Centre of Excellence for Green Energy and Sensor Systems
Indian Institute of Engineering Science and Technology, Shibpur

Complete Course Structure and Syllabus of 2-Year Fulltime M. Tech Programme in Renewable Energy Science and Technology

A. First Semester

Sl.	Paper	Credit
1	Paper-I (Departmental Core)	3
2	Paper-II (Departmental Core)	3
3	Paper-III (Departmental Core)	3
4	Paper-IV (Departmental Elective / Open Elective)	3
5	Paper-V (Departmental Elective / Open Elective)	3
	Theory Subtotal	15
6	Lab - I/ Mini Project - I	2
7	Lab - II/Mini Project - II	2
8	Lab - III/Mini Project - III	2
	Practical Subtotal	6
	Total Credit	21

Table-1

(a) Departmental Core Papers for (Paper-I, II, III)

Paper	Subject Code	Subject Name	Class Load/Wk			Total load	Credit	FM
			L	T	P			
I	GS-5101	Renewable Energy Sources and Materials	3	0	0	3	3	100
II	GS -5102	Solar Cells and Photovoltaic Technologies	3	0	0	3	3	100
III	GS -5103	Energy from Wind and Biomass	3	0	0	3	3	100

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in
Renewable Energy Science and Technology

(b) Departmental Elective Paper (Paper-IV)

Paper	**Subject Code**	Subject Name	Class Load/ Wk			Total load	Credit	FM
			L	T	P			
IV	**GS -5121**	Solar Photovoltaic Power Plants: Design and performance	3	0	0	3	3	100
	GS -5122	Renewable Power generation and Interfacing	3	0	0	3	3	100
	GS -5123	Solar Thermal Technology and Applications	3	0	0	3	3	100
	GS -5124	Biomass Energy Technology: Design and Performance	3	0	0	3	3	100

(c) Open Elective Paper (Paper-V)

Paper	**Subject Code**	Subject Name	Class Load/Wk			Total load	Credit	FM
			L	T	P			
V	**GS -5161**	Fundamentals of Renewable Energy and its Impact on Environment	3	0	0	3	3	100

(d) Departmental Labs for (Lab-I, II, III)

Sl. No	**Subject code**	Subject Name	Class Load/Wk			Total load	Credit	FM
			L	T	P			
1	**GS -5171**	Energy Materials and SRRA Lab Mini Project	0	0	4	4	2	100
2	**GS -5172**	Wind, Biomass Energy and Microgrid Lab / Mini Project	0	0	4	4	2	100
3	**GS -5173**	Solar PV and Thermal Energy Lab Mini Project	0	0	4	4	2	100

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(B) **Second Semester**

Sl.	Paper	Credit
1	Paper - VI (Departmental Core)	3
2	Paper - VII (Departmental Core)	3
3	Paper - VIII (Departmental Core)	3
4	Paper-IX (Departmental Elective / Open Elective)	3
5	Paper-X (Departmental Elective / Open Elective)	3
	Theory Subtotal	**15**
6	M. Tech Project Part - I (Term Paper)	4
7	Term Paper Seminar and Viva-voce	2
8	**Practical Subtotal**	**6**
	Total Credit	**21**

Table-2

(a) Departmental Core Papers (Paper-VI, VII, VIII)

Paper	**Subject Code**	Subject Name	Class Load/ Wk			Total load	Credit	FM
			L	**T**	**P**			
VI	**GS -5201**	Instrumentation and Control in Energy Systems	3	0	0	3	3	100
VII	**GS -5202**	Fuel Cells, Hydrogen Energy and Energy Storage	3	0	0	3	3	100
VIII	**GS -5203**	Smart Microgrid Systems: Design and Performance	3	0	0	3	3	100

(b) Departmental Elective Paper (Paper-IX)

Paper	Subject Code	Subject Name	Class Load/ Wk L	T	P	Total load	Credit	FM
IX	GS -5221	Energy – Policy, Planning and Management	3	0	0	3	3	100
	GS-5222	Wind Energy Technology: Design and Performance	3	0	0	3	3	100
	GS-5223	Small Hydro, geothermal and Ocean Energy	3	0	0	3	3	100
	GS -5224	Advanced Solar Cell Concepts and Related Technology	3	0	0	3	3	100

(c) Open Elective Paper (Paper-X)

Paper	Subject Code	Subject Name	Class Load/ Wk L	T	P	Total load	Credit	FM
X	GS-5261	Renewable Energy Project Management and Economics	3	0	0	3	3	100

(c) M. Tech Project Part-I

Sl. No	Subject code	Subject Name	Class Load/Wk L	T	P	Total load	Credit	FM
1	GS-5291	M. Tech Project Part - I (Term Paper)	0	0	8	8	4	200
2	GS-5292	Term Paper Seminar and Viva-voce	0	0	4	4	2	100

Complete Course Structure and Syllabus of 2-Year Fulltime M. Tech Programme in Renewable Energy Science and Technology

(C) Third Semester

Sl. No	Paper	Credit
1	M. Tech Thesis Part - II (Progress Report)	12
2	Progress Report Seminar and Viva-voce	6
	Total Credit	**18**

Table 3

Sl. No	Subject code	Subject Name	Class Load/Wk			Total load	Credit	FM
			L	T	P			
1.	**GS -6191**	M. Tech Thesis Part - II (Progress Report)	0	0	24	24	12	300
2.	**GS -6192**	Progress Report Seminar and Viva-voce	0	0			6	100

(D) Fourth Semester

Sl. No	Paper	Credit
1	M. Tech Final thesis	22
2	Thesis Seminar and Viva-voce	8
	Total Credit	**30**

Table 4:

Sl. No	Subject code	Subject Name	Class Load/Wk			Total load	Credit	FM
			L	T	P			
1.	**GS -6291**	M. Tech Final thesis	0	0	30	30	22	400
2.	**GS-6292**	Thesis Seminar and Viva-voce	0	0	-	-	8	200

Total Credits = [21+21+18+30]=90

Note on Subject Code:

XX: Department Code (AE, CE, ME, etc.); YY: Year(Y)-Semester(Y) (51, 52, 61, 62, etc.); ZZ: Subject Code (01 to 49 for Theory subjects, 50-99 for practical subjects.

