CURRICULUM

M.Tech. SMART ELECTRIC GRID

Effective from AY: 2024-25



NATIONAL INSTITUTE OF TECHNOLOGY WARANGAL

WARANGAL, TELANGANA

Table of Contents

VISION AND MISSION OF THE INSTITUTE 3
VISION AND MISSION OF THE DEPARTMENT 3
PROGRAM EDUCATIONAL OBJECTIVES 4
PROGRAM OUTCOMES 4
CURRICULUM 5
THE OVERALL CREDIT STRUCTURE 8
SYLLABI 9

Vision and Mission of the Institute
National Institute of Technology Warangal

VISION
Towards a Global Knowledge Hub, striving continuously in pursuit of excellence in Education, Research, Entrepreneurship and Technological services to the society

MISSION
- Imparting total quality education to develop innovative, entrepreneurial and ethical future professionals fit for globally competitive environment.
- Allowing stake holders to share our reservoir of experience in education and knowledge for mutual enrichment in the field of technical education.
- Fostering product-oriented research for establishing a self-sustaining and wealth creating centre to serve the societal needs.

Vision and Mission of the Department
ELECTRICAL Engineering

VISION
To excel in education, research and technological services in electrical engineering in tune with societal aspirations.

MISSION
- Impart quality education to produce globally competent electrical engineers capable of extending technological services
- Engage in research & development in cutting edge and sustainable technologies
- Nurture scientific temperament, professional ethics and industrial collaboration

Program: M.Tech. Smart Electric Grid

Program Educational Objectives

PEO-1	Design and develop independently innovative products and services in the field of Smart Grid Technologies.
PEO-2	Adopt and utilize latest technologies and tools in design of Smart Grid systems.
PEO-3	Communicate effectively to propagate ideas and promote teamwork
PEO-4	Attain intellectual leadership skills to cater to the changing needs of power industry, academia, society and environment

Program Articulation Matrix

PEO / Mission Statements	PEO-1	PEO-2	PEO-3	PEO-4
Impart quality education to produce globally competent electrical engineers capable of extending technological services	3	3	3	2
Engage in research & development in cutting edge and sustainable technologies.	3	3	2	3
Nurture scientific temperament, professional ethics and industrial collaboration	3	3	2	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Program Outcomes

PO-1	**Develop** scientific temperament and rational thinking abilities to pursue research and tackle complex problems related to smart electric grids.
PO-2	**Communicate** with technical communities on engineering issues while creating awareness for all sections of society.
PO-3	**Employ** the knowledge of smart electric grids to contribute towards the development of products / technologies which require a team with multidisciplinary expertise.
PO-4	**Develop** eco-friendly and sustainable technologies using the knowledge of smart electric grids.
PO-5	**Cultivate** an attitude of self-learning to cope with ever changing tools and technologies and be productive throughout his / her career.
PO-6	**Foster** a temperament to manage projects, organizations and entrepreneurial ventures maintaining financial integrity and professional ethics.

CURRICULUM
M.Tech. Smart Electric Grid

1st Semester

S.No.	Code	Course Title	L-T-P	Credits
1	EE 36001	Analysis of Smart Grid Systems	3-0-0	3
2	EE 36003	Microgrid Dynamics and Control	3-0-0	3
3	EE 36005	Challenges and Solutions in Renewable Energy Integration	3-0-0	3
4	EE XXXXX	Professional Elective - I	3-0-0	3
5	EE XXXXX	Professional Elective - II	3-0-0	3
6	EE 36007	Smart Grid Simulation Lab-I	0-1-2	2
7	EE 36009	Microgrid Dynamics and Control Lab	0-1-2	2
			Total Credits	**19**

2nd Semester

S.No.	Code	Course Title	L-T-P	Credits
1	EE 36002	Smart Grid Protection	3-0-0	3
2	EE 36004	Wide Area Monitoring and Control	3-0-0	3
3	EE XXXXX	Professional Elective - III	3-0-0	3
4	EE XXXXX	Professional Elective - IV	3-0-0	3
5	EE XXXXX	Professional Elective - V	3-0-0	3
6	EE 36006	Smart grid Protection Lab	0-1-2	2
7	EE 36008	Smart Grid Simulation Lab-II	0-1-2	2
8	EE 36096	Minor Project	0-0-0	2
			Total Credits	**21**

3rd Semester

S.No.	Code	Course Title	L-T-P	Credits
1	EE 36089	Seminar and Technical Writing	0-0-0	2
2	EE 36091	Summer Internship/ Research Experience	0-0-0	2
3	EE 36093	Comprehensive Viva-Voce	0-0-0	2
4	EE 36097	Dissertation: Part-A	0-0-0	8
			Total Credits	**14**

4th Semester

S.No.	Code	Course Title	L-T-P	Credits
1	EE 36098	Dissertation: Part-B	0-0-0	12
			Total Credits	**12**

Professional Elective Courses

Professional Elective-I		
S.No.	**Code**	**Course Title**
1	EE36021	Restructured Power Systems
2	EE36023	Energy Storage Systems
3	EE36025	Electric Utility Systems Management
4	EE46001	Linear Control System

Professional Elective-II		
S.No.	**Code**	**Course Title**
1	EE16025	Electric Vehicles
2	EE16027	Power Quality Improvement Techniques
3	EE36027	Signal Processing Techniques in Power Engineering
4	MA16063	Numerical Optimization Techniques

Professional Elective-III		
S.No.	**Code**	**Course Title**
1	EE16026	Control and Integration of Renewable Energy Sources
2	EE26024	Distribution System Planning and Automation
3	EE26026	High Voltage Power Transmission
4	EE46024	Digital Control Systems

Professional Elective-IV		
S.No.	**Code**	**Course Title**
1	EE26030	Evolutionary Algorithms Application in Power Engineering
2	EE36022	Smart Grid Communications and Protocols
3	EE36024	Transactive Energy Markets
4	EE36026	Cloud Computing and Big Data Analytics in Smart Grids

5	EE36028	Industrial Internet of Things

Professional Elective-V		
S.No.	**Code**	**Course Title**
1	EE26032	Machine Learning Applications in Power Engineering
2	EE26034	Energy Auditing and Management
3	EE26036	Flexible AC Transmission Systems
4	EE36030	Smart Grid Resiliency and Cyber Security

The Overall Credit Structure

Credits in Each Semester					
	I Sem	**II Sem**	**III Sem**	**IV Sem**	**Total**
Program Core	13	10	0	0	23
Professional Elective	6	9	0	0	15
Seminar and Technical Writing	0	0	2	0	2
Minor Project	0	2	0	0	2
Summer Internship/Research Experience	0	0	2	0	2
Comprehensive Viva-Voce	0	0	2	0	2
Dissertation Project: Part-A	0	0	8	0	8
Dissertation Project: Part-B	0	0	0	12	12
Total credits (Sem. wise)	**19**	**21**	**14**	**12**	**66**

SYLLABI

M.Tech: Smart Electric Grid

1st Semester

EE36001 **3-0-0 (3)**

Analysis of Smart Grid Systems

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand the analysis and planning of smart grids
CO-2	Evaluate the tools for modeling and analysis of smart grid
CO-3	Analyze and synthesize the smart grid operation
CO-4	Assess the influence of distributed generation in smart grid on power systems

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	1	2	2	2	1
CO-2	3	2	3	2	3	3
CO-3	3	3	3	3	3	3
CO-4	2	2	3	3	2	3

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: Conventional power systems and Smart grid, definition of smart grid, need for smart grid, Smart grid architecture, smart grid domains, enablers of smart grid, Communication architecture and protocols for smart grid, smart grid priority standards and regulation, smart-grid activities in India.

Systems of non linear equations: Fixed point iteration, Newton Raphson Iteration, Continuation methods, Power system application: power flow, regulating transformer, Fast decoupled load flow, PV curves and continuation power flow, three phase power flow

Smart Grid Security analysis: Concept of security, Security analysis and monitoring, factors affecting power system security, detection of network problems, an overview of security analysis. Contingency analysis for generator and line outages by Interactive Linear Power Flow (ILPF) method, Fast decoupled inverse Lemma based approach, network sensitivity factors, Contingency selection, concentric relaxation and bounding.

Smart Grid Operation and Planning: Economic Dispatch, Optimal Power Flow, Load forecasting, Operation of smart grid system, Load Dispatch Centre functions, preventive, Emergency and Restorative, control objectives of a smart distribution system, Operational bottlenecks in smart grid. Planning Aspects of smart grid, Planning and operation Standards.

Distributed Generation in Smart Grid: Renewable-based Distributed generations, Energy Storage Technologies, Modeling, Control of energy storage system, Short- mid -long term application of energy storage system in smart grids.

Learning Resources:

Text Books:

1. Muhammad Kamran, Fundamentals of Smart Grid Systems, Academic Press, 2022
2. Mariesa L Crow, Computetional methods for Electric Power Systems, CRC Press, NW, 2016, 3rd Edition.
3. Francisco D´ıaz-Gonz´alez, Andreas Sumper and Oriol Gomis-Bellmunt, Energy Storage in Power Systems, John Wiley & Sons Ltd, 2016

Reference Books:

1. Prabha Kundur, Power System Stability and Control, McGraw Hill Education, 2006, 1st Edition.
2. Math H. J. Bollen, Fainan Hassan, Integration of Distributed Generation in the Power System, Wiley, 2011
3. A. Mahaboob Subahani, G. R. Kanagachidambaresan, M. Kathiresh, Integration of Renewable Energy Sources with Smart Grid, Willey, 2021
4. J. Ekanayake, N. Jenkins, K. Liyanage, J. Wu, A. Yokoyama, Smart Grid: Technology and Applications, John Wiley & Sons, 2015, 1st Edition.
5. Ali Keyhani, Design of smart power grid renewable energy systems, Wiley, 2019, 3rd Edition.

Other Suggested Readings:

1. https://nptel.ac.in/courses/108/104/108104052/

EE36003 **3-0-0 (3)**

Microgrid Dynamics and Control

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understanding of AC and DC microgrids
CO-2	Dynamic modelling and analysis of microgrids
CO-3	Analysis of different hierarchical control schemes for microgrid system and communication implementation of hierarchical control
CO-4	Investigate the stability in microgrids and alternate options for stability improvement in microgrids

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	1	2	2	2	1
CO-2	3	1	3	1	1	1
CO-3	3	–	3	3	2	3
CO-4	3	2	3	3	2	3

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Concept of Microgrids: Introduction to the concept of microgrid, the overview of the structure and architecture of microgrid with brief control, operational aspects. Till date pilot microgrid projects and their outcomes.

Decentralized local controllers: AC-microgrids: Control Mechanism of the DGs connected in microgrid. Virtual synchronous generator (VSG) and Droop control. Transient frequency response, active power Response, reactive power sharing and voltage regulation.

DC-microgrids: DC microgrid control mechanism, droop control, issues in achieving active power sharing with impedance droop, remedies to achieve active power sharing.

Stability Assessment: Classification of Power system stability, definitions of transient, dynamic, and small signal stability, basic synchronous machine dynamic modelling, k1-k6 model and analysis of single machine infinite bus (SMIB) system.

Modelling and stability analysis of microgrid: Dynamic modelling of individual components in AC and DC microgrids, state space modal analysis and influence of system parameters on the microgrid dynamics, brief concept on the design of microgrid stabilizers to improve stability.

Control of Micro Grid System: Load Frequency Control (LFC) in Micro Grid System – Voltage Control in Micro Grid System – Reactive Power Control in micro Grid. Case Studies and Test beds for the Micro Grids.

Multi-microgrid coordination and control: AC-AC, AC-DC and DC-DC microgrid clustering, coordinated control schemes in multi-microgrids, frequency, voltage regulations and volt-VAR support.

Learning Resources:

Text Books:

1. Amirnaser Yazdani, Reza Iravani, Voltage-Sourced Converters in Power Systems: Modeling, Control, and Applications, John Wiley & Sons Inc, 2010.
2. N. D. Hatziargyriou, Microgrids Architecture and control, IEEE Press Series, John Wiley & Sons Inc, 2013, 1st Edition.
3. H. Bevrani, B. François, and T. Ise, Microgrid Dynamics and Control, John Wiley & Sons, 2017, 1st Edition.

Reference Books:

1. Bidram, V. Nasirian, A. Davoudi, F. L. Lewis, Cooperative Synchronization in Distributed Microgrid Control, Springer, 2017, 1st Edition.
2. P. Kundur, Power System Stability and Control, McGraw-Hill Inc, 2006, 2nd Edition.

