M Sc
RENEWABLE ENERGY PROGRAMME

FACULTY OF SCIENCE
UNIVERSITY OF LUCKNOW (NEW CAMPUS)
LUCKNOW – 226 021

SYLLABUS (NEW)

Proposed Course Credit Distribution

Renewable Energy (RE)

SEM	Core Courses (CC)			Value Added Elective Course (VAL)			Freeze Elective Course (FE)			Open Elective Course (OE) (Intradepartmental / Interdepartmental)			Total Credits
	Papers (T+P)	Credits (T+P)	Total Credits	No of Papers	Credits	Total Credits	No of Papers	Credits	Total Credits	No of Papers	Credits	Total Credits	
I	5+1	20+4	24	1	4	4	0	0	0	0	0	0	28
II	5+1	20+4	24	1	0	0	0	0	0	0	0	0	24
III	3+1	12+4	16	0	0	0	1	4	4	1	4	4	24
IV	1+D	12	12	0	0	0	1	4	4	1	4	4	20
Total Papers and Credits	**17 + Dissertation**	**76**	**76**	**2**	**4**	**4**	**2**	**8**	**8**	**2**	**8**	**8**	**96**

D= Dissertation, T=Theory, P=Practical
CC=Core Course, FE=Freeze Elective,
VAL=Value Added Elective, OE=Open Elective

SYLLABUS

Choice-Based Credit System

M Sc (RENEWABLE ENERGY)

FACULTY OF SCIENCE

UNIVERSITY OF LUCKNOW, LUCKNOW

YEAR – 1

SEMESTER – I

CORE SUBJECT	CREDIT				VALUE ADDED ELECTIVE SUBJECT	CREDIT			
	L	T	P	C		L	T	P	C
Module REC-101 : Thermodynamics & Heat Transfer	4	-	-	4	**Module REE-101 :** Energy and Environment	4	-	-	4
Module REC-102 : Electrical Power Technology	4	-	-	4					
Module REC-103 : Solar Photovoltaic Energy Conversion	4	-	-	4					
Module REC-104 : Wind Energy Conversion Systems	4	-	-	4					
Module REC-105 : Numerical Methods and Computational Techniques	4	-	-	4					
Module REC-106 : Energy Laboratory I	-	-	4	4					
Total Credits – 28									

SEMESTER – II

CORE SUBJECT	CREDIT				VALUE ADDED ELECTIVE SUBJECT	CREDIT			
	L	T	P	C		L	T	P	C
Module REC-201 : Bio-Renewable Energy Technology	4	-	-	4	**Module REE-201 :** Solar Photovoltaic Systems	4	-	-	0
Module REC-202 : Alternative Energy Systems	4	-	-	4					
Module REC-203 : Hydrogen Energy and Fuel Cell Technology	4	-	-	4					
Module REC-204 : Solar Thermal Energy Conversion	4	-	-	4					
Module REC-205 : Energy Storage	4	-	-	4					
Module REC-206 : Energy Laboratory II	-	-	4	4					
Total Credits – 24									

YEAR – 2									
SEMESTER – III									
CORE SUBJECT	**CREDIT**				**FREEZE ELECTIVE SUBJECT**	**CREDIT**			
	L	**T**	**P**	**C**		**L**	**T**	**P**	**C**
Module REC-301 : Distributed Generation and Integration of Renewable Energy	4	-	-	4	**Module REE-301 :** Climate Change and Carbon Trading	4	-	-	4
Module REC-302 : Energy Efficient Buildings	4	-	-	4	**OPEN ELECTIVE SUBJECT**	**CREDIT**			
						L	**T**	**P**	**C**
Module REC-303 : Energy Economics, Policy and Planning	4	-	-	4	**MOOC:**	4	-	-	4
Module REC-304 : Industrial Training and Field Visits	4	-	-	4					
Total Credits – 24									

SEMESTER – IV									
CORE SUBJECT	**CREDIT**				**FREEZE ELECTIVE SUBJECT**	**CREDIT**			
	L	**T**	**P**	**C**		**L**	**T**	**P**	**C**
Module REC-401 : Advanced Energy Systems	4	-	-	4	**Module REE-401 :** Energy Conservation and Management	4	-	-	4
Module REC-402 : Dissertation	8	-	-	8	**OPEN ELECTIVE SUBJECT**	**CREDIT**			
						L	**T**	**P**	**C**
					MOOC:	4	-	-	4
Total Credits – 20									
Grand Total (Credits) – 96									

Module: REC 101
Thermodynamics and Heat Transfer
[04 Credit]

Course objectives and outcomes :

1. To understand and apply the concept of availability and to calculate the behavior of real gases.
2. To predict the condition of systems and analyze them by the criteria of equilibrium.
3. To apply the concepts of advanced thermodynamics to combustion systems and refrigeration systems.
4. Students will able to calculate the availability of the systems and cycles
5. Analyze the engineering systems to improve and optimize its performance
6. Understand the working and the design principles of combustion systems and refrigeration systems.

Unit I: Thermodynamics

Thermodynamic system and processes, Equality of temperature- The Zeroth law of thermodynamics, Ideal gas equation, First law of thermodynamics, Calculation of work and heat in various processes, P-V diagram. The Second law of thermodynamics: Kelvin-Plank and Clausius statement of second law, Concept of Heat Engine and Pumps/Refrigerators, Carnot Cycle, Concept of entropy, T-s Diagram.

Unit II: Power Plant

Gas Power Cycle: Brayton Cycle and Improvements- Reheating, Regeneration and Intercooling, Efficiency and T-s Diagram.

Vapour Power Cycle: Rankine Cycle and improvements- Reheating and Regeneration, Efficiency and T-s, h-s and P-V Diagram.

Refrigeration Cycle, Air Standard Cycles: Otto Cycle and Diesel Cycle.

Unit III: Conduction

Introduction to Heat Transfer: Modes of heat Transfer- Conduction, Convection and Radiation, General differential heat conduction equation in the rectangular and cylindrical Co-ordinates, Concept of Thermal Resistance, Analogy between Heat and Electricity flow, Overall Heat Transfer Coefficient, Critical Radius of insulation.

Unit IV: Convection and Heat Exchanger

Forced Convection- Thermal Boundary Layer, Empirical Heat Transfer Relation for Flat Plate, Calculation of Heat Transfer Over Flat Plate for laminar and Turbulent Flow.

Free Convection- Physical Mechanism of Natural Convection, Empirical Heat Transfer Relation for Vertical Plate.

Heat Exchanger: Types of Heat Exchangers, Faulling Factor, Overall Heat Transfer Coefficient, Logarithmic Mean Temperature Difference (LMTD) Method for Parallel and Counter Flow Heat Exchangers.

Unit V: Thermal Radiation

Thermal Radiation: Basic Concept, Radiation Properties of Surfaces, Black Body Radiation, Plank's Law, Wein's Displacement Law, Stefan Boltzmann Law, Gray Body, Shape/View Factor, Black Body Radiation, Radiation Exchange Between Diffuse Non-Black Infinite Parallel and Enclosed Bodies, Radiation Shielding.

TEXT/REFERENCE BOOKS

1. Engineering Thermodynamics, 5th Ed., P.K.Nag,TMH, 2011
2. Fuels and Combustion, S.P.Sharma and Chander Mohan, TMH, 1984
3. Heat and mass transfer, 5th Ed., P.K.Nag,TMH, 2012
4. M.L.Mathur& R.P Sharma: "A Course in Internal Combustion Engines",DhanpatRai&Sons, 7th Edition, 1994
5. D. G. Kern: "Design of Heat Exchangers".
6. S. Kokac: "Heat Exchangers-Thermal Hydraulic Fundamentals and Design", McGraw Hill.
7. J. P. Gupta: "Heat Exchanger Design".

Module:REC 102
Electrical Power Technology
[04 Credit]

Course Objectives and outcomes:

1. Understanding of basic concepts of direct and alternating current.
2. Understanding of power consumption at a site and efficiency estimation of electrical machine is learnt.
3. Future trends to meet out energy crisis in India will be taught.
4. Grid and smart grid concepts will be explained.
5. The student will be able to analyze the distribution network critically.

