Course Name	**:**	**Solar Energy Technologies**
Course Code	**:**	**EER1131**
Credits	**:**	**3**
L T P	**:**	**3-0-0**

Course Objectives:

At the end of the course the students should be able to understand
1. The fundamental concepts of solar cell
2. Solar cell technologies
3. Solar photovoltaic, and solar thermal system.

Total No. of Lectures: 42

Lecture Wise Breakup		No. of Lectures
1	**Introduction to solar cells** Semiconductor as solar cell material, charge carriers and their motion in semiconductor, p-n junction diode, pn junction under illumination, generation of photo-voltage, light generated current, I-V equation of solar cells, Solar cell characteristics	05
2	**Design of solar cells** Upper limits of cell parameters: short circuit current, open circuit voltage, fill factor, efficiency, Quantum efficiency (internal and external), losses in solar cells: model of a solar cell, effect of series and shunt resistance on efficiency, effect of solar radiation on efficiency, effect of temperature on efficiency, Design for high short-circuit current and open-circuit voltage, Design for high fill factor, SQ limit	10
3	**Solar cell technologies** Si solar cells, production of electronic grade Si wafers, CZ and FZ processes, solar grade silicon, Si usage in solar PV, anti-reflective coating, surface texturing, high efficiency Si solar cells, thin film solar cell technologies, emerging solar cell technologies	05
4	**Solar photovoltaic modules** Solar PV modules from solar cells, series and parallel connections of cells, mismatch in cell/module, hotspot in module, mismatch in series connection, bypass diode, mismatch in parallel connection, I-V equation of PV modules, ratings of PV modules	06
5	**Designing of Solar PV systems** Maximum power point tracking (MPPT): algorithms, shading condition MPP tracking, Batteries for PV systems, charge controllers, DC-DC converters topologies, single phase and three phase DC-AC inverters, Standalone PV systems, wire sizing of PV system, Hybrid PV systems, Grid-connected PV systems	09
6	**Solar thermal technologies** Solar thermal energy system, absorption and radiation, solar cooking system, types of solar cooker, solar distillation system, operation of solar distillation, solar heating system, types of heating system. Types of Solar Thermal Collectors Flat plate solar collectors, evacuated tube solar thermal systems, concentrated solar collectors, parabolic trough, parabolic dish, fresnel reflector, heliostat power plant	07

Course Outcomes:

By the end of this course, the students will be able to:

CO1	Design of solar cell circuits
CO2	Study of solar cell technologies
CO3	Apply the fundamental concepts of solar cells for making the string connections
CO4	Design solar photovoltaic systems for various applications
CO5	Design the solar thermal system

Text/ Reference Books

Sr. No.	Name of Book/ Authors/ Publisher	Year of Publication/ Reprint
1	C.S. Solanki, “Solar Photovoltaics - Fundamentals, Technologies and Applications”, Prentice Hall of India.	2010
2	Jenny Nelson, “The Physics of Solar Cells,” (Imperial College, UK).	2003
3	A. Reinders, P. Verlinden, W. Sark, A. Freundlich, “Photovoltaic Solar Energy: From Fundamentals to Applications”, Wiley.	2017
4	Weidong Xiao, “Photovoltaic Power System: Modeling, Design, and Control,” Wiley.	2017
5	S P Sukhatme, J K Nayak , “Solar Energy: Principles of Thermal Collection and Storage,” The McGraw-Hill.	2008

Course Name	**:**	**Energy System Economics and Sustainability**
Course Code	**:**	**EER1132**
Credits	**:**	**3**
L T P	**:**	**3-0-0**

Course Objectives:

At the end of this course, the students should be able to acquire the knowledge of
1. Financial evaluation of energy system
2. Energy demand analysis
3. Energy policy, planning and environment

Total No. of Lectures: 42

	Lecture Wise Breakup	Number of Lectures
1	**Introduction to Energy Economics** Classify energy on the basis of sources – renewable or non-renewable; worldwide energy supply – by country; sources of energy supply –Fossil fuels (coal, oil, natural gas), Renewable energy (Hydro, wind, solar, Geothermal, bio), Nuclear power; Trend and patterns of energy production; Social, Economic and Environmental Effects of Energy Production; Life Cycle of Energy Sources. Relevance of financial and economic feasibility evaluation of energy technologies and systems, Basics of engineering economics	10
2	**Financial Evaluation of Energy Systems** Financial evaluation of energy technologies, Social cost benefit analysis, Case studies on techno-economics of energy conservation and renewable energy technologies**,** Calculation of unit cost of power generation from different sources with examples, different models and methods	10
3	**Energy Demand Analysis** Energy demand analysis and forecasting, Energy supply assessment and evaluation, Energy demand – supply balancing, Energy models. Energy – economy interaction, Energy investment planning and project formulation. Energy pricing.	08
4	**Policy and Planning of Energy Systems** Policy and planning implications of energy – environment interaction, Clean development mechanism. Financing of energy systems. Energy policy related acts and regulations. Software for energy planning.	06
5	**Energy and Environment** Conflict between energy consumption and environmental pollution, Economic approach to environmental protection and management, Energy-Environment interactions at different levels, energy efficiency, cost-benefit risk analysis; Project planning and implementation, Planning for energy security and renewable energy innovations; Regional, National and Global aspirations and requirements; Role of Governments, Societies and NGOs.	08

Course Outcomes: By the end of this course, the students will be able to

CO1	Analyse energy system financially
CO2	Analyse energy demand
CO3	Understand energy policy
CO4	Planning of energy system
CO5	Understand the co-relation & effect between energy and environment

Text/Reference Books

Sr. No.	Name of Book/ Authors/ Publisher	Year of Publication/ Reprint
1	Bhattacharyya S. C. "Energy Economics", Springer	2011
2	Ferdinand E. B. "Energy Economics: A Modern Introduction", First Edition, Kluwer	2000
3	Kandpal T. C. and Garg H. P. "Financial Evaluation of Renewable Energy Technology," Macmilan	2003
4	Munasinghe M. and Meier P. "Energy Policy Analysis and Modeling" Cambridge University Press	1993

Course Name	**:**	**Power Electronics Converters for Renewable Energy Systems**
Course Code	**:**	**EER1133**
Credits	**:**	**3**
L T P	**:**	**2-0-2**

