M.TECH - RENEWABLE ENERGY TECHNOLOGY

Department of Electrical and Electronics Engineering

Renewable energy being the most important application area of engineering and technology in the twenty first century, this graduate programme is designed for quality learning in that sector. RE sector needs manpower with design and engineering skills in RE systems and components – this programme targets to impart these. The curriculum has an emphasis on solar and wind energy systems, in tune with the Indian national missions on these. Job avenues targeted are RE equipment manufacturers, farm developers and system operators; also, the qualified human resource requirement in RE teaching and research is potentially high.

The learning is guided through two parallel streams of electrical and mechanical disciplines. Core courses and electives of specialization are offered by faculty from various departments like Electrical and Electronics, Mechanical, Aerospace, Business Management, Science etc.

A Renewable Energy laboratory developed through assistance from C-WET, MNRE and DST, Government of India, equipped with hard and soft experiment systems and real field data collection systems, provides active training support to the programme. Collaborations with global academic and industrial establishments too help in imparting quality learning in this programme.

Curriculum

Semester I

Course code	Type	Course Title	L T P	Cr
PE 623	SC	Soft Computing	3-0-1	4
RE 601	FC	Electronic Instrumentation Systems	3-0-1	4
RE 611	SC	Solar Energy	3-0-0	3
MA 609	FC	Linear Algebra and Random Process	4-0-0	4
RE 612	SC	Bio and Hydro Energy Sources	3-0-0	3
PE 624	SC	Simulation Laboratory	0-0-1	1
HU 601	H	Cultural Education*		P/F
Total for Sem 1				**19**

* Non-credit course

Semester II

Course code	Type	Course Title	LTP	Cr
RE 602	FC	Energy Economics and Renewable Energy Policy	3-0-0	3
PE 706	SC	Energy Conservation and Management	3-0-0	3
RE 613	SC	Wind Energy	3-0-0	3
	E	Elective I	3-0-0	3
	E	Elective II	3-0-0	3
RE 614	SC	Seminar	0-0-1	1
RE 615	SC	Energy System Laboratory I	0-0-1	1
EN 600	HU	Technical Writing*		P/F
Total for Sem 2				**17**

* Non-credit course

Semester III

Course code	Type	Course Title	LTP	Cr
	E	Elective III	3-0-0	3
	E	Elective IV	3-0-0	3
RE 616	SC	Energy System Laboratory II	0-0-2	2
RE 799	P	Dissertation		10
Total for Sem 3				**18**

Semester IV

Course code	Type	Course Title	LTP	Cr
RE 799	P	Dissertation		12
		Total for Sem 4		**12**
		Total for the programme		**66**

List of Courses
Foundation Core

Course code	Course Title	L T P	Cr
RE 601	Electronic Instrumentation Systems	3-0-1	4
MA 609	Linear Algebra and Random Process	4-0-0	4
RE 602	Energy Economics and Renewable Energy Policy	3-0-0	3

Subject Core

Course code	Course Title	LTP	Cr
PE 623	Soft Computing	3-0-1	4
RE 611	Solar Energy	3-0-0	3
RE 612	Bio and Hydro Energy Sources	3-0-0	3
PE 624	Simulation Laboratory	0-0-1	1
PE 706	Energy Conservation and Management	3-0-0	3
RE 613	Wind Energy	3-0-0	3
RE 614	Seminar	0-0-1	1
RE 615	Energy System Laboratory I	0-0-1	1
RE 616	Energy System Laboratory II	0-0-2	2

Electives

Course Code	Course	L T P	Cr
Elective I			
PE 708	Power System Operation and Control	3-0-0	3
RE 701	Power Electronics for Energy Systems	3-0-0	3
PE 707	Programmable Logic Controllers	3-0-0	3
RE 702	Solar Thermal Engineering	3-0-0	3
Elective II			
RE 703	Power System Modeling	3-0-0	3
RE 704	Flexible AC and High Voltage DC Transmission Systems	3-0-0	3
RE 705	Aerodynamics and Wind Turbines	3-0-0	3
PE 711	Computational Optimization Theory – Linear and Non-Linear Methods	3-0-0	3
Elective III			
RE 706	Wind Electric Generators	3-0-0	3
PE 716	Electrical Machine Analysis Using Finite Element Analysis	3-0-0	3

RE 707	Applied Computational Fluid Dynamics	3-0-0	3
RE 708	Energy Storage Systems	3-0-0	3
Elective IV			
RE 709	Smart Grid	3-0-0	3
PE 705	Electric Power Quality	3-0-0	3
RE 710	Electrochemical Energy Systems	3-0-0	3
RE 711	Project Management	3-0-0	3

Project Work

Course Code	Course	L T P	Cr
RE799	Dissertation		10
RE799	Dissertation		12

PE623   **SOFT COMPUTING**   **3-0-1-4**

Fuzzy Logic (FL) – Membership Functions – Fuzzifications and Defuzzifications – Fuzzy Relations – TSK Fuzzy Modeling – Neural Networks (NN) – Supervised and Unsupervised Learning – Hopfield – RBF Networks – Principal Component Analysis – PNN – Kohonen Self Organizing Networks – Learning Vector Quantization – Hebbian Learning – Adaptive Resonance Theory – Genetic Algorithms (GA) – Standard GA – Schema Theory – Building Block Hypothesis – Chaos and Fractals – One Dimensional Logistic Equation – Hurst Exponent – Fractal Dimension – Non Linear Time Series Analysis – Lyapunov Exponent – Correlation Dimension – Rough Set Theory – Feature Extraction – Dimensionality Reduction – Discernability – Matrix – Introduction to Support Vector Machines – Classification and Regression – Typical Applications Integrating Various Soft Computing Tools.

