REVISED SYLLABUS
2022-2023

M. Tech. (Energy Science & Technology)

Department of Applied Sciences and Humanities
Faculty of Engineering & Technology
Jamia Millia Islamia
Maulana Mohamad Ali Jauhar Marg
New Delhi-110025

Brief About the Course

Modern civilization is completely depending on power and energy to move ahead. Every single electrical device that we use in our daily life, as well as the production of such machine, is not able to function without power. Initially, coal was the main fuel of eighteenth and nineteenth centuries. However, the birth of electricity, automobiles and airplanes saw oil, which is termed as a fossil fuel, comes into the picture as the dominant fuel in twentieth century. Till now, the main contributors in power generation have been fossil fuels like oil and natural gas, coal, and nuclear resources, accounting for 86.2%. Other energy resources like hydro, solar, wind, geothermal, and wood have contributed an infinitesimal 0.9% of global energy production. In the last few years, the world energy consumption has been increased. This results in raising the price of oil from about $15 a barrel to above $100 a barrel, which has made everybody to start thinking about the possibility of alternative energies. On the other hand, burning of fossil fuels causes environmental degradation. The planet is getting hotter day by day. The ice on the mountains is melting and the existence of the planet is getting into danger zone. The time has come to think about these serious issues in our country also and we may need dedicated manpower for both academics as well as energy-based industries to carry out research and development as well as to work as the experts in the commercial units in the energy sector. To fulfill the future demands of the experts in energy sector, we have stared Master of Technology program in the field of Energy Science & Technology. The aim of **M. Tech. in Energy Science & Technology** is to provide advanced understanding of energy production, conversion, utilization and conservation from conventional as well as non-conventional sources with the special emphasis on the Renewable Energy. The focus is being drawn on economic, environmental and policy impact of sustainable energy practice so that the Students will develop the research and communication abilities to be effective leaders in the energy industry.

Program Education Objectives (PEOs);

The objectives of M. Tech. program (Energy Science & Technology) is to empower and enable students to develop advanced knowledge and skills in order to become leaders and managers in the energy sector. Specifically,

- ✓ Students will have a solid understanding of the sciences and technology related to energy production, conversion, utilization and conservation.
- ✓ Students will understand the economic, environmental and policy impact of a sustainable energy practice for a sustainable society.
- ✓ Student will learn basic to advanced aspects of Renewable Energy systems and to be prepared for paradigm shift from fossil fuels to renewable sources.
- ✓ Students will develop the research and communication abilities to be effective leaders in the energy industry.
- ✓ To provide students with an academic environment aware of excellence, leadership, ethical codes and guidelines and the life-long learning needed for a successful professional career.

Programme Specific Outcomes (PSO) :

On successful completion of the programme,

- ✓ Graduates will demonstrate knowledge of the sciences and technology related to energy production, conversion, utilization and conservation.
- ✓ Graduates will demonstrate the understanding of economic, environmental and policy impact of a sustainable energy practice for a sustainable society.
- ✓ Graduate will demonstrate the knowledge of basic to advanced aspects of Renewable Energy systems and to be prepared for paradigm shift from fossil fuels to renewable sources.
- ✓ Graduates will demonstrate an ability to develop the research and communication abilities to be the effective leaders in the energy industry.
- ✓ Graduate will develop confidence for self-education and ability for life-long learning.

Programme Outcomes (POs) :

1. **Engineering knowledge:** Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems**.**
2. **Problem analysis:** Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
3. **Design/development of solutions:** Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
4. **Conduct investigations of complex problems:** Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
5. **Modern tool usage:** Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modelling to complex engineering activities with an understanding of the limitations.
6. **The engineer and society:** Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
7. **Environment and sustainability:** Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
8. **Ethics:** Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
9. **Individual and team work:** Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
10. **Communication:** Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

11. **Project management and finance:** Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.
12. **Life-long learning:** Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change

Total Intake: 20

COURSE STRUCTURE

M. Tech. (Energy Science & Technology)

Semester-I

S. NO.	Paper	PAPER TITLE	CREDIT	PERIOD PER WEEK			DISTRIBUTION OF MARKS			TOTAL
				L	T	P	MID SEMESTER EVALUATION		END SEMESTER EXAM	
							CWS	MST		
FIRST SEMESTER										
THEORY										
01	EST-101	Fundamentals of Energy Sciences	4	3	1	-	-	40	60	100
02	EST-102	Physics and Chemistry of Energy Materials	4	3	1	-	-	40	60	100
03	EST-103	Energy Resources: Concepts and Technologies	4	3	1	-	-	40	60	100
04	EST-104	Energy from Waste	4	3	1	-		40	60	100
05	EST-105	Energy Management Systems	4	3	1	-	-	40	60	100
06	EST-106	Advanced Energy Materials	4	3	1	-	-	40	60	100
07	EST-107	Innovation, Entrepreneurship, and Startup Ecosystems	2	1	1	-	-	20	30	50
08	EST-110	Seminar	4	4	-	-		40	60	100
Practical										
09	EST-111	Energy Sc. & Tech. Lab-I	2	-	-	4	-	20	30	50
	Elective Course (any one)									
1	EST-108	Introduction to Nanotechnology	4	3	1	-	-	40	60	100
2	EST-109	Nanoelectronics (MOOC)	4	3	1	-	-	40	60	100
TOTAL CREDITS			**36**	**TOTAL MARKS**						**900**

Semester-II

S. NO.	Paper	PAPER TITLE	CREDIT	PERIOD PER WEEK			DISTRIBUTION OF MARKS			TOTAL
				L	T	P	MID SEMESTER EVALUATION		END SEMESTER EXAM	
							CWS	MST		
SECOND SEMESTER										
THEORY										
01	EST-201	Energy Storage Systems	4	3	1	-	-	40	60	100
02	EST-202	Wind Energy: Resource, Engineering & Projects	4	3	1	-	-	40	60	100
03	EST-203	Energy Audit	4	3	1	-	-	40	60	100
04	EST-204	Solar Photovoltaic Technology	4	3	1	-	-	40	60	100
05	EST-205	Concepts and Design of Green Building	2	2	1	-	-	20	30	50
06	EST-206	Energy Economics and Energy Policy	2	2	1	-	-	20	30	50
07	EST-207	Hybrid electric vehicles and charging stations	2	2	1	-		20	30	50
08	EST-208	Energy Efficient Lighting and Displays	2	2	1	-	-	20	30	50
09	EST-211	Seminar	4	4	-	-	-	40	60	100
Practical										
10	EST-212	Energy Sc. & Tech. Lab-II	2	-	-	4	-	20	30	50
	Elective Course (any one)									
1	EST-209	Embedded Control Systems	4	3	1	-	-	40	60	100
2	EST-210	Power Electronics (MOOC)	4	3	1	-	-	40	60	100
TOTAL CREDITS			**34**	**TOTAL MARKS**						**850**

S. NO.	Paper	PAPER TITLE	CREDIT	PERIOD PER WEEK			DISTRIBUTION OF MARKS			TOTAL
				L	T	P	MID SEMESTER EVALUATION		END SEMESTER EXAM	
							CWS	MST		
THIRD SEMESTER										
THEORY										
06	EST-308	Minor Project (Dissertation)	8	8	-	-	-	80	120	200
TOTAL CREDITS			**8**				**TOTAL MARKS**			**200**

Semester-IV

S. NO.	Paper	PAPER TITLE	CREDIT	PERIOD PER WEEK			DISTRIBUTION OF MARKS			TOTAL
				L	T	P	MID SEMESTER EVALUATION		END SEMESTER EXAM	
							CWS	MST		
FOURTH SEMESTER										
01	EST-401	Major Project (Dissertation)	12	-	-	-	-	120	180	300
TOTAL CREDITS			**12**	**TOTAL MARKS**						**300**

Semester	Ist	IInd	IIIrd	IVth	Grand Total
Total no. of Credits	36	34	08	12	90
Total no. of marks	900	850	200	300	2250

M. Tech. (Energy Science & Technology)

Semester-I

S. NO.	Paper	PAPER TITLE	CREDIT	PERIOD PER WEEK			DISTRIBUTION OF MARKS			TOTAL
				L	T	P	MID SEMESTER EVALUATION		END SEMESTER EXAM	
							CWS	MST		
FIRST SEMESTER										
THEORY										
01	EST-101	Fundamentals of Energy Sciences	4	3	1	-	-	40	60	100
02	EST-102	Physics and Chemistry of Energy Materials	4	3	1	-	-	40	60	100
03	EST-103	Energy Resources: Concepts and Technologies	4	3	1	-	-	40	60	100
04	EST-104	Energy from Waste	4	3	1	-		40	60	100
05	EST-105	Energy Management Systems	4	3	1	-	-	40	60	100
06	EST-106	Advanced Energy Materials	4	3	1	-	-	40	60	100
07	EST-107	Innovation, Entrepreneurship, and Startup Ecosystems	2	1	1	-	-	20	30	50
08	EST-110	Seminar	4	4	-	-		40	60	100
Practical										
09	EST-111	Energy Sc. & Tech. Lab-I	2	-	-	4	-	20	30	50
	Elective Course (any one)									
1	EST-108	Introduction to Nanotechnology	4	3	1	-	-	40	60	100
2	EST-109	Nanoelectronics (MOOC)	4	3	1	-	-	40	60	100
TOTAL CREDITS			**36**	**TOTAL MARKS**						**900**

EST-101 Fundamental of Energy Sciences

L	T	P	C
3	1	0	4

Course Objectives:

1. To introduce the fundamental concepts of Solar Energy.
2. To provide the knowledge of the basics of energy conversion.
3. To learn the energy conversion techniques and its benefits,
4. To provide an understanding of energy demand and utilization.
5. To study impact of energy on environment.

Course Outcomes: Upon completion of this course, the students shall be able to learn.

1. Concept of energy conversion and the energy conversion techniques and its benefits.
2. Fundamental concepts of Solar Energy.
3. Concept of Nuclear Energy.
4. Beginning of Nuclear reactor work.
5. Impact of energy on environment.

Unit-1 **10 Lectures**

Energy Conservation and Basic Energy Conversion routes

Conventional and Non-Conventional Energy, Sources of Conventional and Non-Conventional energy, Historical, economic and Environmental Perspective, Need of Non-conventional Energy Sources, Types of Conventional and Non-conventional Energy Sources. Introduction to Energy conservation, Approach and modem techniques, Benefits, Trend, Energy conservation technology (Thermal Energy), Energy conservation in Energy Intensive Industries, collection, Limitation and heat and its potential applications, Waste heat survey and measurements Data collection, Limitation and heat affecting factors Heat recovery equipment and systems, Heat Exchangers, Incinerators Regenerators and Recuperates.

Energy Conversion routes, Direct and Indirect way of Energy Conversion, Principles of heat and mass transfer, Thermodynamics, Fluid statics and dynamics, Electricity generation and distribution.

Unit-2 **08 Lectures**

Basics of Solar Energy

Energy and development, Units and measurements, Solar spectrum – Electromagnetic spectrum. Energy balance of the earth, solar constant for earth, specialty and potential – Sun – Earth – Solar Radiation, beam and diffuse – measurement – estimation of average solar radiation on horizontal and tilted surfaces – problems – applications. Measurement of solar radiation – Pyranometer, Pyrheliometer, Sunshine recorder. Solar time - Local apparent time (LAT), equation of time (E), Solar radiation geometry - Earth-Sun angles – Solar angles. Calculation of angle of incidence - Surface facing due south, horizontal, inclined surface and vertical surface. Solar day length – Sun path diagram – Shadow determination. Estimation of Sunshine hours at different places in India. Calculation of total solar radiation on horizontal and tilted surfaces. Prediction of solar radiation availability, Capturing solar radiation – physical principles of collection – types – liquid flat plate collectors – construction details – performance analysis – concentrating collection – flat plate collectors with plane reflectors – cylindrical parabolic collectors – Orientation and tracking.

Unit-3 **08 Lectures**

Introduction to Nuclear Energy

Introduction to Nuclear Energy, Nuclear power scenario; Global and Indian perspective, Mechanism of Nuclear Fission- Nuclides- Radioactivity- Decay Chains- Neutron Reactions- The Fission Process- Reactor physics, neutron cycle, criticality, power evolution, cooling, advanced fuel cycles. Fusion: nuclear fusion reactions, technology of fusion reactors. Nuclear Fuel Cycles- Characteristics of Nuclear Fuels- Uranium- Production and Purification of Uranium- Conversion to UF4 and UF6- Other Fuels like Zirconium, Thorium and Berylium. Nuclear Fuel Cycles- Spent Fuel Characteristics- Role of Solvent Extraction in Reprocessing Solvent Extraction Equipment.