Course Objectives:

At the end of this course, the students should be able to acquire
1. The knowledge of solar PV system
2. Wind energy conversion
3. Fuel cell, power electronics convertors for RES

Total No. of Lectures: 28

	Lecture Wise Breakup	**Number of Lectures**
1	**Introduction** Potential of renewable energies in India's future power generation, need of power electronics for power generation from renewable sources, impact of power electronics on energy system, challenges of the current energy scenario: the power electronics contribution.	02
2	**Solar PV Systems** Solar PV characteristics, grid requirement for PV, power electronic converters used for solar PV, control techniques, MPPT, grid connected and islanding mode, grid synchronization, PLLs, battery charging in PV systems, matrix converters.	08
3	**Wind Energy Conversion** Wind turbine characteristics, grid requirement for wind, PMSM and DFIG for wind generators, power electronic converters for PMSM and DFIG, control techniques, MPPT, grid connected and islanding mode.	06
4	**Electrolyzer and Fuel Cells Systems** Introduction to fuel cell and electrolyzer, types of fuel cells, power converter for electrolyzer operation, PV based green hydrogen generation, power converters for fuel cell application, series-parallel connections of power converters.	04
5	**Power Electronic Converters for Hybrid Renewable Energy System** Need for hybrid systems, types of hybrid systems, multi-input single output converters, multi-input multi-output power converters, cascade operation of converters, parallel operation of converters, AC-DC-AC converters, MPPT and off-MPPT mode operation of converters, model predictive control technique for hybrid renewable energy system, concept of microgrid and co-ordinated control.	08

Sr. No.	**Experiment**	**No. of Turns**
1	Simulation Study of Solar MPPT Converter	**2**
2	Closed Loop Control of Buck, Boost, and Buck-Boost DC-DC Converter	**2**
3	Grid Synchronization of Solar PV	**2**
4	Modelling and Simulation of Wind Power Electronic Converter	**2**
5	Simulation of Series-Parallel Connected Converters	**2**
6	A Study of Multi-Input Multi-Output Converter	**1**
7	A Study of Multi-Input Multi-Output Converter	**1**
8	Parallel Operation of DC-DC and DC-AC Converters	**1**
9	A Study of AC-DC-AC Converters	**1**

Course Outcomes: By the end of this course, the students will be able to

CO1	Understand solar PV system
CO2	Understand wind energy conversion
CO3	Understand fuel cell technologies
CO4	Apply the knowledge pertaining to grid synchronization technologies
CO5	Design different power converters namely AC to DC, DC to DC and DC to AC converters for renewable energy systems

Text/ Reference books

Sr. No.	**Name of Book/ Authors/ Publisher**	**Year of Publication/ Reprint**
1	Haitham Abu-Rub, Mariusz Malinowski, Kamal Al-Haddad, "Power Electronics for Renewable Energy Systems, Transportation and Industrial Applications," Wiley.	2014

2	Remus Teodorescu, Marco Liserre, Pedro Rodriguez, “Grid Converters for Photovoltaic and Wind Power Systems” Wiley-IEEE Press.	2011
3	Suleiman M. Sharkh, Mohammad A. Abu-Sara, Georgios I. Orfanoudakis, Babar Hussain, “Power Electronic Converters for Microgrids” Wiley-IEEE Press.	2014
4	Sudipta Chakraborty, Marcelo G. Simões, William E. Kramer, “Power Electronics for Renewable and Distributed Energy Systems” Springer.	2013
5	Fang Lin Luo, Hong Ye, “Advanced DC/AC Inverters: Applications in Renewable Energy” CRC Press.	2013
6	M. H. Nehrir, C. Wang, “Modeling and Control of Fuel Cells: Distributed Generation Applications,” Wiley.	2009

Course Name	**:**	**Energy Management and Audit**
Course Code	**:**	**EER1134**
Credits	**:**	**3**
LTP	**:**	**3-0-0**

Course Objectives:

At the end of this course, the students should be able to acquire the knowledge of

1. Energy management
2. Energy conservation and recycling
3. Energy monitoring and energy auditing

Total Number of Lectures: 42

Lecture Wise Breakup		Number of Lectures
1	**Energy Scenario** Commercial and non-commercial energy, primary energy resources, commercial energy production, final energy consumption, energy needs of growing economy, long term energy scenario, energy pricing, energy sector reforms, energy and environment, energy security, energy conservation and its importance, restructuring of the energy supply sector, energy strategy for the future, air pollution, climate change. Energy Conservation Act-2001 and its features.	06
2	**Basics of Energy and its Various Forms** Electricity tariff, load management and maximum demand control. Thermal basics: fuels, thermal energy contents of fuel, temperature and pressure, heat capacity, sensible and latent heat, evaporation, condensation, steam, moist air and humidity, heat transfer, units and conversion.	07
3	**Energy Management and Audit** Definition, energy audit, need, types of energy audit. Energy management (audit) approach understanding energy costs, benchmarking, energy performance, matching energy use to requirement, maximizing system efficiencies, optimizing the input energy requirements, fuel and energy substitution, energy audit instruments. Material and energy balance: facility as an energy system, methods for preparing process flow, material and energy balance diagrams.	06
4	**Energy Efficiency in Electrical Systems** Electrical system: electricity billing, electrical load management and maximum demand control, power factor improvement and its benefit, selection and location of capacitors, performance assessment of PF capacitors, distribution and transformer losses. Electric motors: types, losses in induction motors, motor efficiency, factors affecting motor performance, rewinding and motor replacement issues, energy saving opportunities with energy efficient motors.	07
5	**Energy Efficiency in Industrial Systems** Compressed air system: types of air compressors, compressor efficiency, efficient compressor operation, compressed air system components, capacity assessment, leakage test, factors affecting the performance and savings opportunities in HVAC. Fans and blowers: types, performance evaluation, efficient system operation, flow control strategies and energy conservation opportunities. Pumps and pumping system: types, performance evaluation, efficient system operation, flow control strategies and energy conservation opportunities. Cooling tower: types and performance evaluation, efficient system operation, flow control strategies and energy saving opportunities, assessment of cooling towers.	08
6	**Energy Efficient Technologies in Electrical Systems** Maximum demand controllers, automatic power factor controllers, energy efficient motors, soft starters with energy saver, variable speed drives, energy efficient transformers, electronic ballast, occupancy sensors, energy efficient lighting controls, energy saving potential of each technology.	08