Other Suggested Readings:

1. https://archive.nptel.ac.in/courses/108/107/108107143/

EE36005 **3-0-0 (3)**

Challenges and Solutions in Renewable Energy Integration

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand the importance of grid codes for renewable integration
CO-2	Understand challenges due to uncertainties in renewable energies
CO-3	Assess power quality and inertia issues with increased penetration of RES in electric grids
CO-4	Evaluate solutions and apply for renewable energy issues

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	–	1	–	2	1
CO-2	3	1	2	1	1	–
CO-3	3	–	3	3	2	2
CO-4	3	2	3	–	3	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Energy System Challenges: Handling Renewable Energy Variability and Uncertainty in Power System Operation, short-term frequency response challenges in power systems with high nonsynchronous penetration levels, technical impacts of high penetration levels of wind power on power system stability, constraints to the transformation rate of global energy infrastructure, demand supply flexibility, Voltage control, inertia response

Overview of the grid codes: Components of the grid codes, development of the grid codes, classification and specifications of the grid codes, anomalies in grid codes, Fault-Ride Through criterion.

Photovoltaic Penetration in Distribution Network: Mathematical model of grid connected PV system, performance evaluation with conventional MPPT, application of adaptive neuro fuzzy inference system (ANFIS) for DC-DC convertor for PV system. Voltage imbalance sensitivity analysis, stochastic evaluation, Monte Carlo Evaluation, series and parallel custom power devices, dynamic and feasibility issues related to custom power, performance of grid connected solar photovoltaic.

Solution for RES Uncertainties: Storage Technologies for overcoming uncertainty and variability with renewable resources, managing operational uncertainty through improved visualization tools in control centers with reference to renewable energy providers, Synchro phasors for distribution networks with variable resources, Monitoring and control of RES using synchronized phasor measurements.

Solution for Operational Issues: Virtual inertial, reactive power control in response to voltage deviations, use of energy storage systems, advanced control strategies to improve dynamic and transient response

time, De-rated operation of the renewable resources. Dynamic response with Fuel cell and Microturbine combination, virtual inertia concept with PV and Diesel generator combination.

Market Operations and Forecasting Renewables: Analyzing the impact of variable energy resources on power system reserves, Advances in Market Management Solutions for Variable Energy Resources Integration, forecasting Renewable Energy for Grid Operations, Incorporating Forecast Uncertainty in Utility Control Center, Reserve Management for Integrating Renewable Generation in Electricity Markets, renewable generation integration and long-term power purchase agreements (PPA).

Integration of Renewable Energy: The Indian Experience Policy initiatives, Regulatory initiatives, Transmission planning initiatives, Experience with RECs in India, Challenges. German Renewable Energy Sources Pathway: Increasing challenges of RES integration into the German electricity system. Danish Case Study: The Danish markets for balancing the electricity system, making wind as a part of the balancing solution, Decentralized combined heat and power plants of the balancing solution. Texas Case Study: Study of the impacts of wind generation on ancillary service, Ancillary service requirement methodology improvements to integrate wind generation resources. Concept of grid forming and grid following.

Learning Resources:

Text Books:

1. J. Hossain and A. Mahmood, Renewable energy integration: Challenges and Solutions, Springer-Verlag, 2014, 1st Edition.
2. Lawrence E. Jones, Renewable Energy Integration Practical Management of Variability, Uncertainty, and Flexibility in Power Grids, Elsevier, 2017, 2nd Edition.

Reference Books:

1. Ali Keyhani, Mohammad N. Marwali, Min Dai, Integration of Green and Renewable Energy in Electric Power Systems, Wiley publisher, 2009.
2. John Twidell, Renewable Energy Resources, Routledge Taylor and Francis Group publishers, 4th Edition, 2021.

Other Suggested Readings:

1. https://onlinecourses.nptel.ac.in/noc23_ge47/preview
2. https://iitk.ac.in/smartcity/qip/download/ppt/Day-2/Sandeep_Anand_Renewable%20Integration%20and%20Microgrid_shared.pdf
3. Integrating Variable Renewable Energy: Challenges and Solutions, L. Bird, M. Milligan, and D. Lew, Technical Report NREL/TP-6A20-60451 September 2013.
4. Challenges to Grid Integration of Renewable Energy in India, Akshay Urja, MNRE technical report, 2019.

EE36007 **0-1-2 (2)**

Smart Grid Simulation Lab-I

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand the modelling of renewable resources such as PV, Wind, and fuel cell
CO-2	Understand the impacts of virtual inertia in autonomous mode with diesel generators
CO-3	Analyse the dynamics performance of power system with additional sources such as micro turbine, ultra-capacitor
CO-4	Design and development of electrical vehicle and energy storage systems

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	–	1	1	1	–
CO-2	2	1	3	–	1	–
CO-3	3	–	2	2	1	3
CO-4	3	2	2	3	2	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

List of Experiments

1. Modelling of PV system
2. Modelling of DFIG based wind power system
3. Simulation of Grid connected PV MPPT (P&O) single stage
4. Simulation of Grid connected PV MPPT (P&O) double stage.
5. Virtual inertia emulation using PV Battery systems and its studies under varying loads
6. Grid connected DFIG wind generation analysis under varying wind, and grid conditions.
7. PV+BESS+Diesel generator simulation with virtual inertia in autonomous mode.
8. Use of ultra-capacitors to improve dynamic performance of PV+BESS+Diesel generator autonomous system.
9. Fuel Cell grid integration studies and analysis.
10. Improving dynamic response with Fuel cell and Microturbine combination.

11. Forecasting of wind and solar energy for techno-economic analysis.
12. Modelling and simulation of electric vehicle charging system.

Learning Resources:

Text Books:

1. Chetan Singh Solanki, Fundamentals, Technologies & Applications, Solar Photovoltaic, PHI Publishers, 2019, 3rd Edition.
2. Bin Wu, Yongqiang Lang, Navid Zargari, Power Conversion and Control of Wind Energy Systems, IEEE- John Wiley and Sons Ltd. Publishers, 2011, 1st Edition.

EE36009 **0-1-2 (2)**

Microgrid Dynamics and Control Lab

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand the operation of AC microgrid system power sharing and control
CO-2	Understand the concept of DC microgrids and impacts of constant power loads on system
CO-3	Analyse the hierarchical control for AC and DC microgrids
CO-4	Analyse the dynamic behaviour of Micro grid system & its grid integrations issues

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	–	1	–	2	–
CO-2	3	1	2	–	1	–
CO-3	3	–	3	3	2	2
CO-4	3	2	3	–	2	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

List of Experiments

1. Voltage and frequency control of a load connected inverter.
2. Decentralized inverter-based AC microgrid with P-f and Q-V droop control.
3. Impact of droop gains on stability of the inverter-based AC microgrids.
4. Centralized Secondary control design for inverter-based AC microgrids.
5. Distributed secondary control for the inverter-based AC microgrids.
6. Decentralized DC microgrid systems.
7. Dynamic assessment of DC microgrids with constant power loads.
8. Distributed control for converter-based DC microgrid system.
9. Interconnection of AC and DC microgrid system.
10. Design of stabilizer for inverter-based AC microgrid.

Learning Resources:

Text Books:

1. H. Bevrani, B. François, and T. Ise, Microgrid Dynamics and Control, John Wiley & Sons, 2017, 1st Edition.

2nd Semester

EE36002 **3-0-0 (3)**

Smart Grid Protection

Pre-Requisites: **Power System Protection**

Course Outcomes:

CO-1	Understand basic concepts of protection systems and smart grid protection challenges
CO-2	Design relay algorithms and phasor estimation techniques
CO-3	Understanding relay setting computation and adaptive relaying
CO-4	Development of protection schemes for active distribution network and microgrids

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	2	3	1	2	1
CO-2	3	2	3	2	2	1
CO-3	3	2	2	2	3	2
CO-4	3	2	3	3	2	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Protection Challenges in Smart Grid: Electrical protection systems, protection philosophies and protective relays, impact of renewables integration on protection systems, protection system in smart grid, protection challenges in smart grid system.

Numerical Relaying Algorithms: Numerical relays, design aspects of numerical relays, classification of relaying algorithms, algorithms for digital relaying, phasor estimation using discrete Fourier transform algorithms, least square phasor estimation algorithm, Kalman filtering based phasor estimation algorithm, decaying DC current estimation.

Protection Coordination in Transmission and Distribution Systems: High voltage/power protection and low voltage/power protection, Distance protection of transmission lines, protection of multi-terminal lines, carrier-assisted distance protection, Directional overcurrent protection of distribution systems, protection coordination, optimal protection coordination of directional overcurrent relays, linear and nonlinear programming based relay setting calculation.

Wide Area Measurement Based Protection Systems: Adaptive protection, adaptive out-of-step protection, security versus dependability, adaptive system restoration, control of backup relay performance, hidden failures, intelligent islanding, supervisory load shedding, concept of integrated wide area monitoring and wide area protection, system integrity protection scheme using PMU technology.

Protection of Active Distribution Networks and Microgrids: Protection needs for modern distribution systems, islanding detection of active distribution networks and microgrids, active distribution network protection, microgrid protection, protection of islanded and grid connected microgrids, adaptive relay protection of microgrids.

Learning Resources:

Text Books:

1. Computer Relaying for Power systems, A. G. Phadke and James S. Thorp, Wiley India Pvt Ltd, 2012, 2nd Edition.
2. Wide Area Monitoring, protection and control systems the enabler for smarter grids, Vaccaro, Alfredo Zobaa, Ahmed. F, IET publisher, 2016, 1st Edition.
3. Fundamentals of Power System Protection, Y. G. Paithankar and S. R. Bhide, Prentice Hall of India, 2010, 2nd Edition.

Reference Books:

1. Power System Protection and Switchgear, Badriram and D. Vishwakarma, McGraw Hill Education, 2017, 2nd Edition.
2. Protection and Switchgear, B. Bhalja, R. P. Maheshwari and N. G. Chothani, Oxford University Press, 2018, 2nd Edition.
3. Protection of Electricity Distribution Networks, Juan M. Gers and Edward J. Holmes, IET Publication, 2011, 3rd Edition.

Other Suggested Readings:

1. https://archive.nptel.ac.in/courses/108/101/108101039/
2. https://archive.nptel.ac.in/courses/108/107/108107167/
3. https://archive.nptel.ac.in/courses/108/107/108107113/

EE36004 **3-0-0 (3)**

Wide Area Monitoring and Control

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand the concepts of real-time monitoring and control in power systems.
CO-2	Understand monitoring the power system over a wide area using synchronized measurements and visualizing the data obtained from PMUs
CO-3	Implement the state estimation for real-time operation of smart grids
CO-4	Analyzing the Smart Grid dynamics and providing global control.

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	2	3	3	2	2
CO-2	3	2	3	2	3	3
CO-3	3	3	3	3	2	3
CO-4	3	2	2	3	3	3

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Wide area monitoring infrastructure: Need for real - time and computer control of power systems, operating states of a power system, Supervisory Control and Data Acquisition System (SCADA), implementation considerations, control centers. WAMS (Wide Area measurement system): Architecture, Components of WAMS, Applications: Voltage Stability Assessment, Frequency stability Assessment, Power Oscillation Assessment, Needs of communication in WAMS, WAMPAC (Wide Area Monitoring Protection & Control), WAMS Standards.

Wide area monitoring: Synchronized Phasor Measurement (PMU) architecture and Modeling, Phasor data concentrator (PDC), PMU/PDC data transfer files, Synchrophasor applications in power system protection and emergency control; optimal placement of PMUs, PMU and PDC in Indian power system.

State Estimation: Introduction, Power system state estimation, Weighted least Square estimation (WLS). State Estimation of DC and AC Networks, Typical results of state estimation on an AC network. Bad data detection, Dynamic Estimation, Hybrid state estimation in Smart Grid.

Dynamics of wide area oscillation: Framework and Operating Principle of Wide-Area Damping Control, Oscillation dynamics analysis based on phasor measurements, Oscillation characteristics, oscillation dynamics analysis based on phasor measurements, Small Signal Stability assessment of smart Grid, Coordinated Design of Local power system stabilizers and Wide-Area Damping Controller.

Dynamic Estimation and Control: Centralized Dynamic estimation and control, Decentralized Dynamic estimation and Control, Closed loop stability and damping response, Centralized/decentralized linear and

Non Linear control of smart grid using decentralized dynamic state estimation (DSE) and the extended linear quadratic regulator (ELQR) control scheme.

Learning Resources:

Text Books:

1. R. Messina, Wide Area Monitoring of Interconnected Power Systems, IET publisher, 2015, 1st Edition.
2. Yong Li, D. Yang, Fang Liu, Y. Cao, Interconnected Power Systems Wide-Area Dynamic Monitoring and Control Applications, Springer-Verlag Berlin Heidelberg, 2016, 1st Edition
3. Abhinav Kumar Singh, Bikash C Pal, Jonathan Simpson, Dynamic Estimation and control of Power Systems, Academic Press Inc, 2018.

