7TH SEMESTER

EEL 4101 ELEMENTS OF SMART GRID SYSTEM

L-T-P: 3-0-0 **Credit: 3**

Course Outcomes:

- Understand the features of Smart Grid.
- Assess the role of automation and digitization in the Transmission and Distribution
- Analyze Smart grids and Distributed energy resources (DER) with evolutionaryalgorithms.
- Understand the operation and importance of data acquisition devices and their location in Voltage and Frequency control

1. Introduction to Smart Grid

Basics of power systems, the 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.

Lectures: 4

2. 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, and advanced metering infrastructure. The fundamental component of Smart Grid designs, Transmission Automation, Distribution Automation, and Renewable Integration.

Lectures: 6

3. 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 the power system – Artificial Intelligence techniques and applications in power system.

Lectures: 8

4. 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.

Lectures: 6

5. 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.

Lectures: 6

6. Smart-cities

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

Lectures: 6

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.

EEL 4102 DYNAMICS OF RENEWABLE ENERGY RESOURCES

L-T-P: 3-0-0 **Credit: 3**

Course Outcomes:

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

1. Introduction

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

Lectures: 6

2. 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.

Lectures: 8

3. 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.

Lectures: 8

4. 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.

Lectures: 8

5. Microturbine

Operating Principle of Micrograds, 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.

Lectures: 6

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 GenerationModelling and Control", John Wiley & Sons Publishers, Ltd, 1st Edition, 2009.
3. M. H. Nehrir, C. Wang, "Modeling and Control of Fuel Cells: Distributed GenerationApplications", Wiley-IEEE Press, 1st Edition, 2009.
4. P.E Claire Soares, "Microturbines: Applications for Distributed Energy Systems", Elsevier Inc.,1st Edition, 2007.

EEL 4103 ANALYSIS OF POWER CONVERTERS

L-T-P: 3-0-0 **Credit: 3**

Course Outcomes:

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

1. 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.

Lectures: 6

2. 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.

Lectures: 10

3. 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.

Lectures: 10

4. 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.

Lectures: 10

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

EEP 4103 MODELING AND SIMULATION LABORATORY

L-T-P: 0-0-3 **Credit: 1.5**

Course Outcomes:

- Able to use MATLAB, PSIM, and PSCAD.
- Able to program the Modeling and Simulation of various Electrical circuits.
- Exposed to the use of Graphical User Interfaces like SIMULINK etc., for Modeling and Simulation.

List of Experiments

1. To design the gain parameters for a PI and PID controller for a SISO system in MATLAB SIMULINK.
2. To design a Buck- Boost converter in continuous, discontinuous, and critical conduction modes in PSPICE/PSIM.
3. To find the load flow parameters using Newton-Raphson Method in MATLAB.
4. To fast decoupled load flow in MATLAB.
5. To find DC load flow using ETAP.
6. To find economic dispatch problems considering transmission loss in MATLAB.
7. Study of limit cycle analysis of Non-linear system.
8. To model an alternator in SIMULINK.
9. To design an overall system comprising generation transmission and distribution in SIMULINK.
10. Design of State feed back control of DC motor.
11. Design of State feedback control inverted pendulum and EMLS. 12. Transient Study of Induction Motor.

Prescribed Text Book

1. K. Ogata, Modern Control Engineering, Pearson Education, 2009
2. M. Gopal, Digital Control and State Variable Methods, Tata McGraw Hill, 2003
3. D.P. Kothari & J.S Dhillon, Power System Optimization, 2nd Edition, PHI, 2005.
4. M. H. Rashid, Power Electronics-Circuits, Devices and Applications, 3rd Edition, PHI, 2005
5. Mathwork, ETAP, ORCAD-PSPICE manual

EEP 4104 RENEWABLE ENERGY CONTROL LABORATORY

L-T-P: 0-0-3 **Credit: 1.5**

Course Outcomes:

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

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 the varying wind, and grid conditions.
7. PV+BESS+Diesel generator simulation with virtual inertia in autonomous mode.
8. Use of ultra-capacitors to improve the dynamic performance of PV+BESS+Diesel generatorautonomous 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 the electric vehicle charging system

Prescribed Text Books

1. S. Rao and B.B. Parulekar, Energy Technology, Khanna Publishers, 2002.
2. G.D Rai, Non-conventional Energy Sources, Khanna Publishers, 2002.
3. S.P. Sukhatme, Solar Energy, Tata McGraw-Hill Publishing Co. Ltd., 2003

Additional Readings

1. Thomas Ackermann, Wind Power in Power System, John Willey &Sons, 2005.
2. Rai G.D., Non - Conventional Energy Sources, Khanna Publishers, 1993.
3. Rai G.D., Solar Energy Utilisation, Khanna Publishers, 1993.

8TH SEMESTER

EEL 4201 SMART GRID PROTECTION

L-T-P: 3-0-0 **Credit: 3**

Course Outcomes:

- Understand basic concepts of advanced protection systems.
- Design relay algorithms and associated hardware.
- Understand the principles of modern protection systems for substations, transformers, generators, and motors.
- Evaluate the impact and influence of PMUs on the Protections schemes.

1. Introduction to Advanced Protection Systems

Basics of Electrical Protection systems, Protection system in Smart Grid, Importance and challenge ofprotective devices in smart grid.

Lectures: 2

2. Relays and Hardware Consideration

Basics of digital protection and relays, Advantages of microprocessor technology and its application to protection, the subsystem of the digital relay, Numerical relays, Protection of the substation, transformer, generators, and motors. Analog signal conditioning, low pass filters, DSP-based general-purpose hardware, Microcontrollers, and digital relay implementation procedures.

