Malaviya National Institute of Technology Jaipur

Centre for Energy and Environment

M. Tech Program in Renewable Energy

Syllabus

Malaviya National Institute of Technology Jaipur

- **Vision of the Institute**

To create a centre for imparting technical education of international standards and conduct research at the cutting edge of technology to meet the current and future challenges of technological development.

- **Mission of the Institute**

To create technical manpower for meeting the current and future demands of industry: To recognize education and research in close interaction with industry with emphasis on the development of leadership qualities in the young men and women entering the portals of the Institute with sensitivity to social development and eye for opportunities for growth in the international perspective.

Centre for Energy and Environment

- **Vision of the Centre**

To foster renewable energy technologies through pedagogical tools, research, and human resource development at various levels, and disseminate the information for sustainable development.

- **Mission of the Centre**

1. To enable sustainable and cost-efficient innovations and develop interactive facilities pertaining to the multidisciplinary areas of renewable energy and environment.
2. To provide quality higher engineering education (viz. M.Tech., Ph.D.) and training programs (viz. one and/or two weeks) for integrating and providing skilled personnel to academia and industry in the area of energy and environment.
3. To promote education and awareness related to energy and the environment by becoming a nodal centreof international standards.
4. To develop novel, efficient, and affordable testing and standardization methods/protocols for operational reliability of equipment and devices related to energy and environment.
5. To showcase cost-effective, clean, and sustainable renewable energy technologies and energy efficiency.

Program Educational Objectives

PEO1 To provide skilled personnel with integrated learning of sustainable development, energy conservation, design, modeling, and performance analysis to academia and industry in energy and environment.

PEO2 Possess technical competence in the fields of Renewable Energy & allied disciplines and will successfully execute engineering solutions that are technically sound and environmentally friendly.

PEO3 To provide an academic ambiance that allows students to develop good scientific and technical skills to provide sustainable and cost-efficient innovative solutions to society.

PEO4 To inculcate in students professional and ethical attitude, teamwork skills, multidisciplinary approach, and an ability to engage in independent and life-long learning.

PROGRAM OUTCOMES (PO)

A student who has met the objectives of the course will possess:

PO1 An ability to independently carry out research /investigation and development work to solve practical problems

PO2 An ability to communicate, write and present a substantial technical report/document effectively

PO3 An ability to demonstrate a degree of mastery over renewable energy and allied systems, at a level higher than the requirements in the appropriate Bachelor's program

PO4 An ability to design, commission and operate renewable energy and allied systems

PO5 An ability to improve renewable energy systems, and assess their impact on overall sustainable development

Centre for Energy and Environment

ACADEMIC CURRICULUM
M. Tech. (Renewable Energy)

Teaching Scheme					**Contact Hours/week**			**Exam. Duration (Hrs.)**		**Relative Weightage (%)**				
S.No	Subject Code	COURSE TITLE	Subject area	CREDIT	L	T	P	Theory	Practical	CWS	PRS	MTE	ETE	PRE
1st YEAR		**I SEMESTER(AUTUMN)**												
1.	RET 601	Photovoltaic and Fuel Cell Systems	PC	3	3	0	0	2	---	20	---	30	50	---
2	RET 602	Design of Solar Thermal Systems	PC	3	3	0	0	2	---	20	--	30	50	---
3.	RET 603	Wind and Hydro Energy Systems	PC	3	3	0	0	2	---	20	---	30	50	---
4.	RET 604	Energy and Environmental Policies	PC	3	3	0	0	2	---	20	---	30	50	---
5.	RET 605	Sustainable Buildings	PC	3	3	0	0	2	---	20	---	30	50	---
6.	RET 606	Renewable Energy Lab	PC	3	0	0	6	-	3	40	40	--	--	20
		Sub Total		**18**										
		II SEMESTER (SPRING)												
1.	RET XXX	Elective - 1												
2.	RET XXX	Elective - 2												
3.	RET XXX	Elective - 3												
4.	RET XXX	Elective - 4												
5.	RET XXX	Elective - 5												
6.	RET XXX	Elective - 6												
		Sub Total		**18**										
2nd YEAR		**III SEMESTER(AUTUMN)**												
1.	RES-615	Seminar	PC	4										
2.	RED -616	Dissertation	PC	16	--	---	---	---	---	---	---	---	---	---
		Sub Total		**20**										
IV SEMESTER(SPRING)														
1.	RED -617	Dissertation (contd. from III Semester)	PC	16	--	---	---	---	---	---	---	---	---	---
		Sub Total		**16**										
		Total		**72**										

