M. TECH. – POWER AND ENERGY ENGINEERING

Department of Electrical and Electronics Engineering

The restructuring and deregulation of electric utilities together with recent progress in new and renewable energy technologies introduce unprecedented challenges and wide scope for power and energy systems research and open up new opportunities to young Power Engineers. Conventional Power system is redefined and power electronic components are incorporated along with the existing system. This includes flexible ac transmission, HVDC links embedded in the conventional ac transmission networks etc. Further, use of renewable energy such as solar and wind power, coupled with higher efficiency and conservation, will be the key factors to a sustainable world for future generations.

M. Tech. program in Power and Energy Engineering is intended to explore the above mentioned challenges and also initiate research activities. This program provides necessary theoretical background with a good blend of applied mathematics along with in depth coverage in analysis of power and energy systems. The core courses include sustainable, economic, efficient and reliable energy conversion, generation, transmission, distribution, storage and utilization of electric energy, including application of power electronics in power system operation and control.

CURRICULUM

First Semester

Course Code	Type	Course	L - T - P	Credit
MA616	FC	Applied Mathematics	4 - 0 - 0	4
PR612	FC	Computer Applications in Power Systems	3 - 1 - 0	4
PR613	FC	Power Electronic Converters	3 - 0 - 0	3
PR621	SC	Direct Energy Conversion	3 - 0 - 0	3
PR622	SC	Energy Conservation and Management	3 - 1 - 0	4
PR691	SC	Power and Energy Laboratory	0 - 0 - 6	2
HU601	HU	Cultural Education*		P / F
			Credits	**20**

* Non credit course

Second Semester

Course Code	Type	Course	L - T - P	Credit
PR614	FC	Basic Energy Dynamics	3 - 0 - 0	3
PR623	SC	Power Quality	3 - 1 - 0	4
PR624	SC	High Voltage Power Transmission	3 - 1 - 0	4
	E	Elective – I	3 - 0 - 0	3
	E	Elective – II	3 - 0 - 0	3
PR601	FC	Seminar	0 - 0 - 3	1
EN600	HU	Technical Writing*		P/F
			Credits	**18**

* Non credit course

Third Semester

Course Code	Type	Course	L - T - P	Credit
	E	Elective – III	3 - 0 - 0	3
	E	Elective – IV – Open Elective*	3 - 0 - 0	3
PR799	P	Dissertation		6
			Credits	**12**

*Any of the elective subjects offered in any semester in any department may also be permitted with the concurrence of the department.

Fourth Semester

Course Code	Type	Course	L - T - P	Credit
PR799	P	Dissertation .		16
			Credits	**16**

Total Credits: 66

LIST OF COURSES

Foundation Core

Course Code	Course	L - T - P	Credit
MA616	Applied Mathematics	4 - 0 - 0	4
PR612	Computer Applications in Power Systems	3 - 1 - 0	4
PR613	Power Electronic Converters	3 - 0 - 0	3
PR614	Basic Energy Dynamics	3 - 0 - 0	3
PR601	Seminar	0 - 0 - 3	1

Subject Core

Course Code	Course	L - T - P	Credit
PR621	Direct Energy Conversion	3 - 0 - 0	3
PR622	Energy Conservation and Management	3 - 1 - 0	4
PR623	Power Quality	3 - 1 - 0	4
PR624	High Voltage Power Transmission	3 -1 - 0	4
PR691	Power and Energy Laboratory	0 - 0 - 6	2

Electives

Course Code	Course	L - T - P	Credit
Elective I			
CI622	Digital Control Systems	3 - 0 - 0	3
PR711	Microcontrollers and Applications	3 - 0 - 0	3
PR712	Energy Systems Modeling and Analysis	3 - 0 - 0	3
MA708	Numerical Methods and Optimization	3 - 0 - 0	3
Elective II			
PR721	Operation and Control of Power Systems	3 - 0 - 0	3

PR722	Restructured Power Systems	3 - 0 - 0	3
PR723	Nuclear Energy	3 - 0 - 0	3
PR724	Soft Computing Techniques	3 - 0 - 0	3
Elective III			
PR731	Wind Energy Conversion Systems	3 - 0 - 0	3
PR732	Solar Energy Utilization	3 - 0 - 0	3
PR733	Power System Stability	3 - 0 - 0	3
PR734	Electrical Drives and Control	3 - 0 - 0	3
Elective IV*			
PR741	Smart Grid	3 - 0 - 0	3
PR742	Modern Power System Protection	3 - 0 - 0	3
PR743	Bio-Energy Conversion	3 - 0 - 0	3
PR744	Energy Storage Technology	3 - 0 - 0	3

*Any of the elective subjects offered in any semester in any department may also be permitted with the concurrence of the department.

Project Work

Course Code	Course	L - T - P	Credit
PR799	Dissertation		6
PR799	Dissertation		16

MA616 APPLIED MATHEMATICS 4 - 0 - 0 - 4

Vector Algebra: Vector spaces, linear and bilinear transformations, Eigen values, inner product spaces. Probability: joint probability density function of discrete and continuous random variables. Integral equations: formation of Volterra and Fredholm integral equations, solution of integral equations. Transforms: Laplace transforms: inverse transforms. Transform method of solution of partial differential equations: one dimensional wave equation and one dimensional heat equation. Fourier transforms. Z transforms: inverse transforms, application to solution of difference equations. Calculus of variation: optimization by Lagrange multiplier method, Euler-Lagrange condition for extremum of integrals, isoperimetric problems. Differential Equations: first order differential equations, second order differential equations: Euler-Cauchy Equation, Non homogenous equations, modelling of electric circuits. Systems of differential equations: homogenous systems with constant coefficients.

TEXT BOOKS/ REFERENCES:

1. Erwin Kreyzig, "Advanced Engineering Mathematics", John Wiley & Sons, 2006.
2. M. K. Venkataraman, "Higher Engineering Mathematics", (2nd and 3rd volumes), National Publishing Co., Chennai, 2002.
3. B. S. Grewal, "Higher Engineering Mathematics", Khanna Publishers, 2002.
4. Bali, Ashok Saxena and Narayana Iyengar, "Higher Engineering Mathematics", Laxmi Publications (P) Ltd., New Delhi, 2002.
5. A. W. Naylor and George R. Sell, "Linear Operator Theory", Holt Rinehart and Winston, London, 1982.