Lectures: 8

3. Relaying Algorithms

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

Lectures: 4

4. 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).

Lectures: 8

5. System Integrity Protection Scheme (SIPS) based on PMU Technology

SIPS architecture, SIPS data archival system, SIPS applications, Data protocols, SIPS monitoring andtesting functions, Example of SIPS application based on PMU technology.

Lectures: 7

6. Advanced Protection for Smart Grid

Distribution Grid Protection in Smart Grid Environment, Protection Needs for Modern DistributionSystems, Adaptive relay protection.

Lectures: 7

Text Books:

1. A. G. Phadke and James S. Thorp, "Computer Relaying for Power systems" John Wiley and Sons, 2ndEdition, 2009.
2. Vaccaro, Alfredo Zobaa, Ahmed F, "Wide Area Monitoring, protection and control systems theenabler 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, 1stEdition, 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 UniversityPress, 1st Edition, 2011.
4. T.S. Madhava Rao, "Static Relays with Microprocessor Application", TMH, 2nd Edition, 2009.

EEL 4202 SMART GRID COMMUNICATIONS AND PROTOCOLS
L-T-P: 3-0-0 Credit: 3

Course Outcomes:

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

1. 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.

Lectures: 6

2. 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.

Lectures: 8

3. 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.

Lectures: 6

4. 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;

Lectures: 8

5. 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 networking.

Lectures: 8

Text Books:

1. Kenneth C. Budka, Jayant G. Deshpande and 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.

EEP 4203 SMART GRID PROTECTION LABORATORY

L-T-P: 0-0-3 **Credit: 1.5**

Course Outcomes:

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

List of Experiments

1. Study and testing of the 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 a 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

Text Books:

1. Microgrids Architecture and control, N. D. Hatziargyriou, IEEE Press Series, John Wiley & Sons Inc, 2013, 1st Edition.
2. Microgrid Dynamics and Control, H. Bevrani, B. François, and T. Ise, John Wiley & Sons, 2017, 1st Edition.

Reference Books:

1. Cooperative Synchronization in Distributed Microgrid Control, Bidram, V. Nasirian, A. Davoudi, F. L. Lewis, Springer, 2017, 1st Edition.
2. Power System Stability and Control, P. Kundur, McGraw-Hill, Inc., 1994, 2nd Edition

LIST OF DEPARTMENTAL ELECTIVES: for SEMESTER- VII

EEL 4X10 SMART GRID PLANNING AND OPERATION
L-T-P: 3-0-0 **Credit: 3**

Course Outcomes:

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

1. 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.

Lectures: 10

2. 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 the smart grid, Demand response analysis of smart grid, Energy Management, Planning and Design of smart grid systems.

Lectures: 8

3. 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.

Lectures: 9

4. 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, a bottleneck in smart grid control, and Ancillary Services. Advantages and disadvantages of different control schemes.

Lectures: 9

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.

EEL 4X11 MODERN CONTROL SYSTEMS

L-T-P: 3-0-0 Credit: 3

Course Outcomes:

- Developing and analyzing state space models.
- Study the nonlinear system behavior by phase plane and describe function methods.
- Study the stability of linear and nonlinear systems by the Lyapunov method.
- Understand mathematical models of linear discrete-time control systems using transfer functions and state-space models.

1. State Variable Analysis and Design:

State space models, state space representation of simple electrical and mechanical systems, canonical forms, solution of state equation, state transition matrix, the relation between transfer function and state variable representations; controllability and observability, pole-placement using state variable feedback; design of full order and reduced order observer, observer-based and state feedback controller, optimal control concept, solution of a linear quadratic regulator.

Lectures: 12

2. Sample Data Control System:

Mathematical preliminaries- difference equations, Z Transform and properties; sampling quantization and reconstruction process, discrete-time systems, system response, transfer function stability, bilinear transformation and the jury stability criterion, implementation of digital controllers and digital controllers for deadbeat performance. Root loci - Frequency domain analysis - Bode plots - Gain margin and phase margin - Design of Digital Control Systems based on Root Locus Technique, state space analysis of a discrete system.

Lectures: 12

3. Nonlinear Control Systems:

Characteristics of nonlinear systems; linearization techniques; phase plane analysis, singular points, limit cycle vs closed trajectory; stability analysis using phase plane analysis- describing function (DF) of common nonlinearities, stability analysis using DF; stability in the sense of Lyapunov, Lyapunov's stability theorems for linear and nonlinear systems; effect of non-linearity in root locus and Nyquist plot. Introduction to Modern Nonlinear control system. Introduction to a modern nonlinear control system.

Lectures: 12

Readings:

Prescribed Text Books

1. K. Ogata, Modern Control Engineering, Pearson Education, 2009
2. M. Gopal, Digital Control and State Variable Methods, Tata McGraw Hill, 2003
3. H.K.khalil, Nonlinear Systems, prentice, 3rd Edition.

Additional Readings

1. R. C. *Dorf* and R. H. *Bishop*, *Modern Control Systems*, Prentice Hall, 2010.
2. B C. *Kuo*, *Digital Control Systems*, Oxford University Press, 1995
3. M. Gopal, Modern Control System Theory, New Age International, 1993

EEL 4X12 DEREGULATED SMART GRIDS

L-T-P: 3-0-0 **Credit: 3**

Course Outcomes:

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

1. Restructuring of the power industry and Fundamentals of Economics

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

Lectures: 6

2. 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.

