DETAILED SYLLABUS

For
M. Tech. (RENEWABLE ENERGY)

R.16

JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY KAKINADA

KAKINADA - 533 003, Andhra Pradesh, India

I-I **BASICS OF ENERGY ENGINEERING** **L / P / Credits**
4 / -- / 3

Preamble: The course on energy engineering introduces the basics of power systems, power electronic control of electrical machines, fundamentals of thermodynamics, mechanical systems and concepts of heat transfer.

Learning Objectives:

- To understand the concept of power in electrical systems and importance of power factor.
- To understand the operation of power electronic controllers for speed control of machines.
- To know the fundamentals of thermodynamics.
- To study the basics of steady flow mechanical systems.
- To know the methods of heat transfer and applications.

Unit-I: Introduction

Introduction to power generation - transmission and distribution systems - Active, reactive and apparent power - Fundamentals of three-phase balanced and unbalanced systems - Power factor - Definition and improvement techniques.

Unit-II: Converters and Electrical Machines

Pulse width modulation techniques - Principle of operation of DC/DC and DC/AC converters (PWM) - Principle of operation of 3-phase transformer - Induction motor - Synchronous machine - Modern speed control techniques for induction motor.

Unit-III: Thermodynamic Concepts

Thermodynamic system - Types of systems -Reversible and irreversible processes - Thermodynamic and mechanical cycles - Point and path function - Heat and work - Examples of heat and work -Zeroth - First and second law of thermodynamics - First law applications to steady flow systems - Carnot cycle and its specialties - Entropy - P-V and T-S diagrams of Rankine -Brayton, Otto, diesel, dual and Sterling cycles.

Unit-IV: Steady flow Mechanical systems

Steam nozzles - Steam turbines - Steam condensers - Gas turbines - Pumps and compressors-Classification and working principle with schematic diagrams.

Unit-V: Heat Transfer

Modes and mechanisms of heat transfer - Steady - Unsteady and periodic heat transfer - Basic laws and applications - Conduction heat transfer - Fourier equation - Application of conduction heat transfer to homogeneous slabs - Cylinder and spherical geometries - Convection heat transfer - Classification and governing equation - Empirical relations for flat plate - Cylinders and pipes - Condensation and boiling heat transfer.

Learning Outcomes:

At the end of the course, the student should be able to

- Explain the concept of power factor.
- Explain speed control techniques of ac motors by power electronic controllers.
- Gain knowledge on thermodynamics and steady flow mechanical systems.
- Explain methods and applications of heat transfer.

Text Books:

1. Electrical Machinery, P. S. Bimbhra, Khanna Publishers 7th edition.
2. Power electronics: converters,applications, and design Ned Mohan, Tore M. UndelandJohn Wiley & Sons.
3. Thermal Engineering,M.L.Mathur& Mehta, Jain brothers Publishers.
4. Heat transfer, P.K.Nag, TMH publishers.

Reference Books:

1. Heat and Mass Transfer,Arora and Domkundwar, Dhanpatrai Publishers.
2. Thermal Engineering,R.S.Khurmi and J.S.Gupta, S.Chand Publishers.

I-I **RENEWABLE ENERGY TECHNOLOGIES** **L / P / Credits**
4 / -- / 3

Preamble: Basic idea of non-conventional energy sources.

Learning Objectives:

- To learn basic principle of renewable energy sources.
- Adoption of alternative energy sources for power generation.
- Learn alternative energy sources not based on sun.
- Adoption and inter connection of renewable and alternative energy sources to grid.

Unit-I: Solar Energy

Availability - Solar radiation data and measurement - Estimation of average solar radiation - Forced circulation calculation - Evacuated collectors - Basics of solar concentrators - Solar Energy Applications - Solar air heaters-Solar Chimney - Passive solar system - Active solar systems - Water desalination - Output from solar still-Principle of solar ponds- Basics of solar PV systems.

Unit-II: Wind Energy

Nature of wind-Characteristics - Variation with height and time - Power in wind -Aerodynamics of wind turbine - Momentum theory - Basics of aerodynamics - Aero foils and their characteristics - Horizontal axis wind turbine (HAWT) - Blade element theory - Prandtl's lifting line theory (prescribed wake analysis) - Vertical axis wind turbine (VAWT) - Aerodynamics - Wind turbine loads - Aerodynamic loads in steady operation - Yawed operation and tower shadow - Wind energy conversion system - Sitting - Rotor selection - Annual energy output.

Unit-III: Biomass energy

Bio fuel classification - Examples of thermo chemical - Pyrolysis- Biochemical and agrochemical systems - Energy farming - Direct combustion for heat - Process heat and electricity - Ethanol production and use - Anaerobic digestion for biogas - Different digesters - Digester sizing - Applications of biogas - Operation with I.C.Engine.

Unit-IV: Ocean, Wave and Tidal Energy

OTEC Principle - Lambert's law of absorption - Open cycle and closed cycle - heat exchanger calculations-Major problems and operational experience- Tidal Power - Principles of power generation - Components of power plant - Single and two basin systems - Turbines for tidal power - Estimation of energy - Maximum and minimum power ranges - Tidal powerhouse - Wave energy - Concept of energy and power from waves - Wave characteristics - Period and wave velocities - Different wave energy conservation devices (saltor duck, oscillating water column and dolphin types) - Operational experience.

Unit-V: Hydro Power

Hydro power potential, Types of hydroelectric projects-run of river scheme, Storage schemes, Pumped - storage schemes. Power plant classification - low, medium and high head micro hydro - main parts (weir, intake, canal, fore bay, tank penstock, power house and trail race, types of turbines), efficiency of small hydro power

Learning Outcomes: After completion of this course the students will be able to:

- Identify alternate energy sources.
- Classify and analyze different renewable energy systems.
- Adopt different alternate energy sources for power generation.
- Adopt optimally usage of different sources and interconnection with grid.

Text Books:

1. Renewable Energy Resources Basic Principles and Applications, G.N.Tiwari and M.K.Ghosal, *Narosa Publishing* House, New Delhi, India, 2005.
2. Solar Energy - Principles of thermal collection and storage, S.P. Sukhatme, *Tata McGraw Hill Publishing* Company Limited, New Delhi : First Edition.
3. Wind Energy Handbook / Tony Burton, David Sharpe, Nick Jenkins and Ervin Bossanyi / WileyWind Electrical Systems / S.N.Bhadra, D.Kastha and S.Banerjee / Oxford.
4. Biogas Technology - A Practical Hand Book / K.Khendelwal& S.S. Mahdi / McGraw-Hill.

Reference Book:

1. Renewable Energy Resources, John Twidell, Tony Weir, M.A.Laughton, Anthnoy D. Weir, Paperback,460 pages, Published 1990 by E. & F.N. Spon, London.
2. Study materials in Renewable - Trainers Text book (SHP) module, MNRE, India.
3. NPTEL: Module 5: Hydro Power Engineering (Principles of Hydro Power Engineering).

I–I **SOLAR THERMAL SYSTEMS** **L / P / Credits**
4 / -- / 3

Preamble: Solar thermal technology focuses on solar heating systems and outlines various applications. The course provides systems based on solar fundamentals in thermal load analysis**.**

Learning Objectives:

- Identify solar thermal system components.
- Identify system types and applications.
- Explain different storage techniques
- Gain knowledge on financial aspects such as cost, energy savings and return of investments.

Unit-I: Introduction

Solar energy option - Specialty and potential - Sun - Earth - Solar radiation - Beam and diffuse - Measurement - Estimation of average solar radiation on horizontal and tilted surfaces - Problems - Applications.

Capturing solar radiation - Physical principles of collection - Types - Liquid flat plate collectors - Construction details - Performance analysis - Concentrating collection - Flat plate collectors with plane reflectors - Cylindrical parabolic collectors - Orientation and tracking -Performance analysis.

Unit-II: Power generation from Solar Thermal

Power generation - Solar central receiver system - Heliostats and receiver - Heat transport system - Solar distributed receiver system - Power cycles - Working fluids and prime movers - Concentration ratio.

Unit-III: Thermal Energy Storage

Introduction - Need for - Methods of sensible heat storage using solids and liquids - Packed bed storage - Latent heat storage - Working principle - Construction - Application and limitations - Solar devices - Stills - Air heaters - Dryers - Solar Ponds & Solar Refrigeration- Active and passive heating systems.

Unit-IV: Energy Collection, Storage and applications

Flat plate and concentrating collectors- Classification of concentrating collectors- Orientation and thermal analysis- Advanced collectors - Different storage techniques -Sensible- Latent heat and stratified storage- Solar ponds - Solar applications- Solar heating/cooling techniques - Solar distillation and drying - Photovoltaic energy conversion.

Unit-V: Economics

Principles of economic analysis - Discounted cash flow - Solar system - Life cycle costs - Cost benefit analysis and optimization - Cost based analysis of water heating and photo voltaic applications.

Learning Outcome:

At the end of the course, the student should be able to

- Explain the methods employed to gather solar thermal or heat energy.

Text Books/Reference Books:

1. Principles of solar engineering, Kreith and Kerider, Taylor and Franscis, 2nd edition .
2. Solar energy thermal processes, Duffie and Beckman, John Wiley & Sons.
3. Solar energy: Principles of Thermal Collection and Storage, Sukhatme, TMH, 2nd edition .
4. Solar energy,Garg&Prakash, H. P. Garg, Tata McGraw-Hill Education, 2000.
5. Solar energy,B.S. Magal,McGraw-Hill Education (India) Pvt Limited, 01-Nov-1999.
6. Solar Thermal Engineering Systems, Tiwari and Suneja,Narosa Publishing House, 1997.
7. Power plant Technology, M. M. El-Wakil, McGraw-Hill, 1984.

I-I **SOLAR PHOTOVOLTAICS** **L / P / Credits**
4 / -- / 3

Preamble:

In order to meet the requirements of the photovoltaic (PV) industry, research institutions and the academia, a core course on photovoltaic has been introduced as part of the renewable energy engineering course. This course is all encompassing in that it covers pv cell fundamentals, technologies, manufacturing processes, latest trends in PV technologies, system design pertaining to grid-connected and standalone systems, evaluation techniques and economic tools. This course is multi-disciplinary in nature.

Learning Objectives:

Exposes the student to the science relating to solar energy, radiation and its measurement. It gives the student a thorough exposure to semiconductor fundamentals as applicable to solar cell technologies and build on this foundation to give an insight into silicon and non-silicon technologies, their manufacturing processes and the costs involved. PV system design-PV array, balance of systems, performance and accelerated testing are dealt with in sufficient detail.

Unit-I: Review of Energy Scenario and Semiconductor Physics

Review of world energy scenario including contribution from photovoltaic - The solar resource - Availability of energy from the sun and geographic availability - Direct diffuse and global isolation - Concept of air mass - Definition of solar geometric terms - Solar altitude - Inclination of collector - Azimuth angle (solar & surface) - Declination - Incident angle - Hour angle - Solar constant - Zenith angle etc .