PR612 COMPUTER APPLICATIONS IN POWER SYSTEMS 3 - 1 - 0 - 4

Basics: building algorithm for bus impedance matrix, modification of Z_{Bus} matrix due to changes in primitive network. Power system components and their representation: synchronous machine, transmission system, three phase power network. Load flow studies: overview of Gauss, Gauss-Seidel and Newton-Raphson methods, decoupled load flow, fast decoupled load flow, AC/DC load flow, three phase load flow. Sparsity techniques: triangular factorization, optimal ordering, optimal load flow in power systems. Incorporation of FACTS devices in load flow: static tap changing, phase shifting (PS), static var compensator (SVC), thyristor controlled series compensator (TCSC) and unified power flow controller (UPFC). Short circuit studies: types of faults: short circuit study of a large power system, algorithm for calculating system conditions after fault, short circuit studies using bus admittance and impedance matrix. Stability studies: transient stability analysis, stability analysis of multi- machine system, numerical techniques.

TEXT BOOKS/ REFERENCES:

1. L. P. Singh, "Advanced Power Systems Analysis and Dynamics", New Age Intl. Publishers, 2007.
2. J. Arriliga and N.R. Watson, "Computer Modeling of Electrical Power Systems", Wiley, 2001.
3. I. J. Nagrath and D.P. Kothari, "Modern Power System Analysis", Tata McGraw Hill, New Delhi, 2011.

4. Stagg and El-Abiad, “Computer Methods in Power System Analysis”, Tata McGraw Hill, 1987.
5. G. L. Kusic, “Computer Aided Power System Analysis”, Prentice Hall, 1989.

PR613 POWER ELECTRONIC CONVERTERS 3 - 0 - 0 - 3

Overview of power semiconductor switches: MOSFET, IGBT – characteristics, control and power loss estimation. Overview of single phase and three phase converters, rectifier and inverter modes of operation for RL load. DC-DC converters: buck, boost, buck-boost, uk, forward, fly-back and push-pull converter circuits, half bridge, full bridge - operation, waveforms and design, small signal analysis of DC-DC converters and closed loop control. Resonant DC-DC converters: operating principle, waveforms, switching trajectory and losses. Snubbers: turn-off and turn-on snubbers, drive circuits, inductor and transformer design. Inverters: PWM inverter modulation strategies, unipolar and bipolar switching scheme, sine wave PWM, space vector modulation and predictive current control techniques. Introduction to multi level inverter (three level inverter): basic topology and waveform, improvement in harmonics. Grid connected inverters: requirement of dead time on line voltages, compensation of dead time.

TEXT BOOKS/ REFERENCES:

1. Ned Mohan, Tore M. Undeland and William P. Robbins, “Power Electronics: Converters, Applications, and Design”, Third Edition, John Wiley & Sons, 2003.
2. Muhammad H Rashid, “Power Electronics: Circuits, Devices and Applications”, Third Edition, Prentice Hall, 2004.
3. L. Umanand, “Power Electronics: Essentials and Applications” Wiley India, 2009.
4. P. C. Sen, “Modern Power Electronics”, S. Chand Limited, 2005.
5. B. W. Williams, “Power Electronics: Devices, Drivers, Applications and Passive Components”, Second Edition, Tata McGraw Hill, 1992.

PR614 BASIC ENERGY DYNAMICS 3 - 0 - 0 - 3

Heat Transfer: conduction, radiation, convective heat transfer, boiling and condensation, two and three-dimensional heat flow. Thermodynamics: energy transfer by heat, work, and mass, temperature and the zeroth law of thermodynamics. First law and its application, entropy, second law and its application. Irreversibility, heat generation, basic power cycles, refrigeration and heat pumps, dehumidification. Fluid mechanics: stress-strain relations and viscosity, mass and momentum balance, flow through pipe, Bernoulli equation. Energy conversions in fluid systems. Centrifugal pump: operating characteristics of a centrifugal pump. Hydraulic turbines and their performance characteristics.

TEXT BOOKS/ REFERENCES:

1. S. P. Sukhatme, “A Text Book on Heat Transfer”, Orient Longman, 2005.
2. L. Prasuhn, “Fundamentals of Fluid Mechanics, Prentice Hall, 1980.
3. M. W. Zemansky, “Heat and Thermodynamics”, Fourth Edition, McGraw Hill, 1968.

4. Mott, R. L., "Applied Fluid Mechanics", Sixth Edition, Prentice Hall, NJ, 2006.
5. Herbert B. Callen, Thermodynamics and an Introduction to Thermo-statistics, John Wiley& Sons, 1985.

PR601 SEMINAR 0 - 0 - 3 - 1

The student in consultation with the faculty advisor has to select a topic related to Power and Energy area, write a paper and present it.

PR621 DIRECT ENERGY CONVERSION 3 - 0 - 0 - 3

Basics: energy conversion process, indirect and direct energy conversion. Preview of semiconductor physics: basic ideas of quantum physics, Fermi energy, band diagram, intrinsic and extrinsic semiconductors, p-n junction. Introduction to irreversible thermodynamics. Thermoelectric conversion: thermoelectric effects, analysis of thermoelectric generators and coolers, figure of merit, device configuration. Photovoltaic conversion: optical effects of p-n junction, design and analysis of PV cells. Types of PV cells, PV cell fabrication, system design. Thermionic conversion: thermionic effects, analysis of converters, application of heat pipes. Magneto-hydrodynamic conversion: gaseous conductors, analysis of MHD generators. Fuel cell technology: introduction to the principles with electrochemical kinetics and transport phenomena, operation of fuel cells, stack configurations and fuel cell systems. Types of fuel cells with performance comparisons, thermodynamic analysis, fuel cell system design, factors limiting performance, optimization and economics, hydrogen production, fuel cell applications for electric vehicles. Battery: principles, types with chemical energy conservation equations, polarization effects, specification, selection and design parameters, DoD v/s life cycle curves, charging & discharging methods with controller circuit design, other modes of direct energy conversion.