Lectures: 8

3. Smart Grid Bidding Strategies

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

Lectures: 6

4. 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, and Price area congestion management.

Lectures:4

5. 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.

Lectures: 4

6. Ancillary Services within Smart Grid Framework

Reactive power as an ancillary service, Energy Storage System, Power Quality, Reliability analysis.

Lectures: 4

7. Smart Grid Economic and Market Operations

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

Lectures: 4

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).

EEL 4X13 ADVANCED ELECTRIC DRIVES

L-T-P: 3-0-0 **Credit: 3**

Course Outcomes:

- Understand the basics of electric drives and fundamentals of drive dynamics.
- Learn and analyze DC drive.
- Learn and analyze different steady-state speed control methods for Induction motors, and understand the closed-loop block diagrams for different methods.
- Get introduced to modern synchronous motors and drives.

1. Characteristics of Electric Motors:

Characteristics of DC motors, 3-Phase induction motors, and synchronous motors, Starting and braking of electric motors. Dynamics of Electric Drives, Mechanical system, Fundamental torque equations, components of load torque, Dynamic conditions of a drive system, Multi quadrant operation, Criteria for selection of motor for drives Energy loss in transient operations, Steady State Stability, Load equalization.

Lectures: 8

2. Converter Control of DC Drives:

Analysis of series and separately excited DC motor with single-phase and three-phase controlled rectifiers operating in different modes and configurations. Analysis of series and separately excited DC motors fed from different choppers for both time ratio control and current limit control, four quadrant control. Single quadrant variable speed chopper fed DC drives. Four quadrants variable speed chopper fed DC Drives. Single phase/ three phases - dual converter fed DC Drive, design of speed, and current loop control. Different application.

Lectures: 8

3. **AC Motor Drives:**

Induction Motor Drive: Variable voltage variable frequency drive, Slip power recovery, Static Scherbius and Cramer drives. CSI fed Induction motor drives. Synchronous Motor Drive: variable frequency drives, self-control synchronous motor drives.

Lectures: 4

4. Special Motor Drives:

Brushless DC motor, Permanent magnet Synchronous motor, switched reluctance motor, stepper motor, linear induction, synchronous motor, and other advanced drives.

Lectures: 8

5. Advanced Control and Estimation of AC drives:

Small signal models, FOC control, sensor less control, DTC, model reference adaptive control, DSP, FPGA-based implementation control, and estimation technique.

Lectures: 8

Readings:

Prescribed Text Books

1. M. H. Rashid, Power Electronics - Circuits, Devices and Applications, P.H.I Private Ltd. New Delhi.
2. B. K Bose, Modern Power Electronics and AC Drives, PHI
3. G.K. Dubey, Power Semiconductor controlled drives, Prentice Hall inc, A division of Simon and Schester England cliffs, New Jersey.
4. Sheperal, L.N. Wand Hully, Power Electronic and Motor control, Cambridge University Press Cambridge
5. R Krishnan, Electric Drives-Modelling Analysis and control, PHI publication.

Additional Readings

1. S. Dewan, B. Slemon, A.G.R Straughen, Power Semiconductor drives, John Wiley and Sons, New York.
2. P.C. Sen, Thyristor DC Drives, John Wiley and sons, NewYork.
3. V. Subramanyam, Electric Drives–Concepts and applications, TataMcGraw Hill Publishing Co., Ltd., New Delhi.
4. B.K. Bose, Power Electronics and Variable frequency drives, Standard Publishers Distributors

EEL 4X14 POWER SYSTEM DYNAMICS

L-T-P: 3-0-0 **Credit: 3**

Course Outcomes:

- Aware of the power system stability problems.
- Understand the small and large disturbance stabilities.
- Know the modeling of synchronous machines and power system components.
- Understand the different power system stability analyses.
- Measures are taken to improve power system stability.

1. Load Flow Analysis:

Newton Raphson & Fast decoupled method (FDM)

Lectures: 2

2. Optimum Power Flow (OPF):

Formulation of OPF, LP-based gradient, and Newton's method. Bus Incremental Cost (BIC).

Lectures: 2

3. Introduction to Power System Stability:

Basic concepts and definitions; rotor angle stability, voltage stability and voltage collapse, Mid-term, and long-term stability; classification of stability.

Lectures: 4

4. Analysis of Stability: Voltage Stability:

Basic concept, voltage collapse, prevention of voltage collapse mechanism, voltage stability analysis, effects of excitation system, power system stabilizer.

Lectures: 8

5. Small Signal Stability:

A fundamental concept of stability of the dynamic system, small signal stability of single machine infinite bus system, small signal stability of multi-machine systems, characteristics of small signal stability problems.

Lectures: 6

6. Transient Stability:

Analysis using Numerical Integration Techniques, simulation of power system dynamics response, and case study of transient stability of a large system.

Lectures: 4

7. Synchronous Machine Representation in Stability Studies:

Simplifications for large-scale studies; Simplified model with amortisseurs neglected; constant flux linkage models.

Lectures: 6

8. Modeling of Excitation and Prime Mover Systems:

Elements of Excitation System; Types of Excitation System; modeling of excitation system; Hydraulic turbine and Governing System Modeling; Steam turbine and governing systems.