Unit I

AC fundamentals: sinusoidal-average and effective values, form and peak factor, concept of phasors, phasor representation of sinusoidally varying voltage and current Analysis of series, parallel, series-parallel RLC circuit, resonance in series and parallel circuits, bandwidth and quality factor, apparent, active and reactive powers, power factors, problems of low power factor, concept of power factor improvements.

Unit II

Three phase system–necessity and advantages, star and delta connections, Balance supply and balance load, line and phase voltage/current relation, three phase power and its measurements Single phase transformers: principle of operation, construction, EMF equation, equivalent circuit, power losses, efficiency.

Unit III

DC machines: types, EMF equation of generator and torque equation of the motor, characteristics and applications of DC motors, Three Phase Induction Motor: types, principle of operation, slip-torque characteristic, applications, Single Phase Induction Motor: principle of operation and introduction to methods of starting, applications. Three Phase Synchronous Machines: Principle of operation of alternator and synchronous motor and their applications.

Unit IV

Introduction to Power System: Transmission and Distribution. Power crisis in India, future trends, economic considerations, significance of load factor and diversity factor, selection of units, tariff, types of tariff, classification of cost.

Classification sources of power, economic in generation.

Unit V

Basic concept of grid and smart grid; Objectives, benefits and challenges of smart grid, Structure and functions of components of smart grid, Active distribution networks, virtual power plants, comparison.

Measurement, Control and Automation technologies.

TEXTS / REFERENCE BOOKS:

1. Toro V Del, *Principles of Electrical Engineering*, Prentice Hall International
2. Kothari D P, Nagarath I J, *Principles Electrical Engineering*, Tata McGraw Hill
3. Singh S N, *Basic Electrical Engineering*, Prentice Hall International
4. Sahay Kuldeep, *Basic Electrical Engineering*, New Age International Publishers
5. Khartchenko Nikolai V Ed, *Advanced Energy Systems*, Taylor Francis Washington D.C.
6. Hughes Edward, *Electrical and Electronics Technology,* Pearson
7. Hayt W H & Kimerly J E, *Engineering Circuit Analysis*, McGraw Hill
8. Wadhwa C L, *Basic Electrical Engineering*, New Age International
9. Nagsarkar T K, Shukhija M S, *Basic Electrical Engineering*, Oxford University Press

Module: REC 103
Solar Photovoltaic Energy Conversion
[04 Credit]

Course objectives and outcomes

1. To have a knowledge of solar power generation from PV panels. To get an exposure to different cell technologies.
2. An exposure to advanced cell technology and usage of different materials
3. Knowledge of manufacturing processes of various types of solar cell is imparted.
4. Solar module manufacturing process in detail is learnt.
5. An exposure to advanced cell technology and usage of different materials.

Unit I

Basics of solar cell; Intrinsic, extrinsic and compound semiconductor; Energy levels; Electrical conductivity; Determination of Fermi energy level; Probability of occupation of allowed states; Dynamics of energy density of allowed states; Density of electrons and holes.

Carrier transport: Drift, diffusion, continuity equations; Absorption of light; Recombination process; Basic equations of semiconductor devices physics.

Unit II

Solar Cell Physics: pn junction: homo and hetro junctions, Metal semiconductor interface; Dark and illumination characteristics; Figure of merits of solar cell; Variation of efficiency with band-gap and temperature; Spectral response of solar cell, parasitic resistance effect, Working and Efficiency limits: Thermodynamic limit and detailed balance limit of solar cell.

Unit III

Silicon; Physical and chemical properties relevant to photovoltaic. Preparation of metallurgical; Refining, Casting and crushing. Preparation of semiconductor grade silicon (Polysilicon); Siemens process, Union Carbide Process. Solar grade Silicon; Crystallization, Simplification and Polysilicon method.

Growth of single crystal Silicon: Czokralski (CZ) and Float Zone (FZ) method, Multicrystalline Silicon; Ingot fabrication, Doping, Crystal defect, Impurities. Wafering; Multiwire and microscopic process, Saw damage, Description and manufacturing technology.

Unit IV

Solar PV Cell and modules: Cell structure, Front and back surface, optical properties of solar cell, Different losses and mitigation, Anti reflective coating; properties and materials, Surface passivation with back surface, Passivation with Hydrogen, Optical confinement.

The layers of PV modules, Cell matrix, Lamination and curing, Encapsulation and framing, Testing, Electrical and thermal properties, Module mismatching, Shading and hot-spot formation, Environmental effect on PV module performance.

Unit V

High efficiency III-V, II-VI multi-junction solar cell; Photo conversion efficiency, Theoretical limits, spectral splitting, Cell configuration; Four-terminal, three terminal voltage-matched interconnections, two terminal series-connected. Current and voltage characteristics, efficiency and band gap. Deposition of GaAs, GaInP, Ge cells.

Amorphous Silicon-based solar cell; fabrication techniques and material properties. Staebler-Wronski effect. Module manufacturing; Using different substrate, safety and cost.

Dye-sensitized solar cells; Introduction, fabrication and development.

References:

1. Silicon solar cells: advanced principles and practice. Sydney, M. Green, Bridge Printery, 1995.
2. Third Generation Photovoltaics. Berlin, Germany, M. Green, Springer-Verlag, 2003.
3. Crystalline silicon solar cells: advanced surface passivation and analysis, Aberle A. G., Sydney, Centre for Photovoltaic Engineering, UNSW, 1999.
4. The physics of solar cells, J. Nelson, Imperial college press, 2006.
5. Thin-film crystalline silicon solar cells: Physics and technology, R. Brendel, Wiley-VCH, Weinheim, 2003.
6. John A Duffie& William A Beckman "Solar energy Thermal Processes" Wiley Inter science publication, New York.
7. Seminconductors for solar cells, H. J. Moller, Artech House Inc, MA, USA, 1993. Solid State electronic devices, Ben G. Streetman, , Prentice-Hall of India Pvt. Ltd., New delhi 1995.
8. Clean electricity from photovoltaics, M. D. Archer, R. Hill, Imperial college press, 2001
9. Solar Photovoltaics: Fundamentals, Technologies and Applications, C. S. Solanki, Prentice Hall of India, 2011.
10. S. P. Sukhatme "Solar Energy,-Principles of Thermal Collection & Storage", TMHPublishing Co., New Delhi.

Module: REC 104
Wind Energy Conversion Systems
[04 Credit]

Course objectives and outcomes :

1. To enable the students learn regarding various methods of measuring wind speed and facilities available for storage of data.
2. Identify ideal wind site for wind farm
3. Design a wind turbine for a particular application.
4. To develop the skill of understanding the economics of establishing wind system

Unit I

Introduction to wind energy, Atmospheric circulations, Factors influencing wind, Variation of wind speed with height and time, Turbulence, Causes of turbulence, Power estimation in wind, Wind energy conversion principles, Components of wind energy Conversion Systems (WECS),Classification of WECS, Wind Turbine Aerodynamics.

Unit II

Actuator Disc Concept, Power obtained from wind turbine, Density of air, Rotor area, Wind velocity, Energy conversion in wind: Momentum theory, Bernoulli for rotating wake, Pre-Rotor, Post-Rotor, Sabinin's Theory, The Impulse Theory as applied to the horizontal shaft wind turbine hypotheses.

Unit III

Horizontal Axis Wind Turbine (HAWT) & Vertical Axis Wind Turbine (VAWT), Power Developed, Maximum power coefficient (Betz Limit), Thrust, Efficiency, Rotor selection-Rotor design considerations, Diameter of the Rotor.

Aerodynamic design principles, Blade Profile, Blade Element Theory, Choice of the number of blades, Choice of the Pitch angle, Tip speed ratio, Power speed characteristics, Torque speed characteristics, Solidity.

Unit IV

Wind electric generators: Aero generators classification: Synchronous generators, Induction generators, Variable speed generators, Control systems, Power collection system, Power Quality, wind farm and generation protection, interface protection, losses in generation.

