J. F. Manwell , J. G. McGowan, A. L. Rogers , *Wind Energy Explained*, John Wiley & Sons Ltd 2009
5. Loi Lei Lai, Tze Fun Chan, *Distributed Generation- Induction and Permanent Magnet Generators*, IEEE Press, John Wiley & Sons, Ltd., England. 2007.
6. Amirnaser Yazdani, and Reza Iravani, *Voltage Source Converters in Power Systems: Modeling, Control and Applications*, IEEE John Wiley Publications, 2009

EE6723E Smart Grid

Pre-requisites: **NIL**

L	T	P	O	C
3	0	0	6	3

Total Lecture sessions: 39

Course Outcomes:

- CO1: Analyse the need and concept of Smart Grid
- CO2: Assess the role of automation in Transmission and Distribution
- CO3: Identify suitable communication networks for smart grid applications
- CO4: Apply various distribution management function under autonomous operation
- CO5: Differentiate different EMS and DMS functions

Introduction to Smart Grid

Introduction to Smart Grid: Introduction to Smart Grid - Working definitions of Smart Grid and Associated Concepts – Smart Grid Functions – Traditional Power Grid and Smart Grid – New Technologies for Smart Grid – Advantages – Indian Smart Grid – Key Challenges for Smart Grid.

Smart Grid Architecture

Smart Grid Architecture: Components and Architecture of Smart Grid Design – Review of the proposed architectures for Smart Grid. The fundamental components of Smart Grid designs – Transmission Automation – Distribution Automation

Energy Management System

Energy Management System (EMS) - Smart substations - Substation Automation - Feeder Automation, SCADA – Remote Terminal Unit – Intelligent Electronic Devices – Protocols, Phasor Measurement Unit – Wide area monitoring protection and control, Smart integration of energy resources – Renewable, intermittent power sources – Energy Storage.

Distribution Management System

Distribution Management System (DMS) – Volt / VAR control – Fault Detection, Isolation and Service Restoration, Network Reconfiguration, Outage management System, Customer Information System, Geographical Information System, Effect of Plug in Hybrid Electric Vehicles.

Advanced Metering infrastructure

Introduction to Smart Meters – Advanced Metering infrastructure (AMI), AMI protocols – Standards and initiatives, Demand side management and demand response programs, Demand pricing and Time of Use, Real Time Pricing, Peak Time Pricing.

Communication and networking

Elements of communication and networking – architectures, standards, PLC, Zigbee, GSM, BPL, Local Area Network (LAN) - House Area Network (HAN) - Wide Area Network (WAN) - Broadband over Power line (BPL) - IP based Protocols - Basics of Web Service and CLOUD Computing, Cyber Security for Smart Grid.

References:

1. Stuart Borlase *Smart Grid: Infrastructure, Technology and Solution*, CRC Press 2012.
2. Janaka Ekanayake, Nick Jenkins, Kithsiri Liyanage, Jianzhong Wu, Akihiko Yokoyama, *Smart Grid: Technology and Application*, Wiley, 2012.
3. Mini S. Thomas, John D McDonald, *Power System SCADA and Smart Grids*, CRC Press, 2015
4. Kenneth C.Budka, Jayant G. Deshpande, Marina Thottan, *Communication Networks for Smart Grids*, Springer, 2014.
5. Gil Masters, *Renewable and Efficient Electric Power System*, 2nd Edition Wiley–IEEE Press, 2013.

EE6724E Power Quality

Pre-requisites: **NIL**

L	T	P	O	C
3	0	0	6	3

Total Lecture sessions: 39

Course Outcomes:

- CO1: Explain various power quality issues, remedial measures and standards.
- CO2: Develop models to analyse harmonics in networks and components
- CO3: Design active power factor correction based on static VAR compensators and its control techniques
- CO4: Analyze series and shunt active power filtering techniques for harmonic cancellation and isolation
- CO5: Explain voltage quality improvement techniques and NEC grounding requirements and solutions to grounding and wiring problems

Power Quality Issues

Introduction-power quality-voltage quality-overview of power quality phenomena-classification of power quality issues-power quality measures and standards-THD-TIF-DIN-C-message weights-flicker factor transient phenomena-occurrence of power quality problems-power acceptability curves-IEEE guides, standards and recommended practices

Harmonic Analysis

Harmonics-individual and total harmonic distortion-RMS value of a harmonic waveform-triplex harmonics-important harmonic introducing devices-SMPS-Three phase power converters-arcing devices saturable devices-harmonic distortion of fluorescent lamps-effect of power system harmonics on power system equipments and loads. Modeling of networks and components under non-sinusoidal conditions transmission and distribution systems-shunt capacitors-transformers-electric machines-ground systems-loads that cause power quality problems-power quality problems created by drives and its impact on drives.