TEXT BOOKS/ REFERENCES:
1. Timothy Ross, *"Fuzzy Logic with Engineering Applications"*, Second Edition, John Wiley and sons, 2004.
2. Simon Haykin, *"Neural Networks and Learning Machines"*, Third Edition, Pearson Education, 2009.
3. K.F. Man, K.S. Tang and S. Kwong, *"Genetic Algorithms: Concepts and Applications"*, IEEE Transactions Industrial Electronics, Vol-3, 1996.
4. Thomas S.Parker and Leon O Chua, *"CHAOS : A Tutorial for Engineers"*, Proceedings IEEE, Vol-75 , No.8, 1987.
5. Jan Komorowski, Lech Polkowski and Andrzej Skowron, *"Rough Sets: A Tutorial"*, http://Folli.Loria.Fr/Cds/1999/Library/Pdf/Skowron.Pdf

RE601   **ELECTRONIC INSTRUMENTATION SYSTEMS**   **3-0-1-4**

Measuring systems - classification, static and dynamic *characteristics, errors, calibration and standards.* Mechanical transducers: pressure measurement- diaphragms; force measurement, cantilever beams; torque measurement, strain gauge. Vibration measurement. Anemometers – cup, hot wire, SODAR, LIDAR. Sunshine recorder, pyranometer, pyrheliometer. GIS.
Passive electrical transducers: Resistive, thermal radiation detectors, hotwire resistance, resistive displacement, resistive strain, resistive pressure, linear variable differential transformer. Active electrical transducers: Thermoelectric-thermocouples, RTD, piezoelectric, Hall Effect, digital displacement, photo electric.
Feedback transducer systems: Feedback fundamentals, inverse transducers, temperature balance system. Signal processing circuits: oscillators, pulse generators, comparators, Schmitt trigger, PLL detector, first and second order active electrical filters, Modulated signals, sampling circuits, angle modulation counters, encoders and decoders, D-A and A-D converters, voltage to frequency counters, digital multiplexers and demultiplexers
PLC: architecture, programming, ladder diagram, communications and networking, selection and   installation.
Communication Technologies: wired, wireless. RF -Zigbee, Bluetooth, WiFi, Ethernet, GSM, GPRS. Data acquisition systems, data loggers*.*

TEXT BOOKS/ REFERENCES:
1. D.V.S.Murty, *"Transducers and Instrumentation"*, Second Edition, Prentice-Hall of India Private Limited, 2008.
2. Arun K.Ghosh, *"Introduction to Measurements and Instrumentation"*, Third Edition, PHI Learning Private Limited, 2009.
3. S. K. Singh, *"Computer Aided Process Control"*, Prentice-Hall of India Private Limited, 2003.
4. William Stallings, *"Wireless Communications and Networks"*, Second Edition, Pearson Education, 2005.

RE 611   **SOLAR ENERGY**   **3-0-0-3**

History of Solar Energy, Properties of Sun Light- Energy of Photon, Photon Flux, Spectral Irradiance, Solar Radiation- Sun, Terrestrial Solar Radiation-Atmospheric effects, Air Mass, Motion of Sun, Tilt angle calculation, Solar radiation data, Measuring Instruments, Estimation of Solar Radiation, Solar radiation in India.
Difference between Solar Thermal and Solar PV, Solar Thermal Collector and its types, Solar thermal Energy Storage System, Applications of Solar Thermal System.
Photon interactions with semiconductors, PV cell architecture and fabrication steps, crystalline Si substrates, thin film deposition, amorphous Si, CIGS, CdTe etc., dye sensitized cell. Computing PV cell power, equivalent circuit models, short-circuit and open-circuit properties, fill factor, parasitic resistances; External and internal quantum efficiency, spectral response, Theoretical cell efficiency, multijunction devices, the Shockley-Queisser limit.
PV Module and Array - Effects of shaded and faulty cell, Effects of changes in tilt angle, solar radiation and temperature, Sun Tracking, Charge Controllers, MPPT Algorithms, Stand Alone PV System, Grid Connected PV System, Hybrid Systems. Estimation of panel size, charge controller ratings, battery capacity, inverter specifications and cable specifications; Installation of SPV Systems; Cost analysis and pay back calculations; Environmental and safety issues.

TEXT BOOKS/ REFERENCES:
1. Nelson J, *"The Physics of Solar Cell"*, Imperial College Press, 2006.
2. Wenham SR, *"Applied Photovoltaic"*, Second Edition, Earthscan Publications Ltd, 2007.
3. G.N. Tiwari, *"Solar Energy-Fundamentals, Design, Modelling and Applications"*, Narosa Publishers, 2002.
4. F. Kreith and J.F. Kreider, *"Principles of Solar Engineering"*, McGraw Hill, 1978.
5. John Twidell and Tony Weir, *"Renewable Energy Resources"*, Second Edition, Taylor and Francis, 2005.

MA609   **LINEAR ALGEBRA AND RANDOM PROCESS**   **4-0-0-4**

Vector Spaces: Vector spaces - Sub spaces - Linear independence - Basis - Dimension - Inner products - Orthogonality - Orthogonal basis - Gram Schmidt Process - Change of basis - Orthogonal complements - Projection on subspace - Least Square Principle.

Linear Transformations: Positive definite matrices - Matrix norm and condition number - QR- Decomposition - Linear transformation - Relation between matrices and linear transformations - Kernel and range of a linear transformation - Change of basis - Nilpotent

transformations - Similarity of linear transformations - Diagonalisation and its applications - Jordan form and rational canonical form.

Random Processes: General concepts and definitions-Stationarity in random process-autocorrelation and properties-Poisson points, Poisson and Gaussian processes-Spectrum estimation- Ergodicity and mean Ergodic theorem-Power spectral density and properties. Markov processes –Markov Chains – Transition Probability matrix- Classification of states-Limiting Distributions.