Example: AE5124 [Aerospace Engineering, Fifth Year (PG), First Semester, 24 subject code)

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Detailed Syllabus First Semester

GS -5101	**Renewable Energy Sources and Materials**	**3L : 0T : 0P**	**3 credits**

Course Outcomes:

At the end of this course students will demonstrate the ability to:

CO1	Understand renewable energy sources vis-a- vis conventional sources
CO2	Understand different renewable energy technologies
CO3	Learn materials for energy applications

Module-1: Energy fundamentals
Definition and units of energy and power, Forms of energy, Conventional energy sources, Depletion of conventional energy sources and their impact, Environmental aspects of energy utilization, Energy efficiency and energy conservation, Renewable energy resources. Laws of thermodynamics, Basic energy conversion cycles, Principle of combustion.
Module-2: Sun-the principal source of energy
Indian energy scenario, Global energy scenario, Energy consumption and its relation to economics of countries, Energy transition. Source of energy in the sun, Sun–Earth geometric Relationship, Apparent Path of the Sun, Electromagnetic Radiation, Extra-terrestrial Solar Radiation, Terrestrial Solar Radiation, Solar Spectral Distribution, Measurement of Terrestrial Solar Radiation. Manifestation of solar energy in different forms of energy. Visit to Solar resource monitoring station and analysis of at least three days data.
Module-3: Conventional energy
Fossil fuels: Origin, Resource and reserve status, Developments in conversion technologies. Nuclear energy: Nuclear fission, Nuclear fusion.
Module-4: Emerging Renewable Energy Technologies
Solar thermal, Solar photovoltaics, Wind, Biomass, Micro-hydel- Basic principles, Technologies used in practice and applications, Resource assessment criteria, Status in India- Geothermal, wave energy, tidal energy, ocean thermal energy-Basic principles and technology status- Hydrogen economy.
Module-5: Materials for energy applications and their characterization
Silicon: Role of Silicon in solar PV industry, metallurgical grade silicon (MGS), electronic grade silicon (EGS), multi Si ingots, mono-Si ingots, Czochralski (CZ) process, Float zone (FZ) process, feedstock of Solar grade Si, Thin Silicon, Silicon Nanofilm, Characterization of silicon for solar cells. III-V and II-VI Compounds for solar cells application; Fabrications of GaAs, CdTe and CuznTeSe solar cells and their properties; Nanostructure materials and engineering for solar cells; Different characterization techniques.

Text Books:

1. Twidell John W. And Weir Anthony D, Renewable energy Resources, ISBN 0419144706, e &
   F. N. Spin, London, 1986
2. Bansal N.K., Kleemann M. and Meliss M., Renewable Energy Sources and Conversion Technology, Tata McGraw Hill Publishing Company, New Delhi, 1990
3. J N Roy and D N Bose: Photovoltaic Science and Technology, Cambridge University Press, 2018

Reference Books:

1. Dunn P.D., Renewable Energies: Sources, Conversion and Applications, Heftners Printers Ltd., Cambridge, 1986, ISBN 0863410391
2. Johansson Thomas B., Kelly H., Reddy A.K.N., and Williams R.H., Renewable Energy: Sources for Fuels and Electricity, Earthscan Publications Ltd., London, ISBN 1.55963-139-2
3. Kishore V.V.N, Renewable Energy Engineering and Technology, TERI Press, New Delhi, 2008, ISBN 81-7993-093-9

GS-5102	**Solar Cells and Photovoltaic Technologies**	**3L : 0T : 0P**	**3 credits**

Course Outcomes:
At the end of this course students will demonstrate the ability to:

CO1	Learn fundamentals of solar cell technology
CO2	Learn manufacturing of solar cells and its tests

Module-1: Fundamentals of solar cell-1 Semiconductors and junctions, I-V characteristics of p-n junctions. Solar Cell Structure, Light generated Current, Light IV Characteristics, Solar cell parameters, Spectral Response and Quantum Efficiency, Effect of Series Resistances and Shunt Resistances on solar cell I-V characteristics, Effect of Temperature and Light Intensity, effect of shading, Losses in solar cells.	
Module-2: Fundamentals of solar cell-2 Generation recombination in semiconductors; Shockley, Read and Hall expression; Surface and interface recombination; Schockley-Queissser limit of efficiency	
Module-3: Manufacturing of silicon solar cells Cell Fabrication Technologies, Screen Printed Solar Cells, Buried Contact Solar Cells, High Efficiency Solar Cells, Rear Contact Solar Cells.	
Module-4: Solar Cell Production Line Silicon Source Material, Wafers, Cleaning, Texturing, Diffusion, Plasma Ed RE Isolation, Anti- Reflection Coating, Screen-Printed front and rear contact, Testing and Module fabrication	
Module-5: Test and measurements Solar simulator, measurement of efficiency of solar cell, External quantum efficiency (EQE) and Internal quantum efficiency (IQE) measurement, Quantum efficiency analysis, Lifetime measurement	

Text Books:

1. Solanki Chetansingh, Solar Photovoltaics,: Fundamentals, Technologies and Applications, ISBN-978-81-203-3760-2, PHI Learning Pvt. Ltd., New Delhi
2. Bansal N.K., Photovoltaics Systems, ISBN 81-901296-0-0, Omega Scientific Publishers, New Delhi, 2003
3. Brendel R., Thin Film Crystalline Solar Cells: Physics and Technology, Wiley-VCH, Verlag GmbH and Company, Weinheim Germany, 2003
4. J N Roy and D N Bose: Photovoltaic Science and Technology, Cambridge University Press, 2018

Reference Books:

1. Green M.A., Silicon solar Cells: Advance Principles and Practices, BridgeRE Printrey, Sydney,1995
2. Green M.A., Solar Cells: Operating Principles, Technology and system Applications, Prentice Hall Incl. Engelwood Cliffs N.J., USA, 1982
Chopra K.L. and Das S.R., Thin Film Solar Cells, Springer, 1983

GS -5103	**Energy from Wind and Biomass**	**3L : 0T : 0P**	**3 credits**

Course Outcomes:

At the end of this course students will demonstrate the ability to:

CO1	Learn energy harvesting from wind through turbine
CO2	Learn energy harvesting from Biomass through biogas plant

Module-1: Wind Energy: Global Wind Energy resources, Pressure gradient and coriolis forces ,Atmospheric boundary layer , Atmospheric stability, Basic concepts of wind energy converter , surface wind characteristics and related parameters, Wind data assessment and selection of prospective wind energy sites, Estimation of wind energy, Energy equation,	
Module-2:Wind Turbine: Types of wind energy converters or turbines, Different components of wind turbine, selection of turbine rotors, Electrical system used for electrical power REneration, Basic Aerodynamic design principle of turbine, Commercial application of wind turbine, Wind farms, concept of wind tree and wind pump.	
Module-3: Measuring instruments for wind energy application Measurement of wind velocity-Anemometer-vane type – cup type, modern instruments and their principles.	
Module-4: Bio-mass Energy: Different types of thermochemical conversion processes, viz. direct combustion, pyrolysis, gasification, liquefaction, reaction kinetics. Bio-chemical conversion, aerobic and anaerobic conversion, fermentation. Properties of biomass. Bio- methanation and its chemical kinetics. Bio-degradation and bio-degradability of substrates. Bio-conversion of substrates into methanol, ethanol, organic acids, aminoacids and solvents.	
Module-5: Biogas plants Types of plants, design and operation, properties and characteristics of biogas. Economics of biogas plants with their environmental and social impacts. Applications of bio-fuels. Comparison of bio fuels with petroleum fuels. Ethanol as a fuel for IC engines. Relevance with Indian economy.	

