NATIONAL INSTITUTE OF TECHNOLOGY WARANGAL

SCHEME OF INSTRUCTION AND SYLLABI

FOR

M.TECH (SMART ELECRIC GRID) PROGRAM

Effective from 2020-21

DEPARTMENT OF ELECTRICAL ENGINEERING

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.

DEPARTMENT OF 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.

DEPARTMENT OF ELECTRICAL ENGINEERING
M.TECH IN SMART ELECTRIC GRID
PROGRAM EDUCATIONAL OBJECTIVES

PEO1	Design and develop independently innovative products and services in the field of Smart Grid Technologies.
PEO2	Adopt and utilize latest technologies and tools in design of Smart Grid systems.
PEO3	Communicate effectively to propagate ideas and promote teamwork
PEO4	Attain intellectual leadership skills to cater to the changing needs of power industry, academia, society and environment

Program Outcomes: At the end of the program the student will be able to:

PO1	Engage in critical thinking and pursue research/ investigations and development to solve practical problems.
PO2	Communicate effectively on complex engineering activities with the engineering community and with society at large, write and present substantial technical reports, intellectual property rights and patens.
PO3	Demonstrate higher level of professional skills to tackle multidisciplinary and complex problems related to Smart Grid Technologies.
PO4	Nurture a temperament for self-learning and to promote professionally ethical attitude needed to develop innovative, entrepreneurial, eco-friendly and sustainable Smart Grid Technologies

Program Educational Objectives

PO- PEO MAPPING

PO/PEO	PEO1	PEO2	PEO3	PEO4
PO1	3	3	2	3
PO2	2	2	3	3
PO3	3	3	2	3
PO4	3	3	2	3

Total number of credits: (99^{th} Senate guidelines)

	I Sem	II Sem	III Sem	IV Sem	Total	99^{th} Senate guidelines
Core courses	13	13	0	0	26	>=24
Elective courses	9	9	0	0	18	>=18
Seminar	1	1	0	0	2	2
Comprehensive Viva-voce	0	0	2	0	2	2
Dissertation	0	0	9	18	27	27
Total credits (Sem. wise)	23	23	11	18	75	

M. Tech (Smart Electric Grid)

SCHEME OF INSRUCTION AND EVALUATION

I Year I-Semester

S. No.	Course No	Course Title	L	T	P	Credits	Cat. Code
1.	EE5301	Elements of Smart Grid System	3	0	0	3	PCC
2.	EE5302	Microgrid Dynamics and Control	3	0	0	3	PCC
3.	EE5303	Dynamics of Renewable Energy Resources	3	0	0	3	PCC
4.		Elective-I	3	0	0	3	DEC
5.		Elective –II	3	0	0	3	DEC
6.		Elective-III	3	0	0	3	DEC
7.	EE5304	Microgrid Dynamics and Control Lab	0	1	2	2	PCC
8.	EE5305	Renewable Energy Control Lab	0	1	2	2	PCC
9.	EE5341	Seminar-I	0	0	2	1	PCC
		TOTAL	**18**	**2**	**6**	**23**	

I Year II -Semester

S. No.	Course Code	Course Title	L	T	P	Credits	Cat. Code
1.	EE5351	Smart Grid Protection	3	0	0	3	PCC
2.	EE5352	Wide Area Monitoring and Control	3	0	0	3	PCC
3.	EE5353	Smart Grid Communications and Protocols	3	0	0	3	PCC
4.		Elective –IV	3	0	0	3	DEC
5.		Elective – V	3	0	0	3	DEC
6.		Elective – VI	3	0	0	3	DEC
7.	EE5354	Smart grid Protection Lab	0	1	2	2	PCC
8.	EE5355	Smart Electric Grid Simulation Lab	0	1	2	2	PCC
9.	EE5391	Seminar – II	0	0	2	1	PCC
		TOTAL	**18**	**2**	**6**	**23**	

II-Year I - Semester

S. No.	Course Code	Course Title	Credits	Cat. Code
		Industrial Training (8-10 weeks)-**Optional**		
1	EE5342	Comprehensive Viva-voce	2	PCC
2	EE5349	Dissertation-Part-A	9	PCC
		TOTAL	11	

II-Year II - Semester:

S. No.	Course Code	Course Title	Credits	Cat. Code
1	EE5399	Dissertation-Part-B	18	PCC
		TOTAL	18	

ELECTIVES (I-Semester):

1.	EE5311	Smart Grid Planning & Operation
2.	EE5312	Advanced Control Systems
3.	EE5313	Energy Storage Systems
4.	EE5101	Analysis of Power Converters
5.	EE5103	Advanced Digital Signal Processors
6.	EE5211	Data Science Applications in Power Engineering
7.	EE5217	Machine Learning and Deep Learning
8.	EE5314	Numerical Optimization
9.	EE5315	Deregulated Smart Grids
10.	EE5316	Signal Processing in Smart Grids

ELECTIVES (II-Semester):

1.	EE5361	Grid Integration of Electric Vehicles
2.	EE5362	Adaptive and Robust Control Systems
3.	EE5153	Digital Control Systems
4.	EE5268	Evolutionary Algorithms Application in Power Engineering
5.	EE5363	Smart Appliances and Internet of Things
6.	EE5364	Smart Grid Resiliency and Cyber Security
7.	EE5365	Cloud Computing and Big Data Analytics in Smart Grids
8.	EE5366	Transactive Energy Markets
9.	EE5367	Challenges and Solutions in Renewable Integration
10.	EE5368	Smart Electrical Distribution System

DETAILED SYLLABUS

EE5301	Elements of Smart Grid System	PCC	3– 0 –0	3 Credits

Course Outcomes: After completion of the course, the student will be able to

CO1	Understand the features of Smart Grid
CO2	Assess the role of automation and digitization in Transmission and Distribution
CO3	Analyse Smart grids and Distributed energy resources(DER) with evolutionary algorithms
CO4	Understand operation and importance of data acquisition devices and their location in Voltage and Frequency control

CO-PO mapping:

	PO-1	PO-2	PO-3	PO-4
CO-1	3	2	2	2
CO-2	1	2	3	3
CO-3	2	2	3	2
CO-4	3	2	3	2

Detailed Syllabus:

Introduction to Smart Grid
Basics of power systems, definition of smart grid, need for smart grid, smart grid domain, enablers of smart grid, smart grid priority areas, regulatory challenges, smart-grid activities in India.

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

The fundamental components of Smart Grid designs, Transmission Automation , Distribution Automation , Renewable Integration

Tools and Techniques for Smart Grid
Computational Techniques – Static and Dynamic Optimization Techniques for power applications such as Economic load dispatch – Computational Intelligence Techniques – Evolutionary Algorithms in power system – Artificial Intelligence techniques and applications in power system.

Distribution Generation Technologies
Introduction to Distribution Energy Sources, Renewable Energy Technologies – Microgrids – Storage Technologies –Electric Vehicles and plug – in hybrids – Environmental impact and Climate Change – Economic Issues.

Communication Technologies in Smart Grid
Introduction to Communication Technology, Two Way Digital Communications Paradigm, Synchro-Phasor Measurement Units (PMUs) – Wide Area Measurement Systems (WAMS)- Introduction to Internet of things (IoT)- Applications of IoT in Smart Grid

Smart-cities
Smart city pilot projects, essential elements of smart cities, active distribution networks, microgrids, distribution system automation, Reliability and resiliency studies, decentralized operation of power network.

Text Books:

1. S. Borlase, "Smart Grids, Infrastructure, Technology and Solutions", CRC Press, 1st Edition, 2013.

2. G. Masters, "Renewable and Efficient Electric Power System", Wiley–IEEE Press, 2nd Edition, 2013.

Reference Books:

1. A.G. Phadke and J.S. Thorp, "Synchronized Phasor Measurements and their Applications", Springer, 2nd Edition, 2017.

2. T. Ackermann, "Wind Power in Power Systems", Hoboken, N J, USA, John Wiley, 2nd Edition, 2012.

EE5302	Microgrid Dynamics and Control	PCC	3– 0 –0	3 Credits

Course Outcomes: After completion of the course, the student will be able to

CO1	Understand components of AC and DC microgrids
CO2	Model and Analyze the behavior of Dynamic micro grids
CO3	Evaluate different hierarchical control schemes and communication between them
CO4	Analyze the influence of microgrids on electrical markets

CO-PO mapping:

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

Detailed Syllabus:

Concept of Microgrids
Introduction to the concept of microgrid, the overview of the structure and architecture of microgrid with brief control, operational aspects. Recent 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.

