SYLLABUS

Choice-Based Credit System

M Sc (RENEWABLE ENERGY)

FACULTY OF SCIENCE

UNIVERSITY OF LUCKNOW, LUCKNOW

YEAR – 1	
SEMESTER – I	
CORE SUBJECT	**CREDIT**
Module RECC-101 : Thermodynamics & Power Plant	4
Module RECC-102 : Electrical Power Technology	4
Module RECC-103 : Solar Photovoltaic Energy Conversion	4
Module RECC-104 : Fundamentals of Wind Energy	4
Module RECC-105 : Energy Laboratory I	4
Module REVC-101 : Energy and Environment	4
Semester Total Credits – 24	

SEMESTER – II	
CORE SUBJECT	**CREDIT**
Module RECC-201 : Fundamentals of BioEnergy	4
Module RECC-202 : Basics of Tidal, Geothermal and Nuclear Energy	4
Module RECC-203 : Hydrogen Energy and Fuel Cell Technology	4
Module RECC-204 : Solar Thermal Energy Conversion	4
Module RECC-205 : Heat and Mass Transfer	4
Module RECC-206 : Energy Laboratory II	4
Module REVNC : 201 Numerical Methods and Computational Techniques	0
Semester Total Credits – 24	

7. Course Outline

Module: RECC-101

Thermodynamics and Power Plant

[04 Credits]

Course outcomes:

1. To understand and apply the concept of availability in thermodynamics.
2. To apply the concepts of advanced thermodynamics to combustion systems and refrigeration systems.
3. Analyze the engineering systems and optimize its performance
4. Understand the working and the design principles of combustion systems and refrigeration systems.

Unit I

Basics of thermodynamics: Thermodynamic systems, Control Volume of systems, thermodynamic system surrounding and universe and effect of surrounding on system; Types of thermodynamic systems; Macroscopic and Microscopic viewpoints; Concept of Continuum; Thermodynamic Equilibrium; Thermodynamic processes and it's properties; Differentials in thermodynamics: Exact & Inexact Differentials; concept of work and heat (sign convention) in thermodynamic systems, Ideal gas equation, Zeroth law of thermodynamics: Concept of Temperature and it's measurement.

Unit II

First law of thermodynamics: Statement; Displacement work and flow work; Displacement work for various non flow processes; Application of first law of thermodynamics on closed systems (non flow processes): Internal energy and enthalpy; Limitations of first law of thermodynamics; Introduction to Perpetual Motion Machine of first kind (PMM-I); Fundamentals of steady flow thermodynamic systems and their analysis; Steady flow energy equation: Boilers, Condensers, Turbine, Throttling process, Pumps etc.

Unit III

Second law of thermodynamics:Kelvin Planck and Clausius statement of second law of thermodynamics; Concept of thermal reservoirs; Energy conversion into work; Heat engines introduction and efficiency; Reversed heat engine: Heat pump, and Refrigerator, Coefficient of Performance;. Reversible and irreversible processes; Carnot cycle and Carnot engine; Carnot theorem; Temperature Scale for thermal reservoir; Introduction to Perpetual Motion Machine of second kind (PMM-II); Clausius inequality.

Concept of Entropy; Entropy change of pure substance during different thermodynamic processes; Tds equation; Principle of entropy increase; T-S diagram; Statement of the third law of thermodynamics.

Unit IV

Properties of steam: Pure substance, property of pure substance (steam), Triple point, Critical point, Saturation states, Sub-cooled liquid state, Superheated vapour state, Phase transformation process of water, Graphical representation of pressure, volume and temperature, P-V, T-S and H-S diagrams, Steam-Tables, Dryness factor and it's measurement; processes involving steam in closed and open systems: Simple Rankine cycle; Gas Power Cycle and its improvement.

Unit V

Refrigeration Cycles: Vapour compression refrigeration cycle, Refrigeration capacity, unit of refrigeration; Analysis of cycle: effect of superheating, sub-cooling and effect of change in evaporator and condenser pressure on performance of vapour compression refrigeration cycle; Refrigerants: their classification and properties.

Air-water vapour mixture and Psychrometry: Psychometric terms and their definitions, Psychometric chart, Different Psychometric processes and their representation on Psychometric chart.