Tower, Gear Box, Safety Mechanisms, Wind Velocity Measuring Instrument, Wind speed measurement parameters, Monitoring station instrumentation: cup anemometer, propeller anemometer, Ultrasound anemometer.

Unit V

Wind Pumps: Design and working, Principle of wind Energy electricity generation: Stand Alone, Grid connected and hybrid WECS.

Environmental Benefits and problems of wind energy.

Economics of wind energy: Factors influencing the cost of energy generation, Life cycle cost analysis.

Current Status and future prospects of wind energy, Wind energy in India case studies.

Texts/ References:

1. Siraj Ahmed:"Wind Energy-Theory and Practice" Second Edition, PHI Learning Pvt. Ltd, New Delhi, 2011.
2. Paul Gipe , Karen Perez, (1999); Wind Energy Basics: A Guide to Small and Micro WindSystems, Chelsea Green Publishing Company
3. Garg L Johnson: "Wind Energy Systems" Prentice Hall. Inc, New Jersey,1985.
4. Freris L.L., Wind Energy Conversion Systems, Prentice Hall 1990.
5. Spera D.A., Wind Turbine Technology: Fundamental Concepts of Wind Turbine Engineering, ASME Press, NY 1994.
6. Johnson, G.L., Wind Energy Systems, Prentice Hall, 1985.
7. G. D.Rai,-"Non Conventional Energy Sources", Khanna publisher, New Delhi
8. Klaus Von Mitzlaff "Engine for biogas", Published by FriedrVielveg and Sohnraunschweig, Germany -1988.
9. Desire Le Gouriers: "Wind Power Plants: Theory & Design", Pergamon Press,1982
10. D.P.Kothari,K.C.Singal and RakeshRanjan "Renewable Energy Sources and Emerging Technologies",Second Edition Published by PHI Learning private limited, New Delhi.

Module: REC 105
NUMERICAL METHODS AND COMPUTATIONALTECHNIQUES
(04 Credit)

Course objectives and outcomes:

1. Modeling and simulation allow students to reason about the expected behavior of a system without having to physically implement it.
2. To develop key skills with an aim to enable students to use Modeling and Simulation in the design and verification of Renewable and Green Energy systems.
3. A knowledge of working of various simulation tools.
4. A capability to carry out optimal design of renewable energy systems

Unit I

Introduction to Numerical Methods: Solution of algebraic and transcendental equations; Solution of simultaneous algebraic equations; Empirical laws and curve fitting; Regression method for forecasting; Interpolation.

Finite difference methods: forward difference method, backward difference method, central difference method**.**

Unit II

Numerical Differentiation and Integration: Differentiation using forward, backward and central difference formulae. Integration using trapezoidal, Simpson's one third and Simpson's three eighth rule.

Numerical Solution of Differential Equation :Methods: Taylor's series, Euler, Modified Euler, Runge Kutta and Predictor corrector method; Numerical solution of Partial Differential Equation: Solution of Laplace's equation, Poisson's equation; Solution of one dimensional heat equation using Schmidt and Crank Nicholson method; Solution of two dimensional heat equation; Solution of wave equation.

Unit III

Solution of Laplace's equation, Poisson's equation

Solution of one-dimensional heat equation using Schmidt and Crank- Nicholson method; Solution of two-dimensional heat equation**.** Solution of wave equation

Unit IV

Introduction to Optimization Techniques**.**

Linear programming methods: Simplex method, Artificial variables and dual phase method**.**

Introduction to genetic, simulated annealing and global optimization algorithms**.**

Unit V

Introduction to MATLAB, variables and workspace, Arrays, vectors and matrix**.**

Operators, expressions and statements, output, loops (for, each), decisions (if, else, elseif, while etc.)**.**

Program design and algorithm development, MATLAB functions and data import export utilities, logical vectors**.**

Introduction to graphics: basic 2D graphics, 3D plots, function M-files, graphical user interface, introduction to simulation**.**

Books:

1. Balagurusamy E, *Numerical Methods,* Tata Mc Graw Hill, New Delhi.
2. Jain M K, Iyengar S R K, Jain R K, *Numerical Methods for Scientific and Engineering Computation*, New Age International (P) Ltd. New Delhi.
3. Rajsekaran S, *Numerical Methods in Science and Engineering,* Wheeler, Allahabad.
4. Hilderbrand F B, *Introduction to Numerical Analysis,* Tata McGraw Hill, New Delhi.
5. Harman T L, Dabney J B, Richert N J, *Advanced Engineering Mathematics with MATLAB.*
6. Brain D Hahn, Daniel T Valentine, *Essential MATLAB for Engineers and Scientists,* Elsevier.
7. Redfern Darren, Colin Campbell, *The MATLAB5 Handbook,* Springer, New York.
8. Mathews John H, Numerical *Methods for Mathematics, Science and Engineering,* Prentice Hall of India Pvt. Ltd., New Delhi.
9. Sastry S S, *Introductory Methods of Numerical Analysis,* Prentice Hall of India Pvt. Ltd., New Delhi.
10. Deb Kalyanmoy, *Optimization for Engineering DesignAlgorithms and Examples,* Prentice Hall of India Pvt. Ltd., New Delhi.
11. William H, Teuklosky S A, Vellerling W T, Flannery B P, *Numerical Recipes in C The Art of Scientific Computing*, Cambridge University Press.

Module: REC-106
Energy Laboratory I
[04 Credit]

Course Objectives and outcomes:

1. Operational experience on solar cooker.
2. Measurement of I-V characteristic of Mono-Crystalline and Poly-Crystalline PV module.
3. Measurement of energy band gap of semiconductor.
4. Measurement of illumination using Lux meter.
5. Shadow analysis at a given site.

Exp.01	To measure the total solar energy for a day or for a specified period with different inclination: (a) at horizontal (b) at latitude for Lucknow, 26° 50' N (c) at 45° inclination and also calculate the tilt factor at 12.00 hours and measure sunshine hours.
Exp.02	To determine of the Horizontal Shadow Angle (A) and Vertical Shadow Angle (E) at a given site.
Exp.03	To determine the reflectivity of a booster (reflector) in a Box-Type Solar Cooker.
Exp.04	To study the thermal performance of a Box-Type Solar Cooker (a) with air and (b) with water.
Exp.05	To conduct the Heating and Cooling Tests on a Parabolic Concentrator Solar Cooker to determine its Optical Efficiency Factor and Heat Loss Factor and stagnation test.

Exp.06	To draw the I-V characteristics of a Mono-Crystalline Silicon Photovoltaic Module and calculate the Fill-Factor and Efficiency at two Global Radiation (insolation) values. Also to find the variation of current (I) and voltage (V) in different loads.
Exp.07	To draw the I-V characteristics of a Poly-Crystalline Silicon Photovoltaic Module and calculate the Fill-Factor and Efficiency at two Global Radiation (insolation) values.
Exp.08	To study the variation of Voltage with Power in a Poly-Crystalline Silicon Photovoltaic Module.
Exp.09	To determine of the Energy Band Gap of Germanium by using Point Contact Diode.
Exp.10	To study of Inner Photoelectric Effect in case of Photovoltaic Cell by using a Light Source of Continuous Spectrum and determine the Value of Planck's Constant (h).

Module REE- 101
Energy and Environment
[04 Credit]

Course Objectives and outcomes:

1. **T**he basic concepts of energy, its distribution and general energy scenario in India will be discussed.
2. Various types of environmental pollution and their effects will be explained.
3. Understanding of earth's energy system and the potential impacts of human activity on environment will be developed.
4. Evaluation of the environmental effects of energy production and the relationship between energy generation and environment will be achieved.
5. The environmental rules and policies regarding energy generation, environmental pollution impacts will be learnt.