Power System Stability
Power system stability classification, Basic definitions of transient, dynamic, and small signal stability Generator and load modeling, modeling and analysis of SMIB systems.

Dynamic and Stability Analysis of Microgrids
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.

Hierarchical Control Scheme for Microgrids
Control Objectives in AC Microgrids, bottleneck with only local control, need of secondary and tertiary control, implementation of hierarchical control with centralized and distributed control schemes for AC and DC microgrids. Advantages and disadvantages of centralized and distributed control schemes.

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

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

Techno Economic Analysis of Microgrids
Technical, economic and environmental benefits of microgrid, Quantification of microgrids benefits under standard test conditions, market pricing and polices.

Text Books:

1. N. D. Hatziargyriou, "Microgrids Architecture and control", IEEE Press Series, John Wiley & Sons Inc, 1st Edition, 2013.

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

Reference Books:

1. A. Bidram, V. Nasirian, A. Davoudi, F. L. Lewis, "Cooperative Synchronization in Distributed Microgrid Control", Springer, 1st Edition, 2017.

2. P. Kundur, "Power System Stability and Control", McGraw-Hill, Inc., 2nd Edition, 1994.

EE5303	Dynamics of Renewable Energy Sources	PCC	3 – 0– 0	3 Credits

Course Outcomes: At the end of the course student will be able to

CO1	Understand different renewable energy sources
CO2	Evaluate dynamic models of Distributed Energy Systems
CO3	Analyze and simulate control strategies for grid connected and off-grid systems
CO4	Develop control strategies for off Grid and grid integration studies of Distributed Energy Sources**.**

CO-PO Mapping:

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

Detailed Syllabus:

Introduction
Impacts of large scale integration of renewable Energy sources. Types of conventional and nonconventional dynamic generation technologies, principle of operation and analysis of reciprocating engines, gas and micro turbines, hydro, solar and wind based generation technologies.

Solar Photovoltaic Systems
Solar Resource**,** Generic Photovoltaic Cell, Equivalent Circuits, Cells to Modules to Arrays, $I – V$ Curve, Impacts of Temperature and Insolation, Shading impacts on I–V curves, I–V Curves for different loads, MPPT, Grid-Connected Systems, Stand-Alone PV Systems, Dynamics of PV generation sources. Advances in PV controls.

Wind Energy System
Wind Energy-generating Systems, Power extraction in the Wind, Impact of Tower Height, Maximum Rotor Efficiency, Types of Wind Turbines, Fixed-speed Induction Generator (FSIG) based Wind Turbines, Doubly Fed Induction Generator (DFIG) based Wind Turbines, Fully Rated Converter-based (FRC) Wind Turbines, Dynamic modeling and analysis of wind energy system, Wind energy control system, Forecasting and techno-economic analysis of RES.

Fuel Cell
Principles of Operation of Fuel Cells, Dynamic Modeling and Simulation of PEM Fuel Cells, Dynamic Modeling and Simulation of Solid Oxide Fuel Cells, Principles of Operation and Modeling of Electrolyzers, Power Electronic Interfacing Circuits for Fuel Cell Applications, Analysis and Control of Grid Connected Fuel Cell Power Generation Systems, Control of Stand Alone Fuel Cell Power Generation Systems, Hybrid Fuel Cell Based Energy System Case Studies,

Microturbine
Operating Principle of Microgrids, Microturbine Fuel and emissions, design and component of Microturbines, control of Microturbines, Efficiency and Power of Microturbines, Application and performance of microturbines, Site Assessment for Installation of Microturbines. Case studies.

Text Books:

1. G. Masters, “Renewable and Efficient Electric Power Systems”, IEEE- John Wiley and Sons Ltd. Publishers, 2nd Edition, 2013.

2. F. A. Farret, M. G. Simoes, “Integration of Renewable Sources of Energy”, Wiley, 2nd Edition, 2017.

Reference Books:

1. C. S. Solanki, “Solar Photovoltaic: Fundamentals, technologies & Applications”, PHI Publishers, 3rd Edition, 2019.

2. O. Anaya-Lara, N. Jenkins, J. Ekanayake, P. Cartwright, M. Hughes, “Wind Energy Generation Modelling and Control”, John Wiley & Sons Publishers, Ltd, 1st Edition, 2009.

3. M. H. Nehrir, C. Wang, “Modeling and Control of Fuel Cells: Distributed Generation Applications”, Wiley-IEEE Press, 1st Edition, 2009.

4. P.E Claire Soares, “Microturbines: Applications for Distributed Energy Systems”, Elsevier Inc., 1st Edition, 2007.

EE5304	Microgrid Dynamics and Control Lab	PCC	0 – 1 – 2	2 Credits

Course Outcomes: At the end of course, student will be able to

CO1	Understand the operation of AC microgrid system power sharing and control
CO2	Understand the concept of DC microgrids and impacts of constant power loads on system
CO3	Analyze the hierarchical control for AC and DC microgrids.
CO4	Analyse the dynamic behavior of Micro grid system & its grid integrations issues

CO-PO Mapping:

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

List of Experiments

1. Simulation of Voltage and frequency control of a load connected inverter.
2. Simulation of decentralized inverter based AC microgrid with *P-f* and *Q-V* droop control.
3. Impact of droop gains on stability of the inverter based microgrids.
4. Centralized Secondary control design for inverter based AC microgrids.
5. Distributed secondary control for the inverter based AC microgrids
6. Simulation of 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 microgrid

EE5305	Renewable Energy Control Lab	PCC	0 – 1 – 2	2 Credits

Course Outcomes: At the end of course, student will be able to

CO1	Understand the Grid integration of renewable resources such as PV, Wind etc.
CO2	Understand the impacts of virtual inertia in autonomous mode with diesel generators
CO3	Analyse and evaluate the effect of additional sources (like micro turbine, ultra-capacitors) in improving the system dynamics performance
CO4	Chose and design a efficient controller for off-grid/grid fed Renewable Energy applications

CO-PO Mapping:

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

List of Experiments

1. Modeling of PV system
2. Modeling 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. Modeling and simulation of electric vehicle charging system

EE5311	Smart Grid Planning & Operation	DEC	3 – 0 – 0	3 Credits

Course Outcomes: At the end of the course, student will be able to

CO1	Understand the analysis and planning of Smart Grids
CO2	Evaluate the tools for modeling and analysis of smart grid dynamics,
CO3	Analyze and synthesize different control schemes of smart grid operation
CO4	Assess the influence of smart grid on power system

CO-PO Mapping:

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

Detailed Syllabus:

Analysis of Smart Grid System
Smart grid concepts, smart grid components and control elements, Distributed generation resources and Energy Storage, Plug-in-Hybrid Electric Vehicles (PHEV), Smart Homes, Microgrids, Load Flow study for AC/DC smart grid analysis , Economic Dispatch, State Estimation for low voltage networks, smart grid Monitoring, smart grid standards and policies.

Smart Grid Planning
Planning Aspects of smart grid, Operation and control of AC, DC and hybrid smart grid, Optimal power flow, Demand side management of smart grid, Demand response analysis of smart grid, Energy Management, Planning and Design of smart grid systems.

Voltage and Frequency Regulation of Smart Grid
Automatic generation Control, Load frequency control, Tie-line power sharing, Voltage Stability Assessment, Voltage stability Indexing, Concepts on the design of smart grid stabilizers to improve voltage stability, frequency & voltage regulations, and volt-VAR support

Operation and Control of Smart Grids
Operational aspects of smart grid system, active and reactive power response, control objectives smart distribution system, architecture and different schemes of smart grid control, bottleneck in smart grid control, Ancillary Services. Advantages and disadvantages of different control schemes.

Text Books:

1. J. Momoh, "Smart Grid: Fundamentals of Design and Analysis," Wiley-IEEE Press, 1st Edition, 2012.

2. S. K. Salman, "Introduction to the Smart Grid: Concepts, Technologies and Evolution," IET Energy Engineering Series, 1st Edition, 2017

Reference Books:

1. Mini S Thomas and J. D MacDonald, " Power System SCADA and Smart Grid," CRC Press, 1st Edition, 2015.

2. N. Hatziargyriou, "Microgrids Architecture and control", Wiley-IEEE Press Series, 1st Edition 2013.

3. D. Mah, P. Hills, Victor O.K. Li, R. Balme, "Smart Grid Applications and Developments," Springer-Verlag London, 1st Edition, 2014.

4. J. Ekanayake, N. Jenkins, K. Liyanage, J. Wu, A. Yokoyama, "Smart Grid: Technology and Applications," John Wiley & Sons, 1st Edition, 2015.

