UNIVERSITY OF MUMBAI
No. UG/14 of 2014

CIRCULAR:-

The Principals of the affiliated Colleges in Science and the Heads of recognized Institutions concerned are hereby informed that the recommendation made by the Faculty of Science at its meeting held on 25th February, 2014 has been accepted by the Academic Council at its meeting held 4th March, 2014 **vide** item No. 4.60 and subsequently approved by the Management Council at its meeting held on 4th April, 2014 **vide** item No.8 and that in accordance therewith, in exercise of the powers conferred upon the Management Council under Section 54 (1) of the Maharashtra Universities Act, 1994 and the Ordinances 6112 and 6113 and syllabus as per the Credit Based Semester and Grading System for the M.Sc. (Renewable Energy) degree programme is introduced, which is available on the University's web site (www.mu.ac.in) and that the same has been brought into force with effect from the academic year 2014-15.

Sd/-
Director, B.C.U.D.

MUMBAI – 400 032
1st July, 2014

To,

The Principals of the affiliated Colleges in Science and the Heads of recognized Institutions concerned.

A.C/4.60/04/03/2014_
M.C/8/04.04.2014

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No. UG/14-A of 2014 MUMBAI-400 032 1st July, 2014

Copy forwarded with compliments for information to :-

1) The Dean, Faculty of Science,
2) The Professor-cum-Director, Institute of Distance and Open Learning (IDOL),
3) The Director, Board of Colleges and University Development,
4) The offg. Controller of Examinations,
5) The Co-Ordinator, University Computerization Centre.

Sd/-
Director, B.C.U.D.

AC 4-3-2014

Item No. – 4.60

University of Mumbai

Syllabus

Program – M.Sc

Course - Renewable Energy

(as per Credit based Semester & grading system w.e.f. ac. yr 2014-15)

1 Eligibility Criteria

M. Sc. in “Renewable Energy” Program is open to Physics OR Chemistry graduates. A candidate for being eligible for admission to the M. Sc. in “Renewable Energy” programme must have passed the Bachelor of Science degree examination with Physics, Chemistry, Electronic Science, or Energy Sciences as a major subject (i.e. upto the third year B. Sc. level), or Bachelor of Engineering degree (BE / BTech) examination or an examination of another University recognized as equivalent thereto.

2 Course Structure & Distribution of Credits.

M. Sc. in Renewable Energy Program consists of total 12 (twelve) theory courses, total 6 (six) practical lab courses and 1 (one) project. Each theory course will be of 4 (four) credits, a practical lab course will be of 4 (four) credits and a project will be of 24 (twenty four) credits. A student earns 24 (twenty four) credits per semester and total 96 (ninety six) credits in four semesters. The course structure is as follows,

Theory Courses

	Paper-1	Paper-2	Paper-3	Paper-4
Semester-I	Applied Mathematics	Physics for Energy studies	Chemistry for Energy studies	Biochemistry for Energy studies
Semester-II	Energy conversion and Energy Storage	Solar Photovoltaics	Energy from Wind, Geothermal and Water	Biofuels and Bioenergy
Semester-III	Solar Thermal	Hydrogen Production, Storage, and Fuel Cells	Nuclear Energy	Energy Policies and Management
Semester-IV	Project			

Practical Lab courses

Semester-I	Lab Course -1	Lab Course -2
Semester-II	Lab Course -3	Lab Course -4
Semester-III	Lab Course - 5	Lab Course - 6

One Semester Project:

Semester-IV	Project

Semester I

M.Sc. in Renewable Energy Program for Semester-I consists of four theory courses and two practical courses. The details are as follows:

Theory Courses (4): 16 hours per week (One lecture of one hour duration)

Theory Paper	Subject	Lectures (Hrs)	Credits
PSAEN101	Applied Mathematics	60	04
PSAEN102	Physics for Energy studies	60	04
PSAEN103	Chemistry for Energy studies	60	04
PSAEN104	Biochemistry for Energy studies	60	04
	Total	**240**	**16**

Practical lab courses (2): 16 hours per week

Practical Lab Course	Practical Lab Sessions (Hrs)	Credits
PSAENP101	120	04
PSAENP102	120	04
Total	**240**	**08**

Semester II

M.Sc. in Renewable Energy Program for Semester-II consists of four theory courses and two practical courses. The details are as follows:

Theory Courses (4): 16 hours per week (One lecture of one hour duration)

Theory Paper	Subjects	Lectures (Hrs)	Credits
PSAEN201	Energy conversion and Energy Storage	60	04
PSAEN202	Solar Photovoltaics	60	04
PSAEN203	Energy from Wind, Geothermal and Water	60	04
PSAEN204	Biofuels and Bioenergy	60	04
	Total	**240**	**16**

Practical lab courses (2): 16 hours per week

Practical Lab Course	Practical Lab Sessions (Hrs)	Credits
PSAENP201	120	04
PSAENP202	120	04
Total	**240**	**08**

Semester III

M.Sc. in Renewable Energy Program for Semester-III consists of four theory courses, one practical course and one Project. The details are as follows:

Theory Courses (4): 16 hours per week (One lecture of one hour duration)

Theory Paper	Subjects	Lectures (Hrs)	Credits
PSAEN301	Solar Thermal	60	04
PSAEN302	Fuel Cells, Batteries and Energy Storage	60	04
PSAEN303	Nuclear Energy	60	04
PSAEN304	Energy Policies and Energy Management	60	04
	Total	**240**	**16**

Practical lab courses (2): 16 hours per week

Practical Lab Course	Practical Lab Sessions (Hrs)	Credits
PSAENP301	120	04
PSAENP302	120	04
Total	**240**	**08**

Semester IV

M.Sc. in Renewable Energy Program for Semester-IV consists of full time project of 24 credits (600 marks). The project report shall be in the form of Thesis and should be hard bound. One Industrial visit OR visit to Energy park shall be an integral part of the course work.

Project	Credits
PSAENT401: Thesis	24

3. Scheme of Examination and Passing:

1. This course will have 40% Term Work (TW) / Internal Assessment (IA) and 60% external (University written examination of 2.5 Hours duration for each course paper and practical examination of 4 Hours duration for each practical). All external examinations will be held at the end of each semester and will be conducted by the University as per the existing norms.
2. Term Work / Internal Assessment - IA (40%) and University examination (60%)- shall have separate heads of passing. For Theory courses, internal assessment shall carry 40 marks and Semester-end examination shall carry 60 marks for each Theory Course.
3. To pass, a student has to obtain minimum grade point E, and above separately in the IA and external examination.
4. The University (external) examination for Theory and Practical shall be conducted at the end of each Semester during the first three semesters.
5. The candidates shall appear for external examination of 4 theory courses each carrying 60 marks of 2.5 hours duration and 2 practical courses each carrying 100 marks at the end of each semester during the first three semesters.
6. The candidate shall prepare and submit for practical examination a certified Journal based on the practical course carried out under the guidance of a faculty member with minimum number of experiments as specified in the syllabus for each group.
7. The evaluation of Research Project work i.e. Dissertation will be done by the External examiner along with the Thesis Supervisor (Internal Examiner) at the end of the fourth Semester.

Semester-I

M.Sc. (Renewable Energy) Theory Course

Semester –I

Semester-I : Paper-1:

Course no.: PSAEN101: Applied Mathematics (60 lectures, 4 credits)

Applied Mathematics

Unit I:

Complex Number

Review on Complex Number-Algebra of Complex Number, Different representations of a Complex number and other definitions, D'Moivre's Theorem. Powers and Roots of Exponential and Trigonometric Functions. Circular functions of complex number and Hyperbolic functions. Inverse Circular and Inverse Hyperbolic functions. Logarithmic functions. Separation of real and Imaginary parts of all types of Functions. Expansion of sinnθ, cosnθ in terms of sines and cosines of multiples of θ and Expansion of sinnθ, cosnθ in powers of sinθ, cosθ.

Unit II: Vector Algebra and Analysis

Introduction to scalars, vectors: dot product and cross product, Scalar triple product and its geometrical interpretation, Vector triple product and its proof.

Differentiation of vectors with respect to scalar, Scalar and vector fields, Vector differential operator, Gradient of scalar field and its physical significance, Divergence of scalar field and its physical significance, Curl of vector field and its physical significance, Vector integrals: line, surface and volume integral with their examples, Statements of Gauss-Divergence theorem and Stoke's theorem, Vector identities.

Unit III:

Differential Calculus

Successive differentiation: nth derivative of standard functions. Leibnitz's Thoerem (without proof) and problems. Partial Differentiation: Partial derivatives of first and higher order, total differentials, differentiation of composite and implicit functions. Euler's Theorem on Homogeneous functions with two and three independent variables (with proof). Deductions from Euler's Theorem.

Unit IV:

Application of Partial differentiation:

Expansion of functions, Indeterminate forms and curve fitting, Maxima and Minima of a function of two independent variables. Lagrange's method of undetermined multipliers with one constraint. Jacobian, Jacobian of implicit function. Partial derivative of implicit function using jacobian. Taylor's Theorem(Statement only) and Taylor's series, Maclaurin's series (Statement only).Expansion of ex, sinx, cosx, tanx, sinhx, coshx, tanhx, log(1+x), sin-1x, cos1x, Binomial series. Indeterminate forms, L-Hospital Rule, problems involving series also. Fitting of curves by least square method for linear, parabolic, and exponential. Regression Analysis(to be introduced for estimation only).