Unit I: Introduction to Energy

Definition and units of energy and Power; Forms of energy; Primary energy sources; Earth's energy budget and energy flow; Solar radiation and its spectral characteristics; Fossil fuels-classification, composition, physio-chemical characteristics and energy content of coal, petroleum and natural gas; Calorific value of fossil fuels

Unit II: Energy Scenario

Commercial and non-commercial forms of energy; Energy use patterns in India and the world: demand, electricity, access to modern energy production; Sector-wise energy consumption; renewable sources including bio-fuels in India, their utilization pattern; Role of energy in economic development; social and environmental aspects; energy crisis; energy sector reforms; electricity acts; energy pricing; factors affecting energy costs; final energy consumption; energy strategy for the future

Unit III: Fundamentals of Environment

Structure and composition of atmosphere, hydrosphere, lithosphere and biosphere;

Ecosystem- structures and functions; different types of ecosystem; ecosystem theories; energy flow in the ecosystems; Energy flow models; Biogeochemical cycles;

Biodiversity- importance of biodiversity and threats to biodiversity; strategies for biodiversity conservation; concept of sustainable development.

Unit IV: Environmental Pollution

Sources and types of Pollutions; Primary and Secondary Pollutants; Causes and Consequences of Air, water, soil, and noise pollution; Green house gas effect; Global warming; Measurement and Pollution control methods; Sources of thermal pollution- causes and consequences; Radioactive pollution-sources, biological effects of ionizing radiations, radiation exposure. Impacts of nuclear power generation and hydroelectric power stations on ecology and environment

Unit V: Environmental Assessment and Legislations

Aims and objectives of environmental impact assessment (EIA); Environmental Impact Statement (EIS) and Environmental Plan (EMP); EIA guidelines, Impact assessment methodologies; Overview of Environmental laws on pollution control in India; National Environment Policy, 2006;

Textbooks/Suggested Readings

1. Masters G, Introduction to Environmental Engineering and Science, Prentice Hall International Editions
2. Ravindranath NH, Usha Rao, Natrajan B, Monga P, Renewable Energy and Environment-A Policy analysis for India, Tata McGraw hill
3. Fowler, J m, Energy and Environment, 2nd edition, McGraw Hill, New York

Module REC- 201
Bio-Renewable Energy Technology
[04 Credits]

Course Objectives and Outcomes:

The course will be focused on academic achievement, acquisition of knowledge and enhancement of information regarding biomass and bio-energy technologies and their sustainable applications. Students completing this course will be able to:

1. Classify and identify potential biomass feedstock
2. Have an understanding of the existing and emerging biomass to energy technologies
3. Evaluate benefit of various conversion processes
4. Develop the application oriented skills to assess technical and economic feasibility and sustainability of energy production from biomass/wastes in India.

Unit I: Introduction and Characterization of Biomass

Bioenergy- Fundamental concepts, types and overview of bioenergy policy in India; Biomass- Definition, Types of biomass resources and classification, production of biomass, characteristics of renewable feedstock for bioenergy/biofuel production; Basic chemistry of carbon compounds in biomass resources (Carbohydrates and Lipids); Biomass productivity, availability, assessment and estimation; Energy plantation; Biomass pre-processing: drying, size reduction and densification; Briquetting-types of briquettes, utilization and advantages of briquetting

Unit II: Thermo-chemical conversion

Thermo-chemical conversion of biomass to bioheat, biopower and biofuel; direct combustion, incineration, liquefaction, gasification; slow and fast pyrolysis (manufacturing of charcoal and pyrolytic oils and gases) and other thermo-chemical technologies; overview of biorefinery concepts; hydrogenation, solvent extraction of hydrocarbons, solvolysis of wood

Unit III: Biochemical Conversion

Biomass pretreatment/fractionation; different enzymes and their application in bioethanol production; hydrolysis-enzyme and acid hydrolysis, fermentation, Anaerobic digestion, Biomethanation; Trans-esterification method of biodiesel production from oil seeds, waste oils and algae; environmental aspects of biofuel production; analysis of biofuel quality, standards and properties; Design and construction of biogas digesters, biogas utilization; environmental ans social impacts of biogas plant

Unit IV: Waste to Energy Conversion

Introduction, characterization of wastes; classification of wastes; energy production from wastes through incineration, gasification; management and treatment of hazardous and non-hazardous industrial waste; Municipal sewage waste- Energy production from organic waste through anaerobic digestion; Cultivation of algal biomass from wastewater, wastewater treatment and energy production from algae

Unit V: Solid Waste Management

Solid Waste-Definition and classification; Components of solid waste management-Recycling, composting, disposal and waste to energy; Waste disposal- Size reduction and densification of solids, Landfill method of solid waste disposal; Landfill classification, layout and preliminary designing; environmental impacts of waste treatment and monitoring system for landfill gases; Role of pollution control boards and NGOs in solid waste management

Textbooks/Suggested Readings:

1. Sorenson Bent, Renewable Energy, Academic Press, New York
2. Johansson Thomas B, Renewable Energy: Sorbes for Fuels and Electricity, Earthscan Publishers, London
3. Ravindranath NH and DO Hall, Biomass, Energy and Environment: A developing Country Perspective fron India, Oxford University Press
4. Boyles David, Bio-energy Technology Thermodynamics and Costs, Ellis Hoknood, Chichester
5. Mazumdar B, A textbook of Energy Technology: Both conventional and Renewable Source of Energy

Module REC- 202
Alternative Energy Systems
[04 Credits]

Course Objectives and Outcomes:

This Course will enable students to**:**

1. To create awareness about sources of energy and able to estimate how long the available conventional fuel reserves will last.
2. To understand the working of OTEC system and different possible ways of extracting energy from ocean, know about mini-micro hydro systems and geothermal and nuclear energy.
3. To understand the working of geothermal energy power plant and different possible ways of extracting energy from geothermal, know about Magneto-hydro Dynamic systems and nuclear energy.

Unit I: Small Hydro Power Plant

Hydrological cycle, Essential elements of hydraulic electric power plant, Hydraulic Machine: Turbines, General Layout of hydroelectric power plant, Definitions of head and Efficiencies of turbines, Classification of Hydraulic turbine: Impulse Turbine- Pelton Turbine, Reaction Turbine- Francis, Kaplan and Propeller Turbine; Small Hydro power plant, classification, overview of micro, mini and small hydro systems, components of small hydro power plant: diversion structure, desilting arrangement, forebay tank, balancing reservoir, penstock and power house, Site selection of hydropower plant, hydro power in India.

Unit II: Ocean Energy

Introduction to Ocean Thermal Energy Conversion (OTEC), Temperature Gradient Curve with Ocean Depth, Methods of Ocean Thermal Electric Power Generation: Open OTEC, Closed OTEC and Hybrid OTEC, Merits and Demerits of OTEC, Bio-Fouling, Site Selection, Prospects of Ocean Thermal Energy Conversion Systems in India; Introduction to Tides, Basic Principles of Tidal Power, Components of Tidal Power Plants, Methods of Utilization of Tidal Energy: Single Basin and Double Basin, Estimate of energy and Power for Single and Double Basin Tidal Power Generation, Site Requirements, storage, advantages and limitation of Tidal Power Generation and Prospect of Tidal Energy in India; Introduction to Ocean Waves, Advantages and Disadvantages of Wave Energy, Energy and Power from Waves, Wave Energy Conversation Devices.

Unit III: Geothermal Energy Power Plant

Introduction of Geothermal Energy, Geothermal Resources, Nature of geothermal fields, Hydrothermal Power Plant: Vapour Dominated - High Pressure and Low Pressure & Liquid Dominated – Single Flash, Double Flash and Binary System; Geo-Pressurized; Hot dry rock; Magma Resources; Total Flow Concept; Comparison of Flashed Steam and Total Flow Concept, Turbines used in Geothermal Energy Power Plant, Comparison of Geothermal Power Plant with Conventional Power Plants, Advantages and Disadvantages of Geothermal Energy, Application of Geothermal Energy, Geothermal Energy in India.

Unit IV: Magneto-Hydrodynamic

Magneto-hydro-dynamic (MHD) power generation, MHD systems: Open, Closed and Hybrid MHD Systems, Advantages of MHD systems, International status of MHD power generation and its future prospects.