5. G. Strbac, D. K. Rodrigo Moreno, "Reliability Standards for the Operation and Planning of Future Electricity Networks," IEEE, 1st Edition, 2016.

6. Ali Keyhani, "Design of smart power grid renewable energy systems", Wiley IEEE, 2nd Edition 2016.

EE5312	Advanced Control Systems	DEC	3– 0 –0	3 Credits

Course Outcomes: After completion of the course, the student will be able to

CO1	Understand the representation of dynamic system and its behavior.
CO2	Synthesize advanced PID controller for load frequency control in Micro Grid.
CO3	Design and evaluate optimal and adoptive control schemes for Microgrids.
CO4	Design and analyze nonlinear controllers for load frequency and voltage control in Microgrid.

CO-PO mapping:

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

Detailed Syllabus:

Preliminaries

System representation- Review of Classical Control: P, PI, PID control- Review of modern control: **S**tate and state variables - State transition matrix (STM) –Controllability and observability- State variable feedback - Pole placement – Luenberg observer design-Reduced order observer-Stabilizability and Detectability- Kalman Decomposition theorem- Stability in the sense of Lyapunov (Direct Method).

Advanced PID control

The PID controller-Filtering the derivative- Setpoint weighting-Integrator Windup- Controller degrees of freedom- Model based Design methods: Direct Synthesis (DS) method, Internal Model Control (IMC) method- Stability analysis- Robustness Measures-Feedforward design: Inversion based method- Cascade Control- Fractional PID- Case Study: Load frequency control (LFC) in Micro grid system.

Optimal Control

Cost function- Linear Quadratic regulator (LQR)-Algebraic Riccatti Equation (ARE)- Discrete time systems-Development of Kalman Filter: Predictor and Corrector form- Predictive Control: Dead Beat control, Generalized Predictive Control (GPC), Model Predictive Control (MPC): Problem formulation-Recursive feasibility-Stability of MPC- Case Study: Application of MPC to Micro Grid droop control.

Introduction to Nonlinear System and its control

Characteristics of nonlinear systems- Autonomous and Non-autonomous systems- Phase Plane analysis-Classification of Equilibrium Points- Limit Cycles Existence and its condition- Existence of Periodic Orbits- Lyapunov Stability– Nonlinear controller design: Feedback Linearization- Back stepping- Case Study: Nonlinear Load Frequency control design in Microgrid.

Text Books:

1. C.T. Chen, "Linear System Theory and Design", Oxford University Press, 4th Edition, 2013.

2. K. J. Astrom, T. Hagglund, "Advanced PID Control", ISA Publisher, 1st Edition, 2006.

Reference Books:

1. Hassan K Khalil, “Nonlinear Systems”, Prentice - Hall International (UK), 3rd Edition, 2002.
2. E.F. Camacho, C.A.Bordons, “Model Predictive Control”, Springer-Verlag London, 2nd Edition, 2007.
3. D. Subbaram Naidu, “Optimal Control Systems”, CRC Press, 1st Edition, 2002
4. M. Gopal, “Modern Control Systems Theory”, New Age International Private Limited, 3rd Edition, 2014.
5. F. Borrelli,A. Bemporad, M.Morari, “Predictive Control for linear and Hybrid Systems”, Cambridge University Press, 1st Edition, 2017.

EE5313	Energy Storage Systems	DEC	3– 0 –0	3 Credits

Course Outcomes: After completion of the course, the student will be able to

CO1	Understand the characteristics of energy storage devices
CO2	Model and simulate the characteristics of energy storage systems
CO3	Explore the possibilities of deployment of energy storage systems in smart cites and electric vehicles.
CO4	Evaluate and Suggest an efficient storage system in electric transportation.

CO-PO mapping:

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

Detailed 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. Traditional generation costs and optimizations. Power flow and energy balancing in a wide area network. Economics of energy and power, tied electrical rates and demand response.

Electrochemical 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.

Mechanical Energy Storage

Pumped Hydro: Models for pumped hydro capacity and availability, System cost, capacity, conversion efficiency, and siting

Compressed Gas: 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: 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.

Thermal: Introduction to thermal storage in residential and utility scale applications including molten salts, cold reservoirs, and phase change materials, Analysis of design considerations, material selection, and application specific constraints, Applications in renewable energy at utility scale solar and geothermal power production.

Text Books:

1. S. Chowdhury, S. P. Chowdhury, P. Crossley, "Microgrids and Active Distribution Networks", IET Power Electronics Series, 2012.

2. Ali Keyhani Mohammad Marwali and Min Dai, Integration and Control of Renewable Energy in Electric Power System, John Wiley publishing company, 2nd Edition, 2010.

EE5101	Analysis of Power Converters	DEC	3 – 0 – 0	3 Credits

Course Outcomes: At the end of the course, student will be able to

CO1	Appropriate Selection of switching devices and energy Transactive/ handling components for power converters realizations.
CO2	Analyze and design power converter configurations for specific applications
CO3	Suggest efficient control techniques for low and medium power converters
CO4	Design and Evaluate power electronic converters for improved power quality

CO-PO Mapping:

CO/PO	PO-1	PO-2	PO-3	PO-4
CO1	2	2	3	2
CO2	2	2	3	2
CO3	2	2	3	2
CO4	3	2	3	3

Overview of Switching Power Devices
Static and dynamic characteristics of switching devices: BJT, MOSFET, IGBT, GTO, Wide band gap devices (GaN, SiC) - Design of driver and snubber circuit

DC-DC Converters
Non-isolated DC-DC converters: buck, boost, buck-boost, CUK converters under continuous and discontinuous conduction operation - Isolated DC-DC converters: forward, fly-back, push-pull, half-bridge and full-bridge converters - Relationship between I/P and O/P voltages - design of filter inductor and capacitors

Inverters
Single-phase and three-phase inverters - PWM techniques: single, multiple and sinusoidal PWM techniques - selective harmonic elimination, space vector modulation, current source inverter- High power inverters: Multi-pulse inverters, multi-level inverters - Diode-clamped, cascaded and Flying capacitor types, Carrier and Vector based multi-level modulation schemes -Concept of active power filters- Introduction to Matrix Converters.

Front-End (AC-DC) Converters
Conventional methods of power factor improvements: Semi-converter, extinction angle control, symmetrical angle control – active front-end converters - Single phase: Boost, voltage doubler and PWM rectifiers –voltage and current controlled three-phase PWM rectifiers

Text Books:

1. M. H. Rashid, "Power Electronics Handbook", Butterworth-Heinemann, 4th Edition, 2017.

2. N. Mohan, T.M. Undeland, W.P. Robbins, "Power Electronics: Converters, Applications", John Wiley & Sons, 3rd Edition, 2003.

Reference Books:

1. L. Umanand, “Power Electronics: Essentials and Applications”, John Wiley India, 1st Edition, 2009.
2. J. Baliga B, “Fundamentals of Power Semiconductor Devices”, Springer, 1st Edition 2008.
3. Bin Wu, “High Power Converters and AC Drives”, Wiley-Inter Science, 2nd Edition, 2017.
4. D. A Paice, “Power Electronic Converter Harmonics Multipulse Method for Clean Power”, IEEE Press, 1995

EE5103	Advanced Digital Signal Processors	DEC	3 – 0 – 0	3 Credits

Course Outcomes: At the end of the course, student will be able to

CO1	Develop and code in DSP Processors Assembly Languages
CO2	Analyze and Configure the use of Digital I/O and ADCs
CO3	Evaluate the use of Interrupts and Event Managers for PWM generation
CO4	Identify and Assess DSPs & FPGAs for real time control of Power Electronic Controllers

CO-PO Mapping:

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

Detailed Syllabus:

Introduction to the TMSLF2407 DSP Controller:
Brief Introduction to Peripherals - Types of Physical Memory - Software Tools

C2XX DSP CPU and Instruction Set:
Introduction to the C2xx DSP Core and Code Generation - The Components of the C2xx DSP Core - Mapping External Devices to the C2xx Core and the Peripheral Interface -System Configuration Registers –Memory -Memory Addressing Modes - Assembly Programming Using the C2xx DSP Instruction Set

Parallel and Serial Data Transfer:
Pin Multiplexing (MUX) and General Purpose I/O Overview - Multiplexing and General Purpose I/O Control Registers - Using the General Purpose I/O Ports, Serial Communication

Interrupt system of TMS320LF2407:
Introduction to Interrupts - Interrupt Hierarchy - Interrupt Control Registers - Initializing and Servicing Interrupts in Software, real time control with interrupts

Analog-to-Digital Converter (ADC):
ADC Overview - Operation of the ADC and programming modes **Event Managers (EVA, EVB):** Overview of the Event Manager (EV) - Event Manager Interrupts - General Purpose (GP) Timers-Compare Units - Capture Units and Quadrature Encoded Pulse (QEP) Circuitry - General Event Manager Information - PWM Signal Generation with Event Managers and interrupts, Measurement of speed with Capture Units, Implementation of Space Vector Modulation with DSP TMSLF2407A

Field Programmable Gate Arrays:
Introduction to Field Programmable Gate Arrays – CPLD Vs FPGA – Types of FPGA , Configurable logic Blocks (CLB), Input/Output Block (IOB) – Programmable Interconnect Point (PIP)- HDL programming –overview of Spartan 6 & ISE Design Suite, Implementation of PWM technique with SPARTAN-6 FPGA

Text Books:

1. Hamid A. Tolyat, “DSP based Electromechanical Motion Control”-CRC press, 1st Edition, 2004.
2. Wayne Wolf, “FPGA based system design”, Prentice hall, 1st Edition, 2005.