TEXT BOOKS / REFERENCES:
1. Howard Anton and Chris Rorres, "*Elementary Linear Algebra*", Tenth Edition, John Wiley and Sons, 2010.
2. Gilbert Strang, "*Linear Algebra and Its Applications*", Fourth Edition, Cengage, 2006.
3. A. Papoulis and Unnikrishna Pillai, "*Probability, Random Variables and Stochastic Processes*", Fourth Edition, McGraw Hill, 2002.
4. Ravichandran, J. "*Probability and Statistics for Engineers*", Wiley India, 2012.
5. Douglas C. Montgomery and George C. Runger, "*Applied Statistics and Probability for Engineers*", John Wiley and Sons Inc., 2005.

RE612   **BIO AND HYDRO ENERGY SOURCES**   **3-0-0-3**

Energy from biomass: sources, classification, conversion into fuels, photosynthesis, C_3 and C_4 plants on biomass production, physicochemical characteristics ; CO_2 fixation potential. Biomass resource assessment, application of remote sensing for resource assessment; biomass productivity study, waste land utilization through energy plantation.
Biomass conversion process: biochemical - anaerobic digestion, biogas production mechanism and technology, types of digesters, design of biogas plants; chemical - hydrolysis and hydrogenation, bio-fuels, Biodiesel production, fuel characteristics; thermo◻chemical - pyrolysis, combustion and gasification, gasifiers: updraft, downdraft, fluidized bed, biomass carbonization, natural draft and gasification based biomass stoves, gasification based power generation
Hydrology, Selection of site, Resource assessment, Classification of Hydropower Plants, Small Hydropower Systems: mini, micro and pico systems, Hydraulic Turbines: classification and operational aspects, elements of turbine, selection and design criteria, operating characteristic; Generators – synchronous and asynchronous, voltage, speed and power regulation; Electronic load controller; environmental issues related to hydro projects.

TEXT BOOKS/ REFERENCES:
1. Sorensen B., "*Renewable Energy*", Second Edition, Academic Press, 2000.
2. Ravindranath N. H. and Hall D. O., "*Biomass, Energy and Environment*", Oxford University Press, 1995.
3. Rosillo-Calle F. and Francisco R., "*The Biomass Assessment Handbook: Bioenergy for a Sustainable Environment*", Earthscan, 2007.
4. Wagner H. and Mathur J, "*Introduction to Hydro Energy Systems: Basics, Technology and Operation*", Springer, 2011.
5. John Twidell and Tony Weir, "*Renewable Energy Resources*", Second Edition, Taylor and Francis, 2005.

PE624   **SIMULATION LABORATORY**   **0-0-1-1**

Matlab, OrCAD, PSpice, PSCAD,EMTDC, DigSILENT, ANSYS and EMTP – applications in electric power system, SPV system and solar/bio thermal systems

RE602   **ENERGY ECONOMICS AND RENEWABLE ENERGY POLICY**   **3-0-0-3**

Energy economics: Basic concepts, Energy data and energy balance. Energy accounting framework; Economic theory of demand, production and cost market structure. Application of econometrics; input and output optimization and simulation methods to energy planning and forecasting problems. Dynamic models of the economy and simple theory of business fluctuation.
Costing: Time value of money – present worth and future worth; Economic performance indices – simple and discounted payback, Levelised cost - calculation of unit cost of power generation, cost-benefit ratio, E/D ratio, net present value, Internal rate of return.
Energy-GDP elasticity; National and regional energy policies - RE certificate, RE purchase obligation, subsidy and taxation, Renewable Recovery Fund,
Energy-Environment interactions at different levels; Energy security issues.

TEXT BOOKS/ REFERENCES:
1. Bhattacharyya S. C., *"Energy Economics"*, Springer, 2011.
2. Ferdinand E. B., *"Energy Economics: A Modern Introduction"*, Kluwer, 2000.
3. Kandpal T. C. and Garg H. P., *"Financial Evaluation of Renewable Energy Technology"*, Mac Milan, 2003.
4. Munasinghe M. and Meier P., *"Energy Policy Analysis and Modeling"*, Cambridge University Press, 1993.

PE706   **ENERGY CONSERVATION AND MANAGEMENT**   **3-0-0-3**

Historical development of commercial energy supply**:** Commercial energy in ancient times, Renewable Energy utilization in ancient times, Industrial revolution, Growth of fossil fuel systems, Emergence of nuclear power, Realization of environmental concerns, Developments in Renewable Energy Sector; Concept of Energy Efficiency and Clean Production.
Energy conservation on demand side: Efficient Lighting; Energy Efficiency in motors, pumps and fans. Power quality issues related to Energy Efficient Technologies.
Energy Economics**:** Time value of money - Present Worth and Future Worth Economic performance indices: Payback - Simple and Discounted, Net Present Value, Internal Rate of Return, Benefit to Cost Ratio, E/D ratio, Life cycle/levelised cost.
Energy Management in Electrical Power Systems**:** Supply-demand gap on electric power grid: causes and remedial measures. Energy trading; Demand Response; Microgrids and Smart grid.
Energy Management and Audit: Functions and methodologies of preliminary as well as detailed energy audits; Pre-audit, audit and post-audit measures Instruments for energy audit, Energy Conservation Practice – Case Studies**.**

TEXT BOOKS/ REFERENCES:
1. Hamies, *"Energy Auditing and Conservation; Methods, Measurements, Management and Case Study"*, Hemisphere Publishers, Washington, 1980.

2. C.W. Gellings and J.H. Chamberlin, "*Demand-Side Management Planning*", Fairmount Press, 1993.
3. Wayne C Turner, "*Energy Management Handbook*", The Fairmount Press, 2006.
4. Bureau of Energy Efficiency Study material for Energy Managers and Auditors Examination: Paper I to IV, www.energymanagertraining.com
5. S. Pabla, "*Electric Power Systems Planning*", Mac Millan India Ltd., 1998.