Reference:

1. Mathematical Physics by B. D. Gupta
2. Mathematical methods in Physical science by Mary and boas.
3. Vector analysis by Spiegel and Murrey
4. Mathematical methods for Physicists by Arfken and Weber,

Semester-I : Paper-2:

Course no.: PSAEN102: Physics for Energy Studies (60 lectures, 4 credits)

Physics for Energy Studies

Unit I:

Work and Kinetic Energy: Work Done by a Constant Force, The Scalar Product of Two Vectors, Work Done by a Varying Force, Kinetic Energy and the Work-Kinetic Energy Theorem, Power, (Optional) Energy and the Automobile, (Optional) Kinetic Energy at High Speeds;
Potential Energy and Conservation of Energy: Potential Energy, Conservative and Nonconservative Forces, Conservative Forces and Potential Energy, Conservation of Mechanical Energy, Work Done by Nonconservative Forces, Relationship Between Conservative Forces and Potential Energy, Energy Diagrams and the Equilibrium of a System, Conservation of Energy in General, Mass-Energy Equivalence, (Optional) Quantization of Energy;
Fluid Mechanics: Pressure, Variation of Pressure with Depth, Prssure Measurements, Buoyant Force and Archimedes's Principle, Fluid Dynamics, Streamlines and the Equation of Continuity, Bernoulli's Equation, Other Applications of Bernoulli's Equation.

Unit II:

Temperature: Temperature and the Zeroth Law of Thermodynamics, Thermometers and the Celsius Temperature Scale, The Constant-Volume Gas Thermometer and the Absolute Temperature Scale, Thermal Expansion of Solids and Liquids, Macroscopic Description of an Ideal Gas.
Heat and the First Law of Thermodynamics: Heat and Internal Energy, Heat Capacity and Specific Heat, Latent Heat, Work and Heat in Thermodynamic Processes, The first Law of Themodynamics, Some Applications of the First law of Thermodynamics, Energy Transfer Mechanisms.
The Kinetic Theory Of Gases: Molecular Model of an Ideal Gas, Molar specific Heat of an Ideal Gas, Adiabatic Processes for an Ideal Gas, The Equipartion of Energy, The Boltzman Distribution Law, Distribution of Molecular Speeds, Mean Free Path.
Heat Engines, Entropy and Second Law of Thermodynamics: Heat Engines and the Second Law of Thermodynamics, Reversible and Irreversible Processes, The Carnot Engine, Gasoline and Diesel Engines, Heat Pump and Refrigerators, Entropy, Entropy Changes in Irreversible Processes, (optional) Entropy on macroscopic Scale.

Unit III:

Direct Current Circuits: Electromotive Force, Resistors in Series and in Parallel, Kirchhoff's Rules, RC Circuits, Electrical Instruments, Household Wiring and Electrical Safety.

Inductance: Self-Inductance, RL Circuits, Energy in a Magnetic Field, Mutual Inductance, Oscillations in an LC Circuit, The RLC Circuit

Alternating Current Circuits: ac Sources and Phasors, Resistors in an ac Circuit, Inductors in an ac Circuit, Capacitors in an ac Circuit, The RLC Series Circuit, Power in an ac Circuit, Resonance in a Series RLC Circuit, The Transformer and Power Transmission, (Optional) Rectifiers and Filters

Unit IV:

Molecules and Solids: Molecular Bonds, The Energy and Spectra of Molecules Bonding in Solids, Band Theory of Solids, Free-Electron Theory of Metals, Electrical Conduction in Metals, Insulators, and Semiconductors, Semiconductor Devices, Superconductivity

Nuclear Structure: Some Properties of Nuclei, Nuclear Magnetic Resonance and Magnetic Resonance Imaging, Binding Energy and Nuclear Forces, Nuclear Models, Radioactivity, The Decay Processes, Natural Radioactivity, Nuclear Reactions

Nuclear Fission and Fusion: Interactions Involving Neutrons, Nuclear Fission, Nuclear Reactors, Nuclear Fusion, Radiation Damage in Matter, Radiation Detectors, Uses of Radiation

Reference:

1. ***PHYSICS FOR SCIENTISTS AND ENGINEERS,*** Raymond Serway, John Jewett, 2009.

Semester-I : Paper-3:

Course no.: PSAEN103: Chemistry for Energy Studies (60 lectures, 4 credits)

Chemistry for Energy Studies

Unit I

Stoichiometry, Quantitative Chemical relationship: The Mole Concept, Measuring Moles Of Elements and Compounds, Percentage Composition, Empirical and Molecular Formulas, Writing and Balancing Chemical Equations, Using Chemical Equations in Calculations, Limiting Reactant Calculations, Theoretical Yield and Percentage Yield.

Chemical Reactions in Solution: Solutions and Chemical Reactions, Electrolytes and Nonelectrolytes, Acids and Bases as Electrolytes, Acid-Base Neutralization, Ionic Reactions that Produce Precipitates, Ionic Reactions that Produce Gases, Predicting Metathesis Reactions, Oxidation-Reduction Reactions, Balancing Redox Equations by the Ion-Electron Method, Molar Concentration, Stoichiometry of Reactions in Solution.

Energy and Thermochemistry: Kinetic and Potential Energy Revisited, Kinetic Theory of Matter, Energy Changes in Chemical Reactions, Heats of Reaction; Calorimetry, Enthalpy changes: Heats of reaction at Constant Pressure, Standard Heats of Formation and Hess's Law.

Unit II

Chemical Bonding I: Electron Transfer and the Formation of Ionic Compounds, Electron Bookkeeping: Lewis Symbols, Electron Sharing: Formation of Covalent Bonds, Some Important Compounds of Carbon, Electronegativity and the Polarity of Bonds, Drawing Lewis Structures, Formal Charge and the Selection of Lewis Structures, Resonance: When a Single Lewis Structure Fails, Coordinate Covalent Bonds: Lewis Acids and Bases.

Chemical Bonding II: Common Molecular Structures, Predicting the Shapes of Molecules: VSEPR Theory, Molecular Shape and Molecular Polarity, Wave Mechanics and Covalent Bonding: Valence Bond Theory, Hybrid Orbitals, Double and Triple Bonds, Molecular Orbital Theory, Delocalized Molecular Orbitals, Bonding in Solid.

Chemical Reactions: Periodic Correlations, Bronsted Acids and Bases, Strengths of Bronsted Acids and Bases and Periodic Trends, Acid-Base Properties of the Elements and Their Oxides, Reactions of Metals with Acids, Displacement of One Metal by Another from Compounds, Periodic Trends in the Reactivities of Metals, Periodic Trends in the Reactivities of Nonmetals, Molecular Oxygen as an Oxidizing Agent.

Unit III

Intermolecular Attractions and the Properties of Liquids and Solids: Why Gases Differ from Liquids and Solids, Intermolecular Attractions, Some General Properties of Liquids and Solids, Changes of State and Dynamic Equilibrium, Vapor Pressures of Liquids and Solids, Boiling Points of Liquids, Energy Changes during Changes of State, Dynamic Equilibrium and Le Chatelier's Principle, Phase Diagrams, Crystalline Solids, X-ray Diffraction, Physical Properties and Crystal Types, Noncrystalline Solids,

Thermodynamics: Introduction, Energy Changes in Chemical Reactions—A Second Look, Enthalpy Changes and Spontaneity, Entropy and Spontaneous Change, The Third Law of Thermodynamics, The Gibbs Free Energy, Standard Free Energies, Free Energy and Maximum Work, Free Energy and Equilibrium.

Kinetics: The Study of Rates of Reaction: Speeds at Which Reactions Occur, Factors That Affect Reaction Rates, Measuring the Rate of Reaction, Concentration and Rate , Concentration and Time, Theories About Reaction Rates, Measuring the Activation Energy, Collision Theory and Reaction Mechanisms, Catalysts.

Unit IV

Chemical Equilibrium-General Concepts: Dynamic Equilibrium in Chemical Systems, Reaction Reversibility, The Equilibrium Law for a Reaction, Equilibrium Laws for Gaseous Reactions, The Significance of the Magnitude of K, Calculating Equilibrium Constants from Thermodynamic Data, The Relationship between Kp and Kc, Heterogeneous Equilibria, Le Chatelier's Principle and Chemical Equilibria, Equilibrium Calculations

Acid-Base Equilibria: lonization of Water and the pH Concept, Solutions of Strong Acids and Bases, lonization Constants for Weak Acids and Bases, Equilibrium Calculations, Solutions of Salts: Ions as Weak Acids and Bases, Equilibrium Calculations When Simplifications Fail, Buffers; The Control of pH, Acid-Base Titrations Revisited.