Review of semiconductor physics: Semiconductors as solar cell material - Arrangement of atoms in space - Arrangement of electrons in atom - Formation of energy bands - Direct and indirect band gap - Charge carriers and their motion in semiconductors - Charge carriers -Carrier concentration and distribution - Carrier motion - Electric field and energy band bending (density of states, drift, and diffusion).

Unit- II: Solar Cell Design

Upper limits of cell parameters - Short circuit current - Open circuit voltage - Fill factor - Efficiency - Losses in solar cells - Model of a solar cell (equivalent circuit-one diode and two diode models) - Effect of series and shunt resistances on efficiency - Effect of solar radiation on efficiency - Effect of temperature on efficiency - Solar Cell design - Design for high Isc - High Voc - High FF - Analytical techniques - Solar simulator - I-V measurement - Quantum efficiency (QE) measurement - Minority carrier lifetime and diffusion length measurements - Standard test conditions (STC) - Normal operating cell temperature (NOC) - Standard operating conditions (SOC) - Series and parallel connection of PV modules - Mismatch in series and parallel connections - Need for bypass and blocking diodes.

Unit-III: Balance of Systems

Batteries for PV Systems - Lead acid - Nickel Cadmium - Nickel metal hydride - Lithium ion - Factors impacting battery performance - DC to DC Converters -Charge controllers - Maximum Powerpoint Trackers(MPPT)-Inverters-Grid Tied-Off Grid-Hybrid Inverters-Variable Frequency Drive - Types - Set points - Algorithm (for MPPT) -Mounting structures-Single Axis-Dual Axis-Maximum PowerpointTracking - Junction boxes - Array combiner boxes - Cables - Protection devices -Earthing - Lightning arrestor and other safety issues.

Unit-IV: PV System Design and Applications:

Standalone PV systems - Lighting - Water pumping - Hybrid PV Systems - PV wind and PV diesel - Grid connected PV Systems - PV power plants - Roof top and ground mounted small & large power plants.

Unit-V: Evaluations of PV Systems and PV Power Plants

Sensors and data acquisition system - Typical instruments and sensors used - Pyranometer - Anemometer/wind vane - Ambient temperature measuring device - Thermocouples to measure cell temperature - DC and AC energy meters - I-V curve tracers (or Array testers) - IR Thermal Imager - Inverters - Data logger - Server - Web-based software –Latest and Emerging trends in solar cell technologies (organic, dye sensitized, quantum dots, thermo-photovoltaic)-Laser Grooved Buried Contact(LGBC)-Passive Emitter Rear Locally diffused(PERL)-Passive Rear Contact Cells Selecting Emitter(PERC)-Peroskvite Cells-Graphene Based Solar Cells-Environmental impact of photovoltaic - Economic analysis (net present value -Simple payback - Capital recovery factor -Discounted cash flow analysis) - Life cycle costing (example: Solar PV pumping system).

Learning Outcomes:

The student will at the end of this course, together with the mandatory field/factory visits, will be able to meet the demands of the industry, pertaining to renewable energy, solar photovoltaic in particular. He will also be motivated to pursue research in PV technologies, materials, evaluation and their reliability.

Text Books:

1. ***Solar Photovoltaics: Fundamentals, Technologies and Applications,*** Chetan Singh Solanki, PHI Learning Private Limited 2011 (or later edition).
2. ***Solar Cells: Operating Principles, Technology and System Applications***,Martin A, Green, Prentice Hall Inc.
3. ***Modelling of Photovoltaic Systems using MATLAB, WileyTamerKhatib,WilfriedElmeried***.
4. ***Solar Photovoltaic Technology and Systems-A Manual for Technicians and Engineers,***Chetan Singh Solanki.

Reference Books:

1. ***A guide to the Photovoltaic Revolution,***Pauk D. Maycock and Edward N. Stirewalt, Rodale Press, Emmaus, Pa.
2. ***Energy Systems Engineering, Evaluation and Implementation,***Francis M. Vanek, Louis D. Albright, LargusT. Angenent, Second Edition, McGraw Hill.
3. ***Renewable Energy Sources***, Twidell and Weir**,** CRC Press (Taylor & Francis).
4. ***Solar Electricity***, Tomas Markvart, John Wiley & Sons, Ltd.

I – I	COGENERATION AND ENERGY EFFICIENCY (Elective-I)	L / P / Credits 4 / -- / 3

Preamble: The cogeneration concept, main design parameters for cogeneration, cogeneration alternatives, Bottoming and topping, cycles, steam turbine plants, gas turbine plants, diesel and gas engine plants, thermodynamic evaluation, combined cycle applications, sterling engine, industry /utility conservation, Trigeneration, techno economic and environmental aspects, cogeneration sugar, textile, paper and steel industry, case studies.

Learning Objective: To make the students appreciate the importance of cogeneration in improving the overall efficiency, thus reducing fuel consumption, improving economy and limiting global warming. Cogeneration plants may be based on steam turbine, Gas turbine or IC engines: to make the students aware of different technologies. To impart to students knowledge of practical cogeneration possibilities through case studies related to different types of process industries (sugar/textile/paper etc.) and other industries(steel, cement, etc.). Also hotel industries, hospitals etc.

Unit-I: Introduction

Introduction - Principles of thermodynamics - The cogeneration concept design - Parameters for cogeneration - Cycles - Topping - Bottoming - Combined cycle - Organic rankine cycles - Performance indices of cogeneration systems - Waste heat recovery - Sources and types - Concept of tri generation.

Unit-II: Cogeneration Technologies

Configuration and thermodynamic performance - Steam turbine cogeneration systems - Gas turbine cogeneration systems - Reciprocating IC engines cogeneration systems - Combined cycles cogeneration systems - Advanced cogeneration systems - Fuel cell - Stirling engines - Thermodynamic evaluation.

Unit-III: Issues and Applications of Cogeneration Technologies

Cogeneration plants - Electrical interconnection issues - Utility and cogeneration plant interconnection issues - Applications of cogeneration in utility sector - Industrial sector -Building sector - Rural sector - Impacts of cogeneration plants- Fuel - Electricity and environment - Case studies.

Unit-IV: Energy Efficiency

Energy conservation - Need for energy efficiency - Indian energy conservation act 2001 and its Features - Energy star rating of buildings and equipments - Bureau of energy efficiency guidelines and programs - Energy building code - Guidelines - Thermal insulation - Heating - Ventilation and air conditioning system.

Unit-V: Energy Efficiency Improvement in Electrical Systems

Improving energy efficiency in electrical systems - Electrical load management - Maximum demand control - Power Factor - Power factor - Power factor correction - Selection and location of capacitors - Electric motors - Motor efficiency - Factor affecting motor performance - Energy saving opportunities in motors - Energy efficient motors - Soft starter with energy savers - Motor efficiency measurements - Transformers - Energy efficient transformers - Factor affecting the performance of transformers.

Learning Outcomes:

- Importance of cogeneration in improving the overall efficiency, thus reducing fuel consumption, improving economy and limiting global warming will be brought out
- Capability to analyze the basic energy generation cycles
- Detailed knowledge of concepts of cogeneration, its types and probable areas of applications
- To study the significance of waste heat recovery systems and carry out its economic analysis

Text Books:

1. Energy Cogeneration hand book for Central Plant Design,GeorgePolimeros, Industries Press inc, New York, 1981.
2. Power Plant Technology,M. M. El- Wakil, McGraw Hill,1984.
3. "Combined-cycle gas & steam turbine power plants,3rd Edition",R.Kehlhofer, B. Rukes, F. Hannemann, F. Stirnimann, PennWell Books, 2009.
4. Industrial Energy Management and Utilization,LC Witte, PS Schmidt, DR Brown Hemisphere Publication, Washington, 1988.

References Books:

1. Industrial Energy Conservation Manuals, MIT Press, Mass, 1982 .
2. The Efficient Use of Energy, IGC Dryden, Butterworths (Ed), London, 1982 34.
3. Energy Management Handbook, WC Turner (Ed), Wiley, New York, 1982.
4. Technology Menu for Efficient energy use- Motor drive systems, Prepared by National Productivity Council and Center for Environmental Studies- Princeton University, 1993.
5. Hand Book of Energy Efficiency, Frank, Kreith, Ronald E West, CRC Press.
6. Bureau of Energy Efficiency Study Material for Energy Managers and Auditors Examination Paper I to IV.
7. Savings Electricity in Utility Systems of Industrial Plants Efficient use of electricity in industries, BG Desai, BS Vaidya DP Patel and R Parman, .
8. Cogeneration combined heat and power-Thermodynamics and performance, Horlock, J.H., Pergamon press, 1986.
9. Cogeneration, David Hu, S., Reston publishing Co.,USA, 1985.
10. Cogeneration production of heat and power, Robert Noyes, Elsevier applied science, 1990

I – I	**BIOMASS PROCESS AND TECHNOLOGIES (Elective -I)**	**L / P / Credits 4 / -- / 3**

Preamble: Many energy rich materials are derived from biomass such as wood pellets, charcoal, bioethanol, and biodiesel. Biomass is the fourth largest source of energy, accounting for at least 10 % of energy use.

Learning Objectives:
The aim of the course is to provide the necessary technical knowledge to the students regarding the bio mass resources, its energy content, the thermo chemical conversion techniques, the principles of the equipment used for its combustion and typical applications of bio mass as an important removable energy alternative to the conventional energy sources.

Unit - I
Sources and classification - Chemical composition - Properties of biomass - Energy plantations - Size reduction - Briquetting - Drying - Storage and handling of biomass.

Unit - II
Feedstock for biogas - Microbial and biochemical aspects - Operating parameters for biogas production - Kinetics and mechanism - High rate digesters for industrial waste water treatment.

Unit - III
Thermo chemical conversion of lignocelluloses biomass - Incineration - Processing for liquid fuel production - Pyrolysis - Effect of particle size -Temperature and products obtained.

Unit - IV
Thermo chemical principles - Effect of pressure and temperature - Steam and oxygen - Fixed and fluidized bed gasifiers- Partial gasification of biomass by CFB.

Unit -V
Combustion of woody biomass- Design of equipment - Cogeneration using bagasse- Case studies: Combustion of rice husk.

Learning Outcomes:
After completion of the course, the students shall be able to:

- Visualize the bio- mass as an alternative renewable energy resource.
- Understand the properties of biomass and its energy conversion techniques.
- Handle the necessary equipment used for biomass combustion and the related parametric affects.

Text Books:
1. “Biotechnology and Alternative Technologies for Utilization of Biomass or Agricultural Wastes”,Chakraverthy A, Oxford & IBH publishing Co, 1989.
2 “Principles of Solar Engineering”,D. Yogi Goswami, Frank Kreith, Jan. F .Kreider, 2nd Edition, Taylor & Francis, 2000, Indian reprint, 2003[chapter 10].
3. “Biogas Systems: Principles and Applications”,Mital K.M, New Age International publishers (P) Ltd., 1996.
4. BiogasTechnology,Nijaguna, B.T., New Age International publishers (P) Ltd.,2002.