Unit-4 **10 Lectures**

Introduction to Nuclear Reactors

Nuclear Reactors and its Components, General Problems of Reactor Operation, Different Types of Reactors, Pressurised Water Reactors (PWR), Boiling Water Reactors (BWR), Heavy Water – cooled and Moderated CANDU (Canadian Deuterium Uranium) Type Reactors, Gas-cooled Reactors, Breeder Reactors, Reactor Containment Design, Heat Transfer Techniques in Nuclear Reactors- Reactor Shielding. reactor safety. Reactor dynamics, breeding and burn in fast reactors, Location of Nuclear Power Plant, Nuclear Power Station in India, India's 3-stage Programme for Nuclear Power Development, Comparison Nuclear Plants with Thermal Plants, Nuclear Materials, Nuclear Waste and its disposal, Safety rules, Policies, Environmental concerns, Sub classification, Techno-commercial studies, Investigation & Project Planning & Design, Project Management, Operational issues, Test cases.

Unit-5 **04 Lectures**

Energy and Environment

Impact of Energy on Environment, Flow of Energy in Ecological system, Environment Degradation due to Energy, Control of pollution from Energy.

Reference Books:

1. The Science of Energy, Roger G Newton, World Scientific
2. Energy Recourses and Systems (Volume 1), Tushar Ghosh, Mark Prelas, Springer.
3. Energy Technology, O. P. Gupta, Khanna Publishing
4. Nuclear Power Plants: Design, Operating, Experience and Economics, Robert L. Loftness, D Van Nostrand Company Inc, New Jersey.
5. Diamant R.M.E., "Total Energy", Pergamon, Oxford, 1970.
6. ArchieW.Culp, "Principles of Energy Conversion", McGraw-Hill Inc., Singapore, 1991.
7. Goswami D.Y., Kreider, J. F. and Francis., "Principles of Solar Engineering', Taylor and Francis, 2000.
8. Chetan Singh Solanki, "Solar Photovoltatics – Fundamentals, Technologies and Applications", PHI Learning Private limited, 2011.
9. Collier J.G. and Hewitt.G.F, "Introduction to Nuclear Power", Hemisphere Publishing, New York, 1987.
10. Glasstone S. and Sesonske A., "Nuclear Reactor Engineering", 3rd Edition, Von Nostrand, 1984.
11. J. Kenneth Shultis and Richard E Faw, "Fundamentals of Nuclear Science and Engineering," CRC Press, 2008.
12. Kenneth D. Kok, "Nuclear Engineering", CRC Press, 2009.
13. Lalter A.E. and Reynolds A.B., "Fast Breeder Reactor", Pergamon Press, 1981.
14. Lamarsh, J.R., "Introduction to Nuclear Reactor Theory", Wesley, 1996.
15. Tatjana Tevremovic, "Nuclear Principles in Engineering", Springer, 2008.
16. Winterton R.H.S., "Thermal Design of Nuclear Reactors", Pergamon Press, 1981.
17. Benjamin M. M., Van Nostrand "Nuclear Reactor Materials and Applications", ReinholdCompany Inc.
18. Henley E.J., & Herbert Kouts, "Advances in Nuclear Science and Technology".

EST-102 Physics and Chemistry of Energy Materials

L	T	P	C
3	1	0	4

Course Objectives:

1. To understand the fundamentals and basics of material science.
2. To study the basics of polymers and their application in energy systems and devices.
3. To provide an understanding of organic semiconductors.
4. To know the concepts and models of semiconductor physics.
5. To provide the knowledge of the basics and properties of materials.

Course Outcomes: Upon completion of this course, the students shall be able to understand.

1. Fundamentals and basics of material science.
2. Basics of polymers and their application in energy systems and devices.
3. Basics of organic semiconductors.
4. Concepts and theories of semiconductors.
5. Basics and properties of materials.

Unit-1 **08 Lectures**

Elements of Materials Science

Types of crystal systems, Bravais lattices, atomic packing factor, planner atomic density, Miller indices, crystal defects, solid solutions, dispersion in solids, stress and strain diagram of brittle and ductile materials, Plastic Deformation strain hardening in single crystals and polycrystalline materials, Slip of Planes perfect lattices, force on dislocation line

Unit-2 **08 Lectures**

Polymer Chemistry

Introduction, Formation of polymers, classification of polymers, Mechanism of polymerization, Degree of polymerization, Crystallization of polymer, cross linking, vulcanization of rubber, deformation of polymer, Factor affecting the properties of polymer, Advance polymers for engineering applications i.e. vinyl copolymer, composites and nanocomposites, polymer -clay Nano composite, PTFE, electro active polymers, Biodegradable polymers, High Temperature Polymers.

Unit-3 **08 Lectures**

Organic Semiconductors

Electronic Configuration and Concept of Atomic Orbital, Hybridization and Overlapping of orbitals, Molecular Orbital, LCAO theory, Bonding and Antibonding orbitals, Sigma Bonding and pi-bonding, Material Origin of bandgap in organic semiconductors, Charge transport in organic semiconductors, Types of organic semiconductors, Optical and Electrical Properties of Organic Semiconductors
Organic Semiconductor Devices: Principal and Concepts
Processing of Organic Semiconducting Materials and Devices.

Unit-4 **08 Lectures**

Elements of Semiconductor Physics

Introduction to Semiconductors, Types of Semiconductors; Crystalline and Amorphous Semiconductors; Direct and Indirect Bandgap Semiconductors; Intrinsic and Extrinsic Semiconductors; Compound Semiconductors
Behavior of the Chemical Potential, Metal–Semiconductor Junction – Rectifying Contact, Metal–Semiconductor Junction – Ohmic Contact, The p–n Junction, Bipolar Transistor, Field Effect Transistor,

Metal Oxide Semiconductor Field Effect Transistor (MOSFET), CMOS, Processing of Semiconductor Devices

Unit-5 **08 Lectures**

Properties of Materials

Electronic and Electric Properties: free electron theory, fermi energy density of states, elements of band theory, dielectric, piezoelectric, pyroelectric and ferroelectric effect.
Magnetic properties: origin of magnetism, para-, dia-, ferro and ferri-magnetisms.
Thermal Properties: specific heat, thermal conductivity and thermal expansion, thermoelectricity.
Optical and optoelectronic properties. Superconductivity.

Reference Books:

1. Introduction to Solid State Physics, 8th Ed., C. Kittel, J. Wiley & Sons
2. Physics of Functional Materials, Hasse Fredriksson and Ulla Åkerlind, J. Wiley & Sons
3. Textbook of polymer science, Fred W Billmeyer, J. Wiley & Sons
4. Materials Chemistry, Fahlman, Bradley, Sp
5. Billmeyer F, 'Textbook of Polymer Science', Wiley Interscience, 1994
6. Anthoney Kelly, 'Concise Encyclopedia of Composite Materials', Pergamon, 1994
7. Anna Köhler, Heinz Bässler: Electronic Processes in Organic Semiconductors – An Introduction, WileyVCh, April 2015
8. Hofmann, Philip, Solid state physics : an introductionWeinheim: Wiley-Vch, 2008
9. "Solid State Physics", N. W. Ashcroft and N. D. Mermin (W. B. Saunders Company, 1976).
10. A Chemist's Perspective by, Orient Blackswan (21 November 2013)
11. C. Kittel, "Introduction to Solid State Physics" Wiley Eastern Ltd, 2005.
12. V. Raghavan, "Materials Science and Engineering: A First Course", Prentice Hall, 2006
13. A.J. Dekker, "Solid State Physics", Macmillan & Co, 2000.
14. Michael Shur, "Physics of Semiconductor Devices", Prentice Hall of India, 1995.
15. C. Kittel, "Introduction to Solid State Physics", Wiley Eastern Ltd., 2005.
16. V.R.Gowariker, "Polymer science ",New age international Publishers,1986

EST-103 Energy Resources; Concepts and Technologies

L	T	P	C
3	1	0	4

Course Objectives:

1. To provide the deep knowledge of hydro-power plants.
2. To know the concepts, types and design of thermal power plants.
3. To provide the deep knowledge of solar photovoltaics.
4. To know the concepts, types and design of solar thermal system.
5. To study of the concepts of wind and tidal energy.

Course Outcomes: Upon completion of this course, the students shall be able to learn about the;

1. Concepts, working of hydro-power plants.
2. Concepts, types and design of thermal power plants.
3. Concepts and technologies of solar photovoltaics.
4. Concepts, types and design of solar thermal system.
5. Concepts and working of wind turbines.

Unit-1 **06 Lectures**

Hydro Power Generation

Types of hydropower plants and schemes, hydrology: runoff studies, flood estimation studies, assessment of hydropower potential of a basin, storage and pondage, load studies, elements of hydropower plants and their hydraulic design: dams, intakes, conveyance system, types of power house, hydraulic turbines and pumps, Components and design of hydraulic turbines, Standardization and selection of turbine, Components and design of hydraulic Pumps, Hydropower scenario; Global and Indian perspective, Policies, Environmental concerns, Sub classification of Hydropower projects, Conceptualization, Techno-commercial studies, Investigation & Planning, Design Principles, Project Management, Operational issues, Test cases of Hydropower Projects.

Unit-2 **08 Lectures**

Thermal Power Generation

Types of thermal power tubines, Gas turbines; Open and closed cycles, constant pressure and constant volume cycles, cycles with inter cooling, reheating and heat exchanger, compressor and turbine efficiencies, pressure losses, performance characteristics of various cycles, practical problems. Jet Propulsion: Calculation of thrust, Power, speed and efficiency, turbo - jet and turbo propulsion systems. Compressors, Combustion Systems, Steam turbines; Principle and working, type of turbines, stage to blade, speed ratio for optimum efficiency, diagram efficiency, steam s performance. Energy losses in steam turbine, turbine performance at various loads and governing of steam turbines. Constructional details and description of steam turbine, Thermal power scenario; Global and Indian perspective, Policies, Environmental concerns, Sub classification, Techno-commercial studies, Investigation & Planning, Design Principles, Project Management, Operational issues, Test cases

Unit-3 **08 Lectures**

Solar Photovoltaic Systems

Photovoltaic effect - Principle of direct solar energy conversion into electricity in a solar cell. Fundamentals of solar cell, Types of solar cells, First generation solar cells: design, fabrication, performance and drawbacks, Second generation solar cells: design, performance and drawbacks, Third generation solar cells: design, performance and drawbacks, I-V characteristics of a PV module, maximum power point, cell efficiency, fill factor, effect of irradiation and temperature, Classification of PV systems and components - Central Power Station System, Distributed PV System, Stand alone PV system, Grid Interactive PV System, small system for consumer applications, Hybrid solar PV system, Concentrator solar photovoltaic. System components - PV arrays, inverters, batteries, charge controls, net power meters. PV array installation, operation, costs, reliability. Designs of solar PV systems and cost estimation. Case study of design of solar PV lantern, stand alone PV system - Home lighting and other appliances, solar water pumping systems. Building-integrated photovoltaic units, solar cars, aircraft, space solar power satellites. Socio-economic and environmental merits of photovoltaic systems.

Unit-4 **08 Lectures**

Solar Thermal Systems

Solar thermal Energy conversion, Solar Passive Heating and Cooling, Solar Liquid and Air Heating Systems, Solar Cooling and Dehumidification, Solar thermal power plants - Solar thermal electric power plants based on parabolic trough, solar central receiver, parabolic dish-Stirling engine. Concentrated solar power using Fresnel lenses. Fundamentals of design calculations and analysis of solar power plants. Economic analysis, Design of solar water heating system and layout, Power generation – Solar central receiver system – Heliostats and Receiver – Heat transport system – solar distributed receiver system – Power cycles, working fluids and prime movers, concentration ratio, Solar cooking – Performance and testing of solar cookers. Seawater desalination – Methods, solar still and performance calculations. Solar pond - Solar greenhouse.

Unit-5 **10 Lectures**

Wind Energy Conversion System & Tidal Power Generation

Introduction and status of Wind Energy Technology, Wind turbines; Working Principles, Components and Design, Aerodynamics of Wind Turbine, Wind Turbine Blade Manufacture, Role of Non-Crimp fabric in Blade Manufacturing, Drive Train Concepts of Wind Turbine, Wind Turbine Gear Box, Wind Turbine Generator, Control and Protection System in Wind Turbine, Wind Turbine Tower, Wind Turbine Foundation, Wind resource assessment, Wind testing and certification, Wind power scenario; Global and Indian perspective.