Text Books:

1.S.M. Muyeen, Wind energy Conversion systems, Springer
2.Yosif Golfman, Hybrid anisotropic Materials for Wind Power Turbine Blades, CRC Press

3. Manwell J.F., McGowan JG and Rogers A. L., Wind energy Explained : Theory design and application, John Wiley and Sons Ltd., London 2002 4. Kaupp A. And Goss J., Small Scale Gas Producer Engine System, Veihweg 1984
Reference Books: 1. Pramod Jain, Wind Energy Engineering, Mcgraw Hill 2. Wagner H.J. and Mathur J. Introduction to Wind Energy Systems, Springer, Berlin, 2009 3.Golding E. W., The REneration of Electricity by Wind Power, Redwood Burn Ltd., Trowbridge,1976 4.Letcher, Wind Energy Engineering, ISBN 9780128094518, AP

GS -5121	**Solar Photovoltaic Power Plants: Design and Performance**	**3L:0T:0P**	**3 credits**

Course Outcomes:
At the end of this course students will demonstrate the ability to:

CO1	Learn details of solar photovoltaic power plant along with its measuring systems
CO2	Understand fundamental of balance of systems
CO3	Understand fundamentals of stand-alone and grid-tied PV-systems

Module-1: Solar photovoltaic power plants: Estimating power and energy demand, site selection, land requirements, choice of modules, economic comparison, balance of systems, Preparing DPR, Supporting structures, mounting and installation, junction boxes, battery storage, power condition unit, selection of cables and balance of systems, maintenance and schedule, Performance Analysis, Financial Analysis, Life Cycle Costing, Environmental Analysis and Social Costs, worksheet, customer care.	
Module-2: Control and Instrumentation in SPV power plant Sensors and transducers, measuring instruments, measurement techniques, SCADA system, Data logger, Monitoring, Data Management, control techniques, overall plant management	
Module-3: Balance of Systems Electrical Storage: Battery technology, Batteries for PV systems, DC – DC converters, Charge Controllers, DC – AC inverters; single phase, three phase, other balance of system components, MPPT, Array structures and cabling.	

Module-4: Stand-alone and Grid tied PV systems Stand alone: Components; system sizing; batteries; AC vs DC efficiency; Designing a stand- alone system, hybrid PV systems. Grid Tied: Distributed generation, grid support, peak power matching; size and economics, Building Integrated Photovoltaics (BIPV) off grid systems	
Module-5: Field Installation, Commissioning and Trouble-shooting in SPV power plant Installation and commissioning of SPV power plant, steps, precautions, final site performance testing. Operation and running maintenance, trouble-shooting.	

Text Books: 1. Archer M.D. and Hill R., Clean Electricity from Photovoltaics, Imperial College Press, U.K., 2001 2.. Luque L.A. and Andrew V.M., Concentrator Photovoltaics, Springer 2007 3. Boxwell Michael, Solar Electricity Handbook: 2010 Edition, A Simple Practical Guide to Solar Energy, Greenstram Publishing, Uk, 2010 4.Reinders, Verlinden, Van Sark and Freundlich, Photovoltaic solar energy-from fundamentals to applications by Reinders, Verlinden, VanSark and Freundlich, ISBN 9781118927465, Wiley 5. J N Roy and D N Bose: Photovoltaic Science and Technology, Cambridge University Press, 2018.
Reference Books: 1. Archer M.D. and Robert Hill, Clean Electricity From Photovoltaics, Imperial College Press, London UK, 2001 2. Winter C.-J., Sizmann R.L. and Varll-Hull (Eds.), Solar Power Plants : Fundamentals, Technology, Systems, Economics, Springer-Verlag, Berlin, 1991 3.Peter gevorkian, Large Scale Solar Power System Design, Mcgraw Hill

GS -5122	**Renewable Power Generation and Interfacing**	**3L:0T:0P**	**3 credits**

Course Outcomes:
At the end of this course students will demonstrate the ability to:

CO1	Learn rotating generators to interface renewable sources
CO2	Learn interface methods with protections
CO3	Know the relevant appliances

Module-1: Synchronous and Asynchronous Generators Synchronous generator: principle of operation, Parallel operation of synchronous generators, Synchronising techniques, effect of reactance, effects of changes in excitation, driving torque, speed, voltage, load sharing, Load - frequency curve. Synchronous motor: starting, phasor diagram, characteristics, torque-angle relationship, uses. Polyphase induction machine: Brief overview, torque slip curve, Induction generators: operating principle, equivalent circuit, implications and uses, mathematical modeling and analysis.	
Module-2: Permanent Magnet Generator Direct current generator, classification, operation, parallel operation, general maintenance, trouble-shooting, Direct Rotor Coupled generator (Multipole) [Variable Speed, Variable Freq.] Excited Rotor Synch. generator / PMG generator,	
Module-3: Interfacing Methods of Generator to Grid Transformer-equivalent circuit-vector grouping-parallel operation, unit transformer,	

Connection of unit transformer to grid, auxiliaries, protections, Synchronising conditions and effects.	
Module-4: Power Transportation and Protection of Generators Power transfer-AC system and DC system- transmission with series impedance, constant voltage transmission, power circle diagram, renewable source integrated dc and ac distribution, protections of transmission and distributions systems. Protection of generators: Overcurrent, earthfault- directional and non-directional, differential, unbalanced loading, over voltage, under voltage, voltage sensitive overcurrent, prime mover failure, field failure, numerical relays	
Module-5: Appliances Brushless DC machine-working principle-applications, solar pump- working principle-applications, E-vehicles- working principle-applications, lighting applications- working principle-applications.	

