

SAVITRIBAI PHULE PUNE UNIVERSITY



FACULTY OF ENGINEERING

SYLLABUS FOR

B.E. ELECTRICAL ENGINEERING

(2015 course)

WITH EFFECT FROM YEAR 2018-2019

Savitribai Phule Pune University
FACULTY OF ENGINEERING

B.E. Electrical Engineering (2015 Course)
(w.e.f. 2018-2019)

SEMESTER-I													
Sr No	Subject Code	Subject Title	Teaching Scheme (Hrs/Week)			Examination Scheme (Marks)					Total Marks	Credit	
			TH	PR	TU	PP		TW	PR	OR		TH / TU	PR + OR
						In Sem	End Sem						
1	403141	Power System Operation and Control	03	02	--	30	70	25	--	25	150	03	01
2	403142	PLC and SCADA Applications	04	02	--	30	70	25	50	--	175	04	01
3	403143	Elective I	03	02	--	30	70	25	--	--	125	03	01
4	403144	Elective II	03	--	--	30	70	--	--	--	100	03	--
5	403145	Control System II	03	02	--	30	70	25	--	25	150	03	01
6	403146	Project I	--	--	02	--	--	--	--	50	50	02	--
	403152	Audit Course V											
TOTAL			16	08	02	150	350	100	50	100	750	18	04
SEMESTER-II													
Sr No	Subject Code	Subject Title	Teaching Scheme (Hrs/Week)			Examination Scheme (Marks)					Total Marks	Credit	
			TH	PR	TU	PP		TW	PR	OR		TH / TU	PR + OR
						In Sem	End Sem						
1	403147	Switchgear and Protection	03	02	--	30	70	50	--	25	175	03	01
2	403148	Power Electronic Controlled Drives	04	02	--	30	70	25	50	--	175	04	01
3	403149	Elective III	03	02	--	30	70	25	--	25	150	03	01
4	403150	Elective IV	03	--	--	30	70	--	--	--	100	03	--
5	403151	Project II	--	--	06	--	--	50	--	100	150	06	--
	403153	Audit Course VI											
TOTAL			13	06	06	120	280	150	50	150	750	19	03

TH Theory lectures hours/week
 PR Practical hours/week
 TU Tutorial hours/week

TW Term work
 OR Oral
 PP Paper- In semester and End Semester

Elective I (403143) A) <u>Fundamentals of Microcontroller MSP430 and its Applications [Open Elective]</u> B) <u>Power Quality</u> C) <u>Renewable Energy Systems</u> D) <u>Digital Signal Processing</u>	Elective II (403144) A) <u>Restructuring and Deregulation</u> B) <u>Electromagnetic Fields</u> C) <u>EHVAC Transmission</u> D) <u>Electric and Hybrid Vehicles</u> E) <u>Special Purpose Machines</u>
Elective III (403149) A) <u>High Voltage Engineering</u> B) <u>HVDC and FACTS</u> C) <u>Digital Control System</u> D) <u>Intelligent Systems and Applications in Electrical Engineering</u> E) <u>Analog Electronics and Sensing Technology [Open Elective]</u>	Elective IV (403150) A) <u>Smart Grid</u> B) <u>Robotics and Automation</u> C) <u>Illumination Engineering</u> D) <u>VLSI Design[Open Elective]</u>

Audit Course

- Audit Course: Optional for 1st and 2nd term of BE Electrical Engineering
- ‘Audit Courses’ means a Course in which the student shall be awarded Pass or Fail only. It is left to the discretion of the respective affiliated institute to offer such courses to the students. Evaluation of audit course will be done at institute level itself.
- Teaching-learning process for these subjects is decided by concern faculty/industry experts appointed by the affiliated Engineering College based on the syllabus and guidelines given.
- Marks obtained by student for audit course will not be taken into consideration of SGPA or CGPA.

Audit Course V (A) Hydro Energy Systems
403152 (B) Foreign Language – German

Audit Course VI Energy Storage Systems
403153

403141: Power System Operation and Control

Teaching Scheme	Credits	Examination Scheme [150 Marks]
Theory : 03 Hr/Week	03	In Sem : 30 Marks
Practical : 02 Hr/Week	01	End Sem : 70 Marks
		Oral : 25 Marks
		Term work : 25 Marks

Prerequisite:

Basics of Power System

Course Objective: The course aims:-

- To develop ability to analyze and use various methods to improve stability of power systems
- To understand the need for generation and control of reactive power
- To impart knowledge about various advanced controllers such as FACTS controllers with its evolution, principle of operation, circuit diagram and applications
- To illustrate the automatic frequency and voltage control strategies for single and two area case and analyze the effects, knowing the necessity of generation control.
- To understand formulation of unit commitment and economic load dispatch tasks and solve it using optimization techniques
- To illustrate various ways of interchange of power between interconnected utilities and discuss planning, reliability aspects at all stages of power system.

Course Outcome: Upon successful completion of this course, the students will be able to :-

1. Identify and analyze the dynamics of power system and suggest means to improve stability of system.
2. Comprehend the effect of reactive power on Power system and suggest the suitable means of reactive power management.
3. Selection of appropriate FACTS devices
4. Analyze the generation-load balance in real time operation and its effect on frequency and develop automatic control strategies with mathematical relations.
5. Formulate objective functions for optimization tasks such as unit commitment and economic load dispatch and get solution using computational techniques.
6. Evaluate reliability indices of Power system

Unit 01 : Power System Stability

(06 Hrs)

Introduction to stability, dynamics of synchronous machine, swing equation, power angle equation and curve, types of power system stability (concepts of steady state, transient, dynamic stability), equal area criterion, applications of equal area criterion (sudden change in mechanical input, effect of clearing time on stability, critical clearing angle, short circuit at one end of line, short circuit away from line ends and reclosure), solution of swing equation by point by point method, methods to improve steady state and transient stability, numerical based on equal area criteria.

Unit 02 : Reactive Power management

(06 Hrs)

Necessity of reactive power control, reactive power generation by a synchronous machine, effect of excitation, loading capability curve of a generator, compensation in power system: series and shunt compensation using capacitors and reactors, Problems with Series Compensation, synchronous condenser.

Unit 03 : FACTS Technology (06 Hrs)

Problems of AC transmission system, evolution of FACTS technology, Working principle, circuit diagram, VI characteristics, applications, advantages and limitations of SVC, TCSC, STATCOM and UPFC.

Unit 04 : Automatic Generation and Control (AGC) (06 Hrs)

Concept of AGC, complete block diagram representation of load-frequency control of an isolated power system, steady state and dynamic response, control area concept, two area load frequency control. Schematic and block diagram of alternator voltage regulator scheme.

Unit 05 : Economic Load Dispatch and Unit Commitment (06 Hrs)

A. Economic load dispatch: Introduction, revision of cost curve of thermal and hydropower plant, plant scheduling method, equal incremental cost method, method of Lagrange multiplier (neglecting transmission losses), B_{mn} coefficient, economic scheduling of thermal plant considering effect of transmission losses, penalty factor, procedure of load dispatch at state level load dispatch center, Regional Load Dispatch Center, numerical on penalty factor, exact coordination equation.

B. Unit commitment: Concept of unit commitment, constraints on unit commitment – spinning reserve, thermal and hydro constraints, methods of unit commitment – priority list and dynamic programming, Numerical on priority list method.

Unit 06 : Energy Control and Planning and Reliability of Power Systems (06 Hrs)

A. Energy Control: Interchange of power between interconnected utilities, economy interchange evaluation, interchange evaluation with unit commitment, types of interchange, capacity and diversity interchange, energy banking, emergency power interchange, inadvertent power exchange, power pools.

B. Planning and Reliability of Power Systems: Need of short term planning and long term planning in generation, transmission, distribution expansion. Definition of reliability of power system, Hierarchical levels for reliability study, Reliability evaluation of generation system, loss of load probability (LOLP), loss of load expectation (LOLE), Expected Energy Not Supplied (EENS), generation model, load model, risk model, composite system reliability evaluation, Distribution system reliability evaluation for radial and parallel system, customer oriented and energy based reliability indices.

Guidelines for Instructor's Manual

Practical Sessions:-

Instructor's Manual should contain following things related to every experiment-

- Specify prerequisite and objective(s) of experiment.
- List out equipment required to perform the experiment with their ratings (for hardware experiments).
- Include circuit diagram with specifications (for hardware experiments).
- Related theory of the experiment must be included.
- The circuit diagram of the experiment should be drawn at the beginning.
- For simulation experiments using MATLAB, the Simulink diagram with proper details must be included in write up. For programming, take printout of program and result.
- Conclusion based on calculations, result and graph (if any) should be written. Provide space for same.

Guidelines for Student's Lab Journal

- Students should write the journal in own hand writing particularly results, diagram, conclusion, question answers etc.
- Circuit / Connection diagram or construction diagram must be drawn either manually using or using software on graph paper.
- Hand writing and figures must be neat and clean.

Guidelines for Laboratory / TW Assessment

- Continuous assessment is to be carried out. The experiment performed in a particular week must be checked in the next turn in next week.
- After assessment, teacher should put the remark by writing word "Complete" and not simply "C". Put the signature along with date at the end of experiment and in the index.

List of Experiments

[Perform experiment 1 or 2 and any seven from 3 to 11 using any simulation software]

1. To determine Steady state Stability of synchronous motor (performance).
2. To determine Steady state stability of medium transmission line (performance).
3. To plot swing curve by Point by Point method for transient stability analysis.
4. To apply equal area criteria for analysis stability under sudden rise in mechanical power input.
5. To apply equal area criteria for stability analysis under fault condition.
6. To study reactive power compensation using any device.
7. To study Lagrange multiplier technique for economic load dispatch.
8. To develop and execute dynamic programming method for unit commitment.
9. To study load frequency control using approximate and exact model.
10. To study load frequency control with integral control.
11. To study the two area load frequency control.

Industrial Visit:

Industrial visit is mandatory to Load Dispatch Center / Power Station Control Room.

Text Books:

- [T1] I. J. Nagrath, D. P. Kothari, "Modern Power System Analysis", 4th Edition, Tata McGraw Hill Publishing Co. Ltd. (Edition 2)
- [T2] Hadi Saadat, "Power System Analysis", Tata McGraw Hill
- [T3] P. S. R. Murthy, "Power System Operation and Control", Tata McGraw Hill Publishing Co. Ltd.
- [T4] P. S. R. Murthy, "Operation and Control in Power System", B. S. Publication.
- [T5] R. Mohan Mathur, Rajiv K. Varma, "Thyristor based FACTS controller for Electrical transmission system", John Wiley and Sons Inc.
- [T6] Abhijit Chakrabarti, Sunita Halder, "Power System Analysis Operation and Control", Prentice Hall of India.
- [T7] Narain G. Hingorani and Laszlo Gyugyi, "Understanding FACTS", IEEE Press.

Reference Books:

- [R1] Allen J. Wood, Bruce F. Wollenberg, "Power Generation, Operation, and Control", Wiley India Edition.
- [R2] "Electrical Power System Handbook", IEEE Press.
- [R3] Narain G. Hingorani, Laszlo Gyugyi, "Understanding FACTS Concepts and Technology of Flexible AC Transmission Systems," IEEE Press.
- [R4] Olle I. Elgerd, "Electrical Energy System Theory", 2nd Edition, Tata McGraw Hill Publishing Co. Ltd.
- [R5] Prabha Kundur, "Power System Stability and Control", Tata McGraw Hill.

Websites:

1. <http://www.mahasldc.in/>
2. <http://cercind.gov.in/>
3. <http://www.srldc.org/>
4. <https://nrlde.in/>
5. <http://www.mercindia.org.in/>
6. <http://www.erlde.org/>
7. <http://nptel.ac.in/courses/108101040/> (PSOC webcourse)
8. <http://www.powergridindia.com/>

Unit	Text Books	Reference Books
1	T1, T2, T6	R1, R2, R5
2	T3	R5
3	T5,T7	R3
4	T1	R1
5	T2,T4	R1, R4, websites
6	T1	R1

403142: PLC and SCADA Applications

Teaching Scheme	Credits	Examination Scheme [175 Marks]
Theory : 04 Hr/Week	04	In Sem : 30 Marks
Practical : 02 Hr/Week	01	End Sem : 70 Marks
		PR : 50 Marks
		Term work : 25 Marks

Prerequisite:

Logic gates operations, Boolean algebra, Relay logic

Course Objective: The course aims:-

- To understand the generic architecture and constituent components of a Programmable Logic Controller.
- To develop architecture of SCADA explaining each unit in detail.
- To develop a software program using modern engineering tools and technique for PLC and SCADA.
- To apply knowledge gained about PLCs and SCADA systems to real-life industrial applications.

Course Outcome: Upon successful completion of this course, the students will be able to :-

1. Develop block diagram of PLC and explain the working.
2. Classify input and output interfacing devices with PLC.
3. Develop architecture of SCADA and explain the importance of SCADA in critical infrastructure.
4. Execute, debug and test the programs developed for digital and analog operations.
5. Describe various SCADA protocols along with their architecture.
6. Observe development of various industrial applications using PLC and SCADA.

Unit 01 : Introduction to PLC

(08 Hrs)

Role of automation in Industries, benefits of automation, Necessity of PLC, History and evolution of PLC, Definition as per NEEMA (National Electrical Engineering Manufacturers' Association), types – fixed/modular/dedicated, Overall PLC system, PLC Input and output modules (along with Interfaces), CPU, programmers and monitors, power supplies, selection criterion, advantages and disadvantages, specifications, comparison of various PLCs manufactured by Allen Bradley, Siemens, ABB, Mitsubishi, GE, Fanuc and Schneider.

Unit 02 : Interfacing of PLC with I/O devices

(08 Hrs)

Input ON/OFF switching devices, Input analog devices, Output ON/OFF devices, Output analog devices Sensors-temperature, pressure, flow, level Actuators-Electrical, pneumatic, hydraulic Encoders-Incremental, Absolute Transducers, Limit switches, proximity sensors Control Elements- Mechanical, Electrical, Fluid valves

Unit 03 : Programming of PLC

(09 Hrs)

Programming languages for PLC, Ladder diagram fundamentals, Rules for proper construction of ladder diagram Timer and counter- types along with timing diagrams, Reset instruction, latch instruction MCR (master control relay) and control zones Developing ladder logic for Sequencing of motors, ON OFF Tank level control, ON OFF temperature control, elevator, bottle filling plant, car parking, traffic light controller.

Unit 04 : Advance function and Applications of PLC (08 Hrs)

Analog PLC operation and PLC analog signal processing, PID principles, Typical continuous process control curves, simple closed loop systems, closed loop system using Proportional, Integral and Derivative (PID), PID modules, PID tuning, tuning methods including “Adjust and observe” method.

Motors Controls: AC Motor starter, AC motor overload protection, DC motor controller, Variable speed (Variable Frequency) AC motor Drive.

PLC Applications in developing systems- Tank level controller using analog signals, temperature controller using RTD, speed control of electric motor.

Unit 05 : SCADA Systems (08 Hrs)

Introduction, definitions and history of Supervisory Control and Data Acquisition, typical SCADA system Architecture, important definitions HMI, MTU, RTU, communication means, Desirable Properties of SCADA system, advantages, disadvantages and applications of SCADA.

SCADA generations (First generation - Monolithic, Second generation - Distributed, Third generation – Networked Architecture), SCADA systems in operation and control of interconnected power system, Functions and features of SCADA systems, Automatic substation control, Energy management systems (EMS), System operating states, SCADA system in critical infrastructure: Petroleum Refining Process, Conventional electric power generation, Water Purification System, Chemical Plant.

Unit 06 : SCADA Protocols (07 Hrs)

Open systems interconnection (OSI) Model, TCP/IP protocol, Modbus model, DNP3 protocol, IEC61850 layered architecture, Control and Information Protocol (CIP), Device Net, Control Net, Ether Net/IP, Flexible Function Block process (FFB), Process Field bus (Profibus).

Guidelines for Instructor’s Manual

- Specify objective(s) of the experiment.
- Include ladder diagram.
- Related theory of the experiment must be included.
- Include step by step procedure to perform the experiment.
- Tabular representation of results taken from the experiment/observation table must be included wherever applicable.
- Provide space to write conclusion.

Guidelines for Student’s Lab Journal

- Students are expected to write the journal in the following sequence:
 - Aim –
 - Ladder diagram –
 - Theory –
 - Conclusion.
- Students are expected to draw the ladder diagrams on 1mm graph paper.
- They should attach print out or draw SCADA HMI.
- Students should write conclusion.
- Students should get the assignment and lab write up checked within 1 week after performing the experiment.

Guidelines for Laboratory conduction

- Give the safety instructions to students.
- Allow 4-5 students per group for performing the experiment.
- Explain theory related to the experiment to be conducted.
- Introduce PLC and SCADA in detail with specifications to students.
- Explain the ladder diagram of the experiment.
- Ladder diagram should be completed by the students.
- Perform the experiment in the presence of instructor.
- Verify the results obtained.

List of Experiments:

Minimum 11 experiments should be conducted. 6 experiments should be on PLC and 5 experiments should be on SCADA.

- a) Experiments No. 1 to 5 are compulsory.
- b) Any 1 experiment should be conducted from experiment number 6 to 9.
- c) Experiments No. 10 to 13 are compulsory.
- d) Any 1 experiment should be conducted from experiment number 14 to 17.

1. Interfacing of lamp and button with PLC for ON and OFF operation. Verify all logic gates.
2. Set / Reset operation: one push button for ON and other push button for OFF operation.
3. Delayed operation of lamp by using push button.
4. UP/DOWN counter with RESET instruction.
5. Combination of counter and timer for lamp ON/OFF operation.
6. DOL starter and star delta starter operation by using PLC.
7. PLC based thermal ON/OFF control.
8. Interfacing of Encoder with PLC
9. PLC based speed, position, flow, level, pressure measurement system.
10. PLC interfaced with SCADA and status read/command transfer operation.
11. Parameter reading of PLC in SCADA.
12. Alarm annunciation using SCADA.
13. Reporting and trending in SCADA system.
14. Tank level control by using SCADA.
15. Temperature monitoring by using SCADA.
16. Speed control of Machine by using SCADA.
17. Pressure control by using SCADA.

Industrial Visit: Compulsory visit to SCADA and PLC based automation industry.