Introduction to Tidal Power Plants; single basin and two basis plants, Variation in generation level; Ocean Thermal Electricity Conversion (OTEC); Electricity generation from Waves: Shoreline and Floating wave systems, Factors affecting the suitability of the site for tidal power plant, Classification of tidal Power Plants, Working and Design of Different Tidal Power Plants, Advantages and disadvantages of Tidal Power Plants, Components of Tidal Power plants.

Reference Books:

1. Handbook of Hydroelectric Engineering, P. S. Nigam, Nem Chand & Bros., Roorkee
2. Electricity generation using wind power, William Shepard & Li Zhang, World Scientific Singapore
3. Thermal Engineering, P. L. Ballany, Khanna Publishers
4. Solar Energy, by S P Sukhatme& J K Nayak, Mc Graw Hill Publishers
5. Non-Conventional Energy Resources, B. H. Khan, Mc Graw Hill Publishers
6. Yogi Goswami .D, Frank Kreith, Jan F. Kreider, “Principles of Solar Engineering”, Second Edition, Taylor & Francis, 2003.
7. Kalogirou .S.A., “Solar Energy Engineering: Processes and Systems”, Academic Press, 2009. 2. Vogel. W,Kalb .H, “Large-Scale Solar Thermal Power Technologies”, WileyVCH, 2010.
8. Sukhatme .S.P, Nayak .J.K, “Solar Energy”, Tata McGraw Hill Education Private Limited, New Delhi, 2010.
9. G. N. Tiwari, Solar Energy, Narosa Publishing House
10. Martin A Green, “Solar cells: Operating principles, technology and system applications”, Prentice Hall Inc, Englewood Cliffs, NJ, USA, 1981.
11. Twidell.J and T. Weir, “Renewable Energy Resources”, E & F N Spon Ltd, London, 1986.

EST-104 Energy from Waste

L	T	P	C
3	1	0	4

Course Objectives:

1. To understand the concepts of waste and its characterization.
2. To provide the deep knowledge of sources of energy generation.
3. To provide an understanding of the concepts of Biogas, Biomass and Biofuels.
4. To know the concepts and technologies of energy conversion.
5. To study the of the environment and health impact of waste to energy conversion.

Course Outcomes: Upon completion of this course, the students shall be able to understand

1. Concepts of waste and its characterization.
2. About the sources of energy generation.
3. Concepts of Biogas, Biomass and Biofuels.
4. Concepts and technologies of energy conversion.
5. Environment and health impact of waste to energy conversion.

Unit-1 **10 Lectures**

Introduction to Waste and its characterization

Solid Waste Sources, definition, types, composition, Properties, Global warming, Municipal Solid Waste: Characterization &Physical, chemical and biological properties , Industrial waste and Biomedical Waste (BMW),Waste Collection and, Transfer stations, Waste minimization and recycling of solid waste, Life Cycle Analysis (LCA), Material Recovery Facilities (MRF), recycling processes of solid waste, Segregation of waste, Size Reduction , Managing Waste, Waste management hierarchy, Waste Treatment and disposal: Aerobic composting, incineration, different type of incineration; medical and pharmaceutical waste incinerations- land fill classification, types, methods and sitting consideration, layout and preliminary design of landfills: composition, characteristics, generation, movement and control of landfill leachate and gases, environmental monitoring system for land fill gases

Unit-2 **08 Lectures**

Waste to Energy

Energy from waste-thermo chemical conversion: Energy generation sources, incineration and its environmental & health impacts, Strategies for reducing environmental impacts due to incineration, pyrolysis, gasification of waste using gasifiers, briquetting and its utilization and advantages, Energy generation rom waste- Bio-chemical Conversion: Sources of energy generation, Anaerobic digestion of sewage and municipal wastes, direct combustion of MSW-refuse derived solid fuel, industrial waste, agro residues, anaerobic digestion, land fill gas generation and utilization, Latest technologies for energy conversion from waste, design of plants for waste to energy conversion for cities, small townships and villages.

Unit-3 **10 Lectures**

Bio-mass and Bio-gas

Introduction to biomass and farm residue, management and briquetting, Biomass: Sources and Characteristics; Wet biogas plants ; Biomass gasifiers: Classification and Operating characteristics; Updraft and Downdraft gasifiers ; Gasifier based electricity generating systems ; Maintenance of gasifiers, Technology of biogas, Principles, feedstock, types and design of biogas plants, Comparison of plant designs, Main parts of biogas plants, digester, gas holder, pressure gauge, gas controlling cocks and meter, Selection of biogas model and size. Site selection of biogas plants, Appliances of biogas plant - burner, heating plate, lamps, Operation, trouble shooting and maintenance of biogas plant, Safety measures in biogas plants, Biomass Gasification, Different types of biomass gasifiers, Applications of the gasifier, Problems in the developments of Gasifiers, Application of Biogas in domestic, industry and vehicles. Biomass energy program in India, Case study of Hosahalli biomass gasifier engine generator system. Bio-mass resources.

Unit-4 **06 Lectures**

Biofuels

Bio-fuels: Types of Bio-fuels, Production processes and technologies, Ethanol as a fuel for I.C. engines, Bio methanation, Removal of CO2 and H2O, Bio-hydrogen production. Isolation of methane from Biogas and packing and its utilization, Biomethanation Plants; Concept & design, Concept of Bioenergy**:** Photosynthesis process,

Unit-5 **06 Lectures**

Environmental and health impacts

Environmental and health impacts of waste to energy conversion, case studies of commercial waste to energy plants, waste to energy- potentials and constraints in India, eco-technological alternatives for waste to energy conversions - Rules related to the handling, treatment and disposal of MSW and BMW in India.

Reference Books.

1. Rogoff, M.J. and Screve, F., "Waste-to-Energy: Technologies and Project Implementation", Elsevier Store.
2. Young G.C., "Municipal Solid Waste to Energy Conversion processes", John Wiley and Sons.
3. Harker, J.H. and Backhusrt, J.R., "Fuel and Energy", Academic Press Inc.
4. EL-Halwagi, M.M., "Biogas Technology- Transfer and Diffusion", Elsevier Applied Science.
5. Hall, D.O. and Overeed, R.P.," Biomass - Renewable Energy", John Willy and Sons.
6. Mondal, P. and Dalai, A.K. eds., 2017. *Sustainable Utilization of Natural Resources*. CRC Press.
7. Municipal Solid Waste to Energy Conversion Processes: Economic, Technical, and Renewable Comparisons, by Gary C. Young, ISBN:9780470539675, Publisher: John Wiley & Sons, Publication Date: June 2010.
8. Recovering Energy from Waste Various Aspects Editors: Velma I. Grover and Vaneeta Grover, ISBN 978-1- 57808-200-1; 2002.
9. Rich, Gerald et.al., Hazardous Waste Management Technology, Podvan Publishers, 1987.
10. Waste-to-Energy by Marc J. Rogoff, DEC-1987, Elsiever, ISBN-13: 978-0-8155-1132-8, ISBN-10: 0-8155- 1132-9.
11. Parker, Colin, & Roberts, Energy from Waste - An Evaluation of Conversion Technologies, Elsevier Applied Science, London, 1985.
12. Manoj Datta, Waste Disposal in Engineered Landfills, Narosa Publishing House, 1997.
13. Bhide A. D., Sundaresan B. B., Solid Waste Management in Developing Countries, INSDOC, New Delhi, 1983.
14. Robert Green, From Waste to Energy, Cherry Lake Pub. ISBN: 1602795096, 2009.
15. G. Evans, Biowaste and Biological Waste Treatment, 2005.
16. Biogas from waste and renewable resources, by Dieter D. And Angelika S. Wiley-Vch Publication 2010.
17. Bioenergy: Biomass to Biofuels, Anju Dahiya, Academic Press.
18. Nicholas P. Cheremisinoff. Handbook of Solid Waste Management and Waste Minimization Technologies. An Imprint of Elsevier, New Delhi (2003).
19. P. AarneVesilind, William A. Worrell and Debra R. Reinhart. Solid Waste Engineering. Thomson Asia Pte Ltd. Singapore (2002).
20. M. Dutta , B. P. Parida, B. K. Guha and T. R. Surkrishnan. Industrial Solid Waste Management and Landfilling practice. Narosa Publishing House, New Delhi (1999).
21. AmalenduBagchi. Design, construction and Monitoring of Landfills. John Wiley and Sons. New York. (1994).
22. Sofer, Samir S. (ed.), Zaborsky, R. (ed.), "Biomass Conversion Processes for Energy and Fuels", New York, Plenum Press, 1981

EST-105 Energy Management Systems

L	T	P	C
3	1	0	4

Course Objectives:

1. To understand the definition and concept of energy efficiency.
2. To provide the knowledge of Indian transmission and distribution systems.
3. To study the SCADA and smart grids.
4. To provide an understanding of power and energy inter-change.
5. To study different regulatory frameworks for Indian power systems.

Course Outcomes: Upon completion of this course, the students shall be able to understand;

1. Definition and concept of energy efficiency.
2. Indian transmission and distribution systems.
3. SCADA and smart grids.
4. Power and energy inter-change.

5. Different regulatory frameworks for Indian power systems.

Unit-1 **08 Lectures**

Energy Efficiency

Energy Efficiency, Energy Efficient Buildings, Green Buildings, Intelligent Buildings, Energy Conservation Opportunities in Public and Private Buildings Various Energy Efficiency Rating Systems for Buildings- LEEDS, BEE & GRIHA Rating Systems, Energy Conservation Building Code Energy Conservation Act 2001, Revisions and Present State of Implementation Standardization &Labelling, Electricity Act 2003, Revisions and Present Status of Implementation Energy Efficiency Projects, Evaluation of Energy Efficient Projects, Various ways of Financing Energy Efficiency Projects, Role of Financial Institutions and Corporate Banks, Deferred Payment Financing,

Unit-2 **06 Lectures**

Indian Transmission and Distribution Systems

Energy Demand and Utilization; Introduction and Historical Demand, Understanding Current Demand, Energy Markets, Energy and the rebound Effect, Residential Energy, Commercial Energy, Transportation. Architectures, Transmission and distribution systems Planning in India-Strategies, Planning Criteria: Philosophy and General Guidelines, T&D Losses, Power Factor Improvement, Harmonics and its improvement, Transformer Loss Reduction, Tr. Parallel Operation.

Unit-3 **10 Lectures**

SCADA and Smart Grid

Types of Supervisory Systems, Uses of SCADA, SCADA Hierarchy, Components of SCADA System, SCADA Functions, National Grid, Regional Grid, Energy Management System Function, Distribution Automation, Intelligent Electronics Devices (IEDs), Phasor Measurement Units (PMUs). Smart Grid Concept, components, characteristics and technologies; AMI, Demand Side Management (DSM), Demand Response etc.

Unit-4 **08 Lectures**

Interchange of Power and Energy

Interchange of power and energy, economy interchange between interconnected utilities. Interchange evaluation. capacity interchange, Diversity Interchange, Energy Banking, Emergency Power Interchange, Power pools, Energy Broker System, transmission effects and issues; Transfer limitations, Wheeling, Calculation of Rates for transmission services in multiple utilities transactions.

Unit-5 **08 Lectures**

Regulatory Framework for Indian Power Systems Management and Control

Restructuring and Deregulations of Electric Utilities, Indian Electricity Act; Guidelines and their impact, Traditional Central Utility Model, Reform Motivations, Separation of Ownership and Operation, Central Dispatch versus Market Solution, Independent System Operator (ISO). Wholesale Electricity Market Characteristics: Central Auction, Bidding, Market Clearing and Pricing, Bilateral Trading, Scheduling, Gaming, Ancillary. Maximalist ISO, Minimalist ISO Model. Trading Arrangements: The Pool, Pool and Bilateral Trades, Multilateral Trades, Congestion Management in Open-access Transmission Systems,

Reference Books:

1. Power generation Operation & Control, Allen J. Wood and Bruce Woollenberg, John Wiley
2. Mini S. Thomas and John Douglas McDonald, “Power System SCADA and Smart Grids” CRC Press-2015.
3.]Clark W. Gellings, “The Smart Grid: Enabling Energy Efficiency and Demand Response”, CRC Press-2009.