TEXT BOOKS/ REFERENCES:

1. Chetan S. Solanki, "Solar Photovoltaics – Fundamentals, Technologies and Applications", Second Edition, PHI Publications, 2011.
2. Lewis M. Fraas and Larry D. Partain, "Solar Cells and Their Applications", Third Edition, John Wiley & Sons, 2010.
3. Leo J. M. J. Blomen and Michael N. Mugerwa, (Editors) "Fuel Cell System", Plenum Press, New York, 1993.
4. George Sutton, "Direct Energy Conversions", McGraw Hill Publications, 1999.
5. Angrist S. W, "Direct Energy Conversion", Fourth Edition, Allyn and Bacon, Boston, 1982.

PR622 ENERGY CONSERVATION AND MANAGEMENT 3 - 1 - 0 - 4

Energy conservation management: general principles of energy management and energy management planning, conducting energy audit, energy audit instruments, energy audit report, monitoring, evaluating and following up energy saving measures/ projects. Energy efficiency analysis, management of heating, ventilating and air-conditioning (HVAC), management of

process energy, energy efficiency of turbines, compressors and pumps, specific energy consumption, parameters affecting specific energy consumption, flexi targeting technique. Cogeneration: types and schemes, case study. Management of electrical load and lighting: management opportunities with electric drives, lighting, heating and electrolytic systems, electrical load analysis, and peak demand control. Economics of power factor improvement: reactive power management, capacitor sizing, degree of compensation, capacitor losses, location, placement, maintenance, case study. Computer-aided energy management, energy efficiency policy initiatives. Energy economics: financial evaluation of energy projects, evaluation of proposals, profitability index, life cycle costing approach, investment decision and uncertainty, consideration of income taxes, depreciation and inflation in investment analysis.

TEXT BOOKS/ REFERENCES:

1. Barney L. Capehart, Wayne C. Turner and William J. Kennedy, "Guide to Energy Management", Seventh Edition, The Fairmont Press Inc., 2012.
2. Albert Thumann, “Handbook of Energy Audits”, Sixth Edition, The Fairmount Press, 2003.
3. G. G. Rajan, “Optimizing Energy Efficiencies in Industry”, Tata McGraw Hill, 2001
4. Wayne C. Turner, “Energy Management Hand Book”, The Fairmount Press, Inc., 2001.
5. Charles M. Gottschalk, “Industrial Energy Conservation”, John Wiley and Sons, 1996.
6. Craig B. Smith, “Energy Management Principles”, Pergamon Press, 1981.
7. IEEE Recommended “Practice for Energy Management in Industrial and Commercial Facilities”, IEEE std 739 – 1995. (Bronze book).

PR623 POWER QUALITY 3 - 1 - 0 - 4

Review of power quality issues, definitions and standards, causes and effects of power quality issues, measurements. Harmonic studies: circuit analysis and power assessment under non-sinusoidal conditions. Symmetrical components, harmonic propagation studies in large network, Fourier analysis, FFT analysis. Improvement techniques: passive filters, reactive power compensation, design problems. Shunt, series and hybrid active filters- applications, design problems. Estimation of rate/ cost reduction due to hybrid filters. Active filter control schemes/ algorithms: instantaneous reactive power theory (IRPT) algorithm, synchronous detection (SD) algorithm, DC bus voltage algorithm, synchronous reference frame (SRF) algorithm, I cosΦ algorithm, AI based control algorithms, analog/ digital implementation- case studies. Review of single-phase and three-phase improved power quality converters and their applications. Custom power parks: concept, custom power devices and applications.

TEXT BOOKS/ REFERENCES:

1. George J. Wakileh, “Power Systems Harmonics-Fundamentals, Analysis and Filter Design”, Springer-Verlag, New York, 2010.
2. J. Arillaga, N. R. Watson and S. Chen, “Power System Quality Assessment”, John Wiley & Sons, England, 2001.
3. Math J. Bollen, “Understanding Power Quality Problems-Voltage Sags and Interruptions”, John Wiley & Sons, New Jersey, 2000.
4. Enrique Acha and Manuel Madrigal, “Power Systems Harmonics-Computer Modeling and Analysis”, John Wiley and Sons Ltd., 2001.

5. Selected Publications on Power Quality Improvement.

PR624 HIGH VOLTAGE POWER TRANSMISSION 3 - 1 - 0 - 4

Steady state reactive power control in transmission systems: requirements in ac power transmission, uncompensated transmission lines, compensated transmission lines, passive shunt compensation, series compensation, compensation by sectioning. FACTS devices: shunt compensation, thyristor controlled reactor (TCR) and related compensators, three phase TCR, 12 pulse TCR, thyristor switched capacitor, thyristor controlled transformer, static VAR compensator (SVC), STATCOM. Series compensation: thyristor controlled series compensation (TCSC), static synchronous series compensator (SSSC). Combined series and shunt controllers, unified power flow controller (UPFC), interline power flow controller (IPFC). HVDC transmission: comparison of EHVAC and HVDC transmission systems. HVDC links: monopolar, bipolar, homopolar and back to back configurations. Three phase converters: rectifier and inverter modes of operation, 12 pulse converter. DC link power flow control: constant current, constant voltage, constant ignition angle and constant extinction angle control, reactive power requirements. Interconnection between ac and dc systems, converter transformers, design of back to back thyristor converter system.

TEXT BOOKS/ REFERENCES:

1. R. M. Mathur and R. K. Varma, "Thyristor Based FACTS Controllers for Electrical Transmission Systems", Wiley India Pvt. Limited, 2011.
2. J. Arrilliga, "Flexible Power Transmission: The HVDC Options", John Wiley and Sons, 2007.
3. K. R. Padiyar, "Facts Controllers in Power Transmission and Distribution", Anshan Publishers, 2009.
4. K. R. Padiyar," HVDC Power Transmission System", New Academic Science, 2011.
5. Narain G. Hingorani and Laszlo Gyugyi, "Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems", Wiley-IEEE Press, 2001.
6. T. J. E. Miller, "Reactive Power Control in Electric Systems", John Wiley and Sons, 1982.
7. E. W. Kimbark, "Direct Current Transmission", Vol 1, Wiley, 1971.

PR691 POWER AND ENERGY LABORATORY 0- 0 - 6 - 2

This course includes analysis, modeling, designing, and testing of electrical power and energy processing systems carried out in a practical laboratory setup. Included are about 16 experiments on power flow studies, fault analysis, protective relaying, harvesting renewable energy, power electronic converter/ systems for efficient transmission and utilization of available energy sources. A mini project involving design and hardware implementation of the prototype model of any power & energy processing system is also part of the laboratory course.