RE613 **WIND ENERGY** **3-0-0-3**

Meteorology of wind: Global circulation, Forces influencing wind, Local Wind systems, Wind Speed modeling – Weibull parameters and estimation, Wind Rose.
Wind Turbines: Types, Rotor elements; Horizontal and vertical axis wind turbines, Power in the wind, Power extracted from wind, Betz limit, Lift and drag coefficients, thrust and torque, stream tube model, linear momentum theory, power coefficient, thrust coefficient, axial interference factor. Pitch and stall regulation, power curve, energy calculation. Wind turbine generators: stand alone systems – schemes and system design, grid-connected systems – types, topology, characteristics, fixed speed and variable speed systems. Power electronic interface. Brakes. Gears. Testing and certification.
Wind farm development and operation: Techno economic feasibility. Government regulations and guidelines, micrositing and layout, use of software in micrositing, selection of equipment, installation and commissioning. Local infrastructure and power evacuation, influence of grid quality and reliability. Operation and maintenance. Central monitoring system and SCADA. Windfarm performance indices. Economic performance indices. Offshore wind farm development and special considerations. Short term and long term Wind forecasting. Grid code for wind farm operation.

 TEXT BOOKS/ REFERENCES:
1. Joshua Earnest and Tore Wizelius, "*Wind Power Plants and Project Development*", PHI Learning Pvt. Ltd., New Delhi, 2011.
2. G L Johnson, "*Wind Energy Systems*", Manhattan, KS, 2004.
3. E. H. Lysen, "*Introduction to Wind Energy, CWD Report 82-1, Consultancy Services Wind Energy Developing Countries*", The Netherlands, May 1983.
4. Erich Hau, "*Wind Turbines- Fundamentals: Technologies, Application, and Economics*". Springer -Verlag Berlin -Heidelbeg, 2000.

RE 614 **SEMINAR** **0-0-1-1**

Each student in consultation with a faculty advisor has to select a topic related to Energy and write a paper and present it.

RE615 **ENERGY SYSTEM LABORATORY I** **0-0-1-1**

Laboratory experiments on solar photovoltaic panels and BoS, energy conservation.
Software based studies on grid-connected SPV, electrochemical systems/bio energy systems

RE616 **ENERGY SYSTEM LABORATORY II** **0-0-2-2**

Laboratory experiments on wind electric generators, measurements & instruments

Software based studies on wind resource assessment and micro-siting, grid-connected WTG systems, power electronic systems/aerodynamics

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

PE708   **POWER SYSTEM OPERATION AND CONTROL**   **3-0-0-3**

Introduction- System load Variation: System load characteristics, Load curve- weekly and annual duration curve, load factor, diversity factor. Overview of system control: Governor control, LFC, AVR. Linear Models of Synchronous machines- Transient stability- Dynamic Stability. Real power- frequency control: Need for voltage and frequency regulation in power system, basic P-f and Q-V control loops. Fundamentals of speed governing systems and modeling, LFC of Single area and two area systems. Simulink models of single and two area system -Power System Stabilizers. Reactive power – Voltage control: Typical excitation system, static and dynamic analysis, effect of generator loading, static shunt capacitor/reactor VAR compensator, synchronous condenser, tap changing transformer, Static VAR system, modeling, system level voltage control. Economic Dispatch: Incremental cost curve, co-ordination equations with loss and without losses- solution by iteration method. Base point and participation factors. Economic controller added to LFC control.

TEXT BOOKS/ REFERENCES:
1. Olle. I. Elgerd, "*Electric Energy Systems Theory- An Introduction*", Tata Mc Graw Hill Publishing Company Ltd., New Delhi, 2004.
2. D. P. Kothari and I. J. Nagrath, "*Modern Power System Analysis*", Tata Mc Graw Hill Publishing Company Ltd., New Delhi, 2005.
3. Allen .J. Wood, Bruce.F.Wollenberg and Gerald B. Sheble, "*Power Generation Operation and Control*", Third Edition, John Wiley and Sons, 2013.
4. L. K. Kirchmayer, "*Economic Operation of Power System*", Second Edition, John Wiley and Sons, 1967.

RE701   **POWER ELECTRONICS FOR ENERGY SYSTEMS**   **3-0-0-3**

Power semiconductor switches: Power diodes, Thyristors, MOSFETS, and IGBT. Switch waveforms and power loss for simplified clamped inductive circuit. RMS values, THD,

power and power factor with non sinusoidal waveform.   AC voltage controllers: Single phase full wave phase controller with R, L and RL loads. Single phase soft starter, Thyristor controlled reactor. Three phase full wave phase controller.

Converters: Single phase and three phase diode full bridge rectifiers with resistive load, constant dc side current and constant dc side voltage. Single phase and three phase thyristor full bridge converters with constant dc side current - effect of source inductance, practical converters with R-L-E load, inverter mode of operation-Line distortion in ac voltage due to three phase converter. Generation of control signals. DC-DC converters: Analysis and design of buck, boost and buck-boost converters in continuous current mode-Effect of inductor resistance in boost converter. Discontinuous current operation in boost converters.

Inverters: One leg sine PWM inverter. Single phase and three phase bridge sine PWM with unipolar voltage switching: generation of switching signals, fundamental and harmonic voltages and currents in output under linear and over modulation, current ripple in output, dc side current, current regulated modulation, rectifier mode of operation. Full bridge isolated dc -dc converter-Design of transformer and inductor.

Space Vector Modulation: Definition of space vectors -transformation matrices - Transformation from stationary to synchronously rotating reference frame and its inverse - Time durations for different states in three phase inverter.   Protection of devices in circuits.