Course Outcomes: By the end of this course, the students will be able to

CO1	Apply the fundamental knowledge of energy management.
CO2	Perform energy audit & management
CO3	Apply concept of strategies and planning for energy conservation, recycling for energy monitoring and targeting.
CO4	Perform energy audit in the day to day activities involving industries, buildings and any field of life where energy is involved.
CO5	Apply energy efficient technologies in electrical system

Suggested Books:

Sr. No.	Name of Book/Authors/Publisher	Year of Publication/ Reprint
1	Handbook on Energy Audit and Environment Management by Abbi, Y.P. and Jain, S, Teri	2006

	Bookstore	
2	Handbook of Energy Audits by Albert Thumann, Terry Niehus and W. Younger, CRC Press	2008
3	Energy Engineering and Management by Amlan Chakrabarti, 2nd Edition, PHI Learning Pvt. Ltd.	2018
4	Energy Management Principles: Applications, Benefits, Savings, Elsevier	2016
5	Industrial Energy Management: Principles and Applications by Giovanni Petrecca, The Kluwer international series -207	1999
6	Energy Management Handbook by W. C. Turner, John Wiley and sons.	2004
7	Utilization of Electrical Energy and Conservation by S. C. Tripathy, McGraw Hill,	1991
8	Guide books for National Certification Examination for Energy Managers and Energy Auditors by Bureau of Energy Efficiency (BEE) (4 books). Available online for download at https://beeindia.gov.in/content/energy-auditors	

Course Name	:	**Wind, Biomass, and Small Hydro Energy Systems**
Course Code	:	**EER1135**
Credits	:	**3**
L T P	:	**3-0-0**
Course Objectives:		
At the end of the course the students should be able to understand 1. The fundamental concepts of wind energy 2. Small hydro energy system 3.Biomass energy systems		

Total No. of Lectures: 42

Lecture Wise Breakup		No. of Lectures
1	**Wind Energy** Wind flow, power in the wind, wind energy conversion; efficiency limit for wind energy conversion, types of converters, energy derived from a wind turbine, aerodynamics of wind rotors, power ~ speed and torque, speed characteristics of wind turbines, wind turbine control systems. Conversion to electrical power : induction and synchronous generators, grid connected and self-excited induction generator operation, constant voltage and constant frequency generation with power electronic control, single and double output systems, reactive power compensation.	18
2	**Small Hydro System** Classification of hydro power plants, classifications of hydraulic turbines: Francis, Pelton, Kaplan, and propeller, difference between impulse and reaction turbines, efficiency of turbines, types of generators – synchronous, induction, transformers protection and control, Speed and voltage regulation, Economics: cost structure, Initial and operation cost, environmental issues related to large hydro project	12
3	**Biomass Energy** Production of biomass, Photosynthesis, Assessment of biomass resources, types of biomass, Long-term sustainability as feedstock; Environmental issues on biomass based energy generation, Biomass and Biofuel, calorific value, air-to-fuel ratio, combustion vs gasification, gasifiers, updraft, crossdraft,	12

Course Outcomes:	
By the end of this course, the student will be able to:	
CO1	Do the designing of wind power plant for various applications.
CO2	Design the small hydro energy system.
CO3	Apply the concepts of biofuel energy for designing of biomass plant.
CO4	Mitigate environmental issues of large hydro-projects
CO5	Enhance the efficiency of solar & wind energy system

Text/ Reference Books

Sr. No.	Name of Book/ Authors/ Publisher	Year of Publication/ Reprint
1	J.F. Manwell, J.G. Mcgowan, A.L Rogeres. Wind Energy Explained: Theory, Design, and Application.Wiley.	2009
2	Luis Rodríguez and Teodoro Sanchez “Designing and Building Mini and Micro Hydropower Schemes: A Practical Guide”.	2011
3	S.C. Capareda. “Introduction to Biomass Energy Conversions” Taylor & Francis.	2014

Course Name	**:**	**Energy Storage Technologies**
Course Code	**:**	**EER1136**
Credits	**:**	**3**
L T P	**:**	**2-0-2**

Course Objectives:

At the end of this course, the students should be able to acquire the knowledge of
1. Suitable energy storage mediums for renewable energy technologies
2. Various applications of energy storage system
3. System integration of energy storage system

Total No. of Lectures: 28

	Lecture Wise Breakup	Number of Lectures
1	**Introduction** Storage Needs, variations in energy demand, variations in energy supply, interruptions in energy supply, transmission congestion, demand for portable energy, energy storage for power systems, role of energy storage systems, overview of energy storage technologies: thermal, mechanical, chemical, electrochemical, electrical, efficiency of energy storage systems.	04
2	**Electrical and Chemical Energy Storage** Batteries types, supercapacitors, superconducting magnetic energy storage (SMES), charging methodologies, state of charge (SoC), state of health (SoH) estimation techniques, battery modelling. **Mechanical and Thermal Energy Storage** Flywheel, pumped hydro storage, aquiferous cold storage and cryogenic storage, high-temperature storage (PCM).	06
3	**Hydrogen Production and Storage, Fuel Cells** Electrolyzer technologies, hydrogen storage technologies, fuel cell technologies.	04
4	**Mobile Storage System** Storage requirement for electric vehicle, grid-to-vehicle (G2V), vehicle to grid (V2G).	04
5	**Hybrid Energy Storage Systems** Hybrid energy storage requirement, high frequency and low frequency energy storage mediums, configurations and applications.	04
6	**Applications of Energy Storage Systems** Storage for - solar energy, wind energy, fuel cells; energy storage in microgrid and smart grid, energy management with storage systems, increase of energy conversion efficiencies by introducing energy storage.	06

Sr. No.	List of Experiments	No. of Turns
1	Matlab based Modelling of Storage Batteries.	02
2	Integration of Energy Storage Apparatus with Infinite bus.	03
3	Integration of Energy Storage Apparatus with Single Machine Infinite bus power system.	03
4	Modelling of Electric Vehicle.	03
5	Modelling of any RES using Matlab Software.	03