EN600 TECHNICAL WRITING P/F

Technical terms- Definitions- extended definitions- grammar checks- error detection- punctuation- spelling and number rules - tone and style- pre-writing techniques - Online and offline library resources- citing references – plagiarism - Graphical representation - documentation styles- instruction manuals- information brochures- research papers, proposals – reports (dissertation, project reports etc.) - Oral presentations.

TEXTBOOKS / REFERENCES:

1. Hirish H L, *Essential Communication Strategies for Scientists, Engineers and Technology Professionals,* Second Edition, IEEE Press, New York, 2002
2. Anderson P V, *Technical Communication: A Reader-Centred Approach,* Sixth Edition. Cengage Learning India Pvt. Ltd., New Delhi, Reprint 2010.
3. Strunk Jr. W and White E B, *The Elements of Style,* Alliyan & Bacon, New York, 1999.

CI622 DIGITAL CONTROL SYSTEMS 3 - 0 - 0 - 3

Review of Z transforms. Pulse transfer function. Digital control system: introduction, sampling, quantization, data reconstruction and filtering of sampled signals. Z transform analysis of closed loop and open loop systems, multirate Z-transform. Stability analysis of closed loop systems in the z-plane: root loci, frequency domain analysis, stability tests. Discrete equivalents. Digital controller design for SISO systems: design based on root locus method in the z plane, design based on frequency response method, design of lag compensator, lead compensator, lag lead compensator, design of PID Controller based on frequency response method, direct design, method of Ragazzini. Controllability, observability, control law design, decoupling by state variable feedback, effect of sampling period. Estimator/ Observer Design: full order observers, reduced order observers, regulator design.

TEXT BOOKS/ REFERENCES:

1. Gene F. Franklin, J. David Powell and Michael Workman, “Digital Control of Dynamic Systems”, Pearson, Asia, 2000.
2. J. Ioan Doré Landau and Gianluca Zito, “Digital Control Systems: Design, Identification and Implementation”, Springer, 2006.
3. M. Sami Fadali and Antonio Visioli, “Digital Control Engineering: Analysis and Design”, Elsevier, 2013.
4. M. Gopal, “Digital Control and State Variable Methods”, Tata McGraw-Hill, 2006.
5. K. Ogata, “Discrete-Time Control Systems”, Pearson Education, Asia, 2011.
6. C. L. Philips, Troy Nagle and Aranya Chakrabortty, “Digital Control System Analysis and Design", Prentice-Hall, 2014.

PR711 MICROCONTROLLERS AND APPLICATIONS 3 - 0 - 0 - 3

Introduction to Microcontrollers: role of microcontrollers and its comparison with microprocessors. Embedded systems and their characteristics, overview of microcontroller

resources in standard PIC midrange series 8 bit microcontrollers, addressing modes, terminology, linear addressing, segmented addressing and stack addressing. Instruction set: arithmetic operations, logical operations, data transfer operations, control transfer operations. Program memory and data memory. Parallel ports, interrupt structures, introduction to USART, ADC, CCP modules, watch dog timers, assembly language programming. Microcontroller applications: measurement of voltage, current, speed, power and power factor using microcontrollers. Applications of microcontroller based gate firing control of converters. Typical functions of microcontrollers in power electronic systems: PWM implementation, feedback control and processing of feedback signals. Implementation of digital controllers: P, I and PI. Introduction to digital signal controllers: architecture, addressing modes, instruction set, assembly language programming (introduction only). Case studies: buck converter control, boost converter control, DC motor control, IM control.

TEXT BOOKS/ REFERENCES:

1. Muhammad Ali Mazidi, Rolin D. Mckinlay and Danny Causey, "PIC Microcontroller and Embedded Systems using Assembly and C for PIC18", Pearson Education, 2008.
2. Douglas V. Hall, "Microprocessor and Interfacing - Programming and Hardware, Eleventh Edition, TMH, , 2003.
3. John B. Peatman, "Design with PIC Microcontroller", Pearson Education, 2003.
4. Kenjo T., "Power Electronics for Microprocessor Age", Clarendon Press, Oxford, 1999.
5. Kenneth J. Hintz and Daniel Tabak, ''Microcontrollers - Architecture, Implementation and Programming'', McGraw Hill, USA, 1992.
6. Data Sheets and Application notes of 8-bit PIC Microcontrollers.

PR712 ENERGY SYSTEMS MODELING AND ANALYSIS 3 - 0 - 0 - 3

Modeling overview: levels of analysis, steps in model development, examples of models. Quantitative techniques: interpolation-polynomial, Lagrangian. Curve-fitting, regression analysis, solution of transcendental equations. systems simulation, information flow diagram, solution of set of nonlinear algebraic equations, successive substitution, Newton Raphson. Examples of energy systems simulation. Optimisation: objectives/ constraints, problem formulation. Unconstrained problems, necessary & sufficiency conditions. Constrained optimization, Lagrange multipliers, constrained variations, Kuhn-Tucker conditions. Linear programming, simplex tableau, pivoting, sensitivity analysis. Dynamic programming. Search techniques: univariate / multivariate. Case studies of optimisation in energy systems problems. Dealing with uncertainty- probabilistic techniques. Trade-offs between capital & energy using pinch analysis. Energy-economy models: scenario generation, input output model. Numerical solution of differential equations: overview, convergence, accuracy. Transient analysis: application example.

TEXT BOOKS/ REFERENCES:

1. S. S. Rao, "Energy Optimisation: Theory and Practice", John Wiley and Sons, 2009.
2. S. S. Sastry, "Introductory Methods of Numerical Analysis", PHI Learning Private Limited, New Delhi, 2012.

3. Y. Jaluria, “Design and Optimization of Thermal Systems”, Taylor & Francis, CRC Press, 2008.
4. W. F. Stoecker, “Design of Thermal Systems”, McGraw Hill, 1989.
5. Yunus A. Cengel, “Thermodynamics: An Engineering Approach”, McGraw Hill, 2008.
6. R. De. Neufville, “Applied Systems Analysis”, McGraw Hill, International Edition, 1990.