Program elective

Code	Course name	Credits	Teaching scheme (L-T-P)
RET 607	Solar passive heating and cooling	3	3-0-0
RET 608	Biomass energy systems	3	3-0-0
RET 609	Grid connectivity and smart grid	3	3-0-0
RET 610	Life cycle assessment of renewable energy systems	3	3-0-0
RET 611	Management and modeling of environmental systems	3	3-0-0
RET 612	Instrumentation and control of energy systems	3	3-0-0
RET 613	Industrial energy management	3	3-0-0
RET 614	Energy Simulation	3	1-0-4
RET 617	Advanced Energy Storage Technology	3	3-0-0
RET 618	Advanced photovoltaic technologies	3	3-0-0

RET 601
Photovoltaic and Fuel Cell Systems

Course Outcomes:

CO1: To illustrate operation of different types of solar cell

CO2: To evaluate different components of solar PV system and analyze different losses

CO3: To evaluate planning, project implementation and operation of solar PV power generation

CO4:To illustrate different types of fuel cell and its operating principle

Course Content

Solar PV systems: Fundamentals of solar cell, semiconductors as basis for solar cells materials and properties, P-N junction, sources of losses and prevention, estimating power and energy demand, site selection, land requirements, choice of modules, economic comparison, balance of systems, off grid systems, grid interface, Preparing DPR, Supporting structures, mounting and installation, battery storage, power condition unit, selection of cables and balance of systems, planning with software, maintenance and schedule, Monitoring, Data Management, Performance Analysis and FinancialAnalysis

Solar PV power plants: Array design, inverter types and characteristics, Power conditioning system: working algorithms, performance analysis; design of standalone, hybrid and grid interactive plants, commissioning of solar PV plant

Fuel Cells: Thermodynamics of fuel cells; free energy change and cell potentials; effects of temperature and pressure on cell potential; energy conversion efficiency; factors affecting conversion efficiency; polarization losses; important types of fuel cells (hydrogen-oxygen, organic compounds-oxygen, carbon or carbon monoxide-air, nitrogen compounds-air); electrode types; electrolytes for fuel cells; applications.

References

1. Solar Photovoltaics: Fundamentals, Technologies and Applications by Chetan Singh Solanki, Prentice Hall,India

2. Terawatt Solar Photovoltaics, Roadblocks and Opportunities Edited by M. Tao, Springer

3. Handbook of Photovoltaic Science and Engineering, Edited by A. Luque and S. Hegedus, John Wiley & Sons,Ltd

RET 602
Design of Solar ThermalSystems

Course Outcomes:
CO1: To understand different aspects of solar radiation geometry and estimate the solar insolation
CO2:To design various solar thermal collectors and conduct its performance analysis
CO3: To apply the knowledge gained in the power generation aspects from solar thermal systems

Course Content

Solar Radiation: Basics of Solar Radiation, instruments for measuring solar radiation, solar radiation geometry, empirical equations, solar radiation on tilted surfaces.
Liquid Flat plate Collector: Basic elements, performance analysis, transmissivity - absorptivity, heat transfer coefficients and correlations, collector efficiency and heat removal factors, effects of various parameters, types of other liquid flat-plate collectors,transient analysis.