Textbooks/Suggested Readings:

1. Basic and Applied Thermodynamics by PK Nag, MCGRAW HILL INDIA
2. Thermodynamics for Engineers by Kroos & Potter, Cengage Learning
3. Thermodynamics by Shavit and Gutfinger, CRC Press.
4. Thermodynamics- An Engineering Approach by Cengel, MCGRAW HILL INDIA.
5. Basic Engineering Thermodynamics, Joel, Pearson.
6. Fundamentals of Engineering Thermodynamics by Rathakrishnan, PHI.
7. Engineering Thermodynamics by Dhar, Elsevier.
8. Engineering Thermodynamics by Onkar Singh, New Age International.
9. Engineering Thermodynamics by CP Arora.

Module: RECC-102

Electrical Power Technology
[04 Credits]

Course outcomes:

1. Apply the concepts of KVL/KCL and network theorems in solving DC circuits.
2. Analyze the steady state behavior of single phase and three phase AC electrical circuits.
3. Identify the application areas of a single phase two winding transformer as well as an auto transformer and calculate their efficiency. Also identify the connections of a three phase transformer.
4. Illustrate the working principles of induction motor, synchronous machine as well as DC machine and employ them in different area of applications.
5. Describe the components of low voltage electrical installations and perform elementary calculations for energy consumption.

Unit I

Electrical circuit elements (R, L and C), Concept of active and passive elements, voltage and current sources, concept of linearity and linear network, unilateral and bilateral elements, Kirchhoff"s laws, Loop and nodal methods of analysis, Star-delta transformation, Superposition theorem, Thevenin theorem, Norton theorem, Maximum Power transfer theorem

Unit II

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 III

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, DC machines: types, EMF equation of generator and torque equation of the motor, characteristics and applications of DC motors

Unit IV

Single phase transformers: principle of operation, construction, EMF equation, equivalent circuit, power losses, efficiency, 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

Unit V

Three Phase Synchronous Machines: Principle of operation of alternator and synchronous motor and their applications. Introduction to Power System: Transmission and Distribution, Classification sources of power, economic in generation, hydro-electric power plant, steam power plants, Basic concept of grid and smart grid

Textbooks/Suggested Readings:

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: RECC- 103
Solar Photovoltaic Energy Conversion
[04 Credits]

Course 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: p-n junction: homo and hetero 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, CdTe, GaInP cells, perovskites and organic solar cell.

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.

Textbooks/Suggested Readings:

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: RECC-104

Fundamentals of Wind Energy

[04 Credits]

Course outcomes:

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

Unit I

Introduction to wind energy, Atmospheric circulation, Introduction to terms used in wind energy: Aerodynamics, Wind, Windmill, Wind Turbine, Wind Farm, Nacelle, Propeller, Hub, Pitch angle, Pitch Control, Tethering; Calculation of wind power; Application of wind Turbine; Advantages and Disadvantages of wind energy; Sources/Origins of Wind; Factor influencing wind: Variation with height and time.

Unit II

Wind energy conversion Principles, Basic Components of wind energy conversion systems: Tower, Rotor, Gearbox , Generators, Controls, Yaw Control; Types and classification of wind energy conversion systems: Multi-bladed type, Savonius type, Darrieus type; Site Selection Consideration.

Unit III

Horizontal axis and Vertical axis Wind Turbine; Horizontal axis wind turbine: Pressure and Velocity profiles of wind moving through turbine, Calculation of output power from wind turbine (Axial Momentum Theory), Power Coefficient, Betz coefficient, Forces on the blades and Thrust on the turbines.

Unit: IV

Aerodynamics: Concept of Lift and Drag forces acting on the blade, Blade Element and Combine theory; Rotor Characteristics: Solidity, Tip Speed Ratio (TSR), Coefficient of Performance (C_p), Torque Characteristics (C_T); Problems in operating large wind power generators.

Unit: V

Wind Pumps: Design and Working; Principle of wind energy conversion : Stand alone, Grid connected and Hybrid systems; Wind Velocity measuring Instruments: Cup Anemometer; Environmental Problems and Benefits of wind turbine generators; Economy of Wind Energy: Factors influencing the cost of energy generation.

