DETAILED SYLLABUS
For
M. Tech. (RENEWABLE ENERGY), R19

SCHOOL OF RENEWABLE ENERGY AND ENVIRONMENT

INSTITUTE OF SCIENCE AND TECHNOLOGY

JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY

KAKINADA

KAKINADA - 533 003, Andhra Pradesh, India

I Year - M. Tech. I Semester

COURSE CODE –	BASICS OF ENERGY ENGINEERING	CATEGORY	L-T-P 3 -0-0	CREDITS 3

Pre-requisite: Basic knowledge on power systems, power electronics, electrical machines, fundamentals of thermodynamics, mechanical systems and concepts of heat transfer.

Course Outcomes: At the end of the course, student will be able to

		Knowledge Level (K)#
CO1	Understand the concept of power in electrical systems and importance of power factor.	
CO2	Understand the operation of power electronic controllers for speed control of machines.	
CO3	Develop the concepts of thermodynamics.	
CO4	Acquire the basics of steady flow mechanical systems.	
CO5	Explain the methods of heat transfer and applications.	

#Based on suggested Revised BTL

Mapping of course outcomes with program outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

(Please fill the above with Levels of Correlation, viz., L, M, H)

UNIT	CONTENTS	Contact Hours
UNIT – 1	**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 – 2	**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 – 3	**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 - Carnot cycle and its specialties – Entropy - P-V and T-S diagrams of Rankine -Brayton, Otto, Diesel, Sterling cycles.	

UNIT – 4	**Steady flow Mechanical systems** Steam nozzles - steam turbines - steam condensers - gas turbines - pumps and compressors - classification and working principle with schematic diagrams.	
UNIT – 5	**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 infinite slab - composite systems - hallow cylinder - coaxial cylinder and spherical geometries - convection heat transfer - types of convective heat transfer - condensation and boiling heat transfer.	
	Total	**48 Hrs**

Text Books:

1. Electrical Machinery, P. S. Bimbhra, Khanna Publishers 7th edition.
2. Power electronics: converters, applications, and design Ned Mohan, Tore M. Undel and John Wiley & Sons.
3. Thermal Engineering, M.L.Mathur& Mehta, Jain brothers Publishers.
4. Heat transfer, P.K.Nag, TMH publishers.
5. Heat transfer and mass transfer, R.C. Sachdeva, New International 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 Year - M. Tech. I Semester

COURSE CODE –	RENEWABLE ENERGY TECHNOLOGIES	CATEGORY	L-T-P 3 -0-0	CREDITS 3

Pre-requisite: Basic knowledge of non- conventional energy sources like solar energy, wind energy, biomass energy, ocean energy, tidal energy, wave energy, hydro power and geo thermal energy.
Course Outcomes: At the end of the course, student will be able to

		Knowledge Level (K)#
CO1	Identify alternate energy sources.	
CO2	Classify and analyze different renewable energy systems.	
CO3	Adopt different alternate energy sources for power generation.	
CO4	Adopt optimal usage of different sources and interconnection with grid.	
CO5	Understand significance of renewable energy technologies.	

#Based on suggested Revised BTL

Mapping of course outcomes with program outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

(Please fill the above with Levels of Correlation, viz., L, M, H)

UNIT	CONTENTS	Contact Hours
UNIT – 1	**Solar and Wind Energy** Availability of solar radiation – solar radiation measurement instruments - estimation of average solar radiation - basics of solar thermal systems, solar PV systems - solar energy applications. Nature of wind - wind characteristics - power in wind - wind energy extraction - wind energy conversion devices - horizontal axis wind turbine (HAWT) - vertical axis wind turbine (VAWT) - aerodynamics of wind rotor - blade element theory - aerodynamic efficiency - wind turbine control system - tower shadow - rotor selection - wind power generation modes-wind forms.	
UNIT – 2	**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 – 3	**Ocean, Tidal and Wave Energy** Ocean energy fundamental concepts- ocean thermal energy conversion - open cycle and closed cycle - hybrid OTEC systems-advantages and	

	disadvantages of OTEC - environmental impacts of OTEC - tidal power - Components of tidal power plant - power generation from barrages - environmental considerations for tidal barrages - turbines for tidal power - estimation of energy - integration of electrical power from tidal barrages - economics of tidal barrages - environmental impact - wave energy – linear generators - 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 – 4	**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 sources.	
UNIT – 5	**Geo thermal Energy** Introduction to geothermal energy - structure of the Earth's interior - geothermal sites - earthquakes and volcanoes - geothermal resources - hot springs - steam ejection - principle of working of geothermal plants - types of geothermal station schematic representation - site selection for geothermal power plants - advanced concepts.	
	Total	**48 Hrs**

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 / Wiley publications.
4. Wind Electrical Systems / S.N.Bhadra, D.Kastha and S.Banerjee / Oxford Press.
5. Biogas Technology - A Practical Hand Book / K.Khendelwal & S.S. Mahdi / McGraw-Hill.
6. Energy Resources Utilization and Technologies, Anjaneyulu Yerramilli and Francis Tuluri publications.
7. ‘’Ocean wave Energy - Current Status & Future Prepectives”, by Crug Joao Springer, 2008.
8. Renewable Energy Sources and Emerging Technologies, D.P.Kothari, K.C.singal, Rakesh Ranjan, 2013.