Lectures: 4

Readings:

Prescribed Text Books

1. P.Kundur, Power System Stability and Control, McGraw Hill Inc, New York,1995.
2. K.R.Padiyar, Power System Dynamics, Stability & Control, 2nd Edition, B.S. Publications, Hyderabad, 2002.
3. Allen J Wood & Bruce Wollenberg, POWER GENERATION OPERATION & CONTROL, 2ND ED, wiley publisher

Additional Readings

1. P.Sauer & M.A.Pai, Power System Dynamics & Stability, Prentice Hall, 1997.

EEL 4X15 OPTIMIZATION TECHNIQUE

L-T-P: 3-0-0 **Credit: 3**

Course Outcomes:

- Acquire a systematic understanding of optimization techniques.
- Understanding in detail the problem formulation and the solution approaches.
- Understanding a class of nonlinear optimization problems where the optimal solution is also globally optimal.

1. Introduction:

Historical Development; Engineering applications of Optimization; Art of Modeling; Objective function; Constraints and Constraint surface; Formulation of design problems as mathematical programming problems; Classification of optimization problems based on the nature of constraints, the structure of the problem, deterministic nature of variables, separability of functions and the number of objective functions; Optimization techniques – classical and advanced techniques.

Lectures: 6

2. Linear Programming:

Standard form of linear programming (LP) problem; Canonical form of LP problem; Assumptions in LP Models; Graphical method for two variable optimization problem; Examples; Simplex algorithm with equality and inequality constraints, integer programming.

Lectures: 8

3. Optimization using Calculus:

Stationary points - maxima, minima, and saddle points; Functions of single and two variables; Global Optimum; Convexity and concavity of functions of one and two variables; Optimization of a function of single and multiple variables; Gradient vectors; Optimization of a function of multiple variables subject to equality; Lagrangian function;
Hessian matrix formulation; Kuhn-Tucker Conditions.

Lectures: 8

4. Non-Linear Programming Algorithms:

Unconstrained optimization techniques, Direct search methods, Descent methods, 2nd order methods, constrained optimization, Direct and indirect methods.

Lectures: 4

5. Dynamic Programming:

Sequential optimization; Representation of multistage decision process; Concept of sub-optimization and the principle of optimality; Computational procedure in dynamic programming (DP); the curse of dimensionality in DP.

Lectures: 6

6. Robust Optimization Techniques:

Limitation of conventional optimization techniques, robust techniques: Simulated annealing (SA), Genetic Algorithm (GA)

Lectures: 6

Readings:

Prescribed Text Books

1. S S Rao, Engineering Optimization: Theory and Practice, New Age International (P) Ltd.
2. Suresh Chandera, Jaydeva, Numerical Optimization with Applications, Narosa publisher.
3. David Edward Goldberg, Genetic Algorithms in Search, Optimization, and Machine Learning, Addison-Wesley Publishing Company.

Additional Readings

1. Edvin K P Chong, Stanislaw H Zak, An Introduction to Optimization, John Wiley.
2. Mohan C Joshi, Kannan M Moudgalya, Optimization Theory and Practice, Narosa

EEL 4X16 SMART APPLIANCES AND INTERNET OF THINGS

L-T-P: 3-0-0 Credit: 3

Course Outcomes:

- Understand and evaluate the characteristics of smart home appliances.
- Understand the behavior of IoT and its applications.
- Manage smart communication systems with multiple sensors and protocols.
- Design and simulate smart homes and smart cities with IoTs and cloud computing

1. 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.

Lectures: 10

2. IoT Communication Technologies

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

Lectures: 8

3. 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.

Lectures: 10

4. 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.

Lectures: 8

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

EEL 4X17 SCADA SYSTEM AND APPLICATIONS

L-T-P: 3-0-0 **Credit: 3**

Course Outcomes:

- Understand the basics of SCADA systems and their various functions.
- Acquire knowledge regarding SCADA System Components and Programmable Logic Controllers (PLC).
- Explore Various SCADA architectures, advantages, and disadvantages.

- Investigate various industrial communication technologies.
- Learn and apply the SCADA Applications in Transmission and Distribution sector operations and industries.

1. SCADA:

Data acquisition system, evaluation of SCADA, communication technologies, monitoring, and supervisory functions.PLC: Block diagram, programming languages, Ladder diagram, Functional block diagram, Applications, Interfacing of PLC with SCADA.

Lectures: 4

2. SCADA System Components:

Schemes, Remote Terminal Unit, Intelligent Electronic Devices, Communication Network, SCADA server.

Lectures: 4

3. SCADA Architecture:

Various SCADA Architectures, advantages and disadvantages of each system, single unified standard architecture IEC 61850 SCADA / HMI Systems.

Lectures: 6

4. SCADA Communication:

Various industrial communication technologies- wired and wireless methods and fiber optics, open standard communication protocols.

Lectures: 10

5. SCADA Applications

Utility applications, transmission and distribution sector operation, monitoring analysis, and improvement. Industries, oil, gas, and water, Automatic substation control, SCADA requirement and configuration in energy control systems, Energy management system, system operating states, and system security.

Lectures: 12

Readings:

Prescribed Text Books

1. Stuart A Boyer, SCADA: Supervisory Control and Data Acquisition, ISA.
2. Gordan Clark, Deon Reynders, Practical Modem SCADA Protocols, Elsevier

EEL 4X18 Fundamentals of Communication Technology and Security for Smart Grid

Learning outcome

A. Knowledge: The students should

- Understand the most fundamental concepts, principles and technologies underlying computer communication networks and services, including the overall architecture of the Internet, principles of network based services, principles of switching techniques, security mechanisms, functionality and basic protocols of the five network protocol layers.
- Have a basic understanding of risk factors, threats and countermeasures to achieve information security.