4. Loi Lai Lai, "Power Systems Restructuring and Deregulation-Trading , Performance and Information Technologies", John Wiley and Sons Ltd.
5. Krieder J. and Rabi A., "Heating and Cooling of buildings : Design for Efficiency", Mc Graw Hill, 1994.
6. UrsalaEicker, "Solar Technologies for buildings", Wiley publications, 2003.
7. Guide book for National Certification Examination for EnergyManagers and Energy Auditors (Could be downloaded from www.energymanagertraining.com
8. Energy Management: W.R.Murphy, G.Mckay (Butterworths).
9. Energy Management Principles: TEDDY year book published by TERI.
10. The Watt Committee on Energy (Reports).Energy Management Workbook

EST-106 Advanced Energy Materials

L	T	P	C
3	1	0	4

Course Objectives:

1. To understand the fundamentals and basics of materials for solar energy.
2. To provide the knowledge of the synthesis of energy materials.
3. To understand about the characterization of materials.
4. To provide an understanding of energy harvesting materials.
5. To provide an understanding of the energy storage materials

Course Outcomes: Upon completion of this course, the students shall be able to understand;

1. Fundamentals and basics of materials for solar energy.
2. About the synthesis of materials.
3. Characterization techniques of materials.
4. About the basics of energy harvesting materials.
5. About applications of energy storage materials

Unit-1 **08 Lectures**

Materials for photovoltaics

First generation solar cell materials; single and polycrystalline Silicon, amorphous silicon: growth and wafer processing, contact materials, materials for surface engineering. Second generation solar cell materials;CdSe, CdTe, Copper Indium Gallium Selenide (CIGS), Gallium Arsenide for applications in photovoltaics, Materials for thin film solar cells, Thin film processing, and properties. Contact materials for second generation solar cells. Third generation solar cell materials; Quantum Dots, Organic materials, Composites, Dyes, Perovskites and their synthesis, characterization and properties, Interface energetics, photoactive layers and their materials, role of electron transport, hole transport, electron blocking and hole blocking materials and their processing. Contact materials and processing of contact layers.

Unit-2 **08 Lectures**

Materials Synthesis Methods

Physical Methods ; Vacuum Evaporation, Electron beam evaporation Sputtering, Cathodic Arc Deposition, Chemical Vapour Deposition, Atomic Layer Deposition, Pulsed Laser Deposition, Molecular Beam Epitaxy, Lithography and their types, Chemical Methods; Sol-Gel technique, self-assembly, colloidal method, hydro-thermal method, co-precipitation method, solid state synthesis, microwave method, micro-emulsion method.

Unit-3 **08 Lectures**

Materials Characterization Methods

Electron beam instruments: Transmission electron and scanning electron microscopes, Auger electron spectroscope, x-ray spectrometers, scanning probe microscope. Interpretation of diffraction information: selected area and convergent beam Electron diffraction patterns. Analysis of micrographs in TEM, SEM, and HRTEM, Interpretation of analytical data: EDS, WDS, Auger, EELS, ESCA, SIMS. Bulk averaging techniques: Thermal analysis, DTA, DSC, TGA, resistivity/conductivity. Optical spectroscopy: Atomic absorption spectroscopy, infrared spectroscopy and Raman spectroscopy. Scanning Tunneling and Atomic Force Microscopy.

Unit-4 **08 Lectures**

Materials for energy harvesting

Piezoelectric, Pyroelectric and Thermo-electrics materials, Electrostatic (capacitive) Energy Harvesting and materials, energy from Magnetic Induction, Metamaterial, energy from atmospheric pressure changes, electroactive polymers (EAPs), nanogenerators, Ambient radiation sources and nanoantenna, energy from noise.

Unit-5 **08 Lectures**

Materials for Energy Storage

Electrochemistry and electro-chemical Battery materials, Hydrogen Storage materials for fuel cells:Metal hybrids, Nanostructured metal hydrides, Non-metal hydrides, Carbohydrates, Synthesis of hydrocarbons, Aluminum, Liquid organic hydrogen carriers (LOHC), Ammonia, Amine borane complexes, Nano borohydrides and nano catalyst doping, imidazolium ionic liquids, phosphonium borate, Carbonite substances, Metal Organic frameworks, Activated Carbons, Carbon nanotubes, Clathrate hydrates, Glass capillary arrays.

Reference Books:

1. Advanced Energy Materials, Ashutosh Tiwari &SergiyValyukh, J. Wiley & Sons
2. Eco- and Renewable Energy Materials, Young Zho, Springer
3. Materials and Energy (Book Series), Leonard C Feldman (Ed. In Chief), World Scientific
4. Ginley, David S. ;Cahen, D. Fundamentals of materials for energy and environmental sustainability. Cambridge: CambridgeUniversity Press, 2011. ISBN 9781107000230.
5. S.P. Gaponenko, Optical Properties of semiconductor nanocrystals,Cambridge University Press, 1980.
6. G. Cao, Nanostructures & Nanomaterials: Synthesis, Properties &Applications , Imperial College Press, 2004.
7. J. George, Preparation of Thin Films, Marcel Dekker, Inc., New York.2005.
8. B. D. Cullity, “Elements of X-ray Diffraction”, 4th Edition, Addison Wiley,1978.
9. M. H. Loretto, “Electron Beam Analysis of Materials”, Chapman and Hall,1984.
10. Sam Zhang, Lin Li and Ashok Kumar, Materials CharacterizationTechniques, CRC Press, (2008).
11. Yang Leng, Materials Characterization: Introduction to Microscopic andSpectroscopic Methods, Wiley & Sons (2008).
12. Elton N. Kaufmann, Characterization of Materials, Vol.1, Wiley & Sons(2003).
13. Peter E.J. Flewitt and R.K. Wild, Physical Methods of MaterialsCharacterization, 2nd Edition, Taylor & Francis (2003).
14. Willard, Merritt, Dean, Settle, Instrumental Methods of Analysis, CBSpublishers & Distributors, Delhi, Sixth Edition, 1986.
15. Colin N. Banwell and Elaine M. McCash, Molecular Spectroscopy,Mcgraw-Hill College; 4 Sub edition (June 1, 1994), ISBN-10: 0077079760

EST-107 Innovation, Entrepreneurship and Start up Ecosystems

L	T	P	C
1	1	0	2

Course Objectives:

1. To learn the basics of Entrepreneurship & Innovation.
2. To learn the concepts and practices for Entrepreneurial Development.
3. To study start-up ecosystem.
4. To learn start-up project planning and analysis.
5. To learn Start-Up Project Scalability processes.

Course Outcomes: Upon completion of this course, the students shall be able to understand;

1. Concept of Entrepreneurship & Innovation.
2. Entrepreneurial Development.
3. Start-Up Ecosystem and development.
4. Start-Up Project Planning and Analysis**.**
5. Project Scalability Report.

Unit-1 **04 Lectures**

Entrepreneurship & Innovation – Definition, Objective and Features

Key terminology: Entrepreneurship& innovation; Difference between Entrepreneurship and Traditional Businesses; Entrepreneurs and Intrapreneurs; Technological Entrepreneurship: Characteristics and needs of Innovation

Unit-2 **04 Lectures**

Entrepreneurial Development

Business Planning; Mid-career Dilemmas; Entrepreneurial Growth and Competitive Advantage; Changing Role of Entrepreneurs. Entrepreneurship Development Institute; Entrepreneurship development Programs.

Unit-3 **04 Lectures**

Start-Up Ecosystem

General presentation about startup development phases (from formation to validation to scaling) specifically from the support role's perspective; Key terminology: idea & innovation, entrepreneurship & start-ups; Innovation megatrends; Why startups?; Startup as a category; Understanding & mapping startup ecosystems.

Unit-4 **04 Lectures**

Start-Up Project Planning and Analysis

Measuring potential; Success & failure factors; Mission, Vision & Strategy; Co-founder team building; Idea / team fit; Shareholder agreement (SHA); Confirming team commitment; Problem / solution fit; Market timing and journey; Planning in short & long term; Evaluating opportunities; Funding options and strategies at this stage; Additional tools & resources for self-learning.

Unit-5 **04 Lectures**

Start-Up Project Scalability Report

Focus on scaling phase, which is the most crucial phase for getting serious about building a real and scalable business; What things to focus on and why?; Business planning; Go to market strategies; Born global & internationalization; Scaling metrics (KPI's); Recruiting; Building processes; Funding options; Working with big companies; Methods & tools; Additional tools & resources for self-learning.

Reference Books:

1. Innovation and Entrepreneurship by Peter F. Drucker (Special Indian Edition). Routledge
2. Entrepreneurship (11th Edn) by R. Hisrich, M. Peters and D. Shepherd. McGraw Hill
3. Business Model Innovation – The Organizational Dimension by Nicolai J. Foss & Tina Saebi. Oxford University Press
4. Guide to Start-Ups by Taxmann.
5. Entrepreneurship Development by S.S. Khanka. S. Chand Publishers.

EST-108 Introduction to Nanotechnology (Elective Course)

L	T	P	C
3	1	0	4

Course Objectives:

1. To understand the fundamentals and basics of nanotechnology.
2. To provide the knowledge of the basics and properties of semiconductor nanostructures.
3. To know the concepts, types and properties of carbon nanotubes.
4. To provide an understanding of the multidisciplinary applications of nanotechnology.
5. To study the applications of nanomaterials for energy systems and devices.

Course Outcomes: Upon completion of this course, the students shall be able to understand

1. Fundamentals and basics of nanotechnology.
2. Basics and properties of semiconductor nanostructures.
3. Concepts, types and properties of carbon nanotubes.
4. Multidisciplinary applications of nanotechnology.
5. Applications of nanomaterials for energy systems and devices.

Unit-1 **08 Lectures**

Introduction to Nanotechnology

Historical Background of Nanotechnology, Quantum phenomena, Size effect, Electronic confinement in 1D,2D and 3D structures, Nanomaterials, Molecular Nanotechnology, Top-down and Bottom-up approaches, Green Nanotechnology, Applications of Nanotechnology.

Unit-2 **08 Lectures**

Semiconducting Nanostructures

Metal oxide nanostructures: Background, Synthesis, Properties and Applications
Nanochalcogenides: Background, Synthesis, Properties and Applications
Organic Semiconductor Nanostructures: Background, Synthesis, Properties and Applications

Unit-3 **10 Lectures**

Carbon Nanomaterials

Introduction to Carbon allotropes and Carbon nanomaterials Fullerenes: Background, Synthesis, Properties and Applications CNTs (SWNTs and MWCNTs,): Background, Synthesis, Properties and Applications Nano-diamonds: Background, Synthesis, Properties and Applications Graphene: Background, Synthesis, Properties and Applications Carbon Nano-fibers and Carbon nano-yarns: Background, Synthesis, Properties and Applications

Unit-4 **08 Lectures**

Nanotechnology: A Multidisciplinary Approach

Nanobiotechnology; Introduction and applications, Nanomedicine; Introduction and applications. Nanotechnology for clean environment, Nanorobotics; future of robotics and applications, Nanotechnology in water desalination technologies.

Unit-5 **06 Lectures**

Nanomaterials for Energy Applications

Introduction, Nanomaterials for Photovoltaic Devices, Nanomaterials for Energy Storage Devices, Nanomaterials for Thermo-electric Devices, Nanomaterials for Hydrogen Storage, Nanogenerators

References:

1. A Handbook of Nanotechnology, U. Kumar, AGROBIOS
2. Springer Handbook of Nanotechnology, B. Bhooshan, Springer
3. Advances in Nanomaterials, Zishan Husain Khan & M. Husain, Springer
4. Recent Trends in Nanomaterials: Synthesis and Properties (Advanced Structured Materials), Zishan Husain Khan, Springer
5. Nanomaterials and Their Applications, Zishan Husain Khan, Springer
6. Charles P Poole Jr., and Frank J. Ownes, Introduction to Nanotechnology,John Wiley Sons, Inc., 2003
7. H. S. Nalwa (Ed.), "Encyclopedia of Nanoscience & Nanotechnology", American Scientific Publishers, California, 2004.
8. Garcia-Martinez J., ed. “Nanotechnology for Energy Challenge”, Wiley-VCH, Weinheim, 2010.
9. Hari Singh Nalwa, “Nanomaterials for Energy Storage Applications”, Nanomax Technologies, USA , 2009.
10. Li Quan (Ed.), “Nanomaterials for Sustainable Energy”, ISBN 978-3-319-32023-6, Springer Publications, 2016.
11. Tsakalakos L., “Nanotechnology for Photovoltaics”, CRC, 2010.
12. Vayssieres L., “On Solar Hydrogen and Nanotechnology’, Wiley, 2009.