Power factor improvement

Power factor improvement- Passive Compensation- Passive Filtering- Harmonic Resonance- Impedance Scan Analysis- Active Power Factor Corrected Single Phase Front End Converters, Control Methods for Single Phase APFC- Three Phase APFC and Control Techniques- PFC Based on boost conversion technique and Bilateral Single Phase and Three Phase Converters. Static VAR compensators- SVC and STATCOM.

Active Harmonic Filtering Techniques

Active Harmonic Filtering-Shunt Injection Filter for single phase, three-phase three-wire and three-phase four-wire systems. d-q domain control of three phase shunt active filters- series active power filtering techniques for harmonic cancellation and isolation. Uninterruptible Power Supplies- Constant Voltage Transformers - Dynamic Voltage Restorers for sag, swell and flicker problems. Grounding and wiring - introduction - NEC grounding requirements- reasons for grounding-typical grounding and wiring problems-solutions to grounding and wiring problems.

References:

1. G.T. Heydt, *Electric power quality*, McGraw-Hill Professional, 2007.
2. Math H. Bollen, *Understanding Power Quality Problems*, IEEE Press, 2000.
3. J. Arrillaga, *Power System Quality Assessment*, John Wiley, 2000.
4. E Fuchs, M.A.S. Masoum, *Power Quality in Power Systems and Electrical Machines*, Elsevier Inc., 2008.
- A. Moreno, *Power Quality-Mitigation Technologies in a disturbed environment*, Springer, 2007.
5. W.E.Kazibwe, M.H.Sendaula, *Electric Power Quality Control Techniques*, Van Nostrand Reinhold, 1993.
6. J. Arrillaga, B.C. Smith, N.R. Watson & A. R.Wood, *Power system Harmonic Analysis*, Wiley, 1997.
7. IEEE Transaction and IET Journal papers

EE6725E Distribution Systems

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes

- CO1: Describe and apply general concepts of distribution system, load and energy forecasting
- CO2: Analyze distribution system and carry out network cost modelling
- CO3: Analyze distribution system reliability and assess power quality
- CO4: Describe consumer tariffs, costing and pricing
- CO5: Describe and apply the knowledge of Power capacitors in HT and LT installation

Distribution System Parameters, Architecture, and Design

Distribution system - General concepts and architectures - Load and energy forecasting - Factors in power system loading - Optimization of distribution system network cost modeling - Economic loading of distribution transformers Consumer services - consumer load control for power shortages - Tariffs-costing, pricing and metering – Overhead and underground lines - Optimum design considerations - Sizing of capacitors – Voltage design calculations

Distribution System Automation and communication

Distribution Automation System: Necessity, System Control Hierarchy - Basic Architecture and implementation Strategies for SCADA and DAC systems - Basic Distribution Management System Functions. Communication Systems for Control and Automation - Wireless and wired Communications - SCADA and DAC communication Protocols, Architectures and user interface

Distribution System Reliability and Power Quality

Electric power quality: Basic definitions – Power quality problems – Voltage variations and quality measures – Harmonics and mitigation

System reliability: Basic definitions and mathematics – Series systems, parallel systems and their combinations – Markov process – Development of state transition models – Interruption indices -

Distribution System Analysis

Load flow analysis of balanced and unbalanced radial distribution system – Load flow analysis of weakly meshed system - Short circuit analysis of balanced and unbalanced radial distribution system - Short circuit analysis of weakly meshed system – Types of faults