B. Skills: The students should

- Be able to reason and discuss about the architectures, principles and technologies in the design and implementation of computer communication networks and services.

- Be able to explain how and why the basic protocols of the five network layers work.
- Be able to reason and discuss information security at a fundamental level and evaluate risk for communication systems.

1. Basics of Power Systems:
Load and Generation, Power Flow Analysis, Economic Dispatch and Unit Commitment Problems

Lectures: 3

2. Smart Grid:
Definition, Applications, Government and Industry, Standardization

Lectures: 3

3. Smart Grid Communications:
Two-way Digital Communications Paradigm, Network Architectures, IP-based Systems, Power Line Communications, Advanced Metering Infrastructure

Lectures: 5

4. Demand Response:
Definition, Applications, and State-of-the Art, Pricing and Energy Consumption Scheduling, Controllable Load Models, Dynamics, and Challenges, Electric Vehicles and Vehicle-to-Grid Systems, Demand Side Ancillary Services

Lectures: 6

5. Renewable Generation:
Carbon Footprint, Renewable Resources: Wind and Solar, Microgrid Architecture, Tackling Intermittency, Stochastic Models and Forecasting, Distributed Storage and Reserves

Lectures: 6

6. Wide Area Measurement:
Sensor Networks, Phasor Measurement Units , Communications Infrastructure, Fault Detection and Self-Healing Systems, Applications and Challenges

Lectures: 5

7. Security and Privacy:
Cyber Security Challenges in Smart Grid, Load Altering Attacks, False Data Injection Attacks, Defense Mechanisms, Privacy Challenges

Lectures: 5

8. Economics and Market Operations

Lectures: 3

Text Books:

3. Kenneth C. Budka, Jayant G. Deshpande and Marina Thottan, "Communication Networks for Smart Grids," Springer London Heidelberg New York Dordrecht, 1st Edition, 2014.
4. Mini. S. Thomas and John D. McDonald, "Power system SCADA and smart grid," CRC Press Taylor & Francis Group, 1st Edition, 2015

Reference Books:

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

4. 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.

LIST OF DEPARTMENTAL ELECTIVES: for SEMESTER- VIII

EEL 4X20 ENERGY STORAGE SYSTEMS
L-T-P: 3-0-0 **Credit: 3**

Course Outcomes:

- Understand the characteristics of energy storage devices
- Model and simulate the characteristics of energy storage systems
- Explore the possibilities of deployment of energy storage systems in smart cites and electric vehicles.
- Evaluate and suggest an efficient storage system in electric transportation

1. 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 balance in a wide area network. Economics of energy and power tied to electrical rates and demand response.

Lectures: 4

2. 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 a 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 of mobile applications and 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 a focus on large utility-scale energy storage facilities.

Mobile and Fixed Energy Storage: Advantages and disadvantages of mobile vs. stationary energy storage, with a focus on a 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.

Lectures: 16

3. 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, 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.

Lectures: 16

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.

EEL 4X21 ADVANCED DIGITAL SIGNAL PROCESSING

L-T-P: 3-0-0 **Credit: 3**

Course Outcomes:

- Understand the theory of different filters and algorithms
- Understand the theory of multi-rate DSP, solve numerical problems, and write algorithms
- Understand the theory of prediction and solution of normal equations.
- Understand DSP algorithms.
- Know the applications of DSP and radar

1. Random signals:

Review of FIR and IIR filters, DFT and FFT. Correlation functions, and power spectra.

Lectures: 4

2. Spectrum estimation and analysis:

Principles, periodogram method, Blackman – Turkey method, fast correlation method. Autoregressive spectrum estimation.

Lectures: 6

3. Homomorphic signal processing:

concepts, definitions of the complex cepstrum, homomorphic deconvolution, complex cepstrum of exponential sequences, minimum phase and maximum phase sequences, a realization of the characteristic system, and examples of homomorphic filtering.

Lectures: 8

4. Multirate digital signal processing:

Decimation, interpolation, design of practical sampling rate converters, application example.

Lectures: 4

5. Optimal and adaptive filters:

Wiener filtering technique, adaptive filters, and their applications. Hardware for digital signal processing: Digital Signal Processors. Digital image processing.

Lectures: 6

6. Two-dimensional image representations:

Image digitization, image distortion, image transmission encoding and decoding, and image restoration. Image display techniques. Tomographic imaging techniques and their applications. Hardware for digital image processing.

Lectures: 8

Text Books:

1. Digital Signal Processing: Principles Algorithms and Applications, J. G. Proakis and D. G. Manolakis, Pearson Education, 4^{th} Edition, 2007.
2. Digital Signal Processing, A. V. Oppenheim, R. W. Schafer, Pearson Education, 2004.
3. Digital signal processing, S. Salivahanan, AVallavaraj, C Gnanapriya, TMH, 2^{nd} Edition, 2010.

Reference Books:

1. Digital Signal Processing: A computer-based approach, S. K. Mitra,4^{th} Edition, TMH, 2011.
2. Theory and Application of Digital Signal Processing, L. R. Rabiner and B. Gold, Pearson Education, 2004.
3. Digital Filters, Analysis, Design and Applications, Andrias Antonion, 2^{nd} Edition, TMH, 2006.

EEL 4X22 DATA SCIENCE APPLICATIONS IN POWER ENGINEERING

L-T-P: 3-0-0 **Credit: 3**

Course Outcomes:

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

1. 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.

Lectures: 10

2. 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)

Lectures:18

3. 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.

Lectures: 10

4. 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.

Lectures: 8

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.

