Semester I

		L	T	P	C
EN 601	Non-conventional Energy Sources	3	0	0	6
EN 602	Foundation for Energy Engineering	2	0	0	4
EN 606	Energy Resources, Economics & Environment	3	0	0	6
EN 618	Energy Systems Modelling & Analysis	3	0	0	6
HS 791	Communication Skills - I	1	0	0	2*
EN 792	Communication Skills - II	2	0	0	4*
EN 609	Energy Systems Laboratory	0	1	3	4
EN 694	Seminar	0	0	0	4
	Elective I				6
Total					36+6*

Elective I[1]

		L	T	P	C
EN 613	Nuclear Reactor Theory	3	0	0	6
EN 647	Distributed Generation and Microgrids	3	0	0	6
EN 649	Introduction to Particulate Flow	3	0	0	6
CL 601	Advanced Transport Phenomena	2	0	2	6
CL 605	Advanced Reaction Engineering	2	0	2	6
CL 607	Advanced Thermodynamics	2	0	2	6
ME 683	Cryogenic Engineering I	3	0	0	6
ME 663	Advanced Heat Transfer	3	0	0	6
ME 661	Advanced Thermodynamics & Combustion	3	0	0	6
ME 681	Thermal Environmental Engineering	3	0	0	6
EE 653	Power Electronics I	3	0	0	6
EE 655	Computer Aided Power Systems Analysis	3	0	0	6
EE 657	Electric drives	3	0	0	6

Semester II

		L	T	P	C
EN 607	Energy Management	3	0	0	6
EN 642	Power Generation & Systems Planning	3	0	0	6
EN 612	Non-conventional Energy Systems Lab	0	0	3	3
	Electives II, III, and IV				18
Total					33

Elective II, III, and IV[1]

		L	T	P	C
EN 640	Solar Photovoltaics: Fundamentals, Technologies and Applications	3	0	0	6
EN 604	Fuel Cells	3	0	0	6
EN 630	Utilization of Solar Thermal Energy	3	0	0	6
EN 632	Waste to Energy	3	0	0	6
EN 615	Wind Energy Conversion Systems	3	0	0	6
EN 610	Hydrogen Energy	3	0	0	6
CL 603	Optimization	3	0	0	6
CL 604	Process Plant Simulation	3	0	0	6

CL 684	Advanced Process Synthesis	2	0	2	6
CL 625	Process Modelling & Identification	3	0	0	6
ME 662	Convective Heat and Mass Transfer	3	0	0	6
ME 704	Computational Methods in Thermal & Fluids Engg.	3	0	0	6
ME 684	Air Conditioning Systems Design	3	0	0	6
EE 654	Power Electronics II	3	0	0	6
EE 656	Electrical Machine Analysis & Control	3	0	0	6
EE 658	Power Systems Dynamics & Control	3	0	0	6
EE 660	Application of Power Electronics to Power Systems	3	0	0	6
EE 686	H V D C Transmission	3	0	0	6
EN 658	Electrochemical Energy Storage	3	0	0	6
EN 651	Multiphase Petroleum Transportation	3	0	0	6
EN 648	Combustion Engineering	2	1	0	6
EN 649	Introduction to Particulate Flow	3	0	0	6
EN 653	Energy Policy Analysis	3	0	0	6
EN 657	IC Engine, Alternate Fuels and Emissions	3	0	0	6
EN 703	Advanced Concepts in Solar Cell Technologies	3	0	0	6

Semester III

		L	T	P	C
EN 797	I Stage Project				38
	Electives V and VI				12
Total					50

Elective V and VI[1]

		L	T	P	C
EN 628	Materials and devices for energy applications	3	0	0	6
EN 637	Principles and Applications of Hydrogen Storage	3	0	0	6
EN 624	Conservation of Energy in Building	3	0	0	6
EN 619	Solar Energy for Industrial Process Heat	3	0	0	6
EN 645	Process Integration	3	0	0	6
CL 676	Modelling & Simulation	2	1	0	6
CL 611	Electrochemical Reaction Engineering	3	0	0	6
EE 659	Optimization	3	0	0	6
EE 675	Microprocessor Applications in Power Electronics	3	0	0	6

Semester IV

		L	T	P	C
EN 798	II Stage Project				42
Total					42

Notes:

* Communication Skills (HS 699) is a P/NP course.

[1] Out of these six electives, one has to be institute elective and at least two have to be EN (Energy Systems) electives.

Course Contents

EN 601 Non-conventional Energy Sources 3-0-0-6

Energy Alternatives: The Solar Option, The Nuclear Option, Tar sands and Oil Shale, Tidal Energy, Geothermal Energy
Solar Energy: Solar Radiation, availability, measurement and estimation, Solar Thermal Conversion Devices and Storage, Applications
Solar Photovoltaic conversion, Wave Energy and Ocean Thermal Energy Conversion, Wind Energy Conversion, Biomass Energy Conversion
Energy from Waste, Mini/Micro-hydel

Texts/References

- S. P. Sukhatme, Solar Energy - Principles of thermal collection and storage, second edition, Tata McGraw-Hill, New Delhi, 1996
- J. A. Duffie and W. A. Beckman, Solar Engineering of Thermal Processes, second edition, John Wiley, New York, 1991
- D. Y. Goswami, F. Kreith and J. F. Kreider, Principles of Solar Engineering, Taylor and Francis, Philadelphia, 2000
- D. D. Hall and R. P. Grover, Biomass Regenerable Energy, John Wiley, New York, 1987.
- J. Twidell and T. Weir, Renewable Energy Resources, E & F N Spon Ltd, London, 1986.