MA708 NUMERICAL METHODS AND OPTIMIZATION 3 - 0 - 0 - 3

Solution of equations and eigen value problems: linear interpolation methods, method of false position, Newton’s method, statement of fixed point theorem, fixed point iteration, solution of linear system by Gaussian elimination, Gauss-Jordon methods and iterative methods, inverse of a matrix by Gauss Jordon method, eigen value of a matrix by power method. Initial value problems for ordinary differential equations: single step methods, Taylor series method, Euler and modified Euler methods, fourth order Runge – Kutta method for solving first and second order equations. Multistep methods: Milne’s and Adam’s predictor and corrector methods. Linear programming: formulation, graphical and simplex methods, Big-M method, two phase method, dual simplex method, primal dual problems. Unconstrained one dimensional optimization techniques: necessary and sufficient conditions. Unrestricted search methods: Fibonacci and golden section method, quadratic interpolation methods, cubic interpolation and direct root methods. Unconstrained n-dimensional optimization techniques: direct search methods, random search, pattern search and Rosen Brooch’s hill claiming method, descent methods, steepest descent, conjugate gradient, quasi-Newton method. Constrained optimization techniques: necessary and sufficient conditions, equality and inequality constraints, Kuhn-Tucker conditions, gradient projection method, cutting plane method, penalty function method. Dynamic programming, principle of optimality, recursive equation approach, application to shortest route, cargo-loading, allocation and production schedule problems.

TEXT BOOKS/ REFERENCES:

1. S. S. Rao, “Energy Optimisation Theory and Practice”, John Wiley and Sons, 2009
2. Taha H. A., “Operations Research – An Introduction”, Prentice Hall of India, Eighth Edition, 2008.
3. Gerald C. F. and Wheatley P. O, “Applied Numerical Analysis”, Sixth Edition, Pearson Education Asia, New Delhi, 2002.
4. Balagurusamy. E., “Numerical Methods”, Tata McGraw-Hill, New Delhi, 2000.
5. Kandasamy. P., Thilagavathy K. and Gunavathy K., “Numerical Methods”, S.Chand Co. Ltd., New Delhi, 2003.
6. Burden R. L. and Faires T. D., “Numerical Analysis”, Seventh Edition, Thomson Asia Pvt. Ltd., Singapore, 2002.
7. Fox R. L., “Optimization Methods for Engineering Design”, Addition Wesley, 1971.

PR721 OPERATION AND CONTROL OF POWER SYSTEMS 3 - 0 - 0 - 3

Introduction: Review of thermal units. The Lambda iteration method, first order gradient method base point and participation factors. Generation with limited supply, take or pay fuel contract, composite generation production cost function, solution of gradient search techniques. Hard

limits and slack variables. hydro-thermal coordination, long range and short range scheduling, hydro-electric plant models, scheduling problems types of scheduling problems. Scheduling energy, short-term hydrothermal scheduling problem, pumped storage hydro plants, pumped storage hydro scheduling λ-γ iteration. Inter change evaluation and power pools, economy interchange evaluation with unit commitments. Types of interchange. Energy banking. State estimation: introduction to advanced topics, detection and identification of bad measurements, estimation of quantities not being measured, network observability and pseudo-measurements. Power system security-system monitoring, contingency analysis, security constrained optimal power flow, factors affecting power system security. Load frequency control, automatic voltage and frequency control, basic concepts of governor mechanism, block diagram representation and mathematical models of speed governing system. State space model of a single area system & two area systems. Voltage control: AGC including excitation system. MVAR control, application of voltage regulator, synchronous condenser, transformer taps, static VAR compensators. SCADA in power systems.

TEXT BOOKS/ REFERENCES:

1. Allen J. Wood and Wollenberg B.F., "Power Generation Operation and Control", Wiley Student Edition, 2008.
2. Nagrath, I.J. and Kothari D.P., "Modern Power System Analysis", Tata McGraw Hill, New Delhi, 2011.
3. A. Monticelli, "Electric Power System State Estimation", Proc. IEEE, Vol. 88, No.2, 2000.
4. Olle I. Elgerd, "Electric Energy and System Theory – An Introduction", Tata McGraw-Hill Publishing Company Limited, New Delhi, 2004.
5. N. V. Ramana, "Power System Operation and Control", Pearson, 2012.
6. Hassan Bevarani, Masayuki Watanabe and Yasunori Mitani, "Power System Monitoring and Control", Wiley-IEEE Press, 2014.
7. Prabha Kundur, "Power System Stability and Control", McGraw-Hill Education, 2011.

PR722 RESTRUCTURED POWER SYSTEMS 3 - 0 - 0 - 3

Background review: review of concepts, marginal cost of generation, least-cost operation, incremental cost of generation, Kuhn-Tucker's conditions of optimum, inter-utility interchanges. Fundamentals of electricity markets and energy auctions: introduction to restructuring for power systems, key issues in restructuring, restructuring models, independent system operators (ISOs), supply and demand functions, market equilibrium, types of electricity markets, competitive Gencos in markets, price-based UC, strategic bidding, market power and its mitigation, imperfect Markets. Transmission open access: transmission open access, transmission costing and pricing paradigms, concept of distribution factors in power transmission and their application to pricing, LMPs, transmission capacity, ATC calculations, review of transmission pricing practices – OASIS. Transmission congestion management: transmission congestion management and transmission rights congestion management models and firm / financial transmission rights. Ancillary services and system security in deregulation: ancillary services classifications and definitions. System frequency control: primary regulation and automatic generation control, frequency control practices reactive power ancillary services in electricity markets, country practices. System security in deregulation. Review of electric utility markets in India.

TEXT BOOKS/ REFERENCES:

1. Kankar Bhattacharya, Math H.J. Bollen and Jaap E. Daalder, "Operation of Restructured Power Systems", Springer, 2012.
2. M. Shahidehpour, H. Yamin and Zuyi Li, "Market Operations in Electric Power Systems: Forecasting, Scheduling, and Risk Management", John Wiley & Sons, 2003.
3. M. Shahidehpour and M. Alomoush "Restructured Electrical Power Systems – Operation, Trading and Volatility", CRC Press, 2001.