EEL 4X23 MACHINE LEARNING AND DEEP LEARNING

L-T-P: 3-0-0 **Credit: 3**

Course Outcomes:

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

1. 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.

Lectures: 10

2. 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.

Lectures: 8

3. 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)

Lectures: 8

4. Reinforcement Learning

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

Lectures: 4

5. 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 generation and demand, predicting equipment and systems malfunctions and failures.

Lectures: 6

Text Books:

1. C. Bishop, "Pattern Recognition and Machine Learning", Springer, 2011.
2. E. Alpaydin, "Machine Learning", MIT Press, 2010

Reference Books:

1. Ian Goodfellow, 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.

EEL 4X24 NUMERICAL OPTIMIZATION

L-T-P: 3-0-0 **Credit: 3**

Course Outcomes:

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

1. 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, and convexity concerning generalized inequalities. Linear optimization problems, quadratic optimization problems, geometric programming, and vector optimization.

Lectures: 6

2. Duality

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

Lectures: 8

3. 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.

Lectures: 10

4. 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.

Lectures: 8

5. Power System Optimization

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

Lectures: 4

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. 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.

EEL 4X25 ADVANCED POWER ELECTRONICS

L-T-P: 3-0-0 **Credit: 3**

Course Outcomes:

- To review basic concepts of power electronics in the field of power control and drives
- To address the underlying concepts and methods behind Advanced Power Electronics
- To impart knowledge of power semiconductor technologies and their advancement in the field of power conversion.

1. Introduction:

review of power semiconductor devices: Thyristor, IGBT, MOSFET, IGCT, GTO, and their driver circuits, the role of SiC in power semiconductor technology

Lectures: 4

2. AC-DC converter:

Uncontrolled rectifier, semi-controlled rectifiers, fully controlled rectifiers with R, RL, and RLE load, the effect of source inductance on the performance of converter, firing schemes and circuits, MULTIPULSE CONVERTERS: Multi-pulse converters: 12,18 and 24 pulse converters, phase shifting transformers POWER FACTOR: power factor improvement techniques, PWM rectifiers: equal area PWM, sine PWM, Single Phase and Three phase boost rectifier circuits

Lectures: 6

3. DC-AC converters:

Voltage Source Inverter: 120º and 180º conduction modes, PWM techniques of voltage fed converters: Selective Harmonic Elimination (SHE), sine modulation, Third harmonic injection, Hysteresis Current Control, Sigma-Delta Modulation, Space Vector Pulse Width Modulation: under modulation and overmodulation and their implementation Current Source Inverter: Current Source inverters and their role in high power drives: Auto sequential Current Fed inverter, Pulse Width Modulation of CSI Matrix converters: Three phase matrix converters and their control, basic input filter, protection of matrix converter

Lectures: 12

4. Multilevel inverters:

Diode Clamped MLI, Flying Capacitor MLI, Cascaded H-Bridge topology: operation with equal and unequal DC voltages, Carrier modulation schemes of a multilevel inverter, SVPWM of Multilevel inverter, Neutral Point Balancing schemes

Lectures: 6

5. Advance Electrical Drives:

Brushless DC motor: Sinusoidal and Trapezoidal BLDC motor, Electronic Commutator, Torque production in BLDC motor, Control of Brushless DC drives Switched Reluctance Motor: Elementary Operation and Principle of operation, Modes of operation, Converter circuits for SRM: Asymmetric Bridge Converter, R-Dump, Bifilar Type converter

Lectures: 8

Readings:

Prescribed Text Books

1. Ned Mohan, T.M. Undeland and William P.Robbins, Power Electronics: Converters, Applications, 3rd Edition, John Wiley & Sons, 2009.
2. M. H. Rashid, Power Electronics-Circuits, Devices and Applications, 3rd Edition, PHI, 2005
3. C.W Lander, Power Electronics, McGraw-Hill book company, 1981

Additional Readings

1. M. D. Singh & K. B. Khanchandani, Power Electronics, McGraw Hill.
2. Undeland and Robins, Power Electronics – Concepts, applications, and Design Mohan,
3. L. Umanand, Power Electronics, Essentials, and Applications
4. Fundamental of Power Electronics, Robert W.erickson, Academic publishers

EEL 4X26 SOFT COMPUTING TECHNIQUES AND APPLICATIONS

L-T-P: 3-0-0 **Credit: 3**

Course Outcomes:

- Learn about soft computing techniques and their applications.
- Analyze various neural network architectures.
- Understand perceptions and counter-propagation networks.
- Define fuzzy systems.
- Analyze the genetic algorithms and their applications.

1. Introduction to Soft Computing:

Introduction, importance, main components, Fuzzy Logic, ANN, Evolutionary Algorithms, Hybrid Intelligent Systems.

Lectures: 4

2. Artificial Neural Network and Supervised Learning:

Introduction, Comparison of Neural Techniques and AI, Artificial Neuron Structure, Adaline, ANN Learning, Back Propagation Learning, Properties & Limitations.

Lectures: 5

3. Development of Generalized Neuron and Its Validation:

Existing Neuron Model, Development, Advantages, Learning Algorithm of a Summation Type Generalized Neuron, Benchmark Testing of Generalized Neuron Model, Generalization of GN model, Discussion.