Unit V: Nuclear Power Plant

Nuclear fusion: Nuclear fusion reaction, requirement of nuclear fusion, characteristics of D-T reaction; Components of Nuclear Power Plant: Moderators, Reflectors, Shielding, Cladding, Coolant, Nuclear Reactor, Steam Generator, Turbines; Operation of Nuclear Power Plant; Advantages and Disadvantages of Nuclear Power Plants.

Textbooks / Suggested Readings:

1. G. D.Rai,-"Non Conventional Energy Sources", Khanna publisher, New Delhi
2. D.P.Kothari, K.C.Singal and RakeshRanjan “Renewable Energy Sources and Emerging Technologies”,Second Edition Published by PHI Learning private limited, New Delhi.
3. George W. Sutton: "Direct Energy Conversion", McGraw Hill.
4. Archie W. Culp: "Principle of Energy Conversion"
5. Richards Stephenson, Introduction to Nuclear Engineering, McGraw Hill.
6. K.S.Ram, Basic Nuclear Engineering, Wiely Eastern.
7. M N EI Vakil, Nuclear power engineering, McGraw Hill

Module REC- 203
Hydrogen Energy and Fuel Cell Technology
[04 Credits]

Course Objectives and Outcomes:

The objective of the course is to provide comprehensive and logical knowledge of hydrogen production, storage and applications. The course provides an understanding of various fuel cell technologies. Upon completion of this course, the student will be able to:

1. Evaluate the performance of fuel cells under different operating conditions
2. Select appropriate fuel cell technology for a given application
3. Design and develop suitable hydrogen systems to be used along with fuel cell system

Unit I: Introduction to Hydrogen energy

Properties of hydrogen as fuel, Physical and chemical properties of hydrogen gas; overview of hydrogen energy utilization; Hydrogen sensing- methods of hydrogen using thermal conductivity measurements or Gas chromatography, mass spectrophotometry or laser gas analysis

Unit II: Hydrogen Production

Thermal-steam reformation, gasification, pyrolysis, thermo-chemical water splitting, nuclear thermal catalytic and partial oxidation methods; Electrochemical-electrolysis, photo-electro chemical; Biological-anaerobic digestion, fermentation, PM based electrolyser

Unit III: Hydrogen Storage

Hydrogen separation and purification-pressure swing adsorption, solvent based adsorption, membrane separation, cryogenic separation; Hydrogen storage-compressed storage, liquid state storage, solid state storage, different materials for storage-metal hydrides, high surface area materials, complex and chemical hydrides; hydrogen storage system-design and material aspects

Unit IV: Fuel Cells

History, principle, working of fuel cells, thermodynamics and kinetics of fuel cell process; concept of electrochemical potential and Nernst equation, performance and evaluation of fuel cell; Comparison of battery and fuel cells; Types of fuel cell-AFC, PFAC, SOFC, DMFC, PEMFC and Microbial fuel cell, relative merits and demerits

Unit V: Application of Fuel cell Technology

Fuel cell usage foe domestic power systems, large scale power generation, automobile, space, economic and environmental analysis of usage of hydrogen and fuel cells; future trends in fuel cell technology; Hydrogen safety-codes and standards

Textbooks/Suggested Readings:

1. Sorenson B, Hydrogen and Fuel cells, Elsevier, Academic Press, USA
2. Yurum Yuda, Hydrogen Energy Systems, NATO ASI Series, London
3. Baker BS, Hydrogen Fuel cell Technology, Academic Press, New York
4. O'Hayre R, Cha S, Colella W., Prinz F.B, Fuel Cell Fundamentals, John Willey and Sons, New York
5. Hydrogen and Fuel Cells: A comprehensive Guide Rebecca L. Busby, PennWell Books

Module REC-204
Solar Thermal Energy Conversion
[04 Credits]

Course Objectives and Outcomes:

The course aims:

1. To provide the basic technical knowledge about the solar thermal energy conversion systems.
2. Information of different solar thermal energy systems like flat plate and concentrating technology. The syllabus offers the performance evaluation processes of industry use solar thermal systems.

Unit: I

Solar Radiation and Measurement, Solar angles, day length, angle of incidence on tilted surface; Sun-path diagrams; Shadow determination; Extra-terrestrial characteristic; Effect of earth atmosphere; Measurement & estimation on horizontal and tilted surfaces; Analysis of Indian solar radiation data and applications.

Unit: II

Flat plate Collectors: Effective energy losses; Thermal analysis; Heat capacity effect; Testing methods; Evacuated tubular collectors; Air flat plate Collectors: types; Thermal analysis; Thermal drying. Selective Surfaces: Ideal coating characteristics; Types and applications; Anti reflective coating; Preparation and characterization.

Unit: III

Concentrating Collector Designs: Classification, design and performance parameters; Tracking systems; Compound parabolic concentrators; Parabolic trough concentrators; Concentrators with point focus; Heliostats; Comparison of various designs: Central receiver systems, parabolic trough systems, Solar power plant; Solar furnaces.

Unit: IV

Solar Heating & Cooling System: Liquid based solar heating system; Natural, forced and gravity flow, mathematical modelling, Vapour absorption refrigeration cycle; Water, ammonia & lithium bromide water absorption refrigeration systems; Solar operated refrigeration systems; Solar desiccant cooling; Performances of solar collectors: ASHRAE code; Modelling of solar thermal system components and simulation; Design and sizing of solar heating systems: f–chart method and utilizability methods of solar thermal system evaluation.

Unit: V

Solar Energy for Industrial Process Heat: Industrial process heat: Temperature requirements, consumption pattern; Applications of solar flat plate water heater & air heater for industrial process heat; Designing thermal storage; Transport of energy; Solar Thermal Energy Systems: Solar still; Solar cooker: Solar pond and other Solar Systems.

Textbooks/Suggested Readings:

1. Sukhatme S P, *Solar Energy: principles of Thermal Collection and Storage*, TataMcGrawHill.
2. Duffie J A, Beckman W A, *Solar Engineering of Thermal Processes,* Johnn Wiley.
3. Goswami D Y, Frank Kreith and Kreider J F, *Principles of Solar Engineering*, Taylor and Francis, USA.
4. Garg H P, Prakash S, *Solar Energy: Fundamental and Application,* Tata McGrowHill, New Delhi.
5. Kreith F, Kreider J F, *Principles of Solar Engineering*, McGrawHill.
6. Kreider J F, Kreith F, *Solar Energy Handbook,* McGrawHill.
7. Bent Sorensen, *Renewable Energy*, Academic press, New York.
8. Tiwari, G N, *Solar Energy, Fundamentals Design, Modeling and Applications*, Narosa, New Delhi.

Module REC-205
Energy Storage
[04 Credits]

Course Objectives and Outcomes:

This Course will enable students to-

1. Identify the importance of Energy storage & the modes energy can be stored, corresponding to energy density and power density.
2. Learn the applications of thermal energy storage system
3. Understand concept of mechanical Energy Storage
4. Study the basics of Electromagnetic energy storage systems such as Superconducting Magnetic Energy storage.
5. Impart the knowledge of Supercapacitor and its basic components of supercapacitors,

Unit I:

Need of energy storage; Different modes of Energy Storage, Mechanical Energy Storage: Pumped hydro storage-numerical problems, Elastic energy storage, Energy storage in Advanced Flywheels, Compressed air energy storage-numerical problems; Electrical and magnetic energy storage: Capacitors, Electromagnets and Battery storage systems such as primary, secondary, Lithium, Solid-state and Molten solvent batteries.

Unit II:

Thermal energy storage at medium and high temperatures using sensible and latent heat: Sensible heat storage (SHS) mediums; Stratified storage systems; Rock-bed storage systems; Thermal storage in buildings; Earth storage; Energy storage in aquifers; Phase change materials (PCMs); Selection criteria of PCMs; Stefan problem; Solar thermal LHTES systems; Energy conservation through LHTES systems; LHTES systems in refrigeration and Air-conditioning systems; Enthalpy formulation; Numerical heat transfer in melting and freezing process.

Unit III:

Electro-chemical energy conversion and storage: Introduction to batteries, elements and operation of electrochemical cells, theoretical cell voltage and capacity, losses in cells; Battery classification, factors effecting battery performance, batteries for PV system.