Reference Books:

1. Jing Ma, Power system wide-area stability analysis and control, Wiley, Science Press, 2018, 1st Edition.
2. Alfredo Vaccaro, and Ahmed F Zobaa, Wide area monitoring, protection and control systems the enabler for smarter grids, IET publisher, 2016, 1st Edition.
3. Arun G. Phadke, James S. Thorp, Synchronized Phasor Measurements and Their Applications, Springer International Publishing AG, 2017, 2nd Edition.
4. Sarma (NDR) Nuthalapati, “Use of Voltage stability Assessment and Transient Stability Assessment Tools in Gris Operation, Springer, Power Electronics and Power system series, 2021

Other Suggested Readings:

1. https://nptel.ac.in/courses/108107113
2. https://iitk.ac.in/smartcity/qip/download/ppt/Day-3/01_Wide%20Area%20Monitoring%20and%20Control.pdf

EE36006 **0-1-2 (2)**

Smart Grid Protection Lab

Pre-Requisites: **None**

Course Outcomes:

CO-1	Determine the characteristics of power system protection devices and Relays
CO-2	Determine the performance of different protection relays
CO-3	Understand the importance of wide area protection
CO-4	Realize the fault ride through capabilities of renewable energy systems

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	1	1	1	2	1
CO-2	3	1	2	1	1	1
CO-3	3	2	3	3	2	2
CO-4	3	2	3	3	2	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

List of Experiments

1. Study and testing of Overcurrent relay, Over voltage relay and Under Voltage relay
2. Relay coordination in smart grid protection scheme for Radial Circuit Topology
3. Relay coordination in smart grid protection scheme for Bidirectional Circuit Topology
4. Study and testing of islanding protection in microgrids
5. Protection of active distribution network
6. Design of protection scheme for active distribution network using ETAP software
7. Protection of distributed generation sources (wind and solar power generators)
8. Testing of Fault Ride Through (FRT) capability of wind energy source
9. Testing of Fault Ride Through (FRT) capability of solar energy source
10. Islanding detection in an active distribution system.

Learning Resources:

Text Books:

1. Computer Relaying for Power systems, A. G. Phadke and James S. Thorp, Wiley India Pvt Ltd, 2012, 2nd Edition.

EE36008 **0-1-2 (2)**

Smart Grid Simulation Lab-II

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand the PMU monitoring and data visualization
CO-2	Understand the role of PMUs and PDCs in wide area monitoring, protection and control
CO-3	Demonstrate state estimation and suggest an optimal PMU positioning for the system observability
CO-4	Understand the possibility of cyber-threats in smart grids

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	–	1	–	2	–
CO-2	3	1	2	3	1	–
CO-3	3	2	3	3	2	2
CO-4	3	2	3	–	2	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

List of Experiments

1. Optimal PMU placements for monitoring of power system
2. DC state estimation
3. Hybrid state estimation
4. Design of virtual PMU in MATLAB
5. Data capturing from HIL- PMU setup using C-37 protocol
6. PMU data-based power system health monitoring
7. Programmable Relay design and operation of relay with PMU data extracted from PDC in HIL-PMU environment
8. Wide area control of Two area system
9. Real time wide area control of two area system

10. Attack Detection using DC state estimation
11. Pool Based Electricity Market Simulation

Learning Resources:

Text Books:

1. Alfredo Vaccaro, and Ahmed F Zobaa, Wide area monitoring, protection and control systems the enabler for smarter grids, IET publisher, 2016, 1st Edition.
2. Arun G. Phadke, James S. Thorp, Synchronized Phasor Measurements and Their Applications, Springer International Publishing AG, 2017, 2nd Edition.
3. Prabha Kundur, Power System Stability and Control, McGraw Hill Education, 2006, 1st Edition.

EE36096 **0-0-0 (2)**

Minor Project

Pre-Requisites: **None**

Course Outcomes:

CO-1	Apply engineering principles to real-world projects
CO-2	Plan and monitor project tasks individually or as a team
CO-3	Demonstrate practical experience in project execution
CO-4	Communicate project findings clearly through reports and presentations

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	1	2	1	3	1
CO-2	2	1	2	1	3	1
CO-3	2	3	2	1	3	1
CO-4	2	3	2	1	3	1

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Students are expected to choose real world or relevant problems and apply the engineering principles learned, to solve the problem through building prototypes or simulations or writing codes or establishing processes/synthesis/correlations etc. The department constituted panel can decide the suitability and worthiness of the project.

Learning Resources:

1. Journal and conference papers from reputed publishers such as IEEE, Elsevier, and Wiley.
2. Research Articles / Reports available on Internet.

3rd Semester

EE36089 **0-0-0 (2)**

Seminar and Technical Writing

Pre-Requisites: **None**

Course Outcomes:

CO-1	Consolidate ideas based on expert talks attended
CO-2	Prepare a well-organized report employing elements of critical thinking and technical writing
CO-3	Demonstrate the ability to describe, interpret and analyze the subject matter and develop competence in presenting

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	1	1	1	2	2
CO-2	2	1	1	1	2	2
CO-3	2	1	3	1	2	3

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

In Seminar and Technical Writing, every student is expected to prepare a well-organized report based on one / all of the following:

- by attending at least 5 expert lectures/ invited talks/ Seminar/ Popular lectures etc. organized by the institute/any of the departments, ideally in a specific domain or with the same theme.
- prepare a business or marketing plan based on patent search

The student is expected to consolidate the ideas from these lectures/patent searches and may even include material from other sources to strengthen the content of the report. The student should prepare a well-organized report based on the above and present it to the panel constituted by the department, for evaluation.

Learning Resources:

1. Journal and conference papers from reputed publishers such as IEEE, Elsevier, and Wiley.
2. Research Articles / Reports available on Internet.

EE36091 **0-0-0 (2)**

Summer Internship/Research Experience

Pre-Requisites: **None**

Course Outcomes:

CO-1	Apply engineering principles to real-world problems, gaining practical experience
CO-2	Plan, manage and execute the work with ethical consideration
CO-3	Review the social and environmental impact of the work
CO-4	Communicate the learnings through report and presentation

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	1	2	2	3	2
CO-2	1	1	2	2	3	3
CO-3	1	2	2	2	3	2
CO-4	1	3	2	2	3	3

1 - Slightly; 2 - Moderately; 3 - Substantially

Description:

Every student has to undergo either a Summer Internship / Research project. The summer internship may be undergone in an Industry/Research organization or any premier academic Institution, including NIT Warangal for 6-8 weeks. The research project shall be registered under the guidance of any faculty member in the institute. The student is required to submit a report and present the work before an evaluation committee, nominated by the Head of the Department.

Learning Resources:

1.Journal and conference papers from reputed publishers such as IEEE, Elsevier, and Wiley.
2.Research Articles / Reports available on Internet.

EE36093 **0-0-0 (2)**

Comprehensive Viva-Voce

Pre-Requisites: **None**

Course Outcomes:

CO-1	Comprehend the knowledge gained in the course work
CO-2	Demonstrate the ability in problem solving
CO-3	Communicate effectively using engineering terminology

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	2	1	1	2	-
CO-2	1	2	1	1	2	-
CO-3	1	3	1	1	2	-

1 - Slightly; 2 - Moderately; 3 - Substantially

Description:

In Comprehensive viva-voce each student will be evaluated for their overall comprehension of the course work and laboratory training that they have undergone. The students will be expected to answer questions orally, write down simple equations, draw plots, schematics, write simple code etc. as questioned by the panel. Assessment will be done by the panel based on the student response.

Learning Resources:

1. Reading Material of all the courses.
2. Case Studies/Industrial training reports
3. Minor projects taken up.

EE36097 **0-0-0 (8)**

Dissertation: Part-A

Pre-Requisites: None

Course Outcomes:

CO-1	Identify a topic in advanced areas of Electrical Engineering.
CO-2	Review literature to identify gaps and define objectives and scope of the work.
CO-3	Employ the ideas from literature and develop research methodology.
CO-4	Develop a model, experimental set-up and / or computational techniques necessary to meet the objectives.

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	2	3	1	-	3
CO-2	3	2	3	1	-	3
CO-3	3	3	3	3	3	3
CO-4	3	3	3	3	3	3

1 - Slightly; 2 - Moderately; 3 - Substantially

Description:

Students are expected to choose real-world contemporary problem and apply the engineering principles learned, to solve the problem through building prototypes or simulations or writing codes or establishing processes/synthesis/correlations etc. The department constituted panel will decide the suitability and worthiness of the project.

Dissertation Evaluation:

I. The dissertation shall be submitted as per the schedule given in the academic calendar.
II. The dissertation supervisor will periodically review the progress of the student and finally give his/her assessment of the work done by the student.
III. The Dissertation Part – A will be evaluated for 100 marks, with the following weightages:

Sub-component	Weightage
a) Periodic evaluation by Guide	40 marks
b) Mid-term review	20 marks
c) End Semester viva-voce examination	40 marks

Evaluation Criteria

The student will be evaluated by the panel based on the below criteria. Weightage for each criterion will be determined by the panel and will be informed to the students.

Criteria	Description	Weightages
I	Selection of Topic	10
II	Literature Survey	25
III	Defining the Objectives and Solution Methodology	35
IV	Performance of the Task	30

Evaluation Criteria - CO Mapping:

CO / Criteria	CO1	CO2	CO3	CO4
I	**X**			
II		**X**		
III			**X**	
IV				**X**

Refer to the M.Tech. – Regulations for any further information regarding mid-term review and end semester evaluation, etc.

4th Semester

EE36098 **0-0-0 (12)**

Dissertation: Part – B

Pre-Requisites: **None**

Course Outcomes:

CO-1	Identify the materials and methods for carrying out experiments/develop a code.
CO-2	Execute the research methodology with a concern for society, environment and ethics
CO-3	Analyse, discuss and justify the results/trends and draw valid conclusions.
CO-4	Prepare the report as per recommended format and present the work orally adhering to stipulated time.
CO-5	Explore the possibility to publish/present a paper in peer reviewed journals/conference proceedings without plagiarism.

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	-	3	3	2	3
CO-2	2	-	3	3	2	3
CO-3	3	-	3	3	2	3
CO-4	3	3	3	3	3	3
CO-5	3	3	3	-	-	3

1 - Slightly; 2 - Moderately; 3 - Substantially

Description:

Students are expected to choose real-world contemporary problem and apply the engineering principles learned, to solve the problem through building prototypes or simulations or writing codes or establishing processes/synthesis/correlations etc. The department constituted panel will decide the suitability and worthiness of the project.

Dissertation Evaluation:

i. The dissertation shall be submitted as per the schedule given in the academic calendar.
ii. The dissertation supervisor will periodically review the progress of the student and finally give his/her assessment of the work done by the student.
iii. The Dissertation Part – B will be evaluated for 100 marks, with the following weightages:

Sub-component	**Weightage**
a) Periodic evaluation by Guide	40 marks
b) Mid-term review	20 marks
c) End Semester viva-voce examination	40 marks

Evaluation Criteria:

The student will be evaluated by the panel based on the below criteria as a continuation of Dissertation Part A. Weightage for each criterion will be determined by the panel and will be informed to the students.

Task	Description	Weightages
I	Performance of the Task	30
II	Dissertation Preparation	20
III	Review (Presentation & Understanding)	30
IV	Viva-Voce	10
V	Publications /Possibility of publication	10

Evaluation Criteria-CO Mapping:

CO / Criteria	CO1	CO2	CO3	CO4	CO5
I	**X**	**X**			
II				**X**	
III			**X**		
IV				**X**	
V					**X**

Refer to the M.Tech. – Regulations for any further information regarding mid-term review, end semester evaluation, template for report preparation and plagiarism guidelines etc.

Professional Electives

EE36021 **3-0-0 (3)**

Restructured Power Systems

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand the need for restructured power system and economics.
CO-2	Analyze transmission congestion and Estimate loss allocation in Power System
CO-3	Analyze Economic operation of power system in restructured environment
CO-4	Understand the need of ancillary services and Demand response in a restructured power system

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	1	1	–	3	–
CO-2	3	1	2	1	1	2
CO-3	3	1	3	3	2	3
CO-4	3	2	3	1	2	3

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Restructuring of power industry and Fundamentals of Economics- Introduction, Reasons for restructuring / deregulation of power industry, Fundamentals of Deregulation, Motivation of restructuring the power industries, restructuring process – unbundling & privatization, restructuring models, Components of restructured systems, fundamentals of Economics.

