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

First Semester

Course Code	Type	Course Title	LTP	Cr
16MA617	FC	Linear Algebra and Random Process	4-0-0	4
16RE601	FC	Electronic Instrumentation Systems	3-0-1	4
16RE611	SC	Solar Energy	3-0-0	3
16RE612	SC	Bio and Hydro Energy Sources	3-0-0	3
16RE617	SC	Soft Computing	3-0-0	3
16RE624	SC	Modeling and Simulation Laboratory	0-0-1	1
16HU601	H	Cultural Education*		P/F
Total for Sem I				18

*Non-Credit Course

Second Semester

Course Code	Type	Course Title	LTP	Cr
16RE602	FC	Energy Economics and Renewable Energy Policy	3-0-0	3
16RE625	SC	Energy Management	3-0-0	3
16RE613	SC	Wind Energy	3-0-0	3
	E	Elective I	3-0-0	3
	E	Elective II	3-0-0	3
16RE614	SC	Seminar	0-0-1	1
16RE615	SC	Renewable Energy Laboratory I	0-0-2	2
16EN600	HU	Technical Writing*		P/F
Total for Sem II				18

*Non-Credit Course

Third Semester

Course Code	Type	Course Title	LTP	Cr
	E	Elective III	3-0-0	3
	E	Elective IV	3-0-0	3
16RE616	SC	Renewable Energy Laboratory II	0-0-2	2
16RE798	P	Dissertation		8
Total for Sem III				16

Fourth Semester

Course Code	Type	Course Title	LTP	Cr
16RE799	P	Dissertation		14
Total for Sem IV				14
Total for the programme				66

List of Courses

Foundation Core

Course Code	Course Title	LTP	Cr
16MA617	Linear Algebra and Random Process	4-0-0	4
16RE601	Electronic Instrumentation Systems	3-0-1	4
16RE602	Energy Economics and Renewable Energy Policy	3-0-0	3

Subject Core

Course Code	Course Title	LTP	Cr
16RE611	Solar Energy	3-0-0	3
16RE612	Bio and Hydro Energy Sources	3-0-0	3
16RE617	Soft Computing	3-0-0	3
16RE624	Modeling and Simulation Laboratory	0-0-1	1
16RE625	Energy Management	3-0-0	3
16RE613	Wind Energy	3-0-0	3
16RE614	Seminar	0-0-1	1
16RE615	Renewable Energy Laboratory I	0-0-2	2
16RE616	Renewable Energy Laboratory II	0-0-2	2

Electives

Course Code	Course Title	LTP	Cr
	Elective I		
16PE724	Power System Operation and Control	3-0-0	3
16RE701	Power Electronics for Energy Systems	3-0-0	3
16PE711	Programmable Logic Controllers	3-0-0	3
16RE702	Solar Thermal Engineering	3-0-0	3
	Elective II		
16RE703	Power System Modeling	3-0-0	3
16RE704	Flexible AC and High Voltage DC Transmission Systems	3-0-0	3
16RE705	Aerodynamics and Wind Turbines	3-0-0	3
16RE714	Computational Optimization Theory – Linear and Non-Linear Methods	3-0-0	3
	Elective III		
16RE 706	Wind Electric Generators	3-0-0	3
16PE 705	Electrical Machine Analysis Using Finite Element Analysis	3-0-0	3
16RE 707	Applied Computational Fluid Dynamics	3-0-0	3
16RE 708	Energy Storage Systems	3-0-0	3
16RE712	Energy Forecasting and Modeling	3-0-0	3
16RE713	Ocean Energy Conversion	3-0-0	3

Elective IV			
16RE709	Smart Grid	3-0-0	3
16RE715	Electric Power Quality	3-0-0	3
16RE710	Electrochemical Energy Systems	3-0-0	3
16RE711	Project Management	3-0-0	3
16PE733	Distributed Generation	3-0-0	3

Project Work

Course Code	Course Title	LTP	Cr
16RE798	Dissertation		8
16RE799	Dissertation		14

16MA617 LINEAR ALGEBRA AND RANDOM PROCESS 4-0-0-4

Vector Spaces: Vector spaces - Sub spaces – Linearindependence - 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 UnnikrishnaPillai, "*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.