Textbooks/Suggested Readings:

1. G. D. Rai, Non-Conventional Energy Sources, Khanna Publications.
2. R K Rajput, A Textbook of Power Plant Engineering, Fourth Edition, Laxmi Publications (P) Ltd.
3. Johnson G L, Wind Energy Systems, Prentice Hall Inc, New Jersey, USA.
4. Spera David A Ed, Wind Turbine Technology: Fundamental Concepts of Wind Turbine Engineering, American Society of Mechanical Engineers.
5. Kruger P, Alternative Energy Resources: The Quest for Sustainable Energy, Wiley Publications.
6. Boyle G, Renewable Energy: Power for a Sustainable Future, Second Edition, Oxford University Press.
7. Mukund R Patel, Wind and Solar Power Systems, CRC Press.
8. John F Walker, Nicholas Jenkins, Wind Energy Technology, John Wiley and Sons.
9. Hau Erich, Wind Turbines: Fundamentals, Technologies, Application and Economics,SpringerVerlag

Module: RECC-105
Energy Laboratory I
[04 Credits]

Course 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: REVC-101
Energy and Environment
[04 Credits]

Course outcomes:

1. To understand the basic concepts regarding different sources of energy, earth's energy system and overall energy scenario
2. To learn about various types of environmental pollution and their effects
3. To develop an understanding about energy crisis, energy pricing and energy sector reforms

Unit I

Introduction to Energy and Power; Fundamental sources of energy; Classification of energy sources; Commercial and non-commercial forms of energy; Definition of Environment; Structure and composition of environment; Solar radiation and its spectral characteristics; Earth's energy budget and energy flow

Unit II

Ecosystem and its dynamics; Types of ecosystems; The structure/components of ecosystem; Functions and properties of ecosystem; Flow of energy in ecosystem; Models for Energy flow; Biogeochemical cycles; Biodiversity Basics- importance and threats to biodiversity; strategies for biodiversity conservation; concept of sustainable development.

Unit III

Fundamental definition of Fossil fuels; Classification of fossil fuels; Composition of Fossil fuels; Physical and chemical characteristics of coal, petroleum and natural gas; Production, present scenario and consumption patterns of fossil fuels; Calorific value of fossil fuels; Advantages and disadvantages of fossil fuels

Unit IV

Types of environmental pollution; Primary and Secondary Pollutants; Sources and effects of Air, Water, Soil, Thermal and Noise pollution; Sources and consequences of radioactive pollution; Control Measures; Environmental implications of power generation; Impacts of large scale exploitation of solar, wind, hydro and nuclear energy sources

Unit V

Energy Scenario in India and across the world; Sector-wise energy consumption in India; Primary and Final energy consumption; Modern energy production including bio-fuels and

their utilization pattern in India; Role of energy in economic and social development; Energy crisis; Electricity acts; Energy pricing; Factors affecting energy costs; Energy sector reforms; Energy strategy for the future

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
4. Gupta HK and Gupta K, A textbook of Energy, Environment, Ethics and Society, Laxmi Publications, ISBN 9789383828609
5. Sharma, PD, Ecology and Environment, 13th edition, Rastogi Publications, ISBN 978-817339655

Module: RECC-201
Fundamentals of Bio-Energy
[04 Credits]

Course outcomes:

1. Classify and identify potential biomass feedstock
2. Have an understanding of biomass to energy technologies
3. Assess technical/economic feasibility and sustainability of energy production from biomass in India.

Unit I

Definition of biomass and bio-energy; Classification of biomass resources; Primary biomass energy resources; Secondary biomass sources; Characteristics of biomass; Basic chemistry of carbon compounds in biomass resources (Carbohydrates and Lipids); Production of biomass; Availability, assessment and estimation of biomass; Energy plantation

Unit II

Basis of biomass selection; Principles of conversion processes; Physical processing of biomass; Pre-processing: drying, size reduction and densification; Briquetting-types of briquettes; Utilization and advantages of briquetting Chemical processes of biomass conversion- Hydrogenation, Solvent extraction of hydrocarbons; Solvolysis of wood

Unit III

Thermo-chemical conversion of biomass to bioheat, biopower and biofuel; Direct combustion; Incineration; Hydrothermal liquefaction; Gasification; Slow and fast pyrolysis; Utilization of solid biochar, liquid bio-oil and syngas; Environmental monitoring of thermo-chemical conversion processes

Unit IV

Biochemical conversion of biomass; Biomass pretreatment; Biodegradation and biodegradability of substrate; Role of enzymes in biomass conversion; Enzyme hydrolysis and acid hydrolysis; Fermentation; Anaerobic/Acrobic digestion; Bio-methanation; Trans-esterification method of biodiesel production

Unit V

Bioenergy past and present; Overview of policy and Politics of bioenergy; Analysis of biofuel quality, standards and properties; Lifecycle assessment of biofuels; Economics of bio-energy; Environmental benefits and impacts of bioenergy; Health aspects of bio-energy conversion systems; Future prospects of bio-energy

Textbooks/Suggested Readings:

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

Module: RECC-202

Basics of Tidal Energy, Geothermal Energy and Nuclear Energy

[04 Credits]

Course Outcomes:

To understand energy generation from different renewable energy sources and their potential contribution in the energy sector.
To understand the problems associated with energy production from renewable sources and their possible solutions.