Unit IV:

Electromagnetic energy storage: Superconducting Magnetic Energy Storage. Super capacitor: Basic components of super-capacitors like types of electrodes like high surface area activated carbons, metal oxide and conducting polymers, aqueous and organic electrolytes; Disadvantages and advantages of super-capacitors over battery systems and their applications in aspects of energy density, power density, price and market.

Unit V:

Some areas of application of energy storage: Food preservation; Waste heat Recovery; Solar energy storage; Greenhouse heating; Power plant applications; Drying and heating for process industries.

Textbooks / Suggested Readings:

1. Johannes Jensen & Bent Sorensen ': "Fundamentals of Energy Storage", John Wiley & Sons, 1984
2. S.Rao and Dr.P.P.Parulekar:"'Energy Technology", Khanna Pub., 1997.
3. Collins: "Batteries Vo\. I & II'.
4. G.D.Rai: "Non-conventional Energy Sources", Khanna Publishers, 1989.
5. James Larminie: “Fuel Cell Systems Explained”, John Wiley & Sons, 2005.
6. Tetsuya Osaka: “Energy Storage System for Electronics”, Taylor & Francis Ltd., 2000.
7. ChethansinghSolanki “Solar Photovoltaics-Fudmentals, technologies and applications”- PHI II Edition -2012

Module REC-206
Energy Laboratory – II
[04 Credits]

Course Objectives and Outcomes:

This course will enable students to:

1. Learn the functioning of box-type solar cooker, hybrid solar cooker
2. Assess the thermal performance of thermal collectors
3. Assess and estimate the biomass productivity
4. Characterize the biomass qualitatively and quantitatively

Exp.01 Determination of First and Second Figures of Merit of a Box-Type Solar Cooker.

Exp.02 Thermal Performance of a Hybrid Solar Cooker with Top and Bottom Heating.

Exp.03 Performance Evaluation of a Single Basin Solar Still.

Exp.04 Evaluation of U_L, F_R, η of Solar Thermal Flat Plate Collector in Thermo-syphonic Mode of Flow at different Radiation Levels.

Exp.05 Study of the Performance of a Rectangular Dish Type Solar Cooker with Water Heater Through Stagnation Temperature Test and Solar Water Heating Test.

Exp.06 Determine the Performance *(U_L, F_R,* η of the Parabolic Trough Collector with Fixed Parameters with (I) Water and (II) Oil as Working Fluid.

Exp.07 Study of the I-V and P-V Characteristics of Series and Parallel Combination of PV Modules.

Exp.08 Working out Power Flow Calculations of Standalone PV System of DC and AC Load with Battery.

Exp.09 Grid Synchronization of Solar PV Inverter and it Performance Analysis.

Exp.10 Determination of Efficiency of Improved Chulha through Water Boiling Test Procedure.

Exp.11 Determination of moisture content, Volatile matter and ash content in different biomass. Calculate biomass productivity in C3 and C4 plants.

Module REE-201
Solar Photovoltaic Systems
[04 Credits]

Course Objectives and Outcomes:

The course

1. Intends to give the necessary and significant learning regarding solar photovoltaic systems operation and installation.
2. Covers the modern knowledge and on-field practices of solar PV systems.
3. Provides economics of different PV systems based on current market scenario.
4. Presents the assessment methods of kilowatt to megawatt level PV systems in by in-situ methods.

Unit I: Solar Array Designing and Assessment

Introduction to solar cell array systems, solar cell array analysis and performance prediction; Solar cell array design concepts; PV system design; Design process and optimization, Sizing of electrical and electronic components; Storage autonomy; The effect of environment on the performance of PV system: Effect of temperature and irradiance, Operation under soiling conditions, Shadow analysis: Reliability, Self-shading.

Unit II: Site Assessment for PV System

Site assessment, planning, Solar resource assessment; Solar energy potential, Peak sun hours (PSH), Wind pattern, Rainfall, Azimuth, altitude, Module Tilt & Orientation, Shadow analysis, Site specific detail; Roof and soil conditions, type of construction, components location; Designing of solar water pumping set, solar lamp and solar street light, use of computers in system design; designing and simulation software i.e. PVsyst, system advisor model, PV watts, etc.

Unit III: Power conditioning and control

Electrical balance of system: converters, Buck, Boost, Buck and Boost converters, charge controllers for battery: PWM and MPPT. MPPT Techniques: Voltage-controlled technique, Current-controlled technique, Equation-based technique, Hill-climbing techniques, Perturb & observe technique etc.; Inverters for PV systems: Inverters: Square wave inverters, Modified sine wave inverters; Cabling: size, losses, etc.

Unit IV: System Installation

Installation and mounting of SPV array: Roof-mounted arrays; stand-off and open rack mounting, integrated and direct mounting. Ground-mounted arrays; rack mounting, pole mounting, tracking-stand mounting, PV Arrays loading considerations; wind loads estimation; Enhancing array performance; minimizing heating losses, cleaning practices, Installation of electrical and electronic components: array combiner box, inverter, Distribution boxes, safety devices etc.

Unit V: Economics of PV system

Levelized cost of energy (LCOE), Payback period, Net metering, Gross metering, Tariff, Feed-in-tariff, Subsidies, Fiscal, Financial and other incentives associated with PV systems; JNNSM policies and initiatives, DPR preparation for roof-top and MW scale solar plants, PV market analysis; recent PV market trends, Benchmark cost of different PV components**.**

Textbooks/Suggested Readings:

1. Goswami D Y, Frank Kreith and Kreider J F, *Principles of Solar Engineering*, Taylor and Francis, USA.
2. Garg H P, Prakash S, *Solar Energy: Fundamental and Application,* Tata McGrow-Hill, New Delhi.
3. Kreider J F, Kreith F, *Solar Energy Handbook,* McGraw-Hill.
4. Tiwari, G N, *Solar Energy, Fundamentals Design, Modeling and Applications*, Narosa, New Delhi.
5. The physics of solar cells, J. Nelson, Imperial college press, 2006.
6. Thin-film crystalline silicon solar cells: Physics and technology, R. Brendel, Wiley-VCH, Weinheim, 2003.
7. John A Duffie & William A Beckman "Solar energy Thermal Processes" Wiley Inter science publication, New York.

Module: REC 301

Distributed Generation and Integration of Renewable Energy with Grid

[04 Credit]

Course objectives and outcomes

1. To develop a conceptual understanding of grid-connected energy storage schemes & hybrid Energy Systems.
2. Have a sound understanding of the operation of electricity distribution generation systems and an appreciation of the associated challenges.
3. Appreciate the resource characteristics, operation, cost and economic evaluation , challenges and overall impact of highly distributed, renewable energy generators.
4. Have a good understanding of the characteristics of modern electrical loads as well as energy storage technologies and the impact of increased penetration of such technologies in distribution systems.
5. Be conversant in power management aspects of smart and micro-grids.
6. Understand the functionalities and the operational flexibility brought to the power system by the introduction of energy storage schemes and estimation

Unit I

Distributed Generation System: Decentralized versus Central Station generation, Traditional power systems, Load curves and Load curve analysis. Coincidence behavior and Load curves measuring load curve data accurately

Planning and Planning Process: Planning finding the best alternative, Short and long range planning.

Cost and Economic Evaluation of Distributed Generation: Costs, time value of money, decisions bases and cost effectiveness evaluation

Unit II

Basic gas turbine generator concepts: Utility system turbine generators; Mini and micro gas turbine generators

Solar thermal power generations, Utility scale Photovoltaic (USPV) generation; Wind-powered generation; Biomass based generation.