References Books:

1. "Biomass Energy Systems", VenkataRamana P and Srinivas S.N, Tata Energy Research Institute, 1996.
2. "Gasification Technologies, A Primer for Engineers and Scientists",Rezaiyan. J and N. P. Cheremisinoff, Taylor& Francis, 2005.
3 "Bio-Gas Technology",Khandelwal. K. C.and Mahdi S. S Tata McGraw-Hill Pub. Co.Ltd, 1986.

I – I	**POWER QUALITY** **(Elective -I)**	**L / P / Credits** **4 / -- / 3**

Preamble: Power quality has become an important issue both for utilities and customers with the usage of power electronics equipment which are more sensitive to voltage disturbances. Power quality is the combination of voltage quality and current quality. This course mainly discusses the sources of transient over voltages, harmonic distortion, long duration over voltages and the solution to minimize their effect. As the distributed generation in gaining importance, the effect of DG on power quality is also analyzed.

Learning Objectives:

- To understand significance of power quality and power quality parameters.
- To know types of transient over voltages and protection of transient voltages.
- To understand harmonics, their effects, harmonic indices and harmonic minimization techniques.
- To understand long duration voltage variation and flicker
- To know power quality aspects in distributed generation.

Unit-I: Introduction

Overview of power quality - Concern about the power quality - General classes of power Quality problems - Transients - Long- Duration voltage variations – Short- Duration voltage Variations - Voltage unbalance - Waveform distortion - Voltage fluctuation - Power frequency variations - Power quality terms - Voltage sags and interruptions - Sources of sags and interruptions - Nonlinear loads.

Unit-II: Transient over Voltages

Source of transient over voltages - Principles of over voltage protection - Devices for over voltage protection - Utility capacitor switching transients - Utility lightning protection - Load switching transient problems - Computer tools for transient analysis.

Unit-III: Harmonic Distortion and solutions

Voltage vs. current distortion - Harmonics vs. transients - Power system quantities under non sinusoidal conditions - Harmonic indices - Sources of harmonics - Locating sources of harmonics - System response characteristics - Effects of harmonic distortion – Interharmonics - Harmonic solutions - Harmonic distortion evaluation - Devices for controlling harmonic distortion - Harmonic filter design - Standards on harmonics.

Unit- IV: Long Duration Voltage Variations

Principles of regulating the voltage - Device for voltage regulation - Utility voltage regulator application - Capacitor for voltage regulation - End-user capacitor application - Regulating utility voltage with distributed resources - Flicker.

Unit-V: Distributed Generation and Power Quality

Resurgence of distributed generation - DG technologies - Interface to the utility system - Power quality issues - Operating conflicts - DG on low voltage distribution networks - Interconnection standards - Wiring and grounding - Typical wiring and grounding problems - Solution to wiring and grounding problems.

Learning Outcomes: After completion of the course, students are able to:

- Analyze causes of power quality, power quality parameters.
- Understand sources of transient over voltages and providing protection to transient over voltages.
- Understand effects of harmonics, sources of harmonics and harmonic minimization.
- Analyze long duration voltage variations and regulation of voltage variations.
- Describe power quality aspects in distributed generation and develop solutions to wiring and grounding problems.

Text Books:

1. Electrical Power Systems Quality, Dugan R C, McGranaghan M F, Santoso S, and Beaty H W, Second Edition, McGraw-Hill, 2002.
2. Power Quality Primer, Kennedy B W, First Edition, McGraw-Hill, 2000.

Reference Books:

1. Understanding Power Quality Problems: Voltage Sags and Interruptions, Bollen M H J, First Edition, IEEE Press; 2000.
2. Power System Harmonics, Arrillaga J and Watson N R, Second Edition, John Wiley & Sons, 2003.
3. Electric Power Quality control Techniques, W. E. Kazibwe and M. H. Sendaula, Van Nostrad Reinhold, New York.
4. Power Quality, C.shankaran, CRC Press, 2001.
5. Harmonics and Power Systems Franciso C.DE LA Rosa-CRC Press (Taylor & Francis).
6. Power Quality in Power systems and Electrical Machines-EwaldF.fuchs, Mohammad A.S. Masoum-Elsevier.

I–I **ENERGY EFFICIENCY AND GREEN BUILDINGS (Elective -I)** **L / P / Credits 4 / -- / 3**

Preamble: Students require basic concepts of electrical appliances, and building plans.

Learning objectives:

- To know the electrical and mechanical energy efficiency systems.
- To know the green buildings concepts and ecological design concepts applicable to modern buildings.
- Acquaint students with the principle theories of materials, construction techniques and to create green buildings.

Unit-I: Energy Efficient Systems

A) Electrical Systems: Energy efficient motors - Energy efficient lighting and control - Selection of luminaire - Variable voltage variable frequency drives (adjustable speed drives) - Controls for HVAC (heating, ventilation and air conditioning) - Demand side management.

B) Mechanical systems: Fuel cells - Principle - Thermodynamic aspects - Selection of fuels & working of various types of fuel cells - Environmental friendly and energy efficient compressors and pumps.

Unit-II: Energy Efficient Processes

Environmental impact of the current manufacturing practices and systems - Benefits of green manufacturing systems - Selection of recyclable and environment friendly materials in manufacturing - Design and implementation of efficient and sustainable green production systems with examples like environmental friendly machining - Vegetable based cutting fluids - Alternative casting and joining techniques - Zero waste manufacturing.

Unit-III: Green Building Process and Ecological Design

Conventional versus green building delivery systems - Green building project execution - The integrated design process - Green building documentation requirements - Design versus ecological design - Historical perspective - Contemporary ecological design - Future ecological design - Green design to regenerative design.

Unit-IV: Green Building Systems

Sustainable sites and landscaping-enhancing ecosystems - Building envelop- Selection of green materials - Products and practices - Passive design strategy- Internal load reduction-Indoor environment quality- Building water and waste management- Relevance to LEED / IGBC standards.

Unit-V: Green Building Implementation

Site protection planning - Health and safety planning - Construction and demolition waste management - Reducing the footprint of construction operations - Maximizing the value of building commissioning in HVAC System -Lighting and non-mechanical Systems - Costs and benefits relevance to LEED / IGBC standards.

Learning Outcomes:

- To understand the energy efficiency systems in electrical as well as mechanical.
- To understand the green buildings concepts and ecological design concepts applicable to modern buildings.
- Expertise the students with the principle theories of materials, construction techniques and to create green buildings.

Text Books:

1. Green Manufacturing Processes and systems, Edited by J. Paulo Davim, Springer 2013.
2. Green building A to Z, Understanding the buildings, Jerry Yudelson, 2008.
3. Green building guidelines: Meeting the demand for low-energy, resource - efficient homes.Washington, D.C.: Sustainable Buildings Industry Council, 2004.

Reference Books:

1. Green Building through Integrated Design,JerryYudelson, McGraw Hill, 2008.
2. Green building: project planning & cost estimating: a practical guide for constructing sustainable buildings: cost data.,Means, R.S., Kingston, Mass., 2006.
3. Green building: project planning & cost estimating: a practical guide to materials, systems and standards; green, Means, R.S., 2nd Edition. Kingston, Mass., 2006.
4. Green Building Products: the GreenSpec guide to residential building materials, Alex Wilson and Mark Peipkorn., 2 nd Edition, Gabriola Island, BC:
5. The green guide to specification: an environmental profiling system for building materials and components, Jane Anderson, David E. Shiers, and Mike Sinclair. 3 rd Edition, Oxford; Malden, MA: Blackwell Science, 2002.
6. Sustainable Construction: Green Building Design and Delivery,Charles J. Kibert, 2 nd Edition, Wiley, 2007.
7. Bureau of Energy Efficiency,ECBC 2007 Manual New Delhi.

I–I	COMPUTATIONAL FLUID DYNAMICS (Elective -II)	L / P / Credits 4 / -- / 3

Preamble: - Flow simulation & modelling are the important contents of Computational Fluid Dynamics (CFD). CFD is an essential mathematical tool for engineers to understand the physics and dynamic behaviour of fluid flow that avoids the costly and time consuming experimental investigations.

Learning Objectives:

- Students should know fundamentals of Computational Fluid Dynamics and governing equations of fluid flow
- Various techniques of simulation and modelling of fluid flow for variety of flow situations and boundary conditions
- Various methods in finite difference, finite volume and finite element methods.
- Understand the type of flow, its boundary conditions
- Use the appropriate meshing technique for the particular flow situation and get optimum solution

Unit-I: Introduction to Fluid Dynamics and its Applications

Introduction to fluid dynamics - Types of fluid flows - Factors affecting the type of flow - Introduction to CFD - Definition - Applications - Steps involved in CFD analysis -Advantages and limitations - Components of numerical solutions - Properties of numerical solution methods - Conservative and non-conservative form of governing equations of fluid flow - Mass, Momentum, Energy equations of fluid flow.

Unit-II: Various methods in discretization approaches

Discretization approaches - Finite difference method - Forward difference method - Backward difference method - Central difference method - Finite volume method - Upwind interpolation - Linear interpolation - Quadratic upwind interpolation - Application of finite volume method and finite difference methods to fluid flow problems

Unit-III: Multi grid methods and boundary conditions

Introduction to multi grid methods - Multi grid cycles - Boundary conditions – Inlet boundary conditions - Outlet boundary conditions - Wall boundary conditions - Dirichlet boundary conditions - Newmen boundary conditions - Robin boundary conditions - Applications in the field of renewable energy.

Unit-IV: Various methods in Finite element methods

Finite element methods - Stiffness matrix - Variational method - Galerkin’s method - Least square method - Laplace equation - Diffusion or wave equation - Iterative methods - Gauss Siedel - Gauss Jordan - Gauss elimination methods - Turbulent flows - Turbulent flow models

Unit-V: Mesh generation and its types

Structured - Blocked structured - Unstructured mesh - Body fitted meshes - Algebraic meshes - Partial Differential Equation mesh generation - Surface meshing **-** Analysis of Simple Internal flows in pipes - External flows over a solar collector

Learning Outcomes:

Students, after completing the course, shall be able to

- Distinguish between finite difference, finite volume and finite element methods.
- Understand the type of flow, its boundary conditions
- Use the appropriate meshing technique for the particular flow situation and get optimum solution.
- Understand the simulation & modelling of various flows through typical examples.

Text Books:

1. An Introduction to Computational Fluid Dynamics - The finite volume approach by H. K. Versteeg & W. Malalasekara.
2. Applied Finite Element Analysis, by L. J Segerlind, John Wiley & Sons, 2nd edition.
3. Computational Methods for Fluid Dynamics by Joel H.Ferziger/Milovan Peric.
4. Finite element mesh generation by Daniel.S.H.Lo

Reference Books:

1. Computational Fluid Dynamics by John. D. Anderson, McGraw Hill Company.
2. Frontiers of Computational Fluid Dynamics by D.A. Caughey and M.M. Hafez

I-I **ENERGY STORAGE TECHNOLOGIES (Elective-II)** **L / P / Credits 4 / -- / 3**

Preamble: This course will examine the basic physics, chemistry and engineering issues of energy storage devices such as batteries, thermo electric converters, fuel cells, super-capacitors. It is aimed to connect these devices with the power electronic controllers for various applications.