Reference Books:

1. Renewable Energy Resources, John Twidell, Tony Weir, M.A.Laughton, Anthnoy D. Weir, Paperback, 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 Year - M. Tech. I Semester

COURSE CODE –	SOLAR PHOTOVOLTAICS (ELECTIVE–I)	CATEGORY	L-T-P 3 -0-0	CREDITS 3

Pre-requisite: Basic knowledge on semiconductor physics, electrical and electronic circuits.

Course Outcomes: At the end of the course, student will be able to

		Knowledge Level (K)#
CO1	Understand photovoltaics and analyze the technologies and developments in photovoltaics.	
CO2	Develop concepts of photovoltaic technologies in hybrid electrical power generation.	
CO3	Understand various design configurations, troubleshooting.	
CO4	Analyze/Understand components required for photovoltaic power generation.	
CO5	Analyze PV system design and applications and to understand techno-economic-environmental evaluation.	

#Based on suggested Revised BTL

Mapping of course outcomes with program outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

(Please fill the above with Levels of Correlation, viz., L, M, H)

UNIT	CONTENTS	Contact Hours
UNIT – 1	**Photovoltaics and Semiconductor Physics** Review of world energy scenario of photovoltaics - availability of energy from the sun - concept of solar radiation - air mass - solar geometry and related terms. Semiconductor physics of a solar cell - charge carriers and their motion in semiconductors - charge carriers concentration levels - electric field and energy band bending (density of states, drift, and diffusion).	
UNIT – 2	**Solar Cell Design** Solar cell parameters - short circuit current - open circuit voltage - fill factor - efficiency - losses in solar cells - equivalent models of basic solar cell - effect of resistances, solar radiation and temperature on efficiency - solar cell design for higher I_{sc},V_{oc},Fill factor -measurement of minority carrier life time, diffusion length, quantum efficiency and I-V characteristics using solar simulator - STC, NOC and SOC of a solar cell - series and parallel connection of PV modules - mismatch in series and parallel connections - need for bypass and blocking diodes.	
UNIT – 3	**Balance of Systems** Batteries for PV Systems - factors impacting battery performance -	

	application of DC - DC converters in PV - charge controllers - MPPT - off grid and grid tied hybrid inverters - variable frequency drive - types - mounting structures-single axis - dual axis - junction boxes - array combiner boxes - cables - protection devices - earthling - lightning arrestor and other safety issues.	
UNIT – 4	**PV System Design and Applications** PV system sizing - 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 and large power plants.	
UNIT – 5	**Evaluations of PV Systems and Advance concepts in PV** PV data acquisition system - ambient temperature measurement - DC and AC energy meters - I-V curve tracers (or array testers) - IR thermal imager-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 .	
	Total	**48 Hrs**

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, Wilfried Elmeried.
4. Solar Photovoltaic Technology and Systems-A Manual for Technicians and Engineers, Chetan Singh Solanki.
5. Solar Energy Fundamentals, Technology, and Systems, Klaus Jäger, Olindo Isabella, Arno, H.M.
SmetsRené A.C.M.M. van SwaaijMiroZeman, Delft University of Technology, 2014.
6. Photovoltaic System Design: Procedures, Tools and Applications, Suneel Deambi, CRC press, 2016.

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 Year - M. Tech. I Semester

COURSE CODE –	COGENERATION AND ENERGY EFFICIENCY (ELECTIVE–I)	CATEGORY	L-T-P 3 -0-0	CREDITS 3

Pre-requisite: Basic knowledge on cogeneration technologies, waste heat recovery sources, energy efficiency and energy efficient electrical systems.

Course Outcomes: At the end of the course, student will be able to

		Knowledge Level (K)#
CO1	Understand the importance of cogeneration in improving the overall efficiency, economy and limiting global warming.	
CO2	Analyze the basic energy generation cycles.	
CO3	Design of cogeneration technologies, its types and probable areas of applications.	
CO4	Explain the significance of waste heat recovery systems and carry out its economic analysis.	
CO5	Analyse the importance of energy efficiency in electrical system.	

#Based on suggested Revised BTL

Mapping of course outcomes with program outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

(Please fill the above with Levels of Correlation, viz., L, M, H)

UNIT	CONTENTS	Contact Hours
UNIT – 1	**Introduction** Introduction - principles of thermodynamics - The cogeneration concept design - parameters for cogeneration - cycles - topping - bottoming - combined cycle - organic Rankin cycles - performance indices of cogeneration systems - waste heat recovery - sources and types - concept of trigeneration.	
UNIT – 2	**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 - Stirling engines - thermodynamic evaluation.	
UNIT – 3	**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 – 4	**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 – 5	**Energy Efficiency Improvement in Electrical Systems** Improving energy efficiency in electrical systems - electrical load management - maximum demand control - energy efficient motors - factor affecting motor performance - energy saving opportunities in motors - soft starter with energy savers - energy efficient transformers - factor affecting the performance of transformers.	
	Total	**48 Hrs**

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.

Reference 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 Centre 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.

I Year - M. Tech. I Semester

COURSE CODE –	POWER QUALITY (ELECTIVE–I)	CATEGORY	L-T-P 3 -0-0	CREDITS 3

Pre-requisite: Basic knowledge on transient voltages, harmonics and distributed generation networks.

