CENTRE FOR ENERGY AND ENVIRONMENT

ACADEMIC CURRICULUM AND SYLLABUS

MASTER OF TECHNOLOGY PROGRAM IN

RENEWABLE ENERGY

August 2021

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR
Jawahar Lal Nehru Marg, Malaviya Nagar, Jaipur, Rajasthan 302017

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

Institute Vision:

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.

Institute Mission:

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:

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

Mission

1. To enable sustainable and cost-efficient innovations and develop interactive facilities pertaining to the multi-disciplinary areas of renewable energy and environment.
2. To provide quality higher engineering education (viz. M.Tech., Ph.D.) and training programs (viz. 1 and/or 2 week) 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 environment by becoming a nodal centre of international standards.
4. To develop novel, efficient as well as 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.

Malaviya National Institute of Technology Jaipur
Centre for Energy and Environment

Master of Technology - Renewable Energy

PROGRAM EDUCATIONAL OBJECTIVES (PEO)

PEO1 To provide skilled personnel with integrated learning of sustainable development, energy conservation, design, modelling and performance analysis to academia and industry in the area of energy and environment. (Preparation)

PEO2 Possess technical competence in the fields of Renewable Energy & allied disciplines and will be successful for the execution of engineering solutions which are technically sound and environment friendly. (Core competence)

PEO3 To provide an academic ambience that allows to develop good scientific and technical skills in students to enable them to provide sustainable and cost-efficient innovative solutions to society. (Breadth)

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

PROGRAM OUTCOMES (PO)

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

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

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

Malaviya National Institute of Technology Jaipur
Centre for Energy and Environment

ACADEMIC CURRICULUM
Master of Technology - Renewable Energy

Semester. I

S.No.	Course Code	Course Title	Course Category	Type	Credit	L	T	P
1	ENL 601	Photovoltaic Systems	Core	Taught course - Core	3	3	0	0
2	ENL 602	Solar Thermal Systems	Core	Taught course - Core	3	3	0	0
3	ENL 603	Bioenergy Systems	Core	Taught course - Core	3	3	0	0
4	ENL 6xx	------	Elective	Taught course - Program Elective	3	3	0	0
5	ENL 6xx	------	Elective	Taught course - Program Elective	3	3	0	0
6	ENP 606	Renewable Energy Laboratory	Core	Taught course - Core	3	0	0	6

Semester. II

S.No.	Course Code	Course Title	Course Category	Type	Credit	L	T	P
1	ENL 604	Energy Management and Audit	Core	Taught course - Core	3	3	0	0
2	ENL 605	Energy Economics and Policies	Core	Taught course - Core	3	3	0	0
3	ENL 6xx	------	Elective	Taught course - Program Elective	3	3	0	0
4	ENL 6xx	------	Elective	Taught course - Program Elective	3	3	0	0
5	ENL 6xx	------	Elective	Taught course - Program Elective	3	3	0	0
6	ENL 6xx	------	Elective	Taught course - Program Elective	3	3	0	0

Semester. III

S. No.	Course Code	Course Title	Course Category	Type	Credit	L	T	P
1	ENQ 625	Seminar	Mandatory	Seminar	3	0	0	6
2	END 626	Dissertation	Mandatory	Dissertation	9	0	0	18

Semester. IV

S. No.	Course Code	Course Title	Course Category	Type	Credit	L	T	P
1	END 627	Dissertation	Mandatory	Dissertation	12	0	0	24

List of Taught Courses

Sl. no.	Course code	Course title	Core/Elective	L-T-P
1	ENL 601	Photovoltaic Systems	Core	3-0-0
2	ENL 602	Solar Thermal Systems	Core	3-0-0
3	ENL 603	Bioenergy Systems	Core	3-0-0
4	ENL 604	Energy Audit and Management	Core	3-0-0
5	ENL 605	Energy Economics and Policies	Core	3-0-0
6	ENP 606	Renewable Energy Laboratory	Core	0-0-6
7	ENL 607	Energy Storage Technology	Elective	3-0-0
8	ENL 608	Energy Efficiency in Buildings	Elective	3-0-0
9	ENL 609	Wind Energy Systems	Elective	3-0-0
10	ENL 610	Hydro Energy Systems	Elective	3-0-0
11	ENL 611	Advanced Photovoltaic Systems	Elective	3-0-0
12	ENL 612	Renewable Integration Markets	Elective	3-0-0
13	ENL 613	Modeling and Optimization of Energy Systems	Elective	3-0-0
14	ENL 614	Smart Grid Systems	Elective	3-0-0
15	ENL 615	Solar Passive Heating and Cooling	Elective	3-0-0
16	ENL 616	Hydrogen Energy Technology	Elective	3-0-0
17	ENL 617	Energy Simulation	Elective	1-0-4
18	ENQ 625	Seminar	Mandatory	0-0-6
19	END 626	Dissertation - I	Mandatory	0-0-18
20	END 627	Dissertation - II	Mandatory	0-0-24

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

Department/Centre : Centre for Energy and Environment

M.Tech : Renewable Energy

Course Code : ENL601

Course Name : PHOTOVOLTAIC SYSTEMS

Credits : 3 L - 3 T - 0 P - 0

Course Type : Core

Prerequisites : none

Course Contents

Unit 1	Fundamentals of solar PV cells and systems: semiconductors as basis for solar cells materials and properties, P-N junction, I-V and QE curves of solar cells
Unit 2	BOS for power plant: Supporting structures, mounting and installation, battery storage, power condition unit, selection of cables and balance of systems, maintenance and schedule, Monitoring, Data Management,
Unit 3	Solar PV power plant: Estimating power and energy demand, site selection, land requirements, choice of modules, economic comparison, balance of systems, off grid systems, grid interface, simulation with software. sources of losses and prevention. Performance Analysis and Financial Analysis. Preparing DPR.
Unit 4	Recent development in commercial solar cell technologies and systems. Standards and testing of PV modules. Concentrator solar cells, reflector and lens based versions. Performance in Indian climatic conditions. Low, medium and high concentration.