TEXT BOOKS/ REFERENCES:
1. N.Mohan, T.M.Undeland, and W.P.Robbins, "*Power Electronics, Converters, Applications and Design*", Third Edition, John Wiley and Sons Inc., 2006.
2. M.H.Rashid, "*Power Electronics, Circuits, Devices and Applications*", Third Edition, PHI, 2004.
3. L.Umanand, "*Power Electronics- Essentials and Applications*", Wiley India Pvt. Ltd., 2009.

PE707   PROGRAMMABLE LOGIC CONTROLLERS   3-0-0-3

Introduction to PLC; Ladder diagram, relay logic, digital and analog PLC interface; input and output modules; PLC processors, processor data organization, basic relay instruction; timer and counter instruction, sequencer instruction, programme flow instruction. Case studies-motor control.

TEXT BOOKS/ REFERENCES:
1. Dunning Gary, "*Introduction to Programmable Controllers*", Third Edition, Thomson Delmar Learning, 2006.
2. John R. Hackworth and Frederick D, "*Programmable Logic Controllers: Programming Methods and Applications*", Pearson Education Inc., 2004.
3. Bolton W, "*Programmable Logic Controllers*", Fifth Edition, Elsevier, 2009.
4. John W Webb and Ronald A Reis, "*Programmable Logic Controllers: Principles and Applications*", Fifth Edition, PHI learning Pvt. Ltd., 2009.

RE702   SOLAR THERMAL ENGINEERING   3-0-0-3

Modes of Heat Transfer. Conduction : 1D steady-state conduction through plane and cylindrical wall, Resistance Network; Heat transfer from extended surfaces. Transient conduction: Lumped Heat capacitance. Forced Convection : Internal flows, external flow only with help of correlations. Natural convection: in enclosures, heat transfer correlations.

Heat Exchangers: Kinds of heat exchangers, □-NTU method. Radiation: Radiation Intensity and flux, different radiation definitions. Solar Radiation estimation: Beam and diffuse components- hourly, daily and monthly basis. Radiation on sloped surfaces. Measurement of Solar Radiation

Design of basic components of Solar thermal systems:
Solar Collectors: Flat Plate collectors - Configurations, Basic energy balances, Detailed design calculations. Concentrating Collectors - Collector Configurations, Concentration Ratio, Thermal Performance of Concentrating Collectors, Ray-Trace Methods for Evaluating Concentrators. Energy Storage - Types, storage calculation. Solar Process Loads. System Thermal Calculations - Component Models, Collector Heat Exchanger Factor, Duct and Pipe Loss Factors, Collector Arrays - Series Connections, Series Arrays with Sections Having Different Orientations.

Applications: Solar Water Heating - Active and Passive. Building Heating – Active, Passive and Hybrid Methods. Solar Cooling. Solar Industrial Process Heat. Solar Thermal Power Systems, Solar Ponds - Evaporative Processes

TEXT BOOKS/ REFERENCES:
1. John A. Duffie and W. A. Beckman, "*Solar Engineering of Thermal Processes*", John Wiley and Sons, 2013.
2. F.P. Incopera and D.P. Dewitt, "*Fundamentals of Heat Transfer*", John Wiley and Sons, 2011.
3. Brian Norton, "*Solar Energy Thermal Technology*", Springer, 1992.
4. John Twidell and Tony Weir, "*Renewable Energy Resources*", Second Edition, Taylor and Francis, 2005.

| RE703 | **POWER SYSTEM MODELING** | 3-0-0-3 |

Modelling of Power System Components: The need for modelling of power system, classical methods of modeling. Simplified models of non-electrical components like boiler, steam, hydro-turbine and governor system. Transformer modelling - auto-transformer, tap-changing and phase-shifting transformers.

Modelling of Synchronous machine: Basic flux linkage, voltage and torque equations of synchronous machine - Basics of Park's transformation . The current & flux linkage models using Park's transformation - Models for steady-state and dynamic studies. Simulation and analysis of Synchronous machine connected to an infinite bus.

Modelling of Excitation system and prime mover: Excitation configurations- dc and ac excitations, self and separately excited systems, definitions of voltage response ratio and exciter voltage ratings. IEEE excitation systems.

Modelling of Turbine: Hydraulic and steam turbine models, speed governing system model

Modelling of Transmission line, FACTS and load: Transmission line, d-q transformation using □-□variables, modeling of SVC, TCSC and UPFC, load modeling. Analysis of single machine connected to infinite bus including SVC.

TEXT BOOKS/ REFERENCES:
1. K.R.Padiyar, "*Power Systems Dynamics*", B.S. Publications, 2002.
2. Anderson and Foud, "Power *System Control and Stability – Vol. I*", IEEE Press, New York, 1994.
3. Kundur, "*Power System Dynamics & Control*", McGraw Hill, 1994.

4. Olle Elgerd, *"Electrical Energy System Theory – An Introduction"*, Second Edition, TMH Publishing Company, 2003.
5. John J. Granier and W.D. Stevenson Jr, *"Power System Analysis"*, Fourth Edition, McGraw Hill, 1994.