Course Outcomes: At the end of the course, student will be able to

		Knowledge Level (K)#
CO1	Analyze causes of power quality, power quality parameters.	
CO2	Understand sources of transient over voltages and providing protection to transient over voltages.	
CO3	Understand effects of harmonics, sources of harmonics and harmonic minimization.	
CO4	Analyze long duration voltage variations and regulation of voltage variations.	
CO5	Describe power quality aspects in distributed generation and develop solutions to wiring and grounding problems.	

#Based on suggested Revised BTL

Mapping of course outcomes with program outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

(Please fill the above with Levels of Correlation, viz., L, M, H)

UNIT	CONTENTS	Contact Hours
UNIT – 1	**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 – 2	**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 – 3	**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 - inter harmonics - harmonic solutions - harmonic distortion evaluation - devices for controlling harmonic distortion - harmonic filter design - standards on harmonics.	
UNIT – 4	**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 – 5	**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.	
	Total	**48 Hrs**

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 Year - M. Tech. I Semester

COURSE CODE –	SOLAR THERMAL SYSTEMS (ELECTIVE–II)	CATEGORY	L-T-P 3 -0-0	CREDITS 3

Pre-requisite: Basic knowledge on solar thermal system, thermal energy storage and solar thermal applications.

Course Outcomes: At the end of the course, student will be able to

		Knowledge Level (K)#
CO1	Identify solar thermal system components.	
CO2	Identify different technologies for power generation	
CO3	Identify different solar thermal devices.	
CO4	Explain different storage techniques.	
CO5	Identify applications in various fields.	

#Based on suggested Revised BTL

Mapping of course outcomes with program outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

(Please fill the above with Levels of Correlation, viz., L, M, H)

UNIT	CONTENTS	Contact Hours
UNIT – 1	**Introduction and Solar Energy collectors** Solar energy option - specialty and potential - Sun - Earth - solar radiation – solar constant - beam and diffuse - measurement - estimation of average solar radiation on horizontal and tilted surfaces - applications. Collection devices - types - liquid flat plate collectors - evacuated tube collectors - construction details - performance analysis - concentrating collection - classification - flat plate collectors with plane reflectors - cylindrical parabolic collectors - orientation and tracking - parabolic dish collector.	
UNIT – 2	**Power generation from Solar Thermal** Power generation - low, medium, high temperature systems - power generation using liquid flat plate - solar chimney - cylindrical parabolic concentrating collector - solar central receiver system - heliostats and receiver - heliostat operational errors - tower design - heat transfer fluids - storage system.	
UNIT – 3	**Thermal Energy Storage** Introduction - need for - size and duration of storage - methods of energy storage - sensible heat storage using solids and liquids - packed bed	

	storage - latent heat storage - thermo chemical reaction storage - stratified storage - solar ponds - working principle - construction - application and limitations.	
UNIT – 4	**Solar thermal devices** Solar devices - solar stills - air heaters - dryers - furnaces - water heaters - solar cookers - solar pumps - introduction - design - working.	
UNIT – 5	**Unit-V: Solar thermal applications** Applications - distillation - solar refrigeration and space cooling - air heating - water heating - space heating - cooking - solar green houses - agricultural and industrial applications - solar energy for industrial process heat.	
	Total	**48 Hrs**

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 Year - M. Tech. I Semester

COURSE CODE –	COMPUTATIONAL FLUID DYNAMICS (ELECTIVE–II)	CATEGORY	L-T-P 3 -0-0	CREDITS 3

Pre-requisite: Basic knowledge on Flow simulation & modelling in Computational Fluid Dynamics.

Course Outcomes: At the end of the course, student will be able to

		Knowledge Level (K)#
CO1	Explain know fundamentals of Computational Fluid Dynamics and governing equations of fluid flow.	
CO2	Develop simulation and modelling of fluid flow for variety of flow situations and boundary conditions.	
CO3	Understand various methods in finite difference, finite volume and finite element methods.	
CO4	Understand the type of flow, its boundary conditions.	
CO5	Use the appropriate meshing technique for the particular flow situation and get optimum solution .	

#Based on suggested Revised BTL

Mapping of course outcomes with program outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

(Please fill the above with Levels of Correlation, viz., L, M, H)

UNIT	CONTENTS	**Contact Hours**
UNIT – 1	**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 – 2	**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 – 3	**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 – 4	**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 – 5	**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.	
	Total	**48 Hrs**

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/MilovanPeric.
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 Year - M. Tech. I Semester

COURSE CODE	MODELLING, ANALYSIS AND ECONOMICS OF ENERGY SYSTEMS (ELECTIVE–II)	CATEGORY	L-T-P 3 -0-0	CREDITS 3

Pre-requisite: Basic knowledge on conventional as well as non-conventional energy generation, transmission and distribution of power along with fundamental mathematics and economics.

Course Outcomes: At the end of the course, student will be able to

		Knowledge Level (K)#
CO1	Understand basic linear programming and interpretation techniques.	
CO2	Acquire knowledge on economics of energy systems.	
CO3	Assess energy economic trends.	
CO4	Analyze the effect of energy demand and consumption patterns.	
CO5	Understand application of energy optimization methods and economic evaluation approaches to current trends.	