Power Market Reforms- Reforms in Indian power sector, Independent System Operator (ISO): Functions and responsibilities, Smart Grid trading arrangements (Pool, bilateral & multilateral), Open Access Transmission Systems, and Open Access Same Time Information system (OASIS)

Transmission Pricing & Congestion Management- Cost components, Postage Stamp Method, Megawatt Mile Method, Contract Path Method. Classification of congestion management methods, Calculation of ATC-TTC-CBM, Non-market methods, Market based methods, Nodal pricing, Inter-zonal Intra-zonal congestion management, Price area congestion management, Locational Marginal Prices.

Economic Operation in restructured Environment - Economic dispatch problem and methods of solutions, Optimal Power flow (OPF), General OPF formulation, Security constrained OPF, Solution techniques, OPF application in Electricity Market.

Risk Management in Restructured Environment- Energy and Reserve Markets, Market Power, Forward and Future market, Smart grid Optimization with risk constraints-General risk measures, Portfolio selection problem, Financial Transmission Rights.

Ancillary Services Management and Demand Response in Restructured Environment -Reactive power as an ancillary service, Energy Storage System, Power Quality, Reliability analysis, Demand response, Potential benefits of demand response in smart grid, enabling smart technologies for demand response, Demand response for Electric Vehicles.

Impact of Energy Transition on Power System restructuring – Key drivers in energy transition, role of power market in energy transition, re-organizing power systems for the transition.

Learning Resources:

Text Books:

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

Reference Books:

1. S. Hunt,, Making competition work in electricity, John Wiley & Sons, Inc., 2002, 1st Edition.
2. Ashikur Bhuiya: Power System Deregulation: Loss Sharing in Bilateral Contracts and Generator Profit Maximization, VDM Verlag Publisher, 2008

Other Suggested Readings:

1. https://archive.nptel.ac.in/courses/108/104/108104052/
2. https://archive.nptel.ac.in/courses/108/101/108101005/

EE36023 **3-0-0 (3)**

Energy Storage Systems

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand the characteristics of energy storage devices
CO-2	Model and simulate the characteristics of energy storage systems
CO-3	Explore the possibilities of deployment of energy storage systems in smart cities and electric vehicles.
CO-4	Evaluate and suggest an efficient storage system in electric transportation.

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	–	1	1	3	–
CO-2	3	1	2	3	2	–
CO-3	3	–	3	3	3	3
CO-4	3	2	3	2	3	3

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: Impacts and requirements of Electrical Energy Storage system, Classification of Energy Storage Systems, Energy costs and load analysis. Grid Applications of Energy Storage systems, Ancillary Services from Energy storage. Economics of energy and power, tied electrical rates and demand response. Role of energy storage system in handling uncertainties with Renewable systems and in microgrids. Mathematical Modelling of various Energy Storage systems.

Battery Energy Storage: Batteries: Introduction to battery storage including lead acid, lithium ion, flow, and emerging battery technologies. Comprehensive analysis of design considerations and application specific needs. Impacts on system cost in terms of life cycle, environmental, and reliability of the end solutions.

Ultra-Capacitors: Introduction to ultra-capacitors including operation, applications, and emerging technologies. Topics include the usage in mobile applications and close proximity to renewable energy sources. Discussion of primary target market usage in today's energy and power sectors.

Super Conducting Magnetic Energy Storage (SMES): Introduction to Super Conducting Magnetic Energy Storage (SMES) operation, theory of usage and emergent research, with focus on large utility scale energy storage facilities.

Mobile and Fixed Energy Storage: Advantages and disadvantages of mobile vs. stationary energy storage, with focus on vehicle to grid applications and opportunities to leverage existing and emergent technology to provide additional grid support functions.

Concept of time-of-day metering for storage planning and management.

Compressed Gas Storage: Compressed gas storage technologies as bulk energy storage. Models for compressed gas capacity, efficiency, and availability, System cost, capacity, conversion efficiency, siting and associated barriers, possible applications in carbon capture and appropriation.

Flywheel Storage: Flywheel energy storage system, Models for flywheel capacity, availability, efficiency, and self-discharge, Applications in transportation, uninterruptible power supply (UPS), pulse power, and bulk storage, Selection and design of flywheels for safety and availability in various applications.

Fuel Cell Based Storage: fuel cell-based energy storage concepts and applications.

Learning Resources:

Text Books:

1. Andrei Ter-Gazarian, Energy Storage for Power Systems, Institution of Engineering and Technology (IET), 2020, 3rd Edition
2. Ali Keyhani Mohammad Marwali and Min Dai, Integration and Control of Renewable Energy in Electric Power System, John Wiley publishing company, 2010, 2nd Edition.

Reference Books:

1. S. Chowdhury, S. P. Chowdhury, P. Crossley, Microgrids and Active Distribution Networks, IET Power Electronics Series, 2012.
2. Zechun Hu, Energy Storage for Power System Planning and Operation, IEEE Press, 2020, 1st Edition.
3. Slobodan Petrovic, Peter Kurzweil, Jürgen Garche, Electrochemical Energy Storage: Batteries, Fuel Cells, and Hydrogen Technologies, McGraw Hill, 2022,1st Edition.

Other Suggested Readings:

1. https://nptel.ac.in/courses/112106318

EE36025 **3-0-0 (3)**

Electric Utility Systems Management

Pre-Requisites: **None**

Course Outcomes:

CO-1	Describe the different electric utility management structures
CO-2	Analyze the operation of transactional markets
CO-3	Formulate short- and long-term forecasts, life-cycle analyses, as well as planning strategies for electric utility operations
CO-4	Formulate cost-benefit analyses for the adoption of new smart grid systems

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	1	1	1	2	1
CO-2	3	1	2	1	1	2
CO-3	3	1	3	3	2	3
CO-4	3	2	3	1	2	3

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Electric utility management structures - vertical integration and horizontal integration and account for the history behind the implementation of these structures through privatization in key jurisdictions throughout the world, Commercial aspects of traditional and modern power systems, Impact of key smart grid technologies on energy, reserve and carbon (CO2) markets and trading

Operation of transactional markets - Transaction-based operation of electric distribution systems, Transactional markets use in achieving optimal management of the exchange (flow) of energy in power systems in different jurisdictions, Blockchain as a distributed computing approach

Planning strategies for electric utility operations – Distribution planning, Formulate short- and long-term forecasts, life-cycle analyses, planning strategies for electric utility operations, infrastructure expansion & investments, risk assessment and reliability analysis, optimal dispatch schemes for a variety of generation sources

Cost-benefit analyses (CBA) in Smart Grid - CBA for the adoption of new smart grid systems and technologies in traditional electric utility systems, Energy efficiency, Cost-benefit risk analysis. Environmental repercussions and the economic structure. Conflict between energy consumption and

pollution. Systems Design and quantitative economic policy with particular references to energy. Potential & Economy of sustainable sources. Econometric in the context of multiple objectives, conflicting goals and decisions under uncertainty

Smart Cities: Components of Smart Cities, integrated approaches to smart city modelling, Smart Home Systems: Home automation systems, building energy, smart appliances, Smart lighting.

Learning Resources:

Text Books:

1. Subramanian Vadari, Electric System Operations: Evolving to the Modern Grid, 2nd Edition, Artech, 2012.
2. J Raja, P Aja, D Vimal Raj, S Rajasekar, Practices in Power System Management in India, Springer Nature, 2018

Reference Books:

1. Rao Konidena, William Poppert, Vivek Bhandari, Modern Electricity Systems: Engineering, Operations, and Policy to address Human and Environmental Needs, Wiley, August 2022.
2. Fereidoon P. Sioshansi, “Smart Grid: Integrating Renewable, Distributed and Efficient Energy”, Academic Press, Elsevier, 2012
3. S. McClellan Jesus A. Jimenez, George Koutitas, “Smart Cities”, Springer International Publishing, 2018
4. Homer M. Rustebakke, Electric Utility Systems and Practices, 4th Edition, 1983

Other Suggested Readings:

1. https://archive.nptel.ac.in/courses/108/107/108107113/

EE46001 **3-0-0 (3)**

Linear Control System

Pre-Requisites: **None**

Course Outcomes:

CO-1	Model the dynamical systems using the state-space concept.
CO-2	Solve the state space equation and perform the stability analysis
CO-3	Design the control systems using state-space methods.
CO-4	Implement the observer based controller concept and optimal control problem

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	-	2	2	1	1
CO-2	2	-	3	2	1	1
CO-3	2	-	3	2	1	1
CO-4	2	-	3	2	1	1

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Mathematical modelling of LTI control systems - impulse response model, differential equation model, transfer function model, frequency response model, state space model-Introduction to state and state variables – State space - physical systems - Representation using state space approach- Modelling of electrical systems

Control system Analysis in state space: State space representations of transfer functions, Solution of state space equation - State transition matrix -Matrix exponential-Controllability and observability

Control system Design in State space: Pole placement approach to Regulator design-Full order observer- Observer based regulator design-

Stability concept: Stability in the sense of Lyapunov - stability of linear systems – Lyapunov equation-Generation of Lyapunov functions-Krasovskii's method Quadratic optimal control-Lyapunov's approach to quadratic optimal regulator design.

Learning Resources:

Text Books:

1. Katsuhiko Ogata, Modern Control Engineering, Pearson Education India, 2020, 5th Edition.
2. M. Gopal, Modern Control Systems Theory, New Age International Publisher, 2023, 5th Edition

Reference Books:

1. Panos J. Antsaklis, Anthony N. Michel, A Linear Systems Primer, Birkhauser Boston Inc, 2007, 1st Edition.
2. Roy Choudhary, Modern Control Engineering, Prentice Hall India, 2005, 1st Edition.
3. Brogan W. L, Modern Control Theory, Prentice Hall, 2011, 3rd Edition.

Other Suggested Readings:

1. https://nptel.ac.in/courses/108106150
2. https://nptel.ac.in/courses/101108057

EE16025 **3-0-0 (3)**

Electric Vehicles

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand the concepts of electric vehicles, hybrid electric vehicles and their impact on environment
CO-2	Analyze the drive-train topologies and advanced propulsion techniques
CO-3	Analyze hybrid energy storage methodologies
CO-4	Identify the suitable power converter topologies for motor control and hybrid energy storage

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	2	2	3	3	2
CO-2	1	2	2	3	3	2
CO-3	1	2	3	3	3	2
CO-4	2	2	3	3	3	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: Conventional vehicle, basics of vehicle performance, History of electric vehicles, social and environmental importance of electric vehicles, impact of modern drive- trains on energy supplies.

Hybrid Electric Vehicles: Micro hybrid vehicles, mild hybrid vehicles, full hybrid vehicles, configuration of hybrid electric Vehicles -Parallel hybrid, series Hybrid, Series-Parallel Hybrid, Complex Configuration. Power flow diagrams Hybrid electric vehicle configurations for various operating modes. Plug-in Hybrid Vehicles: Operating principle, architectures: series-parallel-series-parallel, challenges related to grid connection. Range-extended Electric Vehicles: Classification and configurations, Fuel Cell Electric Vehicles, Solar electric Vehicles, Electric Bi-cycles and their propulsion systems, Vehicle-to-grid, vehicle-to-home concepts, Electric Hybrid electric vehicles-configurations, Solar powered vehicles.

Electric drive-trains: Basic concept of electric traction, introduction to various electric drive- train topologies, power flow control in electric drive-train topologies, fuel efficiency analysis

Electric propulsion unit: Electric components used in electric vehicles, Configuration and control schemes of DC Motor drives, Induction Motor drives, BLDC motor drives, Permanent Magnet Motor drives, Switch Reluctance Motor drives.

Energy Storage: Storage requirements for Electric Vehicles, Battery energy storage, Fuel Cell based

energy storage, Super Capacitor based energy storage and Super Magnetic Energy storage (SMES). Power pack management systems, Active and passive Cell balancing techniques. Hybridization of different energy storage devices, Flywheel based energy storage, compressed air storage systems, super magnetic storage systems.

Converters for Hybrid Energy Storage Systems: Converter configurations for hybrid energy systems based on Battery and Ultra Capacitors-cascaded converter, multiple parallel- connected converter, dual-active-bridge converter, multiple-input converter- multiple modes single converter, interleaved converter, switched capacitor converter, coupled inductor based configurations.

Fundamentals of Chargers: Charger classifications and standards, selection of AC charging systems, DC charging systems, Converter topologies for charging, wireless chargers.

Learning Resources:

Text Books:

1. Ali Emadi, Advanced Electric Drive Vehicles, CRC Press, 2015.
2. Iqbal Hussein, Electric and Hybrid Vehicles: Design Fundamentals, CRC Press, 2021, 3rd Edition.