Text Books:

- [T1] John W. Webb, Ronald A. Reis, “Programmable Logic Controllers: Principles and Application”, PHI Learning, New Delhi, 5th Edition
- [T2] John R. Hackworth, Frederick D., Hackworth Jr., “Programmable Logic Controllers Programming Methods and Applications”, PHI Publishers
- [T3] Ronald L. Kurtz, “Securing SCADA System”, Wiley Publishing
- [T4] Stuart A Boyer, “SCADA supervisory control and data acquisition”, ISA, 4th Revised edition
- [T5] Sunil S. Rao, “Switchgear and Protection”, Khanna Publication
- [T6] Curtis Johnson, “Process Control Instrumentation Technology”, Prentice Hall of India
- [T7] Gary Dunning, “Introduction to Programmable Logic Controllers”, Thomson, 2nd Edition

Reference Books:

- [R1] Gordan Clark, Deem Reynders, “Practical Modern SCADA Protocols”, ELSEVIER
- [R2] Batten G. L., “Programmable Controllers”, McGraw Hill Inc., Second Edition
- [R3] Bennett Stuart, “Real Time Computer Control”, Prentice Hall, 1988
- [R4] Krishna Kant, “Computer Based Industrial Control”, PHI
- [R5] P. K. Srivstava, “Programmable Logic Controllers with Applications”, BPB Publications

Unit	Text Books	Reference Books
1	T1	R2
2	T1, T2, T6	R3, R4
3	T1, T7	R5
4	T1, T2, T6	R2, R5
5	T3, T4, T5	R1
6	T3	R1

Elective I : 403143 (A) : Fundamentals of Microcontroller MSP430 and its Applications [Open Elective]

Teaching Scheme	Credits	Examination Scheme [125 Marks]
Theory :03 Hr/Week	03	In Sem : 30 Marks
Practical :02 Hr/Week	01	End Sem : 70 Marks
		Term work : 25 Marks

Prerequisite:

Basic knowledge of Number system.
Knowledge of basic logic components.
Programming skills in C Language.

Course Objective: The course aims to:-

- Provide understanding of architecture of MSP430 microcontroller
- Develop ability to write and interpret C language programs for MSP430
- Use advance features in PWM for MSP430
- Interface various devices with MSP430
- Understand use of MSP 430 for IoT applications

Course Outcome: Upon successful completion of this course, the students will be able to:-

1. Explain architecture of MSP430 microcontroller, its instructions and the addressing modes.
2. Develop and debug program in C language for specific applications.
3. Use of Code Composer Studio IDE for simulating the functionalities of MSP430 microcontroller
4. Interface microcontroller MSP430 to various sensing devices.
5. Develop IoT based application using MSP430.

Unit 01 : Overview of MSP430 (06 Hrs)

Basics of Embedded Systems, Introduction to MSP430, RISC Architecture / Functional Block Diagram of MSP430G2553, Pin Diagram, Memory Organization, CPU, On-Chip-Peripherals. Overview of MSP430G2 Launchpad and its Features.

Unit 02 : Digital I/O, Interrupts and basic of programming (06 Hrs)

GPIO programming and I/O multiplexing; Interrupts and interrupt programming, Issues associated with interrupts, Capacitive touch I/O pin interface.

Software and hardware tools for development of MSP430 based system such as assembler, compiler, IDE, Emulators, debugger, programmer.

Unit 03 : Timers, PWM Control and RTC (06 Hrs)

Watchdog timer, Timers, Measurement in Capture Mode, PWM control – Edge-Aligned PWM, Centred PWM and Sine-PWM, Real Time Clock (RTC).

Unit 04 : ADC and Operating Modes (06 Hrs)

Analog-to-Digital Conversion: General Issues, Successive Approximation. Basic Operation of ADC10, Advanced Operation of ADC10, ADC10 Successive Approximation, Digital to Analog Conversion.

Low Power aspects of MSP430: Operating Modes, low power modes, Active vs Standby current consumption, FRAM vs Flash for low power; reliability.

Unit 05 : Communication (06 Hrs)

Serial communication basics, USCI, Synchronous/Asynchronous interfaces (like UART, USB, SPI, and I2C), UART protocol, I2C protocol, SPI protocol, Implementing and programming UART, I2C, SPI interface using MSP430, Interfacing external devices.

Unit 06 : IoT Basics and Applications of MSP430 (06 Hrs)

IoT overview and architecture, Overview of wireless sensor networks and design examples. Various wireless connectivity: NFC, ZigBee and Bluetooth.

Real world application: MSP430 based Embedded Networking Application: “Implementing Wi-Fi or Bluetooth Connectivity in a Smart Electric Meter”.

Guidelines for Instructor’s Manual

Instructor’s Manual shall have

- Brief relevant theory.
- Equipment with specifications.
- Connection diagram/ methodology.
- Format of observation table and sample results.

Guidelines for Student’s Lab Journal

The Student's Lab Journal should contain following related to every experiment –

1. Theory related to the experiment.
2. Apparatus with their detailed specifications.
3. Connection diagram /circuit diagram.
4. Observation table/ simulation waveforms.
5. Sample calculations for one/two reading.
6. Result table.
7. Graph and Conclusions.
8. Few short questions related to the experiment.

Guidelines for Laboratory conduction

Lab Requirement:MSP430F2553 Launch Pad, Desktop/ Laptop with Windows7/8 operating system, System with installed circuit CCS software, Breadboard, Single strand and jumper wires, MSP430 Capacitive Touch Booster-Pack, CC3100 Wi -Fi Booster Pack.

List of Experiments

Minimum 8 experiments are to be performed from the following list:

- 1) Digital I/O: Learn and understand how to configure MSP-EXP430G2553 / MSP-EXP430F5529 digital I/O pins. Write a C program for configuration of GPIO ports for MSP430 (blinking LEDs, push buttons interface).
Exercises: a) modify the code to make the green and red LEDs blink: Together and alternatively
b) Modify the delay with which the LED blinks: Together and alternatively
c) Modify the code to make the green LED blink: Together and alternatively
- 2) Timer/Interrupt: Learn and understand GPIO based Interrupt programming in MSP-EXP430G2553 / MSP-EXP430F5529. Write a C program and associated GPIO ISR using interrupt programming technique.
Exercises:
a) Write the code to enable a timer interrupt for the pin.
b) Write the code to turn on interrupts globally.
c) LED Blink using timer instead of software delay.
- 3) PWM: Implement Pulse Width Modulation to control the brightness of the on-board, green LED. Exercises:
a) Observe the PWM waveform using CRO / DSO.
b) What is the maximum resolution of PWM circuitry in MSP-EXP430G2553 / MSP-EXP430F5529?
c) Change the above code to create a PWM signal of 75% duty cycle on PWM pin.
- 4) PWM (Continued): Implement Advanced Pulse Width Modulation techniques
Exercises:
a) Edge-Aligned and Center Aligned PWM.
b) Sine-PWM generation.
- 5) ADC: Learn and understand how to configure the ADC module to control the brightness of LED.
Exercises:
a) Read ADC value and observe in Watch window
b) Change PWM duty cycle based on ADC value and control brightness of LED using a pot connected to ADC pin.
- 6) Configure of Universal Serial Communication Interface (USCI) module of MSP-EXP430G2553 / MSP430F5529 for UART based serial communication. The main objective of this experiment is to use UART of the MSP-EXP430G2553 / MSP430F5529 to communicate with the computer.
Exercise:
a) Modify the above code to transmit the set of strings to the serial terminal via UART as shown below:
char str1[]="MSP-EXP430G2553 / MSP430F5529 MCU"
char str2[]="Ultra low power mixed signal processing applications"

- 7) Capacitive I/O interface: Understand and interface a Capacitive Booster pack with MSP430.
Exercise:
a) Implementing Capacitive Booster Pack Demo
- 8) On chip temperature Sensor and ADC interface demo: To implement the on-chip temperature sensor demo.
Exercise:
a) Implementing Temperature Sensor and ADC interface Demo
- 9) Bluetooth Interface: Transmit Data wirelessly over Bluetooth for any chosen IoT application
Examples:
a) Temperature Sensor
b) Humidity Sensor
c) Position Sensor
d) Proximity Sensor
e) Current Sensor
f) Voltage Sensor
g) Pressure Sensor
h) Or any other sensor interfaced with MSP430.
- 10) Closed loop temperature/speed control system using MSP430.

Lab Manual:

- 1) www.ti.com/lab-manuals

Embedded System Design using MSP430 Launchpad Development Kit – Lab Manual

Text Books:

- [T1] Getting Started with the MSP430 Launchpad by Adrian Fernandez, Dung Dang, Newness publication ISBN-13: 978-0124115880
[T2] MSP430 microcontroller basics 1st Edition by John H. Davies (Author), Newnes Publication ISBN- 13: 978-0750682763

Other References:

- [R1] <http://www.ti.com/lit/ds/symlink/msp430g2553.pdf>
[R2] <http://www.ti.com/lit/ug/tidu520/tidu520.pdf>
[R3] http://processors.wiki.ti.com/index.php/MSP430_LaunchPad_Low_Power_Mode

Unit	Text Books	Reference Books
1	T1	R1
2	T2	R1, R3
3	T2	R1
4	T2	R1
5	T2	R1
6	-	R2

Elective I: 403143 (B) : Power Quality

Teaching Scheme	Credits	Examination Scheme [125 Marks]
Theory : 03 Hr/Week	03	In Sem : 30 Marks
Practical : 02 Hr/Week	01	End Sem : 70 Marks
		Term work : 25 Marks

Prerequisite:

Fundamentals of Power system and Power electronics.

Course Objective: The course aims to:-

- Develop ability to identify various power quality issues, its sources and effects on various equipments.
- Monitor and analyze various power quality problems
- Describe and selection of cost effective power quality mitigation solutions.
- Explain use of power quality standards

Course Outcome: Upon successful completion of this course, the students will be able to:-

1. Identify importance of various power quality issues.
2. Carry out power quality monitoring
3. List and explain various causes and effects of power quality problems
4. Analyze power quality parameters and carry out power quality analysis
5. Select cost effective mitigation technique for various power quality problems
6. Use IEEE 519-2014 power quality standard for harmonic compliance

Unit 01 : Basics of power quality (06 Hrs)

Introduction and importance of power quality, symptoms of poor power quality. Classification of power quality events, power quality definition as per IEEE 1159. Grounding of sensitive electronic equipments and guidelines of IEEE std 1100. Long duration RMS voltage variations, its sources, effects and solutions.

Unit 02 : Voltage Sag (06 Hrs)

Sources of voltage sags, classification of voltage sags, factors governing severity of voltage sag. Area of vulnerability, critical distance. Voltage sag characteristics. Classification of equipments based on its sensitivity to various characteristics of voltage sag. Effect of voltage sag on various equipments. Voltage tolerance curve, ITIC and SEMI F47 curve, investigation of sensitivity of equipments to voltage sags. Voltage sag mitigation techniques at equipment level, LT power entrance and medium voltage. Voltage sag indices. Study of important provisions in IEEE Std 1346.

Unit 03 : Transient Overvoltage and Flicker (06 Hrs)

Sources of transient over voltages, Impulsive and oscillatory transients. Magnification of capacitor switching transients, pre insertion reactors to control capacitor switching transients, ferroresonance, principle of over voltage protection. Devices for over voltage protection. Voltage flicker, its sources. Factors governing severity of flicker. Flicker measurement, Pst and Plt. Flicker mitigation solutions.

Unit 04 : Fundamentals of Harmonics (06 Hrs)

Waveform Distortion, Harmonics, Harmonic phase sequences. Classification of harmonics harmonic, Voltage Verses Current distortion, AC quantities under non-sinusoidal conditions, Voltage and current harmonic indices, Sources of harmonics, General and special Effects of Harmonics on Electrical Equipments, cables, switchgears, Meters and Communications.

Unit 05 : Harmonic Mitigation Techniques**(06 Hrs)**

System behaviour to harmonics, location of harmonic sources, Series and parallel resonance, Harmonic mitigation, passive tuned and detuned filters, design of tuned filters, Active Filter, Sizing and location of active filters, Advantages of active filters over passive filters, Hybrid filters. IEEE 519-2014 standard.

Unit 06 : Power Quality Monitoring**(06 Hrs)**

Objectives of Power quality monitoring. Types of power quality monitoring, Power quality monitoring equipments, Power quality analyser specification requirement as per EN50160 Standard. Selection of power quality equipments for cost effective power quality monitoring, selection of voltage and current transducers. Power quality indices. IEEE 1159 standard and important provision related with power quality monitoring. Computer Tools for analysis of power quality.

Guidelines for Instructor's Manual

Instructor's Manual shall have

- Brief relevant theory.
- Equipment with specifications.
- Connection diagram/ methodology.
- Format of observation table and sample results.

Guidelines for Student's Lab Journal

The Student's Lab Journal should contain following related to every experiment –

9. Theory related to the experiment.
10. Apparatus with their detailed specifications.
11. Connection diagram /circuit diagram.
12. Observation table/ simulation waveforms.
13. Sample calculations for one/two reading.
14. Result table.
15. Graph and Conclusions.
16. Few short questions related to the experiment.

Guidelines for Laboratory conduction

- Read and understand power quality analyzer manual completely.
- Make sure that connections of power analyzer are done as per manual.
- Follow safety protocols while doing power quality audit.

List of Experiments

Minimum 8 experiments are to be performed from the following list:

Compulsory experiments:

1. Study of power quality analyzer and measurement of voltage, current, power and power factor using it.
2. Measurement of harmonic distortion of various Equipments such as UPS /AC/DC drive
3. Harmonic compliance of institute as per IEEE 519-2014 standard and sizing of active filter.
4. Power quality audit of institute or department.

Any 4 experiments from following list:

1. Harmonic analysis of transformer for various conditions (no load, inrush, full load etc.)
2. Analysis of performance of induction motor/transformer operated with sinusoidal supply and under distorted supply conditions supplied by 3 phase inverter.
3. Measurement of voltage sag magnitude and duration by using digital storage oscilloscope/ power quality analyzer.
4. Design of 7% detuned Passive Filter
5. Simulation study of transient and/or flicker measurement.
6. Simulation studies of harmonic generation sources such as VFD, SVC, STATCOM and FACTS devices and harmonic measurement (THD) by using professional software like MATLAB.
7. Harmonic load flow analysis by using professional software such as ETAP, PSCAD, ATP etc.

Text Books:

- [T1] R. C. Dugan, Mark F. McGranahan, Surya Santoso, H. Wayne Beaty, “Electrical Power System Quality”, 2nd Edition, McGraw Hill Publication.
- [T2] M. H. J. Bollen, “Understanding Power Quality Problems, Voltage Sag and Interruptions”, New York: IEEE Press, 2000, Series on Power Engineering.
- [T3] C.Sankaran “Power quality”, CRC Press
- [T4] Arrillaga, M. R. Watson, S. Chan, “Power System Quality Assessment”, John Wiley and Sons.

Reference Books:

- [R1] Enriques Acha, Manuel Madrigal, “Power System Harmonics: Computer Modeling and Analysis”, John Wiley and Sons Ltd.
- [R2] Ewald F. Fuchs, Mohammad A. S. Masoum, “Power Quality in Power Systems and Electrical Machines” Elsevier Publication.
- [R3] G. J. Heydt, “Electric Power Quality”, Stars in Circle Publications
- [R4] EN50160 and IEEE 1100, 1346, 519 and 1159 standards
- [R5] Arrillaga, M. R. Watson, “Power System Harmonics”, John Wiley and Sons

Unit	Text Books	Reference Books
1	T1, T2, T3	R3, R4
2	T1, T2, T3	R2, R3, R4
3	T1, T2, T3	R2, R3
4	T1, T3, T4	R1, R4, R5
5	T1, T3, T4	R1, R4, R5
6	T1, T3	R1, R4

403143 (C) : Renewable Energy Systems

Teaching Scheme	Credits	Examination Scheme [125 Marks]
Theory : 03 Hr/Week	03	In Sem : 30 Marks
Practical : 02 Hr/Week	01	End Sem : 70 Marks
		Term work : 25 Marks

Prerequisite: Knowledge of basic renewable technologies like solar, wind, biogas, fuel cell, Knowledge of conventional grid

Course Objective: The course aims:-

- To develop fundamental understanding about Solar Thermal and Solar Photovoltaic systems.
- To provide knowledge about development of Wind Power plant and various operational as well as performance parameter/characteristics.
- To explain the contribution of Biomass Energy System in power generation.
- To describe different Storage systems, Integration and Economics of Renewable Energy System.

Course Outcome: Upon successful completion of this course, the students will be able to :-

1. Describe various renewable energy sources such as Solar Photovoltaic, Biomass, Wind, Fuel cell and Solar thermal.
2. Explain different renewable energy sources as an alternate for conventional power sources in any application of energy.
3. Identify and locate the use of renewable energy sources as per the requirement of the location.
4. Analyze, assess and design renewable energy systems such as solar and wind sources.
5. Compare the various storage sources for electrical energy.
6. Describe the standards for renewable energy source integration and evaluate economics related to these sources.

Unit 01 : Solar Thermal (06 Hrs)

Solar radiation at the Earth's surface, solar constant, spectral distribution, Extra-terrestrial radiation, solar terrestrial radiation, solar radiation geometry, Introduction to the concept of monthly average daily and hourly global and diffuse radiation, beam and diffuse radiation under cloudless skies, solar radiation on tilted surfaces: a) beam radiation, b) diffuse radiation, c) reflected radiation, d) flux on tilted surface.

Instruments for measuring solar radiation, Basics of flat plate collector, concepts of solar water heating system and space heating system, solar dryer, introduction to Concentrating Solar Power (CSP) plants using technologies like a) parabolic troughs b) linear Fresnel reflector c) paraboloid dish

Unit 02 : Solar PV (06 Hrs)

Introduction to various solar PV technologies, Single c-Si, Poly c-Si, thin film PV Cell, Module and Array, factors influencing the electrical design of the solar system: a) Sun Intensity b) Sun Angle c) Shadow Effect d) Temperature Effect e) Effect of Climate f) Electrical Load Matching g) Sun Tracking; Peak Power Point Operation, Electrical characteristics of Silicon PV Cells and Modules, PV System Components, Efficiency of PV system.

Design of typical solar PV system with and without battery backup for applications such as homes, commercial complex, agriculture etc.

Unit 03 : Wind Energy System (06 Hrs)

Types of wind turbine, Site selection, Power Contained in Wind, Aerodynamics of Wind Energy, Efficiency Limit for Wind Energy Conversion, Maximum Energy obtained for a Thrust-operated converter (Efficiency limit), Introduction to the Design of Wind Turbine Rotor, Power-Speed Characteristics, Wind Turbine Control Systems: a) Pitch Angle Control b) Stall Control c) Power Electronics Control d) Yaw Control; Control Strategy, Introduction to Offshore Wind Energy System and its comparison with on grid Wind Energy System

Unit 04 : Biomass Energy System (06 Hrs)

Biomass Classification, Biomass Resources and their Energy Potential, Biomass Conversion Technologies: Anaerobic Digestion, Ethanol Fermentation, Biomass Gasification: Gasifiers, Fluidized Bed Gasifier, Biogas Technologies and their factor affecting Biogas Production, Biogas Plants: Floating and Fixed Dome type, Introduction to other bio-reactors such as CSTR and UASB, designing of biogas plant. Power Generation from Municipal Solid Waste (MSW), Land Fill Gas, Liquid Waste. Introduction to organic fertilizers from digest state.