**RE704   FLEXIBLE AC AND HIGH VOLTAGE DC TRANSMISSION
                                        SYSTEMS   3-0-0-3**

Introduction to transmission system interconnections - Power flow in AC system - loading capability and dynamic stability - IEEE Definitions. Shunt Compensation: Objectives – Configuration - Control Scheme and operating characteristics of Variable impedance compensators - Thyristor switched capacitor(TSC)- Thyristor switched reactor(TSR) - Thyristor controlled reactor(TCR) - Fixed Capacitor-Thyristor Switched Reactor(FC-TSR) - Fixed capacitor-Thyristor controlled reactor(FC-TCR) - Thyristor switched capacitor–Thyristor controlled reactor(TSC-TCR) - switched converter type compensators(STATCOM) and hybrid shunt compensators. Series Compensation: objectives – configuration - Control scheme and operating characteristics of variable impedance series compensators - GTO Controlled Series Capacitor (GCSC) Thyristor Switched Series Capacitor (TSSC)-Thyristor Controlled Series Capacitor(TCSC) and switching converter type series compensator(SSSC). Objectives, modes of operation of Voltage Regulator and Phase angle Regulators. Multifunctional FACTS Controllers: Unified Power Flow Controller (UPFC) Interline Power Flow Controller (IPFC) – configuration and control scheme for real power and reactive power control applications. Advances in FACTS Technology – Applications – Case studies
Components of HVDC Transmission system: Converter, Transformer - Smoothing reactor - Harmonic Filter - Types of HVDC Links - Basic power conversion principle - rectifier and inverter operation - Principle of DC Link control - converter control characteristics - Firing angle control - Current and Extinction angle control - Starting and Stopping of DC link - power control - Effect of smoothing inductance on the system Reactive power control - Comparison of AC and DC Transmission - Application and Modern Trends in HVDC system.

TEXT BOOKS/ REFERENCES:
1. Hingorani N. G *"Understanding FACTS - Concepts and Technology of Flexible AC Transmission Systems"*, IEEE Press, 2000.
2. Yong Hua Song and Allan T Johns, *"Flexible AC Transmission System"*, The Institution of Electrical Engineers, UK, 1999.
3. K. R. Padiyar *"FACTS Controllers in Power Transmission & Distribution"*, Ashan Publishers, 2009.
4. K.R. Padiyar, *"HVDC Power Transmission Systems"*, Second Edition, New Academic Science Publishers, 2011
5. Vijay. K. Sood, *"HVDC and FACTS Controllers – Application of Static Converters in Power Systems"*, Kluwer Academic Publishers, Massachusetts, 2004.

RE705   AERODYNAMICS AND WIND TURBINES   3-0-0-3

Basic equations: Continuity, momentum and energy equations. Application of momentum equation. Calculation of drag on two -dimensional body. Inviscid, incompressible flow: Theoretical solutions of potential flow past different bodies. d' Alembert's paradox.

Incompressible flow over aerofoils, aerofoil nomenclature, characteristics, vortex sheet, kutta condition. Kelvin's Circulation Theorem.

Classical thin aerofoil theory, Symmetric and cambered aerofoils, Basic design concepts. Prandt's Lifting line Theory. Numerical source panel and vortex panel methods. Stream tube model, linear momentum theory.

Wind Turbines: Types, Rotor elements; Horizontal and vertical axis wind turbines, slip stream theory. Calculation of axial thrust and efficiency, Pitch and stall regulation. Lift and drag coefficients; thrust and torque calculations, Tip losses, Characteristics of horizontal axis wind turbines and power curve. Concepts of blade design.

Wind pumps. Matching of pump and turbine characteristics

TEXT BOOKS/ REFERENCES:
1. DNV- Riso *"Guidelines for Design of Wind Turbines"*, Second Edition, Riso National Laboratory, Denmark, 2002.
2. Martin O. L. Hansen, *"Aerodynamics of Wind Turbine"*, James & James (Science Publishers) Ltd., London, 2000.
3. Lysen, E. H., *"Introduction to Wind Energy"*, CWD Report 82-1, Consultancy Services Wind Energy Developing Countries, The Netherlands, May 1983.
4. Erich Hau, *"Wind Turbines Fundamentals, Technologies, Application and Economics"*, Springer -Verlag Berlin -Heidelbeg, 2000.

PE711   COMPUTATIONAL OPTIMIZATION THEORY-LINEAR AND NONLINEAR METHODS   3-0-0-3

Single Variable optimization - Optimality criteria, Bracketing methods- Exhaustive search method, Bounding phase method, Region elimination methods - Interval halving, Fibonacci search, Golden section search, Point estimation, Successive quadratic search, Gradient, Newton Raphson, Bisection, Secant and Cubic search method.

Multivariable Optimization - Optimality criteria, Gradient based methods - Steepest descent, Conjugate direction, Conjugate gradient, Newton's, Levenberg Marquardt, Quasi Newton, Variable metric and BFGS method.

Constrained Optimization - Karush-Kuhn-Tucker optimality criteria, Direct methods - Frank-Wolfe method, Cutting plane method, Method of feasible direction - Gradient projection method, Indirect methods-Transformation techniques, Penalty function methods for mixed equality and inequality constraints.

Geometry of Linear programming problems, Simplex methods, Duality in Linear programming, Transportation problems.

Interior Point methods - Primal-Dual Path-Following Algorithm, Primal-Dual Model, Duality Theory and the Central Path, Primal-Dual Newton Method, Strategies in Path-following Algorithms, Self-Regular Functions and their Properties, Primal-Dual Algorithms Based on Self-Regular Proximities.

TEXT BOOKS/ REFERENCES:
1. S. S. Rao, *"Optimization Theory and Practice"*, Fourth Edition, John Wiley and Sons, 2009.

2. Kalyanmoy Deb, *"Optimization for Engineering Design Algorithms and Examples"*, Prentice Hall of India, New Delhi, 2004.
3. Edwin K.P. Chong and Stanislaw H. Zak, *"An Introduction to Optimization"*, Second Edition, Wiley-Interscience Series in Discrete Mathematics and Optimization, 2004.
4. M. Asghar Bhatti, *"Practical Optimization Methods: with Mathematica Applications"*, Springer Verlag Publishers, 2000.