Reference Books:

1. Mehrdad Ehsani, Yimi Gao, Sebastian E. Gay, Ali Emadi, Modern Electric, Hybrid Electric and Fuel Cell Vehicles: Fundamentals, Theory and Design, CRC Press, 2023, 3rd Edition.
2. James D. Halderman, Curt Ward, Pear Son, Electric and Hybrid Electric Vehicles, 2023, 1st Edition.
3. Aunpam Singh, Electric Vehicles and the end of ICE Age, 2022, 2nd Edition.

Other Suggested Readings:

1. https://nptel.ac.in/courses/108/106/108106170/
2. https://nptel.ac.in/courses/108/102/108102121/

EE16027 **3-0-0 (3)**

Power Quality Improvement Techniques

Pre-Requisites: **None**

Course Outcomes:

CO-1	Identify power quality problems in distribution system
CO-2	Evaluate power quality indices in distribution system
CO-3	Develop mitigation techniques for compensating devices to improve power quality in distribution system
CO-4	Suggest compensating devices to improve power quality in distribution system

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	2	2	1	3	2
CO-2	1	2	2	1	3	2
CO-3	3	2	2	1	3	2
CO-4	3	2	2	1	3	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Power Quality: Significance of power quality, Power quality terms: Transients, Long- duration voltage variations, Short-duration voltage variations, Voltage imbalance, Waveform distortion, Voltage fluctuation, CBEMA and ITI curves. Devices for Overvoltage Protection: Surge arresters and transient voltage surge suppressors, Isolation transformers and Low-impedance power conditioners.

Waveform Distortion: Introduction, Voltage versus current distortion, Harmonics versus transients, Harmonics indices: Total Harmonics Distortion (THD) and Total Demand distortion (TDD); Harmonic standards; Harmonic analysis; Harmonic phase sequence; Triplen harmonics; Inter harmonics.

Harmonic Sources: Introduction; Harmonics generated from electrical machines such as transformers and rotating machines; Arcing devices; Static power conversion: Phase controlled and uncontrolled rectifiers, AC voltage regulators, Pulse width modulated inverters; Converter fed ac and dc drives;

Effects of Harmonic Distortion: Introduction; Resonances; Effects of harmonics on rotating machines; Effect of harmonics on static power plant; Power assessment with distorted waveforms; Effect of harmonics on measuring instruments; Harmonic interference with ripple control systems; Harmonic interference with power system protection; Effect of harmonics on consumer equipment; Interference with communication systems.

Harmonic Elimination: Introduction; Passive power filters: Design, A Shunt active power filters: Configurations, State of the art, Design and control strategies. Three-phase four- wire shunt active power filters

Voltage Quality: Introduction; Sources of Sags, Swell, Unbalance and Flicker; Voltage quality standards; Effects of sags, Swell, Unbalance and Flicker; Voltage sag magnitude due to fault; Voltage sag magnitude calculation based on influence of cross section of conductor, transformer and fault levels; Critical distance for a voltage sag magnitude; Causes of phase-angle jumps in voltage; Classification of voltage sags, voltage sag transformation due to transformers.

Methods for improving Voltage Quality: Introduction; Dynamic Voltage Restorer (DVR): Operating principle, Configurations, State of the art, Design and control strategies. Three-phase four-wire DVR.

Unified Power Quality Conditioner (UPQC): Introduction; design and control; Three- phase three-wire UPQC and three-phase four-wire UPQC topologies, Multilevel inverters based UPQC topologies, Mitigation of Flicker.

Learning Resources:

Text Books:

1. Bhim Singh, Ambrish Chandra, Kamal Al-Haddad, Power Quality: Problems and Mitigation Techniques, Wiley, 2015.
2. Math H. J. Bollen, Understanding power quality problems, Wiley-IEEE Press, 2000, 1st Edition.
3. Mahesh Kumar Mishra, Power Quality in Power Distribution Systems Concepts and Applications, CRC Press, 2023.

Reference Books:

1. Ghosh Arindam, Ledwich Gerard, Power Quality Enhancement Using Custom Power Devices, Springer, 2009.
2. Hirofumi Akagi, Edson Hirokazu Watanabe, Mauricio Aredes, Instantaneous Power Theory and Applications to Power Conditioning, Wiley-IEEE Press, 2017.
3. Roger C. Dugan, Mark F. McGranaghan, Surya Santoso and H. Wayne Beaty, Electrical Power Systems Quality, McGraw Hill, 2012, 3rd Edition.
4. J. Arrillaga, N.R. Watson, Power System Harmonics, Wiley, 2003, 2nd Edition.

Other Suggested Readings:

1. https://nptel.ac.in/courses/108/107/108107157/
2. https://nptel.ac.in/courses/108/106/108106025/

EE36027 **3-0-0 (3)**

Signal Processing Techniques in Power Engineering

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand the applications of Digital signal filtering techniques in power systems
CO-2	Apply estimation techniques to evaluate power system parameters
CO-3	Analyse different signal decomposition techniques
CO-4	Evaluate the WAMS signal processing

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	–	1	–	2	–
CO-2	2	1	2	–	1	–
CO-3	2	–	3	3	2	2
CO-4	3	2	3	–	2	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: Need for Signal Processing in Basics of power quality issues, Inrush Current in Power Transformers; Over-Excitation of Transformers; Transients in Instrument Transformers; Frequency Variation; Voltage Magnitude Variations; Voltage Frequency Variations, power system protection, Wide area dynamic analysis.

Basic Signal Processing Techniques: Stochastic gradient based algorithms – LMS algorithm, Normalized LMS algorithm, Gradient adaptive lattice algorithm. Mean-squared error behaviour, Convergence analysis, Prediction, filtering and smoothing, adaptive equalization, noise cancellation, blind deconvolution, adaptive IIR filters, RLS algorithms- GRLS, Gauss-Newton and RM. Basic Digital System, Parametric Notch FIR Filters; Sine and Cosine FIR Filters, Parametric Filters applications in smart grid.

Filters and Electrical Parameters Estimation: Forward and backward linear prediction, prediction error filters, AR lattice and ARMA Lattice– Ladder filters, Kalman filters, Wiener filter, Least Square methods for system modelling & Filter Design. Recursive least squares algorithms, Matrix inversion lemma, Spectrum estimation.

Estimation of autocorrelation. Periodogram, Nonparametric and Parametric methods. Estimation Theory; Least-Squares Estimator; Frequency Estimation; Phasor Estimation; Phasor Estimation in Presence of DC Component; Spectrum Estimation; Windows; Frequency-Domain Windowing; Interpolation in Frequency Domain: Multitoned Signal.

Time-Frequency Signal Decomposition: Short-Time Fourier Transform; Sliding Window DFT; Filter Banks; Pattern Recognition, Feature Extraction on the Power Signal; Signal Detection for Electric Power Systems; Detection Theory.

Applications of Signal ProcessingTechniques: Concepts of wavelet, s-transform, heartly s -transforms; Hillbert transform; Gabor transform and applications in power fluctuations: load fluctuations, wind farm power fluctuations and smart microgrid, Asset Management.

Learning Resources:

Text Books:

1. S. Palani, Principles of Digital Signal Processing: Springer, 2023, 2nd Edition
2. P. F. Ribeiro, C. A. Duque, P. Marcio da Silveira and A. S. Cerqueira, Power Systems Signal Processing for Smart Grids, John Wiley and Sons Ltd., 2014, 2nd Edition.
3. J.G.Proakis, M. Salehi, Advanced Digital Signal Processing, McGraw –Hill, 2000

Reference Books:

1. S. Haykin, Adaptive Filter Theory, Prentice Hall, 2001, 2nd Edition
2. S. K. Mitra, Digital Signal Processing – A computer Based Approach, MGH, 2001, 2nd Edition.

Other Suggested Readings:

1. https://archive.nptel.ac.in/courses/117/105/117105149/
2. https://onlinecourses.nptel.ac.in/noc22_ee62/preview

MA 16063 **3-0-0 (3)**

Numerical Optimization Techniques

Pre-Requisites: **None**

Course Outcomes:

CO-1	Apply concepts of convex sets, convex functions, and optimality conditions
CO-2	Implement one-dimensional optimization methods for searching the optimal solution.
CO-3	Classify and execute both direct and indirect unconstrained optimization methods
CO-4	Solve constrained optimization problems using direct methods
CO-5	Utilize indirect methods like the penalty function and augmented Lagrange multiplier methods

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	2	–	–	–	–
CO-2	2	2	–	3	2	2
CO-3	2	2	2	2	2	2
CO-4	2	–	3	3	2	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Convex Analysis: Convex Sets - Convex Hulls - Closure and Interior of a Set - Weierstrass's Theorem - Separation and Support of Sets - Polyhedral Sets, Extreme Points, and Extreme Directions; Convex Functions - Definitions and Basic Properties - Minima and Maxima of Convex Functions - Generalizations of Convex Functions – Linear Programming - The Fritz John and Karush-Kuhn-Tucker Optimality Conditions.

One-Dimensional Optimization: Introduction - Unimodal Function - Unrestricted Search - Search with Fixed Step Size - Search with Accelerated Step Size - Exhaustive Search - Dichotomous Search - Interval Halving Method - Fibonacci Method - Golden Section Method -Comparison of Elimination Methods.

Unconstrained Optimization: Classification of unconstrained optimization methods - General Approach - Rate of Convergence - Scaling of Design Variables. Direct search methods -Random Search Methods - Grid Search Method - Univariate Method - Pattern Directions - Powell's Method - Simplex Method. Indirect search methods - Gradient of a Function - Steepest Descent (Cauchy) Method - Conjugate Gradient Method – Development of Fletcher-Reeves Method - Newton's Method - Marquardt Method - Quasi-Newton

Methods – Davidon, Fletcher, and Powell (DFP) Method – Broyden, Fletcher, Goldfarb, Shanno (BFGS) Method.

Constrained Optimization: Characteristics of a Constrained Problem. Direct methods - Random Search Methods - Sequential Linear Programming - Basic Approach in the Methods of Feasible Directions - Zoutendijk's Method of Feasible Directions -Rosen's Gradient Projection Method - Generalized Reduced Gradient Method - Sequential Quadratic Programming. Indirect search methods - Penalty Function Method - Parametric Constraints - Augmented Lagrange Multiplier Method - Convergence of Constrained Optimization Problems.

Learning Resources:

Text books:

1. Vanderplaats, G. N., Numerical optimization techniques for engineering design with applications, McGraw–Hill, 2005, 3rd Edition (Reprint).
2. Rao, S. S., Engineering optimization: theory and practice, Wiley, 2019, 5th Edition.

Reference Books:

1. Deb, K., Optimization for Engineering Design: Algorithms and Examples, PHI Learning, 2012, 2nd Edition.
2. Bazaraa, M. S., Sherali, H. D., & Shetty, C. M., Nonlinear programming: theory and algorithms, Wiley, 2013, 3rd Edition.

EE16026 **3-0-0 (3)**

Control & Integration of Renewable Energy Sources

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand different renewable energy sources and storage devices
CO-2	Model and simulate renewable energy sources
CO-3	Analyze and simulate control strategies for grid-connected and off-grid systems
CO-4	Develop converters to comply with grid standards to obtain grid integration

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	3	2	3	3	2
CO-2	3	3	3	3	3	2
CO-3	3	3	3	3	3	2
CO-4	3	3	3	3	3	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: Electric grid, Utility ideal features, Supply guarantee, power quality, Stability and cost; Importance & Effects of Renewable Energy penetration into the grid, Boundaries of the actual grid configuration, Consumption models and patterns.

Dynamic Energy Conversion Technologies: Introduction, types of conventional and nonconventional dynamic generation technologies, principle of operation and analysis of reciprocating engines, gas and micro turbines, hydro and wind-based generation technologies.

Static Energy Conversion Technologies: Introduction, types of conventional and nonconventional static generation technologies; Principle of operation and analysis of fuel cell, photovoltaic systems and wind generation technologies; MPPT techniques and its classifications, principle of operation and partial shading effects; Storage Technologies -batteries, fly wheels, super capacitors and ultra-capacitors.

Control Issues and Challenges: Linear and nonlinear controllers, predictive controllers and adaptive controllers, Load frequency and Voltage Control, PLL, Modulation Techniques, Control of Diesel, PV, wind and fuel cell-based generators, Dimensioning of filters, Fault-ride through Capabilities.

Integration of Energy Conversion Technologies: Introduction & importance, sizing, Optimized integrated systems, Interfacing requirements, Distributed versus Centralized Control, Grid connected Photovoltaic systems –classifications, operation, merits & demerits; Islanding Operations, stability and protection issues,

load sharing, operation & control of hybrid energy systems, Solar Photovoltaic applications. IEEE & IEC codes and standards for renewable energy grid integrations.