Recommended Readings

1. Solar Photovoltaics: Fundamentals, Technologies and Applications by Chetan Singh Solanki, Prentice Hall India, 3rd Edition. ISBN 9788120351110
2. Terawatt Solar Photovoltaics, Roadblocks and Opportunities Edited by M. Tao, Springer, 2014 edition. ISBN 978-1- 4471-5643- 7
3. Handbook of Photovoltaic Science and Engineering, Edited by A. Luque and S. Hegedus, John Wiley & Sons, Ltd, 2012 edition. ISBN 978-0- 470-72169- 8

Course Code : **ENL602**

Course Name : **SOLAR THERMAL SYSTEMS**

Credits : 3 **L -** 3 **T -** 0 **P -** 0

Course Type : Core

Prerequisites : none

Course Contents

Unit 1 Solar Radiation: Basics of Solar Radiation, instruments for measuring solar radiation, solar radiation geometry, empirical equations, solar radiation on tilted surfaces.

Unit 2 Liquid Flat plate Collector: Basic elements, performance analysis, transmissivity - absorptivity, heat transfer coefficients and correlations, collector efficiency and heat removal factors, effect of various parameters, types of other liquid flat-plate collectors, introduction to transient analysis, Evacuated tube collectors

Unit 3 Concentrating Collectors: Type of concentrating collectors and their general characteristics, geometry, heat transfer correlations, tracking requirements, performance analysis, effect of various parameters

Solar thermal power systems, Energy storage in solar process systems, Simulations in solar process design

Unit 4 Performance analysis of miscellaneous solar applications, Codes and Standards, Applications of solar flat plate water heater & air heater for industrial process heat.

Recommended Readings

1. S. P. Sukhatme and J. K Nayak, Solar Energy, 4th Edition, McGraw-Hill Education Pvt., 2018, ISBN 978-93-5260-711-2.
2. J. A. Duffie and W. A. Beckman, Solar Engineering of Thermal Processes, 4th Edition, Wiley, 2013, ISBN 978-0-470-87366-3
3. D. Y. Goswami, Principles of Solar Engineering, 3rd Edition, CRC Press, 2015, ISBN 978-1-4665-6379-7

Course Code : **ENL603**

Course Name : **BIOENERGY SYSTEMS**

Credits : 3 **L -** 3 **T -** 0 **P -** 0

Course Type : Core

Prerequisites : none

Course Contents

Unit 1 Biomass: Biomass resources, types, production, classification and characterization; Techniques for biomass assessment. Concept of Waste segregation, management and treatment.

Unit 2 Thermochemical Conversion: Direct combustion, incineration, pyrolysis. Biomass gasifiers; types of gasifiers, Sizing selection and design of gasifiers. Biomass stoves, improved chulha and designs. Biomass fired boilers and types; Biomass pyrolysis – types, manufacture of charcoal, manufacture of pyrolytic oils and gases; Design and operation of pyrolysis units. Plastic waste management, plastic pyrolysis type of technologies.

Unit 3 Biological Conversion: Biodegradation substrate; Anaerobic digestion, process parameters of biomethanation; chemical kinetics and biomethanation process, biogas plant types, biogas plant design, biogas purification and utilisation; environmental and social impacts; bioconversion of substrates into bioethanol. Concept of Biorefinery and Circular Economy

Unit 4 Chemical Conversion: Biodiesel and biohydrogen production, Fischer-Tropsch diesel hydrolysis and hydrogenation; solvent extraction of hydrocarbons; solvolysis of wood; biocrude; catalytic distillation.

Unit 5 Co-firing and co-generation, Biomass integrated gasification/combined cycles systems, Energy plantation/crops, food security and environmental impacts of biomass conversion to energy; energy from waste.

Recommended Readings

1. Capareda S, Introduction to biomass energy conversion, CRC Press. ISBN: 978-1-466-51333-4

2. Brown RC and Stevens C, Thermo-chemical Processing of Biomass: Conversion into Fuels, Chemicals and Power, Wiley and Sons. ISBN: 978-0-470-72111-7

3. Vaughn C. Nelson, Kenneth L. Starcher, Introduction to Bioenergy (Energy and the Environment), CRC Press. ISBN: 978-1-498-71698-7

4. Yebo Li and Samir Kumar Khanal, Bioenergy: Principles and Applications, Wiley-Blackwell. ISBN: 978-1-118-56831-6

5. Ted Weyland, Bioenergy: Sustainable Perspectives, Callisto Reference. ISBN: 978-1-632-39633-4

Video links: https://nptel.ac.in/noc/individual_course.php?id=noc18-bt15
https://www.youtube.com/watch?v=fR0chD3Ob1M