Learning Objectives:

- To understand the concept of energy storage and market economics of various sustainable energy storage system.
- To understand various types of battery energy storage systems.
- To have basic knowledge on thermoelectric and superconductivity magnetic energy storage system.
- To know the importance of super capacitors.
- To understand the function of different types of fuel cells.

Unit-I: Overview: Energy and Grand challenges on energy storage

Current and prospect for both traditional and renewable energy sources through a detailed analysis of energy market and future need through 2020 which includes energy - Economic growth and the environment - Implications of the kyoto protocol and structural change in the electricity supply industry - The comparative economics of various sustainable energy storage systems and how these factors will affect the renewable energy industry.

Unit-II: Battery

Explore the fundamental concept of batteries - For example: Measuring of battery performance - Charging and discharging of a battery - Storage density - Energy density and safety issues particularly classical batteries, such as (i) Lead acid (ii) Nickel – Cadmium (iii) Zinc Manganese dioxide and modern batteries - For example (i) Zinc-Air (ii) Nickel Hydride (iii) Lithium Battery.

Unit-III: Thermoelectric and Super Conducting Magnetic Energy Storage Systems (SMES)

Explain the fundamental concept of thermoelectric, such as electron conductor and photon glass concept - Introduce several classical thermoelectric materials and the measurements related with thermoelectric such as (i) Four-probe resistivity measurement (ii) Seebeck coefficient measurement and (iii) Thermal conductivity measurement - Concept of SMES and its application.

Unit-IV: Super Capacitor

Examine the basic components of super- Capacitors, including several types of electrodes and some electrolytes - The electrode materials are : high surface area activated carbons, metal oxide and conducting polymers - The electrolyte may be aqueous or organic - Advantages and Disadvantages of super capacitors and comparison with battery systems and their applications in public transport vehicles - Private vehicles and consumer electronics - Discussion on aspects of energy density - Power density - Price and market.

Unit-V: Fuel Cell

Review of basic concepts and types of fuel cells-Using fuel cells in a hybrid configuration-PV-fuel cell-PV-diesel-Fuel cells etc.

Learning Outcomes: At the end of the course the student should be able to:

- Appreciate the importance of energy storage systems from the modern power grid.
- Gain knowledge on battery energy storage systems.
- Appreciate the importance of thermal electrics and super conducting magnetic energy storage.
- Gain knowledge on super capacitors and its applications.
- Gain knowledge on different types of fuel cells.

Text Books/Reference Books:

1. Energy storage systems in electronics,volume 1 of new trends in electrochemical technologybyTetsuya Osaka, MadhavDatta, Published by Taylor & Francis, 2000.
2. Understanding Batteries by R. M. Dell, David Anthony James Rand - 2001, Publishedby RSC paperbacks.
3. Fuel Cell Systems Explained,Larminie, James/ Dicks, Andrew John Wiley &Sons .
4. Energy storage, s Huggins Robert,2010,springer.
5. Thermoelectrics Handbook: Macro to Nano, ISBN # 084932 2642.
6. Fuel Cell and Their Applications, Kordesch. K, and Simader.G, Wiley-Vch, Germany 1996.
7. Hand Book of Batteries and Fuel cells, 3rd Edition, Edited by David Linden and Thomas. B. Reddy, McGraw Hill Book Company, N.Y. 2002.
8. “Thermal Energy Storage Systems and Applications”,IbrahimDincer and Mark A. Rosen, John Wiley & Sons 2010.
9. “Handbook of energy engineering“, 6th Edition, AThumann, D. Paul Mehta, The Fairmont Press, Inc., 2008.

I-I	**CUSTOM POWER DEVICES** **(Elective-II)**	**L / P / Credits** **4 / -- / 3**

Preamble: Many customer loads such as hospital equipment, computers etc. are consideredas sensitive critical loads. Custom power devices are power electronic controllers which are used for network reconfiguration and as compensating devices. This course outlines different custom power devices like static VAR compensators, static transfer switch, DVR, UPFC, IPFC, etc.

Learning Objectives:

- To enable students to understand the power quality problems faced by modern power utilities and customers
- To introduce to students to the various topologies of the compensation devices and energy storage devices.
- To provide basic understanding of the emerging power electronic harmonic compensation devices.
- To enable students to understand the source transfer switches and current limiting devices.
- To enable students to appreciate the operation and control of custom power devices.

Unit-I: Introduction

Custom power and custom power devices - Power quality variations in distribution circuits - Voltage sags, swells, and interruptions - System faults - Over voltages and under voltages - Voltage flicker - Harmonic distortion - Voltage notching - Transient disturbances - Characteristics of voltage sags - Point of initiation - Point of recovery - Phase shift - Impact of phase shift on sizing of static voltage compensator (SVC) - Missing voltage.

Unit-II: Overview of Custom Power Devices

Reactive power and harmonic compensation devices - Static var compensator - Static shunt compensation - Compensation devices for voltage sags and momentary interruptions - Static series compensators - Backup energy supply devices - Battery UPS - Super conducting magnetic energy storage systems - Flywheel - Voltage source converter - Multi-level inverters - Diode clamped, flying capacitor and cascade type inverters.

Unit-III: Reactive Power and Harmonic Compensation Devices

Var control devices - Static var compensator - Topologies - Direct connected static var compensation for distribution systems - Static series compensator - Static shunt compensator (DSTATCOM) - Interaction with distribution equipment and system - Installation considerations.

Unit-IV: High-Speed Source Transfer Switches, Solid State LimitingAnd Breaking Devices

Source transfer switch - Static source transfer switch (SSTS)- Hybrid source transfer switch- High speed mechanical source transfer switch - Solid state current limiter - Solid state breaker.

Unit-V: Application of Custom Power Devices In Power Systems

P-Q theory - Control of P and Q - Dynamic voltage restorer (DVR) - Operation and control - Interline power flow controller (IPFC) - Operation and control - Unified power quality conditioner (UPQC) - Operation and control.

Learning Outcomes:

Upon completion of the subject, students will be able to:

- Explain power quality problems in a distribution system.
- Explain the main topologies of the compensation and energy storage devices.
- Determine the harmonic compensation devices required in a distributed system.
- Identify high source transfer switches and current limiting devices.
- Appreciate the operation and control of custom power devices – DVR, IPFC and UPQC.

Text Books:

1. Guidebook on Custom Power Devices, Technical Report, Published by EPRI, Nov 2000.
2. **Power Quality Enhancement Using Custom Power Devices-Power Electronics and Power Systems, Gerard Ledwich, ArindamGhosh, Kluwer Academic Publishers, 2002.**

Reference Books:

1. Power Quality, C. Shankaran, CRC Press, 2001.
2. Instantaneous power theory and application to power conditioning, H. Akagiet.al., IEEE Press, 2007.
3. Custom Power Devices - An Introduction, ArindamGhosh and Gerard Ledwich, Springer, 2002.
4. **A Review of Compensating Type Custom Power Devices for Power Quality Improvement, Yash Pal et.al., Joint International Conference on Power System Technology and IEEE Power India Conference, 2008. POWERCON 2008.**

I-I **CRYSTALLINE TECHNOLOGY & APPLICATIONS (Elective-II)** **L / P / Credits 4 / -- / 3**

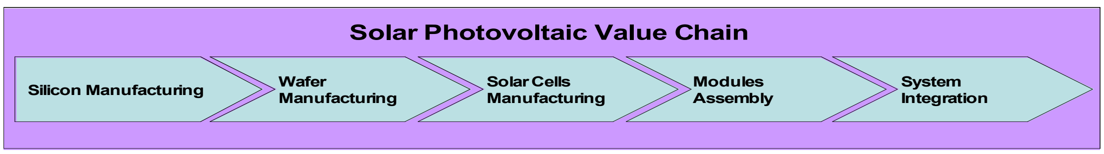
Preamble: The oldest and proven technology of Electricity generation from the light irradiation of Sun is the Crystalline Technology and its evolution started to power the geosynchronous satellites. It started with 1" square size crystalline cell with an efficiency of 3 to 4% and as of now it acquired an efficiency of 22% for a 6" square cell over a period of 40 years that is being use and commercially proven for generation of power that has reached grid parity depending on the application and the area where it is positioned.

Learning Objectives:

- To know the basic ingredients of the Solar Photovoltaic Module that generates electricity from Sun.

Unit-I

Value chain of the crystalline solar module - Solar grade silicon - Mono/poly ingots - N or P type solar wafers - Solar cells - Solar photovoltaic modules.



Various types of silicon material used for making the solar ingots - Metallurgical grade silicon/solar grade poly silicon and manufacturing process (purification of silicon) thereof.

Unit -II

Various types of wafers made from solar grade silicon (SOG) - Casting of mono and poly ingots-Slicing mono/poly wafers - P or N type wafers and manufacturing processes (Foundry) thereof.

Unit- III

Various technologies of solar cells and its advantages/disadvantages - Front contact and back contact cells - Efficiency of the cells - Performance criteria at various temperatures and irradiation levels - Manufacturing process thereof.

Unit- IV

Various types of modules and its performance - Flat plate and CPV crystalline modules - Design of off grid modules and power modules - Use of front and back contact cells and its performance criteria - Efficiency of operation of various modules and its performance related to temperature and irradiance variations - power degradations and manufacturing process thereof.

Unit -V

Applications of both mono and poly crystalline modules and its uses thereof.

a. Off- grid and standalone (battery backup) - Solar lights, Village electrification,
b. Stand Alone with no battery backup-
    i. Solar agricultural pumps,
    ii. Roof mounted grid tied systems
    iii. Free field grid tied systems

Learning outcome:

- Purification process of silicon to various grades and how it is achieved.
- How wafers are obtained through process of foundry & ingot slicing and its utilities thereof for both P and N type wafers.
- How solar cells are made through process of passivation, doping edge isolation, firing, screen printing, firing, testing and gradation.
- How Solar Modules are made through Assembly of the Solar Cells, tabbing & stringing, layup, lamination, grading of the modules, framing etc.,
- How Solar Systems are engineered based on the technological advantages of Mono and Poly Solar Photovoltaic Modules depending on the utility and application thereof.

Text Books:

1. Solar Cells: An Introduction to Crystalline Photovoltaic Technology,Mazer, Jeffrey A., Springer London, Limited, 2011.
2. Crystalline Silicon Solar Cells: Technology and Systems Applications [Hardcover] Adolf Goetzberger, Joachim Knobloch, Bernhard Voss,Wiley, 08-Apr-1998.
3. ThePhysics of Solar Cells, Jenny Nelson,Imperial College Press, 2003.
4. Solar Cells and Their Applications, Larry D. Partain, Wiley, 2010.
5. *Solar Electricity: Making the Sun Work for You.* Bullock, Charles E. and Peter H. Grambs. Monegon, Ltd., 1981.
6. *Practical Photovoltaics.*Komp, Richard J. Aatec Publications, 1984.
7. *Making and Using Electricity from the Sun. Tab* Books, 1979.