Reference Books:

1. Application Notes from the website of Texas Instruments
2. Spartan-6 FPGA Configurable Logic Block, 2010 3. Xilinx Spartan 6 Data sheets

EE5211	Data Science Applications in Power Engineering	DEC	3 – 0 – 0	3 Credits

Course Outcomes: At the end of the course, student will be able to

CO1	Distinguish between Algorithmic based methods and Knowledge based Methods
CO2	Able to distinguish between Artificial Neural Networks and Fuzzy Logic
CO3	Adopt Soft Computing techniques for solving Power Systems and Power Electronics and Drives Problems
CO4	Apply appropriate AI frame work for solving power systems and Power Electronics & Drives Problems

CO-PO Mapping:

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

Artificial Neural Networks (ANN): Introduction to Artificial Neural Networks - Definition and Fundamental concepts -Biological Neural Network – Modeling of a Neuron -Activation functions – initialization of weights -Typical architectures-Leaning/Training laws - Supervised learning Unsupervised learning – Reinforcement learning-Perceptron – architectures-Linear Separability – XOR Problem - ADALINE and MADALINE.

ANN Paradigms: Multi – layer perceptron using Back propagation Algorithm (BPA)-Self-Organizing Map (SOM)- Learning Vector Quantization (LVQ) - Radial Basis Function Network -Functional link network -Hopfield Network -Bidirectional Associate Memory (BAM)

Fuzzy Logic: Introduction – Classical and Fuzzy sets- Properties, Operations and relations-Fuzzy sets – Membership function – Basic Fuzzy set operations -Properties of Fuzzy sets – Fuzzy Cartesian Product - Operations on Fuzzy relations – Fuzzy logic – Fuzzy Cardinalities -Fuzzy Logic Controller (FLC): Fuzzy Logic System Components: Fuzzification- Inference Engine - Defuzzification methods.

Applications of ANN & Fuzzy Logic: Load flow studies -Economic load dispatch -Load frequency control – Single area system and two area systems -Reactive power control -Speed control of DC and AC Motors.- PWM Vector controlled drive -Speed estimation and flux estimation of induction motor

Text Books:

1. S. Rajasekaran and G. A. V. Pai, "Neural Networks, Fuzzy Systems and Evolutionary Algorithms: Synthesis and Applications", PHI, New Delhi, 2nd Edition, 2017.
2. T. J. Ross, "Fuzzy Logic with Engineering Applications", Mc Graw Hill Inc, 3rd Edition, 2011.

Reference Books:

1. Simon Haykin: Neural Networks: A Comprehensive Foundations, Pearson Edition, 2003
2. G.J. Klir and T.A. Folger: Fuzzy sets, Uncertainty and Information, PHI, Pvt. Ltd, 1994.
3. Bart Kosko: Neural Network & Fuzzy System, Prentice Hall, 1992.
4. P.D. Wasserman: Neural Computing Theory & Practice, Van Nostrand Reinhold Co. New York, 1st Edition, 1989.

EE5217	Machine Learning and Deep Learning	DEC	3– 0 –0	3 Credits

Course Outcomes: After completion of the course, the student will be able to

CO1	Understand the basic concepts of Machine Learning and Deep Learning Techniques
CO2	Distinguish between supervised learning and reinforced learning
CO3	Develop the skill in using machine learning and deep learning software for solving practical problems
CO4	Apply Machine learning and deep learning Algorithm to solve electrical Engineering Problems

CO-PO mapping:

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

Detailed Syllabus:

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

K- mean Clustering Algorithm –Gaussian Mixture Model (GMM) –Expectation Maximization (EM)- Vibrational 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.

Deep Learning

Neutral Networks- Back progress Algorithm (BPM)- Deep Architectures- Convolution Neural Networks – Convolution Layer- Pooling Layer- Normalization Layer- Fully Connected Layer- Deep belief Networks- Recurrent Neural Networks.

Use of machine learning and deep learning for forecasting of generation and demand, predicting equipment and systems malfunctions and failures.

Text Books:

1. C. Bishop, “Pattern Recognition and Machine Learning”, Springer, 2011.

2. E. Alpaydin, “Machine Learning”, MIT Press, 2010

Reference Books:

1. Ian Goodfelow, Yoshua Bengio, and Aaron Courville, Deep Learning,” MIT Press Cambridge, Massachusetts, London, England, 2016.

2. Tom, M. Mitchell, “Machine Learning”, McGraw Hill International Edition, 1997.

EE5314	Numerical Optimizations	DEC	3 – 0 – 0	3 Credits

Course Outcomes: At the end of the course, student will be able to

CO1	Understand the concepts of convex sets, convex functions and optimization problems, the concept of Duality, Lagrange dual problems, optimality condition.
CO2	Study few basic algorithms such as Descent methods, Newton's method, Conjugate direction methods, barrier method, Primal-dual methods
CO3	Understand the mixed integer non-linear problem solving methodologies, convex relaxation of non-linear non-convex problems.
CO4	Learn the applications of the optimization for power system problems such as unit commitment, economic load dispatch, optimal power flow, security constrained optimal power flow and state estimation problem

CO-PO Mapping:

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

Detailed Syllabus:

Introduction to Convex sets, function and optimization problems
Affine, convex sets, operations that preserve convexity, generalized inequalities, hyperplanes, basic convex function properties, conjugate functions, quasiconvex functions, convexity with respect to generalized inequalities. Linear optimization problems, quadratic optimization problems, geometric programming, vector optimization.

Duality
The Lagrange dual function,Lagrange dual problem, Geometric interpretation, Saddle-point interpretation, Optimality conditions, Perturbation and sensitivity analysis.

Algorithms
Unconstrained problems: Descent methods, Gradient descent method, Steepest descent method, Newton's method, Self-concordance, Conjugate direction methods.

Equality constrained problems: Newton's method with equality constraints, infeasible start Newton method

Inequality constrained problems: Logarithmic barrier function and central path, barrier method, Feasibility and phase I methods, Complexity analysis via self-concordance, Primal-dual methods

Mixed Integer programming and Convex relaxations
Condensed formulation, Smooth and disjunctive reformulations: Disjunctive constraints, Big M method, smooth binary formulation, convex hull methods, *Block-separable splitting-schemes:* MINLP splitting-schemes, MIQQP splitting-schemes, Convexification of non-convex problems, SDP relaxation, SOCP relaxation, QCQP relaxation.

Power System Optimization

Unit commitment, Economic load dispatch, Optimal power flow, Security constrained optimal power flow, State estimation problems.

Text Books:

1. S. Boyd, L. Vandenberghe, "Convex Optimization", Cambridge university press, 1st Edition, 2004.

2. David G. Luenberger, Yinyu Ye, "Linear and Nonlinear Programming", Springer Media, LLC, 3rd Edition, 2008.

Reference Books:

1. I. Nowak, "Relaxation and Decomposition Methods for Mixed Integer Nonlinear Programming", Birkhäuser Verlag, 1st Edition, 2005

2. J. Zhu, "Optimization of Power System Operation", Wiley IEEE Press, 2nd Edition, 2015.

EE5315	Deregulated Smart Grids	DEC	3-0-0	3 Credits

Course Outcomes: At the end of the course, student will be able to

CO1	Understand the need for restructured power system and economics.
CO2	Discuss and analyze transmission congestion and loss allocation in Power System
CO3	Assess the role of demand response in smart grid systems
CO4	Evaluate economics and ancillary services within the Smart Grid

CO-PO Mapping:

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

Detailed 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 and Trading Arrangements, Components of restructured systems.