Electrochemistry: Electricity and Chemical Change, Electrolysis, Stoichiometric Relationships in Electrolysis, Industrial Applications of Electrolysis, Galvanic Cells, Cell Potentials and Reduction Potentials, Using Standard Reduction Potentials, Cell Potentials and Thermodynamics, Effect of Concentration on Cell Potentials Practical Application of Galvanic Cells,

Reference:

1. Chemistry: The Study of Matter and its Changes, James E. Brady and John R. Holum, John Willey & Sons, Inc. 1996.

<u>Semester-I : Paper-4:</u>

<u>Course no.: PSAEN104: Biochemistry for Energy Studies (60 lectures, 4 credits)</u>

Biochemistry for Energy Studies

Unit I

Review of Organic Chemistry: Nature of Organic Chemistry, Alcohols and Ethers, Organic Derivatives of Water, Amines, Organic Derivatives of Ammonia, Organic Compounds with Carbonyl Groups, Organic Polymers, Major Types of Biochemicals, Carbohydrates, Lipids, Proteins, Nucleic Acids. (Chapter 21 of "Chemistry: The Study of Matter and its Changes", James E. Brady and John R. Holum, John Willey & Sons, Inc. 1996)

An Introduction to Biochemistry: The Roots of Biochemistry, All Living Matter Contains C, H, 0, N, P, and S, Biological Macromolecules, Organelles, Cells, and Organisms, Storage and Transfer of Biological Information

The Biochemistry of Water: Water as the Biological Solvent, Hydrogen Bonding and Solubility, Cellular Reactions of Water, Buffer Systems

Unit II

Amino Acids and Proteins: The Amino Acids in Proteins, Polypeptides and Proteins, Protein Function, Structural Properties of Proteins, Studying Protein Structure and Function.

Protein Structure and Function: General Principles of Protein Design, Elements of Secondary Structure, Protein Tertiary Structure, Protein Quaternary Structure, Protein Structure and Biological Function,

Unit III

Enzymes i: Enzymes as Biological Catalysts, Introduction to Enzymes, The Kinetic Properties of Enzymes, Substrate Binding and Enzyme Action, Enzyme Inhibition,

Enzymes II: Cofactors, Regulation, and Catalytic RNA, Enzyme: Coenzyme Partners, Allosteric Enzymes, Cellular Regulation of Enzymes, Design of New Enzymes, Ribozymes, Biological Catalysts in the Future.

Unit IV

Carbohydrates: Chemical Structure and Biological Function, Monosaccharides, Carbohydrates in Cyclic Structures, Reactions of Monosaccharides, Polysaccharides, Glycoproteins
Structure and Biological Function: Fatty Acids, Nonpolar Lipids—Triacylglycerols, Polar Lipids, Steroids and Other Lipids,

Reference:

1. Concepts in Biochemistry, Rodney Boyer, Third Edition, John Wiley & Sons, 2004.

M.Sc. (Renewable Energy) Practical Lab Course

Semester –I

Semester –I Lab-1

Course number: PSAENP101 (120 hours, 4 credits)

Minimum Eight out of the following experiments.

1. Thermal conductivity of a bad conductor by Lee's disc method.
2. Determination of Stefans's constant.
3. Determination of coefficient of viscosity by Poiseuille's method
4. J by Electrical Method
5. LCR Series Resonance
6. LCR Parallel Resonance
7. Verification of maximum power transfer theorem.
8. Ratio of specific heats of air at constant pressure and constant volume by Clement and Desormen’s method
9. Band gap of energy.
10. Minority Carrier Lifetime measurement
11. Resistivity measurement using Four Probe / Van der Paw methods
12. Verification of Kirchhoff’s Current Law / Kirchhoff’s Voltage Law

References:

1. Advanced Practical Physics – Worsnop & Flint

2. Advanced course in Practical Physics D. Chattopadhya , P.C. Rakshit & B. Saha

3. B. Sc. Practical Physics –C. L. Arora

Semester –I Lab-2

Course number: PSAENP102 (120 hours, 4 credits)

Minimum Eight out of the following experiments.

1. Determination values of Iso-electric point: Amino acids, proteins, phosphoric acids.
2. Fractionation of proteins using: PAGE, PAPER electrophoresis
3. To study of conformational changes in biomolecules using Ostwald viscometer
4. Estimation of glucose by Benedict's method.
5. Separation of sugars by circular paper chromatography
6. Estimation of protein by the Folin-Lowry method
7. Chemical Kinetics – To determine the order between $K_2S_2O_8$ & KI by fractional change method.
8. Viscosity –To determine the molecular weight of high polymer polyvinyl alcohol (PVA) by viscosity measurement.
9. Potentiometry –To determine the amount of Fe(II) in the given solution by titration with a standard $K_2Cr_2O_7$ solution and hence to find the formal redox potential of Fe^{3+}/Fe^{2+}
10. Potentiometry –To determine the solubility product and solubility of AgCl potentiometrically using chemical cell.
11. Gravimetric estimation of Nickel from Nickel Di-Methyle Glyco-oxine
12. Acid Base Titration

References:

1. Practical Biochemistry, David T Plummer, Tata McGraw Hill

Semester-II

M.Sc. (Renewable Energy) Theory Course

Semester –II

Semester-II : Paper-1:

Course no.: PSAEN201: Energy conversion and Energy Storage (60 lectures, 4 credits)

Energy conversion and Energy Storage

Unit I

D.C. GENERATORS

Simple Loop Generator, Practical Generator, Yoke, Pole Cores and pole shoes, Pole Coils, Armature Core, Armature Windings, Commutator, Brushes and Bearings, Armature windings, Pole-pitch, Conductor , Types of Generators, Separately-excited, Self-excited generators': Shunt .Wound, Series Wound, Compound Wound, Measurement of-Generator Efficiency , Irons Loss in Armature, Hysteresis Loss (W_h), Eddy Current Loss (W_e) , Total Loss in a D.C. Generator

D. C. MOTOR

Motor Principle, Comparison of Generator and Motor Action, Significance of the Back e.m.f., Voltage Equation of a Motor, Condition for Maximum power, Torque, Armature Torque of Motor, Shaft Torque, Speed of D. C. Motor, Speed Regulation, Torque and Speed of D. C. Motor, Motor Characteristics, Characteristics. of Series Motors, Characteristics of Shunt Motors, Compound Motors, Cumulative-compound Motors, Differential-Compound, Performance Curves, Shunt Motor, Series Motor, Comparison of Shunt & Series Motors, Power Stages.

Unit II

TRANSFORMER

Working principle of a Transformer, Transformer Construction, Core-type Transformers, Shell-type Transformers, Elementary Theory of an ideal Transformer, D.M.F. Equation of Transformer, Voltage Transformation Ratio (K), Transformer with losses but no magnetic Leakage, Transformer on No-load, Transformer on load, Transformer with winding resistance but no Magnetic leakage, Magnetic leakage, Transformer with resistance and leakage, reactance, Estimation of Transformer Efficiency (at Full Load & Actual Load).

INDUCTION MOTOR

Classification of A.C. motors, Induction Motor : general Principle, Construction, Squirrel-cage rotor, Phase-wound rotor, Production of Rotating field, Three-Phase supply, Mathematical proof, Why does the rotor rotate?, Slip, Frequency of rotor current, Starting Torque of a squirrel-cage motor, Starting Torque of a slip-ring motor, Torque/Speed Curve, Current /speed curve of on induction motor.

SINGLE-PHASE MOTORS

Types of single-phase motors, Single-phase induction motor, Double-field revolving Theory, Making single-phase induction motor self-starting, Types of capacitor-start motors (Single-voltage; externally-reversible motors, single-voltage; non-reversible type, single-voltage; reversible and with thermostat type, Single-voltage; non-reversible with magnetic switch type, Two-voltage; non-reversible Type, Two-voltage; reversible type, single-voltage; three-4ead reversible type, single-voltage; instantly-reversible type, Two-speed type, Two speed with two-capacitor type, Repulsion Type motors, Repulsion motor, Repulsion Principle

Unit III

Batteries:

Battery technology: Reversible cells, Reversibleelectrodes, Relationship between electrical energy and energy content of a cell, Free energy changes and electromotive forces in cells, Activities ofelectrolyte solutions, Calculation of optimum acid volume for a cell, Calculation of energy density of cells, Spontaneous reaction in electrochemical cells.

Battery selection: Primary battery, Batteries in miniaturized equipment's, Secondary battery, Lead-acid batteries, Nickel batteries, Silver- batteries, Mercury batteries, Lithium batteries, Metal Air Cell.

Battery theory and design: Chemical Reactions during battery cycling, Charging and discharging, Castability

Unit IV

Capacitors:

Introduction of Ultracapacitor, Technological Aspects, Principle, Construction, Working, Taxonomy of Ultracapacitor, Electrochemical Double layer capacitor, Pseudocapacitors, Hybrid Capacitors, Comparison with battery and conventional capacitors, Advantages, Disadvantages and Applications.

Latent Heat Thermal Energy Storage Phase:

Change Materials (PCMs): Selection criteria of PCMs, Solar thermal LHTES systems, LHTES systems in refrigeration and air-conditioning systems, Areas of Application of Energy Storage, Food Preservation, Waste Heat Recovery, Solar Energy Storage, Green House Heating, Power Plant Applications, Drying and Heating for Process Industries.