RE706 **WIND ELECTRIC GENERATORS** **3-0-0-3**

Review of DC and AC electrical machines - Motor and generator modes, Transformers, EMF and Torque equations, Characteristics. Wind electric generators - Wind turbine characteristics and controls, WTG topologies.
Induction generator - Squirrel cage and slip ring machines, equivalent circuit, Torque-slip characteristics, Real and reactive power, self excited and grid connected systems, Generalized model of electrical machines- Clarke's and Park's transformation, modeling in synchronous reference frame.
Doubly fed induction generators- Brush type and Brushless types, Four quadrant operation, Rotor side converter, Grid side converter, Control of converters, modeling.
Synchronous generators-Wound type and permanent magnet types, power angle characteristics, Real and reactive power, Salient and Non salient poles, grid interfacing, modeling.
Losses and efficiency of wind electric generators; Power quality issues with grid connected wind electric generators; Reactive power compensation; Harmonics; Voltage unbalance; Voltage flicker; Voltage sag; Fault Ride Through Capability- Low Voltage Ride Through Capability, Grid Code; Methods to improve performance of WTG.

TEXT BOOKS/ REFERENCES:
1. J.F.Manwell, J.G.McGowan and A.L.Rogers, *"Wind Energy Explained-Theory, Design and Application"*, John Wiley and sons Ltd., 2009.
2. Olimpo Anaya Lara, Nick Jenkins, Janaka Ekanayaka, Phill Cartwright and Mike Hughes, *"Wind Energy Generation-Modeling and Control"*, John Wiley and Sons Ltd., 2009.
3. M.Godoy Simoes and Felix A.Farret, *"Renewable Energy Systems-Design and Analysis With Induction Generators"*, CRC Press, 2004.
4. Fernando D.Bianchi, Hernan De Battista and Ricardo J.Mantz, *"Wind Turbine Control Systems-Principles, Modelling and Gain Scheduling"*, Springer-Verlag London Ltd., 2007.
5. Joshua Earnest and Tore Wizelius, *"Wind Power Plants and Project Development"*, PHI, 2011.

PE716 **ELECTRICAL MACHINE ANALYSIS USING FINITE**
ELEMENT ANALYSIS **3-0-0-3**
Review of Electromagnetic theory, basic principles of finite element method, applications of finite element method to two dimensional fields, linear interpolation, variational method, description of electromagnetic fields, analysis procedure using finite element method, reduction of field problem to a two dimensional problem, boundary conditions, drawing flux line, magnetic energy and co-energy, magnetic forces, determination of electrical parameters.

Cylindrical magnetic devices, analytical study of magnetic devices, finite element analysis, single phase transformer, computation of no load inductance, determination of leakage inductance, algorithm for the construction of magnetizing characteristics of a transformer. Single phase variable reactance, computation of reactance.

TEXT BOOKS/ REFERENCES:
1. Nicola Bianchi, *"Electrical Machine Analysis Using Finite Elements"*, CRC Press, 2005.
2. Cheng D K, *"Fundamentals of Engineering Electromagnetic"*, Addison Wesley, 1993.
3. Reece A and Preston T, *"Finite Element Method in Electric Power Engineering"*, Oxford University Press, UK, 2000.
4. Fitzgerald A E, Kingsley C, (Jr), and Umans S D, *"Electric Machinery"*, McGraw Hill, New York, 1983.
5. Nagrath I.J and Kothari D.P, *"Electric Machines"*, Third edition, Tata McGraw Hill Publishing Company Ltd., New Delhi, 2007.

RE707   APPLIED COMPUTATIONAL FLUID DYNAMICS   3-0-0-3

Introduction: Models of fluid flow, Governing equations, continuity equation, momentum equation, Initial and boundary conditions.

Discretization: Introduction to finite differences, Differences equation, Forward, backward and central difference schemes; explicit and implicit methods. Errors and Analysis of stability, Upwind schemes. Finite volume analysis.

CFD Techniques: Lax-Wendroff technique, Mac Cormack's technique. Alternating direction implicit technique. Pressure correction technique: Philosophy of pressure correction method, pressure correction formulae, SIMPLE algorithm.

Application: Design optimization of turbine blade profile, CFD Modeling of wind farms (any one technique).

TEXT BOOKS/ REFERENCES:
1. John D. Anderson, *"Computational Fluid Dynamics"*, McGraw Hill Higher Education, 1995.
2. Joel H. Ferziger and Milovan Peric, *"Computational Methods for Fluid Dynamics"*, Springer, 2001.
3. K. Muralidhar and T. Sundararajan, *"Computational Fluid Flow and Heat Transfer"*, Narosa Publication, 1995.

RE708   ENERGY STORAGE SYSTEMS   3-0-0-3

Introduction, Trends in Power System, Thermal Energy Storage, Energy Storage in Organic Fuels, Mechanical Energy Storage, Pumped Hydro Storage, Electromagnetic Energy Storage, Capacitor and Magnetic Systems, Super Conducting Magnetic Energy Storage, Electrochemical Energy Storage, Hydrogen and synthetic fuels, Fuel Cells, Consideration on the choice of Energy Storage Systems, Integration of Energy Storage Systems, Effect of

Energy Storage on Transient Regimes in Power System, Optimizing Regimes for Energy Storage in Power Systems.

TEXT BOOKS/ REFERENCES:
1. Robert A. Huggins, *"Energy Storage"*, Springer New York Heidelberg Dordrecht London, 2010.
2. A. Ter-Gazarian, *"Energy Storage for Power Systems"*, IET Energy Series 6, London, 2008.
3. Richard Baxter, *"Energy Storage – A Non-Technical Guide"*, Penn Well, Oklahoma, 2006.
4. Ralph Zit, *"Energy Storage- A New Approach"*, Wiley – Scrivener, Wiley Publishers, 2010.
5. Ahmed Faheem Zobaa, *"Energy Storage – Technologies and Applications"*, In Tech Publisher, 2013.

RE709   **SMART GRID**   **3-0-0-3**

Evolution of Electric Grid, Concept of Smart Grid, Definitions, Need of Smart Grid, Functions of Smart Grid, Opportunities & Barriers of Smart Grid.Today's grid versus smart grid.Present development & International policies in Smart Grid.Smart Grid – Overview and stakeholders. Performance analysis tools for smart grid, Stability analysis tools for smart grid.