Text Books: 1. Electric Machinery, A.E.Fitzgerald, Charles Kingsley,Jr. & Stephen D. Umans, 6thEdition, Tata McGraw Hill Edition. 2. Theory of Alternating Current Machinery, Alexander S Langsdorf, Tata Mc Graw Hill Edition 3.The performance and Design of Alternating Current Machines, M.G.Say, CBS publishers & distributors.
Reference Books: 1. Power system stability, Kimbark 2. Art and science of protective relaying, Mason

GS -5123	**Solar Thermal Technology and Applications**	**3L:0T:0P**	**3 credits**

Course Outcomes:

At the end of this course students will demonstrate the ability to:

CO1	Understand different components related to solar thermal technology
CO2	Learn fundamentals of solar thermal power plant
CO3	Learn energy efficient buildings

Module-1: Heat Transfer Processes Review of heat transfer fundamentals, Characteristic of thermal radiation- Radiation laws- Radiation properties- Radiation heat exchange between black/grey surfaces with and without participating medium- Radiation in Enclosures- - Combined conduction, convection and radiative heat exchange.	
Module-2: Solar absorbers and reflectors Solar absorbers, measurement techniques and instrumentation, Anti-reflective coating, Different types of Solar reflectors, Materials for solar reflectors-multi layer and polymer based mirrors, Materials and methods for storage of Solar Thermal Energy.	
Module-3: Solar collectors and systems	
Flat Plate and Evacuated Tube Collectors: general characteristics, thermal analysis, thermosiphon system, short term and long term performance characteristics. Concentrating solar collectors: Concentrators, receivers and orienting systems, general characteristics, thermal analysis, performance, materials, Solar cookers, water heaters; dryers; desalination systems; Solar ponds, Industrial process heat units. Solar refrigeration and air-conditioning, solar cold storage.	
Module-4: Solar thermal power plant Solar thermal power generation systems: power tower, distributed line focus and point focus systems, solar pond based power plants, solar furnaces. Power Plant Layout and Economics - Environmental aspects of thermal power plants	
Module-5: Energy conscious building Passive heating: direct gain, indirect gain, thermal storage wall, roof top collectors, isolated gain, solarium. Passive cooling: Ventilation cooling, wind tower, nocturnal cooling, evaporative cooling, roof surface evaporative cooling (RSEC), direct evaporative cooling using drip-type (desert) coolers, earth coupling, earth-air tunnel system Daylighting: basic principles and systems, Energy efficient windows.	

Text Books: 1. S.P. Sukhatme, Solar Energy : Principles of Thermal Collection & Storage, Tata McGraw Hill, Publications, New Delhi, 1984 2.Duffie J.A. and Beckmann W.A., Solar Engineering of Thermal Processes, 2ndedl, Wiley Interscience, New York, 1991 3.Magal B.S., Solar Power Engineering, Tata McGraw Hill Publishing Company Ltd., New Delhi, 1990
Reference Books: 1. Meinel and Meinel, Applied Solar Energy, Addison Wesley Publishing Co. Inc., Reading, 1976 2. Kreith F. and Kreider J.F., Principles of Solar Engineering, Hemisphere Publishing Corp., New York, 1979 3. Kreider J.F., Medium and High Temperature Solar Processes, Academic Press Inc., Orlando, Florida, USA, 1979 4. Beckmann G. and Gilli P.V., Thermal Energy Storage, Springer Verlag New York Inc., 1984 5. Garg H.P., Treatise on Solar Energy, Vol. I, John Wiley and Sons Ltd., Chichester Sussex VD 1982

GS -5124	Biomass Energy Technology: Design and Performance	3L:0T:0P	3 credits

Course Outcomes:

At the end of this course students will demonstrate the ability to:

CO1	Learn biomass resources and their characteristics for energy generation.
CO2	Understand methods of conversion of biomass to energy

Module-1: Biomass Resources Biomass resources and properties – classification – availability – estimation of availability, consumption and surplus biomass – Proximate analysis, Ultimate analysis, thermo gravimetric analysis and summative analysis of biomass – briquetting. Bio fuels Production and Utilization: Fuel related properties of biomass; pre-conditioning processes such as size reduction and densification; combustion, pyrolysis and gasification of biomass, photosynthetic efficiency, plant productivity and bio-energy yield, biomass waste.	
Module-2: Biomass Chemistry Biomass pyrolysis – types, slow fast – manufacture of charcoal, methods, yields and application – manufacture of pyrolytic oils and gases, yields and applications. Biomass gasification – gasifiers – fixed bed system – downdraft and updraft gasifiers – fluidized bed gasifiers – design, construction and operation – gasifier burner arrangement for thermal heating – gasifier engine arrangement and electrical power – equilibrium and kinetic consideration in gasifier operation.	
Module-3: Process for Biomass to Energy Biomass combustion – biomass stoves – improved chullahs, types, some exotic designs – fixed bed combustors – types, inclined grate combustors – fluidized bed combustors – design, construction and Principals of operation. Thermo-chemical Conversion -Basic aspects of biomass combustion - heat of combustion - different types of grates - Co combustion of biomass – Gasification - Fixed and Fluidized bed gasifier - Gasification technologies for the selected waste like Rice Husk, Coir pith, Bagasse, Poultry litter etc.	

Module-4: Introduction to Energy from waste Classification of waste as fuel – agro based, forest residue, industrial waste, MSW – conversion devices – incinerators, gasifiers, digestors. Solid Waste -Definitions: Sources, types, compositions; Properties of Solid Waste; Municipal Solid Waste: Physical, chemical and biological property; Collection, transfer stations; Waste minimization and recycling of municipal waste. Landfill method of solid waste disposal; Landfill classification; Layout and preliminary design of landfills: Composition, characteristics, generation; Design of Sanitary Land fill - Environmental monitoring system for landfill gases.- Gas Recovery – Applications Waste Treatment and Disposal Size Reduction: incineration.	
Module-5: Energy Generation from Waste Types: Biochemical Conversion: Sources of energy generation, Industrial waste, agro residues; Anaerobic Digestion: Biogas production; Determination of BOD, DO, COD, TOC, and Organic loading, Aerobic and Anaerobic treatments – types of digester –factors affecting biodigestion - Activated sludge process. Methods of treatment and recovery from the in	

industrial waste water – Case Studies in sugar, distillery, dairy, pulp and paper mill, fertilizer, tanning, steel industry, textile, petroleum refining, chemical and power plant. Rural applications of biomass.	

Text Books: 1. Hall D.D., Bernard G.W. and Mass P.A., Biomass for Energy in Developing Countries, Pergamon Press Oxford, 1982 2.San Pietro A.(ed.), Biochemical and Synthetic Aspects of Energy Production, Academic Press, London 1980 3.Slesser M. and Lewis C., Biological Energy Resources, E and F.N. Spon, London, 1979 4. Vergara W. and Piemental D., Fuels from Biomass in Auer P.(ed) Advances in Energy Systems and Technology, Vol 1, Academic Press, New York, 1978
Reference Books: 1. Meynell P.J., Methane-Planning a Digester, Prism Press, Dorchestor, U.K., 1976 2.Reddy A.K.N., Kelly H., Johansson T.B. and Williams R.H., Renewable Energy: Sources for Fuels and Electricity, Earth Scan Publishing Ltd., London 1993 3.Reed T. and Gaur S., A Survey of Biomass Gasification, ISBN 1-890607-13-4180 Encyclopedia of Biomass Thermal Conversion: Pyrolysis, Gasification and Combustion Principles and Technology, ISBN 1-890607-20-7