References

1. Turan Gonen, *Electric Power Distribution Engineering*, 3rd edition, CRC Press, 2015
2. Sallam A. A, & Malik O. P, *Electric Distribution Systems*, 2nd edition, Wiley-IEEE Press, 2018
3. B. Das, *Power Distribution Automation*, IET Power and Energy Series, 2016
4. J. J. Burke, *Power Distribution Engineering: Fundamentals and Applications*, CRC Press, 1994
5. J. A. Momoh, *Electric Power Distribution, Automation, Protection, and Control*, CRC Press, 2007
6. T. A Short, *Electric Power Distribution Handbook*, CRC Press, 2018

EE6726E Energy System Optimization

Pre-requisites: **NIL**

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Formulate optimization problems in renewable energy systems, energy storage, and grid operation

CO2: Solve linear and nonlinear programming problems with practical relevance to sustainable systems

CO3: Apply constrained optimization methods for storage dispatch, RE curtailment, and grid scheduling

CO4: Use metaheuristic and multi-objective techniques for energy system planning and control

CO5: Develop and validate optimization models using tools such as Pyomo, GAMS, or MATLAB for case studies

Linear Programming and Applications in Sustainable Energy

Linear Programming (LP): Formulation, Simplex method, Duality-Economic dispatch with renewables and constraints-Unit commitment incorporating solar and wind forecasts- Optimal power flow (OPF) with variable generation- Case study: Solar PV-wind farm integration into grid using LP

Constrained and Nonlinear Optimization in Energy Systems

Nonlinear Programming (NLP): Gradient-based methods, Lagrange multipliers-Karush-Kuhn-Tucker (KKT) conditions, Energy storage optimization: Battery and pumped hydro dispatch models-Demand response and load shifting optimization-Case study: Residential microgrid optimization with PV and battery storage

Metaheuristics and Multi-Objective Optimization

Genetic algorithms (GA), Particle Swarm Optimization (PSO), Differential Evolution (DE)-Multi-objective optimization: Pareto optimality and trade-off analysis-Grid-aware dispatch optimization considering emissions and cost- Scheduling of electric vehicles and demand-side management using metaheuristics-Tool introduction: Pyomo, MATLAB Optimization Toolbox, GAMS-Case study: Multi-objective planning for hybrid renewable energy systems

References:

1. S. S. Rao, *Engineering Optimization: Theory and Practice*, 4th ed., Wiley, 2009.
2. D. P. Kothari, I. J. Nagrath, *Modern Power System Analysis*, 4th ed., McGraw Hill, 2011.
3. J. Nocedal and S. J. Wright, *Numerical Optimization*, 2nd ed., Springer, 2006.
4. J. Wood, B. F. Wollenberg, and G. B. Sheblé, *Power Generation, Operation, and Control*, 3rd ed. Hoboken, NJ, USA: Wiley, 2013.
5. K. Deb, *Multi-Objective Optimization using Evolutionary Algorithms*, New York, NY, USA: Wiley, 2001.
6. M. Farivar and S. H. Low, "Branch flow model: Relaxations and convexification—Part I," *IEEE Trans. Power Syst.*, vol. 28, no. 3, pp. 2554–2564, Aug. 2013.
7. D. P. Kothari and J. S. Dhillon, *Power System Optimization*, 3rd ed., PHI Learning, 2011.

8. A. Bhattacharya and P. K. Chattopadhyay, "Application of PSO in multi-objective optimal power flow with FACTS devices," *IET Gener. Transm. Distrib.*, vol. 5, no. 7, pp. 705–714, Jul. 2011.
9. A. Mohapatra, B. Mohanty, and N. Kishor, "A review on optimization techniques for economic dispatch in renewable integrated power systems," *Renew. Sustain. Energy Rev.*, vol. 77, pp. 795–813, Sep. 2017.
10. W. Ongsakul and D. N. Vo, *Artificial Intelligence in Power System Optimization*, Boca Raton, FL, USA: CRC Press, 2013.
11. J. Zhu, *Optimization of Power System Operation*, 2nd ed., Hoboken, NJ, USA: Wiley-IEEE Press, 2015.