Learning Resources:

Text Books:

1. G. Masters, Renewable and Efficient Electric Power Systems, IEEE-John Wiley and Sons Ltd. Publishers, 2013, 2nd Edition.
2. A. Mahaboob Subahani, G. R. Kanagachidambaresan, M. Kathiresh, Integration of Renewable Energy Sources with Smart Grid, Willey 2021.
3. Felix A. Farret, M. Godoy Simoes, Integration of Renewable Sources of Energy, Wiley, 2017, 2nd Edition.

Reference Books:

1. Chetan Singh Solanki, Fundamentals, Technologies & Applications, Solar Photovoltaic, PHI Publishers, 2019, 3rd Edition.
2. Quing-Chang Zhong, Control of Power Inverters in Renewable Energy and Smart Grid Integration, IEEE-John Wiley and Sons Ltd. Publishers, 2013, 1st Edition.
3. Bin Wu, Yongqiang Lang, Navid Zargari, Power Conversion and Control of Wind Energy Systems, IEEE- John Wiley and Sons Ltd. Publishers, 2011, 1st Edition.
4. S. Chowdhury, S. P. Chowdhury, P. Crossley, Microgrids and Active Distribution Networks, IET Power Electronics Series, 2012.

Other Suggested Readings:

1. https://nptel.ac.in/courses/108/102/108102145/
2. https://nptel.ac.in/courses/103/103/103103206/

EE26024 **3-0-0 (3)**

Distribution System Planning and Automation

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand and distinguish characteristics of distribution systems from transmission systems
CO-2	To design, analyze and evaluate distribution system design based on forecasted data
CO-3	Identify and select appropriate sub–station location
CO-4	Design and evaluate a distribution system for a given geographical service area from alternate design alternatives

Course Articulation Matrix:

CO/PO	PO1	PO2	PO3	PO4	PO5	PO6
CO-1	3	1	3	1	1	1
CO-2	3	1	3	2	2	1
CO-3	3	1	3	1	1	2
CO-4	3	1	3	2	2	3

1 – Slightly 2 - Moderately 3 – Substantially

Syllabus :

Distribution System Planning- Planning and forecasting techniques – Present and future – Role of computers- Load Characteristics- Load forecasting using ANN – Load management – tariffs and metering of energy

Distribution Transformers: Types - Three phase and single phase transformers – connections – causes and types of failures in distribution transformers

Primary distribution systems and Distribution Sub–Stations: Distribution substations –Bus schemes –comparison of switching schemes- Substation location and rating- Types of feeders – voltage levels

Voltage Drop and Power Loss Calculations: Three phase primary lines – Copper loss – Distribution feeder costs – Loss reduction and Voltage improvement in rural networks

Capacitors in Distribution Systems: Effects of series and shunt capacitors – justification for capacitors – Procedure to determine optimum capacitor size and location.

Distribution system management: Integrated sub–station metering system – Revenue improvement – issues in multi–year tariff and availability based tariff

Distribution System Automation: Reforms in power sector – Methods of improvement – Reconfiguration –Automation – Communication systems – Sensors –Basic architecture of Distribution automation system – software and open architecture – RTU and Data communication – SCADA requirement and application functions –Communication media for distribution system automation- Communication protocols for Distribution systems – IEC 61850 and IEEE 802.3 standards

Learning Resources:

Text Books:

1. Juan M. Gers, Distribution Systems Analysis and Automation, IET power series, 2020
2. James Northcote-Green, Robert G. Wilson, Control and Automation of Electrical Power Distribution Systems: Taylor & Fransis, 2006
3. A. S. PABLA, Electric Power Distribution, TMH, 2000

Reference Books:

1. Dr. M.K. Khedkar, Dr. G.M. Dhole,A Textbook of Electric Power Distribution Automation, Laxmi Publications Ltd., 2010
2. Turan Gonen, Electric Power Distribution Engineering, Mc-Graw Hill,2014

Other Suggested Readings:

1. https://onlinecourses.nptel.ac.in/noc22_ee35

EE26026 **3-0-0 (3)**

High Voltage Power Transmission

Pre-Requisites: None

Course Outcomes:

CO-1	Analyze and evaluate electric field and interference characteristics of HV AC system
CO-2	Design grounding system for HVAC systems
CO-3	Evaluate performance metrics for HVDC converter configuration
CO-4	Filter design and Power Flow analysis in HVDC system

Course Articulation Matrix :

CO/PO	PO1	PO2	PO3	PO4	PO5	PO6
CO-1	3	1	3	1	2	1
CO-2	3	2	3	2	2	2
CO-3	3	2	3	2	1	2
CO-4	3	2	3	1	2	2

1 - Slightly; 2 - Moderately 3-Substantially

Voltage Gradients of Conductors: Conductors configuration, Bundled conductors, Electrostatics, Field of Sphere, Field of Line Charges and their use, Charge-Potential Relations for Multi-Conductor, Surface Voltage Gradient on Conductors, Examples.

Corona and Radio interference: Corona loss formula, Audible noise, its characteristics, limits for audio noise, relation between single phase and 3-phase AN levels, radio interference, limits for radio interference fields, CIGRE formula.

Power System Grounding: Over Voltage in HV Systems -internal and external reasons, Functional Requirements of Earthing System, Equipment Earthing, Neutral Point Earthing, design of Substation grounding System, analysis of simple grounding systems, Measurement of Resistance and Soil Resistivity of Earthing System.

Analysis of HVDC converters: Introduction, Modern trends, Pulse number, Choice of converter configuration Simplified analysis of Graetz circuit: without overlap, with overlap, Analysis of two and three valve conduction mode, Converter Bridge characteristics.

Converter and HVDC system control: Principles of DC link control, Converter control characteristics, System control hierarchy, Firing angle control, Current and Extinction angle control, Starting and stopping of DC link, Power control.

Harmonics & Filters - Introduction, Generation of Harmonics, Types of AC Filters.

Power Flow Analysis in AC/DC Systems - Comparison of AC&DC Transmission, General Modeling of DC links, Solutions of AC- DC power flow.

Learning Resources:

Text Books:

1. Rakesh Das Begamudre , Extra High Voltage AC Transmission Engineering, , New Age International publishers, 2014, 4th Edition.
2. K.R. Padiyar , HVDC Power Transmission Systems,: New Age Publishers, 2017
3. Dragan Jovcic, Khaled Ahmed, High Voltage Direct Current Transmission: Converters, Systems and DC Grids, Wiley Publishers, 2015

Reference Books:

1. Turan Gonen, Electric Power Transmission System Engineering Analysis and Design, CRC Press, 2014, 3rd Edition.
2. Md. Abdus Salam, Quazi M. Rahman , Power Systems Grounding, , Springer publishers, 2016.
3. Edward Wilson Kimbark, Direct Current Transmission, Vol-1, John Wiley & Sons, 1971

Other Suggested Readings:

1. https://archive.nptel.ac.in/courses/108/106/108106160/

EE46024 **3-0-0 (3)**

Digital Control Systems

Pre-Requisites: **EE46001**

Course Outcomes:

CO-1	Model the discrete time (DT) system in state space form
CO-2	Perform the stability analysis for DT dynamical system
CO-3	Design the state feedback control for DT system
CO-4	Formulate and solve the DT optimal control problems

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	1	-	2	2	2	1
CO-2	2	-	3	2	2	1
CO-3	2	-	3	2	2	1
CO-4	2	-	3	2	2	1

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: Continuous and Discrete time system-Digital control systems - Quantizing and quantization error, Sampling theorem.

Z-Transform: Z-transforms of elementary functions, important properties and theorems, Inverse Z-transform, Z-transform method of solving difference equations.

Z-Plane Analysis of Discrete-Time Control Systems: Impulse sampling and data hold, Pulse transfer function, Realization of digital controllers and digital filters, Mapping between s-plane and z-plane, Stability analysis of closed loop systems in z-plane, Transient and steady state analyses.

State Space Analysis of digital control systems: Solution of discrete time state space equations, Discretization of continuous time state space equations, Lyapunov stability analysis for Discrete linear system, Controllability, Observability, Pole Placement and Observer Design.

Discrete Optimal Control Systems: Linear Quadratic Regulator (LQR) Design via pole placement, Steady state quadratic optimal control.

Learning Resources:

Text Books:

1. K. Ogata, Discrete time control systems, Pearson Education India, 2015, 2nd Edition.
2. M. Gopal, Digital Control and State Variable Methods, McGraw Hill Education, 2017, 4th Edition.

Reference Books:

1. C.L. Phillips, H.T. Nagle, A. Chakrabortty, Digital Control System Analysis and Design, Pearson, 2014, 4th Edition.
2. B.C. Kuo, Digital Control Systems, Oxford University Press, 2012, 2nd Edition.
3. C.A. Rabbath, N. Lechevin, Discrete-Time Control System Design with Applications, Springer-Verlag New York Inc, 2014, 1st Edition.

Other Suggested Readings:

1. https://nptel.ac.in/courses/108105186
2. https://nptel.ac.in/courses/108103008

EE26030 **3-0-0 (3)**

Evolutionary Algorithms Applications in Power Engineering

Pre-Requisites: **None**

Course Outcomes:

CO-1	Discriminate the capabilities of bio-inspired system and conventional methods in solving optimization problems
CO-2	Examine the importance of exploration and exploitation of evolutionary algorithm to attain near global optimal solution
CO-3	Distinguish the functioning of various evolutionary algorithms
CO-4	Employ various bio-inspired algorithms for Power Engineering applications

Course Articulation Matrix:

CO\PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	1	3	1	1	1
CO-2	3	1	3	1	1	1
CO-3	3	1	3	1	2	1
CO-4	3	1	3	3	2	1

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Fundamentals Of Soft Computing Techniques- Definition-Classification of optimization problems-Unconstrained and Constrained optimization Optimality conditions- Introduction to intelligent systems-Soft computing techniques- Conventional Computing versus Swarm Computing - Classification of meta-heuristic techniques - Single solution based and population based algorithms – Exploitation and exploration in population based algorithms - Properties of Swarm intelligent Systems - Application domain - Discrete and continuous problems - Single objective and multi-objective problems

Genetic Algorithm and Particle Swarm Optimization-Genetic algorithms: Genetic Algorithm versus Conventional Optimization Techniques - Genetic representations and selection mechanisms; Genetic operators- different types of crossover and mutation operators -Bird flocking and Fish Schooling – anatomy of a particle- equations based on velocity and positions -PSO topologies - control parameters – GA and PSO algorithms for solving ELD problem

Artificial Bee Colony Algorithm And Differential Evolution: Artificial bee colony (ABC) algorithms-binary ABC algorithms – ACO and ABC algorithms for solving Economic Dispatch of thermal units. The Motivation for Differential Evolution (DE), Introduction to Parameter Optimization, Single-Point, Derivative-Based Optimization, Local Versus Global Optimization, Differential Mutation, Recombination, Selection, Benchmarking Differential Evolution, DE Versus Other Optimizers, DE on Parallel Processors.

Shuffled Frog-Leaping Algorithm and Bat Optimization Algorithm- Bat Algorithm- Echolocation of bats-Behaviour of microbats- Acoustics of Echolocation- Movement of Virtual Bats- Loudness and Pulse

Emission- Shuffled frog algorithm-virtual population of frogs-comparison of memes and genes -memeplex formation- memeple updation- BA and SFLA algorithms for solving ELD and optimal placement and sizing of the DG problem

Multi Objective Optimization: Multi-Objective optimization Introduction- Concept of Pareto optimality - Non-dominant sorting technique-Pareto fronts-best compromise solution- min-max method-NSGA-II algorithm and applications - Control of Power Converters.

Learning Resources:

Text Books:

1. Xin-She Yang, Recent Advances in Swarm Intelligence and Evolutionary Computation, Springer International Publishing, Switzerland, 2015, 1st Edition
2. Kalyanmoy Deb, Multi-Objective Optimization using Evolutionary Algorithms, John Wiley & Sons, 2001, 1st Edition.
3. Altaf Q. H. Badar, Evolutionary Optimization Algorithms, CRC Press, 2022

Reference Books:

1. James Kennedy and Russel E Eberheart, Swarm Intelligence, The Morgan Kaufmann Series in Evolutionary Computation, 2001
2. N P Padhy, Artificial Intelligence and Intelligent Systems, Oxford University Press, 2005

Other Suggested Readings:

1. https://archive.nptel.ac.in/courses/112/103/112103301/

EE36022 **3-0-0 (3)**

Smart Grid Communications and Protocols

Pre-Requisites: **EE3601**

Course Outcomes:

CO-1	Understand the role of communication networks in Smart Grid systems
CO-2	Analyze the architectures of the communication networks
CO-3	Understand the different communication protocols for Power System
CO-4	Analyze the system network security and data management.