Course Outcomes: By the end of this course, the students will be able to

CO1	Estimate the State of charge and state of health of various energy storage technologies
CO2	Acquire knowledge pertaining to various ways to store energy
CO3	Design the hybrid energy storage system
CO4	Analyse the effect of energy storage system
CO5	Understand the application of mobile storage system

Text/Reference Books

Sr. No.	Name of Book/ Authors/ Publisher	Year of Publication/ Reprint
1	A.G.Ter-Gazarian, “Energy Storage for Power Systems”, Second Edition, The Institution of Engineering and Technology (IET) Publication, UK.	2011
2	Francisco Díaz-González, Andreas Sumper, Oriol Gomis-Bellmunt,” Energy Storage in Power Systems” Wiley Publication.	2016

3	A. R. Pendse, “Energy Storage Science and Technology”, SBS Publishers & Distributors Pvt. Ltd., New Delhi.	2011
4	Electric Power Research Institute (USA), “Electricity Energy Storage Technology Options: A White Paper Primer on Applications, Costs, and Benefits” (1020676).	2010
5	Paul Denholm, Erik Ela, Brendan Kirby and Michael Milligan, “The Role of Energy Storage with Renewable Electricity Generation”, National Renewable Energy Laboratory (NREL) - A National Laboratory of the U.S. Department of Energy - Technical Report NREL/ TP6A2-47187.	2010
6	Detlef Stolten, “Hydrogen and Fuel Cells: Fundamentals, Technologies and Applications”, Wiley.	2010

Course Name	:	**Hydrogen Energy and Fuel Cells**
Course Code	:	**EER1231**
Credits	:	**3**
L T P	:	**2-0-2**

Course Objectives:
At the end of the course the students should be able to understand the fundamental concepts of 1. Hydrogen generation 2. Fuel cell technologies 3. Fuel cell energy production

Total No. of Lectures: 28

Lecture Wise Breakup		**No. of Lectures**
1	**Hydrogen Energy** Possible role of hydrogen and fuel cells, Production of Hydrogen: steam reforming, partial oxidation, dry reforming, water electrolysis: reverse fuel cell operation, biological hydrogen production: photosynthesis, issues related to scale of production: centralized hydrogen production, distributed hydrogen production,	05
2	**Hydrogen conversion, storage, and transmission** Hydrogen uses as an energy carrier, storage medium, combustion uses, direct uses, hydrogen storage: compressed gas storage, liquid hydrogen storage, hydride storage (solid hydrogen), metal hydride, hydrogen storage in renewable energy systems, comparing storage options, hydrogen transmission: container transport, pipeline transport	08
3	**Fuel cells technologies** Introduction and overview, operating principle, polarization curves, types of fuel cell, electrolytes used in fuel cells, low and high temperature fuel cells, proton exchange membrane, solid oxide, molten carbonate, acid and alkaline, fuel cell stacks, concept of electrochemical potential and emf, Nernst equation, thermodynamic efficiencies of fuel cell in comparison to Carnot efficiencies	08
4	**Fuel cells systems and Implementation scenarios** Storage infrastructure, transmission infrastructure, local distribution, filling stations, safety concerns and requirements, National and international standards, cost expectations: hydrogen production costs, fuel cell costs, hydrogen storage, infrastructure costs, system costs, life cycle analysis of hydrogen production, life cycle analysis of fuel cells, life cycle comparison of conventional passenger car and passenger car with fuel cells	07

List of Experiments		**Number of Hours**
1	Modelling of Electrolyzer System	5
2	Modelling of Proton Exchange Membrane Fuel Cell System	5
3	Simulation of Fuel Cell Technologies	4

Course Outcomes:	
By the end of this course, the student will be able to:	
CO1	Acquire knowledge pertaining to green hydrogen technologies
CO2	Carry out the life cycle cost analysis of long term and short term hydrogen storage system
CO3	Design the electrolyzer-fuel cell system
CO4	Simulation of electrolyzer system
CO5	Simulation of fuel cell system

Text/ Reference Books

Sr. No.	**Name of Book/ Authors/ Publisher**	**Year of Publication/ Reprint**
1	Bent Sorensen. “Hydrogen and Fuel Cells”.	2018
2	Larminie J., Dicks A. and McDonald M. S. Fuel cell systems explained. Vol. 2, Wiley	2003
3	O'Hayre R. P., Cha S. W., Colella W., and Prinz F. B., Fuel cell fundamentals, John Wiley	2008

Course Name	:	Energy System Modelling
Course Code	**:**	**EER1232**
Credits	**:**	**3**
L T P	**:**	**3-0-0**

Course Objectives:

At the end of the course the students should be able to understand
1. To model and simulate the energy systems for performance improvement analysis.
2. To apply quantitative techniques for optimization of operating parameters in energy system.
3. To use economic techniques for energy model development.

Total No. of Lectures: 42

Lecture Wise Breakup		No. of Lectures
1	**Modeling overview** Levels of analysis, steps in model development, examples of models, Need for Energy System Modeling.	04
2	**Quantitative techniques** Interpolation-polynomial, Lagrangian, Curve fitting, regression analysis, solution of transcendental equations.	06
3	**Systems Simulation** Information flow diagram, solution of set of nonlinear algebraic equations, successive substitution, Newton Raphson. Examples of energy systems simulation. Numerical solution of Differential equations- Overview, Convergence, Accuracy. Transient analysis- application example	10
4	**Optimization** Objectives/constraints, problem formulation. Unconstrained problems- Necessary & Sufficiency conditions. Constrained Optimization- Lagrange multipliers, constrained variations, Kuhn-Tucker conditions, Linear Programming - Simplex tableau, pivoting, sensitivity analysis. Dynamic Programming. Search Techniques Univariate / Multivariate	10
5	**Case studies of optimization** in Energy systems problems. Dealing with uncertainty probabilistic techniques. Trade-offs between capital & energy using Pinch Analysis.	06
6	**Energy- Economy Models:** Scenario Generation, Input Output Model	06

Course Outcomes:

By the end of this course, the student will be able to:

CO1	Understand model development process and its application in energy systems.
CO2	Apply quantitative technique in energy systems.
CO3	Simulate the conventional and sustainable energy systems
CO4	Apply optimization with constraints for better solutions.
CO5	Energy- Economy Models.