EE6727E Industrial Energy Audit

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Ability to perform energy audit of industrial systems

CO2: Analyse the energy conversion efficiencies and specific energy consumption of industrial systems

CO3: Analyse the performance of industrial energy systems based on energy

CO4: Perform techno-economic analysis of industrial energy systems

Preliminaries

Efficiency and sustainability in industrial energy systems, current scenario; energy auditing: methodology, instruments for energy audit, analysis of plant data and systematic reporting, application of mass and energy balance; supply and demand side management, DSM measures; steam systems: steam generator performance, excess air control, steam distribution and use of steam traps; thermal Insulation and refractories, energy conservation in furnaces; waste heat recovery options, case studies.

Energy conservation

Cogeneration: different schemes, performance assessment; energy conservation in the built environment and HVAC systems, thermal energy storage systems and applications in energy conservation, case studies; exergy analysis of thermal systems: reversible work and exergy destruction, exergy transfer and exergy balance; exergy efficiency of thermal systems; thermo-economics and pricing of utilities; heat exchanger networking: concept of pinch, energy targeting, composite curves, problem table algorithm

Electrical Energy Management

Electrical energy management: overall structure of electrical systems, economic operation; reactive power, power factor correction and capacitor sizing; transformer loading and efficiency analysis; feeder loss evaluation; energy efficient lighting schemes.

Electric motors

Electric motors: types and operating characteristics of electric motors, energy efficient control and starting, load matching, motor selection; industrial drives and control schemes, variable speed drives and energy conservation options; energy conservation in pumps and fans; case studies.

References:

1. Thumann, A., Niehus, T., and Younger, W. J., 2013, *Handbook of Energy Audits*, CRC Press.
2. Doty, S. and Turner, W. C., 2007, *Energy Management Handbook*, Fairmont Press.
3. Chiogioji, M. H., 1979, *Industrial Energy Conservation*, Marcel Dekker.

4. Kenney, W. F., 1984, *Energy Conservation in the Process Industries*, Academic Press.
5. Morvay, Z. K. and Gvozdenac, D. D., 2008, *Applied Industrial Energy and Environmental Management*, Wiley.
6. Kanoglu, M., Cengel, Y. A., and Dincer, I., 2012, *Efficiency Evaluation of Energy Systems*, Springer.
7. Kemp, I. C., 2007, *Pinch Analysis and Process Integration: A User Guide on Process Integration for the Efficient Use of Energy*, Elsevier.
8. IEEE, 1996, *IEEE Bronze Book: IEEE Standard 739-1984-Recommended Practice for Energy Conservation and Cost-Effective Planning in Industrial Facilities*, IEEE Publications

EE6728E Sustainable Energy Policy and Economics

Pre-requisites: **NIL**

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

- CO1: Explain the fundamentals of sustainable energy systems and policy frameworks
- CO2: Analyse economic principles related to energy markets and investments
- CO3: Evaluate the impact of government policies, subsidies, and market regulations
- CO4: Apply tools for economic assessment of energy technologies
- CO5: Critically assess policy instruments for renewable integration and energy transitions

Introduction to Sustainable Energy Systems

Definition and pillars of sustainability, Overview of global and Indian energy scenarios, Environmental impact of energy systems, Goals of sustainable energy transitions (SDGs, Net Zero targets), Metrics: energy intensity, carbon intensity, energy access

Energy Economics Fundamentals

Principles of energy demand and supply, Cost structures: capital, O&M, fuel costs, Economic indicators: Net Present Value (NPV), Internal Rate of Return (IRR), Levelized Cost of Energy (LCOE), Marginal cost pricing, peak-load pricing, Externalities and environmental economics

Energy Policy Instruments

Command-and-control vs market-based mechanisms, Subsidies, Feed-in Tariffs (FiTs), Renewable Purchase Obligations (RPOs), Renewable Energy Certificates (RECs), Net metering, Time-of-Use tariffs, Emission trading schemes, carbon taxes, Public-private partnerships and risk sharing

International and National Energy Policy Frameworks

UNFCCC, COP agreements, NDCs, EU energy directives, US energy policies, China's energy reforms, India's National Action Plan on Climate Change (NAPCC), National Electricity Policy, National Renewable Energy Act, Energy storage and electric vehicle policy linkages, Regulatory bodies: MNRE, CERC, SERCs