Smart Grid in Power Market
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)

Definitions transfer capability issues: ATC, TTC, TRM, CBM calculations, methodologies to calculate ATC, Electricity Pricing

Smart Grid Bidding Strategies
Forward and Future market; Operation and control: Old vs New, Integrated bidding strategy in smart multi energy system, Smart grid Optimization with risk constraints-General risk measures, Portfolio selection problem, penalty formulation.

Transmission Congestion Management
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.

Demand Response in Smart Grid
Demand response, Potential benefits of demand response in smart grid, enabling smart technologies for demand response, control devices for demand response, Monitoring and communication system. Demand response for Electric Vehicles, Examples

Ancillary Services within Smart Grid Framework
Reactive power as an ancillary service, Energy Storage System, Power Quality, Reliability analysis.

Smart Grid Economic and Market Operations
Energy and Reserve Markets, Market Power, Generation Firms, Locational Marginal Prices, Financial Transmission Rights. Concepts of block chain technologies in energy trading and power purchase agreements (PPA)

Text Books:

1. L. L. Lai, "Power System Restructuring and Deregulation", John Wiley & Sons Ltd., 1st Edition, 2012

2. D. Kirschen and G. Strbac, "Fundamentals of Power System economics", John Wiley & Sons Ltd, 2nd Edition 2019.

Reference Books:

1. S. Hunt, "Making competition work in electricity", John Wiley & Sons, Inc. 1st Edition, 2002.

2. K. Bhattacharya, J. E. Daadler, and Math H.J Bollen, "Operation of restructured power systems", Kluwer Academic Pub. 1st Edition 2001 (Reprint 2012).

EE5316	Signal Processing in Smart Grids	DEC	3-0-0	3 Credits

Course Outcomes: At the end of the course, student will be able to

CO1	Understand the applications of Digital signal filtering techniques in power systems
CO2	Apply estimation techniques to evaluate power system parameters
CO3	Understand different signal decomposition techniques
CO4	Understand the WAMS signal processing

CO-PO Mapping:

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

Detailed Syllabus:

Power Systems signals in terms of Smart Grid
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 Systems and signal processing
Stochastic gradient based algorithms – LMS algorithm, Normalized LMS algorithm, Gradient adaptive lattice algorithm. Mean-squared error behavior, 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 modeling & 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.

Signal Processing Techniques Applications

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

Text Books:

1. J.G.Proakis, M. Salehi, “Advanced Digital Signal Processing”, McGraw –Hill, 1992.
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., 2nd Edition, 2014.

Reference Books:

1. S. Haykin, “Adaptive Filter Theory”, Prentice Hall, 2nd Edition, 2001.
2. J. V. Candy, Signal Processing, The Model Based Approach, McGraw-Hill Book Company, 1987
3. M. H. Hayes, “Statistical Digital Signal Processing and modeling”, John Wiley & Sons, 1996
4. Handouts on DSP Processors.
5. S. K. Mitra, Digital Signal Processing – A computer Based Approach, MGH, 2nd Edition, 2001.

II-Semester

EE5351	Smart Grid Protection	PCC	3-0-0	3 Credits

Course Outcomes: At the end of the course, student will be able to

CO1	Understand basic concepts of advanced protection systems
CO2	Design relay algorithms and associated hardware
CO3	Understand the principles of modern protection systems for substation, transformer, generator and motor
CO4	Evaluate the impact and influence of PMUs on the Protections schemes

CO-PO Mapping:

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

Detailed Syllabus:

Introduction to Advanced Protection Systems
Basics of Electrical Protection systems, Protection system in Smart Grid, Importance and challenge of protective devices in smart grid.

Relays and Hardware Consideration
Basics of digital protection and relays, Advantage of microprocessor technology and its application to protection, subsystem of digital relay, Numerical relays, Protection of substation, transformer, generators and motors. Analogue signal conditioning, low pass filters, DSP based general purpose hardware, Microcontrollers and digital relay implementation procedures.

Relaying Algorithms
Classification of relaying algorithms, Algorithms for digital relaying, Full cycle and half cycle Fourier algorithms, Walsh and Haar algorithms, least square fitting algorithm, Digital harmonic filter algorithms. Microgrid Protection using Hilbert Huang and wavelet transform.

Wide Area Protection
Differential Protection of Transmission Lines, Distance Relaying of Multiterminal Transmission Lines, Adaptive Protection, Adaptive Out-of-Step Protection, Security Versus Dependability, Transformer, Adaptive System Restoration, Control of Backup Relay Performance, Hidden Failures, Intelligent Islanding, Supervisory Load Shedding, Concept of integrated wide area monitoring and protection (WAM &WAP)

System Integrity Protection Scheme (SIPS) based on PMU Technology
SIPS architecture, SIPS data archival system, SIPS applications, Data protocols, SIPS monitoring and testing functions, Example of SIPS application based on PMU technology

Advanced Protection for Smart Grid
Distribution Grid Protection in Smart Grid Environment, Protection Needs for Modern Distribution Systems, Adaptive relay protection

Text Books:

1. A. G. Phadke and James S. Thorp, "Computer Relaying for Power systems" John Wiley and Sons, 2nd Edition, 2009.
2. Vaccaro, Alfredo Zobaa, Ahmed F, "Wide Area Monitoring, protection and control systems the enabler for smarter grids", IET publisher, 1st Edition, 2016.
3. Y. G. Paithankar and S. R. Bhide, "Fundamentals of Power System Protection" Prentice Hall of India, 2nd Edition, 2010.

Reference Books:

1. E. Amir, "Microgrids: Operation, Control, and Protection," LAP Lambert Academic Publishing, 1st Edition, 2014.
2. Badriram and V. Kharma, "Power System Protection and Switchgear", TMH, 2nd Edition, 2011.
3. B. Bhalja, R. P. Maheshwari and N. G. Chothani, "Protection and Switchgear", Oxford University Press, 1st Edition, 2011.
4. T.S. Madhava Rao, "Static Relays with Microprocessor Application", TMH, 2nd Edition, 2009.

EE5352	Wide-Area Monitoring and Control	PCC	3-0-0	3 Credits

Course Outcomes: At the end of the course, student will be able to

CO1	Understand the concepts of Phasor measurements in power system.
CO2	Understand monitoring a wide area power system using synchronized measurements and data obtained from PMUs
CO3	Evaluate the modifications in power systems operation with introduction of PMUs
CO4	Analyze wide area power system dynamics and global control.

CO-PO Mapping:

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

Detailed Syllabus:

Phasor Measurement Units
Importance of PMUs, Phasor Measurement Units and Phasor Data Concentrators

Wide Area Monitoring: WAMS concept, data collection, WAMS architecture, Monitoring systems placement, Advanced data processing.

Time-frequency representation: Hilbert–Huang analysis, Wavelet analysis, The Teager–Kaiser operator, Dynamic harmonic regression,

Multivariant multi scale analysis: Multi-signal Prony analysis, koopman analysis, Data fusion principles

Monitoring Power System Status
Power system health monitoring, Disturbance and anomaly detection, Modal-based health monitoring methods, Wide-area inter-area oscillation monitoring, High-dimensional pattern recognition-based monitoring, Voltage and reactive power monitoring

Visualization of Wide-area PMU measurements
Loss of generation oscillation event, Analysis and visualization of recorded data, Pattern recognition analysis, POD/BSS analysis, Validation of power system model, Evaluation of control performance

False data injection attacks (FDIA) and Countermeasures for Wide Area Measurement System
DC state estimation, Nonlinear SE, Bad data detection, Framework of FDIA on DC SE, Framework of FDIA on AC SE, consistency check-based FDIA detection method

Wide Area Control
Basic Framework and Operating Principle of Wide-Area Damping Control, Coordinated Design of Local PSSs and Wide-Area Damping Controller, Assessment and Choice of Input Signals for Multiple Wide-Area Damping Controllers.

Data science applications in monitoring and control in smart grid.

Text Books:

1. A. R. Messina, "Wide Area Monitoring of Interconnected Power Systems", IET publisher, 1st Edition, 2015.

2. Yong Li, D. Yang, Fang Liu, Y. Cao, "Interconnected Power Systems Wide-Area Dynamic Monitoring and Control Applications", Springer-Verlag Berlin Heidelberg, 1st Edition, 2016.

Reference Books:

1. Alfredo Vaccaro, and Ahmed F Zobaa, "Wide area monitoring, protection and control systems the enabler for smarter grids", IET publisher, 1st Edition, 2016.