Text/ Reference Books

Sr. No.	Name of Book/ Authors/ Publisher	Year of Publication/ Reprint
1	1. Yogesh Jaluria, Design and Optimization of Thermal Systems, McGraw-Hill international editions, 1998	1998
2	2. Stoecker W F, Design of Thermal Systems, Mcgraw Hill.	1981
3	3. S.S.Rao, Optimisation Theory and Applications, Wiley Eastern.	1990
4	4. S.S. Sastry, Introductory Methods of Numerical Analysis, Prentice Hall.	1988
5	5. P. Meier, Energy Systems Analysis for Developing Countries, Springer Verlag.	1984
6	6. R.de Neufville, Applied Systems Analysis, Mcgraw Hill, International Edition.	1990
7	7. Beveridge and Schechter, Optimisation Theory and Practice, Mcgraw Hill.	1970

Course Name	:	Zero Energy Buildings
Course Code	**:**	**EER1233**
Credits	**:**	**3**
L T P	**:**	**3-0-0**

Course Objectives:

At the end of the course the students should be able to understand

1. The fundamental concepts of high energy efficient building design
2. Passive design strategies for building
3. Technology applications in net-zero energy building

Total No. of Lectures: 42

Lecture Wise Breakup		No. of Lectures
1	**Built Environment and Climate Change** Current energy consumption scenario in India, Need to reduce emissions. Status, challenges and opportunities, Definition of Green Building. Impact of design, construction & maintenance of buildings on our environment and natural resources. Benefits of building green. Design of buildings to use renewable energy, optimization of materials use.	08
2	**Highly Energy-Efficient Buildings** Heat transfer processes in buildings. Thermal conductivity, resistance, transmittance, surface characteristics, surface coefficient, heat capacity, insulation, Estimation of building energy performance for heating and cooling for different climatic contexts, Identification of opportunities for reducing energy consumption.	08
3	**Passive Design Strategies, Principles, and Techniques** Climate Issues, Thermal Comfort Requirements, Site and microclimate, Orientation, Solar Geometry/Solar Control, Window Placement, High Performance Window, Daylighting, Shading Devices, Space Arrangements, Continuous Super Insulation, Moisture Control, Air Sealing (Air-tightness), Thermal Mass, Passive Heating/Cooling, Balanced Ventilation, Heat/Energy Recovery Ventilation System (HRV/ERV), Thermal Bridging etc.,	14
4	**Net-Zero Energy Buildings Systems, Technologies and Applications** Integrated Photovoltaic System (BIPV), Solar Thermal Collectors (STC), Building Integrated Wind Turbine (BIWT), Rooftop PV System, Ground-Mounted Solar Panels, Geothermal Heat Pumps (GHP), Combined Heat and Power (CHP) system, LED Lighting Fixtures, etc.	12

Course Outcomes:

By the end of this course, the student will be able to:

CO1	Analyse thermal performance of building
CO2	Estimate heating-cooling performance of building
CO3	Passive design of building
CO4	Net-zero energy building system
CO5	Carry out the sizing of renewable energy sources needed for building.

Text/ Reference Books

Sr. No.	Name of Book/ Authors/ Publisher	Year of Publication/ Reprint
1	Iyengar, K. Sustainable Architectural Design: An Overview, Routledge	2015
2	Chiras, D. The Solar House: Passive Heating and Cooling. Chelsea Green Publishing.	2002
3	Corner, D., Fillinger, J., Kwok, A. Passive House Details: Solutions for High-Performance Design, Routledge.	2017
4	James, M. Net Zero Energy Buildings Passive House+ Renewables, Low Carbon Productions.	2015
5	Attia, shady. Net Zero Energy Buildings (NZEB): Concepts, Frameworks and Roadmap for Project Analysis and Implementation. Butterworth-Heinemann.	2018

Course Name	**:**	**Modern Control System**
Course Code	**:**	**EER1234**
Credits	**:**	**3**
L T P	**:**	**2-0-2**

Course Objectives:

At the end of the course, the student should be able to:
1. Learn the modeling concepts of system using state space.
2. Understand the application of optimal control techniques.
3. Learn the fundamentals of digital control systems and non-linear systems.

Total No. of Lectures: 28

Lecture Wise Breakup		Number of Lectures
1	**Introduction** Control systems design requirements, classical versus modern approaches of design	02
2	**State Space Representation** Concepts related to state space , state space representation, state transition matrix, solution of linear time invariant and linear time varying state equations, canonical forms	05
3	**Control System Design in State Space** Controllability, pole placement design using full state feedback-regulator and tracking systems, observers, observability and compensators, full order and reduced order observers	06
4	**Linear Optimal Control** Optimal control problem, infinite time linear optimal regulator design, optimal control of tracking systems (Riccati equation based designs).	06
5	**Digital Control Systems** Basic concepts, z-transform, stability, performance, state space modeling and solution of linear digital equations, design using pole placement,: regulators and observers and compensators, linear optimal control of digital systems	06
6	**Nonlinear Control Systems** Sources of nonlinearities and characteristics of nonlinear systems, describing function method, phase plane analysis, Lyapunov stability theory	03

List of Experiments		Number of Turns
1	Modeling of synchronous machines, exciter and turbines.	02
2	Pole placement design using state feedback for regulator and tracking systems	02
3	Full and reduced order observer design	02
4	State space modeling of discrete time system and study of responses	02
5	Pole placement design for regulator and tracking discrete time systems	02
6	Observer design for discrete time systems	02
7	Describing function analysis of nonlinear systems	01
8	Phase plane analysis of nonlinear systems	01

Course Outcomes: By the end of this course, the students will be able to	
CO1	Apply the modeling concepts of system modeling using state space and understand the design issues in the framework of modern control
CO2	Apply concepts of digital control system and non-linear systems.