EN 602 Foundation for Energy Engineering 2-0-0-4

Thermodynamics: first law and its application, second law and its application, Irreversibility and energy, basic power generation cycles.

Fluid Mechanics: stress-strain relations and viscosity, mass and momentum balance, flow through pipe. Heat Transfer: conduction, radiation, convective heat transfer. Network analysis: simple network analysis, power factor improvement.
Electrical Machines: Transformer, Induction motor and generators, Synchronous generators, Introduction to modern speed control techniques, DC machines. Power systems: Introduction to power transmission and distribution.

Texts/References

- M. W. Zemansky, Heat and Thermodynamics 4th Edn. McGraw Hill, 1968.
- A. L. Prasuhn, Fundamentals of Fluid Mechanics, Prentice Hall, 1980
- S. P. Sukhatme, A Text book on Heat Transfer, Orient Longman, 1979.
- P. C. Sen, Modern Power Electronics, Wheeler, New Delhi, 1998.
- N. Balbanian, T. A. Bickart, Electrical network theory, John Wiley, New York, 1969
- B. L. Theraja, A. K. Theraja, Text-book of electrical technology: in S.I. units: v.2 AC and DC machines, Nirja Construction & development, New Delhi, 1988.

EN 604 Fuel Cells 3-0-0-6

Introduction to the principles and operation of fuel cells, stack configurations and fuel cell systems. Fuel cell system design, optimization and economics. Overview of fuel cell technology. Thermodynamics of fuel cells, introduction to electrochemical kinetics, transport-related phenomena and conservation equations for reacting multicomponent systems.

Texts/References

- Fuel Cell System, edited by Leo J.M.J. Blomen and michael N. Mugerwa, New York, Plenum Press, 1993.
- Fuel Cell Handbook, by A. J. Appleby and F. R. Foulkers, Van Nostrand, 1989.

EN 606 Energy Resources, Economics & Environment 3-0-0-6

Overview of World Energy Scenario – Dis-aggregation by end-use, by supply Fossil Fuel Reserves - Estimates, Duration Overview of India's Energy Scenario - Dis-aggregation by end-use, by supply, reserves Country Energy Balance Construction - Examples Trends in energy use patterns, energy and development linkage.
Energy Economics - Simple Payback Period, Time Value of Money, IRR, NPV, Life Cycle Costing, Cost of Saved Energy, Cost of Energy generated, Examples from energy generation and conservation, Energy Chain, Primary energy analysis Life Cycle Assessment, Net Energy Analysis
Environmental Impacts of energy use - Air Pollution - SOx, NOx, CO, particulates Solid and Water Pollution, Formation of pollutants, measurement and controls; sources of emissions, effect of operating and design parameters on emission, control methods, Exhaust emission test, procedures, standards and legislation; environmental audits; Emission factors and inventories Global Warming, CO2 Emissions, Impacts, Mitigation Sustainability, Externalities, Future Energy Systems.

Texts/References

- Energy and the Challenge of Sustainability, World energy assessment, UNDP New York, 2000.
- AKN Reddy, RH Williams, TB Johansson, Energy after Rio, Prospects and challenges, UNDP, United Nations Publications, New York, 1997.
- Nebojsa Nakicenovic, Arnulf Grubler and Alan McDonald Global energy perspectives, Cambridge University Press, 1998
- Fowler, J.M., Energy and the environment, 2nd Edn., McGraw Hill, New York, 1984

EN 607 Energy Management 3-0-0-6

Importance of energy management. Energy auditing: methodology, analysis of past trends (plant data), closing the energy balance, laws of thermodynamics, measurements, portable and on line instruments. Steam Systems: Boiler -efficiency testing, excess air control, Steam distribution & use- steam traps, condensate recovery, flash steam utilisation. Thermal Insulation. Electrical Systems: Demand control, power factor

correction, load scheduling/shifting, Motor drives- motor efficiency testing, energy efficient motors, motor speed control. Lighting- lighting levels, efficient options, fixtures, day lighting, timers, Energy efficient windows. Energy conservation in Pumps , Fans (flow control), Compressed Air Systems, Refrigeration & air conditioning systems. Waste heat recovery: recuperators, heat wheels, heat pipes, heat pumps. Cogeneration - concept, options (steam/gas turbines/diesel engine based), selection criteria, control strategy. Heat exchanger networking- concept of pinch, target setting, problem table approach, composite curves. Demand side management.

Texts/References

- L.C.Witte, P.S.Schmidt, D.R.Brown , Industrial Energy Management and Utilisation, Hemisphere Publ, Washington,1988.
- Industrial Energy Conservation Manuals, MIT Press, Mass, 1982.
- I.G.C.Dryden, Butterworths, The Efficient Use of Energy, London, 1982
- W.C.Turner, Wiley, Energy Management Handbook, New York, 1982.
- Technology Menu for Efficient energy use- Motor drive systems, Prepared by National Productivity Council and Center for & Environmental Studies- Princeton Univ, 1993.