Course Code : **ENL604**

Course Name : **ENERGY MANAGEMENT AND AUDIT**

Credits : 3 **L -** 3 **T -** 0 **P -** 0

Course Type : Core

Prerequisites : none

Course Contents

Unit 1	General Aspects of Energy Management & Energy Audit: Energy Scenario; Basics of Energy and its various forms; Energy Conservation Act and related policies; Energy management and Audit; Material and Energy Balance; Energy Action Planning; Financial Management; Energy Monitoring and Targeting.
Unit 2	Energy Efficiency in Thermal Utilities: Fuel and Combustion; Boiler; Steam system; Furnaces; Insulation and Refractories; Cogeneration; Waste Heat Recovery; Heat Exchangers; HVAC and refrigeration system; Compressed Air System
Unit 3	Energy Efficiency in Electrical Utilities: Electrical Systems; Electrical Motors and variable speed drives; Pump and pumping systems, Fan and Blowers, Lighting systems; Power generating system; Energy Conservation in buildings
Unit 4	Energy Performance Assistance: Steel industry; Cement Industry; Textile industry; Pulp and paper Industry; Fertilizer Industry; Buildings and commercial establishments

Recommended Readings

1. Guide to Energy management, by Barney L.Capehart, Wayne C.Turner, and William J.Kennedy, The fairmont press, INC. Fourth edition
2. http://www.nptelvideos.in/2012/11/energy-resources-and-technology.html
3.Bhattacharyya, Subhes C. Energy economics: concepts, issues, markets and governance. Springer Science & Business Media, 2011, ISBN 978-0-85729-268-1.
4. Energy Demand – Analysis, Management and Conservation,Ashok V. Desai, Wiley Eastern Ltd., New Delhi.,1990, ISBN 9788122402025.
5. Handbook of Energy Audits by Albert Thumann.CRC press 9th ed.
6. BEE guide books for energy auditor and energy manager exam https://beeindia.gov.in/content/energy-auditors

Course Code : **ENL605**

Course Name : **ENERGY ECONOMICS AND POLICIES**

Credits : 3 **L -** 3 **T -** 0 **P -** 0

Course Type : Core

Prerequisites : none

Course Contents

Unit 1 **Energy and Policy:** Introduction, sector wise consumption of energy resources: Electricity, Fuel, Transportation, Energy Scenario of different sectors: Indian and International Level – Coal, Oil, Natural Gas, RE, Hydro, Nuclear. Global market outlook, import and export position, Resources, Reserves, All India Energy Scenario, Energy Conservation Act 2001 and amendments, Energy Security - Concept, Issues and Economics, Trade-Off between Energy Security and Climate Change

Unit 2 **Energy Economics** - Time Value of Money Concept, Simple Payback Period, IRR, NPV, Life Cycle Costing, LCA, LCOE, Cost of Saved Energy, Cost of Energy generated, Examples from energy generation and conservation, Energy Chain

Unit 3 **Energy Regulations in Indian Power Sector:** Structure of Indian Power Sector, Indian Electricity Grid Code, Electricity Act 2003 and amendments, National Electricity Policy, Deviation Settlement mechanism, Retail Competition

Unit 4 **Tariff Regulations**: Annual Revenue Requirements, Tariff Structure, Role of State/Central Regulatory Commissions, involved costs – energy purchase, losses, surcharges, O&M, Interests, Depreciation, return on Equity, Total Revenue Requirement, Tariff Policy, Understanding tariff order

Unit 5 **Policies for Renewable Energy:** Renewable Energy Policy, Incentives and subsidies, Foreign Investment, Role of MNES, IREDA, Bio Energy Policy, Solar Policy, National Solar Mission, Waste Management Practices and policies, Renewable purchase obligations, Feed in Tariffs, Renewable Energy Certificates, Hydro Power Policy, Small/Large Scale Hydro Power Plants, PSH, National policy on Hydropower in India, India EV Policy, Other schemes – Saubhagya, UJALA, UDAY, RFMS, Smart Cities, etc.

Unit 6 **Climate Change Policies**: Global Warming, International Environmental Policy Practices, Emissions Trading System (ETS), UNFCCC, Kyoto protocol, Clean development mechanism (CDM), Joint implementation, Emission targets, NAPCC, INDC and latest national/international govt.policies.

Recommended Readings

1. SC Bhattacharyya. Energy Economics, Concepts, Issues, Markets and Governance, Springer Science & Business Media, (2011) ISBN 978-0-85729-268-1.
2. RS Axelrod & SD VanDeveer (Eds.). The Global Environment: Institutions, Law, and Policy. CQ Press; Fifth edition (2019). ISBN 1544330146
3. TF Braun & MG Lisa. Understanding Energy and Energy Policy. Zed Books, (2014) ISBN 1780329342
4. Kandpal, Tara Chandra, and Hari Prakash Garg. Financial evaluation of renewable energy technologies. MacMillam India Limited, 2003.
5. Nersesian, Roy L. *Energy economics: markets, history and policy*. Routledge, 2016, ISBN-13: 978-1138858374, ISBN-10: 1138858374.
6. Zweifel, Peter, Aaron Praktiknjo, and Georg Erdmann. *Energy economics: theory and applications*. Springer, 2017, ISBN 978-3-662-53022-1.