GS -5161	**Fundamentals of Renewable Energy and its Impact on Environment**	**3L:0T:0P**	**3 credits**

Course Outcomes:

At the end of this course students will demonstrate the ability to:

CO1	Learn RE technologies
CO2	Learn the fundamentals of silicon and other energy materials
CO3	Learn energy policy and planning

Module-1: Introduction to Energy and Renewable Energy Technologies National and Global Energy Scenario, Conventional Energy Sources, Impact of Fossil Fuel Nuclear Power on Environment, Necessity for sustainable of clean energy sources.
Module-2: Different Renewable energy Sources Solar Energy , Wind Energy, Biomass energy, Mini Hydro energy Geothermal–Ocean-Tidal Energy

Module-3: Solar Photovoltaics Basic Principals of Solar cells, I-V Characteristics, Conversion efficiency; Different type of solar cells; Solar PV modules; Solar PV Systems.
Module-4: Wind as Biomass Energy Basic Principles of Wind generators; Wind Power plant and their characteristics; Basic Principles of Biomass Power plants and their Grid Integration .
Module-5: Economics of Renewable Energy

Economical viability, Grid parity Concept; Integration of Renewable Energy with conventional Grid; Renewable Energy Management; Renewable energy Policy.

Text Books: 1. Dunn P.D., Renewable Energies : Sources, Conversion and Applications, Heftners Printers Ltd., Cambridge, 1986, ISBN 0863410391 2. Bansal N.K. (ed.), Decentralized Energy: Operations and Technology, Omega Scientific Publishers, New Delhi, 1993, ISBN 81-85399-26-3 3. Sorenson B., Renewable Energy, Academic Press, London,1979 4. J N Roy and D N Bose: Photovoltaic Science and Technology, Cambridge University Press, 2018
Reference Books: 1. Kruger Paul, Alternative Energy Sources, John Wiley & Sons, Inc, 2006, ISBN 13:978047177208- 8. 2. Quaschning Volker, Understanding Renewable Energy Systems, Amaxon.com, 2010. 3.Rub, Power Electronics, ISBN 9781118634035,Wiley

GS -5171	**Energy Materials and SRRA Laboratory/ Mini Project**	**0L:0T:4P**	**2 credits**

Course Outcomes:
At the end of this course students will demonstrate the ability to:

CO1	Characterize different energy materials
CO2	Learn different aspects of solar and other climatic parameters on RE generation.

1. Calculation of Sun's position and Solar Radiation

2. Measurement of Direct, Diffuse, Reflected and Global Radiation: comparison with calculated values.

3. Measurement of temperature, humidity, wind speed and direction and assessing their influence on solar and wind potential.

4. Materials characterization lab

5. Experiment on Water Electrolysis and Hydrogen generation

6. Measurement of Global radiation, Day temperature, Relative humidity and calculations of co- relation among them.

GS - 5172	Wind, Biomass Energy and Microgrid Lab / Mini Project	0L:0T:4P	2 credits

Course Outcomes:

At the end of this course students will demonstrate the ability to:

CO1	Learn different aspects of wind power Generation.
CO2	Learn different aspects of power generation from biomass.
CO3	Familiarise with RE integrated microgrid operation

1.To calculate the cut-in speed of wind turbine

experimentally 2.Evaluate the Tip Speed ratio (TSR) at

different wind
Speeds

3.Evaluate the coefficient of performance of wind

turbine 4.Draw the turbine Power versus wind speed

curve 5.Demonstrate the power analysis at turbine

output

6. To study the power efficiency of the bio gas generator plant.

7. To study the parallel operation and load sharing of the biogas generator with solar and wind sources in the microgrid in **off-grid mode**.

8. To study the parallel operation and load sharing of the biogas generator with solar and wind sources in the microgrid in **on-grid mode**.

9. To study the design and fabrication of grid-tie and off grid inverter

10. Design and Computation Laboratory using PSCAD, PVSyst, COMSOL software

GS -5173	**Solar PV and Thermal Energy Lab / Mini Project**	**0L:0T:4P**	**2 credits**

Course Outcomes:
At the end of this course students will demonstrate the ability to:

CO1	Learn different aspects of solar PV power generation.
CO2	Learn different aspects of solar thermal power generation .

1. To connect the PV modules in series and parallel combination to measure the current voltage (I-V) characteristics of each single panel and their combinations in series and parallel.

2. To measure various parameters like short circuit current, open circuit voltage, fill factor, maximum power and relative power loss.

3. In a single graph, plot I V curves for different illumination intensities. From the curves, determine the solar cell parameters (short circuit current(I_{SC}), open circuit voltage(V_{OC}), fill factor (FF) and efficiency) at each light intensity level.

4. Calculate the series resistance (R_S) of the cells from slope (dV/dI) = dV/dI at $V=V_{OC}$ is equal to R_S.3. Calculate also the series resistance(R_S) of the cells by two intensity method.4. Calculate the shunt resistance of the solar cells (dV/dI) at $I=I_{SC}$ is equal to R_{sh}. Calculate Fill Factor (FF) and Efficiency (η) from the data derived from the I V curves and efficiency at different illumination intensities.

5. At a fixed temperature, plot short circuit current vs illumination intensity

6. At a fixed illumination, plot open circuit voltage vs absolute temperature

7. Estimate the diode quality factor and the band gap energy of silicon forming the homo-junction solar cell

8. Plot V_{OC} vs I_{SC} data and obtain information about diode quality factor and band gap energy of the material forming the solar cell

(a) IV characteristic when panels are connected in series
- (i) No shading
- (ii) A complete panel is shaded.

(b) IV characteristic when panels are connected in parallel
- (i) No shading
- (ii) 25% shade (1 panel is shaded)
- (iii) 50% shade (2 panels are shaded)
- (iv) 75% shade (3 panels are shaded)

9. Evaluation of UL, FR and η in Thermosyphonic mode of flow with fixed input parameters
10. Evaluation of UL, FR, η in Thermosyphonic mode of flow at different radiation level
11. Evaluation of UL, FR, η in Thermosyphonicmode of flow at different inlet water temperature.

Second Semester

GS -5201	**Instrumentation and Control in Energy Systems**	**3L:0T:0P**	**3 credits**

Course Outcomes:
At the end of this course students will demonstrate the ability to:

CO1	Understand the principle and operation of different types of sensors and transducers
CO2	Learn different power electronic devices and their applications.
CO3	Learn different types of measurement and control devices.