16RE601 ELECTRONIC INSTRUMENTATION SYSTEMS 3-0-1-4

Measuring systems - classification, static and dynamic characteristics, errors, calibration and standards. Mechanical transducers: pressure measurement- diaphragms; 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. Level, flow measurements, SCADA, Smart meters (net metering), Phasor measurement unit, basic measurements/sensing with ADC,CCP modules in PIC microcontrollers.

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. ArunK.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.

16RE611 SOLAR ENERGY 3-0-0-3

History of Solar Energy, Properties of Sun Light- Solar Radiation - Solar Radiation– Atmospheric effects - Solar Geometry - Measuring Instruments - Estimation of Solar Radiation.

Solar Thermal Systems: Solar Thermal Collector and its types, Solar-thermal Energy Storage System, Applicationsof Solar Thermal System.

Solar cell physics & characteristics – dark and illuminate junctions,parasitic resistances, Irradiance and temperature effects, STC and NOCT conditions,Maximum power point.

PV cell architecture and fabrication steps, crystalline Si substrates, thin film deposition, amorphous Si, CIGS, CdTe etc., dye sensitized cell.

PV Module and Array –By pass and blocking diodes - Tilt angle and Sun Tracking.Balance of system components and their design – for stand alone and grid connected operation, MPPT Algorithms.

Stand Alone PV System, Grid Connected PV System, Hybrid Systems.

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, Modeling 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.

16RE612 BIO AND HYDRO ENERGY SOURCES 3-0-0-3

Energy from biomass: sources, classification, conversion into fuels, photosynthesis, C3 and C4 plants on biomass production, physicochemical characteristics ; CO2 fixation potential. Biomass 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; thermochemical - pyrolysis, combustion and gasification, gasifiers: updraft, downdraft, fluidized bed, biomass carbonization, natural draft and gasification based biomass stoves, gasification based power generation. Design of power plants.Hydrology, Selection of site, Resource assessment, Classification of Hydropower Plants, Small Hydropower Systems: mini, micro and pico systems, Pumped storage plants, Hydraulic Turbines: classification and operational aspects, elements of turbine, selection and design criteria, Planning of power house, Hydro power from oceans – Wave and Tidal power, 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.
6. M. M. Dandekar and K. N. Sharma, "Water Power Engineering", Vikas Publishing House Pvt. Ltd., Second Edition, 2014.

16RE617 SOFT COMPUTING 3-0-0-3

Fuzzy Logic (FL) – Membership Functions – Fuzzifications and Defuzzifications – Fuzzy Relations – TSK Fuzzy Modeling.Neural Networks (NN) – Supervised and Unsupervised Learning – Hopfield – RBF Networks Kohonen Self Organizing Networks – Learning Vector Quantization – Hebbian Learning.

Neuro-fuzzy models- adaptive neuro-fuzzy inference system (ANFIS)- Architecture – Hybrid Learning Algorithm – Learning Methods that Cross-fertilize ANFIS and RBFN - Applications.

Optiimization - Derivative-based Optimization – Descent Methods – The Method of Steepest Descent – Classical Newton's Method – Step Size Determination – Genetic Algorithms – Random Search – Downhill Simplex Search.

Chaos and Fractals – One Dimensional Logistic Equation – Hurst Exponent – Fractal Dimension.Non Linear Time Series Analysis – Lyapunov Exponent – Feature Extraction – Dimensionality Reduction – 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 AndrzejSkowron, "*Rough Sets: A Tutorial*",http://Folli.Loria.Fr/Cds/1999/Library/Pdf/Skowron.Pdf

16RE624 MODELING AND 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.

16RE602 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.

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 Exchange- deregulated power market, electricity regulations, Grid Code.

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.

16RE625 ENERGY MANAGEMENT 3-0-0-3

Historical development of commercial energy supply: Commercial energy in ancient times, Renewable Energy utilization in ancient times, Industrial revolution, Realization of environmental concerns, Developments in Renewable Energy Sector; Concept of Energy Efficiency and Clean Production. Energy Conservation Act 2001 and its features.

Energy conservation on demand side: Efficient Lighting; Energy Efficiency in motors, pumps and fans. Power quality issues related to Energy Efficient Technologies. Energy saving and trading Evaluation of thermal performance – calculation of heat loss – heat gain, estimation of heating & cooling loads, factors that influence thermal performance, waste heat recovery and co-generation, analysis of existing buildings setting up an energy management programme – electricity saving techniques.