Concentrating Collectors: Type of concentrating collectors and their general characteristics, geometry, heat transfer correlations, tracking requirements, performance analysis.
Solar thermal power plants: Concentration and temperatures, error in concentration, parabolic geometries, paraboloid geometries(dish), heliostats, lay out, central receiver ,
Component design: Energy balance of components, design process and parameters, thermodynamic basis for receiver design, tube receiver concept. Volumetric receiver, direct absorption receiver, receiver loss calculations, thermal storage for solar power plants.
Thermal Energy Storage: Basic methods, Sensible heat storage – liquids- solids-analysis, latent heat storage, thermo chemical storage, application of thermal storage.
Solar field design: array design, control of solar collectors, piping layout, pumping requirements condition monitoring and maintenance systems.
Performance analysis of miscellaneous solar applications: Solar Air heaters, solar pond, solar still, solar refrigeration

References
1. S. P. Sukhatme and J. K Nayak, Solar Energy, 4th Edition, McGraw-Hill EducationPvt.
2. J. A. Duffie and W. A. Beckman, Solar Engineering of Thermal Processes,Wiley,
3. D. Y. Goswami, Principles of Solar Engineering, 3rd Edition, CRCPress,

RET 603
Wind and Hydro Energy Systems

Course Outcomes

CO1: To understand basic of wind and hydro energy systems and resource assessment techniques.

CO2: To evaluate design aspects of wind/hydro plant, components, operation and control

CO3: To create ability on wind/hydro power generation, grid integration and environmental Impacts.

Course Content

Wind Energy Basics: Status, Advantages and disadvantages of wind energy systems, Advantages and disadvantages, Types of wind energy converters, local Effects on wind, site selection: roughness length, wind shear, Wind Speed Variability, Obstacles to wind flow, Working principles of wind energy: Energy content in wind, Energy Conversion at the Blade, Wind variations: Weibull distribution.

Components of a wind energy converter: Rotor Blades, Gearboxes, Synchronous or Asynchronous Generators, Towers, Miscellaneous components, Turbine Selection

Operation and Control of Wind Energy Converters: grid requirements, Issue of Noise and Its Control, Power Curve and Capacity Factor, Pitch control, Stall Control, Yaw Control Hydropower basics: Water Cycle in Nature, Classification of Hydropower Plants, Status of Hydropower Worldwide, Advantages and Disadvantages of Hydropower, Operational Terminology, Legal Requirements

Working principles: Locating a Hydropower Plant, Basics of Fluid Mechanics for hydro power, single and multiple reservoir system, cascaded powerplants

Important Parts of Hydropower Station: Turbine, Electric Generator, Transformer and Power House, Structural parts: Dam and Spillway, Surge Chambers, Stilling Basins, Penstock and Spiral Casing, Tailrace, Pressure Pipes, Caverns, auxiliary parts.

Hydraulic turbines: Classification of Hydraulic Turbines, Theory of Hydro Turbines: Francis, Kaplan, Pelton turbines, efficiency and selection of turbine

References

1. Freris L.L., Wind Energy Conversion Systems, PrenticeHall
2. Spera D.A., Wind Turbine Technology: Fundamental Concepts of Wind TurbineEngineering,
3. Johnson, G.L., Wind Energy Systems, PrenticeHall,
4. James F. Manwell, Jon G. McGowan, Anthony L. Rogers, Wind Energy Explained: Theory, Design andApplicationWiley
5. Paul Gipe, Wind Energy for the Rest of Us: A Comprehensive Guide to Wind Power and How to Use it, Chelsea Green PublishingCo,
6. Brown, G., “Hydro-electric Engineering Practice”, Vol. I, II & III, CBSPublication
7. Nigam, P.S., “Hand book of Hydroelectric Engineering”, Nem Chand and Brothers
8.Clemen, D.M., “Hydro Plant Electrical Systems”, HCIPublication

RET 604
Energy and Environmental Policies

Course outcomes

CO1: To understand the energy carriers, energy technologies, energy challenges

CO2: To apply the geopolitics national and international energy and environment policy

CO3:To analyse the relationships between energy, risk, societal safety, sustainable development and energy economics.