Module-1: Sensors and Transducers Sensors for electrical parameter measurement, sensors for process parameter measurement of temperature, pressure and flow- Gas analyzers-measurement of smoke, dust and moisture, pH-gas chromatography-spectrometry-Smart sensors-generalised operating principles-interfacing-applications, Digital Transducers – Interface system and Standards – Computer automated measurements and controls – Remote monitoring and control.	
Module-2: Solid State Power Controllers Power devices-Thyristor-MOSFET-IGBT- construction-operations-characteristics, Triggering Circuits-Rectifiers-Choppers-Inverters-AC Controllers, operating principles-limitations	
Module-3: Motor Drives and controllers Characteristics of DC and AC motors for various applications-starting and speed control- methods of braking, Single and Three Phase fed DC motor drives-AC motor drives-Voltage Control-Rotor resistance control-Frequency control-Slip Power Recovery scheme	
Module-4: PLC, Microprocessors and microcontrollers in Measurement Introduction to programmable Logic Controllers, Microprocessor and computer in measurement, Data logging and acquisition, use of intelligent instruments for error reduction, element of micro-computer interfacing, intelligent instruments in use.	
Module-5: PC-based Instrumentation DATA acquisition systems: Functional block diagram and components; signal conditioning concepts and ground loops, common instrument interfaces, instrument buses, introduction to virtual instrumentation (VI), software based instruments. Computer Based Monitoring And Communication System: Data acquisition systems - expert based systems for energy management – Fault detection system, PC based and GSM communication systems.	

Text Books: 1.D Patranabis, Sensors and Transducers, PHI 2.M.H. Rashid, Power Electronics, PHI/ Pearson Education 3.M.Mitra and S.Sengupta, Programmable Logic Controllers And Industrial Automation An Introduction, Penram International Publishing (India)
Reference Books:
1. E. A. Doebelin, Measurement Systems: Application and Design ,McGraw Hill, New York 2. P.C. Sen, Power Electronics 3.B.K.Bose, Modern Power Electronics, JAICO 4.John. W. Webb Ronald A Reis, Programmable Logic Controllers -Principles and Applications, Prentice Hall Inc

GS -5202	**Fuel Cells, Hydrogen Energy and Energy Storage**	**3L:0T:0P**	**3 credits**

Course Outcomes:
At the end of this course students will demonstrate the ability to:

CO1	Learn Fuel cells and hydroREn as energy sources.
CO2	Learn battery energy sources with their different aspects.

Module-1: Fuel Cells Principle - working thermodynamics, different types of fuel cells, HydroREn production for fuel cell feeding, fuel flexibility in fuel cells, Polymer electrolyte membrane fuel cell, Portable and stationary application of fuel cells, Electrical analysis of fuel cell with equivalent circuit and small fuel cell power plants, comparison on battery Vs fuel cell, Types of fuel cells – AFC, PAFC, SOFC, MCFC, DMFC, PEMFC, microbial fuel cells, relative merits and demerits. 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, portable fuel cells, laptops, mobiles, submarines.	
Module-2: Hydrogen production process Electrochemical-Electrolysis, photo electro chemical, PM based electrolyser, Photoelectrolysis, Photocatalytic, Biological-Anaerobic digestion reactions-oxidation and reduction, Thermal-Steam reformation, thermo-chemical water splitting, **Hydrogen storage:** zeolites, metal hydride storage, hydrogen as storage medium for renewable energy systems	

Module-3: Electrochemical Energy Storage Systems Electrochemical principles: Electrochemical redox, Oxidation-reduction half cells, Galvanic Cells, Salt Bridge, Electrochemical series, Simple Voltaic Cell, Reversible and Irreversible Cells, Electrode potential, Factors affecting electrode potentials, Reversible electrode (standard electrodes), Nernst Equation, Electrode reactions and Cell Chemistry, Nature of the electrode reaction, Electron Transfer, Mass transport, Ficks Law, Concentration profile, Convection (rotating disc electrode), Potential step technique, Electrochemical double layer, Potential sweep technique, Impedance spectroscopy,	
Module-4: Battery Primary batteries, secondary batteries, Reserve batteries, Operation of a cell, Theoretical cell voltage, capacity and energy, specific energy and energy density of a practical battery Voltage level, Current drain of discharge, Mode of discharge, Temperature of battery during discharge, Service life, Effect of Cell and Battery design, Battery Age and storage condition. Battery Standards: International Standards, Concept of Standardization, IEC and ANSI nomenclature, Rechargeable battery, Electrical performance, Regulatory and Safety	
standards. Charging primary battery, Protection of battery short circuit current, Voltage reversal, Protection of Batteries from external charge.	
Module-5: Battery design Primary Battery design: Types and characteristics of primary battery, Voltage and discharge profile, Comparison of performance of representative primary batteries, Effect of discharge load and duty cycle, effect of temperature, Shelf life, cost, Zinc-carbon batteries. **Secondary Battery design**: Voltage and discharge profile, Effect of discharge rate on performance, Effect of temperature, Life, Charge characteristics, Pb acid battery. Nickel cadmium battery, Li-ion battery. Designing of Lithium primary batteries, Battery dimensions, battery construction, Cell encapsulation, Case design, Terminal contact material.	

Text Books: 1. Pasquale Corbo, Fortunato Migliardini, Ottorino "Hydrogen Fuel Cells For Road Vehicles", Springer 2. Energy Storage in Power Systems by Gonzalez 3. Fuel Cells by Stolten
Reference Books: 1. Ru-Shi Liu, Lei Zhang, Xueliang Sun, Hansan Liu And Jiujun Zhang "Electrochemical Technologies For Energy Storage And Conversion" Wiley-Vch (Set Of 2 Vol.)

GS -5203	**Smart Microgrid Systems: Design and Performance**	**3L:0T:0P**	**3 credits**

Course Outcomes:
At the end of this course students will demonstrate the ability to:

CO1	Learn different types of microgrid
CO2	Understand different operational features of smart microgrid
CO3	Learn stability and protection of smart microgrid

Module-1: Introduction to Smart Microgrid Different types of microgrid-advantages and disadvantages- Decentralized generation technologies-Costs and choice of technology, Demand and benefits forecasting and program development, Principles of cost-benefit calculations. The power grid; DG-Grid interconnection issues, Mini and Micro Grids – Economics – Environmental Factors – Rural electrification-. Forecasting and basic trading, Demand response, Demand Side Management	
Module-2: Smart grid Communications technology Power System communication: Evolution of power system communication, Power line communication, Optical Fiber Communication, Computer Communication Technology:	
Types of Communication Interface, Types of Networking Channels, Parallel and serial communication, Communication Mode, Standard Interface- RS 232, RS 485, Software Protocol, ASCII Protocol, HART Protocol, Manufacturer Specific Protocol, Network Topology, Bus Network- Device Bus, Process Bus, Field Bus, Profi Bus Communication Standards IEC6150	
Module-3: Smart Microgrid communication systems Microgrid automation, Distributed Control System, Supervisory Control and SCADA systems: Real time database processing, server-client and server-server communication, dynamic data exchange (DDE), object linking and embedding (OLE), redundancy, functionality, AMI, AMR and MDA: Principles and applications, Wide Area Situation Awareness (WASA), Network stability, Phasor Measurement Unit (PMU) Distribution Management Systems (DMS) and Meter Data Management (MDM)- basic principle- structure-operation-limitation.	