Text/ Reference books		
Sr. No.	**Name of Book/ Authors/ Publisher**	**Year of Publication/ Reprint**
1	A.Tewari, Modern Control Design with MATLAB and Simulink. John Wiley and Sons Ltd	2002
2	K. Ogata, Modern Control Engineering.PHI.	2014
3	M. Gopal, Modern Control System Theory. New Age International (P) Ltd	2005
4	M.Gopal, Digital Control and State Variable Methods. TMH	2003
5	W. L. Brogan, Modern Control Theory. Pearson Education India	2011

Course Name	**:**	**Power System Operation and Control**
Course Code	**:**	**EER1235**
Credits	**:**	**3**
L T P	**:**	**3-0-0**

Course Objectives:

At the end of this course, the students should be able to acquire the knowledge of
1. Economic load dispatch
2. Load-frequency control
3. Power system security & dispatch

Total No. of Lectures – 42

Lecture Wise Breakup		Number of Lectures
1	**Economic Dispatch** Economic dispatch of hydro, thermal, hydro-thermal generating units, dispatch problem solution methods (any two), economic dispatch with & without transmission line losses, Base point and participation factors, penalty factors.	06
2	**Frequency Control and AGC** Review of theory of frequency dynamics. Multi-area frequency dynamics. Load-frequency and tie line power flow control. Theory of Automatic Generation control, AGC implementation methods.	09
3	**Unit Commitment** Introduction, constraints, Priority lists, Integer Programming, Dynamic Programming, Lagrangian Relaxation and Neural Net Methods.	06
4	**Interconnected Systems Operation** Need of system interconnection, Operating policies, Economic interchange, Optimal multi- area Operation.	05
5	**Energy Management Systems and Real-Time Control** Energy management systems, Software systems, Computer hardware resources and configurations, Data management. Communications and distributed computing, Expert systems for contingency and security evaluation, event analysis, system restoration and reactive control, Short range load forecasting, SCADA.	09
6	**Power Systems Operational Security and Dispatch** Review of security concept and state of operation, contingency analysis; generation dispatch; dynamic security; power system state estimation; maximum likelihood weighted least- squares estimation; and measurements; network observabilities and pseudo-measurements; applications in system control.	07

Course Outcomes: By the end of this course, the students will be able to

CO1	Economic load dispatch/ unit commitment
CO2	Load frequency control
CO3	Interconnected power system operation
CO4	Energy management system and real-time control
CO5	Power system operational security

Suggested Books:

Sr. No.	Name of Book/ Authors/ Publisher	Year of Publication/ Reprint
1	Wood and Wollenberg “Power Generation Operation and Control”, John Wiley.	1984
2	OI Elgerd “Electric Energy Systems, Theory”, McGraw Hill	1983
3	Mahalanabis et al., “Computer-aided power system analysis” Tata McGraw.	1988
4	Anderson & Fouand “Power system control and stability” Lowa State University Press.	1977
5	“Fundamentals of Supervisory Systems” IEEE Tutorial Course Text, 91EH0337-6PWR.	1991

Course Name	:	**Electric Vehicles**
Course Code	:	**EER1281**
Credits	:	**3**
L T P	:	**2-0-2**

Course Objectives:

At the end of this course the students should be able to acquire the knowledge of
1. Electric and hybrid vehicle operation, and architectures
2. Energy storage system for Electric vehicle, energy management
3. Power convertors in electric vehicles

Total No. of Lectures: 28

	Lecture Wise Breakup	Number of Lectures
1	**Introduction to Electric Vehicles** Electric vehicles (EV) development, past, present and future, comparison with IC engine drive vehicles, social and environmental importance of hybrid and electric vehicles, impact of modern drive-trains on energy supplies, basics of vehicle performance, vehicle power source characterization, transmission characteristics. Mathematical models to describe vehicle performance, basic concept of hybrid traction, introduction to various hybrid drive-train topologies, power flow control in hybrid drive-train topologies, fuel efficiency analysis.	05
2	**Electric Propulsion Unit** Introduction to electric components used in hybrid and electric vehicles, different types of motors used in EV and their torque-speed characteristics, configuration and control of DC motor drives, configuration and control: induction motor, permanent magnet motor, switch reluctance motor drives; drive system efficiency.	06
3	**Energy Storage in Vehicles** Introduction to energy storage requirements in hybrid and electric vehicles, storage types: battery, supercapacitor, flywheel, and fuel cell based energy storage and its analysis; hybridization of different energy storage devices.	03
4	**Battery Chargers** Fundamentals of EV battery pack design, AC and DC Chargers, low voltage DC fast charger for electric vehicles, alternate charging sources – wireless & solar, battery management system.	04
5	**Power Converters in Electric Drive Vehicles** Converter topologies: bidirectional DC-DC converters, bidirectional T-type converter, resonant converter, multilevel two-quadrant converter, PWM inverters.	03
6	**Energy Management and Control Strategies** Introduction to energy management strategies used in hybrid and electric vehicles, classification of different energy management strategies, comparison of different energy management strategies, implementation issues of energy management strategies.	04
7	**Electric Vehicle Case Studies** Design of a battery electric vehicle (BEV), design of fuel cell electric vehicle, design of hybrid electric vehicle, design of more electric aircraft.	03

	List of Experiments:	Number of Turns
1	To obtain the performance of lead-acid and li-ion battery energy storage.	02
2	To obtain the performance of supercapacitor.	01
3	To simulate lead-acid/li-ion battery and supercapacitor hybrid energy storage system.	02
4	To simulate the I-V characteristics of fuel cell.	01
5	To obtain the difference in performance of AC and DC chargers.	01
6	To simulate the DC fast chargers for electric vehicles (EV).	01
7	To simulate the battery management system.	01
8	To obtain the performance of bidirectional DC-DC converters.	01
9	To simulate sine PWM inverters.	01
10	To obtain the performance of – permanent magnet, induction and switched reluctance motors.	02
11	To simulate the battery based EV.	01

Course Outcomes: By the end of this course, the students will be able to

CO1	Draw inferiors from electric vehicle characteristics
CO2	Understand electric propulsion unit

CO3	Energy storage devices in electric vehicle
CO4	Power electric application in electric vehicle
CO5	Energy management in electric vehicle system

Text/Reference Books		
Sr. No.	**Name of Book/ Authors/ Publisher**	**Year of Publication/ Reprint**
1	Iqbal Husain, “Electric and Hybrid Vehicles: Design Fundamentals”, 3rd edition CRC Press.	2021
2	Tom Denton, “Electric and Hybrid Vehicles”, Taylor & Francis.	2018
3	Mehrdad Ehsani, Yimin Gao, Stefano Longo, Kambiz M. Ebrahimi, “Modern Electric, Hybrid Electric, and Fuel Cell Vehicles”, Taylor & Francis Group, LLC.	2018
4	John Miller, “Propulsion Systems for Hybrid Vehicles,” Institute of Electrical Engineers, UK.	2004
5	Chris Mi, M A Masrur, D W Gao, “ Hybrid Electric Vehicles – Principles and applications with practical perspectives,” Wiley.	2011
6	James Larminie, John Lowry, “Electric Vehicle Technology Explained”, Wiley.	2003
7	C.M. Jefferson & R.H. Barnard, “ Hybrid Vehicle Propulsion,” WIT Press.	2002