Unit III

DG Evaluation: Cost from past, present, and future, basic DG cost analysis, cost evaluation and schedule of demand

Grid Interconnection Issues and Need of Integration of Renewable Energy: The power grid, Pro & cons of DG-interconnections, type of DG grid interconnection, DG-Grid interconnections issues

Unit IV

Effects on the grid by RE systems integration; Interfacing techniques; Innovations required in technology and policy

Economics: Grid-connected energy storage schemes; response requirement, capacity assessment, cost considerations

Unit V

Hybrid Energy Systems: Principles and applications; comparison of schemes; System design concept:

Techno-economic performance; Energy storage schemes and estimation

Books:

1. Willis H Lee, *Distributed power generation: planning and evaluation* , Marcel Dekker, Inc.
2. Willis H Lee, Power Distribution planning reference book, Marcel Dekker, Inc.
3. Ali Keyhani, Mohammad N Marwali, Min Dai, *Integration of Green and Renewable Energy in Electric Power Systems,* Wiley.
4. Kaushik N D, Kaushik Kshitij, *Energy Ecology and Environment: A Technological Approach*, New Delhi, Capital Publishing Company.
5. Johansson Thomas BEd, *Renewable energy: sources for fuels and electricity*, Earthscan.

Module: REC 302
Energy Efficient Buildings
[04 Credit]

Course objectives and outcomes

1. To supply the essential and important knowledge about sustainable architecture for the different climatic zone.
2. To impart the knowledge about passive cooling and heating techniques to provide thermal comfort inthe building atmosphere.
3. The course provides the idea of green buildings (zero emission) through various energy conservation techniques.
4. Will equip the students to design energy efficient buildings.

Unit I

Climates and buildings, Thermal properties and energy content of building materials, Psychrometry, Thermal comfort: Criteria and various parameters, Air conditioning systems, Energy conservation techniques in Air conditioning systems.

Climate and comfort zones, Introduction to the design of shading devices, Overhangs.

Factors that effects energy use in buildings: ventilation and its significance.

Unit II

Passive and active methods of heating and cooling, Passive heating concepts: direct heat gain, indirect heat gain, isolated gain and sunspaces.

Passive cooling concepts: evaporative cooling, radiative cooling; application of wind, water and earth for cooling; shading, paints and cavity walls for cooling; roof radiation traps; earth air-tunnel.

Unit III

Heat transmission in buildings: surface co-efficient: air cavity, Internal and external surfaces

Overall thermal transmittance, Wall and windows; Heat transfer due to ventilation/infiltration, Internal heat transfer; Decrement factor; Phase lag; Lighting (Day-lighting and Electric lighting), Design of day-lighting, Concept of sol-air temperature and its significance.

Unit IV

Estimation of building loads, Steady state method, Network method, Numerical method, Correlations.

Energy conservation through site selection, Planning and design; Siting and orientation Green buildings, Zero emission buildings**.**

Energy Efficient Landscape Design: Modification of microclimatic through landscape element for energy conservation**.**

Unit V

Bioclimatic classification of India; Passive concepts appropriate for the various climatic zones in India; Typical design of selected buildings in various climatic zones; Thumb rules for design of buildings and building codes Energy Efficient Landscape Design: Modification of microclimatic through landscape element for energy conservation

Books:

1. Tiwari G N, Goyal R K, *Greenhouse Technology: Fundamentals, Design Modeling and Application,* Narosa Publishing House.
2. Krieder J, Rabi A, *Heating and Cooling of Buildings: Design for Efficiency*, McGraw-Hill.
3. Archie, Culp W, *Principles of Energy Conservation*, McGraw Hill.
4. Callaghan P O, *Energy Management*, McGraw - Hill Book Company.
5. Williams J R, *Passive Solar Heating*, Ann Arbar Science.
6. Majumder Milli, *Energy Efficient Buildings*, TERI, New Delhi.
7. David A Bainbridge, Ken Haggard, *Passive Solar Architecture: Heating, Cooling, Ventilation, Daylighting and More Using Natural Flows*, Chelsea Green Publishing Co., UK.
8. Bureau of Energy Efficiency, *Energy Conservation Building Code,* Ministry of Power, Government of India, New Delhi.
9. ASHRAE, *Hand Book: Fundamentals,* Inch-Pound Edition, New York, USA.

Module:REC 303
Energy Economic Policy and Planning
[04 Credit]

Course objectives and outcomes

1. The necessary and significant learning regarding the economics of renewable energy systems will be imparted.
2. The knowledge about the calculation of unit cost of energy of various renewable energy systems and proffers economics of different PV systems based on current market situation will be communicated.
3. Illustration of financial economics of renewable energy systems in India.
4. To get an awareness of present energy pattern and to understand the energy policy.
5. An exposure to Evaluation / utilization of energy usage and finding alternate energy resources and policy implications.

Unit I

Economics of energy systems

Economics and planning of energy systems: Evaluation of energy technologies and systems, unit cost calculation of power generation from different sources with examples; Energy matrices of energy systems; Energy-Payback Time (EPBT), Energy return on energy invested (EROI). Levelized cost of energy (LCOE), Payback period, Net Present Value (NPV), Internal Rate of Return (IRR).

Unit II

Renewable energy economics in India

Energy (and power) policies in the country, Energy utility interface, Private sector in renewable power generation, State role and fiscal policy, Tariffs and subsidies, Energy policy acts and regulations.

Energy and development, National energy plan, Role of modeling in energy policy analysis, Energy data base, Energy balances, Flow diagram, Reference energy system.

Unit III

Energy supply and trading

Energy demand analysis and forecasting, Energy supply assessment and evaluation, Energy demand-supply balancing.

Energy pricing, Policy and planning implications of energy-environment interaction, clean development mechanism, technology transfer and its financing, carbon credits and trading opportunities, Financing of energy systems.

Unit IV

Energy and environment

Costs of exploration and economics of utilization of depletable and renewable resources, Scarcity rent, International energy supply, Energy demand supply balancing.

Energy-economics interaction, Energy investment planning, Energy-environmental interaction. Environmental concerns and issues of renewable energy systems.

Unit V

Scenario of Renewable Energy generation

Overview of national energy use, Energy supply and renewable energy programme during different plan periods. Renewable energy use and target in India, Relevance of economics and financial viability evaluation of renewable energy technologies, financial feasibility evaluation of renewable energy technologies.

Books:

1. Ferdinand Banks E, *Energy Economics: A Modern Introduction,* Kluwer, London.
2. Kandpal T C, Garg H P, *Financial Evaluation of Renewable Energy Technology*, Macmilan India Ltd. New Delhi.
3. Munasinghe M, Meier P, *Energy Policy Analysis and Modeling*, Cambridge University Press.
4. Samuelson P A, William Nordhaus D, *Economics,* McGraw-Hill, New York.
5. Donnelly W A, *The Econometrics of Energy Demand: A Survey of Applications*, Praeger, New York.
6. Dixon, et al, *Economic Analysis of Environmental Impacts*, Earthscan Publications Ltd., London.
7. Hackett Steven C, Sharpe M E, *Environmental and Natural Resources Economics*, New York.
8. White J A, et. al., *Principles of Engineering of Economic Analysis*, John Wiley and Sons.
9. Dasgupta Ajit K, Pearce D W, *Cost Benefit Analysis, Theory and Practice*, Macmilan.

10. United Nations Ed, *Energy Issues and options for Developing Countries*, Taylor and Francis.
11. Hohmeyer O, Ottinger R L Ed, *Social costs of energy: Present Status and Future Trends,* Springer Verlag.
12. Kaplan, Seymour, *Energy Economics: Quantitative Methods for Energy and Environmental Decisions*, McGraw Hill.
13. Meyers Robert A Ed, *Handbook of Energy Technology and Economics*, John Wiley and Sons.

Module: REC 304
Industrial Training and Field Visit
[04 Credit]

Course objectives and outcomes:

1. Industrial training will provide hand on training to students in the area of renewal energy.
2. Provide a pathway of realizing the knowledge in real environment
3. A real experience of working conditions and environment in industries will be gained.
4. Passing the knowledge from books to hand and mind.

Module: REE 301
Climate Change and Carbon Trading
[04 Credit]

Course Objectives and Outcomes:

1. Knowledge imbalance in the global carbon cycle, carbon foot-printing, accounting, requirements and challenges imposed by climate change on Earth's surface and the policy responses to climate change will be imparted.
2. To explain the working of earth's climatic system and summarize the atmospheric circulation patterns.
3. Understanding regarding different mechanisms of carbon trading and the role carbon finance in stabilizing Earth's climate will be developed.
4. An exposure to explore policy issues related to global climate change.
5. A capability to analyze greenhouse gases with an emphasis on carbon management and finance.