Lectures: 5

4. Introduction to Fuzzy Set Theoretic Approach:

Introduction, Uncertainty and Information., Types of Uncertainty, Fuzzy Logic-Introduction, development, Precision and Significance, set, Operations, Union Intersection, Complement, Combination, Concentration, Dilation, Intensification, α-Cuts. Quantifier/Modifier/Hedges, Characteristics, Normality, Convexity, Cross Over Point, Singleton, Height, Cardinality, Properties of Fuzzy Sets, Fuzzy Cartesian Product, shape & defining Membership Functions, Defuzzification, Rule-Based System.

Lectures: 8

5. Applications of Fuzzy Rule-Based System:

Introduction, Modelling and Simulation, approach, selection, Steady State D.C. Machine Model, Control Applications Adaptive Control, PID Control System, Transient Model of D.C. Machine, Fuzzy Control System, Power System Stabilizer Using Fuzzy Logic.

Lectures: 4

6. Evolutionary & Metaheuristic search and optimization Algorithms:

GA-Selection, cross over & mutation, simple GA algorithm, elitism. PSO- Particle swarm, velocity, mutation, selection, algorithm. DE- Selection, cross over & mutation, algorithm, elitism.

Lectures: 6

7. Integration of Neural Networks, Evolution Algorithms, and Fuzzy Systems:

Adaptive Neuro-Fuzzy Inference Systems, Neuro-Fuzzy Approach of Modelling. ANN – GA-Fuzzy Synergism and Its Applications Training of ANN, ANN Learning Using GA, Validation and Verification of ANN-GA Model.

Lectures: 4

Prescribed Text Books

1. S N Sivanandam, S.N. Deepa, Principles of Soft Computing, Wiley.

2. Goldenberg, soft computing, Allied publisher.

Reference Books

1. D K Chaturvedi, Soft Computing - Techniques and its Applications in Electrical Engineering, Springer

EEL 4X27 GRID INTEGRATION OF ELECTRIC VEHICLES

L-T-P: 3-0-0 **Credit: 3**

Course Outcomes:

- Understand the Electric Vehicle concepts and their importance in power systems.
- Assess the role of EVs in modern distribution systems and smart grids
- Understand the technology, design methodologies, and control strategy of hybrid electric vehicles.
- Understand the operation and importance of EVs in Grid Applications, grid balancing, ancillary services and demand response

1. 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.

Lectures: 6

2. Electric Vehicle Batteries

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

Lectures: 8

3. 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.

Lectures: 10

4. 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.

Lectures: 6

5. 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 Ultracapacitors for Hybrid Electric Vehicles, the concept of a vehicle to Home (V2H), Effect of charging infrastructure on grid protection and control.

Lectures: 6

Text Books:

1. James Larminie, John Lowry, "Electric Vehicle Technology Explained", Wiley-Blackwell, 2nd Edition,2012.
2. Sheldon S. Williamson, "Energy Management Strategies for Electric and Plug-in

Hybrid Electric Vehicles", Springer, 1st Edition,2016

References:

1. Sandeep Dhameja, "Electric Vehicle Battery Systems," Elsevier, 1st Edition,2012.
2. Ali Emadi, "Advanced Electric Drive Vehicles," CRC Press, 1st Edition,2017.
3. Iqbal Hussain, "Electric & Hybrid Vehicles Design Fundamentals", 2nd 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., 2nd Edition,2017.
5. T. Muneer and I. Illescas García, "The automobile, In Electric Vehicles: Prospects and Challenges", Elsevier, 1st Edition,2017.
6. S. Rajakaruna, F. Shahnia, and A. Ghosh, "Plug-In Electric Vehicles in Smart Grids", Springer Singapore, 1st Edition,2015.
7. J. Lu, and J. Hossain, "Vehicle-to-Grid: Linking electric vehicles to the smart grid", IET, 1st Edition, 2015

EEL 4X28 ADAPTIVE AND ROBUST CONTROL SYSTEMS

L-T-P: 3-0-0 **Credit: 3**

Course Outcomes:

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

1. 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.

Lectures: 10

2. 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.

Lectures: 8

3. 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.

Lectures: 8

4. 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.

Lectures: 4

5. 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.

Lectures: 6

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.

EEL 4X29 DIGITAL CONTROL SYSTEMS
L-T-P: 3-0-0
Credit: 3

Course Outcomes:

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

1. Introduction:

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

Lectures: 4

2. Z-Transform:

Z-transform - Z-transforms of elementary functions - Important properties and theorems - Inverse z- transform - Z-transform method of solving difference equations.

Lectures: 6

3. 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.

Lectures: 8

4. 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.

Lectures: 8

5. Pole Placement & Observer Design:

Controllability – Observability

Lectures: 5

6. 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.

Lectures: 5

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.

EEL 4X30 SMART GRID RESILIENCY AND CYBER SECURITY

L-T-P: 3-0-0 **Credit: 3**

Course Outcomes:

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

1. 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.

Lectures: 8

2. 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.

Lectures: 8

3. Smart Grid Threat and Cross-Domain Risk

Smart Grid threat Landscape, Smart Grid Risk Assessment, Challenges and solutions, Emerging methods, and techniques for smart grid security.

Lectures: 10

4. Smart Grid Resiliency and Cyberattack

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 systems, Control centric security tools and risk assessment methodology, Secure Communications in Smart Grid: Networking and Protocols.

Lectures: 10

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. 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. 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

EEL 4X31 CLOUD COMPUTING AND BIG DATA ANALYTICS IN SMART GRIDS
L-T-P: 3-0-0 **Credit: 3**

Course Outcomes:

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

1. Introduction

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

Lectures: 4

2. 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.

Lectures: 6

3. 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.

Lectures: 6

4. 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.

Lectures: 10

5. 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.