Reference Books:

1. "DOE's Born-Again Solar Energy Plan," *Science.*March 23, 1990, pp. 1403-1404.
2. "Waiting for the Sunrise," *Economist.*May 19, 1990, pp. 95+.
3. "Solar Cell Update,"Edelson, Edward. *Popular Science.*June, 1992, p. 95.
4. "Solar Power's Bright Hope," Murray, Charles J.*Design News.* March 11, 1991, p. 30.—*Rose Secrest.*
5. http://www.madehow.com/Volume-1/Solar-Cell.html.

I-I **Energy Systems Simulation Laboratory** **L / P / Credits**
-- / 3 / 2

List of Experiments:

1. Review of MATLAB/SIMULINK fundamentals.
2. Review of LAB VIEW fundamentals.
3. Development of model for Solar Cell and simulation of performance curves (IV curves) and their variation with temperature and irradiation using MATLAB/SIMULINK.
4. Study the effect of varying series resistance on the Fill Factor and hence the performance of the PV cell/module.
5. Develop a model for a Wind turbine generator, PV array and a PV-Wind hybrid system to analyze the performance of the hybrid system connected to a pump load under various wind and irradiance conditions at geographical location Kakinada. . Assume PV array capacity of 480 Wp and Wind turbine rating of 700 Watts. Assume data not given.
6. Develop a model for monitoring, modeling and simulation of a DC Surface solar PV pump system using LAB VIEW.
7. Simulate a small PV system designed for a residential rooftop, with a power of 5 kWp. The details of the PV system are as follows:

- PV generator: formed by 90 modules of 55 Wp, series connection in a string 10, parallel strings 9. The PV modules are formed by 36 600 solar cells, and the module characteristics are the following: MPP: Imp= 3.4A, Vmp = 16.2V. Short circuit current Iscr 3.7A and open circuit voltage Voc 20.5V. Inverter parameters: nominal power 4.00 kW, one output line: AC voltage 220 V rms, efficiency 0:85. Minimum input DC voltage is 30 V. AC loads are also connected to the inverter output. Select any daily power load demand but maintain a total energy demand of 4 MWh/year.
- Evaluate the simulation of this PV system over a year. Temperature and irradiance profiles may be ascertained for KAKINADA location.
- Ascertain/assume data not given.

Software required: MATLAB/SIMULINK, LAB VIEW, HOMER, PVSYST

Reference Text:

1. ***Modeling Photovoltaic Systems using PSpice,***LuisCastaner and Santiago Silvestre John Wiley & Sons Ltd, West Sussex, England, 2002.

SCHOOL OF RENEWABLE ENERGY AND ENVIRONMENT, IST

M. Tech. (Renewable Energy)
COURSE STRUCTURE

II Semester **2016 - 2017**

S. No.	Subject	L	P	Credits
1	Hydrogen and Fuel Cells	4	--	3
2	Wind Energy Systems	4	--	3
3	Energy Auditing and Demand Side Management	4	--	3
4	Geothermal , Tide and Wave Energy	4	--	3
5	Elective-III a) Instrumentation for Energy Systems b) System Control and Automation c) Solar Refrigeration and Air- conditioning d) Optimization Techniques	4	--	3
6	Elective-IV a) Industrial waste Management and Recycling b) Modelling, Analysis and Economics of Energy systems c) Smart Grid d) Integration of Renewable Energy Sources	4	--	3
7	Renewable Energy Laboratory	--	3	2
Total Credits				**20**

I-II **HYDROGEN AND FUEL CELLS** **L / P / Credits**
4 / -- / 3

Preamble: To enlighten the student community on various technological advancements, benefits and prospects of utilizing hydrogen/ fuel cell for meeting the future energy requirements.

Learning Objectives:

- To detail on the hydrogen production methodologies, possible applications and various storage options.
- To discuss on the working of a typical fuel cell, it's types and to elaborate on its thermodynamics and kinetics.
- To analyze the cost effectiveness and eco-friendliness of fuel cells.

Unit-I: Hydrogen-Basics in Production Techniques
Hydrogen - Physical and chemical properties - Salient characteristics - Production of hydrogen steam reforming - Water electrolysis- Gasification and woody biomass conversion– Biologicalhydrogen production- Photo dissociation- Direct thermal catalytic splitting of water.

Unit- II: Hydrogen Storage and Applications
Hydrogen storage options- Compressed gas- Liquid hydrogen – Hydride- Chemical storage-Comparisons - Hydrogen transmission systems - Application of hydrogen.

Unit-III: Fuel Cells
History - Principle-Working- Thermodynamics and kinetics of fuel cell processperformanceevaluation of fuel cell- Comparison on battery Vs fuel cell.

Unit-IV: Fuel Cell- Types
Types of fuel cells - AFC - PAFC - SOFC - MCFC – DMFC - PEMFC- Relative merits and demerits.

Unit-V: Application of Fuel Cell and Economics
Fuel cell usage for domestic power systems - Large scale power generation - Automobile - Space - Economic and environmental analysis on usage of hydrogen and fuel cell - Future trends in fuel cells.

Learning outcomes: After completion of this course the students will be able to

- The role of hydrogen of hydrogen energy production and fuel cells in the nearest and distance future energy system.
- Explain basic hydrogen production, storage techniques and working principle of fuel cell.
- Analyse different types of fuel cells.
- Explain applications of fuel cells for large scale power generation.

Text Books:

1. Hydrogen and Fuel Cells: Emerging Technologies and Applications, Bent Sorenson, Sorenson B, Academic Press (2005).
2. Hydrogen and Fuel Cells: Advances in Transportation and Power,Hordeski MF, The Fairmont Press, Inc. (2009)
3. Hydrogen and Fuel Cells: A Comprehensive Guide,Busby RL, PennWell Books (2005)
4. Fuel Cells, Principles and Applications, Viswanathan, B. and Scibioh, Aulice M, Universities Press, 2006.
5. Principles of Fuel Cells, by Xianguo Li, Taylor & Francis, 2006
6. Hydrogen and fuel cells: Emerging Technologies & Applications by Bent Sorensen, 2012, Elsevier Ltd.

Reference Book:

1. “Transport Phenomena in Multiphase Systems”,AFaghri& Y Zhang, Elsevier 2006
2. “Fuel Cells: From Fundamentals to Applications”,SSrinivasan, Springer 2006
3. “Fuel Cell Fundamentals”,O’Hayre, SW Cha, W Colella and FB Prinz, Wiley, 2005
4. “Principles of Fuel Cells”, Xianguo Li, Taylor and Francis, 2005
5. “Fuel Cell Systems Explained, J.Larminie and A Dicks, 2nd Edition”, Wiley,2003
6. “Power, Energy, & Industry Applications”, IEEE Journals.
7. “Fuel Cell and Their Applications”, Kordesch. K, and Simader.G, Wiley-Vch, Germany, 1996.

I-II

WIND ENERGY SYSTEMS

L / P / Credits
4 / -- / 3

Preamble: The purpose of the practical wind energycourse is designed to expand your knowledge of wind energy systems. This will include information on the history of wind energy, an explanation of how today's technology works, definitions of systems components, the advantages and challenges of implementation and also data to help determine if specific sites are viable for wind energy installations.

Learning Objectives:

After taking the course the student will:

- Have an understanding of Wind Turbine and Wind Farm operation.
- Be informed of the pros and cons of wind energy installations.
- Understand the components of a wind energy system.
- Gain knowledge of the different types of wind energy systems.
- Determine if a stand-alone or grid connected system is most desirable.

Unit-I

Measurement and instrumentation - Beau fort number - Gust parameters - Wind type - Power law index - Betz constant -Terrian Value.

Unit-II

Energy in wind - Study of wind applicable to Indian standards - Steel tables - Structural engineering.

Unit-III

Variables in wind energy conversion systems - Wind power density - Power in a wind stream - Wind turbine efficiency - Forces on the blades of a propeller - Solidity and selection curves.

Unit-IV

HAWT - VAWT - Tower design - Power duration curves - Wind rose diagrams - Study of characteristics - Actuator theory - Controls and instrumentations.

Unit-V

Grid - Combination of diesel generators - Battery storage - Wind turbine circuits - Wind forms - Fatigue stress.

Learning Outcomes:

On completion of this course, the student will be able to:

- Measure and analyze the wind resource potential for a given site.
- Explain the measurement instrument characteristics that impact wind speed and wind direction measurements.
- Describe basic aerodynamic theory and turbine operation and control.
- Understand the basic theory of integration of diesel generators, energy storage and wind energy system.

Text Books:

1. “Energy Technology”, S. Rao& B. B. Parulekar,4th edition, Khanna publishers, 2005.
2. Wind energy Handbook, Edited, T. Burton, D. Sharpe, N. Jenkins and E. Bossanyi, john Wiley & Sons, 2001.
3. Wind and Solar Power Systems, Mukund. R. Patel, 2nd Edition, Taylor & Francis, 2001.
4. Wind Energy Conversion Systems,L. L. Freris, Prentice Hall, 1990.
5. Wind Turbine Technology: Fundamental concepts of Wind Turbine Engineering, D.A. Spera,ASME Press.
6. “Wind Electrical Systems”, S. N. Badra, D. Kastha, S. Banerjee, Oxford Universiy Press, 2005.

Reference Books:

1. “Wind Energy Data for India”,Anna Mani &Nooley, 1983.
2. IS 875 Part IV and IS 1893 semics D+STDS materials STDS IS 226 (IS 2862, ASTMS 36, BS 4360 GR 43 D and A).
3. “Turbo Machinery Basic theory and applications”,Logan (EARL), 1981.

I-II **ENERGY AUDITING & DEMAND SIDE MANAGEMENT** **L / P / Credits**
4 / -- / 3

Preamble: The objectives of this course include

Learning Objectives:

- To learn about energy consumption and situation in India
- To learn about Energy Auditing.
- To aware of Energy Measuring Instruments.
- To understand the Demand Side Management.

UNI -I: INTRODUCTION TO ENERGY AUDITING

Energy Situation – World and India, Energy Consumption, Conservation, Codes, Standards and Legislation.Energy Audit- Definitions, Concept, Types of Audit, Energy Index, Cost Index, Pie Charts, Sankey Diagrams, Load Profiles, Energy Conservation Schemes.Measurements in Energy Audits, Presentation of Energy Audit Results.