Unit 05 : Fuel cell and Storage Systems (06 Hrs)

a) Fuel Cells: Introduction to Fuel Cell Technology; type of fuel cells, Operating principles of Fuel Cell, Fuel and Oxidant Consumption, Fuel Cell System Characteristics, application and limits.

b) Energy Storage systems: Hydrogen storage: Hydrogen production, relevant properties, Hydrogen as an Engine Fuel, methods of Hydrogen storage.

Batteries: Introduction to Batteries, Elements of Electro Chemical Cell, Battery classification, Battery Parameters, Factors affecting battery performance.

Grid scale storage, various options available (pumped storage, SMES, compressed air storage, fly wheels, etc.), requirements, future trends, Introduction to the concepts of round trip efficiency and cost of storage.

Unit 06 : Integration and Economics of Renewable Energy Systems (06 Hrs)

a) Integration of RES with grid, standards., Introduction to hybrid systems

b) Economics of RES: Simple payback, Internal Rate of Return (IRR), time value, Net present value (NPV), Life cycle costing, Effect of fuel cost Escalation, Annualized and levelized cost of energy

Guidelines for Instructor's Manual

Manual must have assignment related to theory of each experiment.

Guidelines for Student's Lab Journal

A separate notebook/file is required for experiments. Top of the page must have experiment number, title of experiment, date of experiment. It is to be followed by observations, calculations and results. The laboratory notebook must be checked by the staff in-charge of the experiment. Journal must have observations and conclusions written neatly. The experiments must be assessed by the proper authority before submission.

Guidelines for Laboratory conduction

Minimum 08 experiments should be conducted from the list given below:

List of Experiments

1. To identify and measure the parameters of a Solar PV Module with Series and/or Parallel combination.
2. To plot I-V and P-V characteristics with series and parallel combination of Solar PV Modules for different Insolation and temperature effects.
3. To evaluate effect of Shading and Tilt Angle on I-V and PV characteristics of Solar Module.
4. To estimate effect of sun tracking on energy generation by Solar PV Module.
5. To estimate efficiency of standalone Solar PV Module.
6. To evaluate performance of Solar flat plate collector.
7. To plot characteristics of lead-acid battery for various source and load condition.
8. To analyze effect of blade angles on performance of wind turbine.
9. To evaluate performance of horizontal axis wind turbine.
10. To evaluate performance evolution of vertical axis wind turbine.
11. To study synchronization of wind electric generator.
12. Wind generation analysis using Matlab for variable wind speeds.
13. To evaluate efficiency of DFIG System (Hardware setup only).

Industrial Visit: Field visit to Renewable Energy Sources locations or Manufacturing Industry

Text Books:

- [T1] S.P. Sukhatme, "Solar Energy," Tata McGraw Hill
- [T2] Mukund R. Patel, "Wind and Power Solar System", CRC Press
- [T3] Chetan Singh Solanki, "Solar Photovoltaics-Fundamentals, Technologies and Applications", PHI Second Edition
- [T4] H. P. Garg, J. Prakash, "Solar Energy-Fundamentals and Applications", Tata McGraw hill Publishing Co.Ltd., First Revised Edition
- [T5] Tony Burton, Nick Jenkins, David Sharpe, "Wind Energy Hand Book-Second Edition", John Wiley & Sons, Ltd., Publication
- [T6] Godfrey Boyle, "Renewable Energy", Third edition, Oxford University Press
- [T7] S. Rao, Dr. B. B. Parulekar, "Energy Technology – Non Conventional, Renewable and Conventional", Khanna Publication

Reference Books:

- [R1] D. P. Kothari, K. C. Singal, Rakesh Rajan, "Renewable Energy Sources and Emerging Technologies", PHI Second Edition
- [R2] Donald L.Klass, "Biomass for Renewable Energy, Fuels, and Chemicals, Elsevier, Academic Press
- [R3] B T.Nijaguna, "Biogas Technology", New Age International Publishers
- [R4] Tapan Bhattacharya, "Terrestrial Solar Photovoltaics", Narosa Publishing House
- [R5] Thomas Ackermann, "Wind Power in Power Systems", Wiley Publications

Unit	Text Books	Reference Books
1	T1, T4	R4
2	T2, T3	R1
3	T5	R5
4	T7	R2,R3
5	T3,T6	R1
6	T6, T7	R1

Elective I: 403143 (D): Digital Signal Processing

Teaching Scheme	Credits	Examination Scheme [125 Marks]
Theory : 03 Hr/Week	03	In Sem : 30 Marks
Practical : 02 Hr/Week	01	End Sem : 70 Marks
		Term work : 25 Marks

Prerequisite:

Knowledge of basic signals and systems

Course Objective: The course aims:-

- To elaborate Sampling theorem
- To classify discrete signals and systems
- To analyze DT signals with Z transform, inverse Z transform and DTFT
- To describe Frequency response of LTI system
- To introduce Digital filters and analyze the response
- To demonstrate DSP Applications in electrical engineering

Course Outcome: Upon successful completion of this course, the students will be able to :-

1. Sample and reconstruct any analog signal
2. Construct frequency response of LTI system
3. Evaluate Fourier Transform of discrete signals
4. Design IIR filter and its implementation
5. Design FIR filter and implementation
6. Develop block diagram for DSP applications to electrical engineering

Unit 01 : Classification of Signals: (06 Hrs)

Analog, Discrete-time and Digital signals, Basic sequences and sequence operations, Discrete-time systems, Properties of D. T. Systems and Classification, Linear Time Invariant Systems, impulse response, linear convolution and its properties, properties of LTI systems: stability, causality, parallel and cascade connection, Linear constant coefficient difference equations, Periodic Sampling, Sampling Theorem, Frequency Domain representation of sampling, reconstruction of a band limited Signal, A to D conversion Process: Sampling, quantization and encoding.

Unit 02 : Z-transform, Inverse Z-transform and its properties: (06 Hrs)

Unilateral Z-transform, Z transform properties: Linearity, time shifting, multiplication by exponential sequence, differentiation, conjugation, time reversal, convolution, initial value theorem, Inverse z transform by inspection, partial fraction, power series expansion and complex inversion, solution of difference equation

Unit 03 : Discrete Time Fourier Transform (06 Hrs)

Representation of Sequences by Fourier Transform, Symmetry properties of D. T., F. T. theorems: Linearity, time shifting, frequency shifting, time reversal, differentiation, convolution theorem, Frequency response analysis of first and second order system, steady state and transient response

Unit 04 : Discrete Fourier Transform (06 Hrs)

Sampling theorem in frequency domain. The Discrete Fourier Transform, Relation with z transform Properties of DFT: Linearity, circular shift, duality, symmetry, Circular Convolution, Linear Convolution using DFT, Effective computation of DFT and FFT, DIT FFT, DIF FFT, Inverse DFT using FFT

Unit 05 : Frequency Response of LTI Systems: (06 Hrs)

Ideal frequency selective filters, Concept of filtering, specifications of filter, IIR filter design from continuous time filters: Characteristics of Butterworth, and Cheybyshhev low pass filter, impulse invariant and bilinear transformation techniques, Design examples, Basic structures for IIR Systems: direct form, cascade form

Unit 06 : FIR filter design using windows: (06 Hrs)

specifications of properties of commonly used windows, Design Examples using rectangular, and hanning windows. Basic Structures for FIR Systems: direct form. Comparison of IIR and FIR Filters Applications: Measurement of magnitude and phase of voltage, current, power, frequency and power factor correction, harmonic Analysis and measurement, applications to machine control, DSP based protective relaying.

Guidelines for Instructor's Manual

Instructor's Manual should contain following related to every experiment –

- Theory related to the experiment.
- Basic MATLAB instructions for DSP/ Simulink basics.
- Observation table/ Expected simulation results.
- Sample calculations for one/two reading.
- Result table

Guidelines for Student's Lab Journal

The Student's Lab Journal should contain following related to every experiment –

- Theory related to the experiment
- Circuit diagram/Simulink diagram/MATLAB program
- Simulation results
- Sample calculations for one/two reading
- Result table, Conclusion
- Few short questions related to the experiment

Guidelines for Laboratory conduction

- Assessment must be based on understanding of theory, attentiveness during practical session.
- Assessment should be done how efficiently student is able to perform experiment/simulation and get the results.
- Understanding fundamentals and objective of experiment, timely submission of journal.

List of Experiments: :

[Minimum eight experiments are to be performed]

Note: Perform the practical using C language or any other professional software for group A and B

GROUP-A (Any Three)

1. Plotting of discrete time waveforms (a) Sin, (b) Unit Step, (c) Exponential.
2. Find Linear convolution
3. Plot frequency response of given system function (Magnitude and Phase)
4. Verification of Z-transform properties (any two)

GROUP-B (Any Four)

1. Find DFT and IDFT of sequence
2. Find Circular convolution Using DFT IDFT method and linear convolution using Circular convolution.
- 3 DIT- FFT or DIF-FFT algorithm
4. Design of IIR filter (Butterworth method).
5. Design of FIR filter (window (any one) method).

Group-C (Any one)

1. Study of DSP starter kit and generation of Sine wave.
2. Discrete implementation of FIR Filter using PIC18F/DSP kit.
3. Discrete implementation of IIR Filter using PIC18F/DSP kit.
4. Harmonic analysis of any non-sinusoidal signal using DSP.

Text Books:

- [T1] Proakis J., Manolakis D., "Digital signal processing", 3rd Edition, Prentice Hall, ISBN 81- 203-0720-8
- [T2] P. Ramesh Babu, "Digital Signal Processing", 4th Edition Scitech Publication
- [T3] Dr.S. D. Apte,"Digital Signal Processing",2nd Edition Wiley India Pvt. Ltd ISBN: 978-81-265-2142-5
- [T4] W.Rebizant, J.Szafran, A.Wiszniewski, "Digital Signal Processing in Power system Protection and Control", Springer 2011 ISBN 978-0-85729-801-0

Reference Books:

- [R1] Mitra S., "Digital Signal Processing: A Computer Based Approach", Tata McGraw-Hill, 1998, ISBN 0-07-044705-5
- [R2] A.V. Oppenheim, R. W. Schafer, J. R. Buck, "Discrete Time Signal Processing", 2nd Edition Prentice Hall, ISBN 978-81-317-0492-9
- [R3] Steven W. Smith, "Digital Signal Processing: A Practical Guide for Engineers and Scientists", 1st Edition Elsevier, **ISBN:** 9780750674447

Unit	Text Books	Reference Books
1	T1,T2	R1,R2,R3
2	T1,T2	R2,R3
3	T1,T2	R2,R3
4	T1,T2	R2,R3
5	T1,T2,T3	R1,R2,R3
6	T4	R3

Elective II : 403144 (A) : Restructuring and Deregulation

Teaching Scheme	Credits	Examination Scheme [100Marks]
Theory : 03 Hr/Week	03	In Sem : 30 Marks
		End Sem : 70 Marks

Prerequisites: Knowledge in power system analysis and power system generation, transmission and distribution.

Course Objective: The course aims:-

- To educate students about the process and operation of restructuring of power system.
- To familiarize students about the various power system restructuring models.
- To elaborate students pricing of electricity.
- To explain fundamental concept of congestion, its management and transmission pricing.

Course Outcome: Upon successful completion of this course, the students will be able to: -

1. Enlist the functions of various key entities in India and explain the implications of various policies and acts on restructuring and deregulation.
2. Describe the regulatory process in India along with various methods of regulations.
3. List the components involved in tariff determination.
4. Explain different power sector restructuring models
5. Explain different types of electricity markets.
6. State different transmission pricing methods and discuss congestion management

Unit 01 : Power Sector Reforms in India (06 Hrs)

Need of Regulation. Institutional structure before reforms and after reforms. Roles of various key entities like Ministry of Power, CEA, Planning Commission, CERC and SERC in India. Electricity Act 2003 and 2010 and its implications for Restructuring and Deregulation. National Energy policy. Critical issues and challenges before the Indian power sector.

Unit 02 : Power Sector Regulation (06 Hrs)

Regulatory process in India, Principles of Tariff setting, Phases of Tariff determination, types and methods of Regulation, cost plus, performance-based regulation, price cap, revenue cap, rate of return regulation, benchmarking or yardstick regulation. Considerations of socio economic aspects in regulation.

Unit 03 : Power Sector Economics (06 Hrs)

Introduction to various concepts such as capital cost, debt and equity, depreciation, fixed and variable costs, working capital. Typical cost components of utilities such as return in equity, depreciation, interest and finance charges, O and M expenses etc. Key Indices for assessment of utility performances (Generation, transmission and distribution). Financial tools to compare investment options.

Unit 04 : Power Sector Restructuring Models and Introduction to energy Markets (06 Hrs)

Introduction, models based on energy trading or structural models – monopoly, single buyer, wholesale competition, retail competition. Models based on contractual arrangements – pool model, bilateral dispatch, pool and bilateral trades, multilateral trades. ISO models. Introduction to Energy Exchange, Day ahead market (DAM) and Term ahead market (TAM) procedure adopted in Energy exchanges and trading of Renewable Energy Credits and Carbon Credits.

Unit 05 : Electricity Markets**(06 Hrs)**

Rules that govern electricity markets, peculiarity of electricity as a commodity. Various electricity markets such as spot markets, forward contracts and forward markets, future contracts and future markets, day ahead market, reserve market, ancillary services market, market for differences, Options contracts. Market operation- settlement process, Market Clearing Price (MCP), Market efficiency, Market power.

Unit 06 : Transmission Pricing and Transmission Congestion issues (06 Hrs)

Cost components of transmission system, Cost allocation of Transmission system, Transmission pricing methods, physical transmission rights, Open Access, Role of Load Dispatch centers (SLDC, RLDC and NLDC). Congestion in power network, reasons for congestion, congestion management.

Text Books:

- [T1] Know Your Power: A citizen Primer on the electricity Sector, Prayas Energy Group, Pune
- [T2] Daniel S. Kirschen, Goran Strbac, "Power System Economics" John Wiley and Sons Publication Ltd. August 2006.
- [T3] Mohammad Shahidehpour, Muwaffaq Alomoush, "Restructured Electrical Power Systems: Operation Trading and Volatility" CRC Press, 06-Jun-2001

Reference Books:

- [R1] Steven Stoft, "Power System Economics: Designing Markets for Electricity", John Wiley and Sons, 2002
- [R2] Sally Hunt, "Making Competition Work in Electricity", 2002, John Wiley Inc
- [R3] Geoffrey Rothwell, Tomas Gomez, "Electricity Economics Regulation and Deregulation" A John Wiley and Sons Publication 2003
- [R4] Mohammad Shahidehpour, Hatim Yamin, Zuyi Li, "Market operations in Electric Power System" A John Wiley and Sons Publication.
- [R5] Deregulation in Power Industry – A course under continuing Education Program, Department of Electrical Engineering , IIT , Bombay

Websites:

- 1 <http://www.cercind.gov.in/Function.html>
- 2 www.cercind.gov.in/serc.html
- 3 <http://www.power.gov.ng/index.php/about-us/our-functions>
- 4 <http://www.cea.nic.in/functions.html>
- 5 <http://planningcommission.nic.in/reports/genrep/arep9920/ar9920role.htm>

Unit	Text Books	Reference Books
1	T1	Websites 1-5
2	T1	R3
3	T1	R1
4	T2	R5
5	T2	R5, R2, R4
6	T3	R1

Elective II : 403144 (B) : Electromagnetic Fields

Teaching Scheme	Credits	Examination Scheme [100 Marks]
Theory : 03 Hr/Week	03	In Sem : 30 Marks
		End Sem : 70 Marks

Prerequisite: Coordinate system, Vector algebra, Electric field intensity, Magnetic field intensity, Fundamental relations for electrostatic and magnetostatic fields

Course Objective: The course aims:-

- To impart knowledge on the basics of electric and magnetic fields and their applications for utilization in the development of the theory for power transmission lines and electrical machines.
- To describe how materials affect electric and magnetic fields
- To discuss the boundary conditions
- To analyze the relation between the fields under time varying situations
- To give insight to Maxwell's equations in different form and media

Course Outcome: Upon successful completion of this course, the students will be able to :-

1. Describe time varying Maxwell's equations and their applications in electromagnetic problems
2. Interpret electric and magnetic field with the help of associated laws
3. Solve simple electrostatic and magnetic boundary conditions
4. Determine the relationship between time varying electric and magnetic fields and electromotive force
5. Solve electromagnetic problems with the help of mathematical tools

Unit 01 : Introduction (06 Hrs)

Sources and effects of Electro-Magnetic Fields, Scalar and vector, Unit vector, Mathematical operations of Vector, Scalar and vector fields, Different Co-ordinate System, Operator Del, Physical interpretation of gradient, divergence and curl, Conversion between coordinate system, Expression for gradient, divergence and curl in three coordinate system.

Unit 02 : Basic Electrostatics (06 Hrs)

Coulomb's law, Electric field, Electric Field Intensity (EFI), EFI due to - point charge, line charge, surface charge and volume charge, Electric displacement, Electric flux density, Gauss's law (scalar and vector form), Applications of Gauss law, Electric field due to – point charge, infinite long straight conductor and infinite plane sheet of charge, Divergence theorem, Stoke's theorem.

Unit 03 : Applied Electrostatics (06 Hrs)

Electric Potential, Relationship between E and V, Equipotential surfaces, Electric dipole and flux lines, Electric field due to dipole, Energy density in electrostatic field, Energy stored in terms of D and E, Convection and Conduction currents, Current and current density, Continuity equation for current, Poisson's and Laplace's equations, Capacitor and its capacitance, Parallel plate capacitor, Capacitors with multiple dielectrics, Spherical capacitor, Coaxial capacitor.

Unit 04 : Magnetostatics and Applications**(06 Hrs)**

Magnetic flux density, Magnetic field intensity (MFI), Magnetic permeability, Biot-Savart's law, Applications of Biot-Savart's law, MFI due to - infinite long straight filament, finite length element, on the axis of circular loop, Ampere's Circuital law, Field due to – infinite line current, coaxial cable, uniform current sheet density, Magnetic flux density, Scalar magnetic potential, Vector magnetic potential, Poisson's Equations for Magnetostatic field, Derivations of Biot-Savart law and Ampere's law based on magnetic potential, Forces due to magnetic field, Magnetic dipole.