EST-109 Nanoelectronics (Elective Course)

L	T	P	C
3	1	0	4

Course Objectives:

1. To introduce the fundamental of classical technology.
2. To provide the knowledge of MOS capacitor, interface quality and process techniques.
3. To learn Metal gate transistor
4. To provide an understanding Metal source/drain junctions, Compound semiconductors and material properties
5. To study Synthesis of Nanomaterials and Characterization.

Course Outcomes: Upon completion of this course, the students shall be able to learn;

1. Concept overview and fundamental of classical technology.
2. The knowledge of MOS capacitor, interface quality and process techniques.
3. Concept of transiter
4. Concept of semiconductor materials properties.
5. Knowledge of Nanomaterials and Characterization.

Unit-1 **08 Lectures**

Overview and Fundamental of classical Technology

Nano devices, Nano materials, Nano characterization. Definition of Technology node, Basic CMOS Process flow. MOS Scaling theory, Issues in scaling MOS transistors: Short channel effects, Description of a typical 65 nm CMOS technology. Requirements for Non classical MOS transistor.

Unit-2 **08 Lectures**

MOS capacitor, interface quality and process techniques

Gate oxide thickness scaling trend, SIO2 vs High-k gate dielectrics. Integration issues of high-k. Interface states, bulk charge, band offset, stability, reliability - Qbd high field, possible candidates, CV and IV techniques

Unit-3 **08 Lectures**

Metal gate transistor

Motivation, requirements, Integration Issues. Transport in Nano MOSFET, velocity saturation, ballistic transport, injection velocity, velocity overshoot. SOI - PDSOI and FDSOI. Ultrathin body SOI - double gate transistors, integration issues. Vertical transistors – Fin FET and Surround gate FET

Unit-4 **08 Lectures**

Metal source/drain junctions, Compound semiconductors and material properties

Properties of Schottky junctions on Silicon, Germanium and compound semiconductors -Work function pinning. Germanium Nano MOSFETs: strain, quantization, Advantages of Germanium over Silicon, PMOS versus NMOS. MESFETs Compound semiconductors MOSFETs in the context of channel quantization and strain, Hetero structure MOSFETs exploiting novel materials, strain, quantization.

Unit-5

Synthesis of Nanomaterials and Characterization **08 Lectures**

CVD, Nucleation and Growth, ALD, Epitaxy, MBE.Compound semiconductor hetero-structure growth and characterization: Quantum wells andThickness measurement techniques: Contact - step height, Optical - reflectance and ellipsometry. AFM. Characterization techniques for nanomaterials: FTIR, XRD, AFM, SEM, TEM, EDAX etc. Applications and interpretation of results.Emerging nano materials: Nanotubes, nanorods and other nano structures, LB technique, Soft lithography etc. Microwave assisted synthesis, Self-assembly etc.

References:

1. George W.Hanson,, Fundamental of Nanoelectronics, First edition, Pearson education 2008.
2. Supriyo Dutta; Lessons from Nanoelectronics; A New Perspective on Transport, word Scientific, 2012
3. Advanced Nanoelectronics, First Edition CRC Press, 2017.

4. Colin N. Banwell and Elaine M. McCash, Molecular Spectroscopy,Mcgraw-Hill College; 4 Sub edition (June 1, 1994), ISBN-10: 0077079760
5. B. D. Cullity, "Elements of X-ray Diffraction", 4th Edition, Addison Wiley,1978.
6. Suzzane Bell, Keith Morris; An Introduction to Microscopy CRC Press.
7.

EST-111 Energy Science & Technology Lab.-I

L	T	P	C
0	0	4	2

Course Objectives:

1. To study the properties of semiconductor materials.
2. To study the characteristics of semiconductor devices.
3. To study the solar cell characteristics.
4. To study the energy generation from wind turbine.
5. To study the energy generation from biomass/biofuel.

List of Experiments

1. To calculate the Hall co-efficient (R_H), type of majority charge carriers and number of charge carriers per unit volume (n) in a sample material.
2. By using Four probe method calculate the resistivity of semiconductors.
3. Using PN junction kit, observe the variation of current with voltage and plot the I-V characteristics of PN junction diode at room temperature.
4. To determine the value of Planck's constant 'h' by using a photocell.
5. To determine the Planck's constant by using LED.
6. To study the I-V characteristics of Zener diode and calculate the breakdown voltage of Zener diode.
7. Using solar cell kit, plot the I-V characteristics of solar cell and determine the efficiency of solar cell.
8. Using solar cell kit, study the current and voltage for different parallel and series combination of cells.
9. Using Wind Energy Kit, study the generation of energy from the given wind turbine.
10. Using Bio Energy Kit, study the generation of energy from the given biomass/biofuel.

M. Tech. (Energy Science & Technology)

Semester-II

S. NO.	Paper	PAPER TITLE	CREDIT	PERIOD PER WEEK			DISTRIBUTION OF MARKS			TOTAL
				L	T	P	MID SEMESTER EVALUATION		END SEMESTER EXAM	
							CWS	MST		
SECOND SEMESTER										
THEORY										
01	EST-201	Energy Storage Systems	4	3	1	-	-	40	60	100
02	EST-202	Wind Energy: Resource, Engineering & Projects	4	3	1	-	-	40	60	100
03	EST-203	Energy Audit	4	3	1	-	-	40	60	100
04	EST-204	Solar Photovoltaic Technology	4	3	1	-	-	40	60	100
05	EST-205	Concepts and Design of Green Building	2	2	1	-	-	20	30	50
06	EST-206	Energy Economics and Energy Policy	2	2	1	-	-	20	30	50
07	EST-207	Hybrid electric vehicles and charging stations	2	2	1	-		20	30	50
08	EST-208	Energy Efficient Lighting and Displays	2	2	1	-	-	20	30	50
09	EST-211	Seminar	4	4	-	-	-	40	60	100
Practical										
10	EST-212	Energy Sc. & Tech. Lab-II	2	-	-	4	-	20	30	50
	Elective Course (any one)									
1	EST-209	Embedded Control Systems	4	3	1	-	-	40	60	100
2	EST-210	Power Electronics (MOOC)	4	3	1	-	-	40	60	100
TOTAL CREDITS			**34**	**TOTAL MARKS**						**850**

EST-201 Energy Storage Systems

L	T	P	C
3	1	0	4

Course Objectives :

1. To study the basics of energy storage systems.
2. To study the concept and design of electrochemical batteries.
3. To study the concept and design of supercapacitor.
4. To study Hydrogen production and storage.
5. Other Emerging Energy Storage Techniques.

Course Outcomes: Upon completion of this course, the students shall be able to learn about the;

1. Basics of energy storage systems.
2. Concept and design of electrochemical batteries.
3. Concept and design of supercapacitor.
4. Fuel Cell, Hydrogen production and storage.
5. Other Emerging Energy Storage Techniques.

Unit-1 **08 Lectures**

Introduction

Importance and need of energy storage, modes of energy storage, Energy transmission methods, Electrical energy characteristic's and basic load calculations, Performance characteristics of energy storage systems, Types of load curves, energy shift, Ragone plot. Importance of energy density and power density, Transmission Congestion - Demand for Portable Energy, Demand and scale requirements, Environmental and sustainability issues. Introduction to different energy storage mechanisms.

Unit-2 **08 Lectures**

Rechargeable Batteries

Primary and secondary batteries, battery potential, charge figure of merit, energy and power in battery, polarization losses, thermodynamics of battery materials, tortuosity and porosity of battery materials, reversible and irreversible interfacial reactions, battery architecture and design guidelines, Lead–acid battery, Nickel–cadmium battery (NiCd), Nickel–metal hydride battery (NiMH), Lithium-ion battery, Lithium-ion polymer battery.

Energy density, power density, price and market.

Battery Management systems and System Performance

Unit-3 **08 Lectures**

Super Capacitors

Basic components of supercapacitors like types of electrodes like high surface area activated carbons, metal oxide and conducting polymers, aqueous and organic electrolytes. The disadvantages and advantages of supercapacitors over battery systems and their applications in aspects of energy density, power density, price and market.

Unit-4 **10 Lectures**

Fuel Cell & Hydrogen Storage

Introduction – working and types of fuel cell – low, medium and high temperature fuel cell, liquid and methanol types, proton exchange membrane fuel cell solid oxide, hydrogen fuel cells – thermodynamics

and electrochemical kinetics of fuel cells, Fuel cell performance characteristics, Hydrogen storage technology – pressure cylinders, liquid hydrogen, metal hydrides, carbon fibers – reformer technology – steam reforming, partial oxidation, auto thermal reforming – CO removal,

Background and working of Fuel Cell, Hydrogen production processes, Hydrogen storage: Physical and chemical properties, general storage methods, compressed storage-composite cylinders, glass micro sphere storage, zeolites, metal hydride storage, chemical hydride storage and cryogenic storage, Carbon based materials for hydrogen storage.
Hydrogen safety aspects, backfire, pre-ignition, hydrogen emission NOx control techniques and strategies, Hydrogen powered vehicles.

Unit-5 **06 Lectures**

Other Emerging Energy Storage Techniques

Superconducting Magnetic Energy Storage, Hybrid Energy Storage: Bacitor (Battery + Fuel Cell) and Flow Batteries (Battery + Capacitor + Fuel Cell)
Applications: Storage for Hybrid Electric Vehicles, Regenerative Power, capturing methods.

Reference Books:

1. Detlef Stolten,"Hydrogen and Fuel Cells: Fundamentals, Technologies and Applications", Wiley, 2010.
2. Jiujun Zhang, Lei Zhang, Hansan Liu, Andy Sun, Ru-Shi Liu, "Electrochemical Technologies for Energy Storage and Conversion", John Wiley and Sons, 2012.
3. Francois Beguin and ElzbietaFrackowiak ,"Super capacitors", Wiley, 2013.
4. Doughty Liaw, Narayan and Srinivasan, "Batteries for Renewable Energy Storage", The Electrochemical Society, New Jersy,2010.
   Linden D. and Reddy Thomas B., "Handbook of Batteries", 2001,
5. McGraw Hill Publications.
6. Larminie and A. Dicks, Fuel Cell Systems Explained, 2nd Edition, Wiley
7. (2003).
8. Xianguo Li, Principles of Fuel Cells, Taylor and Francis (2005)
9. S. Srinivasan, Fuel Cells: From Fundamentals to Applications, Springer (2006)
10. O'Hayre, S. W. Cha, W. Colella and F. B. Prinz, Fuel Cell Fundamentals,Wiley (2005)
11. A. J. Bard and L. R. Faulkner, Electrochemical Methods: Fundamentals and Applications, 2nd Edition, Wiley, 2000.
12. A. Faghri and Y. Zhang, Transport Phenomena in Multiphase Systems, Elsevier 2006
13. Barclay F.J., "Fuel Cells, Engines and Hydrogen", Wiley, 2009.
14. Ibrahim Dincer and Mark A. Rosen, "Thermal Energy Storage Systems and Applications", John Wiley & Sons 2002.
15. Kordesch K. and G.Simader, Fuel Cell and Their Applications, Wiley-Vch, Germany 1996.
16. Rebecca L. and Busby, Hydrogen and Fuel Cells: A Comprehensive Guide, Penn Well Corporation, Oklahoma, 2005.
17. Hoogers , "Fuel cell technology handbook", CRC Press, 2003.
18. Ru-shiliu, Leizhang and Xueliang sun, "Electrochemical technologies for energy storage and conversion", Wiley publications, 2012.

EST-202 Wind Energy: Resource, Engineering & Projects

L	T	P	C
3	1	0	4

Course Objectives:

1. To learn about the basic introduction of wind energy.
2. To understand the basics of fluid mechanics and its application in wind energy.
3. To study the wind speeds and wind turbines.
4. To learn about wind resource tools.
5. To learn about the wind industry and wind project development.

Course Outcomes: Upon completion of this course, the students shall be able to learn about the;

1. Basic introduction of wind energy.
2. Basics of fluid mechanics and its application in wind energy.
3. Wind speeds and wind turbines.
4. Wind resource tools.
5. Wind industry and wind project development.