PR723 NUCLEAR ENERGY 3 - 0 - 0 - 3

Atomic and nuclear physics: atomic and nuclear structure, particle wavelengths, excited states and radiation, nuclear stability and radioactive decay, nuclear reactions. Interaction of radiation with matter: neutron interactions, energy loss in scattering collisions, fission, y-ray interactions with matter. Nuclear reactors and nuclear power: fission chain reaction, nuclear reactor fuels, Non-Nuclear Components of Nuclear Power Plants - Components of Nuclear Reactors - Fuel reprocessing, radioactive waste disposal. Neutron diffusion and moderation: Fick's law, equation of continuity, diffusion equation, solutions of the diffusion equation, nuclear reactor theory. Heat removal from nuclear reactors, thermal design of a reactor, radiation protection, computations of exposure and dose, standards for intake of radionuclides, exposure from y- ray sources.

TEXT BOOKS/ REFERENCES:

1. Dan Gabriel Cacuci (Ed.), "Handbook of Nuclear Engineering, Vol. 1: Nuclear Engineering Fundamentals; Vol. 2: Reactor Design; Vol. 3: Reactor Analysis; Vol. 4: Reactors of Generations III and IV; Vol. 5: Fuel Cycles, Decommissioning, Waste Disposal and Safeguards", Springer, 2010
2. Ronald Allen Knief, "Nuclear Engineering: Theory and Technology of Commercial Nuclear Power", LaGrange Park Publishers, American Nuclear Society, 2008.
3. John R. Lamarsh and Anthony J. Baratta, "Introduction to Nuclear Engineering", Third Edition, Prentice Hall, 2001.

PR724 SOFT COMPUTING TECHNIQUES 3 - 0 - 0 - 3

Introduction and basics: comparison of soft computing methods with conventional artificial intelligence (hard computing), least-square methods for system identification, recursive least square estimator, derivative based optimization, descent methods, Newton's method, conjugate gradient methods. Nonlinear least-squares problems, Gauss Newton method, Levenberg-Marquardt method. Neural networks: different architectures, McCulloch Pitts Model, Hebb network rule single layer and multilayer perceptron networks, ADALINE, MADALINE, learning methods. Learning rules: delta rule and Hebb rule, hybrid learning, back-propagation algorithm, supervised learning, unsupervised learning. Competitive learning: Kohnen's self organizing networks, associative memory neural networks, Hopfield networks. Fuzzy set theory: basic concepts, fuzzy set operators, membership functions. Fuzzy relations, fuzzy measures, rule based system and fuzzy reasoning. Fuzzification and defuzzification methods, fuzzy inference systems, Mamdani, Sugeno, and Tsukamoto, graphical techniques of inference. Fuzzy

classification : fuzzy c-means clustering. Fuzzy assocaitive memories, applications. Fuzzy decision making algorithm. Neuro-fuzzy modelling: adaptive neuro-fuzzy inference systems, Neuro-fuzzy controller. Genetic Algorithm: basics of Genetic Algorithms, design issues in Genetic Algorithm, Genetic modelling, hybrid approach, GA based fuzzy model identification. Fuzzy logic controlled Genetic Algorithm, neuro-genetic hybrids & fuzzy-Genetic hybrids. Particle Swarm Optimization: Concept of PSO, algorithm, PSO variations and applications. Ant colony optimization.

TEXT BOOKS/ REFERENCES:

1. Timothy J. Ross, "Fuzzy Logic with Engineering Applications", Wiley India Private Limited, 2010.
2. S. Rajasekharan and S. A. Vijayalekshmi Pai, "Neural Networks, Fuzzy Logic and Genetic Algorithms", Prentice-Hall India, 2003.
3. James A. Freeman and David M Skapura, "Neural Networks", Pearson Education, 2002.
4. David E. Goldberg, "Genetic Algorithms", Pearson Education, 2003.
5. John Yen and Reza Langari, "Fuzzy Logic, Intelligence, Control, and Information", Pearson Education, Delhi, 2003.
6. Laurene Fausett, "Fundamentals of Neural Networks, Architectures, Algorithms, and Applications", Pearson Education, 2002.
7. J. S. R. Jang, C. T. Sun and E Mizutani, "Neurofuzzy and Soft Computing", Prentice-Hall International, Inc., USA, 1997.

PR731 WIND ENERGY CONVERSION SYSTEMS 3 - 0 - 0 - 3

History of wind turbine development and trends. Wind resource assessment, wind regime modeling, measurement instruments, Weibull parameters, height dependency, wind resources worldwide and in India. Wind energy machine types, classification, parameters. Wind turbine aerodynamics, momentum theories, basic aerodynamics, airfoils and their characteristics. Vertical Axis Wind Turbine (VAWT). Horizontal Axis Wind Turbine (HAWT), blade element theory, Betz limit, wake analysis. HAWT rotor design considerations, number of blades, blade profile, 2/3 blades and teetering, coning, power regulation. Wind turbine loads, aerodynamic loads in steady operation, wind turbulence, and tower shadow. Wind turbine components - braking, yaw system, tower, others. Fixed speed and variable speed systems. Electrical machines for wind energy systems, synchronous and asynchronous generators and power electronics. Integration of wind energy systems to electrical networks, converters, inverters, directly connected. Control systems: requirements, components and strategies. Site selection and turbine spacing, rotor selection, annual energy output (AEO). Small wind turbines: special considerations and designs. Off-shore turbines, testing, noise. Financial considerations: installed costs, payback time, levelized energy cost (LEC).

TEXT BOOKS/ REFERENCES:

1. Joshua Earnest and Tore Wizelius, "Wind Power Plants and Project Development", PHI Learning Pvt. Ltd., New Delhi, 2011.
2. J. F. Manwell, J. G. McGowan and A. L. Rogers, "Wind Energy Explained - Theory, Design and Application", Wiley, 2009.

3. G. M. Pillai, (Conceived & Edited) “Wind Power Development in India”, World Institute of Sustainable Energy (WISE), Pune 2006.
4. Freris. L. L., “Wind Energy Conversion Systems”, Prentice Hall 1990.
5. Spera D. A., “Wind Turbine Technology: Fundamental Concepts of Wind Turbine Engineering”, ASME Press, New York 1994.
6. Johnson G. L., “Wind Energy Systems”, Prentice Hall, 1994 (published by the author online).
7. Voker Quashning, "Understanding Renewable Energy Systems", Earthscan, 2005.