Economics of Renewable Energy and Storage

Cost-benefit analysis of solar, wind, biomass, hydro, and storage systems, Financial modeling: cash flows, payback periods, Cost trends in battery storage, green hydrogen, Energy-as-a-service and third-party financing models, Off-grid economics and decentralized systems

E-M.Tech SEE for working professionals

Market Structures and Energy Transitions

Energy market liberalization and competition, Role of power exchanges and spot markets, Flexibility markets and storage, Just transition and socio-economic challenges, Distributed generation and prosumer economics

Case Studies and Policy Evaluation Tools

Policy success and failure case studies: India, Germany, California, etc., Policy evaluation metrics and tools, Integrated Energy Planning, Multi-criteria decision analysis (MCDA) in policy design, Capstone discussion: designing a sustainable energy policy for a given region

Optional Project or Term Paper

- Analyze the economic viability of a grid-connected rooftop solar system
- Develop a policy brief on incentives for electric vehicle adoption in a city
- Model the LCOE of solar + storage systems under different tariff schemes
- Compare the policy outcomes of two countries with different renewable targets

References:

1. T. B. Johansson, H. Kelly, A. K. N. Reddy, and R. H. Williams, *Renewable Energy: Sources for Fuels and Electricity*, Washington, DC, USA: Island Press, 1993.
2. S. Tietenberg and L. Lewis, *Environmental and Natural Resource Economics*, 11th ed., New York, NY, USA: Routledge, 2018.
3. International Energy Agency (IEA), *World Energy Outlook 2023*, Paris, France: IEA, 2023. [Online]. Available: <https://www.iea.org>
4. MNRE, *National Solar Mission Documents*, Govt. of India, [Online]. Available: <https://mnre.gov.in>
5. Planning Commission, Govt. of India, *Integrated Energy Policy*, 2006. [Online]. Available: <https://planningcommission.nic.in>
6. S. Bhattacharyya, *Energy Economics: Concepts, Issues, Markets and Governance*, Springer, 2011.
7. IRENA, *Renewable Energy Policies in a Time of Transition*, Abu Dhabi, UAE, 2018.
8. Central Electricity Regulatory Commission (CERC), *Tariff Regulations and Policy Documents*. [Online]. Available: <https://cercind.gov.in>

EE6729E Python Programming

Pre-requisites: **NIL**

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

- CO1: Develop Python programs using control structures, functions, and data structures
- CO2: Utilize Python libraries for data analysis and visualization in energy systems
- CO3: Simulate energy system components (solar, wind, battery) using Python-based modeling tools
- CO4: Implement optimization models for sustainable grid operation using Python tools
- CO5: Design data-driven solutions for monitoring, forecasting, and control in smart and renewable grids

Python Programming Essentials

Python syntax and semantics: variables, operators, data types, Control structures, functions, file I/O, Data structures: lists, tuples, dictionaries, sets, Object-oriented programming. Introduction to Jupyter notebooks and virtual environments

Energy Context Examples: Basic power calculations, file-based reading of solar generation data, temperature and irradiance data parsing

Scientific Computing and Data Analysis

Numerical computation with NumPy and SciPy -Data handling and preprocessing using pandas- Plotting with matplotlib and seaborn- Time-series analysis and load/generation profiling- Integration with CSV, Excel, and JSON formats

Energy Context Examples: Load forecasting using historical data, Solar irradiance data cleaning and visualization, Wind turbine power curve analysis

Energy Systems Modeling and Optimization

Energy systems modeling using PyPSA/Pyomo- Linear and nonlinear optimization problems using SciPy and PuLP -Battery storage simulation, demand-side management algorithms-Case study: Optimal scheduling of microgrid with PV, battery, and load forecast-Machine learning basics using scikit-learn for energy prediction

Simulation Components: Real-time solar PV data visualization, EV charging schedule optimization using linear programming, Smart meter data anomaly detection using clustering

References:

1. M. Lutz, *Learning Python*, 5th ed., O'Reilly Media, 2013.
2. J. V. Guttag, *Introduction to Computation and Programming Using Python*, 2nd ed., MIT Press, 2016.