Unit 05 : Boundary Conditions and Analysis.**(06 Hrs)**

Conductors, Ohm's law employing mobility, Dielectrics, Polarization in Dielectrics, Dielectric constants and strength, Relaxation time, Boundary conditions : Dielectric-Dielectric boundary conditions, Conductor – Dielectric boundary conditions, Conductor – Free space boundary conditions, Boundary conditions for Magnetostatic fields

Unit 06 : Time Varying Fields and Maxwell's equations**(06 Hrs)**

Faraday's law, Transformer and motional EMFs – stationary loop in time varying B field, moving loop in static B field and moving loop in time varying field, Displacement current, Maxwell's equations in point form and integral form, Power and Poynting theorem, Time varying potentials, Time Harmonic Field, Maxwell's equations in point form and integral form for harmonic field, Concept of uniform plane wave.

Text Books:

- [T1] W. H. Hayt and J. A. Buck, "Engineering Electromagnetics", Tata McGraw Hill
[T2] Mathew Sadiku, "Elements of Electromagnetics", Oxford University Press

Reference Books:

- [R1] R. K. Shevgaonkar, "Electromagnetic Waves", Tata McGraw Hill
[R2] Liang Chi Shen, Jin Au Kong, Amalendu Patnaik, "Engineering Electromagnetics", CENGAGE Learning
[R3] K. B. Madhu Sahu, "Electromagnetic Fields", SciTech Publication
[R4] N. N. Rao, "Elements of Engineering Electromagnetics", Pearson Education
[R5] Edminister J. A., "Electromagnetics", Tata McGraw Hill

Unit	Text Books	Reference Books
1	T2	R2, R3, R4
2	T1, T2	R1, R2, R3
3	T1, T2	R2, R3, R4, R5
4	T1, T2	R2, R3
5	T2	R1, R4, R5
6	T1, T2	R2, R3, R4

Elective II : 403144 (C) : EHV AC Transmission

Teaching Scheme	Credits	Examination Scheme [100Marks]
Theory : 03 Hr/Week	03	In Sem : 30 Marks
		End Sem : 70 Marks

Prerequisite : Fundamental course in Power System

The course aims:-

- To explain the need of EHV and UHV systems.
- To describe the impact of such voltage levels on the environment
- To identify problems encountered with EHV and UHV transmissions
- To describe methods of governance on the line conductor design, line height and phase etc.

Course Outcome: Upon successful completion of this course, the students will be able to :-

1. Highlight need for EHV ac transmission.
2. Calculate line and ground parameters.
3. Enlist problems encountered in EHV transmission.
4. Describe effect of electric and magnetic field on human being
5. Express issues related to UHV transmission discussed

Unit 01 : EHV ac transmission lines (06 Hrs)

Need for EHV transmission lines, Power handling capacity and line loss, Mechanical considerations in line performance, Vibrations.

Travelling wave equations, transmission reflection attenuation and distortion of travelling waves, transmission and reflection coefficients and examples.

Unit 02 : Calculation of line and ground parameters (06 Hrs)

Resistance of conductors, effect of temperature on overhead conductors, temperature rise of conductors and current carrying capacity, Properties of bundled conductors, Inductance of current carrying single conductor, Inductance of EHV line configurations, Line capacitance calculations

Unit 03 : Voltage gradient of conductors (06 Hrs)

Electrostatic Field of a point charge and its properties, Field of sphere gap, Field of line charges and their properties, charge potential relations for multi-conductor lines, Maximum charge condition on three phase line.

Surface voltage gradient on conductors-single conductor, two conductors and multi-conductor bundle, Maximum surface voltage gradient, Mangoldt formula, design of cylindrical cage for corona gradients

Unit 04 : Electrostatic and magnetic fields of EHV lines (06 Hrs)

Electric shock and threshold currents, Effects of high electrostatic fields on humans, animals and plants, Calculation of electrostatic field of single circuit of three phase line, Profile of electrostatic field of line at ground level.

Electrostatic induction on un-energized circuit of a double circuit line. Insulated ground wire and induced voltage in insulated ground wires.

Magnetic field calculation of horizontal configuration of single circuit of three phase lines, Effects of power frequency magnetic fields on human health.

Unit 05 : Corona and its effects**(06 Hrs)**

Corona formation, corona inception voltage, visual corona voltage, critical field for corona inception and for visual corona under standard operating condition and conditions other than standard operating conditions.

Power loss due to corona, corona loss formulae, corona current waveform, charge-voltage diagram and corona loss. Audible noise operation and characteristics limits for audible noise, AN measurement and meters, microphone, weighting networks.

Unit 06 :**(06 Hrs)****A) Design of EHV line**

Design of EHV lines based upon steady state limits and transient over voltages, design factors under state. Design examples: steady state limits. Line insulation design based on transient over voltages

B) Extra high voltage cable transmission

Classification of cables, Electrical characteristics of EHV Cables, Properties of cable insulation materials.

Text Books:

[T1] Rakosh das Begamudre “Extra high voltage transmission”, New Age International publishers

Reference Books:

[R1] S. Rao , “EHV AC and DC Transmission” Khanna publication.

Unit	Text Books	Reference Books
1	T1	R1
2	T1	--
3	T1	--
4	T1	R1
5	T1	R1
6	T1	R1

Elective II : 403144 (D) : Electric and Hybrid Vehicles

Teaching Scheme	Credits	Examination Scheme [100 Marks]
Theory : 03 Hr/Week	03	In Sem : 30 Marks
		End Sem : 70 Marks

Prerequisite: Basic concept of Batteries, Electrical motors, Power electronic conversion

Course Objective: The course aims:-

- To make students aware the need and importance of Electric, Hybrid Electric Vehicles and Fuel cell vehicle.
- To differentiate and analyze the various energy storage devices and battery charging and management systems.
- To impart knowledge about architecture and performance of Electric and Hybrid Vehicles
- To classify the different drives and controls used in electric vehicles.

Course Outcome: Upon successful completion of this course, the students will be able to:-

1. Review history, Social and environmental importance of Hybrid and Electric vehicles.
2. Describe the performance and selection of energy storage systems and Analyze battery management system.
3. Distinguish between the performance and architecture of various drive trains.
4. Describe the different Instrumentation and Control used for electric vehicles.
5. Differentiate between Vehicle to Home, Vehicle to Vehicle and Vehicle to Grid energy systems concepts.

Unit 01 : Introduction (05 Hrs)

Conventional Vehicle: Basic of Vehicle performance, vehicle power source characterization, transmission characterization. Need and importance of transportation development.

History of Electric Vehicle, Hybrid Electric Vehicle and Fuel cell Vehicle. Social and environmental importance of Hybrid and Electric vehicles. Impact of modern drive-trains on energy supplies.

Unit 02 : Energy Storage Systems (07 Hrs)

Introduction to energy storage requirements in Hybrid and Electric vehicles, battery-based energy storage and its analysis, Fuel cell based energy storage and its analysis, Ultra capacitor based energy storage and its analysis, flywheel based energy storage and its analysis.

Hybridization of energy sources for Hybrid and Electric vehicle: - Hybridization of drive trains in HEVs, Hybridization of energy storage in EVs.

Selection of energy storage technology.

Unit 03 : Battery charging and Management systems (06 Hrs)

Introduction, charging algorithm, balancing method for battery pack charging.

Battery management system representation: - battery module, measurement unit block, battery equalization balancing unit, MCU estimation unit, display unit, fault warning block.

SoC and SoH, estimation of SoC, battery balancing, Thermal monitoring of Battery unit.

Unit 04 : Hybrid and Electric vehicles (05 Hrs)

Electric vehicles: - Components, configuration, performance, tractive efforts in normal driving, Advantages and challenges in EV design.

Hybrid Electric vehicles: - Concept and architecture of HEV drive train (Series, parallel and series-parallel).Energy consumption of EV and HEV

Unit 05 : Drives and control systems (07 Hrs)

Drives: - Application of BLDC drives and Switched reluctance motor drive for HEV and EV, performance characteristics of drives.

Instrumentation and control system related to Hybrid and Electric vehicles, speed control, acceleration characteristics, Electric steering, motion control, braking mechanism, Vehicle tracking through GPS, over speed indicating systems, Auto-parking systems

Unit 06 : Vehicle to Home, Vehicle to Vehicle and Vehicle to Grid energy systems (06 Hrs)

Vehicle to Home(V2H): PHEV control Strategies to V2H applications, V2H with demand response.

Vehicle to Vehicle(V2V): - Concept and structure of EV aggregator, control method for EV aggregator for dispatching a fleet of EV.

Vehicle to Grid(V2G): - planning of V2G infrastructure in the smart grid, ancillary services provided by V2G, cost emission optimization.

Text Books:

- [T1] James Larminie and John Lowry, "Electrical Vehicle", John Wiley and Sons, 2012.
- [T2] Ronald K. Jurgen, "Electric and Hybrid-Electric Vehicles", SAE International Publisher.
- [T3] K T Chau, "Energy Systems for Electric and Hybrid Vehicles", The institution of Engineering and Technology Publication
- [T4] D.A.J Rand, R Woods, R M Dell, "Batteries for Electric Vehicles", Research studies press Ltd, New York, John Willey and Sons
- [T5] Electric and Hybrid Vehicles-Design Fundamentals, CRC press
- [T6] Mark Warner, The Electric Vehicle Conversion handbook –HP Books, 2011.

Reference Books:

- [R1] Mehrdad Ehsani, Yimin Gao and Ali Emadi, "Modern Electrical Hybrid Electric and Fuel Cell Vehicles: Fundamental, Theory and design", CRC Press, 2009.
- [R2] Junwei Lu, Jahangir Hossain, "Vehicle-to-Grid: Linking Electric Vehicles to the Smart Grid", IET Digital Library.
- [R3] "Automobile Electrical and Electronic systems", Tom Denton, SAE International publications.
- [R4] "Automotive handbook 5th edition", Robert Bosch, SAE international publication.

Unit	Text Books	Reference Books
1	T1,T2,T3, T4, T5	R1
2	T1,T2,T3, T4, T5	R1, R3
3	T2,T3,T4	R1
4	T1,T2,T5	R1
5	T1,T2,T5	R1
6	T3	R2

Elective II : 403144 (E) : Special Purpose Machines

Teaching Scheme	Credits	Examination Scheme [100 Marks]
Theory : 03Hr/Week	03	In Sem : 30 Marks
		End Sem : 70 Marks

Prerequisite:

- Basic concepts of different electric motors
- Laws related to energy conversion in electrical machines
- Knowhow of D-Q axis theory related to electrical machines

Course Objective: The course aims:-

1. To explain operation and performance of synchronous reluctance motors.
2. To describe operation and performance of stepping motors.
3. To elaborate operation and performance of switched reluctance motors.
4. To familiarize with operation and performance of permanent magnet brushless D.C. motors.
5. To illustrate operation and performance of permanent magnet synchronous motors.

Course Outcome: Upon successful completion of this course, the students will be able to :-

1. Reproduce fundamentals of magnetic circuits
2. Reproduce principal of operation of PMSM, Stepper motor, SRM, Switch reluctance and linear motors.
3. Derive basic transformations used in machine modeling and control
4. Develop torque speed and performance characteristics of above motors
5. Enlist application of above motors
6. Demonstrate various control strategies.

Unit 01 : Generalised Machine Theory (06 Hrs)

Energy in singly excited magnetic field systems, determination of magnetic force and torque from energy. Determination of magnetic force and torque from co-energy, Forces and torques in systems with permanent magnets. MMF of distributed winding, Magnetic fields production of EMFs in rotating machines.

Unit 02 : Permanent Magnet Synchronous and brushless D.C. Motor Drives (06 Hrs)

Synchronous machines with PMs, machine configurations. Types of PM synchronous machines Sinusoidal and Trapezoidal. EMF and torque equations Torque speed characteristics Concept of electronic commutation, Comparative analysis of sinusoidal and trapezoidal motor operations. Applications

Unit 03 : Control of PMSM Machine (06 Hrs)

abc- $\alpha\beta$ and $\alpha\beta$ -dq transformations, significance in machine modelling, Mathematical Model of PMSM (Sinusoidal), Basics of Field Oriented Control (FOC), Control Strategies: constant torque angle, unity power factor.

Unit 04 : Reluctance Motor (06 Hrs)

Principle of operation and construction of Switch Reluctance motor, Selection of poles and pole arcs, Static and dynamics Torque production, Power flow, effects of saturation, Performance, Torque speed characteristics, Synchronous Reluctance, Constructional features; axial and radial air gap motors; operating principle; reluctance torque; phasor diagram; motor characteristics Introduction to control of Reluctance Drive. Applications.

Unit 05 : Stepper Motor**(06 Hrs)**

Construction and operation of stepper motor, hybrid, Variable Reluctance and Permanent magnet, characteristics of stepper motor; Static and dynamics characteristics, theory of torque production, figures of merit; Concepts of lead angles , micro stepping , Applications selection of motor.

Unit 06 : Linear Electrical Machines**(06 Hrs)**

Introduction to linear electric machines. Types of linear induction motors, Constructional details of linear induction motor, Operation of linear induction motor. Performance specifications and characteristics Applications.

Text Books:

- [T1] K. Venkatratnam, 'Special Electrical Machines', University Press
- [T2] A.E. Fitzgerald Charles Kingsley, Stephen Umans, 'Electric Machinery', Tata McGraw Hill Publication
- [T3] T.J.E. Miller, 'Brushless Permanent magnet and Reluctance Motor Drives' Clarendon Press, Oxford 1989.
- [T4] V. V. Athani, 'Stepper Motors: Fundamentals, Applications and Design', New age International, 1997

Reference Books:

- [R1] R Krishnan, 'Permanent Magnet Synchronous and Brushless D.C. Motor Drives' CRC Press.
- [R2] Ion Boldea, 'Linear Electric Machines, Drives and maglevs' CRC press
- [R3] Ion Boldea S. Nasar, 'Linear Electrical Actuators and Generators', Cambridge University Press.

Unit	Text Books	Reference Books
1	T2	--
2	T1,T3	R1
3	T1	--
4	T1	--
5	T1,T4	--
6	--	R2, R3

403145: Control System II

Teaching Scheme	Credits	Examination Scheme [150 Marks]
Theory : 03 Hr/Week	03	In Sem : 30 Marks
Practical : 02 Hr/Week	01	End Sem : 70 Marks
		Oral : 25 Marks
		Term work : 25 Marks

Prerequisite: Basic concepts of Control System, Transfer Function, Pole zero plot.

Course Objective: The course aims to:-

- Explain the basic digital control system and the concept of sampling and reconstruction.
- Elaborate the concept of state and to be able to represent a system in the state space format.
- Solve the state equation and familiarize with STM and its properties.
- Design a control system using state space techniques including state feedback control and full order observer.

Course Outcome: Upon successful completion of this course, the students will be able to :-

1. Recognize the importance of digital control system.
2. Derive pulse transfer function.
3. Analyze digital controllers.
4. Convert system in state space format.
5. Solve state equation.
6. Design observer for system.

Unit 01 : Digital Control System (06 Hrs)

Introduction, Configuration of the basic digital control system. Advantages and limitations of digital control; data conversion and quantization, Sampling and Reconstruction processes, Shannon's Sampling theorem, practical aspects of choice of sampling rate. Zero order hold (ZOH) and its transfer function, Basic concepts and transfer function of first order hold.

Unit 02 : Z-transform and Pulse-transfer-function (06 Hrs)

Review of z-transform, Inverse z-transform, difference equations and solution using z transform method. Pulse transfer function and Z-transfer function, General procedure for obtaining Pulse-transfer-function, pulse transfer function of ZOH.

Unit 03 : Stability Analysis (06 Hrs)

Sampled data closed loop systems, characteristic equation, causality and physical realizability of discrete data system, realization of digital controller by digital programming, direct digital programming, cascade digital programming, parallel digital programming. Mapping between S-plane and Z-plane, stability analysis of closed loop system in z-plane using Jury's test, Bilinear Transformation.

Unit 04 : Introduction to state space analysis (06 Hrs)

Important definitions – state, state variable, state vector, state space, state equation, output equation. State space representation for electrical and mechanical system, n^{th} order differential equation and transfer function. Conversion of transfer function to state model and vice versa. State model of armature control DC motor

Unit 05 : Solution of state equations (06 Hrs)

Concept of diagonalization, eigen values, eigenvectors, diagonalization of system matrices with distinct and repeated eigen values, Vandermonde matrix.

Solution of homogeneous and non-homogeneous state equation in standard form, state transition matrix, its properties, Evaluation of STM using Laplace transform method and infinite series method Cayley Hamilton theorem.

Unit 06 : Design of Control System Using State Space Technique: (06 Hrs)

Concept of controllability and observability, controllability and observability Tests, condition for controllability and observability from the system matrices in Canonical form, Jordan canonical form, effect of pole zero cancellation on the controllability and observability of the system, duality property. Pole placement design by state variable feedback. Necessity of an observer, design of full order observer.

Guidelines for Instructor's Manual

Instructor's Manual should contain following related to every experiment –

- Theory related to the experiment.
- Connection diagram /circuit diagram.
- Basic MATLAB instructions for control system/ Simulink basics.
- Observation table/ Expected simulation results.
- Sample calculations for one/two reading.
- Result table.

Guidelines for Student's Lab Journal

The Student's Lab Journal should contain following related to every experiment –

- Theory related to the experiment.
- Circuit diagram/Simulink diagram/MATLAB program.
- Observation table/ simulation results.
- Sample calculations for one/two reading.
- Result table, Conclusion.
- Few short questions related to the experiment.

Guidelines for Laboratory Conduction

- Assessment must be based on understanding of theory, attentiveness during practical session.
- Assessment should be done how efficiently student is able to perform experiment/simulation and get the results.
- Understanding fundamentals and objective of experiment, timely submission of journal.

List of Experiments

Any 8 experiments out of the list given below:

1. Plotting of discrete time wave forms a) sin, b) Unit step c) Exponential
2. Effect of sampling and verification of sampling theorem
3. Software programming for determination of STM of Discrete Time system.
4. Design and analysis of digital position control system.
5. Software programming for determination of state space representation for given transfer function and vice versa.
6. Check for observability and controllability in MATLAB
7. Verify State Feedback control using pole placement.
8. Convert a continuous time system to digital control system and check response using software.
9. Design state observer and validate it by software.
10. Software programming for determination of STM.

Text Books:

- [T1] K. Ogata, “Discrete Time Control System”, 2nd Edition, PHI Learning Pvt. Ltd. 2009
[T2] Benjamin C. Kuo “Digital Control System”, Prentice Hall of India Pvt. Ltd.
[T3] J. Nagrath, M. Gopal “Control System Engineering”, 5th Edition. New Age International Publishers
[T4] R.Anandanatarajan and P.Ramesh Babu “Control System Engineering”, 4th Edition, SCITECH Publications, India Pvt. Ltd.