UNIT -II: ENERGY EFFICIENT MOTORS AND POWER FACTOR IMPROVEMENT

Energy Efficient Motors , Factors Affecting Efficiency, Loss Distribution , Constructional Details , Characteristics - Variable Speed , Variable Duty Cycle Systems, RMS Hp- Voltage Variation-Voltage Unbalance- Over Motoring- Motor Energy Audit.Power Factor – Methods of Improvement, Power factor With Non Linear Loads,

UNIT –III: LIGHTING AND ENERGY INSTRUMENTS FOR AUDIT

Good Lighting System Design and Practice, Lighting Control, Lighting Energy Audit - Energy Instruments- Watt Meter, Data Loggers, Thermocouples, Pyrometers, Lux Meters, Tongue Testers, Application of PLC's

UNIT –V: INTRODUCTION TO DEMAND SIDE MANAGEMENT

Introduction to DSM, Concept of DSM, Benefits of DSM, Different Techniques of DSM – Time of Day Pricing, Multi-Utility Power Exchange Model, Time of Day Models for Planning. Load Management, Load Priority Technique, Peak Clipping, Peak Shifting, Valley Filling, Strategic Conservation, Energy Efficient Equipment. Management and Organization of Energy Conservation Awareness Programs.

UNIT –V: ECONOMICS AND COST EFFECTIVENESS TESTS OF DSM PROGRAMS

Basic payback calculations, Depreciation, Net present value calculations. Taxes and Tax Credit – numerical problems.Importance of evaluation, measurement and verification of demand side management programs. Cost effectiveness test for demand side management programs - Ratepayer Impact Measure Test, Total Resource Cost, Participant Cost Test, Program Administrator Cost Test

Numerical problems: Participant cost test, Total Resource Cost test and Ratepayer impact measure test.

LEARNING OUTCOMES: After completion of the course the student will able to;

- Understand the concepts of energy auditing
- Analyze efficiency of motors.
- Understand the concept of Demand side management and develop program for demand side management for utilities.

TEXT BOOKS:

1. Industrial Energy Management Systems, Arry C. White, Philip S. Schmidt, David R. Brown, Hemisphere Publishing Corporation, New York, 1994.

2. **Fundamentals of Energy Engineering -** Albert Thumann, Prentice Hall Inc, Englewood Cliffs, New Jersey, 1984.

REFERENCES:

1. Economic Analysis of Demand Side Programs and Projects - California Standard Practise Manual, June 2002 – Free download available online

I-II GEO THERMAL, TIDE, AND WAVE ENERGY L / P / Credits
4 / -- / 3

Preamble: To understand the fundamentals of Geothermal, tide and wave energy and its conversion techniques for electrical energy applications.

Learning objectives:-To create awareness among the students regarding the harnessing of energy from geothermal, tidal and ocean waves; through the knowledge of the principles, working, modeling and simulation of geothermal energy conversion systems, tidal energy conversion systems and ocean wave energy conversion systems, along with the economic aspects and environmental impacts through case studies.

Unit -I : Introduction & Exploration methods for Geothermal Reservoirs.
Introduction to geothermal energy - The source of heat - Physics of deep geothermal resources - volcano related heat sources & fluids - Heat source in sedimentary basins -Geothermal waters - Hot dry rocks.
Exploration Methods - Geological characterization - Electrical methods - Seismic methods - Potential methods - Geo chemistry - Fluids & minerals as indicators of deep circulation & reservoirs - Mud & fluid logging while drilling - Hydrothermal reactions - Boiling& mixing - Chemical &isotopic characteristics of fluids - Estimation of reservoir temperature.

Unit - II: Development & Utilization of Geothermal Reservoirs.
Introduction - Drilling equipment &techniques – Rigs - Hoisting system -Top drive -Mud pumps -Blow out preventer - Drilling mud – Types - Casing and cementation - Planning & drilling a well - Hydraulic, thermal and chemical stimulation of geothermal reservoirs - Applications & case studies - Energetic use of EGS reservoirs - EGS plant design - Case studies - Economic aspects and impacts on the environment.

Unit - III: Tidal Energy:
Introduction - Power generation from barrages - Environmental considerations for tidal barrages - Integration of electrical power from tidal barrages - Economics of tidal barrages - Tidal lagoons - Tidal streams/ currents - Environmental impact - Novel projects and devices around the world - Case studies.

Unit - IV: Wave Energy -Concepts & Resource:
Introduction - Terminology & concepts -Preliminary considerations - Oscillating water column - Sea states & their energy - Wave growth, travel & decay - Wave climate estimation - Numerical and experimental modeling of wave energy conversion systems - Wave tank and wave maker design - Laboratory testing of wave energy conversion systems - Case studies.

Unit - V: Wave Energy - Power take - off systems:
Air turbine design for OWCS - Design configurations - Direct drive -Linear generator systems - Principles and case studies - Full scale WECS - LIMPET - Archimedes wave swing (AWS) - Pelamis& wave dragon - Design & implementation - Environmental impact -Legislation &administrative issues.

Learning outcomes:-After the course completion, it is expected that the students should be able to:

- Understand the technology to harness the geothermal energy.
- Perform the analysis, modeling, & simulation of various geothermal reservoirs.
- Know the techniques of energy conversion from ocean tides.
- Obtain the knowledge of ocean wave energy conversion techniques.

Text Books:

1. Geothermal Energy Systems: Exploration, Development and Utilization. Huenges, Ernst (ed). Wiley – VCH.
2. ‘’Ocean wave Energy –Current Status & Future Prepectives” by Crug Joao, springer, 2008.
3. “Renewable Energy, Power for a Sustainable Future”, Edited by Godfrey Boyle Oxford University Press, Third Edition 2012.
4. Geothermal Reservoir Engineering, Grant. M.A and Bixley, P.F., 20112nd Ed. 359 pp. Elsevier.

I-II INSTRUMENTATION FOR ENERGY SYSTEMS L / P / Credits
(Elective-III) 4 / -- / 3

Preamble: Renewable energy sources are providing a significant portion of the energy needs mainly from solar, wind and biomass. This course highlights industrial use and major applications of instrumentation in solar photovoltaic, solar thermal process, wind energy, wave energy, air pollution, water etc.

Learning objectives:

- To understand the applications of instrumentation in industry
- To study about sample implementations in the industry
- To gain understanding on such implementations in various countries

Unit-I

Basic concepts of measurement, errors in measurement, classification of transducers, static and dynamic characteristics of transducers. Measuring instruments of temperature, pressure, liquid level, velocity, flow and heat flux.

Unit -II

Solar energy measurement requirements, Pyranometer, Rain guage, Hygrometer. LASER dust monitoring system. Stepper motor. LDR sensor. Automatic dusk to dawn sensor. Instruments for energy auditing. General spectroscopy and mass spectroscopy. Measuring instruments for wave energy, surface acoustic wave sensor, Geophone, Hydrophone, Microphone, Seismometer, Altimeter, Gyroscope.

Unit-III

Wind measurement instruments – Wind vane, Anemometer, loggers, pressure, temperature and humidity, Laser-based wind sensors, air pollution sampling and measurement of particulates, SOx, NOx, CO, 03, hydrocarbons, waste water sampling, Determination of organic and in-organic substances, physical characteristic and bacteriological measurements, solid waste measurements and disposal.

Unit-IV

Measurement of phase difference using X-OR and SR Flip-Flop methods, Photo Interrupter sensor, Sample and Hold Circuit, Clipping circuit, Opto-coupler, Photo Interrupter sensor, Voltage to frequency converter.

Unit-V

Analog signal conditioning, A/D and D/A converters, digital data processing and display, computer data processing and control. Characterization of electrical power systems, instruments for monitoring electrical parameters, analysis of power system quantities. Feed back control system, application of PID controllers, general purpose control devices and controller design.

Learning Outcomes:

After completing the course the students are able to:

- Understand various types of uses of instrumentation in the industry
- Understand various types of sensors and its applications
- Assessment of Analogy/Digital control devices, feedback, PID controllers.
- Obtain the knowledge of Instruments in various industries.

Text & Reference Books:

1. John P Bentley, “Principles of Measurement Systems”, Pearson Education.
2. David A Bell, “Electronics Instrumentation and Measurements”, Oxford Higher Education.
3. H S Kalsi, “Electronic Instrumentation”, McGraw-Hill Education (India) Private limited.
4. Helfrick A D, Cooper W D, “Modern Electronic Instrumentation and Measure Techniques”, Prentice Hall India.
5. Shawhney A K, “A Course In Electrical and Electronics Measurements and Instrumentation”, DhanpatRai.
6. Rangan C S, Sarma G R, Mani V S V, “Instrumentation Devices And Systems”, Tata McGraw-Hill.

I-II **SYSTEM CONTROL AND AUTOMATION** **L / P / Credits**
(Elective-III) **4 / -- / 3**

Preamble: Renewable energy systems development is not an option but a necessity from the point of power generation by utilities. The course provides an overall understanding of the technology and energy processes of renewable energy systems. Important types of utility operational systems and control standards are discussed.

Learning objectives:

- To understand the functions of a utility
- To understand various components required to monitor parameters of a grid
- To understand the need to control filed devices both centrally and locally
- To understand importance of standards and interoperability

Unit-I

Introduction - Overview of functions of a utility - front end operations of a utility (power delivery, power restoration, equipment maintenance etc.) - back end operations of a utility (planning, designing, engineering, billing), Role of power system analysis modules (such as load flow, contingency analysis, state estimation, unit commitment, automatic generation control etc.) in utility operations.

Unit-II

Brief introduction to utility operational systems - SCADA (Supervisory Control And Data Acquisition System) - Energy management system (EMS) - Distribution management system (DMS) - Outage management system (OMS) - Enterprise asset management system (EAM) - Mobile workforce management system (MWM) - Geographic information system (GIS) - Customer care & billing system (CC&B) - Customer information system (CIS) - Customer resource management system (CRM).

Unit-III

Types of real time systems - Discussion on example of real time systems such as rocket - Discussion on example of soft real time systems such as power systems - Brief introduction to long term dynamics of power systems - Discussion on impact on response time on power system operations - Observability of power systems network and selection of monitoring points.

Unit-IV

Components of a SCADA system - Introduction to field devices (such as remote terminal units, intelligent electronic devices, ring main units) - Introduction to communication media (power line carrier (PLC), fiber, wireless) - Introduction to control centre systems (front end processors (FEPs) - Application servers (used for processing the data) and workstation (used by dispatchers for performing operations).

Unit-V

Need for interoperability of devices and systems - Role of standard bodies in ensuring interoperability - Standards for field devices - Introduction to IEC 61850 - Standards for communication systems - Introduction to IEC 104 & DNP3 - Standards for control centre system interfacing - Introduction to common interface model (CIM) - Introduction to IEC 61968 & IEC 61970 - Need for smart metering standards - Introduction to DLMS protocol -Need for control centre communication standards - Introduction to ICCP (Inter Control Centre Communication Protocol) (TASE.2).

Learning outcomes:At the end of the course the student should be able to:

- Explain the functions of a utility and gain knowledge on operations of utility.
- Analyze different operational systems related to utilities and customers.
- Explain the dynamics and operation of relation real time power systems.
- Gain knowledge on components of SCADA systems, communication systems.
- Understand standards related to field devices, smart meters and communication devices.