Unit I: Global Carbon Balance

Earth's Carbon pools and fluxes (Natural and Anthropogenic)
Global Carbon cycling (terrestrial and marine carbon cycle)
Carbon footprints-direct and indirect; Anthropogenic impacts on Carbon footprints
Methods of measurement of Carbon dioxide- Physical and Chemical methods

Unit II: Contemporary Environmental Issues

Global environmental issues-Biodiversity loss, climate change, ozone layer depletion, sea level rise; International efforts for environmental protection

National Action plan on climate change (Eight national Missions); Environmental issues related to climate change-adaptability, energy security, food security and sustainability

Unit III: Climate change Mitigation

Carbon Sequestration-Biological and geological, CCS projects; Carbon sequestration Modalities and Procedures

Forests- source or sink of carbon; role of forests in mitigation of carbon emissions, Carbon dioxide removal (CDR) mechanisms; National Forest policy, 1988; Forest Conservation Methods

Climatic impacts of Land use, Land use change and Forestry; Reducing emissions from deforestation and forest degradation (REDD) projects

Unit IV: Climate Change Mitigation Policies: Regulatory Instruments

Introduction to Environmental conventions and agreements-Conference on Human environment, Montreal protocol 1987, Conference of Parties (COP), Earth Summit, 1992;

Kyoto Protocol and its functions; implications of Kyoto Protocol on Developed and Developing countries;

Paris Agreement and its implications on Developed and Developing countries

UNFCCC, IPCC, UNEP, IGBP

Unit V: Climate Change Mitigation Policies: Carbon Market based Instruments

UNFCCC flexible mechanisms; Clean development Mechanisms (CDM) and its operation, modalities and procedures; joint implementation

Carbon Emission trading schemes; difficulties and challenges with CDM

The role of carbon finance- Carbon credits, carbon Funds, Carbon Offsetting

Evaluation of carbon credits of green and clean energy systems; Future of carbon finance

Textbooks/Suggested Readings

1. Hester R E and Harrison RM, Carbon capture: Sequestration and Storage, Environmental Science and Technology
2. Wilson Elizabeth and G. David, Carbon capture and Sequestration Integrating Technology, Monitoring , Regulation
3. AKN Reddy, RH Willams, TB Johansson, Energy after Rio, Prospects and challenges, UNDP, United Nations Publications, New York
4. Nebojsa et al. Global Energy Perspectives, Cambridge University Press

Module: REC 401
Advanced Energy Systems
[04 Credit]

Course objectives and outcomes

1. The course intends to give the necessary and significant learning regarding advanced energy systems on-field operation.
2. Course provides the detailed information about the integration of two different renewable energy systems.
3. Get an awareness of present integrated pattern and understand the merits of integration.
4. An exposure to advanced energy system and techno economic feasibility of hybrid system.

Unit-I: PV-Thermal energy systems

PV/T air heating: PV Integrated with air collector, Double-pass PV/T solar air collector, PV/T water heating: temperature-dependent PV module performance, PV module efficiency and output power as a function of the operating temperature, Overall Thermal and Electrical Efficiency, Market potential of PV/T systems.

Unit-II: Solar-wind power generation systems

Introduction and need of solar-wind conversion systems**,** Concept, design and installation of S-W hybrid systems, Electrical output of the hybrid system, site and resources assessment for the installation of S-W energy systems, Interaction of grid with solar-wind power generation systems, limitation of the S-W generation: cost, technology and environmental issues. Economics and market scenario of these systems.

Unit-III: Building integrated PV systems

Concept, design and Implementation of BIPV systems, Classification of BIPV system and their application, Cell and module design for BIPV systems, Rooftop and Facade based systems, Different parameters of building integrated PV systems, Electrical and thermal analysis, International standards and test conditions, Total energy generation, Performance Issues and limitations of BIPV, Life cycle assessment studies of BIPV modules current scenario and market trend

Unit-IV: Grid integration of Solar systems

Grid and solar power generation, Integration of solar thermal and photovoltaic systems, Matching of voltage, phase and frequency, smart grid technology and challenges, Grid power control and power management, type of electrical power grids, Impact of smart grid on solar power generation.

Unit-V: Advanced designed power systems

Floating PV energy systems: Concept and commercial designs of Floating Solar System, Economical analysis, Comparison between floating Vs land based PV systems, Environmental impacts, Challenges or Issues of floating PV system, Canal top solar PV systems: concept, design and installation criteria, Effect of water evaporation rate, Environmental issues and limitations, techno-economic feasibility studies of these systems.

Textbooks/Suggested Readings

1. Khartchenko, N. V., & Kharchenko, V. M. (2013). *Advanced energy systems*. CRC Press.
2. Russell, C. T., & Vaisberg, O. (1983). The interaction of the solar wind with Venus. In *Venus* (pp. 873-940).
3. Prasad, D., & Snow, M. (2014). *Designing with solar power: a source book for building integrated photovoltaics (BiPV)*. Routledge.
4. Kalogirou, S. A. (2001). Use of TRNSYS for modelling and simulation of a hybrid pv–thermal solar system for Cyprus. *Renewable energy*, *23*(2), 247-260.
5. Gevorkian, P. (2017). *Grid-connected photovoltaic power generation*. Cambridge University Press.

Module: REC 402
Dissertation
[08 Credit]

Course objectives and outcomes:

At the end of the course the student will be able to

1. Identify the problem of a research project through literature survey.
2. Analyze the technical feasibility of the project.
3. Propose the solution for the research problem.
4. Analyze and design the proposed solution using Simulation Tools.

Module: REE 401
Energy Conservation and Management
[04 Credit]

Course Objectives and Outcomes:

1. Willenable students to learn and realize the need for energy conservation and management.
2. Understanding of the concepts: Energy audit, principles of financial appraisal for acceptance of projects and energy conservation methods through efficient use of energy sources.h
3. Calculations of energy saving from efficient use of steam, proper insulation, improved power factor, optimum illumination etc will be learnt.
4. Will equip the student to take up projects on energy audit and decide upon the best option for energy conservation in industries and electrical utilities.

Unit I: Introduction

Importance of energy management; Need, organizing, Initiation phase of energy management program; energy demand and supply; Baseline energy assessment

Energy conservation-basic concepts, Scope of energy conservation in household, transportation, agricultural, service and industrial sectors, lighting, HVAC systems; Energy conservation act

Unit II: Energy Audit

Definition, need and types of energy audit; energy audit approach, understanding energy costs, bench marking, energy performance, matching energy use to requirement, maximizing system efficiencies, optimizing the input energy requirements; fuel and energy substitution; energy audit instruments; duties and responsibilities of auditors; Energy monitoring and targeting

Unit III: Material and Energy balance

Basic principles; Material balances; Facility as an energy system; Heat balances; Methods for preparing process flow; material and energy balance diagrams

Unit IV: Electrical Energy Management

Methods to minimize supply demand gap; renovation and modernization of power plants, reactive power management, HVDC and FACTS; Conservation in motors, pumps and fan systems; energy efficient motors

Unit V: Thermal Energy Management

Energy conservation in boilers, steam turbines and industrial heating systems; Application of FBC; Cogeneration and waste heat recovery; thermal insulation; heat exchangers and heat pumps; building energy management

Textbooks/Suggested Readings

1. L C Witte, PS Schmidt, DR Brown, Industrial Energy Management and Utilization, Hemisphere Publications, Washington
2. Industrial Energy Conservation Manuals, MIT Press
3. IGC Dryden, Butterworths, The efficient Use of Energy, London
4. WC Turner, Wiley, Energy Management Handbook, New York
5. Smith CB, Energy Management Principles, Pergamon Press, New York
6. Hamies, Energy Auditing and Conservation, Methods, Measurements, Management and Case Study, Hemisphere, Washington