Reference Books:

- [R1] K. Ogata, “Modern Control Engineering”, Prentice Hall of India Pvt. Ltd.
[R2] M. Gopal, “Digital Control and State Variable Methods”, Tata McGraw-Hill.
[R3] M. N. Bandyopadhyay, “Control Engineering – Theory and Practice”, Prentice Hall of India Ltd. Delhi.

Unit	Text Books	Reference Books
1	T1,T2	R1,R2
2	T1,T2	R2,R3
3	T1,T2	R2
4	T3, T4	R1, R3
5	T3, T4	R1, R3
6	T3, T4	R1, R3

403146 : Project I

Teaching Scheme

Tutorial : 02 Hr/Week

Credits

02

Examination Scheme [50 Marks]

Oral : 50 Marks

The student shall take up a project in the field closely related to Electrical Engineering. Preferably, group of 3/4 students should be formed for project work.

The project work should be based on the knowledge acquired by the student during the graduation and preferably it should meet and contribute towards the needs of the society. The project aims to provide an opportunity of designing and building complete system or subsystems based on area where the student likes to acquire specialized skills.

Project work in this semester is an integral part of the complete project. In this, the student shall complete the partial work of the project which will consists of problem statement, literature review, project overview and scheme of implementation. As a part of the progress report of project work, the candidate shall deliver a presentation on the advancement in Technology pertaining to the selected project topic.

Guidelines for VIIth Semester for Project work:

1. To identify the problems in industry and society.
2. Perform Literature survey on the specific chosen topic through research papers, Journals, books etc. and market survey if required.
3. To narrow down the area taking into consideration his/her strength and interest. The nature of project can be analytical, simulation, experimentation, design and validation.
4. Define problem, objectives, scope and its outcomes.
5. Design scheme of implementation of project.
6. Data collection, simulation, design, hardware if any, needs to be completed.
7. Presentation based on partially completed work.
8. Submission of report based on the work carried out.
9. Student should maintain Project Work Book.

Audit Course V (A) : 403152: Hydro Energy Systems

Teaching Scheme

Theory : 02 Hr/Week
Field visit : 1 Day

Examination Schemes: Audit (P/F)

Written / MCQ / Term paper

Course Objectives:

- To elaborate various hydro electric generators
- To be familiar with basic operation and various elements of hydro electric systems

Course Outcomes:

On completion of the course, students will be able to:-

- Explain and differentiate various types of hydro electric generators; pico, micro and small hydro

Description:

The following topics may be broadly covered in the classroom. The course will introduce the basics of: hydro energy, availability, introduction to hydraulic machines, turbines, basics of design of hydro electric generators, pico, micro and small hydro, grid interaction, advantages and limitations of the technology, environmental impact, and introduction to manufacturing of the systems, characterization, quality assurance, standards, certification and economics. The site visit will be organized to understand the basic operation and system elements.

Details:

- Energy in water
- Basic hydro energy conversion
- Types of turbines and their applications
- Decentralized hydroelectric plants
- Pico, Micro, small and large hydroelectric power plants
- Energy conversion calculations
- Hydro turbine basics and design
- Generator designs for hydro power
- Controllers for hydroelectric power
- Site requirements for hydro power
- Grid integration of micro-hydro
- Operation and maintenance of hydro power plants
- Financial modeling of hydro power
- Software tools for simulation, validation and economics of hydro power
- Environmental impact of various capacity hydroelectric plants
- Manufacturing and assembly
- Quality assurance and standards
- Standards and certification for hydroelectric power plants

Field Trip:

- Visit to Pico, Micro or Small hydroelectric plant

Audit Course V (B) : 403152

Foreign language- German

Teaching Scheme

Theory : 02 Hr/Week

Examination Schemes: Audit (P/F)

Written / MCQ / Term paper

Course Objectives:

- To meet the needs of ever growing industry with respect to language support
- To get introduced to German society and culture through language

Course Outcomes:

On completion of the course, students will be able to:-

- Comprehend everyday expressions and very simple sentences
- Read, write, listen and grasp German Language
- Develop interest to pursue professional German language

Description:

On a professional level, speaking and understanding another language opens many career opportunities. Knowing more than one language enhances employment opportunities in business, teaching, technology, communications, social service, etc.

In an increasingly globalized world, knowledge of German gives students access to the language, culture, and marketplace of few leading nations.

Speaking German gives significant advantages in the world of business since many companies nowadays would choose a competent German speaker over an equally qualified candidate for a job. A proficiency in German prepares you to function productively on behalf of a multinational employer who wants to capitalize on business.

Course Contents:

- Introduction to alphabets, numbers, months, days of the week and time of the day
- Pronouns, Modal and normal verbs, W/V questions
- Bestimmt, Unbestimmt Artikel, Akkusative and Akkusative prepositions
- Hobbies and Freizeit activities, Perfekt tense, basic adjectives and conjunctions.

References:

- Netzwerk Deutsch als Fremdsprache A1, Langenscheidt, First Indian Edition 2015
- www.dw.de

403147: Switchgear and Protection

Teaching Scheme	Credits	Examination Scheme [175Marks]
Theory : 3 Hrs./Week	03	In Sem : 30 Marks
Practical : 2 Hrs./Week	01	End Sem : 70 Marks
		Oral : 25 Marks
		Term work : 50 Marks

Prerequisite:

- Different type of faults in power system
- Various switchgears and their use in substation
- Principle and working of rotating machines and transformer with vector groups

Course Objective: The course aims to:-

1. Acquaint about construction and working principle of different types of HVCBs
2. Elaborate the Need of protective Relaying and operating principles of different types of relays.
3. Explain different type of faults in transformer, alternator and 3 phase Induction motor and various protective schemes related to them.
4. Impart knowledge about transmission line protection schemes and characteristics of different types of distance relays

Course Outcome: Upon successful completion of this course, the students will be able to :-

1. Describe arc interruption methods in circuit breaker.
2. Derive expression for restriking voltage and RRRV in circuit breaker
3. Explain construction and working of different high voltage circuit breakers such as ABCB, SF₆ CB, and VCB.
4. Classify and Describe different type of relays such as over current relay, Reverse power relay, directional over current relay, Differential relay, Distance relay, Static relay and numerical relay
5. Describe various protection schemes used for transformer, alternator and busbar
6. Describe transmission line protection schemes.

Unit 01 : Fundamentals of protective relaying (08 Hrs)

Need for protective system, nature and causes of fault, types of faults, effects of faults, evolution of protective relaying, classification of relays, zones of protection, primary and backup protection, essential qualities of protective relaying. Trip circuit of circuit breaker, zone of protection. Various basic operating principles of protection- over current, (current graded and time graded), directional over current, differential, distance, induction type relay, torque equation in induction type relay, current and time setting in induction relay, Numericals on TSM , PSM and operating time of relay

Unit 02 : Fundamentals of arc interruption (06 Hrs)

Ionization of gases, deionization, Electric arc formation , Current interruption in AC circuit breaker, high and low resistance principles, arc interruption theories, arc voltage, recovery voltage, derivation and definition of restriking voltage and RRRV, current chopping, interruption of capacitive current, resistance switching, Numerical on RRRV, current chopping and resistance switching.

Unit 03 : Circuit Breaker (05 Hrs)

Different ratings of circuit breaker (like rated voltage, rated current, rated frequency, rated breaking capacity – symmetrical and unsymmetrical breaking, making capacity, rated interrupting duties, rated operating sequence, short time rating). Classification of high voltage circuit breaker. Working and constructional features of ACB, SF₆ VCB- advantages, disadvantages and applications. Auto reclosing.

Unit 04 : (05 Hrs)

A) Static and Digital Relaying

Overview of Static relay, block diagram, operating principal, merits and demerits of static relay. Numerical Relays :-Introduction and block diagram of numerical relay, Sampling theorem, Anti –Aliasing Filter, Block diagram of PMU

B) 3 Phase Induction Motor Protection

Abnormal conditions and causes of failures in 3 phase Induction motor, single phasing protection, Overload protection, Short circuit protection.

Unit 05 : (06 Hrs)

A) Transformer Protection

Types of faults in transformer, Percentage differential protection in transformers, Restricted E/F protection, incipient faults, Buchholz relay, protection against over fluxing, protection against inrush current,

B) Alternator Protection

Various faults in Alternator, abnormal operating conditions- stator faults, longitudinal percentage differential scheme and transverse percentage differential scheme. Rotor faults- abnormal operating conditions, inter turn fault, unbalance loading, over speeding, loss of excitation, protection against loss of excitation using offset Mho relay, loss of prime mover.

Unit 06 : Transmission line protection (06 Hrs)

Over current protection for feeder using directional and non directional over current relays, Introduction to distance protection, impedance relay, reactance relay, mho relay and Quadrilateral Relays, Introduction to PLCC, block diagram, advantages, disadvantages, three stepped distance protection, Effect of arc resistance, and power swing on performance of distance relay. Realization of distance relays(impedance, reactance, and mho relay) using numerical relaying algorithm(flowchart, block diagram), Introduction to Wide Area Measurement (WAM) system.

Guidelines for Instructor's Manual

Prepare 3/4 sets of standard experiments. It must contain title of the experiment, Aim, Apparatus

- **Theory:** Brief theory explaining the experiment
- **Circuit / connection diagram** or construction diagram must be drawn either manually using geometrical instruments or using software on A-4 size quality graph paper / plain white paper.
- **Procedure:** Write down step by step procedure to perform the experiment.
- **Specifications of Switchgear:**
- **Observation table:**
- **Graph:**
- **Detailed constructional diagram with nomenclature:**
- **Conclusion:**

Guidelines for Student's Lab Journal

- Students should write the journal in his own hand writing using A4 size both side ruled paper.
- Circuit / Connection diagram or construction diagram must be drawn either manually or using software. [Do not use Photo copy of standard journal] on A4 size blank/graph paper.
- Hand writing must be neat and clean.
- Journal must contain certificate indicating name of the institute, student, department, subject, class/ year, number of experiments completed, signature of staff, Head of the department and the Principal.
- Index must contain sr. number, title of the experiment, page number, and the signature of staff along with date.
- (Use black or blue ink pen for writing.)

Guidelines for Laboratory conduction

- Check whether the MCB / main switch is off.
- Make connections as per circuit diagram. Do not keep loose connection. Get it checked from teacher / Lab Assistant.
- Perform the experiment only in presence of teacher or Lab Assistant.
- After completion of experiment, switch off the MCB / main switch.
- Write the experiment in the journal and get it checked within a week

List of Experiments :

A) Compulsory Experiments

1. Study of switchgear testing kit.
2. Study of bus-bar protection schemes.

B) Minimum 6 Experiments to be performed from the following list:

1. Study of Fuse, MCB and MCCB
2. Testing of MCB and MCCB.
3. Study and testing of contactors.
4. Study and testing of ACB.
5. Study and testing of thermal overload relay for Induction Motor protection.
6. Study and plot Characteristics of IDMT type Induction over current relay
7. Study and plot Characteristics of digital over current relay
8. Percentage differential protection of transformer.
9. Protection of alternator.
10. Protection of Transmission line using Impedance relay
11. Study of various LT switchgears like RCCB, timers.

Industrial Visit:

A compulsory industrial visit to switchgear training centre /or switchgear/relay manufacturing unit/ or 220 kV substation visit and report to be submitted as a part of term-work.

Assignments:

Minimum 3 assignments (at least 4 to 6 questions in each) to be submitted as a part of term-work.

Text Books:

- [T1] S. Rao, “Switchgear Protection and Power Systems”, Khanna Publications
- [T2] Y. G. Paithankar, S. R. Bhide, “Fundamentals of Power System Protection”, Prentice Hall of India
- [T3] Bhavesh Bhalja, R.P. Maheshwari, N.G. Chothani, “Protection and Switchgear”, Oxford University Press, 2011 Edition.
- [T4] J.B. Gupta “Switchgear and Protection”, S.K. Kataria and Sons.

Reference Books:

- [R1] Badri Ram, D. N. Vishwakarma, “Power System Protection and Switchgear”, Tata McGraw Hill Publishing Co. Ltd.
- [R2] J Lewis Blackburn, “Protective Relaying- Principles and Applications”, Dekker Publications.
- [R3] Prof. Dr S.A. Soman, IIT Mumbai, A Web course on “Digital Protection of power System”
http://www.cdeep.iitb.ac.in/nptel/Electrical%20Engineering/Power%20System%20Protection/Course_home_L27.html
- [R4] A.G. Phadke, J.S. Thorp, Computer relaying for Power System, Research Studies Press LTD, England. (John Wiley and Sons Inc New York)
- [R5] Mason C.R., “Art and Science of Protective Relaying”, Wiley Eastern Limited.
- [R6] Arun Ingole, “Switchgear and Protection”, Pearson.

Unit	Text Books	Reference Books
1	T1, T2, T4	R1, R2, R6
2	T1, T3, T4	R1, R6
3	T1, T4	R1
4	T2, T3, T4	R3, R4, R6
5	T1	R5
6	T1, T4	R2, R5

403148: Power Electronic Controlled Drives

Teaching Scheme	Credits	Examination Scheme [175 Marks]
Theory : 4 Hrs./Week	04	In Sem : 30 Marks
Practical : 2 Hrs./Week	01	End Sem : 70 Marks
		PR : 50 Marks
		Term work : 25 Marks

Prerequisite:

1. Construction, working and characteristic of different electrical motors and soft starting methods.
2. Power Electronic Applications such as converter, inverter, chopper etc.
3. Basic concept of control system

Course Objective: The course aims to

- To understand motor load dynamics.
- To analyze the operation of the converter fed and chopper fed dc drives.
- To elaborate braking methods of D.C. and Induction motor drive.
- To explain vector control of induction motor.
- To differentiate synchronous and BLDC motor drive.
- To identify classes and duty of motor.
- To describe the modes of operation of drive in various applications.

Course Outcome: Upon successful completion of this course, the students will be able to

1. Explain motor load dynamics and multi quadrant operation of drives
2. Analyze operation of converter fed and chopper fed DC drives.
3. Describe braking methods of D.C. and induction motor drive.
4. Explain vector control for induction motor drives
5. Describe synchronous motor drive.
6. Identify classes and duty cycles of motor and applications of drives in industries.

Unit 01 : Electrical Drives

(08 Hrs)

A. Definition, Advantages of electrical drives, Components of Electric drive system, Types of Electrical Drives (DC and AC).

B. Motor-Load Dynamics, Speed Torque conventions and multi quadrant operation, Equivalent values of drive parameters. Load Torque Components, Nature and classification of Load. Constant Power operation of a Drive. Steady state stability, Numerical based on motor load dynamics.

Unit 02 : DC Motor Drives

(08 Hrs)

A. Braking methods: Rheostatic, Plugging, and Regenerative. Closed loop control of drives: current limit control, torque control and speed control.

B. Single phase and three phase fully controlled converter drives and performance of converter fed separately excited DC Motor for speed control operations.

Chopper controlled drives for separately excited and series DC Motor operations.

Numerical based on above. Closed loop speed control of DC motor below and above base speed.

Unit 03 : Induction motor Drives I (08 Hrs)

Braking methods: DC Dynamic Braking, AC Rheostatic braking, Plugging, Regenerative Braking, V/f control and comparison with stator voltage control, voltage source inverter (VSI) control, Steady State Analysis. Current source inverter (CSI) control-open and closed loop, Regenerative braking and multi-quadrant operation of Induction motor drives, relative merits and demerits of VSI and CSI for induction motor drives, Numerical on VSI and CSI fed I.M. drives

Unit 04 : Induction Motor Drives II (08 Hrs)

- A. Principle of vector control, Block diagram of Vector control of induction motor. Servo mechanism in drives and block diagram for position control (Descriptive treatment only).
- B. Thermal model of motor for heating and cooling, classes of motor duty, types of enclosures for motor.

Unit 05 : Synchronous motor Drives (08 Hrs)

Types of motor, cylindrical rotor wound field motor, equivalent circuit, speed torque characteristics and effect of power factor, salient pole wound field motor, phasor diagram, simple numerical based on above, closed loop speed control of self-controlled synchronous motor drives fed from VSI and CSI.

BLDC drives, block diagram and speed torque characteristics.

Unit 06 : Industrial application (08 Hrs)

A. Specific requirement and choice of drives for following applications.

1. Machine tools
2. Textile mills
3. Steel rolling mills
3. Sugar mills
4. Traction drives
5. Crane and hoist drives
6. Solar and battery powered drives

Guidelines for Instructor's Manual

- Title and circuit diagram of power electronic controlled drives/ electrical machine circuit.
- Working operation and output characteristics / output waveforms of power electronic switching device /converter circuit used to control the electric motor.
- Procedure to carry out the experiment

Guidelines for Student's Lab Journal

- Title, aim, circuit diagram, procedure and theory of power electronic switching device or converter circuit and expected machine performance with speed torque characteristics.
- Equipments along with the specifications needed to carry out the experiment.
- Circuit diagram, observation table, calculations must be written on left side of the journal and aim, theory related to experiment and procedure must be written on right side.
- Analyse and interpret the experimental results and write the conclusions appropriately.

Guidelines for Laboratory conduction

- Each group in the lab should have not more than three students.
- All the students in the group must do the connections and perform the practical under the guidance of the staff member.
- Staff member has to check the result of all the groups.

List of Experiments: Minimum eight experiments are to be performed out of the list mentioned as below:

GROUP A: Any FIVE Experiment (Hardware)

1. Study of Electrical braking of D.C. Shunt motor (Rheostatic, Plugging).
2. Study speed control characteristics of single phase fully converter fed separately excited D.C. motor
3. Study speed control characteristics of 3-ph fully converter fed separately excited D.C. motor
4. Study of Chopper fed D.C. series/separately motor speed control characteristics.
5. Study of electrical braking of 3 phases Induction Motor (DC Dynamic Braking, Plugging).
6. Study of VSI fed 3 phase Induction motor (using V/f control PWM inverter) speed control characteristics.
7. Study of Solid state stator voltage control of 3 phase Induction motor (Using AC voltage Regulator).
8. Study of constant torque and constant power characteristic of induction motor.

GROUP B: Any THREE Experiment (Software)

1. Simulation of starting characteristics of D.C. motor.
2. Simulation of starting characteristics of 3 phase Induction motor.
3. Study of Closed loop speed control of separately excited D.C. motor/ Induction Motor.
4. Simulation of an electric drive system for steady state and transient analysis.
5. Simulation of closed loop control of synchronous motor
6. Simulation of chopper controlled DC series motor.

Industrial Visit:

Minimum one industrial visit must be organized for drives application in industry such as railways, sugar mill, machine shop, textile mill, paper mill etc.