Module-4: Smart Microgrid Operational Features Demand Side Integration-need-Demand Response-Demand Side manaREment-implementing technologies- Components of DSI, Concept of energy efficient load, consumers participation in DSI-prosumers. generation and load scheduling in a smart microgrid, Virtual Power Plants (VPP)-operating principles-advantages. Integration techniques of smart microgrid with smart grid-advantages and limitations.	
Module-5: Stability and Protection of Smart Microgrid Basic concept, angle stability, voltage stability, classification of angle stability-steady state- transient stability- implications with system operation-methods of improvement-use of AVR- switching. Voltage stability-concept- voltage collapse-assessment methods-index-methods of improvement- Principles of Circuit Interruption-Circuit Breakers. Protection of transformers, motors, generators. Transmission lines- critical applications; Power swing conditions.	

Text Books: 1. Mahmoud “Microgrid”, ISBN: 9780081017531, Elsevier 2. Gabbar, ”Smart energy Grid Engineering”, AP, ISBN: 9780128953430
Reference Books: 1. Fan, “Control and Dynamics in power systems and microgrids”, CRC Press, ISBN: 9781138034990

Centre of Excellence for Green Energy and Sensor Systems
Indian Institute of Engineering Science and Technology, Shibpur

Complete Course Structure and Syllabus of 2-Year Fulltime M. Tech Programme
in
Renewable Energy Science and Technology

GS -5221	` **Energy – Policy, Planning and Management**	**3L:0T:0P**	**3 credits**

Course Outcomes:
At the end of this course students will demonstrate the ability to:

CO1	Understand different facets of energy policy and planning
CO2	Learn modern energy management systems

Module-1: Overview: Global and National Energy Scenarios, Issues & Challenges, Energy and economic development, Energy intensity, Energy access, Energy poverty, Energy security, Energy pricing, Energy vision. Indian energy demand and supply options. The Pattern of Energy use, Fossil fuel reserves. The First Law efficiency, Second Law efficiency and Exergy, Energy quality and energy productivity. Energy-Environment Linkage, pollutants from energy uses and control measures, Greenhouse Gases, Greenhouse Effect, Global Warming, Climate Change, Inter Governmental Panel on Climate Change (IPCC), Montreal Protocol, Kyoto Protocol, Emission Trading, Clean Development Mechanism, National Action Plan on Climate Change (NAPCC), National Solar Mission (NSM), National Mission on Enhanced Energy Efficiency (NMEEE), National Mission on Sustainable Habitat (NMSH).	
Module-2: Energy Audit and Management: Energy Audit: Need, Types, Methodology and Approach. Energy Management Approach, Understanding Energy Costs, Bench marking, Energy performance, Matching energy usage to requirements, Maximizing system efficiency, Optimizing the input energy requirements, Fuel and Energy substitution. Managerial functions, Role and responsibilities of Energy Manager, Requirements for Energy Action Planning. Information Systems: Designing, Barriers, Strategies, Marketing and Communication, general Principles of Energy Management.	
Module-3: Elements of economic principle: Economic calculation. Energy economics basic concepts, unit cost of power generation from different sources, payback period, NPV, IRR and benefit cost analysis. Direct and indirect costs, pricing system and project management: Different types of electricity Pricing, different components, Cost-Benefit analysis of RE project, Case studies of Financial Evaluation of Renewable Energy Technologies, Business opportunity models in RE.	

Module-4: Energy policy Energy Policy-Purpose, Perspective, Contents and Formulation: Contents of energy policy, Features of good policy making, Drivers of energy policy, Policy instruments, Energy return on investment, Concept of welfare economics, Energy goods and energy services, Production functions and objective functions, Evolution of energy and electricity policies in India, Energy (and power) policies in the country, Tariffs and subsidies, Energy utility interface, Emergence of policy and regulatory framework for sustainable energy. Review of solar ground mounted and rooftop policies and regulations. State solar policy formulation exercise.	
Module-5: Energy planning	
Energy planning-purpose and functions, Components, Consequences, Real world expectations, Mathematical tools for decision making, Mathematical models, Energy transition, Energy efficiency and conservation, Jevons' paradox, Renewable energy use as a measure of energy conservation, Global energy planning analysis-declining energy intensity, Energy models-classification and discussions , Absolute and relative decoupling: resource use and GDP, Energy planning and policy analysis, Integrated planning, An exercise on planning for solar power.	

Text Books: 1. Blaic "Energy Production systems engineering", Wiley, ISBN:9781119238003

GS -5222	**`Wind Energy Technology: Design and Performance**	**3L:0T:0P**	**3 credits**

Course Outcomes:
At the end of this course students will demonstrate the ability to:

CO1	Learn components and processes of wind power plants
CO2	Learn control and monitoring in wind power plants
CO3	Learn fundamentals of integration of wind power plants to grid

Module-1: Wind Energy Fundamentals Wind Energy Basics, Wind Speeds and scales, Wind Mechanics, Power Content, Class of wind turbines, Atmospheric Boundary Layers, Turbulence. Wind Measurements, Analysis and Energy Estimates, Wind data analysis, Wind resource estimation, Betz's Limit, Turbulence Analysis,	

Module-2: Wind Turbines Aerodynamics Theory: Airfoil terminology, Blade element theory, Blade design, Rotor performance and dynamics, Balancing technique (Rotor & Blade), Wind turbines types: Vertical Axis Type, Horizontal Axis, Constant Speed Constant Frequency, Variable speed Variable Frequency, Stall Control, Pitch Control, generator type, Direct generator Drive /PMG/Rotor Excited Synchronous generator. Wind Turbine Technology, Wind Turbine Components and their construction	
Module-3: Modern Wind Turbine Control and Monitoring System Details of Pitch System and Control Algorithms, Protections used and Safety Consideration in Wind turbines, Wind Turbine Monitoring with Error codes, SCADA and Databases: Remote Monitoring and generation Reports, Operation and Maintenance for Product Life Cycle, Electronics Sensors /Encoder /Resolvers, Wind Measurement: Anemometer and Wind Vane	
Module-4: Concept of Wind Farms and Economics Project planning, Site selection, Project execution, Operation and maintenance Environmental concerns: Pollution free power; Noise; birds; Aesthetics; Radio waves	
interference; Wind resource assessment, Value of wind energy, Life cycle costing Wind energy market	
Module-5: Wind Generation Forecasting Wind speed forecasting – models and functions, different methods for forecasting, load matching with generation, error calculation, error minimization techniques.	