#Based on suggested Revised BTL

Mapping of course outcomes with program outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

(Please fill the above with Levels of Correlation, viz., L, M, H)

UNIT	CONTENTS	**Contact Hours**
UNIT – 1	Modelling 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 – 2	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 – 3	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 – 4	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 – 5	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.	
	Total	**48 Hrs**

Text Books:

1. Energy and the environment, 2^{nd} 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.

Reference Books:

1. Introductory methods of numerical analysis, S.S.Sastry Prentice Hall, 1988.

2. Energy Systems analysis for developing countries, P.Meier, Springer Verlag,1984.

3. Applied System Analysis, R.DeNeufville, McGraw Hill, International Edition, 1990.

4. Optimization Theory and Practice, Beveridge and Schechter, MCgraw Hill,1970.

I Year - M. Tech. I Semester

I-I **Energy Systems Simulation Laboratory-I** **L / P / Credits**
-- / 4 / 2

List of Experiments:

1. Review of simulation software fundamentals.
2. Development of Solar Cell model and simulation of performance curves and their variation with temperature and irradiation.
3. Development of model for PV module and simulation of performance curves and their variation with temperature and irradiation.
4. Development of model for PV array and simulation of performance curves and their variation with temperature and irradiation.
5. Study the effect of varying series resistance on the fill factor and hence the performance of the PV cell/module.
6. Develop a model for a Wind turbine generator and simulate performance curves (C_p V_s λ) and (T_m V_s N).
7. 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.
8. Study the Characterization of the Resistance Temperature Detector (RTD)
9. Study the Characterization of the Linear variable differential transformer (LVDT)
10. Study the Characterization of the Thermocouple.

Reference Text:

1. **D. Patranabis, “Sensors and Transducers”**
2. **Doeblin, “Measurement Systems Applications and Design”**

I Year - M. Tech. I Semester

I-I **RENEWABLE ENERGY LABORATORY-I** **L / P / Credits**
-- / 4 / 2

List of Experiments:

1. Identifying PV modules of different technologies and measure the performance parameters (outdoor).
2. Measurement of current-voltage characteristics of two solar cells connected in series and parallel.
3. Series and parallel connection of PV modules.
4. Carrier life time measurement of a solar cell using RRT and OCVD methods.
5. Spectral Response Measurement of a solar cell.
6. White LED lighting systems (solar PV powered)-home lighting and street lighting: Study, Design and evaluation.
7. Dependence of solar cell I-V characteristics on irradiance and temperature.
8. Photovoltaic System sizing exercise.
9. Measurement of global solar irradiation using a solar cell.
10. Dark and illuminated current-voltage characteristics of solar cell.

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.

I Year - M. Tech. II Semester

COURSE CODE –	INSTRUMENTATION FOR ENERGY SYSTEMS	CATEGORY	L-T-P 3 -0-0	CREDITS 3

Pre-requisite: Basic knowledge on instruments used in various industries, analog to digital and digital to analogy converters and various types of sensors.

Course Outcomes: At the end of the course, student will be able to:

		Knowledge Level (K)#
CO1	Understand various types of instruments used in the industry.	
CO2	Understand various types of sensors and its applications.	
CO3	Assessment of analog/digital control devices, feedback and PID controllers.	
CO4	Obtain the knowledge of instruments used in various industries.	
CO5	Understand methods to measure air pollutants, waste water and solid waste.	

#Based on suggested Revised BTL

Mapping of course outcomes with program outcomes

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**	**PO12**
CO1												
CO2												
CO3												
CO4												
CO5												

(Please fill the above with Levels of Correlation, viz., L, M, H)

UNIT	CONTENTS	**Contact Hours**
UNIT – 1	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 – 2	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 – 3	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, O_3, hydrocarbons, waste water sampling, Determination of organic and	

	in-organic substances, physical characteristic and bacteriological measurements, solid waste measurements and disposal.	
UNIT – 4	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 – 5	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, feedback control system, application of PID controllers, general purpose control devices and controller design.	
	Total	**48 Hrs**

Text Books:

1. John P Bentley, "Principles of Measurement Systems", Pearson Education.
2. David A Bell, "Electronics Instrumentation and Measurements", Oxford Higher Education.

Reference Books:

1. H S Kalsi, "Electronic Instrumentation", McGraw-Hill Education (India) Private limited.
2. Helfrick A D, Cooper W D, "Modern Electronic Instrumentation and Measure Techniques", Prentice Hall India.
3. Shawhney A K, "A Course In Electrical and Electronics Measurements and Instrumentation", DhanpatRai.
4. Rangan C S, Sarma G R, Mani V S V, "Instrumentation Devices And Systems", Tata McGraw-Hill.

I Year - M. Tech. II Semester

COURSE CODE –	ENERGY AUDITING AND DEMAND SIDE MANAGEMENT	CATEGORY	L-T-P 3 -0-0	CREDITS 3

Pre-requisite: Basic knowledge on conventional as well as non-conventional energy generation, transmission and distribution of power along with fundamental mathematics and economics.

Course Outcomes: At the end of the course, student will be able to:

		Knowledge Level (K)#
CO1	Understand the concepts of energy auditing, conservation, policies and codes in India	
CO2	Understand and apply energy auditing procedures in utilities.	
CO3	Acquire knowledge on energy measuring instruments for data collection	
CO4	Understand the concept of demand side management	
CO5	Analyze and develop energy efficient programs for demand side management in utilities.	