References:

1. Text Book of Electrical Technology, Vol.II, B.L. Theraja & A.K. Theraja, S. Chand Publications.
2. Electrical Machines by P.S. Bhimbra.
3. R. M. Dell, David Anthony James Rand Understanding Batteries, Royal Society of Chemistry.
4. Robert Huggins, Advanced Batteries: Materials Science Aspects, Springer
5. Thomas P J Crompton, Battery Reference Book, Elsevier.
6. Aiping Yu, Victor Chabot, Jiujun Zhang, Electrochemical Supercapacitors for Energy Storage and Delivery, CRC press,John Wiley & Sons Ltd.
7. Petar J. Grbovic, Ultra-Capacitors in Power Conversion Systems: Analysis, Modeling and Design, IEEE Press, Wiley.

Semester-II : Paper-2:

Course no.: PSAEN202: Solar Photovoltaics (60 lectures, 4 credits)

Solar Photovoltaics

Unit I:

Charge Carriers and Their Motion in Semiconductor: Charge Carriers in Semiconductors (Bonding in Semiconductors, Intrinsic Semiconductor, Electrons and Holes, Extrinsic Semiconductor, Controlling Carrier Concentration), Carrier Concentration and Distribution (Density of Energy States, The Carrier Distribution Function, How many Electrons and Holes?, Electron and Hole Concentration in Doped Semiconductor), Carrier Motion in Semiconductors (Drift—Motion due to Electric Field), Electric Field and Energy Band Bending (Diffusion—Motion due to Concentration Gradient, Diffusion Current Density, Drift and Diffusion Together, Diffusion Coefficient), Generation of Carriers, Recombination of Carriers, Continuity of Carrier Concentrations

P-N Junction Diode: An Introduction to Solar Cells: Why P-N Junction Diode?, Introduction to P-N Junction: Equilibrium Condition (Space Charge Region, Energy Band Diagram Of P-N Junction, P-N Junction Potential, Width of Depletion Region, Carrier Movement and Current Densities, Carrier Concentration Profile), P-N Junction in Non-Equilibrium Condition (P-N Junction I-V Relation: A Qualitative Analysis, P-N Junction I-V Relation: A Quantitative Analysis), P-N Junction Under Illumination: Solar Cell (Generation of Photovoltage, Light Generated Current, I-V Equation of Solar Cells, Solar Cell Characteristic).

Solar Radiation: The Sun and the Earth (Extra-terrestrial Solar Radiation, Solar Spectrum at the Earth's Surface), The Sun-Earth Movement (Declination Angle δ, Apparent Motion of the Sun and Solar Altitude), Angle of Sunrays on Solar Collector (Local Apparent Time (LAT), Sunrise, Sunset and Day Length, Path of Sun's Motion, Optimal Angle for Fixed Collector Surface, Optimal Inclination of Collector in Summer and Winter), Sun Tracking.(Two-axes Tracking, One-axis Tracking, Vertical Axis or Azimuth Tracking, Rotation Around Horizontal E-W Axis and Movement in the N-S Direction, Rotation Around Horizontal N-S and Movement in E-W Direction, Rotation around Inclined N-S Axis and Movement in the E-W Direction), Estimating Solar Radiation Empirically (Monthly Average Daily Global Radiation on Horizontal Surface, Monthly Averaged Daily Diffuse Radiation on Horizontal Surface, Monthly Averaged Hourly Global and Diffuse Radiation on Horizontal Surface, Solar Radiation on Tilted Surface), Measurement of Solar Radiation

Unit II:

Design of Solar Cells: Upper Limits of Cell Parameters (Short Circuit Current, Open Circuit Voltage, Fill Factor, Efficiency), Losses in Solar Cells (Model of a Solar Cell) Effect of Series and Shunt Resistance on Efficiency, Effect of Solar Radiation on Efficiency, Effect on Temperature on Efficiency), Solar Cell Design, Deigns for High Isc (Requirement for High Short Circuit Current, Choice of Junction Depth and its Orientation Minimization of Optical Losses, Minimization of Recombination), Design for High Voc (Requirements for High Open Circuit Voltage), Design for High FF (Base Resistance, Emitter Resistance), Analytical Techniques (Solar Simulator: I-V Measurement, Quantum Efficiency (QE) Measurement, Minority Carrier Lifetime and Diffusion Length Measurement)

Si Wafer-Based Solar Cell Technology: (Development of Commercial Si Solar Cells, Improvement from the Use of CZ Single Crystal, Improvement from Optimised Junction, Front Metal and Surface Texturing, Use of Screen Printing, Multicrystalline Si and First Terrestrial PV Modules), Process flow of Commercial Si Cell Technology, Processes used in Solar Cell Technologies (Saw Damage Removal and Surface Texturing,.P-N Junction Formation: The Diffusion Process, Thin-film Layers for ARC and Surface Passivation, Metal Contacts: Pattern Defining and Deposition), High Efficiency Si Solar Cells (Passivated Emitter Solar Cells (PESC), Buried Contact Solar Cells, Rear Point Contact Solar Cells, Passivated Emitter and Rear Contact)

Thin Film Solar Cell Technologies: Amorphous Si Solar Cell Technology (Key Aspects of Material, Solar Cell Structure, Fabrication of Solar Cells), Cadmium Telluride Solar Cell Technology (Key Material Properties, Solar Cell Structure, Fabrication of Cells and Modules), Chalcopyrite (CIGS) Solar Cell Technology. .

Concentrator PV Cells And Systems: Light Concentration (Opportunities, Challenges) Optics for Concentrator PV (CPV) (V-trough Concentrator Modules, Compound Parabolic Concentrator (CPC) and Parabolic Trough Concentrator, Paraboloid Reflector Fresnel's Lens Concentrator), High Concentrator Solar Cells (Si Solar Cells for Concentration, GaAs Solar Cells)

Unit III:

Emerging Solar Cell Technologies And Concepts: Organic Solar Cells (Material Properties, Solar Cell Structure, Commonly used Materials), Dye-sensitised Solar Cells (DSC) (Operation of Dye-sensitised Solar Cells, Materials and their Properties), GaAs Solar Cells, Thermo-Photovoltaics (TPV), Need to Go Beyond Current Cell Technologies, Beyond Single Junction Efficiency Limit, Approaches to Overcome S ingle Junction Efficiency Limit (Crystalline Si Multijunction Solar Cells I, Intermediate Band Gap, Impurity PV and Qunatum Well Solar Cells, Spectrum Modification Approaches: Up and Down, Photon Energy Converstion, Hot Carrier Solar Cells)

Solar Photovoltaic Modules: Solar PV Modules from Solar Cells (Series and Parallel Connection of Cells, Mismatch in Cell/Module), Mismatch in Series Connection (Hot Spots in the Module, Bypass Diode), Mismatching in Parallel Connection, Design and Structure of PV Modules (Number of Solar Cells in a Module, Wattage of Modules, Fabrication of PV modules), PV Module Power Output (Ratings of PV Modules, Fand Power Curve of Module, Effect of Solar Irradiation, Effect of Temperature)

Unit IV:

Balance of Solar PV Systems: Basics of Electrochemical Cell (Introduction to Batteries, Elements of an Electrochemical Cell, Operation of an Electrochemical Cell, Theoretical Cell Voltage and Capacity, Losses in a Cell, Battery Classification, Cell to Battery, Battery Parameters), Factors Affecting Battery Performance (Battery Voltage Level, Battery Discharge Current, Battery Temperature during Discharge, Choice of a Battery, Battery Charging and Discharging Methods), Batteries for PV Systems (Lead-acid Batteries, Nickel-Cadmium (Ni-Cd) Batteries, Comparison of Batteries), DC to DC Converters (Buck Type DC to DC Converter, Boost Type DC to DC Converter Buck-boost Type DC to DC Converter, Control of DC to DC Converters, Input Side Reflected Impedance of the DC to DC converters, Higher Order DC to DC Converters), Charge Controllers (Commonly used Set Points, Types of Charge Controllers), DC to AC Converter (Inverters) (Single Phase DC to AC Converter, Three Phase DC to AC Converter, Inverter with Pulse Width Modulation), Maximum Power Point Tracking (MPPT) (Algorithms for MPPT)
Photovoltaic System Design And Applications: Introduction to Solar PV Systems, Standalone PV System Configurations (Type-a: Standalone System with DC Load, Type-b: Standalone System with DC Load, Type-c: Standalone System with Battery and DC Load, Type-d: Standalone System with Battery and AC/DC Load, Type-e: Hybrid System with AC/DC Load, Type-f: Grid-connected System without Energy Storage), Design Methodology of PV Systems (Design of PV Powered DC Fan without Battery (Type-a Configuration), Standalone System with DC Load using MPPT (Type-b Configuration), Design of PV Powered DC Pump, Design of Standalone System with Battery and AC/DC Load), Wire Sizing in PV Systems, Precise Sizing of PV Systems, Hybrid PV Systems (Why Hybrid Systems?, Types of Hybrid PV Systems, Issues with Hybrid Systems), Grid-connected PV Systems, Simple Payback Period, Lifecycle Costing (LCC) (Time Value of Money, Present Worth of Future One Time Investments, Present Worth of Future Recurring Investments, Lifecycle Cost, Annualised LCC (ALCC), Unit Cost of Generated Electricity)

References:

1. Solar Photovoltaics: Fundamentals, Technologies and Applications, Chetan Singh Solanki, PHI Learning Private LTD, 2009..