Text Books: 1. Letcher "Wind Energy Engineering", AP, ISBN:9780128094518 2. S.M. Muyeen "Wind Energy Conversion Systems", Springer
Reference Books: 1. Pramod Jain "Wind Energy Engineering" McGraw Hill

GS -5223	`Small Hydro, Geothermal and Ocean Energy	3L:0T:0P	3 credits

Course Outcomes:
At the end of this course students will demonstrate the ability to:

CO1	Learn components and processes of mini, micro and macro hydro power plants
CO2	Learn geothermal and ocean energy power plants

Module-1: Hydro Energy Basic Concepts: Importance of Hydro-electric power, National and International scenario - Load Study and Estimation - Available power - Power duration curve – Forecasting Techniques - Storage and pondage - Firm power - Secondary power - Load duration curve. Types of plants, Classification based on capacity, Rainfall and Run of measurements- Hydrographs- flow duration graph and mass storage graphs- Selection of site - types hydro- electric power plants- general arrangements and Layouts- Components of different types of plants, Essential requirements – Classification of PSP development, Components.	
Module-2: Hydro Power Station Operation, Maintenance and Trouble Shooting: Governing of Power Turbines-Functions of Turbine Governor-Condition for Governor Stability-Surge Tank Oscillation and Speed Regulative Problem of Turbine Governing in Future Planning, Design and Construction of Hydroelectric Power Stations-Remaining Lifecycle Analysis – Numerical problems.	
Module-3: Economics and Sustainability of Large, Small, Mini And Micro Hydro Power Plants: Introduction — Advantages and disadvantages of different hydro-power systems Economical and Electrical Aspects of Small, mini and micro hydro turbines- Cost of power generated - potential developments – Sustainability and reliability of Small, mini and micro hydro turbines – Case Study	
Module-4: Geothermal Energy: Availability of geothermal Energy-size and Distribution, Recovery of geothermal Energy, Various Types of Systems to use geothermal Energy, Direct heat applications, Power	
generation using geothermal Heat, Sustainability of geothermal Source, Status of geothermal Technology, Economics of geothermal Energy.	

Module-5: Ocean Energy: Introduction to the ocean environment, Ocean circulation and stratification, Available resources and actual installation, Indian scenario, Ocean thermal energy conversion, Ocean surface waves , Linear wave theory, Wave spectrum, Ocean tidal currents, Governing equation for measurement and/or estimation of efficiency and other performance parameters related to various ocean energy conversion systems, Wave energy systems , Types of wave energy converters, Linear wave-structure interactions, Marine current turbines: Types of marine current turbines,– Sustainability and economic issues .	

Text Books: 1. Bryan Leyland "Small Hydroelectric Engineering Practice", CRC Press

GS -5224	**`Advanced Solar Cell Concepts and Related Technology**	**3L:0T:0P**	**3 credits**

Course Outcomes:
At the end of this course students will demonstrate the ability to:

CO1	Learn advanced solar cell concepts
CO2	Learn application areas of advanced solar cells

Module-1: Silicon solar cells: **Amorphous silicon:** Single junction, double, triple junction, micromorph **Advanced Silicon:** Losses in solar cell; optical loss; electrical loss; Passivation of interface/surface states; standard Al-BSF; Passivated emitter rear locally diffused (PERL); Passivated emitter rear cell on p-type c-Si (p-PERC); Passivated emitter rear totally diffused on n-type c-Si (n-PERT); Interdigitated back contact (IBC); Heterojunction intrinsic thin layer (HIT). **Non-Silicon:** Dye-sentisied Solar Cell, Perovskite Solar Cell.	
Module-2: Nano-structures in solar energy conversion (a) Dye sensitized solar cells: Introduction, principle of operation, Factors influencing the efficiency, Current DSSC research and development including plasmonics. (b) Organic hetero-structured solar cells: Device Structures, mechanism of operation and characteristics of nano-structured heterojunction organic solar cells, factors for improvement of efficiency, device fabrication techniques, Current research and development.	

Module-3: Quantum well solar cells: Quantum confinement in solids (Quantum well , quantum wire and quantum dot) and its effect on the structural, electrical and optical properties , different structures of QW solar cells, principle of operation and I-V characteristics of QW solar cells , current research and development of QW solar cells.	
Module-4: Quantum dot sensitized solar cells: Fundamentals, fabrication process, structures and drawbacks.	

Module-5: Black silicon solar cells with organic heterostructure. Ultrathin c-Si wafer based **flexible solar cells:** Fundamentals, fabrication process and structures.	

Text Books: 1. Advanced Photovoltaic Installations By Balfour 2. Tetsuzo Yoshimura "Thin-Film Organic Photonics: Molecular Layer Deposition And Applications", CRC Press
Reference Books: 1. Tetsuo Soga, Nanostructured Materials For Solar Energy Conversion, 1st Edition, Elsevier

GS-5261	**`Renewable Energy Project Management and Economics**	**3L:0T:0P**	**3 credits**

Course Outcomes:
At the end of this course students will demonstrate the ability to:

CO1	Understand the basic features of RE project management
CO2	Learn the basic principles of energy audit
CO3	Learn the basic principles of RE project economics

Module-1: Introduction to RE project management Project life cycle, Project selection and evaluation, Organizational concepts in project management, Authority/ Responsibility relationships, Project scheduling and control, Importance of Energy consideration in project Management, Energy Economics - Discount Rate, Payback Period, Internal Rate of Return, Life Cycle Costing. Cost Analysis - Budgetary Control - Financial Management	
Module-2: Techniques for RE Project Evaluation Financial evaluation and RE viability, basics of engineering economics, social cost benefit analysis, technology dissemination models, dynamics of fuel substitution, fiscal, financial and other benefits of renewable energy systems, financing of RE systems, carbon financing of renewable energy, software evaluation, case studies.	
Module-3: Energy Audit Need of energy audit, basic techniques, types of assessment, methods of rectification suggestions, economic analysis, report writing.	

Module-4: Energy conservation in thermal system Management and organization of energy conservation programs, analysis of thermal fluid systems, energy conservation in combustion systems, fuels and their properties, combustion systems efficiency calculations, testing efficiency.	
Module-5: Energy conservation in electrical system	

Assessment of electrical energy consumption, measurement of efficiency, methods of conservation, economic analysis.	

Text Book:
1. Robert L. Pirog, Stephen C. Stamos, Jr., "Energy Economics Theory And Policy", Prentice-Hall

GS -5291	M. Tech. Project Part-1 (Term Paper)
GS -5292	Term Paper Seminar and Viva Voce
GS -6191	M. Tech Thesis Part - II (Progress Report)
GS -6192	Progress Report Seminar and Viva-voce
GS -6291	M. Tech Final thesis
GS -6292	Thesis Seminar and Viva-voce