Energy Management in Electrical Power Systems: Supply-demand gap on electric power grid: causes and remedial measures. 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 Service Companies (ESCOs), Energy Conservation Policies and Regulations, 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.
6. MoncefKrarti, "*Energy Audit of Building Systems: An Engineering Approach*", Second Edition, CRC Press, 08-Nov-2010 // e-book//.
7. Amit K. Tyagi, "*Handbook on Energy Audits and Management*", TERI, 2003.

16RE613 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 Windforecasting. 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.ErichHau, "*Wind Turbines- Fundamentals: Technologies, Application, and Economics*". Springer -Verlag Berlin -Heidelbeg, 2000.

16RE 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.

16RE615 RENEWABLE ENERGY LABORATORYI 0-0-2-2

Laboratory experiments on solar photovoltaic panelsand Energy storage, energy conservation. Software based studies on grid-connected SPV, electrochemical systems/bio energy systems.

16RE616 RENEWABLE ENERGY 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.

16EN 600 TECHNICAL WRITING P/F

(Non-credit Course)

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.)

TEXTBOOKS/REFERENCES:

1. H.L. Hirsch, *Essential Communication Strategies for Scientists, Engineers and Technology Professionals*, Second Edition, New York: IEEE press, 2002.
2. P.V. Anderson, *Technical Communication: A Reader-Centered Approach*, Sixth Edition, Cengage Learning India Pvt. Ltd., New Delhi, 2008, (Reprint 2010).
3. W.Jr. Strunk and E.B.White, *The Elements of Style*, New York. Alliyan & Bacon, 1999.

16PE724 POWER SYSTEM OPERATION AND CONTROL 3-0-0-3

Introduction- Operating states of a power system- state estimation and security assessment. Overview of system control: Governor Control, LFC, AVR. Need for voltage and frequency regulation in power system, basic P-f and Q-V control loops.

Real power- frequency control: Fundamentals of speed governing systems and modeling, LFC of Single area and two area systems. Power system stabilizer and its modeling.

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 LoadDispatch: Incremental cost curve, co-ordination equations 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 McGraw Hill Publishing Company Ltd., New Delhi, 2004.
2. D. P. Kothari and I. J. Nagrath, "*Modern Power System Analysis*", Tata McGraw 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. P.S.R. Murty, "*Operation and Control in Power Systems*", Second Edition, CRC Press, 2011.

16RE701 POWER ELECTRONICS FOR ENERGY SYSTEMS 3-0-0-3

Power semiconductor switches: Power diodes, Thyristors, MOSFETS, and IGBT, IPMs. Switch waveforms and power loss. Non sinusoidal waveform analysis.

AC voltage controllers: Single phase & three phase controller with RL loads (Qualitative). Soft starters, Thyristor controlled reactor and reactive power compensation – SVC.

AC-DC Converters: Single phase and three phase diode bridge rectifiers - Single phase and three phase thyristor full converters - effect of source inductance, converters with R-L-E load, inverter mode of operation- Line notching & distortion.

DC-DC converters: Analysis and design of buck, boost and buck-boost converters.Full bridge isolated dc-dc converter.

Inverters: Single phaseand three phase bridge sine PWM with unipolar voltage switching –Harmonic analysis of output voltages and currents - over modulation - dc side current - current regulated PWM, rectifier mode of operation. Space Vector Modulation.

Concept of Solid State Transformer and High Frequency Isolation – Concept of Grid Synchronization of converters and power flow control - Protection of devices in circuits.Design of transformer and inductor.

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.

16PE711 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.

16RE702 SOLAR THERMAL ENGINEERING 3-0-0-3

Fundamentals of Thermodynamics and Heat Transfer – Heat engines, refrigerators and heat pumps; Heat Transfer – Thermal resistance network – Overall heat transfer coefficient - Critical radius of insulation – Initial and Boundary conditions; Non-dimensional Numbers in heat transfer; Heat transfer from extended surfaces; Heat Exchangers: Types and applications - LMTD and NTU methods.

Solar Thermal Collectors – Flat plate collector construction and analysis – Thermal resistance network model – Heat transfer correlations – Concentrating type collectors – Construction and working – Tracking mechanisms – Heliostats with central receiver – Solar air heater – Solar chimney; Solar thermal power plants– Low, medium and high temperature systems – Performance analysis; Solar Process Loads – Collector Heat Exchanger Factor, Duct and Pipe Loss Factors, Collector Arrays - Series Connections, Series Arrays with Sections Having Different Orientations.