Unit – 1 **06 Lectures**

General Introduction

Main Drivers of Wind Industry; Climate Change, Energy Access, Indigenous Resource, Energy – Economy – Development Linkage, Worldwide developments; Predominant Technology Description, Worldwide Potential, Multi-disciplinary aspect of Wind Energy, Careers in Wind Industry, Onshore, Offshore, Trends, Wind – The Energy Source; Global Energy Balance, Global Wind Systems, Pressure Systems, Pressure Zones on Earth, El Nino & La Nina, Inter Tropical Convergence Zone, Regional Wind Systems, Monsoon System; Indian Summer Monsoon, Asian Australian Monsoon, North American Monsoon, West African Monsoon, Local Wind Systems; Sea and Land system, Mountain Valley System, Katabatic Winds, Desert Wind, Principal Forces; Pressure force, Isobars, Coriolis force, Inertial force, Frictional force, Geostrophic Wind, Gradient Wind

Unit – 2 **06 Lectures**

Fluid Mechanics and Wind Energy

Basic concepts; Vector Fields, Line Integral and Surface Integral, Divergence and Curl, Eulerian &Lagrangian Approach, Concept of Continuum, Control Volume, Overview of Governing Equations; Continuity Equation and its derivation, Euler's Equation, Bernoulli's Equation, Explanation Cauchy's Equation, Explanation Navier- Stokes (NS) Equation, NS Approximations applicable to Wind, Concept of Boundary Layer, Atmospheric Boundary Layer, Overview of Aerofoil Theory; Stream function, Streamlines and Stream Tubes, Conformal Mapping, Different types of Aerofioils, Lift and Drag

Unit–3 **12 Lectures**

Wind Speeds and Wind Turbines

Extrapolation of Wind Speeds; Laws of Vertical Extrapolation, Surface Roughness, Flow over obstacles, Slopes & Speed-up Factor, Wind Measurement Systems; Anemometers, Wind Vanes, Lidars, Wind Data Recording and Averaging Time, Calibration, Standards, Wind Data Handling; Cleaning and Filling in Missing data, Wind Speed Frequency Distribution, Mean Wind Speed, Standard Deviation, Weibull

Distribution and its Estimation, Turbulence Intensity, Wind Rose, Gust, Extreme wind speeds. Different types of wind turbines; Vertical Axis and Horizontal Wind Turbine, Off-grid, On-grid and Hybrids, Onshore and Offshore wind turbines, Fixed Speed, Variable Speed, DFIG, Gearless, Permanent Magnet Gen, Electro-magnetic Gen, Modern Wind Turbine Basics; Typical Type & Specs, Wind Turbine as an Autonomous Generating Unit, Power Curve and Power Regulation, Power Curve Measurements, Wake and wake modeling, Wind turbine Classifications, Energy Yield Assessment from a Wind Turbine; Time Series Method, Frequency Distribution Method, Weibull Function Method , Actuator Disk; Power in Wind, Axial Induction factor, Momentum theory, Coefficient of Performance, Betz Limit, Power and Rotational Speed, Thrust Coefficient, Tip Speed Ratio, Wake rotation, Angular Momentum, Vortex Cylinder, Flow field, Rotor Blade Theory; Blade Element Theory, Free Mixing, Blade geometry, Rotor Design, Blade Losses, Functioning of wind turbines; Wind Turbine components, Blade Pitch, Yaw mechanism, SCADA, Availability, Predictive and Preventive maintenance.

Unit–4 **08 Lectures**

Wind Resources Tools

Spatial Wind Resource Tools; GIS – Overview, GIS Layers, Working with Google Earth Imagery, Land-Use Land Cover, Mesomap Studies, Wind Site Prospecting, Site Selection Criteria, Geomorphological Indicators, Biological Indicators, Wind atlas analysis and application programme, Re-analysis Data, Long-Term Assessments of wind speeds; Measured Data and Re-analysis, Construction of Long term Time Series, Variation in wind speeds, Long term Cycles, Windfarm Models; Boundary Layer based models, CFD Models, Wake Models, Wind Power Model, Losses from a Windfarm, Gross and Net Yield Assessment, Risks, losses, & Uncertainties; Industry norms on losses, Estimation & breakdown of losses, Sources of Uncertainty, Quantification of Uncertainties, P50, P75, and P90 numbers, Windfarm Layout; Project feasibility Assessment, Micrositing, Spacing between wind turbines, Grid Connection aspects, Logistic and Infra requirements, Functioning, Operation & maintenance;

Unit–5 **08 Lectures**

Wind Industry Overview and Wind Project Development

Wind Industry Overview**;** Industry structure and main stake holders**,** Supply Chain,Major Suppliers, Type and size of wind turbines,Quality and Certification of Wind Turbines,Wind Power Project Development; Main activities,Scheduling,Timeline,Monitoring and Supervision.

Reference Books:

1. Anna Mani : Wind Energy Data for India
2. C-Wet : Wind Energy Resources Survey in India VI
3. S. Rangrajan : Wind Energy Resources Survey in India V
4. SathyajithMathew : Wind Energy
5. Prepared by WISE: Wind Power in India (5000MW BY 2015)
6. B.H.Khan: Non-Conventional Energy Sources
7. Duffie A. and Beckmann W. A., “Solar Engineering of Thermal Processes, John Wiley, 1991.
8. Freris L.L., “Wind Energy Conversion Systems”, Prentice Hall, 1990.
9. Godfrey Boyle, “Renewable Energy, Power for a Sustainable Future”, Oxford University Press, 1996.
10. John D Sorensen and Jens N Sorensen, “Wind Energy Systems”, Woodhead Publishing
11. Ltd, 2011.
12. Kaldellis J.K., “Stand – alone and Hybrid Wind Energy Systems”, CRC Press, 2010.
13. Mario Garcia –Sanz, Constantine H. Houpis, “Wind Energy Systems”,CRC Press 2012.
14. Spera D.A., “Wind Turbine Technology: Fundamental concepts of Wind Turbine Engineering”, ASME Press, 1994.
15. Twidell J.W. and Weir A., “Renewable Energy Sources”, EFN Spon Ltd., 1983.

EST-203 Energy Audit

L	T	P	C
3	1	0	4

Course Objectives:

1. To understand the objectives of energy audit.
2. To provide the knowledge of procedures and techniques used in energy audit.
3. To study the energy balance and MIS.
4. To provide an understanding of evaluation and understanding of thermal systems.
5. To study the evaluation and understanding of mechanical systems.

Course Outcomes: Upon completion of this course, the students shall be able to understand;

1. Objectives of energy audit.
2. Procedures and techniques used in energy audit.
3. Energy balance and MIS.
4. Evaluation and understanding of thermal systems.
5. Evaluation and understanding of mechanical systems.

Unit-1 **06 Lectures**

General Aspects

General Philosophy and need of Energy Audit, Definition and Objective of Energy Audit, General Principles of Energy Audit, Energy Audit Methodology, Energy Audit Approach, Understanding Energy Costs, Bench marking, Energy performance, Matching energy usage to requirements, maximizing system efficiency, Optimizing the input energy requirements, Fuel and Energy substitution.

Unit-2 **06 Lectures**

Procedures and Techniques-I

Basic measurements – Electrical measurements, Light, Pressure, Temperature and heat flux, Velocity and Flow rate, Vibrations, etc. Instruments Used in Energy systems: Load and power factor measuring equipment, Wattmeter, flue gas analysis, Temperature and thermal loss measurements, air quality analysis etc. Mathematical and statistical modelling and analysis. Energy Measurement & Verification, Measurement & Verification (M & V) Protocol

Unit-3 **08 Lectures**

Procedures and Techniques-II

Data gathering: Level of responsibilities, energy sources, control of energy and uses of energy get Facts, figures and impression about energy /fuel and system operations, Past and Present operating data, Special tests, Questionnaire for data gathering.

Analytical Techniques: Incremental cost concept, mass and energy balancing techniques, inventory of Energy inputs and rejections, Heat transfer calculations, Evaluation of Electric load characteristics, process and energy system simulation.

Evaluation of saving opportunities: Determining the savings in Rs, Noneconomic factors, Conservation opportunities, estimating cost of implementation.

Energy Audit Reporting: The plant energy study report- Importance, contents, effective organization, report writing and presentation,

Energy Balance & MIS: First law of efficiency and Second law of efficiency, Facility as an Energy system, Methods for preparing process flow, Materials and Energy Balance diagram, Identification of losses, Improvements. Energy Balance sheet and Management Information System (MIS) Energy Modelling and Optimization.

Unit-4 **10 Lectures**

Thermal Systems-Evaluation and Assessment

Boilers- performance evaluation, Loss analysis, Water treatment and its impact on boiler losses, integration of different systems in boiler operation. Advances in boiler technologies, FBC and PFBC boilers, Heat recovery Boilers- it's limitations and constraints. Furnaces- Types and classifications, applications, economics and quality aspects, heat distributions, draft controls, waste heat recovering options, Furnaces refractories- types and sections. Thermic Fluid heaters need and applications, Heat recovery and its limitations. Insulators- Hot and Cold applications, Economic thickness of insulation, Heat saving and application criteria. Steam Utilization- Properties, steam distribution and losses, steam trapping, Condensate, Flash steam recovery. Integrated analysis of steam base co-gen system, Gas turbine combine cycle operation, IC engine base co-generation and tri-generation, extraction turbines and steam cycle of cogeneration.

Unit-5 **10 Lectures**

Mechanical Systems-Evaluation and Assessment

Pumps, types and application, unit's assessment, improvement option, parallel and series operating pump performance. Energy Saving in Pumps & Pumping Systems, Blomers (Blowers) types & application, its performance assessment, series & parallel operation applications & advantages. Energy Saving in Blowers Compressors, types & applications, specific power consumption, compressed air system, & economic of system changes. Energy Saving in Compressors & Compressed Air Systems Cooling towers, its types and performance assessment & limitations, water loss in cooling tower. Energy Saving in Cooling Towers HVPC & Psychometric, vapour compression cycles & comfort cooling, refrigerants new trends, COP, Capacity assessment, Vapor absorption refrigeration's – Li Br & Ammonia Cycles, working principle and system analysis, comparison of different cooling systems, heat pump off ions for HVPC systems improvements and its analysis. Energy Saving in HVAC Systems, Water system and water analysis for power generation, water audit and it utilization, Hydro-pneumatic applications for optimization of water pumping cost.

Reference Books:

1. Handbook of Energy Audits, Albert, Terry Niehus, William J. Younger, Fairmont Press
2. Energy Audit: Thermal Power, Combined Cycle, and Cogeneration Plants, Y. P. Abbi, The Energy and Resources Institute, TERI
3. Efficient Use of Energy :I.G.C.Dryden (Butterworth Scientific)
4. Industrial Energy Conservation : D.A. Reay (Pergammon Press)
5. Hamies "Energy Auditing and Conservation; Methods Measurements,
6. Energy Management Handbook – W.C. Turner (John Wiley and Sons, A Wiley Interscience Publication)
7. Industrial Energy Management and Utilization – L.C. Witte, P.S. Schmidt, D.R. Brown Hemisphere Publication, Washington) 8. Industrial Energy Conservation Manuals, MIT Press, Mass, 1982
8. Energy Conservation guide book Patrick/Patrick/Fardo (Prentice Hall)
9. Handbook on Energy efficiency –
10. ASHRAEE Energy Use (4 Volumes)
11. CIBSI Guide –Users Manual (U.K.)
12. CRC Handbook of Energy Efficiency – CRC Press.

13. ECBC Code 2007 (Edition 2008) published by Bureau of Energy Efficiency, New Delhi Bureau of Energy Efficiency Publications-Rating System, TERI PUBLICATIONS – GRIHA Rating System, LEEDS Publications
14. Industrial Furnaces (Vol I & II) and M.H. Mawhinney, (John Wiley Publications)
15. The efficient use of steam – Oliver Lyle, (HMSO London)
16. Boilers – Types, Characteristics and functions – Carl D. Shields (Mcgraw Hill book)
17. The Efficient use of steam generation – General editor – P.M.Goodall
18. Efficient use of Steam by Oliver Lylee, Amazon Publications
19. Efficient use of Steam by P M Goodall, Amazon Publications.

EST-204 Solar Photovoltaic Technology

L	T	P	C
3	1	0	4

Course Objectives:

1. To study the concept of PV systems.
2. To study about PV devices, modules and arrays and their technical parameters.
3. To study the components and working of solar power plant.
4. To study the concepts of solar power management.
5. To learn Grid Codes and Standards.