Course Code : **ENP606**

Course Name : **RENEWABLE ENERGY LABORATORY**

Credits : 3 **L -** 0 **T -** 0 **P -** 6

Course Type : Core

Prerequisites : none

Course Contents

List of Experiments

- Solar cooker
- Solar Thermal Training Kit
- Thermal energy storage
- Heat recovery wheel
- PV system characterization and performance analysis
- Hybrid Smart Grid Solution
- Solar PV Grid tied Training System
- Wind energy training system
- Biogas production
- Battery testing

Course Code : **ENL607**

Course Name : **ENERGY STORAGE TECHNOLOGY**

Credits : 3 **L -** 3 **T -** 0 **P -** 0

Course Type : Elective

Prerequisites : none

Course Contents

Unit 1 Introduction of energy storage technology, requirement for energy storage, Current status, electricity storage services and benefits, cost performance and maturity of storage technology, methods and tools for evaluation of storage, future prospect of storage.

Unit 2 Electrochemical energy storage: lead acid battery, Li ion battery, Ni metal hydride battery, Flow Battery, Capacitor etc.
Comparison, Ragone plot and state-of-art application, their function and deployments. Technical characteristics, battery states and their estimation methods, battery-based hybrid storage system, battery aging.
Performance characteristics, testing, safety, standards and system sizing for mobile and stationary application, operation with renewable systems. Introduction of battery management system, battery thermal management, requirement of battery storage integration. Case study/project.

Unit 3 Thermal energy storage (TES) methods - Sensible TES, Passive and active systems. Main means of accumulation, Importance of thermal stratification, Strategies to enhance the thermal stratification - Latent TES Selection of phase change materials depending on the application. Types of storage systems by change of phase, - Cold TES - Seasonal TES - Characteristics of heat storage materials.
Design and operation of thermal storage systems - Performance characteristics, testing, safety, standards and system sizing, Energy conservation using TES - Energy and Exergy Analyses of TES Systems - Energy savings by TES, Case study/project.

Unit 4 Mechanical energy storage systems, flywheel energy storage (FES), pumped hydropower storage (PHS), and compressed-air energy storage (CAES). Comparison and application state-of-art including principle, function and deployments. Performance characteristics, testing, safety, standards and system sizing. Case study/project based on mechanical energy storage.

Recommended Readings

1. Christopher D. Rahn and Chao-Yang Wang, Battery system engineering, Wiley, 2013, ISBN: 9781119979500
2. DOE/EPRI Electricity Storage Handbook, U.S. Department of Energy and the Electric Power Research Institute in collaboration with the National Rural Electric Cooperative Association.
3. Frank S Barnes, John G Levine, Large Energy Storage Systems Handbook. CRC press 2011, ISBN 9781420086003
4. Robert Huggins, Energy Storage, Springer Nature; 2nd ed. 2016 edition ISBN 3319212389
5. Ibrahim Dincer and Marc A. Rosen, Thermal energy storage systems and applications, ISBN:9780470747063, 2nd edition, 2011.
6. Luisa F. Cabeza, Advances in Thermal Energy Storage Systems: Methods and Applications, Woodhead Publishing, ISBN-13: 978-1782420880, 2014

Course Code : **ENL608**

Course Name : **ENERGY EFFICIENCY IN BUILDINGS**

Credits : 3 **L -** 3 **T -** 0 **P -** 0

Course Type : Elective

Prerequisites : none

Course Contents

Unit 1 Energy Efficiency, Overview of energy efficiency (EE) in buildings and its benefits, Approach to EE in Buildings, Basics of energy systems in buildings interface of systems and envelope, over view on energy consuming end uses, energy consumption patterns of different end use for varying building typologies, energy consumption benchmarks in buildings. Concept of passive building design.

Unit 2 HVAC basics, types of HVAC systems, psychrometric analysis, Thermal comfort basics, Heating and cooling load of buildings: elements of heating and cooling load, load reduction approaches, comfort zone. Indoor Environment quality.

Unit 3 Standards, codes and rating of buildings (international and national perspective) related to energy efficiency in commercial buildings. Calculation and documentation for compliance and rating. Envelope, HVAC, lighting, controls for code compliance.

Unit 4 Standards, codes and rating of buildings (international and national perspective) related to energy efficiency in residential buildings. Calculation and documentation for compliance and rating. Envelope, HVAC, lighting, controls for code compliance.

Recommended Readings

1. Christopher D. Rahn and Chao-Yang Wang, Battery system engineering, Wiley, 2013, ISBN: 9781119979500
2. DOE/EPRI Electricity Storage Handbook, U.S. Department of Energy and the Electric Power Research Institute in collaboration with the National Rural Electric Cooperative Association.
3. Frank S Barnes, John G Levine, Large Energy Storage Systems Handbook. CRC press 2011, ISBN 9781420086003
4. Robert Huggins, Energy Storage, Springer Nature; 2nd ed. 2016 edition ISBN 3319212389
5. Ibrahim Dincer and Marc A. Rosen, Thermal energy storage systems and applications, ISBN:9780470747063, 2nd edition, 2011.
6. Luisa F. Cabeza, Advances in Thermal Energy Storage Systems: Methods and Applications, Woodhead Publishing, ISBN-13: 978-1782420880, 2014

Course Code : **ENL609**

Course Name : **WIND ENERGY SYSTEMS**

Credits : 3 **L -** 3 **T -** 0 **P -** 0

Course Type : Elective

Prerequisites : none

Course Contents

Unit 1 Wind Energy Basics, types of wind energy converters advantages and disadvantages of wind energy systems Introduction of modern wind energy and its origins.
Wind characteristics and resources: wind characteristics, atmospheric boundary layer, local effects on wind, site selection: roughness length, wind shear, wind speed variability, wind variations: Weibull, Rayleigh distribution, wind resources estimation, wind measurement and instrumentation

Unit 2 Small and hybrid wind turbines: introduction of micro/small and hybrid wind turbines, siting small turbines in complex terrain, offshore wind turbines, operation and challenge of offshore wind farms.