Semester-II : Paper-3:

Course no.: PSAEN301: Energy from Wind, Geothermal and Water (60 lectures, 4 credits)

Energy from Wind, Geothermal and Water

Unit I

Introduction (History of wind energy, Current status and future prospects).

Basics of Wind Energy Conversion: Power available in the wind spectra, Wind turbine power and torque, Classification of wind turbines,
(Horizontal axis wind turbines, Vertical axis wind turbines, Darrieus rotor, Savonius rotor, Musgrove rotor), Characteristics of wind rotors, Aerodynamics of wind turbines(Airfoil, Aerodynamic theories, Axial momentum theory, Blade element theory, Strip theory), Rotor design, Rotor performance.

Analysis of wind regimes: The wind (Local effects, Wind shear, Turbulence, Acceleration effect, Time variation), Measurement of wind (Ecological indicators, Anemometers, Cup anemometer, Propeller anemometer, Pressure plate anemometer, Pressure tube anemometers, Sonic anemometer, Wind direction), Analysis of wind data (Average wind speed, Distribution of wind velocity, Statistical models for wind data analysis; Weibull distribution, Rayleigh distribution), Energy estimation of wind regimes (Weibull based approach, Rayleigh based approach).

Unit II

Wind energy conversion systems: Wind electric generators (Tower, Rotor, Gear box, Power regulation, Safety brakes, Generator; Induction generator, Synchronous generator. Fixed and variable speed operations, Grid integration), Wind farms, Offshore wind farms, Wind pumps (Wind powered piston pumps, Limitations of wind driven piston pumps; The hysteresis effect, Mismatch between the rotor and pump characteristics, Dynamic loading of the pump’s lift rod, Double acting pump, Wind driven roto-dynamic pumps, Wind electric pumps)

Performance of wind energy conversion systems: Power curve of the wind turbine, Energy generated by the wind turbine (Weibull based approach, Rayleigh based approach), Capacity factor, Matching the turbine with wind regime, Performance of wind powered pumping systems (Wind driven piston pumps, Wind driven roto-dynamic pumps, Wind electric pumping systems).

Unit III

Wind energy and Environment: Environmental benefits of wind energy, Life cycle analysis (Net energy analysis, Life cycle emission), Environmental problems of wind energy (Avian issues, Noise emission, Visual impact)

Economics of wind energy: Factors influencing the wind energy economics (Site specific factors, Machine parameters, Energy market, Incentives and exemptions, The 'present worth' approach, Cost of wind energy; Initial investment, Operation and maintenance costs, Present value of annual costs), Benefits of wind energy, Yardsticks of economic merit (Net present value, Benefit cost ratio, Pay back period, Internal rate of return), Tax deduction due to investment depreciation

Unit IV

Geothermal Energy : Introduction (Geothermal Resources), Geothermal Power Plants (Dry Steam Units, Single-Flashing Units, Dual Flashing Units, Several Flashing Processes: A Useful Theoretical, Binary Units, Hybrid Geothermal-Fossil Power Units), Effects of Impurities in the Geothermal Fluid, Cooling Systems, Geothermal District Heating: An Example of Exergy Savings and Environmental Benefit, Environmental Effects.

Power from the Water: Hydroelectric Power (Global Hydroelectric Energy Production, Planned Hydroelectric Installations and Future Expansion, Environmental Impacts and Safety Concerns), Tidal Power (Systems for Tidal Power Utilization, Environmental Effects of Tidal Systems, Ocean Currents), Wave Power (Wave Mechanics and Wave Power, Systems for Wave Power Utilization, Environmental Effects of Wave Power and Other Considerations), Ocean Thermal Energy Conversion (OTEC) (Two Systems for OTEC, Environmental Effects of OTEC and Other Considerations), Types of Water Power Turbines, Concluding Remarks on Water Power.

References:

1. Wind Energy: Fundamentals, Resource Analysis and Economics, Sathyajith Mathew, Springer, 2006.
2. Renewable Energy Sources, Efstathios E. (Stathis) Michaelides, Springer, 2012.

Semester-II : Paper-4:

Course no.: PSAEN401: Biofuels and Bioenergy (60 lectures, 4 credits)

Biofuels and Bioenergy

Unit I

Biorefinery, Biofuel production and use, Harvesting Energy from Biochemical Reaction, Biochemical Pathways, Review for Organo-heterotrophic metabolism, Aerobic respiration, Anaerobic respiration, Fermentation, Overview for Lithotrophic growth, Overview for Phototrophic metabolism, Light reactions, Anabolic dark reactions, Definition and importance of Chemical oxygen demand.

Microbial modeling of biofuel production, summary of microbial growth models, unstructured single limiting nutrient models, inhibition models, models for multiple limiting substrates, yield parameters, kinetic rate expressions, temperature effect, bioreactor operation and design for biofuel production, batch reactors, continuous stirred tank reactors, CSTR with cell recycle, Fed-batch systems, plug flow systems, bioreactor design strategies, modeling of glucose utilization and hydrogen production, batch fermentations and simulations, CSTR fermentations and simulation.

Unit II

Biofuel feedstocks, starch, cereal grains, other grains, tubors and roots, suger feedstcks, sugarcane sugerbeet, lignocellulosic feedstocks, forest products and residues, agricultural residues, agricultural processing bioproducts, dedicated energy crops, plant oils and animal fats, misceleneous feedstocks, animal waste, municipal solid waste.

Methane, Microbiology of methane production, Methanogenic environment, Methane process Description, Microbial communities, Biomass sources for methane generation, Systems, Reactor conditions, Process design, biogas composition and use.

Unit III

Ethanol production, Ethanol production from sugar and starch feedstocks, micro-organisms, process technology, Ethanol production from lingocellulosic feedstocks, The sugar platform, The syngas platform.

Unit IV

Biodiesel production, Chemistry and thermodynamic aspects, Trans-esterification, esterification, lipase-catayzed inter-esterification and Trans-esterification, side reactions, saponification, hydrolysis, alcocohol effect, Base or alkali catalysis, Acid catalysis, Enzyme catalysis, Super-critical esterfication and Trans-esterification, thermodynamics and reaction kinetics, Oil sources and production, plant oils, microbial and algal oils, used cooking oils, straight vegetable oil, biosynthesis of oils and modification, co-products, methods of biodiesel production, general biodiesel production procedures, pilot and commercial scale, quality control and analytical techniques, economics, feedstock cost, manufacturing cost, capital cost, operating cost.

Reference:

1. Biofuels Engineering Process Technology, Caye M. Drapcho, Nghiem Phu Nhuan, Terry H. Walker. 2008, The McGraw-Hill Companies

M.Sc. (Renewable Energy) Practical Lab Course

Semester –II

Semester –II Lab-1

Course number: PSAENP201 (120 hours, 4 credits)

Minimum Eight out of the following experiments.

1. Solar cell dark and illuminated characteristics
2. Solar cells in series and parallel- effect of series and shunt resistance.
3. Solar cell - Spectral response
4. Effect of temperature and light intensity on solar cell characteristics
5. Solar PV system (with/without charge controller)
6. Effect of sun tracking on solar PV module efficiency
7. Comparison of performance of solar pumps vs. conventional pumps
8. Wind turbines, Savonius rotors
9. Determine aerodynamic characteristics of wind turbine blades
10. Comparison of performance of wind pump with conventional pump
11. Estimation of battery and inverter efficiency
12. Performance of heat exchanger

Semester –II Lab-2

Course number: PSAENP202 (120 hours, 4 credits)

Minimum Six out of the following experiments.

1. Preparation of Samples for Compositional Analysis
2. Structural Carbohydrates and Lignin in Biomass
3. Sugars, Byproducts, and Degradation Products in Liquid Fraction Process Samples
4. Insoluble Solids in Pretreated Biomass Material
5. Sugars determination with HPLC
6. Determination of Glucose by FTIR
7. Determination of Enzyme activities
8. Acid neutralization capacity of feedstock

Following (at least 3) long experiments should be demonstrated and students should report in the journal.

1. Total Solids in Biomass and Total Dissolved Solids in Liquid Process Samples
2. Ash in Biomass
3. Protein Content in Biomass
4. Extractives in Biomass
5. Enzymatic Saccharification of Lignocellulosic Biomass
6. SSF Experimental Protocols: Lignocellulosic Biomass Hydrolysis and Fermentation
7. Fermentation
8. Enzymatic hydrolysis of lignocellulosic biomass

References: http://www.nrel.gov/biomass/analytical_procedures.html

Semester-III

M.Sc. (Renewable Energy) Theory Course

Semester –III

Semester-III : Paper-1:

Course no.: PSAEN301: Solar Thermal (60 lectures, 4 credits)

Solar Thermal

Unit I

Heat Transfer: Concepts and Definitions: introduction, Conduction (Temperature Field, Fourier's Law , Thermal Conductivity, Differential Equation of Conduction, Solution of Heat, Conduction in a Medium), Boundary Conditions, Overall Heat Transfer (Single and Parallel Slabs, (a) Parallel Slabs with Air Cavity, (b) Heat Transfer in Parallel Paths, Coaxial Cylinders, Concentric Spheres), Dimensionless Heat-conduction Parameters, Convection (Dimensionless Heat-Convection Parameters, Bulk Temperature, Free Convection, Empirical Relations, Free Convection from Inclined Surfaces, Forced Convection, Combined Free and Forced Convection, Convective Heat Transfer Due to Wind), Radiation (Radiation Involving Real Surfaces, Kirchoff's Law, Laws of Thermal Radiation, Radiative Heat Transfer Coefficient, Radiation Shape Factor), Heat and Mass Transfer (Problems).