#Based on suggested Revised BTL

Mapping of course outcomes with program outcomes

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**	**PO12**
CO1												
CO2												
CO3												
CO4												
CO5												

(Please fill the above with Levels of Correlation, viz., L, M, H)

UNIT	CONTENTS	**Contact Hours**
UNIT – 1	**INTRODUCTION TO ENERGY AUDITING** Energy situation – World and India, energy consumption, conservation, codes, standards and legislation energy audit- definitions and Concept, Types of audit, energy index, cost index, pie charts, sankey diagrams and load profiles, energy conservation schemes. Measurements in energy audits, presentation of energy audit results. Modern/recent energy policies & codes.	
UNIT – 2	**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 nonlinear loads.	
UNIT – 3	**LIGHTING AND ENERGY INSTRUMENTS FOR AUDIT** Illumination requirements for task and non-task areas, good lighting system design and practice, lighting control, lighting efficiency, lighting	

	energy audit - energy instruments- watt meter, data loggers, thermocouples, pyrometers, lux meters, tongue testers, application of PLC's.	
UNIT – 4	**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, and 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 – 5	**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.	
	Total	**48 Hrs**

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.

Reference Books:

1. Economic Analysis of Demand Side Programs and Projects - California Standard Practise Manual, June 2002 – Free download available online
2. Integrated Energy Policy, August 2006, Planning Commission, Government of India.
3. New Technologies for Energy Efficiency - Michael F. Hordeski, Fairmont press, 2002.

I Year - M. Tech. II Semester

COURSE CODE –	ENERGY STORAGE TECHNOLOGIES (ELECTIVE–III)	CATEGORY	L-T-P 3 -0-0	CREDITS 3

Pre-requisite: Basic knowledge on conventional and non-conventional energy sources and integration of electrical and electronic circuits.

Course Outcomes: At the end of the course, student will be able to:

		Knowledge Level (K)#
CO1	Understand the concept of energy storage and market economics of various sustainable energy storage system.	
CO2	Understand various types of battery energy storage systems.	
CO3	Have basic knowledge on thermoelectric and superconductivity magnetic energy storage system.	
CO4	Know the importance of super capacitors.	
CO5	Understand the developments in new energy storage technologies.	

#Based on suggested Revised BTL

Mapping of course outcomes with program outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

(Please fill the above with Levels of Correlation, viz., L, M, H)

UNIT	CONTENTS	Contact Hours
UNIT – 1	**Overview: Energy and Grand challenges on energy storage** Overview of current development in energy storage technologies - historic and current trends (global, regional and domestic energy storage trends, storage growth to date, future storage growth, drivers and key dynamics, supply & demand dynamics-trends), grand challenges. Classification of energy storage systems, energy storage system sizing.	
UNIT – 2	**Battery (Electrochemical energy storage)** Explore the fundamental concept of batteries - 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. Flow batteries, comparison and economic features of different battery technologies.	
UNIT – 3	**Electrical/Electromagnetic Energy Storage - 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) see beck coefficient measurement and (iii) thermal conductivity measurement - concept of SMES and its application.	
UNIT – 4	**Electrical Energy Storage - Supercapacitor** Examine the basic components of supercapacitors, 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 – 5	**Thermo chemical energy storage/ Emerging Storage Technologies** Hydrogen and fuel cells, hybrid electrical energy storage, solar hydrogen and solar metals -solar fuels, synthetic natural gas, power to gas.	
	Total	**48 Hrs**

Text Books:

1. Energy storage systems in electronics, Volume 1 of new trends in electrochemical Technology by Tetsuya Osaka, Madhav Datta, Published by Taylor & Francis, 2000.
2. Understanding Batteries by R. M. Dell, David Anthony James Rand - 2001, published by RSC Paper backs.
3. Fuel Cell Systems Explained, Larminie, James/ Dicks, Andrew John Wiley &Sons.
4. Energy storage, S Huggins Robert, 2010, springer.
5. Thermo electrics 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, Ibrahim Dincer and Mark A. Rosen, John Wiley & Sons 2010.
9. “Handbook of energy engineering“, 6th Edition, A.Thumann, D. Paul Mehta, The Fairmont Press, Inc., 2008.
10. World Energy Investment, 2019.

Reference Books:

1. Solar energy storage, Bent Sorensen, 2015, Academic press.
2. Energy storage technologies and applications, Ahmed faheemzobaa, Intech open, 2013.

3. Thermal Energy Storage Technologies for Sustainability Systems Design, Assessment and Applications, Kalaiselvam .S & R. Parameshwaran , First edition, 2014, academic press.
4. Energy Storage at Different Voltage Levels: Technology, integration, and market aspects, Ahmed F. Zobaa et al, 2018, The Institution of Engineering and Technology.
5. Essentials of Energy Technology: sources, transport, storage and conservation, Jochen Fricke and Walter L. Borst, Wiley-VCH, 2013.
6. Design and Management of Energy-Efficient Hybrid Electrical Energy Storage Systems, Younghyun Kim &Naehyuck Chang, 2014, Springer international publishing.
7. Synthetic Natural Gas from Coal, Dry Biomass, and power-to -gas applications, Tilman J. Schildhauer Serge M.A. Biollaz, 2016, John Wiley & Sons.