Text Books:

- [T1] G. K. Dubey, "Fundamentals of Electric Drives", 2nd Edition, Narosa Publishing House
- [T2] N. K. De, P. K. Sen, "Electric Drives", Prentice Hall of India Eastern Economy Edition
- [T3] S. K. Pillai, "Analysis of Thyristor Power Conditioned Motors", University Press
- [T4] R. Krishnan, "Electric Motor Drives – Modeling Analysis and Control", PHI India
- [T5] G.K. Dubey, "Power Semiconductor controlled drives", PHI publication

Reference Books:

- [R1] B. K. Bose, "Modern Power Electronics and AC Drives", Pearson Education
- [R2] Malcolm Barnes, "Practical Variable Speed Drives and Power Electronics", Elsevier Newnes Publications
- [R3] V. Subrahmanyam, "Electric Drives: Concepts and Application", Tata Mc-Graw Hill (An imprint of Elsevier)
- [R4] M.D. Singh and Khanchandani "Power Electronics", Tata Mc-Graw Hill
- [R5] Austin Huges, "Electrical motor and drives: Fundamental, types and applications", Heinemann Newnes, London
- [R6] Tyagi MATLAB for engineers oxford (Indian Edition)

Unit	Text Books	Reference Books
1	T1	R3
2	T1,T5	R2,R4
3	T1,T4	R1,R5
4	T1,T2,T5	R1,R2
5	T1,T3,T5	R1,R6
6	T1,T2	R3,R5

Elective –III : 403149 (A): High Voltage Engineering

Teaching Scheme	Credits	Examination Scheme [150 Marks]
Theory : 03 Hrs./Week	03	In Sem : 30 Marks
Practical : 02 Hrs./Week	01	End Sem : 70 Marks
		Oral : 25 Marks
		Term work : 25 Marks

Prerequisite: Atomic and molecular structure of gaseous and solid materials, basic properties of conductors and insulators, knowledge of material science.

Course Objective: The course aims to:-

- To enable students to know and compare the various processes of breakdown in solid, liquid and gaseous dielectric materials
- To enable students understand and apply various methods of generation and measurement of DC, AC, impulse voltage and current.
- To enable students to know the charge formation and separation phenomenon in clouds, causes of overvoltage and lightening phenomenon
- To develop ability among learners to execute testing on various high voltage equipments as per standards
- To introduce students to the design, layout, safety precautions, earthing, and shielding of HV laboratory.

Course Outcome: Upon successful completion of this course, the students will be able to

1. Identify, describe and analyze the breakdown theories of solid, liquid and gaseous materials
2. Describe as well as use different methods of generation of high AC, DC, impulse voltage and current.
3. Demonstrate and use different methods of measurement of high AC, DC, impulse voltage and current.
4. Identify the occurrence of overvoltage and to provide remedial solutions
5. Demonstrate an ability to carry out different tests on high voltage equipment and devices as well as ability to design the high voltage laboratory with all safety measures

Unit 01 : Breakdown in Gases

(06 Hrs)

Ionization process in gas, Townsend's Theory, current growth equation in presence of primary and secondary ionization processes, Townsend's breakdown criterion, primary and secondary ionization coefficients, limitations of Townsend's theory, Streamer mechanism of breakdown, Paschen's Law and its limitations, Corona discharges for point plane electrode combination with positive and negative pulse application, time lag and factors on which time lag depends. (Numerical on Townsend's theory and Paschen's law).

Unit 02 : (06 Hrs)

1. **Breakdown in Liquid Dielectrics:** Pure and commercial liquids, Different breakdown theories: Breakdown in Pure liquid and breakdown in commercial liquids: Suspended Particle theory, Cavitations and bubble theory, Thermal mechanism of breakdown and Stressed Oil volume theory

2. **Breakdown in Solid Dielectrics:** Intrinsic breakdown: electronic breakdown, avalanche or streamer breakdown, electro-mechanical breakdown, thermal breakdown, treeing and tracking phenomenon, Chemical and electrochemical breakdown, Partial discharge (Internal discharge), Composite dielectric material, Properties of composite dielectrics, breakdown in composite dielectrics. (Numerical on theories of liquid and solid dielectric materials)

Unit 03 : Generation of High Voltages and Current (06 Hrs)

a) Generation of high ac voltages-Cascading of transformers, series and parallel resonance system, Tesla coil

b) Generation of impulse voltages and current-Impulse voltage definition, wave front and wave tail time, Multistage impulse generator, Modified Marx circuit, Tripping and control of impulse generators, Generation of high impulse current

Unit 04 : Measurement of High Voltage and High Currents: (06 Hrs)

Sphere gap voltmeter, electrostatic volt meter, generating voltmeter, peak reading voltmeter, resistive, capacitive and mixed potential divider, capacitance voltage transformer, cathode ray oscilloscope for impulse voltage and current measurement, measurement of dielectric constant and loss factor, partial discharge measurements. Measurement of high power frequency a.c. using current transformer with electro-optical signal converter, Radio interference measurements.

Unit 05 : Lightning and Switching Over Voltages (06 Hrs)

Causes of over voltages, lightning phenomenon, Different types of lightning strokes and mechanisms of lightning strokes, Charge separation theories, Wilson theory, Simpson theory, Reynolds and Mason theory, Over voltage due to switching surges and methods to minimize switching surges. Statistical approach of insulation coordination

Unit 06 : High Voltage Testing of Electrical Apparatus and H V Laboratories: (06 Hrs)

a) Testing of insulators and bushings, Power capacitors and cables testing, testing of surge arresters.

b) Design, planning and layout of High Voltage laboratory:-Classification and layouts, earthing and shielding of H.V. laboratories.

Guidelines for Instructor's Manual

The Instructor's Manual should contain following related to every experiment

- Brief theory related to the experiment.
- Circuit diagram and apparatus with their detail specification as per IS code.
- Students should be encouraged to visit industries/HV laboratories/HV installations.
- Students should be encouraged to use virtual labs.
- Few short questions related to each practical.

Assignments based on use of IS and IEC

Guidelines for Student's Lab Journal

The Students lab journal should contain:

- Brief theory related to the experiment.
- Circuit diagram and apparatus with their detail specification as per IS code.
- Observations, result tables and proper inferences/ conclusion from each experiment conducted.
- Reports on visit to industries/HV laboratories/HV installations.
- Simulations and print outs of use of virtual labs.
- Few short questions and answers related to each practical.
- Assignments based on use of IS and IEC.

Guidelines for Laboratory conduction

- There should be continuous assessment for the TW.
- Assessment must be based on understanding of theory, attentiveness during practical.
- Session, how efficiently the student is able to do connections and get the results.
- Timely submission of journal.

List of Experiments

1. To find the constants of breakdown equation of transformer oil.(Analytical and graphical method)
2. Measurement of unknown high a.c. voltage using sphere gap
3. To obtain breakdown strength of composite insulation system, and observe the effect of parameter like no. of layers, thickness of layer, effect of interfacing.
4. To find out the breakdown of air in uniform and non uniform field and compare it.
5. To study surface flashover on corrugated porcelain/polymeric insulation system.
6. To understand basic principle of corona and obtain audible and visible corona inception and extinction voltage under non uniform field.
7. To perform experiment on horn gap arrestor and understand arc quenching phenomenon.
8. To observe development of tracks and trees on polymeric insulation system.
9. Parametric analysis of Impulse current generator using virtual Laboratory.
10. To perform experiment on rod gap arrestor.
11. To Study effect of barrier on breakdown voltage of air/ transformer oil.
12. Simulation of lightening and switching impulse voltage generator using any simulation software.
13. To perform various HV insulation tests on cables as per IS.
14. Study of layout /earthing/safety of HV installation /lab in any industry by visit /virtual lab
15. Study of any IS for any power apparatus (Power Transformer/Induction Motor/ Alternator etc)

Industrial Visit: Industrial visit to high voltage equipment manufacturing industry/EHV substation/High Voltage Testing Unit.

Text Books:

- [T1] M. S. Naidu, V. Kamaraju, "High Voltage Engineering", Tata McGraw Hill Publication Co. Ltd. New Delhi
- [T2] C. L. Wadhwa, "High Voltage Engineering", New Age International Publishers Ltd.

Reference Books:

- [R1] E. Kuffel, W. S. Zaengl, J. Kuffel, “High Voltage Engineering Fundamentals”, Newnes Publication
- [R2] Prof. D. V. Razevig Translated from Russian by Dr. M. P. Chourasia, “High Voltage Engineering”, Khanna Publishers, New Delhi
- [R3] Ravindra Arora, Wolf Gang Mosch, “High Voltage Insulation Engineering”, New Age International
- [R4] High Voltage Engineering Theory and Practice by M. Khalifa Marcel Dekker Inc. New York and Basel.
- [R5] Subir Ray, “An Introduction to High voltage Engineering” PHI Pvt. Ltd. New Delhi
- [R6] NPTEL lectures
- [R7] IS 731-1971: Porcelain insulator for overhead power lines with nominal voltage > 1000 Volt
- [R8] Bushings :IS2099-1986, specification for bushings for A.C. Voltages > 1000 Volts
- [R9] Pollution test :IEC 60507-1991 on external and internal insulator
- [R10] High voltage test techniques, general definitions and test requirements: IS 2071(part 1) 1993, IEC Pub 60-1(1989)

Unit	Text Books	Reference Books
1	T1,T2	R1,R2,R3,R6
2	T1,T2	R1,R2,R3,R5,R6
3	T1,T2	R1,R2,R3,R5,R6
4	T1,T2	R1,R2,R3,R4,R5,R6
5	T1,T2	R1,R2,R3,R4,R5,R6
6	T1,T2	R1,R2,R3,R7,R8,R9, R10

Elective –III : 403149 (B): HVDC and FACTS

Teaching Scheme	Credits	Examination Scheme [150 Marks]
Theory : 03Hrs./Week	03	In Sem : 30 Marks
Practical : 02Hrs./Week	01	End Sem : 70 Marks
		Oral : 25Marks
		Term work: : 25 Marks

Prerequisite:

1. Fundamental knowledge of Power Electronics and power controllers
2. Fundamentals of Power system Operation of three phase converters
3. Inverter topologies
3. Operation of VSI

Course Objective: The course aims to:-

- To provide students knowledge about modern trends in Power Transmission Technology
- To make students describe applications of power electronics in the control of power transmission.
- To educate students for utilization of software such as PSCAD, MATLAB for power transmission and control.

Course Outcome: Upon successful completion of this course, the students will be able to :-

1. Compare HVDC and EHV AC systems for various aspects
2. Reproduce the layout of HVDC system with various components including protective devices
3. Differentiate VSC HVDC and conventional HVDC system
4. Differentiate various types of Power Electronic Controllers
5. Analyze modeling of FACTS Controllers
6. Simulate various controllers and HVDC systems using softwares

Unit 01 : (06 Hrs)

EHVAC versus HVDC transmission, power flow through HVDC link, Graetz circuit, equation for HVDC power flow bridge connection, control of DC voltage and power flow, effects of angle of delay and angle of advance commutation, CIA, CC and CEA control.

Unit 02 : (06 Hrs)

Twelve pulse converter operation, Harmonics in HVDC systems. HVDC system layout and placement of components, HVDC protection, grounding, multi terminal HVDC systems, configurations and types.

Unit 03 : VSC HVDC Technology (06 Hrs)

Introduction to VSC transmission, power transfer characteristics, structure of VSC link, VSC DC system control, HVDC light technology. HVDC plus, introduction, construction, operation and applications to renewable energy sources

Unit 04 : Power Electronic Controllers (06 Hrs)

Basics, Challenges and needs, Review of rectifiers and inverters, back to back converter, dc link converter, static Power converter structures, AC controller based structures, DC link converter topologies, converter output and harmonic control, power converter control.

Unit 05 : Shunt and Series Compensation**(06 Hrs)**

Operation and control of SVC, STATCOM configuration and control, characteristics and applications of SVC and STATCOM, TCSC layout and modes of operation, layout, operation and characteristics of Static Synchronous Series Compensator (SSSC).

Unit 06 : Unified Power Flow Controller**(06 Hrs)**

UPFC configuration, steady state operation, control and characteristics, operational constraints of UPFC, Power flow studies in UPFC embedded systems.

Guidelines for Instructor's Manual

- Title and circuit diagram of experiment (block diagram) /power network.
- Working operation and output characteristics / output waveforms of power electronic Controllers/FACTS devices /converter circuit used to control.
- Procedure to carry out the experiment
- For simulation experiments print out of model and simulation results

Guidelines for Student's Lab Journal

- Title, aim, circuit diagram, procedure and theory of power electronic switching device or converter circuit and expected machine performance with speed torque characteristics.
- Equipment along with the specifications needed to carry out the experiment.
- Circuit diagram, observation table, calculations if any.
- Analyse and interpret the experimental results and write the conclusions appropriately.

Guidelines for Laboratory conduction

- Minimum eight experiments are to be performed out of the list mentioned as below:
- Out of which at least two experiments shall be conducted on hardware setups.
- For simulation experiment ready models/demo models can be used. However study should simulate models for different conditions and attached prints of simulation models and test results.
- Term work should be assessed continuously.
- Term work marks are based on quality of work, initiative, timely submission

List of Experiments

Minimum eight experiments are to be performed out of the list mentioned as below:

A) Hardware experiments

1. Study effects of angle of delay and angle of advance commutation, CIA, CC and CEA control on single bridge converter
2. Study of Single Phase Thyristor Control Reactor(A) Study of Voltage and Current Waveforms with different delay angles (B) harmonic analysis (C) Basic control law (D) V-I characteristics
3. Single Phase TCR with fixed capacitor and filter.
4. Complete characteristics of a three phase voltage source converter, constant alpha and extinction angle control.

B) Simulation Experiments

1. Study and simulation of Three phase TCR with and without shunt capacitor
2. Study and simulation of resonance in electrical Power systems
3. Application study of SVC in Power System.
4. Application study of TCSC in Power System
5. Study and simulation of 6 pulse HVDC system
6. Study of 12 pulse or 24 pulse or 48 pulse inverter
7. Application study of DSTATCOM in Power System
8. Study and simulation of Power Flow control in a five bus system using any one of the following FACTS Controllers: (i) SVC (ii) STATCOM (iii) SSSC (iii) UPFC

Industrial Visit: Desirable visit to nearest HVDC substation

Text Books:

- [T1] E. Acha, V.A. Agelidis, O.Anaya-lara and TJE Miller, “Power Electronic control in Electrical Systems” Newnes, Oxford.
- [T2] J. Arrillaga, “High Voltage Direct Current Transmission” Peter Peregrinus Ltd., London, UK.
- [T3] N.G. Hingorani and L.Gyugi, “Understanding FACTS” IEEE Press[Indian Edition], New York.
- [T4] J. Arrillaga, Y.H.Liu and N.R.Watson, “Flexible Power Transmission The HVDC Options”, John Wiley and sons Ltd., New York.
- [T5] Erich Uhlmann, “Power Transmission by Direct Current” Springer International.

Reference Books:

- [R1] Yong Hua Song and Allan T Johns, “Flexible ac transmission systems(FACTS), Published by The Institution of Electrical Engineers, London.
- [R2] K.R.Padiyar, “FACTS controllers in transmission and Distribution” New Age Publications, New Delhi.
- [R3] K.R.Padiyar , “HVDC Power Transmission Systems”, New Age Publications, New Delhi, (2nd Edition)
- [R4] M.H.Rashid , “Power Electronics Handbook”, Academic Press.
- [R5] PrabhaKundur, “Power System Stability and Control”, McGraw Hill
- [R6] S Kamakshaiah, V Kamaraju, “HVDC Transmission”, McGraw Hill

Unit	Text Books	Reference Books
1	T2,T4,T5	R3,R6
2	T1, T3	R3, R4,R7
3	T1, T2	R1, R6
4	T2	R5, R8
5	T6	R2
6	T2, T3	R6

Elective –III : 403149 (C) : Digital Control Systems

Teaching Scheme	Credits	Examination Scheme [150 Marks]
Theory : 03 Hrs./Week	03	In Sem : 30 Marks
Practical : 02Hrs./Week	01	End Sem : 70 Marks
		Oral : 25Marks
		Term work : 25 Marks

Prerequisite : Z-Transform, Basics of discrete systems.

Course Objective: The course aims to:-

- Make students elaborate basic concepts of discrete signals and systems.
- Educate students to analyze the stability of discrete systems.
- Explain formulation of state space discrete model and design the digital controllers.
- Elaborate digitize analog controllers using various numerical methods.
- Explore application of the theory of digital control to practical problems.

Course Outcome: Upon successful completion of this course, the students will be able to :-

1. Analyze digital control system and its stability.
2. Differentiate between various control systems
3. Present system in state space format.
4. Design observer for system.
5. Understand digital controllers
6. Elaborate applications such as digital temperature control and position control

Unit 01 : Discrete systems and Signals (06 Hrs)

Standard discrete test signals, Basic operations on signals. Classification of discrete systems. Detail analysis of frequency aliasing and quantization, Brief review of Sampling theorem, Ideal low pass filter. Transfer function of ZOH, Frequency domain characteristics of ZOH, First order hold, frequency domain characteristics of first order hold.

Unit 02 : State - Space analysis (06 Hrs)

Conversion of Pulse transfer functions to State space model and vice a versa. Solution of LTI Discrete –time state equation; State Transition Matrix (STM) and properties of STM; Computation of STM by Z-transform method, by power series expansion method, by Cayley Hamilton theorem, by Similarity transformation method, Discretization of continuous time state space equation.

Unit 03 : Design using state space (05 Hrs)

Controllability and observability of linear time invariant discrete-data system, Tests for Controllability and observability; Principal of Duality; Effect of pole- zero cancellation; Relationship between controllability, observability and stability. Pole placement design using linear state-feedback.

Unit 04 : Design of State Observers (06 Hrs)

Full order state observer, reduced order state observer, State estimation and full order observer design. Ackermann's formula. Compensator design by the separation principle, State feedback with integral control, State regulator design.

Unit 05 : State space model and digitising analog controllers (07 Hrs)

State space model of digital systems: Transformation of state-space model to various forms (controllable, observable, diagonal and Jordan canonical forms). Numerical approximation of differential equations, Eulers foreword and backward method, Trapezoidal method, Bilinear transformation with frequency warping. Numerical differentiation, Matching step and other response. Pole-zero matching.

Unit 06 : Digital control system applications (0 6 Hrs)

Hybrid system simulation, Computer program structure for simulation of discrete time control of continuous time plant. Digital temperature control, position control, Stepper motor control, Block diagram presentation and control algorithms.