Unit 3 Aerodynamics of wind turbine, one dimensional momentum theory, Betz limit, wake rotation, blade elemental theory, blade shape, effect of drag and blade number on performance. Airfoils and general concepts of aerodynamics.

Unit 4 Components of wind turbines and their selection: Rotor Blades, Gearboxes, Synchronous or Asynchronous Generators, Towers, Miscellaneous components, etc.

Unit 5 Wind farm design, testing and standards: design procedure, topologies, Wind turbine/farm simulation, wind turbine testing and standards, technical specifications, wind turbine design loads, power curve prediction, wind turbine component testing, safety aspects. Case study

Unit 6 Operation and Control of Wind Energy Converters: Pitch control, Stall Control, Yaw Control, grid connectivity, requirement and related issue, reactive power control.
Wind turbine environmental aspects and impacts: Issue of Noise and Its Control, visual impacts, electromagnetic interference

Recommended Readings

1. Freris L.L., Wind Energy Conversion Systems, ISBN 978-0139605277 Prentice Hall 1990.
2. Spera D.A., Wind Turbine Technology: Fundamental Concepts of Wind Turbine Engineering, ISBN 978-0791812051, 1994.
3. Johnson, G.L., Wind Energy Systems, Prentice Hall, ISBN 978-0139577543, 1985.
4. James F. Manwell, Jon G. McGowan, Anthony L. Rogers, Wind Energy Explained: Theory, Design and Application 2nd Edition, Wiley ISBN: 978-0470015001, 2010.
5. Paul Gipe, Wind Energy for the Rest of Us: A Comprehensive Guide to Wind Power and How to Use it, Chelsea Green Publishing Co; Com edition (12 December 2016) ISBN 978-0997451818.

Course Code	**:**	**ENL610**					
Course Name	**:**	**HYDRO ENERGY SYSTEMS**					
			L		**T**		**P**
Credits	**:**	3	-	3	-	0	- 0
Course Type	**:**	Elective					
Prerequisites	**:**	none					

Course Contents

Unit 1	Hydropower basics: Water Cycle in Nature, Classification of Hydropower Plants, Status of Hydropower Worldwide, Advantages and Disadvantages of Hydropower, Hydro potential and exploitation in India, small/mini/micro hydel Power Projects , Major hydroelectric Power Plants in India, Operational Terminology, Legal Requirements
Unit 2	Working principles: Locating a Hydropower Plant, Basics of Fluid Mechanics for hydro power, single and multiple reservoir system, cascaded power plants Structural parts of Hydropower Station: Dam and Spillway, Surge Chambers, Stilling Basins, Penstock and Spiral Casing, Tailrace, Pressure Pipes, Caverns, auxiliary parts.
Unit 3	Types of hydro electric equipment, characteristics and testing of ac generators; Sizing and specification of single and three phase generators ; Power factor and its correction methodologies, excitation systems; Electro-mechanical and digital governor, electronic load controller ; Types of relays, contactors and control schemes for hydro power stations,; Supervisory control and data acquisition (SCADA), integrated computer control system for hydro station; Switchyard equipments, power and instrument transformers, circuit breakers, bus-bar; Protection schemes for generator, transformer and bus-bar, design of circuit diagram for auxiliary and grounding systems
Unit 4	Classification and working principles of hydro turbines, different components of impulse and reaction turbines; Design concepts of hydro turbines, pump-as-turbine and other non conventional hydro turbines; Characteristics of hydro turbines, geometric similarity, main characteristic and operating characteristic curves, hill curves; Governing of hydro turbines, mechanical and electro-mechanical governors, electronic load controller, mechanical drives, gear box, pulleys ; Selection of hydro turbines based on specific speed and their optimal selection; Classification, components and selection of gates and valves; Model testing of hydro turbines, performance testing of turbines at site; Causes and impact of cavitation, silt erosion and their combined effect on operation of hydro turbines; Erection, commissioning, operation and maintenance of turbines

Recommended Readings

1. Brown, G., “Hydro-electric Engineering Practice”, Vol. I, II & III, CBS Publication
2. Nigam, P.S., “Hand book of Hydroelectric Engineering”, Nem Chand and Brothers
3. Clemen, D.M., “Hydro Plant Electrical Systems”, HCI Publication
3. http://www.nptelvideos.in/2012/11/energy-resources-and-technology.html

Course Code : **ENL611**

Course Name : **ADVANCED PHOTOVOLTAIC SYSTEMS**

Credits : 3 **L -** 3 **T -** 0 **P -** 0

Course Type : Elective

Prerequisites : none

Course Contents

Unit 1 **1st and 2nd generation of PV technologies**

Technologies for manufacturing of Crystalline Si solar cells by different methods. PERC, PERL, PERT, rear contact solar PV technology. Fabrication, working principle and performance of Bifacial solar cells/panels.

Fabrication Technology for Thin Film Solar Cells, High efficiency multi-junction solar cell, Polymer, organic, dye sensitized solar cell. PECVD, APCVD, Sputtering and other methods to fabricate thin film solar cells.

Unit 2 **3rd generation PV technologies**

Quantum dot solar cells, structure, working principle, present applications, near future trends. Perovskite solar cell. Fabrication of 3rd generation solar cells.