2. Arun G. Phadke, James S. Thorp, "Synchronized Phasor Measurements and Their Applications", Springer International Publishing AG 2008, 2nd Edition, 2017.

3. Ma, Jing, "Power system wide-area stability analysis and control", Wiley Blackwell, Science press, 1st Edition, 2018.

EE5353	Smart Grid Communications and Protocols	PCC	3-0-0	3 Credits

Course Outcomes: At the end of the course, student will be able to

CO1	Understand the role of communication networks in Smart Grid systems
CO2	Analyze the architectures of the network communications
CO3	Evaluate advanced communication protocols for power system automation
CO4	Analyze system network security and data management.

CO-PO Mapping:

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

Detailed 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

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, Synchrophasor standard; Wireless technologies for home automation; Protocols in the power system communication: Deployed and evolving such as LPWAN, 5G etc. for networki

Text Books:

1. Kenneth C. Budka, Jayant G. Deshpandeand Marina Thottan, “Communication Networks for Smart Grids,” Springer London Heidelberg New York Dordrecht, 1st Edition, 2014.

2. Mini. S. Thomas and John D. McDonald, “Power system SCADA and smart grid,” CRC Press Taylor & Francis Group, 1st Edition, 2015

Reference Books:

1. F. Bouhafs, M. Mackay and M. Merabti, “Communication Challenges and Solutions in the Smart Grid,” Springer New York Heidelberg Dordrecht London, 1st Edition, 2014.

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, 1st Edition, 2014.

EE5354	Smart Grid Protection Lab	PCC	0–1–2	2 Credits

Course Outcomes: At the end of the course, student will be able to

CO1	Determine the characteristics of power system protection devices and Relays
CO2	Determine the performance of different protection relays
CO3	Understand the importance of wide area protection
CO4	Realize the fault ride through capabilities of renewable energy systems

CO-PO Mapping:

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

List of Experiments

1. Study and testing of following relays
   i. Overcurrent relay
   ii. Over voltage relay
   iii. 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. Programmable Relay design and operation of relay with PMU data extracted from PDC in HIL-PMU environment
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

EE5355	Smart Electric Grid Simulation Lab	PCC	0 – 1 – 2	2 Credits

Course Outcomes: At the end of course, student will be able to

CO1	Understand the PMU monitoring and data visualization
CO2	Understand the role of PMUs and PDCs in wide area monitoring, protection and control
CO3	Demonstrate and suggest an optimal PMU positioning for the system observability

CO-PO Mapping:

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

List of Experiments

1. Optimal PMU placements for proper monitoring of power system
2. DC state estimation
3. Hybrid state estimation
4. Design of virtual PMU in MATLAB
5. Data capturing from PMU using 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 Kundur system
9. Real time wide area control of two area system
10. Attack Detection using DC state estimation

EE5361	Grid Integration of Electric Vehicles	DEC	3– 0 –0	3 Credits

Course Outcomes: At the end of the course, the student will be able to

CO1	Understand the Electric Vehicle concepts and its importance in power system.
CO2	Assess the role of EV in modern distribution system and smart grids
CO3	Understand the technology, design methodologies and control strategy of hybrid electric vehicles
CO4	Understand operation and importance of EVs in Grid Applications, grid balancing, ancillary services and demand response

CO-PO mapping:

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

Detailed Syllabus:

Fundamentals of Electric Vehicles (EV)
Introduction to Electric Vehicle technology – Types –Fundamental issues related to electric vehicles (EVs) and hybrid electric vehicles (HEVs) – Interdisciplinary Nature of EVs – State of the Art of EVs – Advantages and Disadvantages – Challenges and Key Technologies of EVs – Challenges for EV Industry in India

Electric Vehicle Batteries
Electric vehicle battery efficiency – type – capacity –charging/discharging –technical characteristics – performance – testing, EV battery for stationary applications (B2U).

Charging Techniques
Architecture/Components of EV charging station –EVSE (Electric Vehicle Supply Equipment) – Type of EV Chargers – Charging Methods – Automotive networking and communication, EV and EV charging standards.

Grid Applications
Concept of Vehicle to Grid (V2G/G2V)–Ancillary Services – peak saving – load-generation balance – Demand Response – Energy time shift – Energy Management strategies and its general architecture – integration of EVs in smart grid, social dimensions of EVs.

Advanced Topics
Different design and control aspects of electric drives and chargers for EVs and HEVs, Battery Charger Topologies, and Infrastructure for Plug-In-Electric and Hybrid Vehicles –Impact of Plug-in Hybrid Electric Vehicles on smart Grid/Distribution Networks – Sizing Ultra capacitors for Hybrid Electric Vehicles, concept of vehicle to Home (V2H), Effect of charging infrastructure on grid protection and control

Text Books:

1. James Larminie, John Lowry, “Electric Vehicle Technology Explained”, Wiley-Blackwell, 2^{nd} Edition, 2012.
2. Sheldon S. Williamson, “Energy Management Strategies for Electric and Plug-in Hybrid Electric Vehicles”, Springer, 1^{st} Edition, 2016

References:

1. Sandeep Dhameja, “Electric Vehicle Battery Systems,” Elsevier, 1^{st} Edition, 2012.
2. Ali Emadi, “Advanced Electric Drive Vehicles,” CRC Press, 1^{st} Edition, 2017.
3. Iqbal Hussain, “Electric & Hybrid Vehicles Design Fundamentals”, 2^{nd} Edition, CRC Press, 2011.
4. Chris Mi, M. Abul Masrur, D. Wenzhong Gao, A Dearborn, “Hybrid electric Vehicles Principles and applications with practical perspectives,” John Wiley & Sons Ltd., 2^{nd} Edition, 2017.
5. T. Muneer and I. Illescas García, “The automobile, In Electric Vehicles: Prospects and Challenges”, Elsevier, 1^{st} Edition, 2017.
6. S. Rajakaruna, F. Shahnia, and A. Ghosh, “Plug In Electric Vehicles in Smart Grids”, Springer Singapore, 1^{st} Edition, 2015.
7. J. Lu, and J. Hossain, “Vehicle-to-Grid: Linking electric vehicles to the smart grid”, IET, 1^{st} Edition, 2015
8. N. B. Arias, S. Hashemi, P. B. Andersen, C. Træholt, and R. Romero, “Distribution System Services Provided by Electric Vehicles: Recent Status, Challenges, and Future Prospects”, IEEE Transactions on Intelligent Transportation Systems, 2019, (early access)

EE5362	Adaptive and Robust Control Systems	DEC	3-0-0	3 Credits

Course outcomes: At the end of course, student will be able to

CO1	Understand the fundamental concepts of adaptive and Robust control system
CO2	Design the adaptive controllers for Micro Grid system
CO3	Suggest robust control and design robust droop controller using loop shaping methods
CO4	Design and apply nonlinear robust controller with suitable and efficient control approach for Micro Grids

CO-PO Mapping:

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

Detailed Syllabus:

Introduction
Overview of Adaptive Control-Adaptive Schemes-Formulation of Adaptive Control problem-Preliminaries: Lyapunov stability-Parameter Estimation**:** Least squares and Regression models-Recursive least squares (RLS)- Estimating parameters in Dynamic systems- Convergence of Parameter Estimation algorithms- Prediction error (PE) model structures-One step ahead PE method.

Self Tuning Regulator (STR)/ Model Reference Adaptive Systems (MRAS)
Certainty Equivalent Principle-Pole placement design- direct self-tuning regulators -Indirect self tuning regulators, continuous time self-tuners, Hybrid self tuners- disturbances with known characteristics- The MIT rule- Determination of Adaptation gain- Design of MRAS using Lyapunov theory- Relationship between MRAS and STR.

Auto Tuning and Gain Scheduling
Auto tuning Principle and Techniques, Transient response methods- Methods based on Relay feedback-Relay Oscillation- Gain scheduling: the principle - Design of Gain scheduling controllers- Case Study: Adaptive droop control of Microgrid.

Robust Control
Types of Uncertainty -Kharitonov Theorem: Applications to Robust PI/PID controller design- Robust Stability /Performance Condition- H_2 and H_∞ norms-Concept of Loop shaping-Controller design using the loop shaping methods: H_∞ Control, Quantitative feedback theory (QFT)- Case Study: Loop shaping methods to Robust droop control of Microgrid.

Sliding Mode Control (SMC)
Motivation-Matched and Unmatched Uncertainty-Sliding surface design- Stability of SMC- Equivalent control concept- Integral Sliding Mode Control (ISMC)- Composite nonlinear feedback (CNF) controller-Application of SMC to Load frequency control in Microgrid.