EN 609 Energy Systems Lab 0-1-3-4

Boiler, Pump & motor efficiency testing, Properties of fuel oils & biomass, Testing of Gasifier, wind machines, and Fuel cell, Pollutant level measurement, electrical machines characteristics, refrigeration system

EN 610 Hydrogen Energy 3-0-0-6

Hydrogen Production – Production of hydrogen from hydrocarbons –Oxidative and non-oxidative processes, coal. H2 production using nuclear energy and renewables- wind, biomass, solar. Hydrogen separation and purification – Pressure swing adsorption; Solvent based absorption, membrane separation, cryogenic separation etc. Hydrogen storage – compressed storage, liquid state storage, solid state storage, different materials for storage – metal hydrides, high surface area materials, complex and chemical hydrides, hydrogen storage system – design and materials aspects. Hydrogen sensing – Traditional methods of hydrogen sensing using thermal conductivity measurements or GC, MS or laser gas analysis; Solid state sensors- their working principle and applications in industrial scale applications. Hydrogen Safety – History of accident;, physiological, physical and chemical hazards; hydrogen properties associated with hazards; Hazard spotting, evaluation and safety guidelines; Hydrogen safety codes and standards.

EN 612 Non-conventional Energy Systems Lab 0-0-3-3

Measurement of solar radiation and sunshine hours, Measurement of albedo, UV & IR radiation, Measurement of emissivity, reflectivity, transmittivity, Performance testing of solar flat plate water heater – forced flow & thermosyphon systems, Performance testing solar air heater & dryer & desalination unit, Performance testing of solar thermal concentrators, Characteristics of photovoltaic devices & testing of solar PV operated pump, Energy consumption & lumen measurement of lights & ballasts

EN 613 Nuclear Reactor Theory 3-0-0-6

Radioactivity, Nuclear reactions, Cross sections, Nuclear fission, Power from fission, Conversion and breeding, Neutron transport equation, Diffusion theory approximation, Fick's law, Solutions to diffusion equation for point source, Planar source, etc. Energy loss in elastic collisions, Collision and slowing down densities, Moderation in hydrogen, Lethargy. concept, Moderation in heavy nucleus. Moderation with absorption, Resonance absorption, NR and NRIM approximations. Multi-region reactors, Multigroup diffusion methods, Thermal reactors, Heterogeneous reactors. Reactor kinetics. in hour equation, Coefficients of reactivity, Control, Fission product poison. Perturbation theory

Texts / References

- J.R. Lamarsh, Introduction to Nuclear Reactor Theory, Wesley, 1966
- J.J. Duderstadt and L.J. Hamilton, Nuclear Reactor Analysis, John Wiley, 1976

EN 615 Wind Energy Conversion Systems 3-0-0-6

Wind machine types, classification, parameters.
Wind, its structure, statistics, measurements, data presentation, power in the wind.
Wind turbine aerodynamics, momentum theories, basic aerodynamics, airfoils and their characteristics, Horizontal Axis Wind Turbine (HAWT) - Blade Element Theory, wake analysis, Vertical Axis Wind Turbine (VAWT) aerodynamics.
HAWT rotor design considerations, number of blades, blade profile, 2/3 blades and teetering, coning, power regulation, yaw system, tower.
Wind turbine loads, aerodynamic loads in steady operation, wind turbulence, static - dynamic - fatigue analysis, yawed operation and tower shadow, WECS control system, requirements and strategies.
Wind Energy Conversion System (WECS) siting, rotor selection, Annual Energy Output (AEO).
Synchronous and asynchronous generators and loads, integration of wind energy converters to electrical networks, inverters.
Testing of WECS. Noise. Miscellaneous topics.

Texts/ References:

- Freris L.L., Wind Energy Conversion Systems, Prentice Hall 1990.
- Spera D.A., Wind Turbine Technology: Fundamental Concepts of Wind Turbine Engineering, ASME Press, NY 1994.
- Johnson, G.L., Wind Energy Systems, Prentice Hall, 1985.

EN 618 Energy Systems Modelling & Analysis 3-0-0-6

Modelling overview-levels of analysis, steps in model development, examples of models. Quantitative Techniques: Interpolation-polynomial, Lagrangian. Curve-fitting, regression analysis, solution of transcendental equations. Systems Simulation-information flow diagram, solution of set of nonlinear algebraic equations, successive substitution, Newton Raphson. Examples of energy systems simulation Optimisation : Objectives/constraints, problem formulation. Unconstrained problems- Necessary & Sufficiency conditions.

Constrained Optimisation- Lagrange multipliers, constrained variations, Kuhn-Tucker conditions. Linear Programming - Simplex tableau, pivoting, sensitivity analysis. Dynamic Programming. Search Techniques- Univariate / Multivariate. Case studies of optimisation in Energy systems problems. Dealing with uncertainty- probabilistic techniques. Numerical solution of Differential equations- Overview, Convergence, Accuracy. Transient analysis- application example.

Texts/References

- W. F. Stoecker Design of Thermal Systems, Mcgraw Hill, 1981
- S.S.Rao Optimisation theory and applications, Wiley Eastern, 1990
- S.S. Sastry Introductory methods of numerical analysis,Prentice Hall, 1988
- P. Meier Energy Systems Analysis for Developing Countries, Springer Verlag, 1984
- R.de Neufville, Applied Systems Analysis, Mcgraw Hill, International Edition, 1990
- Beveridge and Schechter,Optimisation Theory and Practice,Mcgraw Hill, 1970

EN 619 Solar Energy for Industrial Process Heat 3-0-0-6

Industrial process heat – temperature requirements, consumption pattern,
Applications of solar flat plate water heater & air heater for industrial process heat, designing thermal storage, transport of energy, Concentrating Solar collector systems, Basic concepts & parameters, Solar – Earth geometry, Insolation, Optics – ray tracing, Concentrating collector designs, Tracking systems, Absorbers for Concentrators; Parabolic trough concentrators, Concentrators with point focus, Heliostats, Comparison of various designs, industrial applications of concentrating collectors, Exercises in Industrial Applications