Unit 3 **Characterization instruments and standards & certification**

Electroluminescence imaging, Thermal imaging, IV curve Tracer. Working principles of AFM, SEM, TEM and other film characterization instruments.

International Electrotechnical Commission (IEC) certification, IEC 61215, Power measurements to standard test conditions (STC), Performance at low irradiance, Climatic tests, Ultra violet (UV) preconditioning tests, Hot spot endurance tests, Mechanical load tests, Wet leakage current tests, Insulation tests.

Unit 4 **Application, future trend and recycling**

Working principle of semitransparent photovoltaics, application to building envelop. Agro/organic-PV cells, traditional and innovative solar power applications. Methods of recycling of commercial PV Panels.

Recommended Readings

1. Solar PV Power Design, Manufacturing and Applications from Sand to Systems by Rabindra Satpathy, Venkateswarlu Pamuru, Academic Press, 2020, ISBN 978-0-128-17627-6
2. Solar Cell Materials Developing Technologies by Gavin Conibeer and Arthur Willoughby, Wiley 2014.ISBN 978-0-470-06551-8
3. Terawatt Solar Photovoltaics, Roadblocks and Opportunities Edited by M. Tao, Springer, 2014 edition. ISBN 978-1- 4471-5643- 7
4. Handbook of Photovoltaic Science and Engineering, Edited by A. Tuque and S. Hegedus, John Wiley & Sons, Ltd, 2012 edition. ISBN 978-0- 470-72169- 8

Course Code : **ENL612**

Course Name : **RENEWABLE INTEGRATION MARKETS**

Credits : 3 **L -** 3 **T -** 0 **P -** 0

Course Type : Elective

Prerequisites : none

Course Contents

Unit 1 **System impacts of RE integration on power systems** : Primary economic effects of RE, Role of forecasts in power economics, Other potentially important effects at local level and aggregated level, Weather fronts and wind/PV (RE) ramps

Unit 2 **Challenges and issues with RE Integration in markets** : Why to integrate RE in Electricity market structure?, Organization of the pool-based electric energy market, Impact of RE in different time frames (Short Term, Long Term), Planning issues with RE, Flexibility, flexibility resources, incentivizing flexibility, Intraday and balancing markets, Concepts of Capacity and Flexibility markets

Unit 3 **Ancillary Service Markets** : Issues with the present market design, Ancillary services recognized in various markets, Ancillary service procurement, Ancillary service auction - sequential and simultaneous approach, Automatic generation control, AGC pricing, present practices.

Unit 4 **Balancing Markets** : Need of balancing markets, impact of RE, multiple levels of balancing, Day ahead, Intraday and Real Time energy markets, Balancing market auctions, Two price imbalance settlement, Active demand side participation, Impact of Network Constraints, Procurement of Balancing Services, Procurement of Frequency-Based Balancing Services, Volume of Frequency Control Balancing Services Required, Allocating the Costs of Balancing Services

Unit 5 **System impacts of RE integration on power systems** : Primary economic effects of RE, Role of forecasts in power economics, Other potentially important effects at local level and aggregated level, Weather fronts and wind/PV (RE) ramps

Unit 6 **Flexibility from distribution system** : Evolving vision for the future energy trading, Smart Grid and smart utility, Transition from DNO to DSO and consumers to prosumers, Active distribution system management, Role of Microgrids in future electricity grids, Concepts of Local Energy Transactions

Unit 7 **Local Energy trading** : Concepts of VPP, Microgrids and Local electricity market, Energy collective or community markets, Distributed optimization, coordination of distributed energy resources, Role of Aggregator, Peer-to-peer energy market, Re-designing network charges

Recommended Readings

1. Morales, Juan M., Antonio J. Conejo, Henrik Madsen, Pierre Pinson, and Marco Zugno. Integrating renewables in electricity markets: operational problems. Vol. 205, Springer Science & Business Media, 2013, ISBN 978-1-4614-9411-9
2. Ken Dragoon, Valuing Wind Generation on Integrated Power Systems, Elsevier's Science & Technology Rights Department in Oxford, UK, First edition 2010, ISBN–13: 978-0-8155-2047-4.
3. Darryl R. Biggar and Mohammad Reza Hesamzadeh, The Economics of Electricity Markets, John Wiley & Sons Ltd, 2014, ISBN:9781118775752.
4. S. Chowdhury, S.P. Chowdhury and P. Crossley, Microgrids and Active Distribution Networks, The Institution of Engineering and Technology, London,

United Kingdom, 2009, ISBN: 9781849191029.
5. Koutitas, George, and Stan McClellan. The Smart Grid as an Application Development Platform, Artech House, 2017, ISBN: 9781630811099.
6. T. Morstyn, N. Farrell, S. J. Darby, and M.D. McCulloch, "Using peer-to-peer energy-trading platforms to incentivize prosumers to form federated power plants," in Nature Energy, vol. 3, no. 2, pp. 94, Feb 2018.
7. Y. Parag and B. K. Sovacool, "Electricity market design for the prosumer era," in Nature Energy, vol. 1, no. 4, pp. 1–6, Mar 2016.
8. Aris Spanos, "Statistical Foundations of Econometric Modelling" Cambridge University Press, June 2011, ISBN 9780511599293.