3. R. Johansson, *Numerical Python: A Practical Techniques Approach for Industry*, 2nd ed., Apress, 2019.
4. T. Brown, J. Hörsch, and D. Schlachtberger, "PyPSA: Python for Power System Analysis," *J. Open Res. Softw.*, vol. 6, no. 1, pp. 1–5, 2018.
5. A. Mohapatra, B. Mohanty, and N. Kishor, "A review on optimization techniques for economic dispatch in renewable integrated power systems," *Renew. Sustain. Energy Rev.*, vol. 77, pp. 795–813, Sep. 2017.
6. K. Deb, *Multi-Objective Optimization Using Evolutionary Algorithms*, New York, NY, USA: Wiley, 2001.
7. A. A. Thatte and L. Xie, "Towards a Unified Operational Value Index of Energy Storage in Smart Grid Environment," *IEEE Trans. Smart Grid*, vol. 3, no. 3, pp. 1418–1426, Sep. 2012.
8. S. J. Pan and Q. Yang, "A Survey on Transfer Learning," *IEEE Trans. Knowl. Data Eng.*, vol. 22, no. 10, pp. 1345–1359, Oct. 2010.

EE6730E Energy Storage Systems and Applications

Pre-requisites: **NIL**

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

- CO1: Explain the fundamental principles and classifications of energy storage technologies.
- CO2: Analyse the operational characteristics and design considerations of electrical, electrochemical, thermal, and mechanical storage systems.
- CO3: Evaluate the performance and efficiency of energy storage systems in various applications.
- CO4: Examine the integration of energy storage with renewable energy and power systems.
- CO5: Assess the techno-economic and environmental aspects of energy storage systems.

Introduction to Energy Storage

Need and importance of energy storage in modern power systems-Classification of storage technologies: electrical, electrochemical, thermal, mechanical-Key performance metrics: energy and power density, efficiency, self-discharge, life cycle, response time-Applications: renewable integration, grid support, EVs, backup power

Electrical and Mechanical Storage Systems

Supercapacitors: working principles, charge/discharge behavior, equivalent circuit models, applications, Flywheel Energy Storage: construction, operation, high-speed flywheels, losses, control mechanisms, Pumped Hydro Storage (PHS): operating principle, design considerations, location and environmental issues, Compressed Air Energy Storage (CAES): adiabatic and diabatic systems, thermodynamic cycles, integration with renewables

Electrochemical Storage Systems (Batteries)

Electrochemical principles, cell characteristics, performance parameters, Battery Types- Lead-acid: structure, efficiency, typical uses, Nickel-based: NiCd, NiMH characteristics, Lithium-ion: Li-ion, LiFePO₄ – chemistry, advantages, degradation mechanisms, Flow Batteries: redox flow batteries, vanadium redox, operation, control

Battery Management Systems (BMS): SoC/SoH estimation, charge balancing, safety protocols-Thermal management and battery safety-Battery modeling using equivalent circuits

Thermal Energy Storage

Need and classification: sensible, latent, and thermochemical storage, Sensible Heat Storage: water tanks, packed beds, molten salts, Latent Heat Storage: phase change materials (PCMs), melting/solidification behavior, Thermochemical Storage: absorption and chemical reaction-based systems, Design considerations, thermal losses, and applications in solar thermal plants and buildings

Applications and Grid Integration

Storage for: Renewable energy integration (PV, wind), Grid support: frequency regulation, spinning reserve, peak shaving, voltage control, Load shifting and energy arbitrage, Islanded and microgrid operation, Electric vehicles: onboard storage, charging infrastructure, Hybrid systems and storage sizing techniques, Grid codes and standards for storage interconnection

Techno-Economic, Safety, and Policy Aspects

Cost analysis: capital and operational costs, cost/kWh and cost/kW, Life Cycle Cost Analysis (LCCA), Levelized Cost of Storage (LCOS), Environmental impacts and recycling issues, Safety standards and certification: UL, IEC standards, Indian energy storage mission, global trends, government incentives, Energy storage in electricity markets: ancillary services, energy trading

Emerging Trends and Case Studies

Innovations in battery chemistries: solid-state batteries, sodium-ion, zinc-air, etc., Storage for green hydrogen systems, Case studies from India and international projects (e.g., Tesla Megapack, India's MNRE pilot projects, EV battery swap)