Flat-plate Collectors: Introduction, Flat-plate Collector (Glazing Materials, Collector Plates), Classification (Evacuated Tubular Collectors, Type of Flat-plate Collector), Testing of Collector (Orientable Test Rig, Series-connected Test Ring, Testing of Solar Collector with Intermittent Output, The ASHRAE Method), Heat Transfer Coefficients (Loss Coefficients, Back Loss Coefficient, Edge Loss Coefficient, Heat Loss Coefficient, Film Heat Transfer Coefficient), Optimization of Heat Losses (Transparent Insulating Material (Honeycomb), Selective Surface), Determination of Fin Efficiency, Thermal Analysis of Flat-plate Collectors (Basic Energy Balance Equation, Effective Transmittance-Absorptance Product, Collector Efficiency Factor F’, Temperature Distribution in Flow Direction, Collector Heat Removal Factor F_R, Threshold Radiation Flux), Configuration of FPC Connection (Collectors Connected in Series, Outlet Temperature at N^{th} Collector, Collectors Connected in Parallel, Collectors Connected in Mixed Mode), Effect of Heat Capacity in Flat-plate Collector, Optimum Inclination of Flat-plate Collector, Effect of Dust in Flat-plate Collector, Problems.

Evacuated-tube Cover Collector: Introduction, Evacuated-tube cover Collector, (Solaron Collector, Phillips (Germany) Collector, Thermal Efficiency), Evacuated tubular Collector (Sanyo Evacuated-tube Collector, Corning Evacuated-tube Collector, Phillips (Germany) Evacuated-tube Collector, Roberts Evacuated-tube Collector, Owens-Illinois (OI) Evacuated-tube Collector, General Electric (GC) TC-100 Evacuated-tube Collector), Analysis of Owens-Illinois (OI) Collector, Evacuated-tube Collector with Heat Pipe (Heat Pipe, Corning Collector with Internal Reflector, Gumman Evacuated-tube Collector, Thermal Analysis, Problems.

Unit II

Solar Water Heating System: Introduction, Heat Exchanger, Choice of Fluid, Analysis of Heat Exchanger, Heat Exchanger Factor, Natural Convection Heat Exchanger), Heat Collection in a Storage Tank (Heat Collection with Stratified Storage Tank, Heat Collection with Well-mixed Storage Tank, Effect of Heat Load, Problems.

Solar Air Heaters: Introduction, Description and Classification (Non-porous Type, Porous Type), Conventional Heater (Thermal Analysis), Double Exposure Heaters, Air Heater with Flow above the Absorber (Steady State Analysis, Transient Analysis), Air Heater with Flow on Both Sides of the Absorber, Two Pass Solar Air Heater, Comparison with Experimental Results, Heater with Finned Absorber, Heater with Vee-corrugated Absorber, Reverse Absorber Heater (Working Principle, Energy Balance, Performance Study), Air Heaters with Porous Absorbers (Matrix Air Heaters, Materials for Matrix Absorber, Overlapped Glass Plate Air Heaters, Air Heater With Honeycomb Absorber), Testing of Solar Air Collector, Parametric Studies (Effect of Air Leakage, Effect of Paniculate), Comparison of Performance of Liquid and Air Collector, Applications of Air Heater (Heating and Cooling, Drying), Problems.

Solar Crop Drying: Introduction, Working Principle (Open Sun Drying (OSD), Direct Solar Drying (DSD), Indirect Solar Drying (ISO)), Thermal Modelling of Open Sun Drying (OSD) (Introduction Computational Procedure for Convective Heat Transfer, Prediction of Crop Temperature and Moisture Evaporation, Analysis for Steady State Condition, Experimental Setup for Open Sun Drying (OSD), Methodology and Input Parameters for Computation, Results and Discussion), Thermal Analysis of Cabinet Dryer, Energy Balance for Reverse Absorber Cabinet Dryer (RACD) (Thin Layer Drying, Deep Bed Grain Drying), Energy Balance for Indirect Solar Drying (ISO) System (Solar Air Heater, Drying Chamber) Problems.

Unit III

Solar Concentrators: Introduction, Characteristic Parameters, (Aperture Area, Acceptance Angle, Absorber Area, Geometric Concentration Ratio, Local Concentration Ratio or Brightness Concentration Ratio, Intercept Factor, Optical Efficiency, Thermal Efficiency, Concentration Ratio), Classification, Types of Concentrators (Tracking Concentrators, Non-tracking Concentrators), Geometrical Optics in Concentrators (Ray Tracing in a Reflecting Surface, Ray Tracing in a Refracting Surface), Theoretical Solar Image, Thermal Analysis (Cylindrical Parabolic Concentrator, Dimensional Concentrator, Hemispherical Bowl Mirror, V-trough), Tracking Methods (Three Dimensional Concentrators, Two Dimensional Concentrators) Materials for Concentrators (Reflecting and Refracting Surfaces, Receiver Cover and Surface Coatings, Working Fluids, Insulation), Problems.

Solar Distillation: Introduction, Working Principle, Thermal Efficiency (Instantaneous Efficiency, Overall Thermal Efficiency), Heat Transfer, External Heat Transfer (Top Loss Coefficient, Bottom and Side Loss Coefficient), Internal Heat Transfer (Radiative Loss Coefficient, Convective Loss Coefficient, Evaporative Loss Coefficient), Overall Heat Transfer (Top Loss Coefficient, Bottom Loss Coefficient), Determination of Distillate Output, Passive Solar Stills (Conventional Solar Still, Basin Construction, Thermal Analysis of Conventional Solar Still, Approximate Solution For $T_{w)}$, Effect of Various Parameters (Effect of Ambient Temperature, Effect of Wind Velocity, Effect of Solar Radiation and Loss Coefficient, Effect of Double-glass Cover and Cover Inclination, of Salt Concentration on Output, Effect of Thermal Capacity on Output, Effect of Charcoal Pieces on the Performance of a Still, Effect of the Formation of Algae and Mineral Layers on Water and Basin Liner Surface on the Performance of a Still), Other Design of Solar Still (Single Slope Solar Still with Condenser, Hybrid Single Slope Solar Still, Reverse Absorber Solar Still, Multi-Wick Solar Still, Conical Solar Still, Active Single Slope Solar Still), Modified Internal Heat Transfer (Methodology to Evaluate C and n, Experimental Setup), Problems.

Unit IV

Solar House: Introduction (Physical Parameters, Physiological Parameters, Intermediate Parameters), Solair Temperature and Heat Flux (For Bare Surface, For Wetted Surface, Blackened/Glazed Surface), Thermal Gain (Direct Gain, Indirect Gain, Isolated Gain), Various Thermal Cooling Concepts (Evaporative Cooling, Infiltration/Ventilation, Wind Tower, air Tunnel Earth, Air Vent, Shading, Rock Bed Regenerative Cooler, Radiative Cooling, Heating and Cooling), Time Constant, Approximate Methods, Solar-load Ratio Method, Problems.

Other Applications: Collection-cum-storage Water Heater (Built-in Storage Water Heater, Shallow Solar Pond Water Heater), Non-convective Solar Pond (Salt-stabilized Pond, Partitioned Salt-stabilized Pond, Viscosity Stabilized Pond, Stability Criteria, applications of non-convective solar pond), Solar water heating system (Natural Circulation, Forced Circulation Water Heater), Heating of Swimming Pool by Solar Energy, Pass.ve Heating of Swimming Pools (Heating of Swimming Pool,

Active heating of Swimming Pool, Description of Indoor Swimming Pool), Controlled Environment Greenhouse (Working Principle of a Greenhouse, Energy Balance, Cooling), Heating of Biogas Plant by Solar Energy (introduction, Classification, Heating Process, Design of Digester), Solar Cooker, Design Method (Hourly Utilizability, Daily Utilizability, Hybrid System), Solar Fraction, Solar Cooling (Introduction, Solar Absorption Cooling, COP of Absorption Cooling, Solar Desiccant Cooling and Absorption Cooling, Solar-mechanical Cooling), Problems.

Energy Storage: Introduction, Sensible Heat Storage, Liquid Media Storage (Well Mixed Liquid Storage, Space Heat and Hot Water), Solid Media Storage (Packed-bed Storage), Dual Media Storage (Ground Collector), Basics of Latent Heat Storage (Heat Transfer in PCM, Thermal Analysis of Freezing of Top of Ponds, Analysis of Phase Change Material (PCM)), Chemical Storage, Problems.

Reference:

1. Solar Energy: Fundamentals, Design, Modelling and Applications, G.N. Tiwari, Narosa Publishing House, 2009.

Semester-III : Paper-2:

Course no.: PSAEN302: Hydrogen Production, Storage, and Fuel Cells (60 lectures, 4 credits)

Hydrogen Production, Storage, and Fuel Cells

Unit I:

Why Hydrogen Energy?: Security of Energy Supplies, Climate Change (Global Warming), Atmospheric Pollution, Electricity Generation, Hydrogen as a Fuel, A Note of Caution.