Course content

Introduction to Energy codes and policies: Energy Conservation act, Electricity Act, Solar policy, Hydro policy, Biomass policy

International scenario: world energy outlook, international protocols for energy and environment, governing and nodal national/international agencies and their role

Financial tools: incentives and subsidies, calculation of required subsidy for penetration, concept of shadow price Concept of micro-financing for RE, funding agencies for RE projects in India, application development for RE funding Tariff policies, use of Demand Side Management as a policy tool

References

1. SC Bhattacharyya. Energy Economics, Concepts, Issues, Markets and Governance, Springer Science & BusinessMedia

2. TF Braun & MG Lisa. Understanding Energy and Energy Policy. ZedBooks

3. Kandpal, Tara Chandra, and Hari Prakash Garg. Financial evaluation of renewable energy technologies. MacMillam IndiaLimited,

RET 605
SustainableBuildings

Course Outcomes:
CO1: To develop knowledge of contemporary issues pertaining to habitat planning and building construction
CO2: To develop ability to apply knowledge of engineering in design of environmentally sound buildings
CO3: To build environmentally sustainable and healthy buildings using multidisciplinary teams

Course content
Concept of green buildings features of green building rating systems in India: LEED, GRIHA. Sustainable site, water, energy, material and indoor environment issues for green buildings;

Intent and documentation for credits/points for green rating systems; difference in evaluation and documentation for new construction, existing buildings, core and shell projects.
Green home rating system, green factory rating, green neighborhood concept; Concept of Net zero energy building, net zero community.

Energy Conservation Building Code: requirements of code, applicability, compliance options: prescriptive, trade-off, whole building performance routes for compliance

References

1. Construction Manual, Ministry of Environment & Forests, Government of India, NewDelhi
2. Sustainable Building Design Manual- Volume I &II, The Energy and Resources Institute (TERI)
3. Environmental Impact Assessment Guidance Manual for Building, Construction, Townships and Area Development Projects, Ministry of Environment & Forests, Government of India, New Delhi

RET 606

Renewable Energy Laboratory

Course outcome:

CO1: To understand the principle and functioning of RE systems.
CO2: To analyse operation of RE system elements.
CO3: To evaluate and present graphically the collected data
CO4: To coordinate and function in multidisciplinary team
CO5: To integrate RE system to grid and synchronization
CO6: To assess and manage safety and maintenance issue of RE systems
CO7: To create substantial technical report/document effectively

Experiments related to following topics:

- Solar waterheating
- Solarcooking
- Solarconcentrator
- PV modulecharacterization
- Inverter performance analysis
- Wind energyconvertor
- Biomass forenergy
- Solar passive concepts and thermalcomfort

Program Electives

RET 607
Solar Passive Heating and Cooling

Course Outcomes:
CO1:To understand the basics of climatology-based building design and solar geometry
CO2:To apply solar passive heating and cooling techniques in building design to reduce heating/cooling load
CO3: To analyse energy performance of solar passive heating and cooling systems

Course content
Heating and cooling load of buildings: elements of heating and cooling load, load reduction approaches, building energy codes, thermal mass

Solar geometry and exposure: sun path diagram, shading analysis, graphical design tools, solar control issues Passive heating: Direct and indirect solar passive heating systems; solarium, trombe wall, trans-wall.

Passive cooling systems: thermal mass, courtyard effect, wind tower design, earth air tunnel system, evaporative cooling, radiative cooling,

Solar ventilation: stack effect, solar chimney for ventilation, absorber design, stack design, issues in openingdesign

References
1. M. S. Sodha, N. K. Bansal, P. K. Bansal, A. Kumar and M. A. S. Malik, Solar Passive Building: science and design, Pergamon Press, NewYork,
2. J. A. Duffie and W. A. Beckman, Solar Engineering of Thermal Processes, John Wiley, New York,
3. D. Y. Goswami, F. Kreith and J. F. Kreider, Principles of Solar Engineering, Taylor and Francis,Philadelphia,

RET 608
Biomass Energy Systems

Course Outcomes

CO1: To analyse the biomass energy conversion system and its utilisation

CO2:To develop the designs for biomass energy conversion and utilisation within the context of a whole systems approach