Texts / References

- A. Rabl, Active Solar Collectors and Their Applications, Oxford University Press, New York, 1985
- D. Y. Goswami, F. Kreith and J. F. Kreider, Principles of Solar Engineering, Taylor and Francis, Philadelphia, 2000
- W. T. Welford, R. Winston, The Optics of Nonimaging Concentrators – Light & Solar Energy, Academic Press, New York, 1978

EN 624 Conservation of Energy in Building 3-0-0-6

Climates and buildings. Thermal properties and energy content of building materials, Psychrometry, Comfort conditions, Airconditioning systems. Energy conservation techniques in Airconditioning systems. Lighting (Daylighting and Electric lighting). Passive and active methods of heating and cooling. Estimation of building loads. Steady state method, Network method, Numerical method, Corelations. Computer packages for carrying out thermal design of buildings and predicting performance.

Texts / References

- M.S.Sodha, N.K. Bansal, P.K. Bansal, A. Kumar and M.A.S. Malik, Solar Passive Building, Science and Design, Pergamon Press, 1986.
- J.R. Williams, Passive Solar Heating, Ann Arbar Science, 1983.
- R.W.Jones, J.D. Balcomb, C.E. Kosiewiez, G.S. Lazarus, R.D. McFarland and W.O. Wray, Passive Solar Design Handbook, Vol. 3, Report of U.S. Department of Energy (DOE/CS-0127/3), 1982.
- J.L. Threlkeld, Thermal Environmental Engineering, Prentice Hall, 1970.

EN 630 Utilization of Solar Thermal Energy 3-0-0-6

Solar Radiation, availability, measurement and estimation; Flat plate and concentrating collectors; Solar thermal storage; Modelling of solar thermal systems and simulations in process design; Design of active systems by f-chart method; Water heating systems: active and passive; Passive heating and cooling of buildings; Solar distillation; Solar thermal power generation; Solar drying; Solar cooking

Texts/References:

- S. P. Sukhatme, Solar Energy - Principles of thermal collection and storage, second edition, Tata McGraw-Hil, New Delhi, 1996
- J. A. Duffie and W. A. Beckman, Solar Engineering of Thermal Processes, second edition, John Wiley, New York, 1991
- D. Y. Goswami, F. Kreith and J. F. Kreider, Principles of Solar Engineering, Taylor and Francis, Philadelphia, 2000
- 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
- M. A. S. Malik, G. N. Tiwari, A. Kumar and M.S. Sodha, Solar Distillation. Pergamon Press, New York, 1982.
- Tiwari and Tiwari, Handbook of Solar Energy - Theory, Analysis and Applications, Springer, 2016

EN 632 Waste to Energy 3-0-0-6

Introduction to energy from waste: characterisation and classification of waste as fuel – agrobased, forest residues, industrial waste, Municipal solid waste; Waste to energy options: Biochemical and Thermochemical routes; Biochemical Options – Anaerobic Digestion, Fermentation; Thermochemical Options – Pyrolysis, Gasification and Incineration; Other options – Biodiesel synthesis, Briquetting and Torrefaction, Hazardous waste management; Properties of fuels derived from waste to energy technology: Producer gas, Biogas, Ethanol and Briquettes, Comparison of properties with conventional fuels; Landfills: Gas generation and collection in land fills, Introduction to transfer stations.

Texts/References

- M.M. EL-Halwagi, Biogas Technology- Transfer and diffusion, Elsevier Applied science Publisher, New York, 1984.
- D.O Hall and R.P. Overeed, Biomass – regenerable energy, John Willy and Sons Ltd. New York. 1987.

EN 637 Principles and Applications of Hydrogen Storage 3-0-0-6

Introduction: Properties of hydrogen; Need for hydrogen storage in stationary and mobile applications; Types of hydrogen storage (Gaseous, Liquid, Solid hosts); Department of Energy (USA) Targets for storage, Techno-politics

Thermodynamics: Gibbs Phase Rule; Pressure-Composition-Temperature plots; Van't Hoff plots for absorption desorption enthalpies; Gravimetric capacities; Hysteresis in cycling; Joule-Thomson Effect, Non-ideal treatment of hydrogen gas

Kinetics: Hydrogen absorption/desorption phenomena (chemisorption, nucleation and growth and diffusion); Kinetic models: interfacial, 1D/2D/3D diffusional mechanisms, sequential vs simultaneous phenomena; Kissinger analysis for activation energy estimation (Temperature programmed desorption); Hydrogen adsorption isotherms: BET, Langmuir, Freundlich, Polanyi; Boltzmann statistics

Design and Applications of Storage Systems: Design considerations for stationary and mobile applications; Selection of type and materials for storage; Thermal management; Hybrid storage systems; Life cycle analysis; Hydrogen storage for automobiles; Stand alone grids; McPhy Analysis (Industrial high capacity storage); Hydrogen-IC Engines

Texts / References

- Angelo Basile, Adolfo Iulianelli, Advances in Hydrogen Production, Storage and Distribution, 1st Edition, Woodhead Publishers, Cambridge (UK), 2014.
- Michael Hirscher, Hand Book of Hydrogen Storage, 1st Edition, Wiley-VCN Verlag GmbH, 2010.
- Gavin Walker, Solid State Hydrogen Storage: Materials and Chemistry, 1st Edition,Woodhead Publishers, Cambridge (UK), 2008.
- Rober A. Varin, Tomasz Czujko, Zbigniew S. Wronski, Fuel Cells and Hydrogen Energy Series: Nanomaterials for Solid State Hydrogen storage, 1st Edition, Springer, 2009.
- Lennie Klebanoff, Hydrogen Storage Technology: Materials and Applications, 1st Edition, CRC Press, 2012.
- Darren P Broom, Hydrogen Storage Materials: The Characterisation of Their Storage Properties, 1st Edition, Springer, London, 2011.
- Said Al-Hallaj, Kristofer Kiszynski, Hybrid Hydrogen Systems: Stationary and Transportation Applications, 1st Edition, Springer, London, 2011