Solar energy collection / storage devices – Solar water heaters – Thermosyphon heaters – Active and passive heating. Solar Ponds – Convective and non-convective ponds – Salt gradient solar pond – Experimental studies; Water desalination using solar still; Solar refrigeration.

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.
5. G.N. Tiwari, "*Solar Energy-Fundamentals, Design, Modelling and Applications*", Narosa Publishers, 2002.

16RE703 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 alpha-beta 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. OlleElgerd, "*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.

16RE704 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 impedancecompensators - 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 Regulatorand 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 powerconversion 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 – Applicationand 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.YongHua 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.

16RE705 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, "*WindTurbines Fundamentals, Technologies, Application and Economics*", Springer -Verlag Berlin -Heidelbeg, 2000.

16RE714 COMPUTATIONAL OPTIMIZATIONTHEORY – LINEAR AND NON-LINEAR 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-FollowingAlgorithm, 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. AsgharBhatti, "*Practical Optimization Methods: with Mathematical Applications*", Springer Verlag Publishers, 2000.

16RE 706 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, JanakaEkanayaka, Phill Cartwright and Mike Hughes, "*Wind Energy Generation-Modeling and Control*", John Wiley and Sons Ltd., 2009.

3.M.GodoySimoes 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.

16PE705 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.

16RE 707 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 MilovanPeric, "*Computational Methods for Fluid Dynamics*",Springer, 2001.

3.K. Muralidhar and T. Sundararajan, "*Computational Fluid Flow and Heat Transfer*", Narosa Publication, 1995.

16RE708 ENERGY STORAGE SYSTEMS 3-0-0-3

Introduction, 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, Optimizing Regimes for Energy Storage in Power Systems, Distributed energy storage with grid interface.

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 FaheemZobaa, "*Energy Storage – Technologies and Applications*", In Tech Publisher, 2013.

16RE712 ENERGY FORECASTING AND MODELING 3-0-0-3

Energy Scenario: Role of energy in economic development and social transformation: Energy & GDP, GNP and its dynamics-Energy Sources and Overall Energy demand and Availability-Energy Consumption in various sectors and its changing pattern-Status of Nuclear and Renewable Energy: Present Status and future promise.

Forecasting Model: Forecasting Techniques-Regression Analysis-Double Moving Average-Double Experimental Smoothing-Triple Exponential Smoothing– ARIMA model-Validation techniques–Qualitative forecasting–Delphi technique-Concept of Neural Net Works.

Optimization Model: Principles of Optimization-Formulation of Objective Function -Constraints-Multi Objective Optimization–Mathematical Optimization Software–Development of Energy Optimization Model - Development of Scenarios– Sensitivity Analysis.

TEXT BOOKS / REFERENCES:

1.S. Makridaki s, "*Forecasting Methods and Applications*", Wiley 1983.

2.Yang X.S., "*Introduction to Mathematical Optimization: From Linear Programming to Metaheuristics*", Cambridge, Int. Science Publishing, 2008.

3. Armstrong, J.Scott (ed.),"*Principles of Forecasting: A Hand Book for Researchers and Practitioners*", Norwell, Masschusetts: Kluwer Academic Publishers.2001

16RE713 OCEAN ENERGY CONVERSION 3-0-0-3

Fundamentals of thermodynamic cycles – power and refrigeration cycles – Rankine cycle – components of a power plant – cogeneration; Ocean Energy – Environmental impacts of ocean energy utilization – Ocean energy routes; Ocean Thermal Energy Conversion – Open and closed cycles for operation – Efficiencies of OTEC plants and their influence on plant size – Cogeneration of electricity and fresh water from open cycle OTEC; Tidal Energy –Origin of tides – Single basin and Double basin systems – Tidal plants in India and around the world in operation;

Wave energy – Parameters of progressive wave – Equation of wave – Energy and power in ocean waves - Types of wave energy convertors – Dolphin-Buoy type, Oscillating float-air pump type, three-raft type converters; Ocean biomass energy – Principal marine bio-energy resources – Kelp bio-energy conversion process; Ocean Geothermal Energy – Availability and limitations – Conversion methods.