CO3: To evaluate the environmental benefits and consequences of biomass energy production

Course content

Biomass Resource: Characteristics of Biomass fuel, technologies for using biomass, comparison of direct combustion with other tehcnologies

Biomass Gasifiers: Basics of Gasification and types of Gasifiers, Thermodynamic Analysis Biogas Technology, Sizing/Selection and design of Gasifiers,

Industrial use of biomass: Industrial Boilers, biomass as fuel, co-firing and co-generation, Economic analysis, Testing and Performance Evaluation of Gasifiers, Use of biomass for liquid fuel, Biomass policy Biogas: Types of biogas plants, design and performance analysis, application of biomass

References

1. Capareda S, Introduction to biomass energy conversion, CRCPress.

2. Brown RC and Stevens C, Thermo-chemical Processing of Biomass: Conversion into Fuels, Chemicals and Power, Wiley andSons.

3. Vaughn C. Nelson, Kenneth L. Starcher, Introduction to Bioenergy (Energy and the Environment), CRCPress.

4. Yebo Li and Samir Kumar Khanal, Bioenergy: Principles and Applications,Wiley-Blackwell.

5. Ted Weyland, Bioenergy: Sustainable Perspectives, CallistoReference.

RET 609
Grid Connectivity and Smart Grid

Course outcomes

CO1: To illustrate and explain the concept and related infrastructure of a smart grid

CO2: To model and simulate smart grid operation

CO3: To discuss the modern and innovative application fields of distributed generating units and relative merits

Course content

Introduction to grid connectivity of RE systems, smart grid and emerging technologies, Operating principles and models of smart gird components, Key technologies for generation, networks, loads and their control capabilities; decision-making tools,

Non conventional energy source models grid integration, Micro-turbine model and grid integration, Fuel cell model and grid integration, Energy storage and electric vehicle models and grid integration,

Distribution line models, Communication infrastructures for smart grid operation, Advanced metering infrastructure and advanced control methods,

Economic dispatch, Demand response and demand management, Distribution feeder analysis, Continuous voltage and frequency control, Contingencies and their management, Unit commitment (selection of generators & loads to operate),

Energy constraints: hydro, fuel management and maintenance scheduling, The operational challenges of distributed energy resources, Operation and control issues associated with intermittent generation,

Electricity industry operation in a carbon constrained and „smart grid" future, Impact of smart grid component integration on distribution network operation, Artificial Intelligence based approaches for estimation, scheduling, management and control of next generation smart grid.

References

1. Stuart Borlase, Smart Grid: Infrastructure, Technology and Solutions, CRC Press 2012, ISBN 9781439829059.

2. JanakaEkanayake, Nick Jenkins, KithsiriLiyanage, Jianzhong Wu, Akihiko Yokoyama, Smart Grid: Technology and Applications, Wiley, 2012, Print ISBN:9780470974094 |Online ISBN:9781119968696.

3. Mini S. Thomas, John D McDonald, Power System SCADA and Smart Grids, CRCPress,

4. Kenneth C. Budka, Jayant G. Deshpande, Marina Thottan, Communication Networks for Smart Grids, Springer, 2014, ISBN978-1-4471-6302-2.

5. Henrik Lund, "A Smart Energy Systems Approach to the Choice and Modeling of100% Renewable Solutions" Academic Press,.

RET 610
Life Cycle Assessment of Renewable Energy Systems

Course outcomes

CO1: To evaluate the financial feasibility of any energy project
CO2: To evaluate the environmental properties of different energy and production systems
CO3: To conduct a simplified LCA as independent work, as well as more complex assessments

Course content

Financial evaluation: simple pay back analysis, return on investment, time based value of money, NPV method, annuity method, calculation of IRR.
Energy analysis: concept of embodied energy, energy analysis methodologies: process chain analysis, input-output method, inventory method; cumulative energy demand, energy yield ratio, energy payback.
Environmental analysis: concept of carbon footprint of materials and systems, cumulative emission for renewable energy systems, environmental indicators of RE systems.
Data quality of embodied energy, and specific emission of materials