Text Books:

1. K.J. Astrom, B. Wittenmark, "Adaptive Control", Addison-Wesley, 2nd Edition, 1995.
2. I. Postlethwaite, S.Skogestad, "Multivariable Feedback control: Design and Analysis", Wiley Publisher, 2nd Edition, 2014.

Reference Books:

1. P.A. Ioannou, J. Sun, "Robust Adaptive Control", Dover Publications, 2nd Edition, 2013.
2. C. Edwards, S.K. Spurgeon, "Sliding Mode Control: Theory and Applications", Taylor and Francis Publisher, 1st Edition, 1998
3. I.D. Landau, R. Lozano, and M. M'Saad, A. Karimi, "Adaptive Control: Algorithms, Analysis and Applications", Springer, 2nd Edition, 2011.

EE5153	Digital Control Systems	DEC	3-0-0	3 Credits

Course outcomes: At the end of course, student will be able to

CO1	Evaluate the output of a digital system for a given input.
CO2	Describe the dynamics of a Linear, Time Invariant and Causal digital systems through difference equations
CO3	Analyze digital systems using the Z-transformation
CO4	Design digital controllers for Power Electronic Systems

CO-PO Mapping:

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

Detailed Syllabus:

Introduction:
Digital control systems - Quantizing and quantization error - Data acquisition - Conversion and distribution system

Z-Transform:
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:
State space representation of digital control systems - Solution of discrete time state space equations - Pulse transfer function matrix – Discretization of continuous time state space equations - Lyapunov stability analysis

Pole Placement & Observer Design:
Controllability - Observability

Quadratic Optimal Control Systems:
Design via pole placement - State observer. - Quadratic optimal control - Steady state quadratic optimal control - Quadratic optimal control of a servo system

Text Books:

1. M. Gopal, "Digital control engineering", New Age Int. Ltd., India, 2nd Edition, 2014.

2. K. Ogata**, "**Discrete time control systems"**,** Pearson Education, 2nd Edition, 2015.

Reference Books:

1. K. Ogata, **"**Modern control engineering" Pearson Education India, 5th Edition, 2015.
2. B. C. Kuo**, "**Digital control systems" Oxford University Press, 2nd Edition, 2012.

EE5268	Evolutionary Algorithms Application in Power Engineering	DEC	3-0-0	3 Credits

Course Outcomes: At the end of the course, students will be able to

CO1	Discriminate the capabilities of bio-inspired system and conventional methods in solving Optimisation problems.
CO2	Examine the importance of exploration and exploitation swarm intelligent system to attain near global optimal solution.
CO3	Distinguish the functioning of various swarm intelligent systems.
CO4	Employ various bio-inspired algorithms for Power systems engineering applications.

CO-PO Mapping:

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

Detailed 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 Algorithms and Differential evolution
Artificial Bee Colony (ABC) Algorithm Binary ABC Algorithm- ACO and ABC algorithms for solving Economic dispatch of thermal Units, Motivation for differential Evolution (DE), Introduction to parameter optimization, single point, derivative based optimization, Local vs Global optimization, Differential mutation, Recombination, Selection, Benchmarking differential evolution, DE vs other Optimizers, DE and 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- memeplex 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 to power systems.

Advanced Techniques
Soft sensor concepts in power systems

Text Books:

1. Xin-She Yang, "Recent Advances in Swarm Intelligence and Evolutionary Computation," Springer International Publishing, Switzerland, 2015.
2. Kalyanmoy Deb, "Multi-Objective Optimization using Evolutionary Algorithms," John Wiley & Sons, 2001.
3. James Kennedy and Russel E Eberheart, "Swarm Intelligence," The Morgan Kaufmann Series in Evolutionary Computation, 2001.

Reference Books:

1. Eric Bonabeau, Marco Dorigo and Guy Theraulaz, "Swarm Intelligence-From natural to Artificial Systems," Oxford University Press, 1999.
2. David Goldberg, "Genetic Algorithms in Search, Optimization and Machine Learning," Pearson Education, 2007.
3. Konstantinos E. Parsopoulos and Michael N. Vrahatis, "Particle Swarm Optimization and Intelligence: Advances and Applications," Information science reference, IGI Global, 2010.
4. N P Padhy, "Artificial Intelligence and Intelligent Systems," Oxford University Press, 2005.

Reference Papers:

1. Muzaffar eusuff, Kevin lansey and Fayzul pasha, Engineering Optimization "Shuffled frog-leaping algorithm: a memetic meta-heuristic for discrete optimization", Taylor & Francis, Vol. 38, No. 2, pp.129–154, March 2006.
2. "A New Metaheuristic Bat-Inspired Algorithm" by Xin-She Yang, Nature Inspired Cooperative Strategies for Optimization (NISCO 2010) (Eds. J. R. Gonzalez et al.), Studies in Computational Intelligence, Springer Berlin, 284, Springer, 65-74 (2010).
3. Xin-She Yang, O. Watanabe and T. Zeugmann (Eds.) "Firefly Algorithms for Multimodal Optimization", Springer-Verlag Berlin Heidelberg, pp. 169–178, 2009.

EE5363	Smart Appliances and Internet of Things	DEC	3-0-0	3 Credits

Course Outcomes: At the end of the course, students will be able to

CO1	Understand and Evaluate the characteristics of smart home appliances.
CO2	Understand the behavior of IoT and their applications
CO3	Manage smart communication systems with multiple sensors and protocols
CO4	Design and simulate smart homes and smart cities with IoTs and cloud computing

CO-PO Mapping:

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

Detailed Syllabus:

Modern Domestic 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.

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.

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.

Text Books:

1. Vinod Kumar Khanna, “Fundamentals of Solid State Lighting”, CRC press, 1st Edition, 2014.

2. Chang-liang Xia, “Permanent Magnet Brushless DC Motor Drives and Controls”, John Wiley & Sons Singapore Pte. Ltd, 1st Edition, 2012.

3. K. Siozios, D. Anagnostos, D. Soudris, E. Kosmatopoulos, “IoT for Smart Grids Design Challenges and Paradigms”, Springer, 1st Edition, 2019.

References:

1. Craig Di Louie, “Advanced Lighting Controls: Energy Saving Productivity, Technology & Applications”, Fairmont Press, Inc., 1st Edition, 2006.

2. Robert S Simpson, “Lighting Control: Technology and Applications”, Focal Press, 1st Edition, 2003.

3. Arturas Zukauskus, Michael S. Shur & Remis Gaska, “Introduction to solid state lighting”, Wiley-Interscience, 1st Edition, 2002.

4. Mohan, Undeland and Robbins, “Power Electronics: Converters, Applications and Design”, John Wiley and Sons, 1st Edition, 1989.

5. www.aboutlightingcontrols.org.

6. www.ti.com

EE5364	Smart Grid Resiliency and Cyber Security	DEC	3-0-0	3 Credits

Course Outcomes: At the end of the course, students will be able to

CO1	Understand the key technical threat types, communication protocols and resilient smart grid architectures
CO2	Deploy risk management, operational security and secure development of Smart Grid.
CO3	Assess static and dynamic security analysis techniques to validate
CO4	Verify smart grid security and resiliency

CO-PO Mapping:

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

Detailed Syllabus

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

Text Books:

1. Al-Shaer, Ehab, Rahman and Mohammad Ashiqur, "Security and Resiliency Analytics for Smart Grids', *Springer Intr.*, 1st Edition, 2016.

2. S. Goel, Goel, Y. Hong, V. Papakonstantinou, D. Kloza, "Smart Grid Security", *Springer-Verlag*, 1st Edition, 2015

Reference Books:

1. A. Abdallah and X. Shen, “Security and Privacy in Smart Grid”, *Springer Intr.*, 1st Edition, 2018.
2. Abdul Rahaman *et al.,* ‘Smart grids security challenges: Classification by sources of threat’, Journal of Electrical Systems and Information Technology, 5 (3), pp. 468-483, 2018.
3. A. Abur and A. G. Exposito, “Power System State Estimation: Theory and Implementation”, CRC Press, 1st Edition, 2004.
4. Roy D. Yates, David J. Goodman, “Probability and Stochastic Processes: A Friendly Introduction for Electrical and Computer Engineers”, Wiley, 3rd Edition, 2014.
5. J. A. Momoh, “Smart Grid: Fundamentals of Design and Analysis” Wiley India, 1st Edition, 2015

EE-5365	Cloud Computing & Big Data Analytics in Smart Grids	DEC	3-0-0	3 Credits

Course Outcomes: At the end of the course, students will be able to

CO1	Enumerate research integrating cloud computing and big data applications for smart grid
CO2	Analyze the benefits of cloud computing and big data analytics for smart grid technology
CO3	Explore applications of big data and cloud computing
CO4	Evaluate current status of smart grid simulation tools

CO-PO Mapping:

CO/PO	PO-1	PO-2	PO-3	PO4
CO-1	2	2	2	2
CO-2	2	2	3	3
CO-3	3	2	3	3
CO-4	3	2	3	3

Detailed Syllabus:

Introduction
Introduction to Cloud Computing in Smart Grid - Introduction to Big Data Analytics - Fundamental Mathematical Prerequisites, Big Data Era, 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

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.