EN 640 Solar Photovoltaics: Fundamentals, Technologies and Applications 3-0-0-6

Quantum mechanics, Crystals structures, atomic bonding, types of semiconductors, energy band diagram, p-type and n-type semiconductors, doping and carrier concentration, diffusion and drift of carriers, continuity equation, P-N junction and its properties, dark I-V equation of P-N junction, junction under illumination, solar cell

parameters, production of silicon, fabrication of solar cells, design of solar cells, optimization of process parameters, measurements of solar cell parameters; short circuit current, open circuit voltage, fill factor, efficiency; optical losses; electrical losses, surface recombination velocity, quantum efficiency, I-V curve; thin film solar cell technologies, amorphous Si solar cells, CdTe, CIGs solar cells, solar cells and solar PV modules, issues with solar PV modules, bypass diode and blocking diode, applications of solar PV systems, electronic circuits in PV, design of solar PV systems; battery sizing, PV panel sizing, inverter sizing, solar lanterns, water pumping application, home lighting application, cathodic protection, remote lighting.
Last Update

Texts / References

- Solar cells: Operating principles, technology and system applications, by Martin A. Green, Prentice-Hall Inc, Englewood Cliffs, NJ, USA, 1981.
- Semiconductors for solar cells, H. J. Moller, Artech House Inc, MA, USA, 1993.
- Solid State electronic devices, Ben G. Streetman, , Prentice-Hall of India Pvt. Ltd., New Delhi 1995.
- The physics of solar cells, J. Nelson, Imperial college press, 2006.
- Thin-film crystalline silicon solar cells: Physics and technology, R. Brendel, Wiley-VCH, Weinheim, 2003.
- Clean electricity from photovoltaics, M. D. Archer, R. Hill, Imperial college press, 2001.

EN 642 Power Generation & System Planning 3-0-0-6

Overview of the Indian power sector, Thermodynamic analysis of Conventional Power Plants. Advanced Power Cycles, Kalina (Cheng) Cycle, IGCC, AFBC/PFBC

Steam Turbine - Superheater, reheater and partial condenser vacuum. Combined Feed heating and Reheating. Regenerative Heat Exchangers, Reheaters and Intercoolers in Gas Turbine power plants. Hydro power plants - turbine characteristics. Auxiliaries - Water Treatment Systems, Electrostatic Precipitator / Flue gas Desulphurisation, Coal crushing / Preparation - Ball mills / Pulverisers, ID/FD Fans, Chimney, Cooling Towers.

Power plant control systems- Review of control principles, Combustion control, pulveriser control, control of air flow, Furnace pressure and feed water, steam temperature control, Safety provisions / Interlocks

Analysis of System load curve -plant load factor, availability, Loss of load Probability calculations for a power system, Maintenance Scheduling Pricing of Power - Project cost components, Analysis of Power Purchase Agreements (PPA), Debt/Equity Ratio and effect on Return on Investment, Environmental Legislations/Government Policies Optimal Dispatch - Scheduling of Hydro-Thermal plants. Load Forecasting - Time series, Econometric, end use techniques. Least Cost Power Planning - Integration of DSM, Renewable into supply.

Texts/References

- R.W.Haywood, Analysis of Engineering Cycles, 4th Edition, Pergamon Press, Oxford, 1991.

- D. Lindsay, Boiler Control Systems, Mcgraw Hill International, London, 1992.
- H.G. Stoll, Least Cost Electrical Utility / Planning, John Wiley & Sons, 1989.
- T.M. O' Donovan, Short Term Forecasting: An introduction to the Box Jenkins Approach, Wiley, Chichester, 1983.
- A.B.Gill, Power Plant Performance, Butterworths, 1984.
- Wood, A.J., Wollenberg, B.F., Power Generation, operation & control, John Wiley, New York, 1984.

EN 645 Process Integration 3-0-0-6

Process Integration, Targeting for energy, Area, unit and cost Heat exchanger network design and evolution, Heat exchanger design, Retrofit design, Mathematical optimization techniques, Process integration of different systems: fired heater, Cogeneration and utility system, Solar thermal, stand alone power system distillation column, evaporators, Resource management: Water management, Hydrogen management, Environmental management, Recent developments.

Texts/References

- Linnhoff, B.D. W. Townsend, D. Boland, G. F. Hewitt, B. E. A. Thomas, A. R. Guy, and R. H. Marsland, User Guide on Process Integration for the Efficient Use of Energy. The Institution of Chemical Engineers, Rugby, UK, 1982.
- Shenoy U. V., Heat Exchanger Network Synthesis: Processes Optimization by Energy and Resource Analysis, Gulf Publishing Company, Houston, 1995.
- Douglas J. M., Conceptual Design of Chemical Processes, McGraw-Hill, New York, 1988.