Course Outcomes: Upon completion of this course, the students shall be able to understand;

6. Concept of PV systems.
7. About the PV devices, modules and arrays and their technical parameters.
8. Components and working of solar power plant.
9. Concepts of solar power management.
10. About the learn Grid Codes and Standards.

Unit-1 **08 Lectures**

Introduction to photovoltaic (PV) systems

Review and Advancements in Solar PV Technology, Overview of Composition of Solar PV based power plants, Types of Solar PV based power plants. Overview of Government policies and standards, Installation, operation and technical survey of Solar PV based power plants.

Unit-2 **08 Lectures**

Solar PV based power plants: Types and Configuration

Types of Solar PV based power plants: Stand Alone, Grid Connected, Hybrid etc. Configuration of Stand Alone, Grid Connected, Hybrid etc. Standards of Stand Alone, Grid Connected, Hybrid etc solar PV based power plants.

Unit-3 **08 Lectures**

Power Electronics Converters in Solar PV Technology

Role of Power Electronics technology in Solar PV power plant. Types of DC- DC Converter and working. Types of DC-AC Inverters and working. Control and modelling of DC-DC and DC- AC power electronics Converters.

Unit-4 **08 Lectures**

Solar PV plant- Power Management

Power conditioning and maximum power point tracking (MPPT) algorithms based on buck- and boost-converter topologies, Maximum power point tracking (MPPT) algorithms, requirement and control of power electronics converters for Solar power management in Solar PV system.

Unit-5 **08 Lectures**

Advance Control and New Application of Solar PV based plants

Grid Codes, Anti Islanding protection, LVRT protection, HVRT Protection, Active and Reactive Power Control, Electric vehicle charging station after integration of Solar PV based technology. Solar PV based house hold power plant.

Reference Books:

1. Photovoltaics: Designs, Systems and Applications, Michael Stock, Larsen and Keller Education
2. Photovoltaics: Engineering and Technology for Solar Power, Catherine Waltz, Syrawood Publishing House
3. Principles of Solar Engineering, D. Goswami, CRC Press
4. Solanki S. Chetan. Solar Photovoltaics: Fundamentals, Technologies and Applications, New Delhi, PHI, 2012.
5. Gilbert M. Masters: Renewable and Efficient Electric Power Systems. John Wiley &Sons, 2004
6. Roger A. Messenger & Jerry Venter: Photovoltaic Systems Engineering. CRC Press,2004, 2nded.
7. Jha .A.R, "Solar Cell Technology and Applications", CRC Press, 2010.
8. John R. Balfour, Michael L. Shaw, SharlaveJarosek., "Introduction to Photovoltaics", Jones & Bartlett Publishers, Burlington, 2011.
9. Partain .L.D, Fraas L.M., "Solar Cells and Their Applications", 2nd ed., Wiley,2010.
10. Sukhatme .S.P, Nayak .J.K, "Solar Energy", Tata McGraw Hill Education Private Limited, New Delhi, 2010.

EST-205 Concepts and Design of Green Building

L	T	P	C
2	1	0	2

Course Objectives:

1. To understand the basic concepts of green building their social and economic aspects.
2. To learn the basic techniques and processes involved in Energy Efficiency and Energy Conservation through various techniques. The study and application of various software are involved in the process.
3. To understand the basic principles of Energy modelling that would be pertinent to simple and advance design building design
4. To understand the contribution made by new materials and technology to contemporary buildings.
5. Provide students the basic concepts and thorough knowledge and operation of building services in modern, large high-rise buildings complexes.

Course Outcomes: Upon completion of this course, the students shall be able to learn about the;

1. Concepts of green building.
2. Basics techniques and process of energy efficiency and energy conservation.
3. National and international codes of the energy modeling system.

4. Study and application of various software for new building materials.
5. Study and application of various software for advanced energy materials.

Unit-1 **06 Lectures**

Introduction

Green Building, Environmental Economic & Social Benefits of Green Buildings, Sustainable features for Green Building, Case Study of Green Buildings, Energy and Resource saving through Green Buildings, Professional Accreditation, Incentive Programs, Certifications.

Unit-2 **06 Lectures**

Building Energy Efficiency

Why energy efficiency?, Multiple Aspects of Building Design & Construction, Thermal Comfort, Heat exchange in buildings, Passive design (Natural Ventilation), Passive design (Building form and envelope), Passive design (Daylight), Passive design (Case Studies), Renewable energy integration, Energy Conservation Opportunities in Public and Private Buildings.

Unit-3 **06 Lectures**

National & International Codes

ECBC Code, Application of ECBC in Indian Buildings, Analysis of saving of Energy by the application of ECBC, Introduction to other codes-ECONIWAS, ASHRAE, NCC 2019.

Rating System-: IGBC (Indian Green Building Council), GRIHA (Green Rating for Integrated Habitat Assessment) Buildings, LEED (Leadership in Energy and Environmental Design).

Compliances: - ECBC Compliances, Section J.

Unit-4 **06 Lectures**

Energy Simulations

Introduction to Building Energy Simulation- Geographical Location, Building Envelope (walls, roof, floors, ceiling, windows), Interior Loads (Lighting, Internal heat gain for appliances and equipment, Internal heat gain for occupants, metabolic rate & Schedules (Occupancy, Appliances, Lighting, HVAC & others), Software Setups, Introduction to Design Builder, Application of ECBC & Simulation.

Unit-5 **06 Lectures**

Advance Energy Modelling

Energy Plus: Integrated, Simultaneous solution, Sub-hourly, user-definable time steps,
Advanced fenestration models, Standard summary and detailed output reports.

Overview of BEE Approved Software's: Design Builder, Energy Plus, eQuest, HAP, Open Studio, IDA-ICE and others.

References:

1. Heating and Cooling of Buildings, Design for Efficiency, Revised 2nd Edition Jan_F. Kreider Curtiss Ari Rabl ECBC (Energy Conservation Building Code) 2017
2. NBC (National Building Code), ASHRAE Comprehensive HVAC Deign: A Handbook on Practical Approach to Air Conditioning, Heating and Ventilation System, by N.C. Gupta

EST-206 Energy Economics and Energy Policy

L	T	P	C
2	1	0	2

Course Objectives:

1. To understand the global scenario of energy and its impact of GDP.
2. To provide the knowledge of Indian energy scenario; consumption and supply.
3. To know about the global and national energy policies.
4. To provide an understanding of energy policy planning.
5. To study the economics of energy.

Course Outcomes: Upon completion of this course, the students shall be able to learn about the;

1. Global scenario of energy and its impact of GDP.
2. Indian energy scenario; consumption and supply.
3. Global and national energy policies.
4. Energy policy planning.
5. Economics of energy.

Unit-1 **06 Lectures**

Global Energy Scenario

Role of energy in economic development and social transformation: Energy & GDP, GNP and its dynamics, Energy Consumption in various sectors and its changing pattern, Energy Security: Chemical and Nuclear: Non Proliferation, Energy Security, Energy Consumption and its impact on environmental climatic change, International Energy Policies of G-8 Countries, G-20 Countries, OPEC Countries, EU Countries. International Energy Treaties (Rio, Montreal, Kyoto), INDO-US Nuclear Deal.

Unit-2 **06 Lectures**

Indian Energy Scenario

Sector wise energy consumption in India, Impact of Energy on Economy, Energy and Environmental policies, Status of Nuclear and Renewable Energy: Present Status and future promise Energy Policy Issues: Fossil Fuels, Renewable Energy, Power sector reforms, restructuring of energy supply sector, energy strategy for future. Energy Conservation Act-2001 & its features, Electricity Act-2003 & its features. Framework of Central Electricity Authority (CEA), Central & States Electricity Regulatory Commissions (CERC & ERCs)

Unit-3 **04 Lectures**

Energy Policy

Global Energy Issues, National & State Level Energy Issues, National & State Energy Policy, Industrial Energy Policy, Energy Security, Energy Vision, Energy Pricing & Impact of Global Variations, Energy Productivity (National & Sector wise productivity).

Unit-4 **06 Lectures**

Energy Policy Planning

Key Elements of Energy Policy Planning: Force Field Analysis, Energy Policy-Purpose, Perspective, Contents and Formulation, Implementation of Energy Policy: Location of Energy Manager, Top Management Support, Managerial functions, Role and responsibilities of Energy Manager,

Accountability, Motivation of employees, Requirements for Energy Action Planning, Information Systems: Designing, Barriers, Strategies, Marketing and Communicating Training and Planning.

Unit-5 **08 Lectures**

Energy Economics

Energy economics: Basic concepts, energy data, energy cost, energy balance, Energy accounting framework; Economic theory of demand, production and cost market structure; National energy map of India, Energy subsidy – National and international perspectives, Concepts of economic attributes involving renewable energy, Application of econometrics; input and output optimization; energy planning and forecasting different methods, Concepts of economic attributes involving renewable energy, Application of econometrics; input and output optimization; energy planning and forecasting different methods.

Reference Books:

1. Energy Economics, Concepts, Issues, Markets and Governance, Subhes C. Bhattacharyya, Springer
2. Energy Economics, Peter M. Schwarz, CRC Press
3. Energy Law and Policy, NawneetVibhaw, Lexis Nexis
4. Energy Economics A.V.Desai (Wieley Eastern)
5. Energy for a sustainable world: Jose Goldenberg, Thomas Johansson, A.K.N.Reddy, Robert Williams (Wiley Eastern).
6. Energy policy for :B.V.Desai (Weiley Eastern),
7. Modeling approach to long term demand and energy implication :J.K.Parikh.
8. Energy Policy and Planning :B.Bukhootsow.
9. TEDDY Year Book Published by Tata Energy Research Institute (TERI),
10. World Energy Resources : Charles E. Brown, Springer2002.
11. 'International Energy Outlook' EIA annual Publication
12. Heat and Thermodynamics – M.W. Zemansky (McGraw Hill Publication)
13. Principles of Energy Conversion: A.W. Culp (McGraw Hill International edition.)
14. BEE Reference book: no.1/2/3/4.
15. Fuel Economy Handbook, NIFES

EST-207 Hybrid electric vehicles and charging stations

L	T	P	C
2	1	0	2

Course Objectives:

1. To study the basics and introduction of electric vehicles.
2. To study components of electric vehicles.
3. To study plug-in hybrid electric vehicles
4. To study the concept of charging stations
5. To study integrations of subsystems.

Course Outcomes: Upon completion of this course, the students shall be able to learn about the;

1. Basics of electrical vehicles
2. Components of electric vehicles.
3. Plug-in hybrid electric vehicles
4. The concept of charging stations
5. Integrations of subsystems.

Unit-1 **06 Lectures**

Introduction to Electric Vehicles

Fundamentals of the EV, Types of Electric Vehicles, Hybrid Electric Vehicles, Plug-In Hybrid Electric Vehicle (PHEV), Fuel Cell Vehicles (FCVs). HEV Fundamentals: Introduction, Vehicle Model, Vehicle performance, EV Power-train Component Sizing, Series Hybrid Vehicle, Parallel Hybrid Vehicle, Wheel Slip Dynamics.

Unit-2 **06 Lectures**

Components of Electric Vehicles

Electric Machines and Drives in HEVs: Introduction, BLDC motors, Induction Motor Drives, Permanent Magnet Motor Drives, Switched Reluctance Motors, Doubly Salient Permanent Magnet Machines, Design and Sizing of Traction Motors, Thermal Analysis and Modelling of Traction Motors.

Unit-3 **06 Lectures**

Plug-in Hybrid Electric Vehicles

Plug-in Hybrid Electric Vehicles: Introduction to PHEVs, PHEV Architectures, Equivalent Electric Range of Blended PHEVs, Fuel Economy of PHEVs, Power Management of PHEVs, Component Sizing of EREVs, Component Sizing of Blended PHEVs, Vehicle-to-Grid Technology. Power Electronics in HEVs: Power electronics including switching, AC-DC, DC-AC conversion, electronic devices and circuits used for control and distribution of electric power, Thermal Management of HEV Power Electronics.

Unit-4 **06 Lectures**

Charging Stations

Need and modelling of charging stations. Batteries, Ultra capacitor, Fuel Cells, and Controls: Introduction, Different batteries for EV, Battery Characterization, Comparison of Different Energy Storage Technologies for HEVs, Battery Charging Control, Fuel Cells and Hybrid Fuel Cell Energy Storage System and Battery Management System.