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
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.

Text Books:

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

Reference Book:

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

EE5366	Transactive Energy Markets	DEC	3-0-0	3 Credits

Course Outcomes: At the end of the course, student will be able to

CO1	Understand Transactive Energy (TE)
CO2	Understand Transactive Energy Resources
CO3	Detail TE Techniques
CO4	Model TE and understand it's application

CO-PO Mapping:

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

Detailed Syllabus:

Introduction to Transactive Energy (TE)
Potential impact of TE, Applications for Utilities and Distribution System Operators, Customer Applications

Renewable energy sources in a Transactive Energy market
Transactive Energy Products, Transactive Energy Market Participants, Transactive Energy Classification scheme for renewable market participants, Grid stability and protection, energy market management

Transactive Energy Techniques
Conceptual View of Distributed Power Generation and Management Transactive Energy Construct, End-to-End Transactions of Information, Prices and Power, Centralized and Decentralized Transactive Energy

Extension of Transactive Techniques from Wholesale to Retail
Price-based resource scheduling and dispatch, Congestion management, Transmission/distribution capacity auction, Market-clearing and pricing, End-to-End Transactive Solutions Closing the Gap between Wholesale and Retail.

Mathematical Modeling and Economic Interpretation of Transactive Energy-based distribution system, case studies

Transactive Energy Application to Modern Grid and concept of block chain techniques

Text Books:

1. S. O. Muhanji, A.E. Flint, A. M. Farid, "eIoT: The Development of the Energy Internet of Things in Energy Infrastructure, Springer, 1st Edition, 2019.

2. S. Barrager, E. Cazalet, “Transactive Energy: A Sustainable Business and Regulatory Model for Electricity”, Baker Street Publishing, 1st Edition, 2014.

References:

1. P. H. Divshali, B. J. Choi, H Liang, “Multi-agent transactive energy management system considering high levels of renewable energy source and electric vehicles”, IET Generation, Transmission and Distribution, Vol. 11, No. 15, pp. 3713-3721, 2017.

2. ‘Transactive Control and Coordination of Distributed Assets for Ancillary Services’, U.S. Department of Energy, September 2013.

3. https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-22942.pdf

4. T. Sahin and D. Shereck, "Renewable energy sources in a transactive energy market,” The 2014 2nd International Conference on Systems and Informatics (ICSAI 2014), Shanghai, pp. 202-208, 2014.

5. Z. Liu, Q. Wu, S. Huang and H. Zhao, “Transactive energy: A review of state of the art and implementation,” 2017 IEEE Manchester Power Tech, Manchester, pp. 1-6, 2017.

6. P. H. Divshali, B. J. Choi and H. Liang, “Multi-agent transactive energy management system considering high levels of renewable energy source and electric vehicles,” in IET Generation, Transmission & Distribution, vol. 11, no. 15, pp. 3713-3721, 2017.

7. F. Lezama, J. Soares, P. Hernandez-Leal, M. Kaisers, T. Pinto and Z. Vale, “Local Energy Markets: Paving the Path Toward Fully Transactive Energy Systems,” in IEEE Transactions on Power Systems, vol. 34, no. 5, pp. 4081-4088, Sept. 2019.

8. R. Ghorani, M. Fotuhi-Firuzabad and M. Moeini-Aghtaie, "Main Challenges of Implementing Penalty Mechanisms in Transactive Electricity Markets," in IEEE Transactions on Power Systems, vol. 34, no. 5, pp. 3954-3956, Sept. 2019.

EE5367	Challenges and Solutions in Renewable Integration	DEC	3-0-0	3 Credits

Course Outcomes: At the end of the course, students will be able to

CO1	Understand the available grid Codes for the renewable integration in multiple countries
CO2	Understand market and forecasting challenges due to uncertainties in renewables
CO3	Assess power quality and inertia issues with increased penetration of RES in electric grids
CO4	Evaluate solutions and apply for RES operational and uncertainty issues

CO-PO Mapping:

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

Detailed 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.

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, an hour with negative prices for downward regulation, Challenges to participation in the tertiary reserve market, 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, Regulation-up and -down reserve service

Photovoltaic Penetration in Distribution Network
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 system with MPPT controllers, mathematical model of grid connected three phase SPV system, performance evaluation of P&O and INC based MPPT algorithms, application of adaptive neuro fuzzy inference system (ANFIS) for control of DC-DC convertor for SPV system.

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, Scandinavian Experience of Integrating Wind Generation in Electricity Market, Economics of renewable generation integration and long term power purchase agreements (PPA)

Solution for RES Uncertainties
Enabling and disruptive technologies for renewable integration, Enhancing situation awareness in power systems: 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, Derated operation of the renewable resources.

Text Books:

1. J. Hossain and A. Mahmood, *Renewable energy integration: Challenges and Solutions,* Springer-Verlag, 2014 Edition, 2014.

2. L. E. Jones, “Renewable Energy Integration Practical Management of Variability, Uncertainty, and Flexibility in Power Grids”, Elsevier Inc., 2nd Edition, 2017.

References

1. L. Bird, M. Milligan, and D. Lew, “Integrating Variable Renewable Energy: Challenges and Solutions”, Technical Report NREL/TP-6A20-60451 September 2013.

2. Akshay Urja, “Challenges to Grid Integration of Renewable Energy in India”, MNRE technical report, 2019.

3. F. Katiraei and J. R. Aguero, “Solar PV Integration Challenges,” *IEEE Power and Energy Magazine*, vol. 9, no. 3, pp. 62-71, May-June 2011.

4. L. Xie *et al*., “Wind Integration in Power Systems: Operational Challenges and Possible Solutions,” in *Proceedings of the IEEE*, vol. 99, no. 1, pp. 214-232, Jan. 2011.

EE5368	Smart Electrical Distribution System	DEC	3-0-0	3 Credits

Course Outcomes: At the end of the course, students will be able to

CO1	Understand structure and load patterns of a power distribution system
CO2	Model and analyze modern smart power distribution system
CO3	Analyze the performance of distribution power flow and short circuit studies
CO4	Suggest/follow Regulations and Market Models for Smart distribution system

CO-PO Mapping:

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

Detailed Syllabus:

Introduction
Fundaments of the Electrical Power Distribution System and feeder configuration, Distribution system loading, Load Characteristics, SAIDI, SAIFI, Distribution Transformer, Single phase and three Phase Transformer connections.

Distribution system Modeling
Impedance of distribution system, Modeling of distribution line, cables, Distribution Transformer, Distributed generation, loads and reactive power sources. Modeling and study of voltage regulators in distribution network.

Distribution System Analysis
Load flow for distribution system: Backward/forward method, Direct method, load flow application for weakly meshed distribution system, Short Circuit analysis: Sequence based, Thevenin Equivalent and Phase variable based, LG, LL, LLG, LLLG fault analysis and its applications.

Smart Distribution Technologies
Distribution automation, outage management systems, automated meter reading (AMR), automated metering infrastructure (AMI), Net Metering, Automated Fault Location, Isolation and Service Restoration, Outage Management Systems (OMS), Energy Storage, Renewable Integration, Microgrids. Impacts of microgrids, EV charging and roof top solar in smart electric distribution system.

Regulations and Market Models for Smart Distribution System
Demand Response, Tariff Design, Time of the day pricing (TOD), Time of use pricing (TOU), Consumer privacy and data protection, consumer engagement etc. Cost benefit analysis of smart grid projects.

Text Books:

1. A.S. Pabla, "Electric Power Distribution", Tata McGraw Hill Publishing Co. Ltd., 4th Edition, 2017

2. Abdelhay A. Sallam and Om P. Malik, “Electric Distribution Systems,” IEEE Press Series, 2nd Edition, 2019.

Reference Books:

1. W. H. Kersting, “Distribution System Modeling and Analysis”, CRC Press, 4th Edition, 2017.

2. John D. McDonald (Editor), “Electric Power Substations Engineering”, CRC Press, 3rd Edition, 2016.

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