References

1. Basosi, R., Cellura, M., Longo, S., Parisi, M.L , Life Cycle Assessment of Energy Systems and Sustainable Energy Technologies,Springer
2. Kandpal, Tara Chandra, and Hari Prakash Garg. Financial evaluation of renewable energy technologies. MacMillam IndiaLimited,

RET 611

Management and Modeling of Environmental Systems Course

Outcomes

CO1: To design energy systems for engineering applications and model their performance
CO2: To analyze energy systems under design and off-design operating conditions
CO3: To formulate and optimize the performance of different energy systems

Course Content

Human - environment relationship, normative criteria, descriptive and prescriptive models, limits ofgrowth;
Environmental and natural resources economics, pollution control policy, growth in a finite environment; Environmental protection laws;
Numerical/mathematical modelling of environmental systems, subsystems, and pollutant transport processes;
Planning and management of environmental systems: optimization techniques, stochastic modelling, statistical inferences;
Large scale systems; Optimal monitoring network design, identification of sources; Risk reliability and uncertainty in environmental systems;
Topics in groundwater and surface water quality management.

References

1. Andrew Ford, Modeling the Environment: An Introduction To System Dynamics Modeling Of Environmental Systems. Island Press,
2. M. C. Dash, Concepts of Environmental Management for Sustainable Development, IK International Publishing House Pvt. Ltd,

RET 612
Instrumentation and Control of Energy Systems

Course Outcomes

A student who completes the course is expected to acquire,

CO1: An ability to design experiments and measurement systems

CO2: An ability to identify suitable mechanical and electrical measurement systems and conduct experiments

CO3: An ability to carry out uncertainty analysis of the measured data

Course Content

Basic measurement concepts, Error analysis, transducer classification, static and dynamic characteristics of transducers,

Real time monitoring and data processing, instrumentation for measuring temperature, humidity, radiation, flow, pressure, thermal conductivity, specific heat etc.;

Data loggers: type of loggers, configuring and checking data-loggers

Measurement of electrical quantifies: current, voltage, power, power factor, stability, transient analysis of power generating systems

References

1. T.-W. Lee: Thermal and Flow Measurements, CRCPress,
2. J.P. Holman: Experimental Methods for Engineers, McGraw HillEducation;
3. S. P. Venkateshan: Mechanical Measurements, ANEBooks,
4. E.R.G. Eckert and R.J. Goldstein: Measurements in Heat Transfer, McGrawHill,
5. E.O. Doebelin: Measurements Systems: Application and Design.

RET 613
Industrial Energy Management

Course Outcomes

CO1: To understand the national energy scenario and identify the improvement process of demand supply gap through energy management
CO2: To evaluate the techno economic feasibility of any energy conservation technique adoptedCO3: To perform energy audit of an industry/organization and create an energy audit report

Course Content

Energy consumption in industries: Energy and material flow assessment, specific energy consumption, industry benchmarks for energy consumption.
Energy audit: Process of energy audit, preliminary audit, detailed audit, reporting of energy audit, concept of ESCO, energy performance contracting, instruments for energy audit, management and organization of energy conservation programs in industries
Energy conservation in industrial systems: boilers, furnaces, pumps, fans and blowers, steam system, motors and transformers, power factor.

References

1. Handbook of Energy Audits by Albert Thumann. CRCpress.
2. Guide to Energy management, by Barney L.Capehart, Wayne C.Turner, and William J.Kennedy, The fairmont press, INC. Fourthedition
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RET 614
EnergySimulation

Course Outcomes:
CO1:To understand underlying concepts, modelling inputs and modelling methods of renewable energy systems.
CO2: To model and simulate different renewable energy systems.
CO3: To interpret and validate simulation results.