Text Books:

1. **Monitoring, Control and Protection of Interconnected Power Systems,** Häger**, Ulf,** Rehtanz**, Christian,** Voropai**, Nikolai (Eds.)2014, springer.**

I-II	SOLAR REFRIGERATION AND AIRCONDITIONING (Elective-III)	L / P / Credits 4 / -- / 3

Preamble: Potential and scope of solar cooling, types of solar cooling systems, solar collectors and storage systems for solar refrigeration and air-conditioning, solar operation of vapour absorption and vapour compression refrigeration cycles and their thermodynamics assessment, Rankine cycle, sterling cycle based solar cooling systems, jet ejector solar cooling systems, fuel assisted solar cooling systems solar desiccant cooling systems, open cycle absorption/desorption solar cooling alternatives, advanced solar cooling systems, thermal modeling and computer simulation for continuous and intermittent solar refrigeration and air-conditioning systems, refrigerant storage for solar absorption cooling systems, solar thermoelectric refrigeration and air-conditioning, solar thermo acoustic cooling and hybrid air-conditioning, solar economics of cooling systems.

Learning Objectives:- To equip the students with the necessary information pertaining to the application of solar energy for refrigeration and air conditioning purposes; through the knowledge of the working of various refrigeration cycles, air conditioning systems, their thermodynamic and economic analysis, modeling, simulation and performance evaluation.

Unit-I

Concept of solar energy - Review of solar collectors - Solar concentrators - Potential and scope of solar cooling - Types of solar cooling systems - Solar collectors and storage systems for solar refrigeration and air-conditioning.

Unit-II

Solar operation of vapor absorption and vapor compression refrigeration cycles and their thermodynamic assessment - Rankine cycle - Sterling cycle based on solar cooling systems -Jet ejector solar cooling systems - Fuel assisted solar cooling systems - Solar desiccant cooling systems.

Unit-III

Open cycle absorption / desorption solar cooling alternatives - Advanced solar cooling systems - working principles - Energy analysis and performance.

Unit-IV

Thermal modelling and computer simulation for continuous and intermittent solar refrigeration and air-conditioning systems - Performance evaluation and case studies.

Unit-V

Refrigerant storage for solar absorption cooling systems - Solar thermoelectric refrigeration and air-conditioning - Solar thermo acoustic cooling and hybrid air-conditioning - Solar economics of cooling systems - Numerical examples.

Learning outcomes: After the course completion, it is expected that the students should be able to:

- Appreciate the solar energy option, which reduces the burden and conventional energy, and is renewable and abundant, for providing cooling/ air conditioning of required space/ area.
- Perform the analysis, modeling, & simulation of various cycles and systems that use solar energy for cooling/ air conditioning.

Text books:

1. solar Refrigeration and space conditioning, Kaushik S.C., Divyajyoti publications, Jodhpur (India).1989.

Reference Books :

1. " Solar air conditioning and refrigeration", M. Sayigh, J. C. McVeigh,Pergamon Press, 1992.
2. "Low Energy Cooling for Sustainable Buildings", Ursula Eicker, John Wiley and Sons, 2009.
3. "Solar-assisted air conditioning in buildings: a handbook for planners", Hans-Martin Henning, Springer, 2007.
4. "Passive cooling of buildings", M. Santamouris, D. Asimakopoulos,Earthscan, 1996.

I-II **OPTIMIZATION TECHNIQUES** **L / P / Credits**
(Elective-III) **4 / -- / 3**

Prerequisites: Concepts of engineering mathematics and mathematical methods.

Course Educational Objectives:

- To define and state single and multi variable optimization problems, without and with constraints.
- To study and explain numerical methods for optimization
- To study and explain unconstrained or constrained nonlinear programming techniques.
- To introduce evolutionary programming techniques.
- To introduce basic principles of Genetic Algorithms and Partial Swarm Optimization methods.

UNIT – I:
Introduction and Classical Optimization Techniques:
State and define optimization problem, design vector, design constraints, constraint surface, objective function, objective function surfaces, classification of optimization problems.Single variable optimization, multi-variable optimization without constraints, necessary and sufficient conditions for minimum/maximum,multi-variable optimization with equality constraints.Solution by the method of Lagrange multipliers, multi-variable optimization with inequality constraints, Kuhn-Tucker conditions.

UNIT – II:
Numerical Methods for Optimization:
Nelder Mead's Simplex search method, Gradient of a function, Steepest descent method, Newton's method, Pattern search methods, conjugate method, types of penalty methods for handling constraints, advantages of numerical methods.

UNIT – III:
Nonlinear Programming:
Unconstrained cases - One dimensional minimization methods: Classification, Fibonacci method and Quadratic interpolation method, univariate method, Powell's method.
Constrained cases - Characteristics of a constrained problem, classification, basic approach of penalty function method.Introduction to convex programming problem.

UNIT – IV:
Introduction to Evolutionary Methods:
Evolutionary programming methods: Introduction to Genetic Algorithms (GA)– control parameters – number of generations, population size, selection, reproduction, crossover and mutation – operator selection criteria – simple mapping of objective function to fitness function – constraints – Genetic Algorithm steps – stopping criteria – simple examples.

UNIT – V:
Introduction to Swarm Intelligence Systems:
Swarm intelligence programming methods - Basic Partial Swarm Optimization method – characteristic features of PSO procedure of the global version – parameters of PSO (Simple PSO algorithm – operator selection criteria – fitness function constraints) – comparison with other evolutionary techniques – engineering applications of PSO.

Course Outcomes:
After completion of this course the students will be able to:

- State and formulate the optimization problem, without and with constraintsfor an engineering design problem.
- Apply classical optimization techniques to minimize or maximize a multi-variable objective function.
- Apply gradient and non-gradient methods to nonlinear optimization problems
- Able to apply Genetic algorithms for simple electrical problems.
- Able to solve practical problems using PSO.

Text Books

1. Engineering optimization: Theory and practice - by S. S. Rao, New Age International (P) Limited, 3rd edition, 1998.
2. Soft Computing with MATLAB Programming by N.P.Padhy&S.P.Simpson, Oxford University Press – 2015

Reference Books:

1. Optimization methods in operations Research and Systems Analysis - by K.V.Mital and C.Mohan, New Age International (P) Limited, Publishers, 3rd edition, 1996.
2. Genetic Algorithms in search, optimization, and Machine Learning - by David E.Goldberg,ISBN:978-81-7758-829-3, Pearsonby Dorling Kindersley (India) Pvt. Ltd.
3. Operations Research: An Introduction - by H.A.Taha, PHI Pvt. Ltd., 6th edition.

I-I

INDUSTRIAL WASTE MANAGEMENT AND RECYLING
(Elective-IV)

L / P / Credits
4 / -- / 3

Preamble: Solid waste management treatment and disposal, sanitary landfills, leachate and gaseous emissions estimation.Resourcerecovery and cycle of materials, waste management in different industries like steel, aluminum, chemical, paper, petroleum, petro-chemical, energy from waste, waste water treatment techniques, agriculture pollution, application of air pollution control in industries.

Learning Objectives :- To make the students realize the importance of treatment, disposal and energy recovery of waste from various industries including agriculture through the knowledge of processes, equipment, materials, characteristics & composition of industrial waste and the pollution control techniques.

Unit-I: Integrated Solid Waste Management:
Solid waste in history - Economics and solid waste - Legislation and regulations - Materials flow - Reduction - Reuse - Recycling-Recovery - Disposal of solid waste in landfills - Energy conversion - The need for integrated solid waste management - Special wastes.

Unit-II: Landfills:
Planning, siting, and permitting of landfills - Planning - Siting - Permitting - Landfill processes - Biological degradation - Leachate production - Gas production - Landfill design -Liners - Leachate collection - Treatment and disposal - Landfill gas collection and use -Geotechnical aspects of landfill design – Stormwater management - Landfill cap - Landfill operations - Landfill equipment - Filling sequences - Daily cover - Monitoring - Post closure care and use of old landfills - Landfill mining.

Unit-III: Sources of Effluent from the Process of Industries:
Manufacturing process and sources of effluent from the process of industries like chemical - Fertilizer - Petroleum - Petrochemical - Paper - Sugar - Distillery - Textile - Tannery - Food processing - Dairy and steel manufacturing - Characteristics and composition of effluent and different methods of treatment & disposal of effluent for the following industries steel - Petroleum refineries - Textiles - Tanneries - Atomic energy plants and other mineral processing industries.

Unit-IV: Waste Water Treatment Methods:
Nitrification and de-nitrification - Phosphorous removal - Heavy metal removal - Membrane separation process - Air stripping and absorption processes - Special treatment methods - Disposal of treated waste.

Unit -V: Environmental Issues in Agriculture:
Types of farming systems - Agro meteorology - Water and nutrients requirement - Fertilizers: Types of fertilizers - Pesticides and other agrochemicals - Soil and water conservation practices.

Learning Outcomes: - upon completion of the course, the students shall be able to:

- Categorize the waste from various industries & recycle for energy extraction.
- Plan for the proper treatment and disposal of industrial waste, which ensures pollution free environment.

Text Books:

1. Hand book of solid waste management and Waste Minimization Technologies. Nicholas P. Chermissionoff. An imprint of Elsevier, New Delhi (2003).
2. Solid Waste Engineering,P. AarneVesilind, William A. Worrell and Debra R. Reinhart. Thomason Asia Pte Ltd. Singapore (2002).
3. Industrial Solid Waste Management and Landfilling practice,M. Dutta, B. P. Parida, B. K. Guha and T. R. Surkrishnan.Narosa Publishing House, New Delhi(1999).
4. Design, Construction and Monitoring of Landfills,AmalenduBagchi.John Wiley and Sons. New York. (1994).
5. Environmental Pollution Control Engineering,C. S. Rao Wiley Eastern Ltd. New Delhi (1995).

Reference Books:

1. Industrial Waste Water Pollution Control, W. Wesley Eckenfelder Jr., McGraw-Hill, 2000.
2. Wastewater Treatment for Pollution Control, McGraw-Hill, Arceivala, S.J.,1998..M.N.Rao&Datta, Waste Water Treatment, 3rd Edition, Oxford &IBH publishingCompany Pvt Ltd.
3. Treatment of Industrial Effluent,Callegly, Forster and Stafferd, Hodder and Stonghton 1988.

I-I MODELLING, ANALYSIS AND ECONOMICS OF ENERGY SYSTEMS (Elective-IV) **L / P / Credits 4 / -- / 3**

Preamble: This course mainly gives an understanding of basic concepts of optimization methods and energy evaluation approaches is needed.

Learning Objective:

- Able to learn the basic linear programming techniques and interpretation.
- Able to learn the basic economics and cost of energy.
- Able to learn the overview of Indian energy scenario.

Unit-I

Modeling over view - Levels of analysis - Steps in model development - Examples of models - Quantitative techniques - Interpolation polynomial - Lagrangian - Curve fitting - Regression analysis - Solution of transcendental equations.