PR732 SOLAR ENERGY UTILIZATION 3 - 0 - 0 -3

Solar energy fundamentals: solar radiation, solar cell & its characteristics, solar PV modules: series & parallel connection. Solar energy collectors, concentrator PV cells and heliostat systems. Solar photovoltaic applications: types of systems, system design, balance of solar PV systems. Maximum power point tracking, solar PV inverter & converter design, energy storage options for solar PV systems with controllers, battery & fuel cell, design of off-grid PV systems, design of grid-connected PV systems, hybrid system design, life cycle cost analysis, installation & maintenance of SPV plants with standards. Solar street lighting & water pumping applications: design considerations & system design. Solar thermal applications: space/ air heating & cooling, active & passive heating and cooling of buildings, solar cooking, solar distillation, solar dryers for process plants, solar pond, solar collector and thermal storage: steady state and dynamic analysis, modelling of solar thermal systems and simulations in process design. Design of active systems by f-chart and utilizability methods. Thermoelectric - photovoltaic integrated modules for heating and electricity applications.

TEXT BOOKS/ REFERENCES:

1. Chetan Singh Solanki, “Solar Photovoltaics: Fundamentals, Technologies and Applications”, Second Edition, Prentice Hall of India, 2011.
2. S. P. Sukhatme, “Solar Energy - Principles of Thermal Collection and Storage”, Third Edition, Tata McGraw-Hill, New Delhi, 2008.
3. D. Y. Goswami, F. Kreith and J. F. Kreider, “Principles of Solar Engineering”, Taylor and Francis, Philadelphia, 2000
4. M. S. Sodha, N. K. Bansal, P. K. Bansal, A. Kumar and M. A. S. Malik, “Solar Passive Building: Science and Design”, Pergamon Press, New York, 1986.
5. M. A. S. Malik, G. N. Tiwari, A. Kumar and M. S. Sodha, “Solar Distillation”, Pergamon Press, New York, 1982.

PR733 POWER SYSTEM STABILITY 3 - 0 - 0 - 3

Introduction to power system stability: classical model of single machine connected to infinite bus and a multi machine system. Mathematical modeling of power system elements for stability studies: synchronous machines, excitation system, and power system stabilizer. Small signal analysis. Fundamental concepts of stability of dynamic systems: state space representation, linearization, eigen properties of state matrix, small signal stability of single machine infinite bus (SMIB system, block diagram representation with exciter and AVR, power system stabilizer

(PSS), state matrix including PSS, small signal stability of multi machine systems, characteristics of small signal stability problems, small signal stability enhancement. Transient stability analysis: modeling, enhancement methods, high speed excitation systems, discontinuous excitation control, control of HVDC transmission links. Equal area criterion. Sub synchronous resonance. Voltage stability analysis, mechanism of voltage collapse. Determination of shortest distance to instability, important voltage stability indices, prevention of voltage collapse, system design measures, system operating measures.

TEXT BOOKS/ REFERENCES:

1. K. R. Padiyar, "Power System Dynamics", Second Edition, B.S. Publishers, 2008.
2. P. W. Sauer and M. A. Pai, "Power System Dynamics and Stability", Pearson, 2003.
3. P. M. Anderson and A. A. Fouad, "Power System Control and Stability", John Wiley and Sons, 2008.
4. P. Kundur, "Power System Stability and Control", Tata McGraw Hill, 2011.
5. E. W. Kimbark, "Power System Stability", Wiley and IEEE Press, 1995.
6. Jan Machowski and Janusz Bialek, "Power System Dynamics: Stability and Control", Second Edition, Wiley, 2008.

PR734 ELECTRICAL DRIVES AND CONTROL 3 - 0 - 0 - 3

Fundamentals of electric drives, dynamics of electric drives, multi quadrant operation, closed loop control of drives. DC motors: methods of speed control, dual converter fed DC motor drives, chopper fed drives, single, two and four quadrant chopper drives. Speed control of 3 Phase induction motors, stator voltage control, principle, operation and applications. Slip power recovery scheme, principle, static Kramer's drive, static Scherbius drive, applications. V/f control, constant torque and constant power control. Speed control of synchronous motors, principles of synchronous motor control, self controlled synchronous motor with electronic commutation, self controlled synchronous motor drive using load commutated thyristor inverter. Primitive machine: unified approach to the analysis of electrical machine, basic two pole model of rotating machines, Kron's primitive machine, voltage, power and torque equation, linear transformation from 3 phase to 2 phase and from rotating axes to stationary axes, invariance of power. Principle of vector Control: vector controlled induction motor drive, basic principle, direct rotor flux oriented vector control, estimation of rotor flux and torque, implementation with current source and voltage source inverters. Stator flux oriented vector control, indirect rotor flux oriented vector control scheme, implementation, tuning (include lab practice). Vector control strategies for synchronous motor. Introduction to sensorless control, basic principle of direct torque control.

TEXT BOOKS/ REFERENCES:

1. R. Krishnan, "Electric Drives: Modeling, Analysis and Control", PHI, 2007.
2. Vedam Subramaniam, "Electric Drives: Concepts and Applications", Tata McGraw Hill, 2011.
3. Bose B. K, "Modern Power Electronics and AC Drives", Pearson Education Asia , 2002.
4. N. K. De and P. K. Sen, "Electric Drives", PHI, New Delhi 2001.

5. M. D. Singh and K. B. Khanchandani, “Power Electronics”, Tata McGraw Hill, 1998.
6. G. K. Dubey, “Power Semiconductor Controlled Drives”, Prentice Hall, 1989.
7. P.S. Bimbhra, “Generalized Theory of Electrical Machines”, Khanna Publications,1987.

PR741 SMART GRID 3 - 0 - 0 - 3

Review: energy scenario, energy constraints, renewable energy sources, classical power grids. Smart power grid systems: basic concepts, load factor and real time pricing, smart grid development. Smart grid architectural designs, legacy grid versus smart grid, smart grid components. Smart grid communications and measurement technology: wide area monitoring systems, phasor measurement units, smart meters and appliances, advanced metering interface. Sizing of inverter, rectifier and dc-dc converter for micro-grid operation. Synchronous and asynchronous operation of micro-grids, load flow control for smart grid, micro-grid fault studies. Demand side energy management: demand response, role of smart grid technology in demand response, building automation systems, dynamic energy management system. Distributed generation, recent trends in power electronic DG interconnection. Demand-side planning: economical consideration, tariff policies, real time pricing, micro-grid energy market, demand side ancillary services. Energy efficiency: cost-effectiveness, financial impacts, drivers of energy efficiency. Smart power grid modeling, energy mix for sustainable communities. Resource assessment and project development.