Unit-5 **06 Lectures**

Integration of Subsystems

Matching the electric machine and the internal combustion engine (ICE), Sizing the propulsion motor, sizing the power electronics, selecting the energy storage technology, Communications, supporting subsystems. Energy Management Strategies: Introduction to energy management strategies used in hybrid and electric vehicle, classification of different energy management strategies, comparison of different energy management strategies, implementation issues of energy strategies.

Reference Books

1. Iqbal Hussein, Electric and Hybrid Vehicles: Design Fundamentals, CRC Press , 2003
2. Mehrdad Ehsani, Yimi Gao, Sebastian E. Gay, Ali Emadi, Modern Electric, Hybrid Electric and Fuel Cell Vehicles: Fundamentals, Theory and Design, CRC Press , 2004

EST-208 Energy Efficient Lighting and Displays

L	T	P	C
2	1	0	2

Course Objectives:

1. To study the basics of lighting and lighting system elements.
2. To study solid-state lighting.
3. To study organic light-emitting diodes.
4. To study the concept of fiber optic lighting.
5. To study display technology.

Course Outcomes: Upon completion of this course, the students shall be able to learn about the;

1. Basics of lighting and lighting system elements.
2. Solid-state lighting.
3. Organic light-emitting diodes.
4. The concept of fiber optic lighting.
5. Display technology.

Unit-1 **06 Lectures**

Introduction to Lighting and Lighting System Elements

Need for Energy Management, Illumination requirements for various tasks Activities/Locations; Basic Terms in Lighting System and Features, Light Sources, Luminaries, Ballasts; Lamp Types and their Features, Methodology of Lighting System, Day lighting, lighting system controls, system maintenance, operating schedule, psychology of changeover. Lighting energy management in buildings: Case Studies Some Good Practices in Lighting, History of Lighting

Unit-2 **06 Lectures**

Solid State Lighting

Florescence, Phosphorescence, Electroluminescence. Inorganic Luminescent Materials and Devices (Light Emitting Diodes and Light Emitting Transistors).Blue and Ultraviolet LEDs, White LEDs, RGB system Phosphor Based LEDs

Unit-3 **06 Lectures**

Organic Light Emitting Diodes

Introduction to Organic Semiconductors, Classification of Organic Semiconductors, Florescence, Phosphorescence, Thermally Active Delayed Fluorescence and Hyper-fluorescence in Organic Materials, Different generations of Organic Light Emitting Diodes and their processing, Blue OLEDs and White OLEDs, Technical aspects of OLEDs.

Unit-4 **02 Lectures**

Fiber Optic Lighting

Types of Fibers, fabrication technology, Materials development for fiber optic, Transmission losses, Use of fiber in lighting

Unit-5 **10 Lectures**

Display Technology

History of Display Technology, LCD display technologies and devices, thin-film transistor (TFT) technology for LCD. Back lighting technologies for LCDs, Field-emissive, electro-chromic, and photo-chromic displays, Plasma Display, Electronic-ink, electronic paper (e-paper) and flexible display technologies and their applications, Laser based projection displays, digital micromirror devices (DMD) and pico-projectors, Three-dimensional (3-D) display technologies, Micro displays, STEREOSCOPIC 3D displays, integral imaging, polarization based 3Ddisplays, HOLOGRAPHIC 3-D displays and laser-based 3D-TV.

Reference Books:

1. Fundamentals of Solid-State Lighting: LEDs, OLEDs, and Their Applications in Illumination and Displays, Vinod Kumar Khanna, CRC Press
2. Materials for Solid-State Lighting and Displays, Adrian Kitai, John Wiley & Sons Ltd.
3. Handbook of Display Technology, Joseph A. Castellano, Gulf Professional Publishing
4. Handbook of Visual Display Technology, Janglin Chen, Wayne Cranton, MarkFihn, Springer
5. Introduction to Light Emitting Diode Technology: 2009 Taylor and Francis Group, LLC.
6. Fundamentals of Phosphors, Eiichiro Nakazawa, : 2009 Taylor and FrancisGroup, LLC
7. Luminescence: From theory to Applications, Ed. Cees Roonda, WileyVCH publication
8. Luminescent Materials, Andy Edgar.
9. Organic Light-Emitting Diodes (OLEDs), Materials, Devices andApplications, Editor: Alastair Buckley, Hardcover ISBN: 9780857094254, eBook ISBN: 9780857098948.
10. City of Light: The Story of Fiber Optics, Jeff HechtOxford University Press, 2004 - Science - 340 pages.
11. Fiber Optic Lighting: A Guide for Specifiers, Russell L. DeVeauThe Fairmont Press, Inc., 2001 - Aydınlatma - 179 pages

EST-209 Embedded Control System Design (Elective Course)

L	T	P	C
3	1	0	4

Course Objectives :

1. To understand the concepts of embedded systems.
2. To provide the knowledge of design of embedded systems.
3. To study the system identification and model structures.
4. To provide an understanding of control design.
5. To study the fundamentals of robust control systems.

Course Outcomes : Upon completion of this course, the students shall be able to understand;

1. Concepts of embedded systems.
2. About the design of embedded systems.
3. System identification and model structures.
4. About the control design.
5. Fundamentals of robust control systems.

Unit-1 **08 Lectures**

Embedded Systems – Basic Concepts

What Is an Embedded System? The Main Architecture of Embedded Control Systems, Electric Power Level, Signal Processing Level , Communication Networks in Embedded Systems , Main Features of a Controller Area Network (CAN) Communication, CAN Message Frames ,Error Detection and Signaling, CAN Controller Modes , CAN Implementations , Multi-tasking Embedded Control Systems , Planning Embedded System Development.

Unit-2 **08 Lectures**

Introduction into Embedded Control System Design

Requirements for Control System Design, Safety Requirements, Identification of the System to Be Controlled, Control Device Specification, Design, Installation and Maintenance, Mathematical Models for Control, Models from Science, Models from Experimental Data, Linearization of Nonlinear Models, Control System's Characteristics, Disturbance Attenuation, Tracking, Sensitivity to Parameter Variations ,Control System's Limitation. Stability and Relative Stability, Performance Specifications for Linear Systems

Unit-3 **08 Lectures**

System Identification and Model-Order Reduction

Model Building and Model Structures, Input Signal Design for System Identification Experiments, Model Validation in Time and Frequency Domain, Model-Order Reduction Methods, Nominal Plant and Plant Uncertainties, Identification of a Fuel Cell.

Unit-4 **08 Lectures**

Controller Design

Based on Pole-Zero Cancellation, The Influence of Controller Zero, Controller Design for Deadbeat Response , Controller Design Using the Root Locus Technique, PID Controller Design, Ziegler-Nichols Tuning Formula, Monte Carlo Simulation, Controller Design for Systems with Time Delays, Systems with Time Delays – Smith Predictor, Controller Design for Disturbance Rejection, Disturbance Observers

Unit-5 **08 Lectures**

Fundamentals of Robust Control

Review of Norms for Signals and Systems, Internal Stability, Youla Parametrization, Unstructured Plant Uncertainties, Robust Stability for Different Uncertainty Models, Controller Design Using Youla Parametrization, Risk Assessment and Safety Levels, Fault Categories and Failure Rates.

Reference Books:

1. Applied Control Theory for Embedded Systems. A volume in Embedded Technology. Book • 2006. Authors: Tim Wescott; Elsevier
2. "Embedded Systems Design" by Steve Heath. Publisher: Butterworth-Heinemann.
3. Principles of Embedded computing system design, WynewoffMprgankoffmanpublication 2000
4. Embedded Systems- Architecture, Programming and Design by Rajkamal, 2007, TMH.
5. Real Time Concepts for Embedded Systems – Qing Li, Elsevier, 2011
6. Introduction to Embedded Systems - Shibu K.V, Mc Graw Hill.
7. Embedded System Design - Frank Vahid, Tony Givargis, John Wiley.
8. Barrett, S.F. and Pack, J.D., Embedded Systems, Pearson Education (2008).

9. Haung, H.W., The HCS12 / 9S12: An Introduction to Software and Hardware Interfacing, Delmar Learning(2007).
10. Sigurd Skogestad and Ian Postlethwaite, Multivariable Feedback Control Analysis and Design – JohnWiley & Sons Ltd., 2nd Edition, 2005.
11. D. W. Gu, P. Hr. Petkov and M. M. Konstantinov "Robust Control Design with MATLAB" Spring - Verlag London Ltd., 2005.
12. Kennin Zhou, "Robust and Optimal Control", Prentice Hall, Engle wood Cliffs, New Jersy.

EST-210 Power Electronics (Elective Course)

L	T	P	C
3	1	0	4

Course Objectives:

1. To introduce the fundamentals of Power Electronics.
2. To provide the basic knowledge, and operations of Power Electronic Devices.
3. To provide in-depth knowledge on AC-DC Converters.
4. To provide in-depth knowledge on AC-AC, and DC-DC Converters.
5. To provide in-depth knowledge on DC-AC Inverters.

Course Outcomes: Upon completion of this course, the students shall be able to learn;

1. The Concept overview and fundamentals of power electronics.
2. The concept of AC-DC Converters.
3. The Concept of AC-AC, and DC-DC Converters.
4. The concept of DC-AC Inverters.
5. The concept of VSI, CSI, and MLI.

Unit-1

Basics of Power Electronics **08 Lectures**

Power Electronics - Introduction: Definitions and applications, Basic building blocks, Passive components (R, L, C), Active components (introduction to switches). Review of basic concepts- Engineering Maths, Electronics etc.

Unit-2 **08 Lectures**

Power Electronics Devices

Power Devices: Power Diodes, SCRs, GTO, BJT, MOSFET, IGBT- Characteristics, working, selection and protection.

Unit-3 **08 Lectures**

Power Electronics: AC-DC Converters

AC-DC converters: half wave & full wave; uncontrolled, semi-controlled & fully controlled; single-phase and three-phase.

Unit-4 **08 Lectures**

Power Electronics: AC-AC, DC-DC Converters

AC-AC converters: AC voltage controllers and cycloconverters.: Non-isolated DC-DC converters: Buck, Boost, Buck-boost & Cuk. Isolated DC-DC converters

Unit-5: Power Electronics: DC-AC Inverters **08 Lectures**

DC-AC Inverters: Single-phase and three-phase inverters, modulation techniques. Current Source inverter, VSI, CSI: Topology and Basic Operations, MLI: Topology and Basic Operations.

Reference Books:

1. Power Electronics; M D Singh, K B Kanchandani, McGraw Hill Publications.
2. Robert W. Erickson; Fundamentals of Power Electronics, Second Edition.
3. Bin Wu, Mehdi Narimani, High Power Converters and drives, Second Edition, 2005.

EST-212 Energy Science & Technology Lab.-II

L	T	P	C
0	0	4	2

Course Objectives:

1. To study the Solar Photovoltaic system.
2. To study different elements of photovoltaics energy systems.
3. To study the characteristics of fuel cells and their applications.
4. To study Hydro Turbine Energy Generator.
5. To study SCADA system.

List of Experiments

1. Study of I-V characteristics of Solar Cell
2. Study of various modes of Constant Voltage Charging technique.
3. Study of Buck and Boost Converter.
4. Study of Bypass Diodes.
5. Study of Dusk to Dawn Switch.
6. Fuel Cell:
   (a) Study of Current-Voltage Characteristic of Electrolyzer's function of Reversible PEM Fuel Cell.
   (b) Study of the Application of Fuel Cell function of Reversible Fuel Cell of providing electrical energy to the loads such as buzzer, fan and bulb.
7. To study the generation of electricity by using Bio Energy & run the different applications using generated electricity.
8. Hydro Turbine Energy Generator:
   (a) To study the Hydro Turbine (Pelton wheel Type) with Resistive Load.
   (b) To study the Hydro Turbine (Pelton wheel Type) with Motor Load.
   (c) To study the Hydro Turbine (Pelton wheel Type) with Bulb Load.
9. To demonstrate the I-V and P-V characteristics of different types of solar cells with varying radiation and temperature level.
10. To demonstrate the impact of partial shading on solar cell performance.
11. To demonstrate the impact of tilt angle on solar cell performance.
12. Construct and describe the Hardware architecture of the SCADA system for the given power system field pump in the SCADA laboratory of the Department of Electrical Engineering.
13. Demonstrate how to connect the FBD logic to the field signal through SCADA project. Describe the RTU architecture. List the functions of each of its subsystem.
14. Demonstrate how to test the communication between workstations and the controller.