List of Experiments Perform any eight experiments using MATLAB

1. Design and analysis of digital temperature control system
2. Design and analysis of digital position control system.
3. Software programming for determination of STM of DT system.
4. Software programming to design DT system by pole placement through state feedback.
5. Software programming for determination of controllability and observability of DT System.
6. Software programming to observe effect of sampling on response of the system
7. Software programming to observe effect of sampling on stability of DT system.
8. Solution of state equation of L.T.I. systems by the use of digital computer.
9. Digital computer aided difference equation solution.
10. Conversion of continuous time state space model to discrete time state space model

Text Books:

- [T1] K. Ogata, "Discrete Time Control System", 2nd Edition, PHI Learning Pvt. Ltd. 2009
[T2] B. C. Kuo, "Digital Control Systems", 2nd Edition, Oxford University Press
[T3] M. Gopal, "Digital Control Engineering", New Age International Publishers
[T4] M. Gopal, "Digital Control and State Variable Methods", 3rd Edition The McGraw Hill Co.

Reference Books:

- [R1] Load D. Landau, Gianluca Zito, 'Digital Control Systems: design, Identification and Implementation' Springer.
[R2] Mohammed Santina, Allen Stubberud, Gene Hostetter 'Digital control System Design', Sanders College publishing
[R3] K.J. Astrom, B Wittenmark 'Computer Controlled Systems: Theory and Design' Prentice-Hall Inc New Jersey, 2011 Dover.

Unit	Text Books	Reference Books
1	T2,T3	R3
2	T2,	R3
3	T1,T2	R3
4	T1,T2	R1,R2
5	T1,T3	R1,R2
6	T2,T4	R3

Elective – III : 403149 (D): Intelligent Systems and Applications in Electrical Engineering

Teaching Scheme	Credits	Examination Scheme [150 Marks]
Theory : 03 Hrs./Week	03	In Sem : 30 Marks
Practical : 02 Hrs./Week	01	End Sem : 70 Marks
		Oral : 25 Marks
		TW : 25 Marks

Prerequisite: Knowledge of MATLAB, C- Programming

Course Objective: The course aims to:-

- To enhance knowledge of intelligence system to carry out power system problems.
- To impart knowledge about Artificial neural network and fuzzy logic programming for electrical engineering applications like load dispatch and load shedding.

Course Outcome: Upon successful completion of this course, the students will be able to :-

1. Classify neural networks
2. Compare various AI tools
3. Develop algorithms for AI tools
4. Apply AI tools for Applications in electrical engineering

Unit 01 : Introduction to Artificial Neural Network (06 Hrs)

Organization of the Brain, Biological Neuron, Biological and Artificial Neuron Models, Historical Developments. Essentials of Artificial Neural Networks: Artificial Neuron Model, operations of Artificial Neuron, Types of Neuron Activation Function, ANN Architectures

Unit 02 : Classification Taxonomy of ANN (06 Hrs)

Connectivity, Neural Dynamics (Activation and Synaptic), Learning Strategy (Supervised, Unsupervised, Reinforcement), Learning Rules.

Perceptron Models: Training Algorithms: Discrete and Continuous Perceptron Networks, Perceptron Convergence theorem. Multilayer feed forward Neural Networks

Unit 03 : Memory (06 Hrs)

Associative Memory, Bi-directional Associative Memory (BAM) Architecture, BAM Training Algorithms: Storage and Recall Algorithm, BAM Energy Function, Self-Organizing Maps (SOM) and Adaptive Resonance Theory (ART).

Unit 04 : Introduction to Fuzzy Logic system (06 Hrs)

Fuzzy versus crisp, fuzzy sets: membership function, Basic fuzzy set operations, properties of fuzzy sets, fuzzy relations.

Unit 05 : Fuzzy Control (06 Hrs)

Predicate logic (Interpretation of predicate logic formula, Inference in predicate logic), fuzzy logic (Fuzzy quantifiers, fuzzy Inference), fuzzy rule based system, defuzzification methods

Unit 06 : Introduction to other Intelligent tools (06 Hrs)

Introduction to Genetic Algorithm: biological background, GA operators, selection, encoding, crossover, mutation, chromosome.

Expert System: software architecture, rule base system

List of Experiments

Minimum eight experiments are to be performed out of the list mentioned as below:

[Matlab Programming based experiments.]

1. Write program to evaluate output of any given architecture of neural network with different transfer functions such as linear logsig tanh, threshold function.
2. Verify the fault tolerant nature of neural network by disconnecting few weight link for a given architecture
3. Write program for perceptron learning algorithm.
4. To study some basic neuron models and learning algorithms by using ANN tool
5. Power system failure analysis using ANN tool
6. Predict power factor of four bus system using neural network
7. Predict system analysis for measurements like rms voltage using ANN tool
8. Write supervised and unsupervised ANN program for Signal Frequency Separation using Perceptron
9. Temperature monitoring using fuzzy logic
10. Speed control of DC motor using fuzzy logic
11. Fuzzy logic based washing machine control
12. Fuzzy logic based air conditioner
13. Design of a Fuzzy Multi-Objective Power System Stabilizer via Linear Matrix Inequalities

Text Books:

- [T1] Simon Haykin, “Neural Networks: A Comprehensive Foundation”, 2nd Edition, Pearson Education
- [T2] S. Rajsekaram, G. A. Vijayalaxmi Pai, “Neural Networks, Fuzzy Logic and Genetic Algorithms Synthesis and Applications”, Practice Hall India
- [T3] James A. Anderson, “An Introduction to Neural Networks”, Practice Hall India Publication
- [T4] Mohamed H. Hassoun, “Fundamentals of Artificial Neural Network”, Practice Hall India

Reference Books:

- [R1] Kelvin Waruicke, Arthur Ekwille, Raj Agarwal, “AI Techniques in Power System”, IEE London, U.K.
- [R2] S. N. Sivanandam, S. Sumathi, S. N. Deepa, “Introduction to Neural Network Using MATLAB 6.0”, Tata McGraw Hill
- [R3] Jacek Zurada, “Introduction to Artificial Neural Network”, Jaico Publishing House India

Unit	Text Books	Reference Books
1	T1,T2	R1,R2
2	T1,T2	R1,R2
3	T1,T2	R1,R2
4	T2	R1
5	T2	R1
6	T1	R1,R2

Elective – III : 403149 (E): Analog Electronics and Sensing Technology [Open Elective]

Teaching Scheme	Credits	Examination Scheme [150 Marks]
Theory : 03 Hrs./Week	03	In Sem : 30 Marks
Practical : 02 Hrs./Week	01	End Sem : 70 Marks
		Oral : 25 Marks
		TW : 25 Marks

Course Objective: The course aims to:-

- Study operational amplifiers for various analog operations.
- Understand different types of analog filters and waveform generation techniques.
- Study advance applications such as mux/demux and multipliers.
- Understand various analog sensors for various applications.

Course Outcome: Upon successful completion of this course, the students will be able to :-

1. Develop various analog circuits using operational amplifiers.
2. Design filters and waveform generators and various signal converter circuits.
3. Find characteristics of sensors used for system monitoring and protection.
4. Interface various position sensors to microcontrollers.
5. Find characteristics of sensors used for light and image sensing.

Unit 01 : Operational Amplifier & Applications (06 Hrs)

Study of Various types of Operational Amplifiers and their applications; Op-Amp: Block diagrams of LM741 and TL082, ideal and practical parameters, open loop and close loop configuration, Power supply configurations, DC and AC parameters.

Applications of Op- Amp- Comparator, zero crossing detectors, Voltage limiters, Integrator and Differentiator, V-I and I-V converters, V to f and f to V circuits using LM331, peak detector.

Unit 02 : Waveform generators, Filters & Regulators (06 Hrs)

Waveform generation using Op-amp - sine, square, saw tooth and triangular generator, Active filters-Its configuration with frequency response, Analysis of first order Butterworth low pass and high pass filters, bandpass and band-stop filters, notch filter, all pass filters, Universal Active filter design using UAF42.

OP-AMP Voltage regulator, Fixed and Adjustable Voltage Regulators, Basic Switching Regulator and characteristics of standard regulator ICs –TPS40200 and Low Drop out (LDO) Regulators ICs- TPS7250.

Unit 03 : Advanced applications (06 Hrs)

Introduction to analog multiplier e.g.MPY634, Basic application of Analog multiplier: AM, FM, FSK; Typical application using op-AMP and analog multipliers: Voltage Controlled Oscillator, Phase Locked Loop and its applications, self-tuned filters.

Analog Switches and Multiplexers Overview, MUX507 Multiplexer, SN74LV4051A-Q1 8-Channel Analog Multiplexer/Demultiplexer

Unit 04 : System monitoring & protection sensing**(06 Hrs)**

Principle of operation and application of following sensors for Real-time system protection, feedback control and high-accuracy system monitoring: LM35 Temperature Sensor, INA240 current sense amplifier, DRV5053 Hall Effect based current sensor, HDC1080 / HDC1010 / HDC2010 Humidity Sensor.

Unit 05 : Position Sensing**(06 Hrs)**

Absolute and relative position sensing solutions including: angular, presence, proximity, distance, flow, level, and velocity basics, DRV 5032 Hall Effect Sensor, mmWave Sensor, AFE5805 Ultrasonic sensor, Encoder, Resolver, Inductive position sensor, Capacitive Position Sensor, LVDT.

Unit 06 : Light & image sensing**(06 Hrs)**

Sensors and sensing AFEs for capturing a broad range of wavelengths introduction, 3D Depth Sensor, Near Infrared spectroscopy, OPT3007 Light Sensor, Optical Isolators.

Guidelines for Instructor's Manual

Instructor's Manual shall have

- Brief relevant theory of all analog and sensing devices.
- Equipment with specifications.
- Connection diagram/ methodology.

Format of observation table, analog device characteristics and sample results.

Guidelines for Student's Lab Journal

The Student's Lab Journal should contain following related to every experiment –

1. Theory related to the experiment.
2. Apparatus with their detailed specifications.
3. Connection diagram /circuit diagram.
4. Observation table/ simulation waveforms.
5. Sample calculations for one/two reading.
6. Result table.
7. Graph and Conclusions.
8. Few short questions related to the experiment.

Guidelines for Laboratory conduction

Lab Requirement: LM741, TL082, LM331 operational amplifiers, ICs – TPS40200, TPS7250, TPS 7A4901, TPS7A8300, UAF42, MPY634, MUX507 and SN74LV4051A-Q1; LM35, INA240, DRV5053, HDC1080 modules; Angular, Presence, Proximity, Distance, Flow, level and other position sensor modules and OPT3007 light sensor module with relevant power supply and DSO/CRO and other metering equipment for characterization of all analog devices.

List of Experiments

Minimum eight experiments are to be performed out of the list mentioned as below:

1. LM741 based comparator circuit.
2. LM318 based zero crossing detector.
3. LM331 based V to f and f to V converter.
4. LM741 based triangular, square and sinusoidal waveform generation.
5. Universal Active filter design using UAF42.
6. Voltage Regulators using TPS40200 and TPS7250.
7. Analog multiplier using MPY634
8. Analog Multiplexer using MUX507
9. Study characteristics of LM35 based temperature sensor module
10. Study characteristics of HDC 1080 based Humidity sensor module
11. Hall Effect based position sensing / Ultrasonic based distance sensing.
12. Study characteristics of OPT 3007 light sensor module.

Text Books:

- [T1] HANDBOOK OF OPERATIONAL AMPLIFIER APPLICATIONS, <http://www.ti.com/lit/an/sboa092b/sboa092b.pdf>
- [T2] Thomas L. Floyd, "Electronics Devices", Pearson Education.
- [T3] Mottershed, "Electronics Devices & Circuits", PHI New Delhi
- [T4] Muhammad H. Rashid, "Power Electronics: Circuits, Devices and Applications", 3rd edition, Pearson Education.
- [T5] Linear Integrated Circuits and its Applications: <https://www.ti.com/seclit/ml/ssqu016/ssqu016.pdf>
- [T6] <http://www.ti.com/lit/ds/symlink/tps40200.pdf>
- [T7] www.ti.com/lit/ds/symlink/lm35.pdf
- [T8] AIP Handbook of Modern Sensors: Physics, Design and Applications, Jacob Fraden, American Institute of Physics.

Reference Books:

- [R1] K. R. Botkar, "Integrated Circuits", Khanna Publication, New Delhi.
- [R2] James, "Operational Amplifier and Linear Integrated Circuits Theory and Application." P John Paul, "Electronics Devices and circuits", New Age international Publications.
- [R3] P. S. Bimbhra, "Power Electronics", Khanna Publications
- [R4] <http://www.ti.com/lit/an/sboa092b/sboa092b.pdf>
- [R5] The Signal e-Book, Texas Instruments
- [R6] <http://www.ti.com/lit/ds/symlink/uaf42.pdf>
- [R7] <https://www.ti.com/lit/ds/symlink/mpy634.pdf>
- [R8] www.ti.com/lit/ds/symlink/mux506.pdf
- [R9] www.ti.com/lit/ds/symlink/hdc1080.pdf
- [R10] The fundamentals of millimeter wave, Texas Instruments
- [R11] www.ti.com/lit/ds/sbos864/sbos864.pdf

Unit	Text Books	Reference Books
1	T1, T2, T3	R1, R2, R6
2	T4, T5, T6	R3, R4, R5, R6, R7
3	-	R6, R8, R9
4	T7, T8	R6, R10
5	T8	R6, R11
6	T8	R6, R12

Elective –IV : 403150 (A): Smart Grid

Teaching Scheme	Credit	Examination Scheme [100 Marks]
Theory : 03 Hrs / Week	03	In Sem : 30 Marks
		End Sem : 70 Marks

Prerequisite: Knowledge of power system and power electronics

Course Objective: The course aims:-

- To explain the concept of Smart Grid, compare with conventional grid, and identify its opportunities and barriers.
- To describe the concept of Smart Meter, Smart Appliances, Automatic Meter Reading, Outage Management System, Plug in Hybrid Electric Vehicles, Vehicle to Grid, Smart Sensors, Home and Building Automation, Phase Shifting Transformers.
- To elaborate the concept of Substation Automation, Feeder Automation. Intelligent Electronic Devices, Smart storage like Battery, Pumped Hydro, Compressed Air Energy Storage, Wide Area Measurement System, Phase Measurement Unit.
- To elaborate the concept of microgrid
- To acquaint Power Quality issues of Grid connected Renewable Energy Sources, Web based Power Quality monitoring, Power Quality Audit.

Course Outcome:

1. Apply the knowledge to differentiate between Conventional and Smart Grid.
2. Identify the need of Smart Grid, Smart metering, Smart storage, Hybrid Vehicles, Home Automation, Smart Communication, and GIS
3. Comprehend the issues of micro grid
4. Solve the Power Quality problems in smart grid
5. Apply the communication technology in smart grid

Unit 01 : Introduction to Smart Grid: (06 Hrs)

Concept of Smart Grid, Need of Smart Grid, Functions of Smart Grid, Opportunities and Barriers of Smart Grid, Drivers of SG in India, Functionalities and key components of smart grid, Difference between conventional and smart grid, Smart Grid Vision and Roadmap for India, Concept of Resilient and Self-Healing Grid, Present development and International policies in Smart Grid, Smart Cities, Pilot projects in India.

Unit 02 : Smart Grid Technologies (06 Hrs)

Remote Terminal Unit (RTU):Block diagram and function of each block, Intelligent Electronic Devices (IED), Phase Measurement Unit (PMU). Smart Substations, Substation and Feeder Automation, application for monitoring, protection and control, Plug in Hybrid Electric Vehicles(PHEV), Vehicle to Grid(V2G), Grid to vehicles(G2V), Smart storage technologies and applications – Battery(flow and advanced), SMES, Super Capacitors, Compressed Air Energy Storage(CAES) and its comparison, Optimal location of PMUs for complete Observability.

Unit 03 : Smart Meters and Advance Metering Infrastructure: (06 Hrs)

Introduction to Smart Meters, Advanced Metering Infrastructure (AMI), Real Time Pricing, Automatic Meter Reading (AMR), Outage Management System (OMS) Smart Sensors, Smart Appliances, Home and Building Automation, Geographic Information System (GIS).

Unit 04 : Microgrids: (06 Hrs)

Concept of Microgrid, need and applications of Microgrid, Microgrid Architecture, DC Microgrid, Formation of Microgrid, Issues of interconnection, protection and control of Microgrid, Integration of renewable energy sources, Smart Microgrid, Microgrid and Smart Grid Comparison, Smart Microgrid Renewable Green Energy System, Cyber Controlled Smart Grid.

Unit 05 : Power Quality Management in Smart Grid (06 Hrs)

Power Quality and EMC in Smart Grid, Power Quality issues of Grid connected Renewable Energy Sources, Power Quality Conditioners for Smart Grid, Web based Power Quality monitoring, Power Quality Audit.

Unit 06 : Communication Technology for Smart Grid (06 Hrs)

Communication Architecture of SG, Wide Area Measurement System (WAMS), Home Area Network (HAN), Neighbourhood Area Network (NAN), Wide Area Network (WAN), ZigBee, GPS, Wi-Fi, Wi-Max based communication, Wireless Mesh Network, Basics of CLOUD Computing and Cyber Security for Smart Grid, Broadband over Power line (BPL).

Text Books:

- [T1] Ali Keyhani, Mohammad N. Marwali, Min Dai “Integration of Green and Renewable Energy in Electric Power Systems”, Wiley
- [T2] Clark W. Gellings, “The Smart Grid: Enabling Energy Efficiency and Demand Response”, CRC Press
- [T3] Janaka Ekanayake, Nick Jenkins, Kithsiri Liyanage, Jianzhong Wu, Akihiko Yokoyama, “Smart Grid: Technology and Applications”, Wiley Publications.
- [T4] Stuart Borlase, “Smart Grids-Infrastructure, Technology and Solutions”, CRC Press, Taylor and Francis group
- [T5] James Momoh, “Smart Grid-Fundamentals of design and analysis”, Wiley Publications.

Reference Books:

- [R1] Nikos Ziargyriour, “Micro grid, Architecture and Control”, IEEE Press, Wiley Publications.
- [R2] Yang Xiao, “Communication and Networking in Smart Grids”, CRC Press, Taylor and Francis group
- [R3] Lars T. Berger and Krzysztof Iniewski, “Smart Grid-Applications, Communications and Security”, Wiley Publications.
- [R4] Mladen Kezunovic, Mark G. Adamiak, Alexander P. Apostolov, Jeffrey George Gilbert “Substation Automation (Power Electronics and Power Systems)”, Springer Publications.
- [R5] Smart grid handbook for regulators and policy makers November 2017, ISGF

Unit	Text Books	Reference Books
1	T1,T3,T5	R5
2	T1	R5
3	T1,T4	R4, R5
4	T1,T3	R5, R1
5	T5,T2	R5, R2
6	T4	R2, R3, R5

Elective – IV : 403150 (B): Robotics and Automation

Teaching Scheme	Credits	Examination Scheme [100Marks]
Theory : 03 Hrs./Week	03	In Sem : 30 Marks
		End Sem : 70 Marks

Course Objective: The course aims to:-

- To know basic parts of a typical industrial robot system with its anatomy with human body.
- To analyze mathematically kinematic and dynamic modeling of a typical robot manipulator.
- To select an appropriate type of robot with given specifications for different industrial applications.
- To know the basics of actuators, sensors and control of an industrial robot for different applications

Course Outcome: Upon successful completion of this course, the students will be able to :-

1. Differentiate between types of robots based on configuration, method of control, types of drives, sensors used etc.
2. Choose a specific robot for specific application with given specifications.
3. Analyze the robot arm dynamics for calculation of torques and forces required for different joints of robots for control of robot arm.
4. Determine the D-H parameters for a robot configuration using concepts from robot arm kinematics which further leads to forward/inverse kinematics.
5. Calculate the Jacobian matrix for robot arm velocity and decide the singular positions.