I Year - M. Tech. II Semester

COURSE CODE –	SMART GRID SYSTEMS AND TECHNOLOGIES (ELECTIVE–III)	CATEGORY	L-T-P 3 -0-0	CREDITS 3

Pre-requisite: Basic knowledge on smart concept communication protocols, renewable energy systems and electronic circuits.

Course Outcomes: At the end of the course, student will be able to:

		Knowledge Level (K)#
CO1	Understand smart grids and analyze the smart grid policies and developments in smart grids.	
CO2	Develop concepts of smart grid technologies in hybrid electrical vehicles.	
CO3	Understand smart substations, feeder automation and GIS etc.	
CO4	Analyze micro grids and distributed generation systems	
CO5	Analyze the effect of power quality in smart grid and to understand latest developments in ICT for smart grid.	

#Based on suggested Revised BTL

Mapping of course outcomes with program outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

(Please fill the above with Levels of Correlation, viz., L, M, H)

UNIT	CONTENTS	**Contact Hours**
UNIT – 1	**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 – 2	**Smart Grid Technologies: Part 1** Introduction to smart meters, real time pricing, smart appliances, Automatic Meter Reading (AMR), Outage Management System (OMS), Plug in Hybrid Electric Vehicles(PHEV), vehicle to grid, smart sensors, home & building automation, phase shifting transformers.	
UNIT – 3	**Smart Grid Technologies: Part 2** Smart substations, substation automation, feeder automation. Geographic Information System(GIS), 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), Phase Measurement Unit(PMU).	

UNIT – 4	**Microgrids and Distributed Energy Resources** Concept of microgrid, need & applications of microgrid, formation of microgrid, issues of interconnection, protection & control of microgrid. Captive power plants, integration of renewable energy sources.	
UNIT – 5	**Power Quality Management in Smart Grid** Power quality & EMC in smart grid, power quality issues of grid connected renewable energy sources, power quality conditioners for smart grid, web based power quality monitoring, power quality audit. **Information and Communication Technology for Smart Grid** Advanced Metering Infrastructure (AMI), Home Area Network (HAN), Neighborhood Area Network (NAN), Wide Area Network (WAN).	
	Total	**48 Hrs**

Text Books:

1. Ali Keyhani, Mohammad N. Marwali, Min Dai "Integration of Green and Renewable Energy in Electric Power Systems", Wiley
2. Clark W. Gellings, "The Smart Grid: Enabling Energy Efficiency and Demand Response", CRC Press

Reference Books:

1. JanakaEkanayake, Nick Jenkins, KithsiriLiyanage, Jianzhong Wu, Akihiko Yokoyama, "Smart Grid: Technology and Applications", Wiley
2. Jean Claude Sabonnadière, NouredineHadjsaïd, "Smart Grids", Wiley Blackwell 19
3. Peter S. Fox Penner, "Smart Power: Climate Changes, the Smart Grid, and the Future of Electric Utilities", Island Press; 1 edition 8 Jun 2010
4. S. Chowdhury, S. P. Chowdhury, P. Crossley, "Microgrids and Active Distribution Networks." Institution of Engineering and Technology, 30 Jun 2009
5. Stuart Borlase, "Smart Grids (Power Engineering)", CRC Press
6. Andres Carvallo, John Cooper, "The Advanced Smart Grid: Edge Power Driving Sustainability: 1", Artech House Publishers July 2011

I Year - M. Tech. II Semester

COURSE CODE –	INTEGRATION OF RENEWABLE ENERGY SOURCES (ELECTIVE–III)	CATEGORY	L-T-P 3 -0-0	CREDITS 3

Pre-requisite: Basic knowledge on renewable energy sources, isolated systems and hybrid systems.

Course Outcomes: At the end of the course, student will be able to:

		Knowledge Level (K)#
CO1	Identify the characteristics of renewable energy sources and converters.	
CO2	Analyze the importance of storage and sizing of hybrid systems.	
CO3	Realize the problems related to isolated systems.	
CO4	Analyze the challenges faced by the grid by integrating renewable energy sources.	
CO5	Understand the importance of interconnection issues.	

#Based on suggested Revised BTL

Mapping of course outcomes with program outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

(Please fill the above with Levels of Correlation, viz., L, M, H)

UNIT	CONTENTS	Contact Hours
UNIT – 1	**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 climb and incremental conductance).	
UNIT – 2	**Converter Topologies** DC/DC converter (buck, boost, buck boost) - DC/AC inverters (sine, triangular, PWM techniques) - phase locked loop for inverters.	
UNIT – 3	**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 – 4	**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 – 5	**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 modelling intermittent nature of renewable power in a power system.	
	Total	**48 Hrs**

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 Integration Challenges and Solutions Series: Green Energy and Technology**Hossain**, Jahangir,** Mahmud**, Apel (Eds.)**
3. **Integration of Alternative Sources of EnergyFelix A. Farret, M. Godoy Simões** December 2005, Wiley-IEEE Press.

I Year - M. Tech. II Semester

COURSE CODE –	SOLAR REFRIGERATION AND AIRCONDITIONING (ELECTIVE-IV)	CATEGORY	L-T-P 3 -0-0	CREDITS 3

Pre-requisite: Basic knowledge on solar cooling, types of solar cooling systems, solar collectors and storage systems for solar refrigeration and air-conditioning.