EN 628 Materials and devices for energy applications 3-0-0-6

Device fabrication technologies: diffusion, oxidation, photolithography, sputtering, physical vapor deposition, chemical vapor deposition (CVD), plasma enhanced CVD (PECVD), hot wire CVD (HWCVD), etc. Introduction to material characterization: Scanning electron microscopy (SEM), Transmission electro microscopy (TEM), X-ray diffraction (XRD), Raman spectroscopy, Atomic force microscopy (AFM), Spectral response of solar cells, quantum efficiency analysis, dark conductivity, I-V characterization. Introduction to physics of semiconductor devices and basics of solar cells High efficiency solar cells, PERL Si solar cell, III-V high efficiency solar cells, GaAs solar cells, tandem and multi-junction solar cells, solar PV concentrator cells and systems, III-V, II-VI thin-film solar cells (GaAs, Cu(In,Ga)Se2, CdTe) Nano-, micro- and poly-crystalline Si for solar cells, mono-micro silicon composite structure, crystalline silicon deposition techniques, material and solar cell characterization, advanced solar cell concepts and technologies (Porous Si layer transfer, Metal induced crystallization, etc.). Amorphous silicon thin-film (and/or flexible) technologies, multi-junction (tandem) solar cells, stacked solar cells. Conjugated polymers, organic/plastic/flexible solar cells, polymer composites for solar cells, device fabrication and characterization. Materials and devices for energy storage; Batteries, Carbon Nano-Tubes (CNT), fabrication of CNTs, CNTs for hydrogen storage, CNT-polymer composites, ultra-capacitors etc. Polymer membranes for fuel cells, PEM fuel cell, Acid/alkaline fuel cells.

Texts/References

- Solar cells: Operating principles, technology and system applications, by Martin A. Green, Prentice-Hall Inc, Englewood Cliffs, NJ, USA, 1981.
- Seminconductors for solar cells, H. J. Moller, Artech House Inc, MA, USA, 1993. Solid State electronic devices, Ben G. Streetman, , Prentice-Hall of India Pvt. Ltd., New delhi 1995.
- Carbon nanotubes and related structures: New material for twenty-first century, P. J. F. Harris, Cambridge University Press, 1999.
- Thin-film crystalline silicon solar cells: Physics and technology, R. Brendel, Wiley-VCH, Weinheim, 2003.
- Clean electricity from photovoltaics, M. D. Archer, R. Hill, Imperial college press, 2001.
- Organic photovoltaics: Concepts and realization, C. Barbec, V. Dyakonov, J. Parisi, N. S. Sariciftci, Springer-Verlag 2003.
- Fuel cell and their applications, K. Kordesch, G. Simader, VCH, Weinheim, Germany, 1996.
- Battery technology handbook, edited by H.A. Kiehne, Marcel Dekker, New York, 1989

EN 647 Distributed Generation and Microgrids 3 – 0-0 – 6

Introduction to distributed generation and microgrids, components, micro-sources, loads, power electronic interface, architecture (dc/ac/hybrid) of microgrids, storage.

Integration issues of distributed generation, synchronization, stability aspects in microgrids, islanding techniques. Motor starting in Microgrids

Power management and operation, maximum power point tracking algorithms for renewable energy systems, remote monitoring of microgrids/power plants, demand side management (demand response, energy efficiency programs) centralized and decentralized systems.

Introduction to multi-agent system and smart grid.

Texts/References

- Distributed Generation: Induction and Permanent Magnet Generators, Lai, L. L. and Chan, T. F. (2007) John Wiley & Sons, Ltd, Chichester, UK.
- Distributed generation : the power paradigm for the new millennium, Edited by Annie-Marie Borbely and Jan F. Kreider, (2001), CRC Press.
- Distributed Generation, N. Jenkins, G. Strbac and J. Ekanayake, (2010) IET, First Edition.
- Industrial Power Systems, Shoaib Khan, CRC Press, (2008), First Edition.
- Microgrids and Active Distribution Networks by S. Chowdhury, S.P. Chowdhury and P. Crossley, IET, (2009), First Edition.
- Design of Smart Power Grid Renewable Energy Systems, Ali Keyhani, (2011), Wiley-IEEE Press

EN 648 Combustion Engineering 2- 1- 0- 6

Introduction: Motivation to study combustion; Definition of combustion; Combustion modes and flame types; Fuels: Types of fuel; Fuel usage; Choice of fuels; Classification of fuels; Properties of liquid fuel

Combustion and Thermochemistry: Review of property relations (Extensive and intensive properties, Equation of state, Ideal gas mixtures, Latent heat of vaporization); Reactant and product mixtures (Stoichiometry, Absolute enthalpy and enthalpy of formation, enthalpy of combustion and heating values); Adiabatic flame temperatures; Chemical equilibrium; Equilibrium products of combustion; Exhaust gas recirculation

Chemical Kinetics: Elementary Reaction Rates: Rates of reaction for multistep mechanisms; Relation between rate coefficients and equilibrium constants; Chain and chain branching reactions; CO and higher paraffins oxidation; Methane combustion; Chemical time scales

Ignition Phenomena: Autoignition based on thermal theory; Effect of pressure on auto-ignition temperature; Piloted ignition; Condensed fuel ignition

Laminar Premixed Flames: Physical processes in a premixed flame; Flammability limits; Flame quenching; Minimum energy for sustained ignition and flame propagation; Factors influencing flame velocity and thickness; Flame speed correlations for selected fuels; Brief on SI engine combustion

Laminar Diffusion Flames: Description of a candle flame; Laminar jet flame height; Condensed fuel fires; Brief on CI engine combustion

Droplet Evaporation and Combustion: Droplet vaporization in quiescent air; Droplet combustion; Initial heating of a droplet; Droplet distribution

Emissions: Negative effects of combustion products; Pollutant formation; Quantification of emissions; Emissions from premixed combustion; Emissions from diffusion combustion.