TEXT BOOKS/ REFERENCES:

1. Ali Keyhani, “Design of Smart Power Grid Renewable Energy Systems”, John Wiley & Sons, IEEE Press, 2011.
2. James Momoh, “Smart Grid - Fundamentals of Design and Analysis”, John Wiley & Sons, IEEE Press, 2012.
3. Clark W. and Gellings P. E., “The Smart Grid: Enabling Energy Efficiency and Demand Response”, The Fairmount Press, Taylor & Francis, 2009.
4. Francis Vanek, Louis Albright and Largus Angenent, “Energy Systems Engineering Evaluation and Implementation”, McGraw Hill, 2008.

PR742 MODERN POWER SYSTEM PROTECTION 3 - 0 - 0 - 3

Introduction to electromagnetic relays: thermal relays, static relays, microprocessor based relays. Static relays: merits and demerits, comparators, amplitude and phase comparators, duality between amplitude and phase comparators. Over-current protection: time current characteristic, special characteristic, different types of static over current relays, static over voltage and under voltage relays, static directional relays. Distance protection scheme: standard 3 zone protection, types of static distance relays, impedance, reactance, mho, quadrilateral, elliptical, effect of arc resistance and power surges in the performance of distance relays, pilot relaying scheme, wire pilot protection, carrier current protection. Microprocessor based protective relays: over current relay, impedance relay, directional relay, reactance relay. Basic protection scheme using microcomputers. Computer application to protective relays: digital simulation of power system disturbance, digital simulation of distance relay during transients, on line and off line application of computers to protection. Reliability and protection: reliability, redundancy, continuous

supervision and self-diagnosis, automatic testing, test methods for static relays, maintenance and field testing of relays.

TEXT BOOKS/ REFERENCES:

1. T. S. Madhava Rao, "Power System Protection: Static Relays", Tata McGraw Hill, 2004.
2. Badari Ram and D. N. Viswakarma, "Power System Protection and Switchgear", Tata McGraw Hill, 2011.
3. Bhuvanesh A. Oza, "Power System Protection and Switchgear", Tata McGraw Hill, 2010.
4. C. R. Mason, "The Art and Science of Protective Relays", Wiley Eastern, 1992.
5. M. V. Deshpande, "Switchgear Protection", Tata McGraw Hill, 1993.
6. Mac Donald, "Power System Protection. Volume- I, II & III Edited by the Electricity Council", Tata McGraw Hill, 1993.

PR743 BIO - ENERGY CONVERSION 3 - 0 - 0 - 3

Bio-energy: bio-mass gasification and biogas systems, types of biomass gasification, pyrolysis. Anaerobic digestion of wastes, high performance bio-gas systems, cleaning of bio-gas, use of bio-mass for electricity production, conversion of CO_2 in bio-gas to CO, bio-gas compression and storage. Micro algae for oil production, straight vegetable oil (SVO) in engines, organic wastes to electricity, waste to energy (WTE) systems for municipal solid wastes (MSW), vegetable, fish and meat processing residues. Direct combustion, bio-energy for off-grid electrification, hybrid renewable energy systems.

TEXT BOOKS/ REFERENCES:

1. Prabir Basu, "Biomass Gasification and Pyrolysis", Elsevier Inc., 2010.
2. Sunggyu Lee and Y. T. Shah, "Biofuels and Bioenergy: Processes and Technologies", CRC Press, Taylor & Francis Group, 2013.
3. Erik Dahlquist, "Biomass as Energy Source Resources, Systems and Applications", CRC Press, Taylor & Francis Group, UK, 2013.

PR744 ENERGY STORAGE TECHNOLOGY 3 - 0 - 0 – 3

Energy storages: Issues of energy accumulation in various forms. Possibility of energy storage. Thermal energy storage, (long and short term - heat storage tanks, ground storage, PCM storage), mechanical energy storage (flywheels). Compressed air energy storages (CAES) - energy storage systems for power plants, industry and air weapons. Hydrogen as an energy carrier, hydrogen production and storage. Fuel cells as energy storage and conversion system. Hydro storage power plant. Electrical energy storages - batteries, capacitors, super capacitors, electromagnetic systems, superconducting magnetic energy storage (SMES). Examples of energy storage systems. Energy management, efficiency of energy storage in different forms. Increase of energy conversion efficiencies by introducing the energy storage.

TEXT BOOKS/ REFERENCES:

1. Aiping Yu, Victor Chabot and Jiujun Zhang, "Electromechanical Energy Storage and Conversion", CRC Press, Taylor & Francis Group, (ISBN - 978-1-4398-6989-5), 2013.
2. A.G.Ter-Gazarian, "Energy Storage for Power Systems", Second Edition, The Institution of Engineering and Technology (IET) Publication, UK, (ISBN - 978-1-84919-219-4), 2011.
3. Robert A. Huggins, "Energy Storage", Springer Science (ISBN - 978 -1-4419-1023-3), 2010.
4. A. R. Pendse, "Energy Storage Science and Technology", SBS Publishers & Distributors Pvt. Ltd., New Delhi, (ISBN - 13:9789380090122), 2011
5. Frank S. Barnes and Jonah G. Levine, "Large Energy Storage Systems Handbook", Taylor and Francis Group (ISBN - 978-1-4200-8600-3), 2011.
6. Electric Power Research Institute (USA), "Electricity Energy Storage Technology Options: A White Paper Primer on Applications, Costs, and Benefits" (1020676), December 2010.
7. International Electro-technical Commission (IEC), Switzerland, "White Paper on Electrical Energy Storage", December 2011.
8. Paul Denholm, Erik Ela, Brendan Kirby and Michael Milligan, "The Role of Energy Storage with Renewable Electricity Generation", National Renewable Energy Laboratory (NREL) - A National Laboratory of the U.S. Department of Energy - Technical Report NREL/ TP6A2-47187, January 2010.