Optional Project Work

- Modeling and simulation using tools: MATLAB/Simulink, PSCAD, OpenDSS
- Battery testing and SoC estimation
- Simulating grid-connected storage integration
- Design of a hybrid PV + BESS microgrid system
- Case study analysis of storage economics and policies

References:

1. Dincer and M. A. Rosen, *Thermal Energy Storage: Systems and Applications*, 2nd ed. Hoboken, NJ, USA: Wiley, 2011.
2. G. Ter-Gazarian, *Energy Storage for Power Systems*, 2nd ed. London, U.K.: IET, 2011.
2. D. Linden and T. B. Reddy, *Handbook of Batteries*, 4th ed. New York, NY, USA: McGraw-Hill, 2011.
3. R. F. Nelson, "Power requirements for batteries in hybrid electric vehicles," *J. Power Sources*, vol. 91, no. 1, pp. 2–26, Nov. 2000.
4. International Renewable Energy Agency (IRENA), "Electricity Storage and Renewables: Costs and Markets to 2030," IRENA, Abu Dhabi, UAE, Oct. 2017. [Online]. Available: <https://www.irena.org>
5. Central Electricity Authority (CEA), "Report on Optimal Generation Capacity Mix for 2030," Ministry of Power, Government of India, Jan. 2020. [Online]. Available: <https://cea.nic.in>
6. Ministry of New and Renewable Energy (MNRE), "Energy Storage Mission: Roadmap for India," Government of India, 2019. [Online]. Available: <https://mnre.gov.in>
7. IEEE Standards Association, "IEEE 2030.2-2015 - IEEE Guide for the Interoperability of Energy Storage Systems Integrated with the Electric Power Infrastructure," IEEE, 2015.
8. IEC 62933-1-1:2017, *Electrical Energy Storage (EES) Systems - Part 1-1: Vocabulary*, International Electrotechnical Commission, 2017.

EE6731E Electrical Energy System Reliability

Pre-requisite: **NIL**

L	T	P	O	C
3	0	0	6	3

Total Lecture sessions: 39

Course Outcomes

- CO1: Model and assess the reliability of systems undergoing stochastic events
- CO2: Model variations in load demand and output of renewable energy sources
- CO3: Apply probabilistic models to evaluation of power system reliability
- CO4: Execute load flow algorithm with variable generation sources

Introduction to Probability and Statistics

Introduction to Probability and Statistics: Introduction to probability, probability density function, probability distribution function, Expectation, Variance, Covariance and Correlation and stochastic processes, Bernoulli Random Variable, Binomial Random Variable, Poisson Random Variable, Uniform Random Variable, Exponential Random Variable, Normal Random Variable, Weibull Random Variable

General reliability modeling and evaluation

General reliability modeling and evaluation: System modeling for reliability; methods of reliability assessment: state space, decomposition

Reliability modeling and analysis of electric power systems

Reliability modeling and analysis of electric power systems: Component modeling: generator modeling, transmission line modeling, load modeling; capacity outage table; probability and frequency distributions; unit addition algorithm; load modeling algorithm. Generation adequacy assessment using discrete convolution: discrete convolution of generation and load models; generation reserve model; determination of LOLP, LOLF, EUE; Distribution system reliability studies-A case study

Reliability of multi-node

Reliability of multi-node systems: methods for multi-area and composite system analysis; contingency enumeration/ranking; equivalent assistance; stochastic/ probabilistic load flow; state space decomposition; Monte Carlo simulation, Analysis of risk in power systems; understanding of causes and remedial measures; Modelling of variable energy resources-A case study

References:

1. Chanan Singh, Panida Jirutitijaroen, Joydeep Mitra, *Electric Power Grid Reliability Evaluation: Models and Method*, 1st edition, Wiley-IEEE Press, 2018.
2. Marko Čepin, *Assessment of Power System Reliability: methods and Applications*, 1st edition, Springer, 2011.
3. G.F. Kovalev, L.M. Lebedeva, *Reliability of Power Systems*, 1st edition, Springer, 2019.
4. Wenyuan Li, *Risk Assessment of Power Systems: Models, Methods, and Application*, 2nd edition, Wiley-IEEE Press, 2014.
5. Roy Billington, Ronald N Allan, *Reliability Evaluation of Power Systems*, 2nd edition, Springer, 1996.