Unit-II

System simulation - Information flow diagram - Solution of set of nonlinear algebraic equations - Successive substitution - NR techniques - Examples of energy systems simulation optimization - Linear programming - Simplex tableau - Pivoting - Sensitivity analysis.

Unit-III

Tradeoffs between capital and energy using pinch analysis - Energy economy models - Scenario generation - Input output models - Numerical solution of differential equations -Overview - Convergences and accuracy - Transient analysis - Application example.

Unit-IV

Analysis of system load curve- Plant load factor - Availability - Loss of load probability calculations for a power system - Maintenance scheduling - Pricing of power - Project cost components - Analysis of power purchase agreements - Debt equality ratio - Return on investment.

Unit -V

Overview of Indian energy scenario - Trends in energy use patterns - Energy and development linkage - Calculation of simple payback period - Time value of money - Net present value - Internal rate of return -Life cycle cost - Cost of saved energy - Cost of energy generated - Examples from energy generation and conservation - Energy chain - Primary energy analysis.

Learning Outcomes: After completion of the course the student will be able to:

- Understand the basic linear programming techniques and interpretation.
- Understand the basic economics and cost of energy.
- Understand the overview of Indian energy scenario.

Text/Reference Books:

1. Energy and the environment,2nd edition., Fowler,J.M., McGraw Hill, New York,1984.
2. Energy /management Handbook, W.C.Turner,Wiley, New York,1982.
3. Design of Thermal Systems,W.F.Stoecker, McGraw Hill, 1981.
4. Optimization theory and applications, S.S.Rao, Wiley Eastern,1990.
5. Introductory methods of numerical analysis,S.S.Sastry Prentice Hall, 1988.
6. Energy Systems analysis for developing countries,P.Meier, Springer Verlag,1984.
7. Applied System Analysis,R.DeNeufville, McGraw Hill,International Edition,1990.
8. Optimization Theory and Practice,Beveridge and Schechter, MCgraw Hill,1970.

I-II | **SMART GRID (Elective-IV)** | **L / P / Credits 4 / -- / 3**

Preamble: Smart grid the biggest technological revolution which has the potential to decarbonisation and to reduce green house gases by integration of distributed renewable energy sources. smart grid increases the reliability of electricity supply by using energy storage devices and distributed generation. This course outlines smart grid technologies, micro grids and distributed energy resources. A brief introduction on information and communication technologies is discussed to improve bi directional power flow and net metering.

Learning Objectives:

- To understand concept of smart grid and developments on smart grid.
- To understand smart grid technologies and application of smart grid concept in hybrid electric vehicles etc.
- To have knowledge on smart substations, feeder automation and application for monitoring and protection.
- To have knowledge on micro grids and distributed energy systems.
- To know power quality aspects in smart grid.

Unit-I: Introduction to Smart Grid

Evolution of electric grid- Concept of smart grid - Definitions- Need of smart grid- Functions of smart grid- Opportunities &barriers of smart grid- Difference between conventional & smart grid- Concept of resilient &self-healing grid- Present development &international policies on smart grid - Case study of smart grid.

Unit-II: Smart Grid Technologies: Part 1

Introduction to smart meters- Real time prizing- Smart appliances- Automatic meter reading(AMR)- Outage management system(OMS)- Plug inhybrid electric vehicles(PHEV)- Vehicle to grid- Smart sensors- Home &building automation.

Unit-III: Smart Grid Technologies: Part 2

Smart Substations- Substation automation- Feeder automation - Intelligent electronic devices(IED) & their application for monitoring & protection- Smart storage like battery - SMES- Pumped hydro- Compressed air energy storage- Wide area measurement system(WAMS) - Phasormeasurement unit(PMU).

Unit- IV: Micro grids and Distributed Energy Resources

Concept of micro grid- Need & applications of micro grid- Formation of microgrid- Issues of interconnection- Protection & control of micro grid - Plastic &organic solar cells- Thin film solar cells- Variable speed wind generators - Fuel cells- Micro turbines- Captive power plants- Integration of renewable energy sources.

Unit-V: Information and Communication Technology for Smart Grid

Advancedmetering infrastructure (AMI)- Home area network (HAN)-Neighborhood area network (NAN)- Wide area network (WAN).

Learning Outcomes:

After completion of the course, students are able to:

- Understand smart grids and analyse the smart grid policies and developments in smart grids.
- Develop concepts of smart grid technologies in hybrid electrical vehicles etc.
- Understand smart substations, feeder automation, GIS etc.
- Analyze micro grids and distributed generation systems.
- Analyze the effect of power quality in smart grid and to understand latest developments in ICT for smart grid.

Text Books:

1. “Integration of Green and Renewable Energy in Electric Power Systems”, Ali Keyhani, Mohammad N. Marwali, Min Dai Wiley.
2. “The Smart Grid: Enabling Energy Efficiency and Demand Response”, Clark W. Gellings, CRC Press.
3. “Smart Grid: Technology and Applications”, JanakaEkanayake, Nick Jenkins, KithsiriLiyanage, Jianzhong Wu, Akihiko Yokoyama, Wiley.
4. “Smart Grids”, Jean Claude Sabonnadière, NouredineHadjsaïd ,Wiley Blackwell.
5. “Smart Power: Climate Changes, the Smart Grid, and the Future of Electric Utilities”, Peter S. Fox Penner, Island Press; 1 edition 8 Jun 2010.
6. “Microgrids and Active DistributionNetworks.” S. Chowdhury, S. P. Chowdhury, P. Crossley, Institution of Engineering and Technology, 30 Jun 2009.
7. “Smart Grids (Power Engineering)”, Stuart Borlase,CRC Press.

Reference Books:

1. “The Advanced Smart Grid: Edge Power DrivingSustainability: 1”, Andres Carvallo, John Cooper, Artech House Publishers July 2011.
2. “Control and Automation of Electric Power Distribution Systems (Power Engineering)”, . James Northcote, Green, Robert G. Wilson CRC Press.
3. “Substation Automation (Power Electronics and Power Systems)”, MladenKezunovic, Mark G. Adamiak, Alexander P. Apostolov, Jeffrey George
4. Gilbert Springer.
5. “Electrical Power System Quality”, . R. C. Dugan, Mark F. McGranghan, Surya Santoso, H. Wayne Beaty, 2nd Edition, McGraw Hill Publication.
6. “Communication and Networking in Smart Grids”, Yang Xiao, CRC Press.

I-II INTEGRATION OF RENEWABLE ENERGY SOURCES (Elective-IV) **L / P / Credits 4 / -- / 3**

Preamble: A comprehensive discussion of renewable energy resources, the associated conversion technologies for electric power generation and challenges in renewable energy integration to the grid are provided in this course. The course also introduces the importance hybrid systems and isolated systems.

Learning Objectives: Upon successful completion of the course the students will be familiar with:

- To introduce the characteristics of various types of renewable energy sources and converters.
- To explain the importance of storage and sizing of hybrid systems.
- To introduce the control issues of isolated systems.
- To explain the harmonics, power quality, voltage imperfections, power injection issues on the grid by integrating renewable energy sources.

Unit- I: Review of characteristics of power sources
Basic review of power generation from wind - Solar PV - Thermal - Small hydro - Biomass power strategies in each of these energy conversion systems - Review of maximum power point tracking techniques in solar PV and wind (perturb & observe, hill climbs, incremental conductance).

Unit-II: Converter Topologies
DC/DC converter (buck, boost, buck boost)- DC/AC inverters (sine, triangular, PWM techniques)- Phase locked loop for inverters.

Unit-III: Hybrid Systems
Advantages of hybrid power systems - Importance of storage in hybrid power systems - Design of hybrid power system based on load curve - Sizing of hybrid power systems.

Unit-IV: Isolated Systems
Control issues in isolated systems for voltage and frequency - Small signal stability in isolated power systems - Importance of storage and dump load in isolated systems.

Unit-V: Issues in integration of renewable energy sources
Overview of challenges in integrating renewable sources to the grid - Impact of harmonics on power quality - Need to maintain voltage within a band and fluctuations in voltage because of renewable integration - Power inverter and converter technologies - Mechanism to synchronize power from renewable sources to the grid - Overview of challenges faced in designing power

injection from offshore generation sources - Challenges in modeling intermittent nature of renewable power in a power system.

Learning Outcomes: At the end of the course, the student should be able to:

- Identify the characteristics of renewable energy sources and converters.
- Analyze the importance of storage and sizing of hybrid systems.
- Realize the problems related to isolated systems.
- Analyze the challenges faced by the grid by integrating renewable energy sources.

TEXT BOOKS:

1. Power Electronics, Converters, Applications and Design" by N. Mohan; T.M. Undeland; W.P. Robbins. 1995, John Wiley and Sons.
2. **Renewable Energy IntegrationChallenges and SolutionsSeries: Green Energy and TechnologyHossain, Jahangir, Mahmud, Apel (Eds.)**
3. **Integration of Alternative Sources of EnergyFelix A. Farret, M. Godoy Simões** December 2005, Wiley-IEEE Press.

I-II **RENEWABLE ENERGY LABORATORY** **L / P / Credits**
-- / 3 / 2

List of Experiments:

1. Identifying PV modules of different technologies and measuring the performance parameters (outdoor).
2. Series and parallel connection of PV modules.
3. Estimating the effect of sun tracking on the energy generation by PV modules.
4. Efficiency measurement of a standalone PV System.
5. Wire to water efficiency measurement of a Solar PV Water Pumping System. Also generation of Head-Discharge, Efficiency-Discharge and Input power-Discharge performance curves.
6. a) Estimation of the average wind speed over a protracted period of time with the help of an anemometer and data logger.

   b) Construction of a wind rose.
7. Dependence of solar cell I-V characteristics on irradiance and temperature.
8. Carrier life time measurement for a solar cell.
9. Spectral Response Measurement.
10. Solar cell simulation using PCID simulator.
11. Circuit Simulation using SEQUEL (Computers loaded with Windows or Linux (http://www.ee.iitb.ac.in/~sequel)).
12. Fabrication and Testing of Charge Controllers (Series and Shunt type).
13. White LED lighting systems (solar PV powered)-home lighting and street lighting: Study, Design and evaluation.
14. Testing of MPPT System at various tilt angles under series and shunt configuration.

Reference Books (Practical)

1. ***Solar Photovoltaics: A Lab Training Manual,*** Chetan S. Solanki et al, IIT Bombay**,** Cambridge University Press India Pvt. Ltd, 2013.
2. ***System Technician Training Manual Part II, Solar Photovoltaic Training Programme*** CEC, IIT Madras, (under IREDA/World Bank/Siemens/IITM programme).
3. ***SPV Training Program.***IREDA/World Bank/Siemens.

Note:

The details of experiments (Objectives, Expected outcome of the experiment, equipment required, methodology for measurements, Observation table, inferences drawn, Questions to be answered etc) will be as per Reference 1.