EN 649 Introduction to Particulate Flow 3 – 0 - 0 – 6

Introduction to particulate matter: Definition, occurrence and examples of granular and particulate flow Basics: particle characterisation, size distribution and shape, inter-particle interactions, collisions, deformation, friction, angle of repose, Janssen effect, flow regimes Theory of slow flow: Mohr-Coulomb yield condition, flow rules and co-axiality condition modelling of flow through hoppers Theory of Rapid flow: kinetic theory of granular materials, analysis of flow in simple geometries, Hybrid theory: example of chute flow Modelling of Solid-Fluid Mixture: continuum and discrete approach through example of fluidised beds

Texts/References **

- An Introduction to Granular Flow, K Kesava Rao and Prabhu R Nott; Cambridge University Press, First Edition, 2008

- An Introduction to Particle Technology, Martin Rhodes; John Wiley & Sons, Second Edition, 2007 Multiphase Flow Handbook, Clayton Crowe (ed), CRC Press, First Edition, 2006;

- Processing of Particulate Solids, J P K Seville, U Tuzun and R Clift, Blackie A & P, First Edition, 1997 Selected research articles

EN 651 Multiphase Petroleum Transportation 3 – 0 - 0 – 6

- Fundamentals of Single Phase Flow: Introduction of mass, momentum and energy balance for single phase flow. Introduction of frictional factor in Laminar and turbulent single phase pipe flow.
- Fundamentals of Multiphase Flow: Introduction to principles of multiphase flow, different flow regimes, pressure and temperature prediction in the pipeline and methodology for pipeline sizing.
- Phase Behaviour and Physical Properties of different oil: Analysis of physical properties for oil recovered from different climatic region and prediction of their compositional phase behaviour and PVT prediction software.
- Steady State Multiphase flow: Introduction to steady state multiphase flow, wells, flowlines and risers. Pipeline design for fluid consisting oil/gas and gas. Design for slugging flows. Solids transportation. Design for heavy oil transport. Introduction of available software for reservoirs design.
- Design of Offshore and Onshore Pipelines: Pipeline sizing, installation, thermal insulation and corrosion protection.
- Subsea transportation in oil industries: Subsea production system architecture.
- Transient Multiphase Flow: Management of pipeline inventory and sizing of slug catcher. Their integration with process plant. Transient thermal analysis.

Texts/References **

- Brennen, Christopher E. Fundamentals of multiphase flow. Cambridge university press New York, 2005.

- Batchelor, George Keith. An introduction to fluid dynamics. Cambridge university press, London, 2000.

- Crowe, Clayton T., John D. Schwarzkopf, Martin Sommerfeld, and Yutaka Tsuji. Multiphase flows with droplets and particles. CRC press, Boca Raton, 2011.

- John L. Kennedy. Oil and gas pipeline fundamentals. Pennwell books, Tulsa Oklahoma, 1993.

- Szilas, A. Pál. Production and transport of oil and gas. Elsevier, Amsterdam, 2010.

EN 658 Electrochemical Energy Storage 3 – 0 - 0 – 6

Thermodynamics and Kinetics of Electrochemical Reactions. Introduction to Electrochemical Techniques: (a) Electrochemical Impedance Spectroscopy (EIS) and its applications(b) Cycling Voltammetry and Linear Polarization (c) Galvanostatic Intermittent Titration. Electrochemical Energy Storage Systems(a) Advanced Rechargeable Batteries(b) Supercapacitors. Hybrid power systems: Differences/interactions between batteries and supercapacitors. Current distribution in electrochemical Systems. Fluid flow and mass transfer problems in Electrochemical systems Porous electrode theory Modelling and Simulation of Batteries and Supercapacitors.

Texts/References **

1. Linden`s Handbook of Batteries, 4th Edition edited by T. Reddy, McGraw-Hill Professional 2011.
2. Advanced Batteries :Materials Science Aspects.Robert A. Huggins, Springer US, 2009
3. Electrochemical Methods: Fundamentals and Applications, 2nd Edition, A.J. Bard and L.R. Faulkner. john Wiley & Sons. Inc.20014.Electrochemical Systems, 3rd Edition, John Newman and Karen E.Thomas-Alyea, John Wiley & Sons,Incl.,2004.

EN 653 Energy Policy Analysis 3 0 0 6

The course will provide the tools and techniques necessary for analyzing energy policies. Students will be expected to carry out a project to analyse an existing policy in a specific context or design a policy intervention for a specific goal.

- Overview of energy policy instruments – pricing, regulation, Incentives, subsidies
- Framework for policy analysis, stakeholders, criteria – energy access, security, sustainability, development
- Case studies of a few energy policies – successes and failures, Free riders and rebound effect
- Reference Energy system, End Use Analysis
- Modelling Energy Demand, Elasticities
- Susbtitution- S-shaped Logistic curves, Examples of accelerated diffusion- factors affecting diffusion
- Economy wide impacts- Input-Output models, Optimisation models, TIMES-MARKAL
- Scenario generation – approach and examples
- Energy policy analysis project

Texts / References:

- M. Munasinghe Energy Policy Analysis and Modelling, Cambridge University Press, 2008 .
- P. Meier Energy Systems Analysis for Developing countries, Springer Verlag 1984.
- Shell Energy Scenarios till 2050, https://rjohnwilliams.files.wordpress.com/2016/02/shell-energy-scenarios2050.pdf (last accessed 10 November 2018)
- India Energy Scenarios 2047, i*ess2047.gov.in/* last accessed 20th February 2018