Course Name	**:**	**Grid Integration of Renewable Energy Systems**
Course Code	**:**	**EER1282**
Credits	**:**	**3**
L T P	**:**	**2-0-2**

Course Objectives:
At the end of the course the students should be able to acquire the knowledge of 1. Appropriate integration of renewable energies into the power grid 2. Power flow control in grid integration 3. Synchronization to grid codes

Total No. of Lectures: 28

Lecture Wise Breakup		**Number of Lectures**
1	**Introduction** Basics of power processing – AC-DC conversion, DC-DC conversion, DC-AC conversion, AC-AC conversion; solar power systems – introduction to solar power, processing of solar power; wind power systems- basics of wind power generation, wind turbines, generator and topologies; grid integration – operation paradigms of power systems, requirements for grid integration, issues in renewable energy integration to grid, power quality issues, reference frames.	06
2	**Power Flow Control** Current proportional–integral control : synchronously rotating reference (dq) frame, natural (abc) frame; current proportional- resonant control : control structure in stationary reference (αβ) frame, abc frame; synchro-converters : grid friendly inverters that mimic synchronous generators, parallel operation of inverters, conventional droop control, limitations of conventional droop control, robust droop control for R, C and L inverters.	06
3	**Voltage and Current Source Converters to Integrate Renewable Energy to Grid** Single phase voltage source and current source converter, three phase voltage source and current source converter, voltage and current mode control, real/reactive power controller, controlled-frequency voltage source converter system, variable frequency voltage source converter system.	06
4	**Synchronization** Conventional synchronization techniques: zero-crossing method, phase locked loop (PLL), PLL in the synchronously rotating reference frame (SRF-PLL), second-order generalized integrator-based (SOGI-PLL), sinusoidal tracking algorithm, sinusoidal-locked loops: single-phase synchronous machine (SSM) connected to the grid, structure of a sinusoidal-locked loop, tracking of frequency and phase, tracking of voltage amplitude, parameters tuning.	06
5	**Grid Codes and Stabilization** Grid standards and codes, IEEE standard 1547 etc., demand side management, weak-grid, voltage source inverter stability in weak grid, grid stability.	04

Sr. No.	**Experiment**	**No. of Turns**
1	Simulation Study of PLL Control Strategy	3
2	Simulation Study of Synchronous Reference Frame Theory	3
3	A Study of Voltage Source Converters	1
4	A Study of Current Source Converters	1
5	Simulation Study of Grid Forming Inverter	3
6	A Simulation Study of Grid Following Inverter	3

Course Outcomes: By the end of this course, the students will be able to	
CO1	Apply the various techniques available for integration of hybrid renewable energy system.
CO2	Power flow control method
CO3	Power flow control application in grid integration
CO4	Synchronization techniques
CO5	Acquire knowledge on various grid codes.

Text/ Reference books		
Sr. No.	**Name of Book/ Authors/ Publisher**	**Year of Publication/ Reprint**
1	Vittal V, Ayyanar R, “Grid Integration and Dynamic Impact of Wind Energy”, Springer.	2012
2	Remus Teodorescu, Marco Liserre, Pedro Rodriguez, “Grid Converters for Photovoltaic and Wind Power Systems” Wiley-IEEE Press.	2011
3	Qing-Chang Zhong, Tomas Hornik., “Control of Power Inverters in Renewable Energy and Smart Grid Integration”, Wiley-IEEE Press.	2012
4	Amirnaser Yazdani, Reza Iravani. , “Voltage-Sourced Converters in Power Systems: Modeling, Control, and Applications”, Wiley-IEEE Press.	2012

Course Name	**:**	**Distributed Energy Management of Electrical Power System**
Course Code	**:**	**EER1283**
Credits	**:**	**3**
L T P	**:**	**2-0-2**

Course Objectives:

At the end of the course, the students should be able to acquire
1. The knowledge of importance of various distributed algorithms for active and reactive power control
2. Distributed active/reactive power control, optimization
3. Distributed social welfare, state estimation

Total No. of Lectures – 28

Lecture Wise Breakup		**Number of Lectures**
1	**Introduction to Power Management and Algorithm Evaluation** Power Management, Traditional Centralized vs. Distributed Solutions to Power Management, Existing Distributed Control Approaches, Communication Network Design for Distributed Applications, convergence of Distributed Algorithms with Variant Communication Network Typologies, Multi Agent System	07
2	**Distributed Active and Reactive Power Control** Conventional Droop Control Approach, Subgradient-Based Active Power Sharing, Control of Multiple Distributed Generators, DFIG Control Approach, Converter Control Approach, PV Generation Control Approach, Distributed Dynamic Programming for Economic Dispatch in Smart Grids, Distributed Optimal Active Power Dispatch, Q-Learning-Based Reactive Power Control, Sub-gradient-Based Reactive Power Control,	08
3	**Distributed Demand-Side Management** Distributed Dynamic Programming-Based Solution for Load Management in Smart Grids, Distributed Dynamic Programming, Optimal Distributed Charging Rate Control of Plug-in Electric Vehicles for Demand Management	05
4	**Distributed Social Welfare Optimization and State Estimation** Market-Based Self-interest Motivation Model, Distributed Price Updating Algorithm, Distributed Supply–Demand Mismatch Discovery Algorithm, Distributed Approach for Multi-area State Estimation Based on Consensus Algorithm, Multi-agent System-Based Integrated Solution for Topology Identification and State Estimation	08

List of Experiments		**No. of Turns**
1	Simulation Study of Constant Maximum Available Renewable Generation and Load	3
2	Study of Variable Maximum Available Renewable Generation and Load	2
3	Study of Droop Control Approach for Power Sharing	2
4	Simulation Study of Active Power Control	3
5	Simulation study of Reactive Power Control	3
6	Study of Demand Side Management	1