Smart Grid Technologies: Communication Technologies for Smart Grid, Interoperability and connectivity, Layered Architecture and Protocols, Standards for Information Exchange. Information Security in smart grid - Encryption and decryption, Authentication, Digital Signatures, Cyber Security standards. Smart Meters, Demand response. Distribution Side automation and Transmission side automation – WAMS. Power electronics in Smart grid.

Renewable Energy and Storage Technologies – Distributed generation and storage. Solar, Wind, Pumped Hydro, PHEVs. Market Model for smart grid. Regulation and standardization of smart grid.

TEXT BOOKS/ REFERENCES:
1. James Momoh, *"Smart Grid: Fundamentals of Design and Analysis"*, Wiley-IEEE Press, March 2012.
2. Janaka Ekanayake, Nick Jenkins, Kithsiri Liyanage, Jianzhong Wu and Akihiko Yokoyama, *"Smart Grid: Technology and Applications"*, Wiley, February 2012.
3. Nouredine Hadjsaïd and Jean-Claude Sabonnadière, *"Smart Grids"*, Wiley-ISTE, May 2012.
4. Ali Keyhani and Muhammad Marwali, *"Smart Power Grids"*, Springer, 2011.

PE705   **ELECTRIC POWER QUALITY**   **3-0-0-3**

Introduction to Electric Power Quality- Voltage Variations - Imbalances- Voltage Fluctuations- Distortion- Power Frequency variation. Power Quality measures and Indices:
Sources of Voltage Sag- Calculation of Voltage Sag/ Swell under faults- capacitor switching- motor starting- imbalance. Symmetrical Components- Simple protection methods.

Harmonic studies- Electric Circuit Analysis and power assessment under non-sinusoidal conditions- Fourier Analysis- FFT Analysis- Harmonic propagation in large Network. Effect of Harmonics on custom side and Utility side.
Compensation Techniques- Shunt and Series Compensators - Static VAR Compensators- Harmonic filters. Case studies

TEXT BOOKS/ REFERENCES:
1. Alexander Kusko and Marc Thompson, *"Power Quality in Electrical Systems"*, Mc Graw-Hill, 2007.
2. Ewald and Mohammad Masoum, *"Power Quality in Power Systems and Electrical Machines"*, Elsevier Academic Press, 2008.
3. George G. Wakileh, *"Power System Harmonics-Fundamentals, Analysis and Filter Design"*, Springer-Verlag, 2001.
4. Math J. Bollen, *"Understanding Power Quality Problems-Voltage Sags and Interruptions"*, John Wiley and Sons, New Jersey, 2000.
5. Enrique Acha and Manuel Madrigal, *"Power Systems Harmonics-Computer Modeling and Analysis"*, John Wiley and Sons Ltd., 2001.

RE710   **ELECTROCHEMICAL ENERGY SYSTEMS**   **3-0-0-3**

Background Theory: Origin of potential - electrical double layer – reversible electrode potential-emf series-reference and indicator electrodes - Nernst equation - Butler-Volmer equation - Activation, concentration and IR overpotentials - Tafel plots - Primary and secondary batteries: The chemistry, fabrication and performance aspects, packing classification and rating of zinc and lithium primary batteries-Lead acid, nickel, silver and lithium ion secondary batteries-VRLA batteries-Sodium-beta and Redox batteries for vehicles - Thermally activated reserve batteries - Fuel Cells: Working principle, fabrication of electrodes and other components, and environmental aspects of Proton Exchange Membrane Fuel Cells, Alkaline fuel cells, Phosphoric acid, Solid oxide, Molten carbonate, Direct methanol fuel cells - Reformation clean up and storage for hydrogen –Testing and Assessment of Batteries - Shelf life and service life **–** effect of temperature and pressure – effect of aging – memory effect – test conditions, mechanical and environmental, load and electromagnetic compatibility testing.. Selected international standards – performance characteristics –Peuckert discharge curves, Ragone plots, Supercapacitors.

TEXT BOOKS/ REFERENCES:
1. Dell, Ronald M Rand, and David AJ, *"Understanding Batteries"*, Royal Society of Chemistry, 2001.
2. M. Aulice Scibioh and B. Viswanathan, "Fuel *Cells – Principles and Applications"*, University Press, India, 2006.
3. F. Barbir, *"PEM Fuel Cells: Theory and Practice"*, Elsevier, Burlington, MA, 2005.
4. David Linden and Thomas B Reddy, *"Handbook of Batteries"*, Third Edition, McGraw-Hill, 2001.
5. Derek Pletcher and Frank C. Walsh, *"Industrial Electrochemistry"*, Blackie Academic and Professional, 1993.

RE711   **PROJECT MANAGEMENT**   **3-0-0-3**

Project Life Cycle Concept; Nature of Project Management: An overview of Project Management. Scope Management. PM tools & techniques: using MS Project: a) Time b) Resources, c) Cost, d) Updating. Project Feasibility. Project Appraisal and Simulation. Project Accounts.

Project Design: Detailed Project Report. Project Execution: Procurement, Project Control, Earned Value Construction Resource Plan, Engineering Management, Site Management, Project Reviews Role of Agencies.

Behavioural aspects of PM: PM Organization, Project Teams, Project leadership. Project Quality Management. Project Management Information System. Project Risk Management. Project Termination. Project Evaluation. PM Case Study.

TEXT BOOKS/ REFERENCES:
1. Meredith, Jack R, Samuel J and Mantel Jr., "*Project Management- A Managerial Approach*", John Wiley, 1995.
2. Klastorin Ted, "*Project Management, Tools, and Trade-offs*", John Wiley, 2004.
3. Mantel, Meredith, Shafer and Sutton A, "*Core Concepts of Project Management*", John Wiley, 2001.