Hydrogen from Fossil Fuels: Present and Projected Uses for Hydrogen, Natural Gas, Reforming of Natural Gas (Gas Separation Processes, Characteristics of Steam Reforming of Methane, Solar-Thermal Reforming), Partial Oxidation of Hydrocarbons, Other Processes (Autothermal Reforming, Sorbent-enhanced Reforming, Plasma Reforming), Membrane Developments for Gas Separation (Membrane Types, Membrane Reactors), Coal and Other Fuels (Gasification Technology, Entrained-flow Gasifier, Moving-bed Gasifier, Fluidized-bed Gasifier, Combined-cycle Processes, FutureGen Project).

Hydrogen from Biomass Photobiological hydrogen production potential, hydrogen production by fermentation, Overview, Energetics, Thermotogales, Biochemical pathway for fermentative hydrogen production, thermotoga, hydrogen production by other bacteria, Co-product formation, Batch fermentation, hydrogen inhibition, role of sulpher, Sulphedogenesis, use of other carbon sources obtained from agricultural residues, process and culture parameters, hydrogen detection, quantification and reporting, total gas pressure, water vapour pressure, hydrogen partial pressure, hydrogen gas concentration expressed as "mole H_2/L-media", hydrogen production rate, dissolved H2 concentration in liquid, fermentation bioreactor sizing for PEM fuel cell use.

Unit II:

Hydrogen from Water: Electrolysis, Electrolyzers, Water Splitting with Solar Energy (Photovoltaic Cells, Solar-Thermal Process, Photo-electrochemical Cells, Dye-sensitized Solar Cells, Direct Hydrogen Production, Tandem Cells, Photo-biochemical CellS), Thermochemical Hydrogen Production (Sulfur_Iodine Cycle, Westinghouse Cycle, Sulfur-Ammonia Cycle, Metal Oxide Cycles, Concluding Remarks,

Hydrogen Distribution and Storage: Strategic Considerations, Distribution and Bulk Storage of Gaseous Hydrogen (Gas Cylinders, Pipelines, Large-scale Storage), Liquid Hydrogen, Metal Hydrides, Chemical and Related Storage (Simple Hydrogen-bearing Chemicals, Complex Chemical Hydrides, Nanostructured Materials), Hydrogen Storage on Road Vehicles.

Unit III:

Fuel Cells: Fuel Cell History, Why Fuel Cells?, Fuel Cell Operation, Types of Fuel Cell: Low-to-Medium Temperature (Phosphoric Acid Fuel Cell (PAFC), Alkaline Fuel Cell (AFC), Direct Borohydride Fuel Cell (DBFC), Proton-exchange Membrane Fuel Cell (PEMFC), Direct Methanol Fuel Cell (DMFC), Miniature Fuel Cells), Types of Fuel Cell: High Temperature (Molten Carbonate Fuel Cell (MCFC), Internal Reforming, Direct Carbon Fuel Cell (DCFC), Solid Oxide Fuel Cell (SOFC)), Fuel Cell Efficiencies, Applications for Fuel Cells (Large Stationary Power Generation, Small Stationary Power Generation, Mobile Power, Portable Power), Prognosis for Fuel Cells.

Microbial fuel cells: biochemical basis, Fuel cell design, Anode compartment, Microbial cultures, Redox mediators, Cathode compartment, Exchange membrane, Power density as function of circuit resistance. MFC performance methods, Substrate and biomass measurements, basic power calculations, MFC performance, power density as function of substrate, Single chamber vs two chamber designs, Single chamber design, Waste water treatment effectiveness, Fabrication examples.

Unit IV:

Hydrogen-fuelled Transportation: Conventional Vehicles and Fuels, Hybrid Electric Vehicles (HEVs) (Classification of Hybrid Electric Vehicles, Cars, Buses, Batteries, Conventional versus Hybrid Vehicles), 'Green' Fuels for Internal Combustion Engines, Hydrogen-fuelled Internal Combustion Engines (Road Vehicles, Aircraft), Fuel Cell Vehicles (FCVs) (Buses, Delivery Vehicles, Cars (Automobiles), Other Vehicles, Submarines), Hydrogen Highways, Efficiency Calculations and Fuel Consumption.

Hydrogen Energy: The Future?, World-wide Energy Problems (Security of Energy Supply, Climate Change), Hydrogen Energy: The Challenges (Production, Distribution and Storage, Fuel Cells), The Role of Government (Energy Conservation Policies, Energy Diversification, Electricity, Transportation, Carbon Emissions, Renewable Energy), Hydrogen Energy: The Prospects.

References:

1. Hydrogen Energy: Challenges and Prospects, D.A.J. Rand and R.M. Dell, Royal Society of Chemistry Publication.
2. Biofuels Engineering Process Technology, Caye M. Drapcho, Nghiem Phu Nhuan, Terry H. Walker. 2008, The McGraw-Hill Companies

Semester-III : Paper-3:

Course no.: PSAEN303: Nuclear Energy (60 lectures, 4 credits)

Nuclear Energy

Unit I

Nuclear Power Development: Present Status of Nuclear Power;Early History of Nuclear Energy (Speculations Before the Discovery of Fission, Fission and the First Reactors);Development of Nuclear Power in the United States (Immediate Postwar Developments, History of U.S. Reactor Orders and Construction, Reactor Cancellations);Trends in U.S. Reactor Utilization (Permanent Reactor Closures, Capacity Factors, Consolidation in the U.S. Nuclear Industry, Renewal of Reactor Operating Licenses);Worldwide Development of Nuclear Power (Early History of Nuclear Programs, Nuclear Power Since 1973, Planned Construction of New Reactors);National Programs of Nuclear Development (France, Japan, Other Countries); Failures of Prediction.

Radioactivity and Radiation Exposures: Brief History; Radiation Doses (Radiation Exposure and Radiation Dose, Basic Units of Exposure and Dose, Effective Dose Equivalent or Effective Dose); Radioactive Decay (Half-life and Mean Life, Units of Radioactivity, Specific Activity); Natural Radioactivity (Origin of Natural Radioactivity, Radioactive Series in Nature, Concentrations of Radionuclides in the Environment); Survey of Radiation Exposures (Natural Sources of Radiation, Radiation Doses from Medical Procedures, Other Sources of Radiation).

Effects of Radiation Exposures: The Study of Radiation Effects (Agencies and Groups Carrying out Radiation Studies, Types of Studies, Types of Effects: Deterministic and Stochastic); Effects of High Radiation Doses (Deterministic Effects, Stochastic Effects: Observational Evidence for Cancerat High Doses); Effects of Low Radiation Doses (Importance of Low Doses, Observational Evidence for Cancer at Low DoseRates, The Shape of the Dose–Response Curve, Conclusions of Advisory Bodies on Low-Dose Effects, Genetic Effects); Radiation Standards and Health Criteria (Standards for the General Public, Standards for Occupational Exposures, Alternative Risk Criteria, Collective Doses and de Minimis Levels); Radionuclides of Special Interest (Radium-226, Radon-222, Neptunium-237).

Unit II

Neutron Reactions: Overview of Nuclear Reactions (Neutron Reactions of Importance in Reactors, Reaction Cross Sections, Neutron Reactions in Different Energy Regions); Cross Sections in the Resonance Region (Observed Cross Sections, Shape of the Resonance Peak, Level Widths and Doppler Broadening); Cross Sections in the Continuum Region; The Low-Energy Region (Low-Energy Region and the $1/v$ Law, Thermal Neutrons).

Nuclear Fission: Discovery of Fission; Simple Picture of Fission (Coulomb and Nuclear Forces, Separation Energies and Fissionability, Fission Cross Sections with Fast and Thermal Neutrons); Products of Fission (Mass Distribution of Fission Fragments, Neutron Emission, Decay of Fission Fragments); Energy Release in Fission (Energy of Fission Fragments, Total Energy Budget).

Chain Reactions and Nuclear Reactors: Criticality and the Multiplication Factor (General Considerations, Formalism for Describing the Multiplication Factor, Numerical Values of Thermal Reactor Parameters); Thermalization of Neutrons (Role of Moderators, Moderating Ratio); Reactor Kinetics (Reactivity, Buildup of Reaction Rate); Conversion Ratio and Production of Plutonium in ThermalReactors; Control Materials and Poisons (Reactor Poisons, Controls, Xenon Poisoning).

Unit III

Types of Nuclear Reactors: Survey of Reactor Types (Uses of Reactors, Classifications of Reactors, Components of Conventional Reactors, World Inventory of Reactor Types); Light Water Reactors (PWRs and BWRs, Components of a Light Water Reactor, PWR Reactor Cores); Burners, Converters, and Breeders (Characterization of Reactors, Achievement of High Conversion Ratios in ThermalReactors, Fast Breeder Reactors); The Natural Reactor at Oklo.