Course Code	**:**	**ENL613**
Course Name	**:**	**MODELING AND OPTIMIZATION OF ENERGY SYSTEMS**
Credits	**:**	3 **L -** 3 **T -** 0 **P -** 0
Course Type	**:**	Elective
Prerequisites	**:**	none

Course Contents

Unit 1	Modeling and simulation principles - Modelling overview-levels of analysis, steps in model development, examples of models. Hardy-Cross method - Multivariable Newton-Raphson simulation method - Simulation of renewable energy systems/Case studies - Simulation using differential equations - Mathematical modeling of thermodynamic properties - Steady state simulation of large systems - Simulation of dynamic systems.
Unit 2	Optimization : Objectives/constraints, problem formulation. Unconstrained problems-Necessary & Sufficient conditions. Constrained Optimization-Lagrange multipliers, constrained variations, Kuhn-Tucker conditions. Case studies of optimization in Energy systems problems. Dealing with uncertainty-probabilistic techniques. Linear programming - Dynamic programming - Non-traditional optimization techniques Introduction system design - Curve fitting - Search methods - Univariate / Multivariate
Unit 3	Characteristics of measurement systems, time response of measurement systems, System response- first and second order systems and analysis, error estimates and uncertainty analysis, propagation of uncertainty
Unit 4	Statistical analysis of experimental data- normal error distributions (confidence interval and level of significance, Chauvenet's criterion), Chi-square test of goodness of fit, method of least squares (regression analysis, correlation coefficient), multivariable regression, error estimates using Gaussian distribution, Static and dynamic characteristics; dimensional analysis and similitude, Design of experiments
Unit 5	Energy Demand Forecasting : Simple and advanced Techniques, Econometric Approach to Energy Demand Forecasting, End-Use Method of Forecasting, Input–Output Model, Scenario based approach, ANN, Hybrid Approach.

Recommended Readings

1. J. Randolph and G. M. Masters, Energy for Sustainability: Technology, Planning, Policy, Island Press, 2018, ISBN-13: 978-1597261036.
2. M. Munasinghe and P. Meier, Energy Policy Analysis and Modeling, Cambridge University Press, 1993, ISBN:9780511983573.
3. Bhattacharyya, Subhes C. *Energy economics: concepts, issues, markets and governance*. Springer Science & Business Media, 2011, ISBN 978-0-85729-268-1.
4.Adrian Bejan, George Tsatsaronis, Michael Moran, Thermal Design and Optimization, John Wiley, 1995, ISBN: 978-0-471-58467-4.
5. Y. Jaluria, Design and Optimization of Thermal Systems, 2e, CRC Press, 2008, ISBN 9781498778237.
6. W.F. Stoeker, Design of Thermal Systems, 3e, McGraw Hill, 2011, ISBN 10: 125900239X / ISBN 13: 9781259002397.
7. C. Balaji, Essentials of Thermal System Design and Optimization, ANE books, 2011, ISBN 13: 9781439891544.
8. Fabio De Bellis, "Energy Systems Simulation and Optimization", Lambert academic, ISBN-13: 978-3848420216.

Course Code : **ENL614**

Course Name : **SMART GRID SYSTEMS**

Credits : 3 **L -** 3 **T -** 0 **P -** 0

Course Type : Elective

Prerequisites : none

Course Contents

Unit 1 **The Smart Grids**: Introduction to Smart Grids - Definition, justification for smart grids, smart grid conceptual model, smart grid architectures, Interoperability, communication technologies, role of smart grids standards, intelligrid initiative, National Smart Grid Mission (NSGM) by Govt. of India

Unit 2 **Smart Transmission & Distribution Technologies:** Substation automation, SCADA Systems, energy management system (EMS), phasor measurement units (PMU), Wide area measurement systems (WAMS), Distribution automation, outage management systems, automated meter reading (AMR), fault location, isolation and service restoration (FLISR), Outage Management Systems (OMS), Energy Storage, Renewable Integration.

Unit 3 **Monitoring and measurement**: Wide area monitoring system, Phasor measurement units, Smart meters, Smart Appliances, Advanced metering infrastructure (AMI), other monitoring and measurement technologies.

Unit 4 **Information and Communication Technologies**: Distribution line models, Communication infrastructures and protocols for smart grid operation, Standard for information exchange, State of art Interoperability, Information Security, Cyber Security Standards

Unit 5 **Distributed Generation and Smart Consumption**: Distributed energy resources (DERs), smart appliances, low voltage DC (LVDC) distribution in homes / buildings, home energy management system (HEMS), Net Metering, Building to Grid B2G, Vehicle to Grid V2G, Solar to Grid, Microgrid.

Unit 6 **Economic Grid Operation**: Basic Concepts Related to Electricity Systems, Economic Dispatch, Merit Order Dispatch, Incremental Cost Method, Unit Commitment, Demand Response (selection of generators & loads to operate), Energy constraints: hydro, fuel management and maintenance scheduling.

Recommended Readings

1. Stuart Borlase , Smart Grid: Infrastructure, Technology and Solutions, CRC Press 2012, ISBN 9781439829059.
2. Janaka Ekanayake, Nick Jenkins, Kithsiri Liyanage, 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, CRC Press, 2015, ISBN-13: 978-1482226744.
4. Kenneth C.Budka, Jayant G. Deshpande, Marina Thottan, Communication Networks for Smart Grids, Springer, 2014, ISBN 978-1-4471-6302-2.
5. Henrik Lund, “A Smart Energy Systems Approach to the Choice and Modeling of 100% Renewable Solutions” Academic Press, ISBN: 9780124104235.