EN 657 IC Engine, Alternate Fuels and Emissions 3 – 0 – 0 - 6

Introduction: IC engines classifications (SI & CI engine, 2-stroke & 4-stroke engine), Thermodynamic Cycles
Combustion in IC engine: Thermochemistry of Fuel-Air mixture, characterization of flame, Combustion stoichiometry, Chemical equilibrium, Chemical kinetics
Properties of fuel and its effect on combustion: Engine knock & detonation, abnormal combustion
Engine Emissions and Control: Theory of NO_x, SO_x, CO, UHC & PM formation, Emission norms, role of fuel, lubricant, engine design and operation parameters on emissions
Alternate fuels, properties, suitability and emissions: CNG, LPG, H_2, Hythane, Di-Methyl Ether, Ethanol, Biodiesel
Novel technologies and strategies to curb emissions: Homogeneous charge CI (HCCI) engines, Premixed Charge Compression Ignition (*PCCI*), Emission control technologies (EGR, SCR, DOC, DPF etc) (To be updated periodically with new technologies and strategies)
Hands on exposure (in lab) on Petrol & Diesel engine, and fuel properties study

Texts / References

- Internal Combustion engine fundamentals: J B Heywood, Tata Mc-Graw Hill Publications
- Internal Combustion Engines: V Ganeshan, Tata Mc-Graw Hill Publications
- IC Engines: Combustion and Emissions: BP Pundir, Narosa Publishing House
- The Internal combustion Engine in theory and practice: C F Taylor, MIT Press, Cambridge
- Alternative Fuels Guidebook, Properties, Storage, Dispensing, and Vehicle Facility Modifications: RL. Bechtold, SAE Publications, 1997
- Emission from Combustion Engines and their Control: Patterson DJ and Henein NA, Ann Arbor science publishers
- Advanced Engine Technology: Heinz Heisler, SAE Publications

EN 703 Advanced Concepts in Solar cell Technologies 3 – 0 – 0 – 6

Advanced Concepts: Fundamental limits on conversion efficiency, Shockley-Queisser theory, Multiple Junction solar cells, Quantum dot solar cells, Intermediate band solar cells, Photon splitting and multi application High efficiency c-Si solar cells, losses in solar cells; optical, electrical, ways to overcome the losses, concept of selective emitter, N-type and P-type cells, alternative surface recombination, alternative metallization, novel cell structures, metal wrap through cells, point contacts, buried contact cell, PERL cell, HIT cells, Thin film silicon cells

Concepts of thin film, thin film deposition techniques, CVD, PECVD, sputtering, Physics of amorphous and nano-crystalline Si and alloys transport properties, Defect density and recombination, Structural considerations, Optical properties, Staebler-Wronski effect, Single and multi junction solar cells, Deposition and manufacturing techniques, From cell to module, Advanced Thin film solar cells (CdTe, CIGS), Electrical and optical properties of materials, solar cell structure, principle of operation, material deposition techniques, cell performance, Multi-junction III-V solar cells, Introduction to III-V Compound semiconductors and Hetero-structures, Single junction III-V cell: Design considerations, Tandem cells: Design considerations, Characterization of multi- junction

solar cells: special, requirements, Multi-junction Concentrator solar cells, synthesis techniques, pseudomorphic structures, Organic Solar cells, Physics of organic semiconductors, Transport properties Photo-conduction and Luminescence Defects, Hetero-junction solar cells, Small molecule and polymer cells, Physics of degradation of organic cells, Fabrication techniques and manufacturing Sensitized solar cells, Basic photoelectrochemistry, double layer concept, Band bending to flat, band transformation, semiconductor-liquid junction, charge and ion, transport, band bending/flat/slant in nanocrystalline materials, diffusionand ballistic transport, hot electron, photoelectrochemical solar cell, effect of electrolyte, Dye sensitized, solar cell, Charge transport mechanism, Characterization techniques, (Carrier lifetime, microwave conductivity, Kelvin probe SPV/CPD etc.), Solid state DSSC - problems and solutions, Semiconductor sensitized solar cells - advantages and disadvantages, solid state hole conductor, Nano-porous oxide semiconductor.

References:

1. Silicon solar cells: advanced principles and practice. Sydney, M. Green, Bridge Printery, 1995.
2. Third Generation Photovoltaics. Berlin, Germany, M. Green, Springer-Verlag, 2003.
3. Crystalline silicon solar cells: advanced surface passivation and analysis, Aberle A. G., Sydney, Centre for Photovoltaic Engineering, UNSW, 1999.
4. The physics of solar cells, J. Nelson, Imperial college press, 2006.
5. Thin-film crystalline silicon solar cells: Physics and technology, R. Brendel, Wiley-VCH, Weinheim, 2003.
6. Solar cells: Operating principles, technology and system applications, by Martin A. Green, Prentice-Hall Inc, Englewood Cliffs, NJ, USA, 1981.
7. Seminconductors for solar cells, H. J. Moller, Artech House Inc, MA, USA, 1993.
Solid State electronic devices, Ben G. Streetman, , Prentice-Hall of India Pvt. Ltd., New delhi 1995.
8. Clean electricity from photovoltaics, M. D. Archer, R. Hill, Imperial college press, 2001
9. Solar Photovoltaics: Fundamentals, Technologies and Applications, C. S. Solanki, Prentice Hall of India, 2011.