Nuclear Fuel Cycle: Characteristics of the Nuclear Fuel Cycle (Types of Fuel Cycle, Steps in the Nuclear Fuel Cycle); Front End of the Fuel Cycle (Uranium Mining and Milling, Enrichment of Uranium, Fuel Fabrication, Other Fuel Types); Fuel Utilization (Burnup as a Measure of Fuel Utilization, Uranium Consumption and Plutonium Production, Energy from Consumption of Fuel, Uranium Ore Requirement); Back End of Fuel Cycle (Handling of Spent Fuel, Reprocessing, Alternative Reprocessing and Fuel Cycle Candidates, Waste Disposal); Uranium Resources (Price of Uranium, Estimates of Uranium Resources, Uranium from Seawater, Impact of Fuel Cycle Changes and Breeder Reactors).

Nuclear Reactor Safety: General Considerations in Reactor Safety (Assessments of Commercial Reactor Safety, The Nature of Reactor Risks, Means of Achieving Reactor Safety, Measures of Harm and Risk in Reactor Accidents); Accidents and their Avoidance (Criticality Accidents and Feedback Mechanisms, Heat Removal and Loss-of-Coolant Accidents); Estimating Accident Risks (Deterministic Safety Assessment, Probabilistic Risk Assessment, Results of the Reactor Safety Study); Post-TMI Safety Developments (Institutional Responses, 1990 NRC Analysis: NUREG-1150, Predictions of Core Damage and Precursor Analyses, Other Indications of Performance); Reactor Safety Standards (U.S. Nuclear Regulatory Commission Position, Standards Adopted by Other Bodies, Standards for Future Reactors: How Safe Is SafeEnough?).

Unit IV

Future Nuclear Reactors: General Considerations for Future Reactors (The End of the First Era of Nuclear Power, Important Attributes of Future Reactors, Reactor Size, U.S. Licensing Procedures); Survey of Future Reactors (Classification of Reactors by Generation, U.S. DOE Near-Term Deployment Roadmap, Illustrative Compilations of Reactor Designs); Individual Light Water Reactors (Evolutionary Reactors Licensed by the U.S. NRC, Innovative Light Water Reactors); High-Temperature, Gas-Cooled Reactors (HTGR Options, Historical Background of Graphite-ModeratedReactors, General Features of Present HTGR Designs, HTGR Configurations); Liquid-Metal Reactors (Recent United States Programs, Safety Features of LMRs); The Generation IV Program (Overview of the Program, Systems Emphasized in the United States); Radical Nuclear Alternatives to Present Reactors (Fusion, Accelerator-Driven Fission).

Nuclear Waste Disposal Amounts of Waste: Categories of Nuclear Waste (The Nature of the Problem, Military and Civilian Wastes, High- and Low-Level Wastes, Inventories of U.S. Nuclear Wastes, Measures of Waste Magnitudes); Wastes from Commercial Reactors (Mass and Volume per GWyr, Radioactivity in Waste Products, Heat Production); Hazard Measures for Nuclear Wastes (Approaches to Examining Hazards, Comparisons Based on Water Dilution Volume, Comparisons of Activity in Spent Fuel and in Earth'sCrust).

Storage and Disposal of Nuclear Wastes: Stages in Waste Handling (Overview of Possible Stages, Storage of Spent Fuel at Reactor Sites, Interim Storage of Waste or Spent Fuelat Centralized Facilities, Nuclear Waste Transportation); Deep Geologic Disposal (Multiple Barriers in Geologic Disposal, Alternative Host Rocks for a Geologic Repository, Motion of Water and RadionuclidesThrough Surrounding Medium, Thermal Loading of the Repository, The Waste Package); Alternatives to Deep Geologic Disposal (Variants of Geologic Disposal, Subseabed

Disposal, Partitioning and Transmutation of Radionuclides, Summary of Status of Alternatives to GeologicDisposal); Worldwide Status of Nuclear Waste Disposal Plans.

References:

1. Nuclear Energy: Principles, Practices, and Prospects, David Bodansky, Springer 2004.

Semester-III : Paper-4:

Course no.: PSAEN304: Energy Policies and Energy Management (60 lectures, 4 credits)

Energy Policies and Energy Management

Unit-1:

Evolution of Energy Security; India's Energy Scenario; Evolution o£ Energy Security Policies in India; India's Energy Resources; Classification of Energy Resources; Lignite; Hydrocarbons; Renewable Energy; Trends in India's Energy Sector: Elasticity and Growth Dummy-variable Approach Trends in Energy Consumption of Major Sources of Energy Trends in Total Energy Consumption, Production, and Imports; Total Energy Production in India; Energy Imports in India; Trends in Energy Security; Trends in Energy Elasticity and Efficiency in India; Energy Elasticity, Energy Growth, and Economic Growth; Causality between India's Energy Consumption and GDF; Granger Causality Test Vector Error Correction Model; Energy Efficiency and Conservation; Energy Efficiency Indicators; Energy Efficiency Policies; Evaluation of Energy Efficiency Measures in India; Energy in the Building Sector; Appliances and Equipment; Transport Sector; Power Sector.; Energy Conservation; 6. Energy and Environment; Coal, ; Hydrocarbons; Residential Sector; Fugitive Emissions; Nuclear Hydropower; Geothermal Energy; Urban Waste; Solar Energy; Bio-energy; Wind Energy; Data collection of Emission and Climate Change assessment; Action plan on Climate Change

Ref: Chapters 1 to 6: Energy Security and Economic Development in India: a holistic approach, Bala Bhaskar, TERI

Unit-2:

Water for Energy; Coal and Lignite; Oil Supply; Natural Gas Supply and Gas Hydrates; Nuclear Power Supply; Hydropower Supply; Renewable Energy; Transportation Sector; Energy Pricing; Evolution of Pricing Mechanism for Oil and Petrolium Products; Evolution of Coal Pricing in India; Evolution of Electricity Pricing Mechanism; Pricing of Renewable Energy; Geopolitics and Energy Diplomacy; Reserves; Unconventional Oils; Gas-to-liquids; Geopolitics of Gas; Shale Gas Revolution and Energy Diplomacy; Geopolitics of Coal; Geopolitical Dynamics in Latin America and Caribbean countries; Geopolitics of Renewable Energy Resources: Diplomacy for Technology; Policy Framework; Need for a Holistic Approach; Comprehensive Sectoral Energy Policy; Smart Grid for Intelligent Management of Power; Coal; Hydrocarbons; Kerosene Natural Gas; Gas Hydrates; Nuclear Poer, Hydropower; Wind; Solar Energy; Geothermal; Biofuels

Ref: Chapters 7 to 10: Energy Security and Economic Development in India: a holistic approach, Bala Bhaskar, TERI

Unit-3:

Energy Audit: Industrial energy conservation: an overview; Electric motors; Lighting; Electrical load management; Power quality; Energy management information system; Boilers; Compressed air network; Steam distribution systems; Refrigeration and air conditioning.

Ref: Chapters 1 to 10: Handbook on Energy Audit and Environment Management, Y P Abbi and Shashank Jain, TERI

Unit-4:
Energy Audit: Pumps and pumping system; Fans and blowers; Cooling tower; Industrial furnaces; Thermic fluid heaters; Water audit and conservation; Solar energy options for industries; Energy, climate change, and clean development mechanism; Environmental management in industries; Future cleaner energy options.

Ref: Chapters 11-21: Handbook on Energy Audit and Environment Management, Y P Abbi and Shashank Jain, TERI

Reference:

1. Energy Security and Economic Development in India: a holistic approach, Bala Bhaskar, TERI
2. Handbook on Energy Audit and Environment Management, Y P Abbi and Shashank Jain, TERI

M.Sc. (Renewable Energy) Practical Lab Course

Semester –III

Semester –III Lab-1

Course number: PSAENP301 (120 hours, 4 credits)

Minimum Eight out of the following experiments.

1. solar water heater,
2. solar cooker
3. Parabolic reflector
4. The basic functions of the fuel cell system
5. The characteristic curve of a fuel cell
6. Parameters influencing the characteristic curve
7. Determination of the hydrogen current curve
8. Efficiency of the fuel cell stack
9. Set-up of a fuel cell power supply
10. Efficiency of a fuel cell power supply
11. Fuel cell application I: Remote traffic light
12. Fuel cell application II: Fuel cell car

Semester –III Lab-2

Course number: PSAENP302 (120 hours, 4 credits)

Minimum Eight out of the following experiments.

1. Gamma ray scintillation spectrometer and pulse height distribution
2. Gamma ray detection efficiency of the scintillation spectrometer
3. Absorption of mono-energetic gamma rays
4. Geological dating and determination of long half life
5. Range of alpha particles in air/aluminium
6. To determine activity of a given gamma ray source using radiation monitor
7. To determine resolving/dead time of a GM counter by a double source method
8. Calculation of heating and cooling load
9. Preparation of energy audit plan and analysing energy audit data
10. Preparation of heat balance for a thermal machine
11. Determination energy efficiency of different machines
12. Preparation process flow diagram and energy utility diagram

Semester-IV

Semester IV **Full time Project work**

M.Sc. in Renewable Energy Program for Semester-IV consists of full time project of 24 credits (600 marks). The project report shall be in the form of Thesis and should be hard bound. One Industrial visit OR visit to Energy park shall be an integral part of the course work.

Project	Credits
PSAENT401	24