Course Content
Introduction to energy simulation tools , Modeling techniques, validation of simulation model Simulation of renewable energy systems Simulation for energy efficiency of buildings, Software to be used: EnergyPlus, TRNSYS, HOMER, PVSyst,eQUESTetc

RET 617
Advanced Energy Storage Technology

Course outcome

CO1: To determine different aspects and parameters of energy storage systems.

CO2: To assess sizing and operation of different energy storage systems

CO3: To evaluate energy storage integration and hybrid energy storage systems

Course content

Unit I: Introduction of energy storage technology, requirement for energy storage, Current status, Future prospect of storage

Unit II: Mechanical energy storage systems, flywheel energy storage (FES), pumped hydropower storage (PHS), and compressed-air energy storage (CAES). Comparison and application state-of-arts including principle, function and deployments. Technical characteristics in terms of power rating and discharge time, storage duration, energy efficiency, energy density, cycle life and life time, capital cost etc. Case study/project based on mechanical energystorage.

Unit III: Electrochemical energy storage: Flow Battery, Battery, Fuel Cell, and Capacitor. Comparison and application state-of-arts including principle, function and deployments. Technical characteristics of various electrochemical energy storage systems. Case study/project

Unit IV: Hydrogen energy: hydrogen economy, Hydrogen based FCV, hybrid electric vehicle, maintenance of FCV, safety

Unit V: Thermal energy storage: sensible heat storage (SHS), latent heat storage (LHS) or phase-change materials (PCMs), and thermal chemical energy storage (TCES). Comparison and technical characteristics. Case study/project

Unit VI: Hybrid energy storage systems: capacitor-battery hybrid systems, hybrid PCMs energy storage, hybrid CAESetc.

References

1. Christopher D. Rahn and Chao-Yang Wang, Battery system engineering,Wiley,
2. DOE/EPRI Electricity Storage Handbook, U.S. Department of Energy and the Electric Power Research Institute in collaboration with the National Rural Electric CooperativeAssociation.
3. Frank S Barnes, John G Levine, Large Energy Storage Systems Handbook. CRCpress
4. Robert Huggins, Energy Storage, SpringerNature;
5. Ibrahim Dincer and Marc A. Rosen, Thermal energy storage systems andapplications,
6. Luisa F. Cabeza, Advances in Thermal Energy Storage Systems: Methods andApplications, WoodheadPublishing,

RET 618
Advanced photovoltaic technologies

Course outcome
CO1: To investigate the use of different semiconductor materials used in solar cell
CO2: To evaluate the techno-economic aspects of different photovoltaic technologies
CO3: To design highly efficient commercial photovoltaic module.

Course content
Overview of different types of solar cells/panels. Photovoltaic industries in India and World. International certification of solar panels and Indian scenario.
Wafer based silicon solar cells and its market trend. Cost breakup of wafer based solar panels, future trends Concentrator solar cells, reflector and lens based versions. Performance in Indian climatic conditions. Low, medium and high concentration, combined thermal and concentration PV system.
Semi-transparent solar cells and related materials, applications in buildings (BIPV), thin film and wafer based versions, appearance and structure of thin film solar cells, Flexible solar cells.
Multi-junction solar cells, its working principles.
Hetero-junction with intrinsic thin layer (HIT) solar cells, structure and working principle, comparison with conventional bulk solar cells,
Polymer, organic, dye sensitized and quantum dot solar cells, structure, working principle, present applications, near future trends.

References
1. Terawatt Solar Photovoltaics, Roadblocks and Opportunities Edited by M. Tao,Springer
2. Handbook of Photovoltaic Science and Engineering, Edited by A. Luque and S. Hegedus, John Wiley & Sons,Ltd
3. Practical Handbook of Photovoltaics: Fundamentals and Applications Edited by A. Mcevoy, T.Markvart, L. Castañer, Elsevier
4. Building integrated photovoltaics/a handbook Edited by S. Roberts &N.Guariento, Birkhäuser, Germany
5. Photovoltaics System Design and Practice Edited by H. Haberlin, John Wiley & Sons,Ltd
6. Photovoltaics Fundamentals, Technology and Practice Edited by K. Mertens, John Wiley & Sons, Ltd