Course Articulation Matrix:

CO\PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	–	1	–	3	1
CO-2	3	1	2	–	1	–
CO-3	3	3	2	3	2	2
CO-4	3	2	3	–	2	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Power system Automation: Evolution of power system Automation, SCADA System, Elements of Communication Networking; Control in Traditional Power Networks; Distributed Generation and Active Control; Communications Challenges in Active Control

Elements of Communication Networking: Elements of Data Communication Networks; Protocols and Protocol Layers; OSI Reference Model; TCP Reference model; Practical Protocol Layering in Network; Data Networking Technologies; Different network topologies and Classification of communication network.

Communication Network Architecture: Architecture Framework; Core-Edge Architecture; Smart Grid Network Protocols; Smart Grid Domains and Smart Grid Communication Network; WAN Architecture; WAN over Network Service Provider; Local Traffic Aggregation; Putting It All Together; Field Area Networks; FAN Protocol Options; Summary of FAN Networking Technologies; Logical End-to-End Connectivity (A Few Examples); Automated Demand Response; Volt, VAR, Watt Control in Distribution System; Wide Area Situational Awareness and Control.

Network Security: Importance of Smart Grid Security; Regulations, Standards, and Best Practices; Smart Grid Security Architecture; Security Zones; Transmission Zone; Distribution SCADA Zone; Distribution Non-SCADA Zone; Interconnect Zone; Additional Security-Related Operations.

Smart Grid Data Management: Characterization of Smart Grid Data; Technology Challenges; Secure Information and Data Management Architecture; Design Requirements; Secure Data Management; Secure End-to- End Protocols; Data Management Platform; Applications of Smart Grid Data; Utility-Centric Applications; Consumer-Centric Analytics; Market-Centric Analytics; Power Line Communication.

Smart Grid Protocols: Modbus; Modbus message frame; Protocol architecture, IEC 60870-5-101/103/104; Distributed network protocol 3; Inter-control center protocol; Ethernet; IEC 61850, Synchro phasor standard; Wireless technologies for home automation; Protocols in the power system communication: Deployed and evolving such as LPWAN, 5G etc. for network; Parallel Redundancy Protocol (PRP) and High-availability Seamless Redundancy (HSR) may be included/added. Digital substation communication, Role of digital substation in smart grid.

Learning Resources:

Text Books:

1. Kenneth C. Budka, Jayant G. Deshpandeand Marina Thottan, Communication Networks for Smart Grids, Springer London Heidelberg New York Dordrecht, 2014, 1st Edition.
2. Mini. S. Thomas and John D. McDonald, Power system SCADA and smart grid, CRC Press, 2015, 1st Edition.

Reference Books:

1. F. Bouhafs, M. Mackay and M. Merabti, Communication Challenges and Solutions in the Smart Grid, Springer New York Heidelberg Dordrecht London, 2014, 1st Edition.
2. Wonkyu Han, Mike Mabey, Gail-Joon Ahn and Tae Sung Kim, Simulation-Based Validation for Smart Grid Environments: Framework and Experimental Results, Springer International Publishing Switzerland, 2014, 1st Edition.

Other Suggested Readings:

1. https://onlinecourses.nptel.ac.in/noc23_ee124/preview
2. https://iitk.ac.in/smartcity/qip/download/ppt/Day-1/04_Smart%20grid%20Comm.pdf

EE36024 **3-0-0 (3)**

Transactive Energy Markets

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand Transactive Energy (TE) and Transactive Energy Market (TEM) Models
CO-2	Analyze Transactive Energy as a Grid Support service
CO-3	Model Transactive Control for Stable and economic operation of Smart Grid
CO-4	Develop TEM models and understand its application

Course Articulation Matrix:

CO\PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	1	1	–	3	–
CO-2	3	1	2	–	2	–
CO-3	3	1	3	3	3	3
CO-4	3	2	3	3	3	3

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction to Transactive Energy (TE): Transactive Energy Definition, Transactive Energy Products, Transactive Energy Market Participants, Transactive Energy Classification scheme for renewable market participants

Transactive Energy Market Models: Transactive Energy Market Models: Transactive Node based Energy Management model, Hierarchical Energy Management Model. Conceptual View of Distributed Power Generation and Management, Centralized and Decentralized Transactive Energy, Transactive energy vs. demand response, TE market management,

Transactive Energy as Grid Support Services: Ancillary Services from TEM, Characterization of Residential Distributed Energy Resource Potential to Provide Ancillary Services, New Emerging ASs to Be Offered by DRESs, Synthetic Inertia from TEM, Inertia response from wind turbines, Voltage control and reactive power supply from solar PV and Battery Energy Storage System, Harmonic mitigation as ancillary service from DERs, Ancillary Service Transactive Energy Market design.

Transactive Control: Transactive control (TC) in Smart Grid, Time scale for TC, TC implanting methodologies, Transactive Control for HVAC systems, Transactive Control model for distribution congestion management, Transactive Control for EV chargers, TE based Auction mechanism, Price-based resource scheduling and dispatch, Congestion management, Market-clearing and pricing in TEM.

Transactive Energy Applications: Concept of Prosumers and Peer-to-peer (P2P) market, P2P and P2G Energy Trading, Energy Management under uncertainties in P2P Market, Game Theory in TEM, Concept of Blockchain techniques, Multi-agent Transactive energy management, Challenges in Transactive

Electricity Market.

Learning Resources:

Text Books:

1. Mohammadreza Daneshvar, Behnam Mohammadi-Ivatloo and Kazem Zare, “Emerging Transactive Energy Technology for Future Modern Energy Networks”, Academic Press, 1st Edition, 2022.
2. S. Barrager, E. Cazalet, “Transactive Energy: A Sustainable Business and Regulatory Model for Electricity”, Baker Street Publishing, 1st Edition, 2014.

Reference Books:

1. Aisultan Alimkhan, Ileskhan Kalysh, and Ilyas Temirtayev, “Transactive Energy Management System”, Lambert Academic Publishing, 1st edition, 2019
2. Meng Song, Ciwei Gao, “Integration of Distributed Resources in Smart Grids for Demand Response and Transactive Energy: A Case Study of TCLs”, Springer Verlag, Singapore; 1st edition, 2022

Other Suggested Readings:

1. https://nptel.ac.in/courses/129105004
2. http://www.tea-web.org/discussion-topics.html

EE36026 **3-0-0 (3)**

Cloud Computing and Big Data Analytics in Smart Grids

Pre-Requisites: **None**

Course Outcomes:

CO-1	Understand cloud computing and big data applications for smart grid
CO-2	Analyze the benefits of cloud computing and big data analytics for smart grid technology
CO-3	Explore applications of big data and cloud computing in Smart Grid
CO-4	Understand Probability Concepts for Big Data Analysis

Course Articulation Matrix:

CO\PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	1	1	–	2	–
CO-2	3	1	2	–	1	–
CO-3	3	1	3	3	2	2
CO-4	3	2	3	1	2	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: Introduction to Cloud Computing in Smart Grid - Introduction to Big Data Analytics- Fundamental Mathematical Prerequisites, Big Data Era, Big data characteristics in smart grid, General Security Challenges

Cloud Computing Applications for Smart Grid: Cloud computing in smart grid, Cloud computing architecture, Demand Response - Geographical Load- Balancing - Dynamic Pricing - Virtual Power Plant - Advanced Metering Infrastructure - Cloud-Based Security and Privacy.

Big Data Core Components in Smart Grid: Data acquisition, Data storing and processing, Data querying, Data Analytics

Smart Grid Data Management and Applications: Pricing and energy forecasting in Demand Response, case study on Energy Forecast, Smart Meter Data Management -PHEVs: Internet of Vehicles - Smart Buildings., Energy Management related application, Parameter and State Estimation, Cyber Security

Smart Grid Design and Deployment: Attack detection, current problem and techniques, Secure Data Learning Scheme, Logical Security Architecture, Smart Metering Data Set Analysis—A Case Study, Security Schemes for AMI Private Networks, Simulation Tools- Worldwide Initiatives

Probability and Statistics for Data Understanding : Random variable and sample space, empirical approach to probability - conditional probability - independent events - Bayes' Theorem, mathematical expectation - moment generating function - Chebyshev's inequality - Bernoulli trials - the Binomial, negative

binomial, geometric, Poisson, normal, rectangular, exponential, Gaussian, beta and gamma distributions, sampling and large sample tests, chi- square test, theory of estimation, linear and polynomial fitting by the methods, correlation of bivariate frequency distribution.

Learning Resources:

Text Books:

1. S. Misra and S. Bera, Smart Grid Technology: A Cloud Computing and Data Management Approach, Cambridge University Press, 2018, 1st Edition.
2. F. Ye, Y. Qian and R.Q. Hu, Smart Grid Communication Infrastructure: Big Data, Cloud Computing and Security, Wiley IEEE Press, 2018, 1st Edition.

Reference Books:

1. James A. Momoh, Smart Grid: Fundamentals of Design and Analysis, Wiley India, 2015, 1st Edition.

Other Suggested Readings:

1. Big Data Analytics For Smart Grid : https://onlinecourses.swayam2.ac.in/arp19_ap60/preview
2. Big Data Computing: https://onlinecourses.nptel.ac.in/noc20_cs92/preview
3. Cloud Computing and Distributed Systems: https://onlinecourses.nptel.ac.in/noc21_cs15/preview
4. Zhang, Y., Huang, T. & Bompard, E.F. 'Big data analytics in smart grids: a review'. Energy Inform 1, 8 (2018).
5. Bishnu P. Bhattarai, Sumit Paudyal, et. Al., 'Big data analytics in smart grids: state-of-the-art, challenges, opportunities, and future directions', IET Smart Grid, March 2019,

EE36028 **3-0-0 (3)**

Industrial Internet of Things

Pre-Requisites: None

Course Outcomes:

CO-1	Understand and evaluate the characteristics of Domestic & Industrial appliances.
CO-2	Understand the behaviour of Industrial IoT and their applications
CO-3	Manage smart communication systems with multiple sensors and protocols
CO-4	Design and simulate smart homes and smart cities with IoTs and cloud computing

Course Articulation Matrix:

CO/PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	–	1	–	2	–
CO-2	3	1	2	–	1	–
CO-3	3	–	3	3	2	2
CO-4	3	2	3	2	2	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

IoT Communication Technologies: Introduction to IoT, Sensing, Actuation, Basics of Networking, Communication Protocols, Sensor Networks, Machine-to-Machine Communications. Interoperability in IoT.

IoT Control Technologies and Programming: Introduction to Arduino Programming, Integration of Sensors and Actuators with Arduino, Internet of Things Open-Source Systems. Introduction to Python programming, Introduction to Raspberry. Implementation of IoT with Raspberry Pi, Smart Grid Hardware Security.

Domestic & Industrial Appliances: Solid State Lamps: Introduction - Review of Light sources - white light generation techniques-Characterization of LEDs for illumination application. Power LEDs- High brightness LEDs-Electrical and optical properties. LED driver considerations-Power management topologies -color issues of white LEDs- Dimming of LED sources, BLDC motors for pumping and domestic fan appliances, inverter technology-based home appliances, Smart devices and equipment. Industrial IoT applications- Factories and Assembly Line- Power Plants, Plant Safety and Security (Including AR and VR safety applications)- Oil and chemical Industry- Applications of UAVs in Industries.

IoT Cloud Computation and Applications: Introduction to SDN. SDN for IoT, Data Handling and Analytics, Cloud Computing, Sensor- Cloud. Fog Computing, Smart Cities and Smart Homes, Electric Vehicles, Industrial IoT, Case Study: Agriculture, Healthcare, Activity Monitoring, Role of ML and AI in IoT.

Learning Resources:

Text Books:

1. Sudip Misra, Chandana Roy, Anandarup Mukherjee, Introduction to Industrial Internet of Things and Industry 4.0, CRC press, 2021.
2. Kostas Siozios, Dimitrios Anagnostos, Dimitrios Soudris, Elias Kosmatopoulos, IoT for Smart Grids: Design Challenges and Paradigms, Springer publishers, 2019.
3. Vinod Kumar Khanna, Fundamentals of Solid-State Lighting: LEDs, OLEDs, and Their Applications in Illumination and Displays, CRC press, 2014, 1st Edition.