Unit 01 : Introduction

(06 Hrs)

Robot components, Degrees of freedom, Robot joints, Robot reference frames, Robot specifications: repeatability, spatial resolution, compliance, load carrying capacity, speed of response, work volume, work envelope, reach etc., end effectors (Wrist), concept of: yaw, pitch and roll. Robot classification: according to Co-ordinate system: Cartesian, cylindrical, spherical, SCARA, Articulated, Control Method: Servo controlled and non-servo controlled, their comparative study, form of motion: P-T-P (point to point), C-P (continuous path), pick and place etc. and their comparative study.

Unit 02 : Mathematical preliminaries

(06 Hrs)

Homogeneous Coordinate, Translational Transformation, Rotational Transformation, coordinate reference frames, Effect of pre and post multiplication of transformation, Concept of Homogeneous transformation, Euler angles and singularities

Unit 03 : Forward Kinematics

(06 Hrs)

Denavit-Hartenberg (D-H) representation of kinematic chains. Rules for establishing link co-ordinate frames. Forward solution of robotic manipulator for SCARA Robot and PUMA Robot. Forward solution for simple robot systems.

Unit 04 :

Inverse Kinematics: Concept of Inverse Kinematics, general properties of inverse solution such as existence and uniqueness of solution, inverse solution by direct approach, Geometric approach, inverse solution for simple SCARA Robots, numericals for simple three axis robots based on direct approach.

Robot Dynamics: Lagrange's Equation, Kinetic and potential energy Equations, Euler-Lagrange analysis for a single prismatic joint working against gravity and single revolute joint. Equation of motion.

Unit 05 : Differential motion and Control**(06 Hrs)**

Manipulator Differential Motion: Concept of linear and angular velocity, Relationship between transformation matrix and angular velocity, manipulator Jacobian, Jacobian for prismatic and revolute joint, Jacobian Inverse, Singularities.

Control of Robot Arm: Modeling of DC motor and load, closed loop control in position servo, the effect of friction and gravity, control of a robotic joint, position velocity and acceleration profiles for trapezoidal velocity profile.

Control of Robot manipulator: joint position controls (JPC), resolved motion position controls (RMPC) and resolved motion rate control (RMRC).

Unit 06 : Actuators and Sensors**(06 Hrs)**

Drive Technology: Hydraulic, Pneumatic, Electric (stepper motor, D.C. servo motor, BLDC Motors) in detail with selection criteria. Sensors in servo control system: Resolver, rotary shaft encoders, potentiometers, tacho-generators.

Industrial Applications of Robots: Welding, Spray-painting, Grinding, Handling of rotary tools, Parts handling/transfer, Assembly operations, parts sorting, parts inspection, Potential applications in Nuclear and fossil fuel power plant etc. (Details for the above applications are selection criterion of robots, sensors used, selection of drives and actuators, methods of control, peripheral devices used etc).

Industrial Visit: At least one industrial visit should be arranged supporting the classroom teaching and student should submit a report on that industrial robot application including type of robot, method of control, type of application, sensor interface, method of programming etc.

Text Books:

- [T1] Mikell P. Groover, Mitchell Weiss, Roger N. Nagel, Nicholas G. Odrey, Ashish Dutta, "Industrial Robotics: Technology, Programming and Applications", Tata- McGraw Hill Education Private Limited, New Delhi, 2012.
- [T2] Richard D. Klafter, Thomas A. Chmielowski, Michael Neign, "Robotic Engineering – An Integral Approach", Prentice Hall of India Pvt. Ltd., New Delhi. Eastern Economy Edition.
- [T3] Robert J. Schilling, "Fundamentals of Robotics: Analysis and Control", Prentice Hall of India, New Delhi

Reference Books:

- [R1] K. S. Fu, R. C. Gonzalez, C. S. G. Lee, “Robotics: Control Sensing, Vision and Intelligence”, International Edition, McGraw Hill Book Co.
- [R2] John J. Craig, “Introduction to Robotics: Mechanics and Control”, Pearson Education
- [R3] R. K. Mittal, I. J. Nagrath, “Robotics and Control”, Tata McGraw Hill Publishing Company Ltd., New Delhi.
- [R4] Saeed b. Niku, “Introduction to Robotics: Analysis, Control, Applications”, Wiley Publication, 2011.

Unit	Text Books	Reference Books
1	T1,T2	R3
2	T1,T2,T3	R1, R2,R3,R4
3	T1,T2,T3	R1,R3,R4
4	T1,T2,T3	R1,R3,R4
5	T2, T3	R1,R2, R3
6	T2	R1

Elective IV :403150 (C): Illumination Engineering

Teaching Scheme	Credits	Examination Scheme [100Marks]
Theory : 03 Hr/Week	03	In Sem : 30 Marks
		End Sem : 70 Marks

Prerequisite:

The working of the conventional lamps, generation of light and physics of light, techniques for natural and artificial lighting

Course Objective: The course aims :-

- To explain conventional and modern lamps and their accessories.
- To get detailed insight of indoor and outdoor illumination system components, control and design aspects.
- To know the requirements of energy efficient lighting.
- To introduce the modern trends in the lighting

Course Outcome: Upon successful completion of this course, the students will be able to :-

1. Define and reproduce various terms in illumination.
2. Identify various parameters for illumination system design.
3. Design indoor and outdoor lighting systems.
4. Enlist state of the art illumination systems.

Unit 01 : Importance of Lighting in Human Life (05 Hrs)

Optical systems of human eye, Dependence of human activities on light, performance characteristics of human visual system, External factors of vision-visual acuity, contrast, sensitivity, time illuminance, colour, visual perception, optical radiation hazards, Good and bad effects of lighting and perfect level of illumination, Artificial lighting as substitute to natural light, Ability to control natural light, Production of light, physics of generation of light, Properties of light, Quantification and Measurement of light.

Unit 02 : Light Sources and Electrical Control of Light Sources (08 Hrs)

(A) **Light Sources**- Lamp materials: Filament, glass, ceramics, gases, phosphors and other metals and non-metals. Discharge Lamps: Theory of gas Discharge phenomena, lamp design considerations, characteristics of low and high pressure mercury and Sodium vapour lamps, Low Vapour Pressure discharge lamps - Mercury Vapour lamp, Fluorescent Lamp, Compact Fluorescent Lamp (CFL)

High Vapour Pressure discharge lamps - Mercury Vapour lamp, Sodium Vapour lamp, Metal halide Lamps, Solid Sodium Argon Neon lamps, SOX lamps, Electro luminescent lamps, Induction lamps.

Ballast, ignitors and dimmers for different types of lamps

(B) Control of Light Sources

Photometric Control of Light Sources and their Quantification: Types of Luminaries, factors to be considered for designing luminaries Types of lighting fixtures.

Optical control schemes, design procedure of reflecting and refracting type of luminaries. Lighting Fixture types, use of reflectors and refractors, physical protection of lighting fixtures, types of lighting fixtures according to installation type, types of lighting fixtures according to photometric usages, luminaries standard (IEC-598-Part I).

Unit 03 : Design Considerations for illumination schemes (04 Hrs)

Zonal cavity method for general lighting design, determination for zonal cavities and different shaped ceilings using COU (coefficient of utilization), beam angles and polar diagrams. Factors to be considered for design of indoor illumination scheme

Unit 04 : Design of lighting schemes-I (06 Hrs)

Indoor illumination design for following installations-

Residential (Numerical)

Educational institute

Commercial installation

Hospitals

Industrial lighting

Special purpose lighting schemes

Decorative lighting

Theatre lighting

Aquarium, swimming pool lighting

Unit 05 : Design of lighting schemes-II (08 Hrs)

Factors to be considered for design of outdoor illumination scheme

Outdoor Lighting Design: Road classifications according to BIS, pole arrangement, terminology, lamp and luminaries' selection, different design procedures, beam lumen method, point by point method, isolux diagram, problems on point by point method.

Outdoor illumination design for following installations:

Road lighting (Numerical)

Flood lighting (Numerical)

Stadium and sports complex

Lighting for advertisement/hoardings

Unit 06 : Modern trends in illumination (05 Hrs)

LED luminary designs

Intelligent LED fixtures

Natural light conduiting

Organic lighting system

LASERS, characteristics, features and applications, non-lighting lamps

Optical fiber, its construction as a light guide, features and applications

Text Books:

- [T1] H. S. Mamak, "Book on Lighting", Publisher International lighting Academy.
- [T2] Joseph B. Murdoch, "Illumination Engineering from Edison's Lamp to Lasers" Publisher -York, PA : Visions Communications
- [T3] M. A. Cayless, A. M. Marsden, "Lamps and Lighting", Publisher-Butterworth-Heinemann(ISBN 978-0-415-50308-2)
- [T4] Designing with light: Lighting Handbook., Anil Valia; Lighting System 2002

Reference Books:

- [R1] “BIS, IEC Standards for Lamps, Lighting Fixtures and Lighting”, Manak Bhavan, New Delhi.
- [R2] D. C. Pritchard, “Lighting”, 4th Edition, Longman Scientific and Technical, ISBN 0-582-23422-0.
- [R3] “IES Lighting Handbook”, (Reference Volume 1984), Illuminating Engineering Society of North America.
- [R4] “IES Lighting Handbook”, (Application Volume 1987), Illuminating Engineering Society of North America
- [R5] IESNA lighting Handbook., Illuminating Engineering Society of North America 9th edition 2000
- [R6] Applied Illumination Engineering, Jack L. Lindsey FIES (Author), Scott C. Dunning PHD PECCEM (Author) ,ISBN-13: 978-0824748098 ISBN-10: 0824748093, 3rd Edition.
- [R7] IS 3646: Part I: 1992, Code of practice for interior illumination.
- [R8] Organic Light Emitting Diodes (OLEDs): Materials, Devices and Applications, Alastair Buckley, University of Sheffield, UK, ISBN: 978-0-85709-425-4.

Unit	Text Books	Reference Books
1	T1,T4	R6
2	T3,T4	R1,R3,R4,R8
3	T2,T4	R2,R3,R7
4	T3,T4	R2,R3,R4,R5,R7
5	T3,T2,T4	R3,R4,R6,R7
6	T1,T2,T4	R8,R5,R3,R2

403150 (D) : VLSI Design [Open Elective]

Teaching Scheme	Credits	Examination Scheme [100 Marks]
Theory : 03 Hrs. /Week	03	In Sem : 30 Marks
		End Sem : 70 Marks

Prerequisite : Concepts of Digital Electronics, Number systems, any programming language like C

Course Objective: The course aims to:-

- Develop Digital designing skills of Students
- Train the students for Hardware Description Language.
- Develop various applications using VHDL coding.

Course Outcome: Upon successful completion of this course, the students will be able to :-

1. To understand Modeling of Digital Systems Domains for different combinational and sequential circuits
2. To understand Levels of Modeling using Modeling Language VHDL.
3. To Understand Modeling and programming Concepts by Learning a New Language
4. To develop of logic design and programming skills in HDL language.
5. To study HDL based design approach.
6. To learn digital CMOS logic design

Unit 01 : Overview of Digital Logic Circuits and Introduction to VLSI (06 Hrs)

Combinational circuits: Decoders, Multiplexer, ALU. Sequential circuits: latch, flip flop – RS, JK, D,T., shift registers ,Counters, Moore, Mealy Machines. Introduction to VLSI: complete VLSI design flow (with reference to an EDA tool), IEEE Standards ,VHDL Terms Definitions – Entity, architecture, Schematic, Components, Configuration.

Unit 02 : VHDL Modeling (06 Hrs)

Data objects, Data types, Entity, Architecture and types of modeling: Behavioral, data flow, and Structural with the help of digital functions like multiplexer, Shift Register, counter. Sequential statements, Concurrent statements. VHDL Test bench. VHDL modeling of Combinational, Sequential logics.

Unit 03 : VHDL and Finite State Machines (06 Hrs)

Synthesizable and non synthesizable statements, functions, procedures, attributes, configurations, packages. Synchronous and asynchronous machines, Finite State Machines (FSM), metastability, state diagrams and VHDL codes for FSMs.

Unit 04 : Programmable Logic Devices (PLDs) (06 Hrs)

Need of PLDs. Comparison with ASIC, general purpose processor, DSP processor, microcontroller, memories etc. Features, specifications, detail architectures, application areas, limitations of Complex Programmable Logic Device (CPLD) and Field Programmable Logic Devices (FPGA).

Unit 05 : Digital CMOS Design (06 Hrs)

CMOS INVERTER, CMOS NAND and CMOS NOR, voltage transfer curve, body effect, hot electron effect, velocity saturation. Static and dynamic dissipations. Power delay product. Noise margin. Combinational logic design, comparison of CMOS and NMOS. Comparative study of TTL, ECL, CMOS.

Unit 06 : VLSI Design Applications**(06 Hrs)**

Barrel shifter, signed and unsigned comparators, Carry ripple and carry look, Ahead address, Fixed- point division, serial data receiver, parallel to serial converter, playing with a seven segment display and key board, signal generators, memory design, Vending - Machine controller.

Text Books:

- [T1] Douglas Perry, “VHDL”, Tata McGraw Hill.
- [T2] John F. Wakerly, “Digital Design, Principles and Practices”, Prentice Hall Publication
- [T3] Wolf, “Modern VLSI Design”, Pearson Education.
- [T4] R.P.Jain, “Modern Digital electronics”, 3rd edition, Tata McGraw-Hill.
- [T5] Donald P. Leach, Albert Paul Malvino, “Digital Principles and Applications”, Glencoe Publisher.
- [T6] Neil H. Weste and Kamran, “Principles of CMOS VLSI Design”, Pearson Publication.

Reference Books:

- [R1] Charles H. Roth, “Digital System Design Using VHDL”, PWS Publishing Company (Thomson Learning) 2.
- [R2] Sung-Mo(Steve) Kang, Yusuf Leblebici, “CMOS Digital Integrated Circuits”, Tata McGraw Hill Publication.
- [R3] J. Bhaskar, “VHDL Primer”, 3rd Edition, Addison Wesley Longman Singapore Pte Ltd.
- [R4] Volner A. Dedroni, “Circuit Design with VHDL”, PHI Publications
- [R5] Xilinx Data Manual “The Programmable Logic Data Book”.
- [R6] LizyKurian John, “Principles of Digital Systems Design and VHDL” Paperback – 2008 .
- [R7] Peter J. Ashenden (Author), Jim Lewis, “ VHDL-2008: Just the New Stuff”, (Systems on Silicon) Paperback – Import, 7 Dec 2007.
- [R8] Data Sheets of PLDs.

Unit	Text Books	Reference Books
1	T2,T4,T5	R3, R6
2	T1,T3	R3, R4, R7
3	T2,T1	R1, R6
4	T2	R5, R8
5	T6	R2
6	T2,T3	R6

403151: Project II

Teaching Scheme	Credits	Examination Scheme [150 Marks]
Tutorial : 06 Hrs./Week	06	Oral : 50 Marks Term work : 100 Marks

Course Objectives:

- To explore and to acquire specified skill in areas related to Electrical Engineering
- To develop skills for carrying literature survey and organize the material in proper manner.
- To provide opportunity of designing and building complete system/subsystem based on their knowledge acquired during graduation.
- To understand the needs of society and based on it to contribute towards its betterment and to learn to work in a team.
- To ensure the completion of given project such as fabrication, conducting experimentation, analysis, validation with optimized cost.
- Present the data and results in report form
- Communicate findings of the completed work systematically.

Course outcomes: Students will be able to

- Work in team and ensure satisfactory completion of project in all respect.
- Handle different tools to complete the given task and to acquire specified knowledge in area of interest.
- Provide solution to the current issues faced by the society.
- Practice moral and ethical value while completing the given task.
- Communicate effectively findings in verbal and written forms.

Guidelines :

The student shall complete the remaining part of the project which is an extension of the work carried out in VIIth Semester. For exceptional cases, change of topic has to be approved by Internal Assessment Committee consisting of Guide, Project Coordinator and Head of Department.

Student should incorporate suggestions given by examiner in project I.

The student shall complete the remaining part of the project which consists of design, simulation, fabrication of set up required for the project, analysis and validation of results and conclusions.

The student shall prepare duly certified final report of the project work in the standard format in MS Word / LaTeX.

Student should maintain Project Work Book.

Audit Course VI : 403153: Energy Storage Systems

Teaching Scheme

Theory : 02 Hrs. / Week
Field visit : 1 Day

Examination Schemes: Audit (P/F)

Written / MCQ / Term paper

Course Objectives:

- To elaborate various energy storage systems
- To be familiar with various aspects such as hybridization, selection and sizing of energy storage systems

Course Outcomes:

On completion of the course, students will be able to:-

- Explain and differentiate various types of energy storage systems

Energy Storage Systems:

1. Introduction to Energy Storage System: need, its types and applications.

a) Battery as an energy storage device, its types, Basic terms related to battery Energy Storage System such as Energy Density, Power Density, Cycle Life, C₁₀ Rating, State of Charge (SOC), Depth of Discharge (DOD), its characteristics and analysis of various batteries.

b) Types of Batteries: Characteristics, construction, economics, development status, future trends in batteries such as advanced lead-acid, lithium ion, polymer, Ni-Cd, metal hydride, sodium, and various types of flow batteries (vanadium, zinc, manganese, etc.).

c) Fuel Cell as an energy storage device and its analysis.

d) Supercapacitor as an energy storage device and its analysis.

e) Superconducting Energy Storage as an energy storage device and its analysis.

f) Flywheel as an energy storage device and its analysis.

Hybridization of different energy storage devices.

Sizing and selecting the energy storage technology and its supporting subsystems.

2. Case Studies: Design of a Hybrid Electric Vehicle (HEV), Design of a Battery Electric Vehicle (BEV) Introduction to energy management strategies used in hybrid and electric vehicles.

Experiments: There shall be a 3-4 exercises based on MATLAB and Simulink related to **Battery** energy storage, **Fuel Cell** energy storage and **Supercapacitor** energy storage.

Industrial Visit: Industrial visit to manufacturing industry of battery/ supercapacitor.