Unit I

Introduction to ocean energy; Ocean thermal energy conversion (OTEC): Basic Principle of OTEC System; Methods of Ocean Thermal Energy power generation: Open cycle OTEC Systems, Closed or Anderson OTEC Cycle and Hybrid Cycle; Heat Exchangers; Bio-Fouling; Site selection and prospects of Ocean Thermal Energy in India.

Ocean Wave: Introduction, energy and power estimation; Wave energy conversion Devices: Wave energy conversion by floats and oscillating water columns; Advantages and Disadvantages of ocean wave energy; Problems associated with wave energy collection.

Unit II

Energy from tides: Introduction; Basic principle of tidal energy generation: Tidal Range, Spring Tides, Neap Tides; Tidal power plant: introduction and it's components; utilization and operation of tidal energy: Single and Double basin arrangement; Estimation of energy and power: in a simple single basin tidal system and in a double cycle system, ways of storing electricity produced by tidal energy; site requirements; Advantages and Limitation of tidal power generation.

Unit III

Geothermal Energy: Introduction, nature and division of geothermal fields; Geothermal sources; Hydrothermal (Convective) resources: Vapour-dominated systems and Liquid dominated systems, comparison of flashed steam and total flow concept; Hot Dry Rock (HDR): resources of Petrothermal systems; Geopressured resources; Magma resources; Interconnection of geothermal and fossil fuel systems (Hybrid Systems); Advantages and disadvantages of geothermal energy over other forms of energy; Operational and environmental Problem.

Unit IV

Nuclear reactions; Mass defect and binding energy; Chain reaction; Radioactivity; Cross section of a nuclear reaction; Nuclear fission and fusion, Power from fission, Nuclear fission reactors and fuels; Different types of Nuclear fission Reactors; Nuclear Waste Disposal and pollution control measures.

Nuclear Fusion: fundamentals of nuclear fusion and characteristics of DT reaction, plasma physics and magnetic confinement, Low temperature nuclear fusion, Nuclear fusion reactors.

Unit V

Magneto Hydro Dynamic (MHD) power: Introduction, basics of steam and gas power cycle; MHD systems: Introduction, open cycle systems, closed cycle systems, MHD design problems and developments; Advantages of MHD generators; International status of MHD power generation and its future prospects.

Textbooks/Suggested Readings:

G. D. Rai, Non-Conventional Energy Sources, Khanna Publications.
R K Rajput, A Textbook of Power Plant Engineering, Fourth Edition, Laxmi Publications (P) Ltd.

1. Kruger P, Alternative Energy Resources: The Quest for Sustainable Energy, Wiley Publication.
2. Rosa Aldo V, Fundamentals of Renewable Energy Processes, Second Edition, Academic Press.
3. Boyle G, Renewable Energy: Power for a Sustainable Future, Second Edition, Oxford University Press

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

Course Outcomes:

1. To learn about comprehensive and logical knowledge of hydrogen production, storage and applications
2. To develop an understanding of various fuel cell technologies
3. To design and develop suitable hydrogen systems to be used along with fuel cell system

Unit I

Introduction of hydrogen as an element; Properties of hydrogen as fuel; Physical and chemical properties of hydrogen gas; Overview of hydrogen energy utilization; Hydrogen sensing methods using Thermal conductivity measurements, Gas chromatography, Mass Spectrometry

Unit II

Methods of 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, Catalysts and electrolyzers

Unit III

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

History of Fuel cells; Principle and 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 for domestic power systems; Large scale power generation; Application of fuel cells in automobiles and 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: REC204

Solar Thermal Energy Conversion

[04 Credits]

Course Outcomes:

To provide the basic technical knowledge about the solar thermal energy conversion systems.

To impart knowledge of different types of solar thermal energy systems like flat plate and concentrating technology.

To offer performance estimation ability of solar thermal systems used in Industry.

Unit I

Solar radiation: Extra terrestrial and terrestrial radiation; Solar radiation geometry - Earth-Sun angles – Solar angle, Solar day length – Sun path diagram – Shadow determination; Calculation of total solar radiation on horizontal and tilted surface; Effect of earth atmosphere on solar radiation; Measurement & estimation of solar radiation on horizontal and tilted surfaces; Analysis of Indian solar radiation data and it's applications.