Reference Books:

1. Alasdair Gilchrist, Industry 4.0: The Industrial Internet of Things, Apress Publishers, 2016.
2. Craig Di Louie, Advanced Lighting Controls: Energy Savings, Productivity, Technology and Applications, River publishers, 2006, e-book, 2021,1st Edition.
3. Chang-liang Xia, Permanent Magnet Brushless DC Motor Drives and Controls, John Wiley & Sons Singapore Pte. Ltd., 2012, 1st Edition.

Other Suggested Readings:

1. https://nptel.ac.in/courses/106105166

EE26032 **3-0-0 (3)**

Machine Learning Applications in Power Engineering

Pre-Requisites: None

Course Outcomes:

CO-1	Understand basic concepts of Machine Learning Techniques
CO-2	Distinguish between supervised learning, unsupervised learning and reinforced learning
CO-3	Develop the skills in using machine learning software for solving practical problems
CO-4	Apply Machine Learning Algorithms for Electrical Engineering problems

Course Articulation Matrix:

CO\PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	1	3	1	1	1
CO-2	3	1	3	1	1	1
CO-3	3	1	3	3	2	1
CO-4	3	1	3	2	2	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Neural networks- Introduction to Neural Networks, Models of Neuron Network, Architectures – Knowledge representation, Artificial Intelligence and Neural Networks – Learning Process, Error Correction Learning, Multi-layer perceptron using Back Propagation Algorithm (BPA)

Learning Theory- Introduction to Machine Learning: What is Learning – Learning Objectives – Data needed – Bayesian inference and Learning – Bayes theorem – inference – naïve Bayes – Regularization – Bias-Variance Decomposition and Trade-off – Concentration Inequalities – Generalization and Uniform Convergence – VC –dimension- Types of Learning- Supervised Learning – Unsupervised Learning and Reinforcement Learning

Supervised learning- Simple linear Regression – Multiple Linear Regression- Logistic Regression – Exponential Family and Generalized Linear Models- Generative Models: Gaussian Discriminate Analysis, Naïve Bayes – Kernal Method: Support Vector Machine (SVM) – Kernal function – Kernal SVM - Gaussian Process – Tree Ensembles: Decision Trees- Random Forests – Boosting and Gradient Boosting

Unsupervised learning (clustering)- K –means Clustering Algorithm – Gaussian Mixture Model (GMM) – Expectation Maximization (EM) – Variational Auto Encoder (VAE) – Factor Analysis – Principle Components Analysis (PCA) – Independent Component Analysis (ICA)

Reinforcement learning- Markov Decision Processes (MDP) – Bellman's Equations- Value Iteration and Policy Iteration - Value Function Approximation – Q – Learning

Applications of ML- Load Forecasting **–** Energy Market forecasting – Renewable energy forecasting, Fault identification and localization – Renewable Uncertainty estimation. ML for solar power MPPT, False data injection attack detection, and Control of Power Converters.

Learning Resources:

Text Books:

1. Christopher Bishop, Pattern Recognition and Machine Learning, Springer, 2011
2. E. Alpaydin, Machine Learning, MIT Press, 2010
3. Anuradha Srinivasaraghavan , Vincy Joseph , Machine Learning, Wiley 2019

Reference Books:

1. Giuseppe Bonaccorso , Machine Learning Algorithms, Packt Publishing; 2018 2nd Edition
2. Tom M. Mitchell, Machine Learning, McGraw Hill International Edition, 2013

Other Suggested Readings:

1. https://onlinecourses.nptel.ac.in/noc22_cs24
2. https://nptel.ac.in/courses/106106198

EE26034 **3-0-0 (3)**

Energy Auditing and Management

Pre-Requisites: None

Course Outcomes:

CO-1	Understand the need and significance of energy audit and management
CO-2	Identify the equipment and domain of energy conservation and audit in power system
CO-3	Assess the need and type of instruments for energy audit and energy management
CO-4	Design, analyze and evaluate an energy audit and the benefits of different energy management techniques

Course Articulation Matrix:

CO\PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	1	3	1	2	1
CO-2	3	2	3	2	1	1
CO-3	3	1	3	2	1	2
CO-4	3	1	3	2	1	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Energy Audit and Demand Side Management (DSM) In Power Utilities: Energy Scenario & Conservation -Demand Forecasting Techniques- Integrated Optimal Strategy for Reduction of T&D Losses - DSM Techniques and Methodologies- Loss Reduction in Primary and Secondary Distribution system and capacitors - Energy Management – Role of Energy Managers - Energy Audit – Metering

Energy Audit: Energy audit concepts, Basic elements and measurements, Mass and energy balances, Scope of energy auditing in industries

Energy Audit of Electrical Equipment: Evaluation of energy conservation opportunities and environmental management- Preparation and presentation of energy audit reports, case studies for Induction motors, Transformers, Cables, Lighting, AC systems, Pumps, Capacitor banks and potential energy savings

Instrumentation: Evaluation and instrumentation techniques for renewable energy systems (solar thermal, photovoltaic and wind energy); energy management devices; micro controller based systems

Energy Conservation: Energy conservation in HVAC systems and thermal power plants, Solar systems, Fan and Lighting Systems - Different light sources and luminous efficacy, Energy conservation in electrical devices and systems, Economic evaluation of energy conservation measures, Electric motors and transformers, Inverters and UPS, Voltages stabilizers

Learning Resources:

Text Books:

1. Dr. Subhash Gadhave , Anup Goel , Siddu Patil , Laxmikant D. Jathar , Energy Audit & Management Re-Print , Aug 2020
2. Amlan Chakrabarti, Energy Engineering and Management, PHI, 2018
3. Rajiv Shanker, Energy Auditing in Electrical Utilities, Viva books Pvt. Ltd., 2015

Reference Books:

1. Roosa, S., Doty, S., & Turner, W, Energy Management Handbook, River Publishers, 2020
2. Hodge B.K, Analysis and Design of Energy Systems, Prentice Hall, 2002

Other Suggested Readings:

1. https://nptel.ac.in/courses/108106022
2. https://nptel.ac.in/courses/112105221

EE26036 **3-0-0 (3)**

Flexible AC Transmission System

Pre-Requisites: **Power Systems, Power Electronics**

Course Outcomes:

CO-1	Understand the need for control of Real and Reactive power flows
CO-2	Identify the objectives of series and shunt compensation of power systems
CO-3	Analyze the performance of Series, Shunt and combined FACTS controllers
CO-4	Evaluate the performance and stability of power systems with FACTS controllers

Course Articulation Matrix:

CO\PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	3	1	3	-	1	1
CO-2	3	1	3	-	1	1
CO-3	3	3	3	-	1	1
CO-4	3	3	3	-	1	1

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Introduction: Need for power system interconnections, Evolution of AC and DC transmission systems, Comparison of HVDC and HVAC Transmission systems, Power flow in AC systems, Relative importance of controllable parameters, Basic types of FACTS controllers, shunt and series controllers. Overview of power converters used in FACTS controllers

Objectives of shunt compensation, Methods of controllable VAR generation, Static Var Compensator, its characteristics, TCR, TSC, FC-TCR configurations, STATCOM, basic operating principle, control approaches and characteristics

Objectives of series compensator, variable impedance type of series compensators, switching converter type compensators, TCSC, TSSC- operating principles and control schemes, SSSC, Power Angle characteristics, Control range and VAR rating

Static Phase Angle Regulators – power flow control by phase angle regulator and improvement of transient stability

Introduction to Unified Power Flow Controller, Basic operating principles, Conventional control capabilities, Control structure of UPFC, Interline power flow controller

Virtual and Synthetic Inertia: Introduction to virtual Synchronous machine, Virtual and synthetic Inertia. Estimating the inertia of traditional and RES power systems. Modeling of virtual and synthetic inertia for frequency control. Effects of fast acting storage units on fast frequency control of micro grid.

Learning Resources:

Text Books:

1. Suman Bhowmick, Flexible AC Transmission Systems (FACTS):CRC Press, 2023 1st Edition
2. Yong Hua Song & Allan T Johns, Flexible AC Transmission Systems (FACTS), IEE power and energy series, 2008
3. NarainG.Honorani, Laszlo Gyugyi, Understanding FACTS – Concepts and Technology of Flexibile AC Transmission Systems, Wiley-IEEE Press, 1999

Reference Books:

1. K.R. Padiyar, FACTS Controllers in Power Transmission and Distribution, New Age International Publishers, 2016
2. R. Mohan Mathur and Rajiv K. Varma, Thyristor- Based FACTS controllers for electrical transmission systems, IEEE Press, 2002

Other Suggested Readings:

1. https://nptel.ac.in/courses/108/107/108107114/
2. Prachal Jadeja and Vijay K Sood, “Synthetic/virtual Inertia in RES Grid, A Review”, IEEE explore, 2023.

EE36030 **3-0-0 (3)**

Smart Grid Resiliency and Cyber Security

Pre-Requisites: **Power system Analysis**

Course Outcomes:

CO-1	Understand the key technical threat types, communication protocols and resilient smart grid architectures
CO-2	Deploy risk management, operational security and secure development of Smart Grid.
CO-3	Assess static and dynamic security analysis techniques to validate
CO-4	Verify smart grid security and resiliency

Course Articulation Matrix:

CO\PO	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6
CO-1	2	1	1	–	2	–
CO-2	3	2	3	–	2	2
CO-3	3	–	3	3	2	2
CO-4	3	2	3	1	2	2

1 - Slightly; 2 - Moderately; 3 - Substantially

Syllabus:

Basic Concepts: Smart Grid communication, physical and network, introduction to SCADA, MTU, HMI, PLCs, RTU, Physical communications and protocols, Power system observability, bad data detection and identification using state estimation results, Zero injection measurements, pseudo measurements for improving observability.

Power system contingency: Contingency, security assessment and ranking metrics: using conventional load flow, DC sensitivity factors GSF, LODF (for line overloading), 1P and 1Q method (for voltage violations), Concentric relaxation method, using voltage sub network, and system equivalencing, Security constrained Optimal power flows, n-1 and n-1-1 contingency operations

Reliability Vs Resilience: contingency Vs resiliency analysis: need of resiliency, Elements of Power System Resilience, metrics for system resiliency, EXTREME EVENTS MODELING: WEATHER-RELATED EVENTS, CYBER-ATTACKS, Generic Framework for Resilience Analyses, Damage Prevention, System Recovery, Survivability, enhancing power system resiliency.

Smart Grid Security Challenges: Security Goals and Challenges, Importance of security, Classification of the threats, Security

Analytics for AMI and SCADA, Security Analytics for EMS Modules, Overview of SMT and Probabilistic Model Checking.

Security and Data Privacy in Smart Grid: Security Challenges in Smart Grid Implementation, Legal Protection of Personal Data in Smart Grid and Smart Metering Systems, Phases of smart grid system development cycle, Smart Grid Security and Privacy of Customer-Side Networks, Smart Grid Security Protection against False Data Injection (FDI) Attacks, Smart Grid Security, Secure V2G Connections, End-to-End security with devices/equipment, sensors, controllers, actuators, communication and systems.

Smart Grid Threat and Cross-Domain Risk: Smart Grid threat Landscape, Smart Grid Risk Assessment, Challenges and solutions, Emerging methods and techniques for the smart grid security.

Smart Grid Resiliency and Cyber-attack: Types of physical attack on smart grid devices, Hardware security modules, Analytics for Smart Grid Security and Resiliency, Cyber security solutions for control and monitoring system, Control centric security tools and risk assessment methodology, Secure Communications in Smart Grid: Networking and Protocols, Ukraine power plant cyberattack case study, European ENTSO-E cyberattack case study

Learning Resources:

Text Books:

1. Security and Resiliency Analytics for Smart Grids, Al-Shaer, Ehab, Rahman and Mohammad Ashiqur, Springer Intr., 1st Edition, 2016.
2. Smart Grid Security, S. Goel, Y. Hong, V. Papakonstantinou, D. Kloza, Springer-Verlag,2015, 1st Edition.

Reference Books:

1. A. Abdallah and X. Shen, Security and Privacy in Smart Grid, Springer Intr., 2018, 1st Edition.
2. Abdul Rahaman, Smart grids security challenges: Classification by sources of threat, Journal of Electrical Systems and Information Technology, 2018.
3. Roy D. Yates, David J. Goodman, Probability and Stochastic Processes: A Friendly Introduction for Electrical and Computer Engineers, Wiley, 2014, 3rd Edition.
4. J. A. Momoh, Smart Grid: Fundamentals of Design and Analysis, Wiley India, 2015, 1st Edition.

Other Suggested Readings:

1. https://onlinecourses.nptel.ac.in/noc23_ee60/preview
2. https://www.nsgm.gov.in/sites/default/files/Smart-Grid-Training-Course-July-2016.pdf