Lectures: 10

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

EEL 4X32 CHALLENGES AND SOLUTIONS IN RENEWABLE INTEGRATION
L-T-P: 3-0-0 **Credit: 3**

Course Outcomes:

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

1. 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.

Lectures: 6

2. 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 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.

Lectures: 8

3. 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, the performance of the grid-connected solar photovoltaic system with MPPT controllers, a 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.

Lectures: 4

4. 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 the Utility Control Center, Reserve Managementfor

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).

Lectures: 8

5. 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 concerning renewable energy providers, Synchro phasors for distribution networks with variable resources, Monitoring and control of RES using synchronized phasor measurements.

Lectures: 6

6. 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, and Derated operation of renewable resources.

Lectures: 4

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.

EEL 4X33 SIGNAL PROCESSING IN SMART GRIDS

L-T-P: 3-0-0 Credit: 3

Course Outcomes:

- Understand the applications of Digital signal filtering techniques in power systems
- Apply estimation techniques to evaluate power system parameters.
- Understand different signal decomposition techniques.
- Understand the WAMS signal processing

1. 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.

Lectures: 4

2. 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.

Lectures: 6

3. Filters and Electrical Parameters Estimation

Forward and backward linear prediction, prediction error filters, AR lattice and ARMA Lattice – Ladder filters, Kalman filters, Wiener filters, and 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.

Lectures: 8

4. 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.

Lectures: 8

5. Signal Processing Techniques Applications

Concepts of wavelet, s-transform, heartily s-transforms; Hilbert transform; Gabor transforms and applications in power fluctuations: load fluctuations, wind farm power fluctuations, and smart microgrid.

Lectures: 10

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.

EEL 4X34 MICROGRID DYNAMICS AND CONTROL

L-T-P: 3-0-0 **Credit: 3**

Course Outcomes:

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

1. 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.

Lectures: 4

2. Decentralized Local Controllers

AC-microgrids: Control Mechanism of the DGs connected in the 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.

Lectures: 6

3. 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.

Lectures: 4

4. Dynamic and Stability Analysis of Microgrids

Dynamic modeling 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.

Lectures: 4

5. Hierarchical Control Scheme for Microgrids

Control Objectives in AC Microgrids, bottleneck with only local control, need for 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.

Lectures: 6

6. 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.

Lectures: 4

7. 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.

Lectures: 4

8. Techno-Economic Analysis of Microgrids

Technical, economic, and environmental benefits of microgrids, Quantification of microgrids benefits under standard test conditions, market pricing, and policies.

Lectures: 4

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. 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.

EEL 4X35 EVOLUTIONARY ALGORITHMS APPLICATION IN POWER ENGINEERING

L-T-P: 3-0-0 **Credit: 3**

Course Outcomes:

- Discriminate the capabilities of the bio-inspired system and conventional methods in solving Optimization problems.

- Examine the importance of exploration and exploitation of swarm intelligent systems to attain near-global optimal solutions.
- Distinguish the functioning of various swarm intelligent systems.
- Employ various bio-inspired algorithms for Power systems engineering applications.

1. 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.

Lectures: 8

2. 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.

Lectures: 8

3. 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.

Lectures: 10

4. Shuffled Frog-Leaping Algorithm and Bat Optimization Algorithm

Bat Algorithm- Echolocation of bats- Behavior 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.

Lectures: 4

5. 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.

Lectures: 3

6. Advanced Techniques

Soft sensor concepts in power systems.

Lectures: 3

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.

EEL 4X36 EMBEDDED SYSTEM
L-T-P: 3-0-0 **Credit: 3**

Course Outcomes:

- To introduce the Building Blocks of an Embedded System
- To Educate in Various Embedded Development Strategies
- To Introduce Bus Communication in processors, Input/output interfacing.
- To impart knowledge in various processor scheduling algorithms.
- To introduce the Basics of Real-time operating system and example tutorials to discuss one real-time operating system tool

1. Introduction to Embedded systems:

Introduction, Features, microprocessors, microcontrollers, mixed-signal processor, digital signal processor, Application.

Lectures: 4

2. Embedded Systems Architectures:

Von Neumann, Havard, Modified Havard, Characteristics application, CISC and RISC, Instruction pipelining, Microcontroller: characteristics and features, overview and architectures of Atmel 89C52 and Microchip PIC16F877 and 18F452, Floating point and Fixed point Prosser.

Lectures: 6

3. PIC Microcontrollers:

16F877 Architecture and instruction set, External interrupts, Timers, watch-dog timer, I/O port Expansion, Analog to Digital converter, UART, 12C, and SPI bus for peripheral chips, Accessories, and special features.

Lectures: 4

4. Software Architecture and RTOS:

Software Architecture: Round robin, Round robin with interrupts, Function queue, Scheduling, Architecture RTOS: Architecture-Tasks and task states-task and data-semaphores and shared data.

Lectures: 6

5. Software development Tools and debugging Techniques:

Development tool: cross-complier, cross-assemblers, linker/locator, Programming Tool: PROM Programmers, ROM, Emulator, In-circuit Emulators, debugging techniques and instruction set simulators.

Lectures: 8

6. Basic Design using of Embedded system:

Overview, General, principles, Design of embedded system, Examples of embedded systems, case study.

Lectures: 8

Readings:

Prescribed Text Books:

1. Raj Kamal, Embedded systems architechture,Programming and design,TMH.
2. D.E Simon, An Embedded software primer, Pearson Education.

Additional Reading:

1. J.B Peatman, Design with PIC Microcontrollers, Pearson Education.