Unit II

Fundamentals of solar collectors: Introduction and estimation of conversion of solar energy into heat energy, Evacuated tubular collectors; Calculation of heat capacity of flat plate collector; Air flat plate Collectors: types, thermal analysis and drying; Solar flat plate collector: useful energy gain, energy losses, efficiency; Ideal coating characteristics to enhance the collector efficiency: Types and applications, anti reflective coating, preparation and characterization.

Unit III

Line-focusing and point-focusing concentrators: parabolic trough, parabolic dish, heliostat field with central receiver, Fresnel lenses, compound parabolic concentrator; Sun tracking mechanisms; Concentrating collector designs: Classification, design and performance parameters; ASHRAE standards and performance estimation of solar collectors via ASHRAE; Tracking systems; Central receiver systems; parabolic trough systems; 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 and water absorption refrigeration systems; Solar operated refrigeration systems; Solar desiccant cooling; Design and sizing of solar heating systems: f–chart method, utilizability methods of solar thermal system evaluation.

Unit V

Solar Energy for Industrial Process: heat generation, temperature requirement, consumption pattern; Applications of solar flat plate: water heater & air heater for industrial process heat; Designing of 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: RECC-205

Heat and Mass Transfer

[04 Credits]

Course outcomes:

1. To understand the mechanisms of heat transfer under steady and transient conditions.
2. To understand the concepts of heat transfer through extended surfaces.
3. To analyze heat exchangers and to understand the basic concepts of mass transfer.
4. To apply heat and mass transfer principles on different thermal systems.

Unit I

Conduction Heat Transfer: Introduction; general heat conduction equation in cartesian and cylindrical coordinate system, one dimensional steady state heat conduction equation, heat conduction through plane and composite wall; The overall heat transfer coefficient; Heat transfer through hollow and composite cylinder: Logarithmic mean area for hollow cylinder; heat conduction through composite cylinder and estimation of critical thickness for insulation.

Unit II

Convection Heat Transfer: Introduction to convection; Newton's Law of heating and cooling; Introduction to hydrodynamic boundary layer; Types of convection: Forced and free convection; Forced convection: Thermal boundary layer, Empirical heat transfer correlation for flat plate and circular pipe; Calculation of heat transfer over flat plate for laminar and turbulent flow; Free Convection: Physical mechanism of natural convection; Empirical correlation for free convection: vertical and horizontal planes.

Unit III

Heat Exchanger: Introduction and types of heat exchangers; Heat exchanger analysis: Logarithmic Mean Temperature Difference (LMTD) for Parallel and Counter flow; Over all heat transfer coefficient; Effectiveness of heat exchanger and number of transfer units (NTU) in heat exchanger

Unit IV

Thermal Radiation: Basic concepts; Properties: Absorptivity, reflectivity and transmissivity; Concept of black body and it's radiation; Gray body; Stefan Boltzmann Law; Plank's Law; Wein's Displacement Law; Shape/View Factor; Radiation heat exchange between non -black bodies: Infinite Parallel Bodies and Radiation Shield.

Unit V

Mass transfer: Introduction to mass transfer, modes of mass transfer, mass concentration, velocities and flux; Fick's Law: Mass Diffusion coefficient; Interaction of radiation with medium: boiling and condensation.

Textbooks/Suggested Readings:

1. Heat Transfer A Practical Approach by Yunus A. Cengel, Tata McGraw Hill, 2010
2. Heat Transfer by Venkateshan S.P., Ane Books, New Delhi, 2004.
3. Heat Transfer by Ghoshdastidar, P.S, Oxford, 2004,
4. Heat Transfer by Nag, P.K., Tata McGraw Hill, New Delhi, 2002
5. Heat and Mass Transfer by Holman, J.P., Tata McGraw Hill, 2000
6. Heat Transfer by Ozisik, M.N., McGraw Hill Book Co., 1994.
7. Fundamentals of Heat and Mass Transfer by Kothandaraman, C.P., New Age International, New Delhi, 1998.
8. Heat and Mass Transfer by Yadav, R., Central Publishing House, 1995.
9. Fundamentals of Heat and Mass Transfer by M.Thirumaleshwar : First Edition, Dorling Kindersley, 2009

Module: RECC-206
Energy Laboratory – II
[04 Credits]

Course Outcomes:

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: REVNC - 201
Numerical Methods and Computational Techniques
[Non-Credited]

Course 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. Knowledge of working of various simulation tools.
4. 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.

Textbooks/Suggested Readings:

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.