Course Code : **ENL615**

Course Name : **SOLAR PASSIVE HEATING AND COOLING**

Credits : 3 **L -** 3 **T -** 0 **P -** 0

Course Type : Elective

Prerequisites : none

Course Contents

Unit 1	Basics of climatology relevant to building design, understanding of climate zones and bioclimatic charts; details on climate zones in India; climatic factors and impact on energy use in buildings and human comfort
Unit 2	Solar geometry and exposure: sun path diagram, shading analysis, graphical design tools, solar control issues, thermal mass
Unit 3	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,
Unit 4	Solar ventilation: stack effect, solar chimney for ventilation, absorber design, stack design, issues in opening design.

Recommended Readings

1. Otto H Koenigsberger, Ingersoll, T. G., Mayhew , Szokolay, S. V, Manual Of Tropical Housing & Building – Climatic Design, Universities Press, 2018.
2. M. S. Sodha, N. K. Bansal, P. K. Bansal, A. Kumar and M. A. S. Malik, Solar Passive Building: science and design, Pergamon Press, New York, 1986
3. J. A. Duffie and W. A. Beckman, Solar Engineering of Thermal Processes, 4th Edition, John Wiley, New York, 2013 ISBN: 978-0-470-87366-3

D. Y. Goswami, F. Kreith and J. F. Kreider, Principles of Solar Engineering, Taylor and Francis, Philadelphia, 2000 ISBN 978-1560327141

Course Code : **ENL616**

Course Name : **HYDROGEN ENERGY TECHNOLOGY**

Credits : 3 **L -** 3 **T -** 0 **P -** 0

Course Type : Elective

Prerequisites : none

Course Contents

Unit 1 Need for Hydrogen Energy: Global energy picture, Present and Projected Uses for Hydrogen, Prospects, Prognosis and Future for Hydrogen energy, challenges. Production of Hydrogen: from Fossil fuels, synthetic fuels. Electrolysis of water: high pressure electrolysis, low pressure electrolysis, high-temperature electrolysis. Electrolyzers. High-temperature electrolysis. Using Solar energy: Photochemical, Photo-catalytic, the water oxidation in nature, Artificial photosynthesis. Solar cracking: photo-electrochemical. Water Splitting with Solar Energy, Photovoltaic Cells, Solar Thermal Process, Photo-electrochemical Cells, Dye-sensitized Solar Cells, Direct Hydrogen Production Tandem Cells, Photo-biochemical Cells.

Unit 2 Transportation, Distribution and Storage - Strategic Considerations, Distribution and Bulk Storage of Gaseous, Dewars for transport applications Gas Cylinders, Pipelines, Large-scale Storage, Metal Hydrides, Chemical and Related Storage, Simple Hydrogen-bearing Chemicals, Complex Chemical Hydrides, Nano-structured Materials, Hydrogen Storage in Road Vehicles, Industrial scale pressurized hydrogen storage.

Unit 3 Hydrogen as a fuel in heat engines: Stationary and powering vehicles in road transport and aviation industry, Hydrogen energy, Hydrogen as a fuel, Liquid and Gaseous Fuels. Physico-chemical characteristics. Efficiency calculations and fuel consumption, Internal combustion engines and aircraft. Hydrogen-fuelled Transportation

Fuel cell systems, basic principles and classification; proton exchange membrane fuel cell, fuel cell poisoning. Reversible and irreversible losses, efficiency of FC.

Fuel Crossover/Internal Current Losses, Ohmic Losses, Mass Transport /Concentration Losses. System integration; Power management, Thermal management, Fuel cell system design, application of fuel cells to automotive sectors. Case study/project.

Unit 4 Metering, instrumentation and safety issues: Hydrogen gas and Liquified hydrogen properties and associated hazards - Safety regulations - Codes and Standards - Physiological, physical and chemical hazards of hydrogen, Safety of hydrogen storage facilities - Effects of Hydrogen on Materials of Construction - Hydrogen Embrittlement - Loss of Thermal Stability. Hydrogen use in vehicles - Onboard vehicle hydrogen storage and safety - Hydrogen Fueling of Vehicles - Case studies

Recommended Readings

1. Angelo Basile, Adolfo Iulianelli (Editors), Advances in hydrogen production, storage and distribution, ISBN 978-0-85709-768-2, 2014 Elsevier Ltd.
2. Broom, Darren P, Hydrogen Storage Materials: The Characterisation of Their Storage Properties, 2011, ISBN 978-0-85729-221-6, Springer
3. Arno A. Evers, 2010. The Hydrogen Society. Hydrogeit Verlag. ISBN 978-3-937863-31-3.
4. Vladimir Molkov, Fundamentals of hydrogen safety engineering - I, Bookboon.com, ISBN 978-87-403-0226-4
5. Vladimir Molkov, Fundamentals of hydrogen safety engineering - II,

Bookboon.com, ISBN 978-87-403-0279-0
Fotis Rigas and Paul Amyotte, Hydrogen Safety, CRC Press, ISBN 978-1-4398-6231-5

Course Code : **ENL617**

Course Name : **ENERGY SIMULATION**

Credits : 3 **L -** 1 **T -** 0 **P -** 4

Course Type : Elective

Prerequisites : none

Course Contents

Unit 1

- Introduction to energy simulation tools
- Modeling techniques used in various tools
- Validation of simulation model
- Simulation of renewable energy systems (single source based and hybrid systems)

Simulation for energy efficiency of buildings