Course Outcomes: By the end of this course, the students will be able to

CO1	Familiarize with objectives of power management and distributed algorithm for electrical power systems.
CO2	Perform the control of active and reactive power for interconnected system
CO3	Gain knowledge regarding the distributed demand side management.
CO4	Optimization and state estimation in distributed power management

Suggested Books:

Sr. No.	**Name of Book/ Authors/ Publisher**	**Year of Publication/ Reprint**
1	Yinliang Xu, Wei Zhang, Wenxin Liu, Wen Yu, "Distributed Energy Management of Electrical Power Systems". Wiley-IEEE Publications.	2020
2	Ali Arefi, Farhad Shahnia, Gerard Ledwich "Electric Distribution Network Management and Control" Springer.	2018
3	Lingfeng Wang "Modeling and Control of Sustainable Power Systems" Springer	2012

Course Name	:	**Power System Stability and Control**
Course Code	:	**EER1284**
Credits	:	**3**
L T P	:	**3-0-0**
Course Objectives:		
At the end of the course, the students should be able to 1. Formulate the transient stability for large scale systems 2. Study of power system control and multi area control 3. Power system with smart grid integration		

Total No. of Lectures – 42

Lecture Wise Breakup		Number of Lectures
1	**Introduction to Power System Stability Problem** Evolution of electrical power systems, structure of power system, Design and operating criteria for stability, Basic concepts and definition: rotor angle stability, voltage stability, mid-term and long-term stability,	07
2	**Synchronous Machine Modelling** Basic equations of a synchronous machine, dq0 transformation, per unit stator and rotor voltage equations, steady-state analysis: phasor representation, rotor angle, electrical transient performance characteristics, synchronous machine parameters, synchronous machine representation in stability studies, AC transmission, power flow analysis, power system loads, excitation systems, control of active and reactive power.	13
3	**Power System Stability** Small-signal stability: Eigen-properties of state matrix, small-signal stability of a single-machine infinite bus system, transient stability: numerical integration methods, voltage stability, sub-synchronous oscillations, mid-term and long term stability, methods of improving stability	12
4	**Power System Control** Phasor measurements and Smart Grid Integration Issues: generator protection and monitoring, wide area protection control and monitoring, power system communications, information processing, information security, protection system reliability and testing, substation protection control and monitoring system design	10

Course Outcomes: By the end of this course, the students will be able to	
CO1	Power system apparatus modelling
CO2	Identify component models for system stability and study transient stability issues and their solution techniques.
CO3	Apply the control techniques required for power system stability
CO4	Power system control and smart grid integration

Suggested Books:		
Sr. No.	**Name of Book/ Authors/ Publisher**	**Year of Publication/ Reprint**
1	P Kundur, “Power System Stability and Control”. McGraw-Hill Inc.	2006
2	P. M. Anderson, A.A. Fouad “Power System Control And Stability” Wiley.	2018

Course Name	**:**	**Power Quality**
Course Code	**:**	**EER1285**
Credits	**:**	**3**
LTP	**:**	**3-0-0**

Course Objectives:

At the end of this course, the students will have in depth knowledge of
1. Various aspects of power quality issues and their mitigation methods
2. Power converters and power quality
3. Active power line conditioners

Total No. of Lecture - 42

Lecture Wise Breakup		Number of Lecture
1	**Introduction to Power Quality** Various types of power quality issues: frequency fluctuation, slow voltage variation, voltage fluctuation, voltage sag or dip and shot interruptions, voltage imbalance, harmonic voltage. Overview of Active power line conditioners. Electrical Power Terms in the IEEE Std 1459 Framework. IEEE working group discussions on non-sinusoidal situations.	4
2	**Power Definitions and Instantaneous Reactive Power Theory** Concepts and Evolution of Electric Power Theory, Electric Power Definitions, Instantaneous Power Theory: Basis of the *pq* Theory, Clarke Transformation, *pq* theory application to 3φ-3 wire and 3φ-4 wire systems, Modified *pq* theory, Instantaneous *abc* theory. Comparison of *pq* theory and Instantaneous *abc* theory. Synchronous Reference Frame Theory and applications.	10
3	**Power Electronic Converter Harmonics and Multipulse Methods** Power Electronic Converter Harmonics. Multi pulse methods for harmonic elimination: delta/wye, delta zigzag/Fork, Delta Polygon, Delta/delta/Double Polygon, Delta/Hexagon. Auto Wound Transformers, Interphase and Current Balancing Transformers.	8
4	**Active Power Line Conditioners** Fundamentals of shunt active power filters (APF), shunt APF structures and compensation strategies. Design considerations of shunt APF. Fundamentals of series active power filters. State space models of series APF and different control strategies. Hybrid active power filters: series active shunt passive and shunt active shunt passive. Comparison of hybrid active filters with control strategies. Combined shunt and series active power filters: unified power quality conditioners (UPQC), control strategy of UPQC and passive parameters design. Unified power line conditioners (UPLC). Distributed generation impact in power quality, distribution line compensation: instantaneous unity power factor control, positive sequence control.	20

Course Outcomes: By the end of this course, the students will be able to

CO1	Identify various power quality related issues arising in power system due to different non-linear loads
CO2	Understand reactive power theory
CO3	Design compensators and convertors for mitigation of harmonics for different scenarios and systems
CO4	Apply series concept of active power filters

Suggested Books:

Sr. No.	Name of Book/Authors/Publisher	Year of Publication/ Reprint
1.	Patricio Salmerón Revuelta, Active Power Line Conditioners: Design, Simulation and Implementation for Improving Power Quality. Elsevier. ISBN 978-0-12-803216-9	2016
2.	Derek A Paice, “ Power Electronic Converter Harmonics (Multipulse methods for Clean Power)” IEEE Press	1995
3.	H Akagi, E.H. Watanabe and M Aredes, “Instantaneous power Theory and applications to Power Conditioning”, IEEE Press, John Wiley and sons Incorporate	2007

4.	J Arrilaga and N.R Watson, “Power System Harmonics”, John Wiley and Sons Ltd	2003
5.	A.E.Emanuel, “Power Definitions and the Physical Mechanism of Power Flow”, IEEE Press, John Wiley and sons Ltd	2010