Course Outcomes: At the end of the course, student will be able to:

		Knowledge Level (K)#
CO1	Review on solar collectors and storage systems for refrigeration and air conditioning.	
CO2	Equip the students with the necessary information pertaining to the application of solar energy for refrigeration and air conditioning purposes.	
CO3	Acquire knowledge on advanced cooling systems.	
CO4	Explain various types of refrigeration systems and cooling systems.	
CO5	Understand the thermal modelling and simulation of various refrigeration and air conditioning systems.	

#Based on suggested Revised BTL

Mapping of course outcomes with program outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

(Please fill the above with Levels of Correlation, viz., L, M, H)

UNIT	CONTENTS	Contact Hours
UNIT – 1	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 – 2	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 - 3	Open cycle absorption / desorption solar cooling alternatives - Advanced solar cooling systems - working principles - Energy analysis and performance.	
UNIT – 4	Thermal modelling and computer simulation for continuous and intermittent solar refrigeration and air-conditioning systems - performance evaluation and case studies.	

UNIT – 5	**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.	
	Total	**48 Hrs**

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 Year - M. Tech. II Semester

COURSE CODE –	Evolutionary Algorithms and Applications (ELECTIVE-IV)	PE	3-0-0	3

Course Outcomes: At the end of the course, student will be able to:

		Knowledge Level (K)#
CO1	Explain the methods of soft computing	
CO2	Understand evolutionary methods of genetic algorithm and particle swarm optimization	
CO3	Apply Ant colony and Artificial Bee colony methods for RES	
CO4	Understand Shuffeled Frog-leaping algorithm and Bat optimization algorithm	
CO5	Apply multi-objective optimization methods for engineering problems	

#Based on suggested Revised BTL

Mapping of course outcomes with program outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

(Please fill the above with Levels of orrelation, viz., L, M, H)

UNIT	CONTENTS	Contact Hours
UNIT– 1	**Fundamentals of soft computing techniques** Definition-classification of optimization problems- unconstrained and constrained optimization - optimality conditions- introduction to intelligent systems- soft computing techniques- conventional computing versus swarm computing - classification of meta-heuristic techniques - single solution based and population based algorithms – exploitation and exploration in population based algorithms - properties of swarm intelligent systems - application domain - discrete and continuous problems - single objective and multi-objective problems.	
UNIT– 2	**Genetic algorithm and particle swarm optimization** Genetic algorithms- genetic algorithm versus conventional optimization techniques - genetic representations and selection mechanisms; genetic operators- different types of crossover and mutation operators -bird flocking and fish schooling – anatomy of a particle- equations based on velocity and positions -PSO topologies - control parameters – GA and PSO algorithms for solving ELD problem without loss.	
UNIT– 3	**Ant Colony Optimization and Artificial Bee Colony algorithms** Biological ant colony system - artificial ants and assumptions - stigmergic communications - pheromone updating- local-global - pheromone evaporation - ant colony system- ACO models-touring ant colony system-max min ant system - concept of elistic ants-task partitioning in honey bees - balancing foragers and receivers - Artificial Bee Colony (ABC) algorithms-binary ABC algorithms.	

UNIT– 4	**Shuffled Frog-Leaping Algorithm and Bat Optimization Algorithm** Bat algorithm- echolocation of bats- behaviour of microbats- acoustics of echolocation- movement of virtual bats- loudness and pulse emission- shuffled frog algorithm-virtual population of frogs - comparison of memes and genes - memeplex formation- memeplexupdation- BA and SFLA algorithms for solving ELD without loss and PI controller tuning.	
UNIT– 5	**Multi Objective Optimization** Multi-objective optimization introduction- concept of pareto optimality - non-dominant sorting technique-pareto fronts-best compromise solution-min-max method-NSGA-II algorithm and application to general two objective optimization problem.	
	Total	**48 Hrs**

Text Books

1. Xin-She Yang, Recent Advances in Swarm Intelligence and Evolutionary Computation, Springer International Publishing, Switzerland, 2015.
2. Kalyanmoy Deb, Multi-Objective Optimization using Evolutionary Algorithms, John Wiley & Sons, 2001.
3. James Kennedy and Russel E Eberheart, Swarm Intelligence, The Morgan Kaufmann Series in Evolutionary Computation, 2001.

Reference Books:

1. Eric Bonabeau, Marco Dorigo and Guy Theraulaz, Swarm Intelligence-From natural to Artificial Systems, Oxford university Press, 1999.
2. David Goldberg, Genetic Algorithms in Search, Optimization and Machine Learning, Pearson Education, 2007.
3. Konstantinos E. Parsopoulos and Michael N. Vrahatis, Particle Swarm Optimization and Intelligence: Advances and Applications, InformatIonscIence reference, IGI Global, , 2010.
4. N P Padhy, Artificial Intelligence and Intelligent Systems, Oxford University Press, 2005.