TEXTBOOKS/ REFERENCES:

1. M. M. El-Wakil, "*Power Plant Technology*", McGraw Hill, 2010

2. A. W. Culp Jr, "*Principles of Energy Conversion*", McGraw Hill, 2001

3. RH Charlier, Charles W Finkl, " *Ocean ENERGY: Tide and Tidal Power*", Springer, 2009.

4. W H Avery, Wu, "*Renewable Energy from the Ocean – A guide to OTEC*", Oxford University Press, 1994.

5. Joao Cruz, "*Ocean Wave Energy – Current Status and Future Prospectives*", Springer, 2008.

16RE709 SMART GRID 3-0-0-3

Evolution of Electric Power Grid, Scope and Avenues of automation in power grid,Smart Grid–Need, Definitions, Concept, Functions & Barriers. Present development & International scenario in Smart Grid.

Smart Grid – System architecture and Stakeholders.Communication Technologies for Smart Grid, Interoperability, Protocols, Standards for Information Exchange. Information Security in smart grid, Cyber Security standards.

Real time monitoring in power transmission – PMU and WAMPAC.Distribution Automation- Smart Meters, AMI, Demand response.Distributed generation and Energy storage–Micro grids in grid-connected and off-grid modes, Pumped Hydro, Battery, PHEV, Hydrogen storage etc.Real time control of power electronic interfaces on smart grid.

Performance analysis tools for smart grid, Stability analysis tools for smart grid.Market Models for smart grid. Standards and regulationsfor smart grid.

TEXT BOOKS / REFERENCES:

1. James Momoh, "*Smart Grid: Fundamentals of Design and Analysis*", Wiley-IEEE Press, March 2012.

2. JanakaEkanayake, Nick Jenkins, KithsiriLiyanage, Jianzhong Wu and Akihiko Yokoyama, "*Smart Grid:Technology and Applications*", Wiley, February 2012.

3. NouredineHadjsaïd and Jean-Claude Sabonnadière, "*Smart Grids*", Wiley-ISTE, May 2012.

4. Ali Keyhani and Muhammad Marwali, "*Smart Power Grids 2011*", Springer, 2011.

16RE715 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*", McGraw-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.

16RE710 ELECTROCHEMICAL ENERGY SYSTEMS 3-0-0-3

Background Theory: Origin of potential –electricaldouble layer – reversible electrode potential-emf series-reference and indicator electrodes - Nernst equation – Butler-Volmerequation - Activation, concentration and IR overpotentials - Tafel plots - Primary and secondary batteries: The chemistry, fabrication andperformance 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 Assessmentof 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 –Peuckertdischarge curves, Ragone plots, Supercapacitors.

TEXT BOOKS/ REFERENCES:

1.Dell, Ronald M Rand and David AJ, "*Understanding Batteries*", Royal Society of Chemistry, 2001.

2.M. AuliceScibioh 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.

16RE711 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, ProjectTeams, Project leadership. ProjectQuality 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.

16PE733 DISTRIBUTED GENERATION 3-0-0-3

Overview of Wind and Solar photovoltaic power generation system - Distributed Generation –Reasons for DG – Technical Impacts of DG – Economic impacts of DG – Barriers to DG development – Recommendation and guidelines to DG planning

Power Electronic Interface for Photovoltaic energy conversion systems – Grid Connected Mode, Standalone mode – Design of converters, Sizing of battery storage system - Current controller for Grid connected PV system, Bidirectional converter, Power Conditioner – Control of converter for battery storage system

Power Electronic interface for wind energy conversion systems-SCIG, DFIG concept – Power converter topologies - Design of dual bi-directional converter with DC-link capacitance, Design of ac filter – inductor design, capacitor design – rotor side and grid side converter control, dc-link control - Grid Synchronization and Phase locking – intentional and unintentional islanding – Control of grid connected converters

Design of Hybrid wind-solar, and wind-hydro standalone systems with dual bi-directional converters: Case studies, Design and simulations

TEXT BOOKS/ REFERENCES:

1. Loi Lei Lai and Tze Fun Chan, "*Distributed Generation-Induction and Permanent Magnet Generators*", IEEE Press, 2007.
2. Haitham Abu-Rub, Mariusz Malinowski and Kamal Al-Haddad, "*Power Electronics for Renewable Energy Systems, Transportation and Industrial Applications*",Wiley Publishers, June 2014.
3. Massey, G. W., "*Essentials of Distributed Generation Systems*", Jones & Bartlett Learning, 2010.
4. Bollen, M. H., and Hassan, F., "*Integration of Distributed Generation in the Power System*", Vol. 80, John Wiley and Sons, 2011.