Reference Papers:

1. “Shuffled frog-leaping algorithm: a memetic meta-heuristic for discrete optimization” by Muzaffareusuff, Kevin lansey and Fayzul pasha, Engineering Optimization, Taylor & Francis, Vol. 38, No. pp.129–154, March 2006.
2. “A New Metaheuristic Bat-Inspired Algorithm” by Xin-She Yang, Nature Inspired Cooperative Strategies for Optimization (NISCO 2010) (Eds. J. R. Gonzalez et al.), Studies in Computational Intelligence, Springer Berlin, 284, Springer, 65-74 (2010).
3. “Firefly Algorithms for Multimodal Optimization” Xin-She Yang, O. Watanabe and T. Zeugmann (Eds.), Springer-Verlag Berlin Heidelberg, pp. 169–178, 2009.

I Year - M. Tech. II Semester

COURSE CODE –	HYDROGEN AND FUEL CELLS (ELECTIVE-IV)	CATEGORY	L-T-P 3 -0-0	CREDITS 3

Pre-requisite: Basic knowledge on various technological advancements, benefits and prospects of utilizing hydrogen/ fuel cell.

Course Outcomes: At the end of the course, student will be able to:

		Knowledge Level (K)#
CO1	Explain the hydrogen production methodologies, possible applications and various storage options.	
CO2	Analyse the working principle of a typical fuel cell, types of fuel cells.	
CO3	Understand the challenges in the applications of fuel cell.	
CO4	Analyse the cost effectiveness and eco-friendliness of fuel cells.	
CO5	Understand the working of fuel cell vehicle.	

#Based on suggested Revised BTL

Mapping of course outcomes with program outcomes

	PO1	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**	**PO12**
CO1												
CO2												
CO3												
CO4												
CO5												

(Please fill the above with Levels of Correlation, viz., L, M, H)

UNIT	CONTENTS	**Contact Hours**
UNIT – 1	**Hydrogen-Basics in Production Techniques** Hydrogen - physical and chemical properties - salient characteristics - production of hydrogen steam reforming - water electrolysis- gasification and woody biomass conversion - biological hydrogen production- photo dissociation- direct thermal catalytic splitting of water.	
UNIT – 2	**Hydrogen Storage and Applications** Hydrogen storage options- compressed gas- liquid hydrogen – hydride- chemical storage- comparisons - hydrogen transmission systems - application of hydrogen.	
UNIT – 3	**Fuel Cells** History – fuel cell system - principle – working - comparison on battery Vs fuel cell - types of fuel cells – Alkaline Fuel Cell – Phosphoric Acid Fuel Cell – Solid Oxide Fuel Cell – Molten Carbonate Fuel Cell – Direct Methanol Fuel Cell - Proton Exchange Membrane Fuel Cell- relative merits and demerits.	
UNIT – 4	**Application of Fuel Cell and Economics** Fuel cell usage for domestic power systems - automobile – space - economic and environmental analysis on usage of hydrogen and fuel cell - future trends in fuel cells.	

UNIT – 5	**Fuel cell vehicles and its Constituents** Concept of fuel cell vehicles – operating principle – fuel cell Stack – fuelling option for fuel cell vehicle – fuel cell vehicle integration – technical issues – fuel cell vehicle Vs hybrid vehicle.	
	Total	**48 Hrs**

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 .

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 Year - M. Tech. II Semester

I-II **Energy Systems Simulation Laboratory-II** **L / P / Credits -- / 4 / 2**

List of Experiments:

1. Review of fundamentals of simulation software.
2. Develop a model for monitoring, modelling and simulation of a DC Surface solar PV pump system.
3. Solar cell simulation using simulator.
4. Construction of a wind rose using spread sheet for a particular given interval.
5. Construction of a wind rose using hydrognomon software tool for a particular given interval.
6. Simulate a small PV system designed for a residential rooftop, with a power of 50 kWp. The details of the PV system are as follows:

- PV generator: formed by 200 modules of 250 Wp, series connection in a string 10, parallel strings 9. The PV modules are formed by 60 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 75MWh/year.
- Evaluate the simulation of this PV system over a year. Temperature and irradiance profiles may be ascertained for Ka location.
- Ascertain/assume data not given.

7. Review of design tools.
8. Design model using any design software.
9. Write a C/C++ programme to calculate the load current of a solar cell using relevant mathematical equations for the given data.
10. Write a C/C++ programme to calculate efficiency of a wind turbine using relevant mathematical equations for the given data.

Reference Text:

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

I Year - M. Tech. II Semester

I-II **RENEWABLE ENERGY LABORATORY-II** **L / P / Credits**
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List of Experiments:

1. Estimating the effect of sun tracking on the energy generation by PV modules.
2. Efficiency measurement of a standalone PV System.
3. Testing of MPPT System at various tilt angles under series and shunt configuration.
4. Study and analysis of a solar still / distillation plant.
5. Performance evaluation of a solar flat plate thermo syphon water heating system
6. Conversion efficiency of a solar flat plate forced circulation water heating system
7. Conversion efficiency of a solar Concentrating water heating system.
8. Estimation of average wind speed over a protracted period of time with the help of an anemometer and data logger.
9. 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.
10. Testing of Charge Controllers (Series and Shunt type).

Reference Books (Practical)

4. ***Solar Photovoltaics: A Lab Training Manual,*** Chetan S. Solanki et al, IIT Bombay**,** Cambridge University Press India Pvt. Ltd, 2013.
5. ***System Technician Training Manual Part II, Solar Photovoltaic Training Programme*** CEC, IIT Madras, (under IREDA/World Bank/Siemens/IITM programme).
6. ***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.