

**DIGITAL CONTROL SYSTEMS****Preamble:**

In recent years digital controllers have become popular due to their capability of accurately performing complex computations at high speeds and versatility in leading nonlinear control systems. In this context, this course focuses on the analysis and design of digital control systems.

**Learning objectives:**

- To understand the concepts of digital control systems and assemble various components associated with it. Advantages compared to the analog type.
- The theory of z-transformations and application for the mathematical analysis of digital control systems.
- To represent the discrete-time systems in state-space model and evaluation of state transition matrix.
- To examine the stability of the system using different tests.
- To study the conventional method of analyzing digital control systems in the w-plane.
- To study the design of state feedback control by “the pole placement method.”

**UNIT – I:****Introduction and signal processing**

Introduction to analog and digital control systems – Advantages of digital systems – Typical examples – Signals and processing – Sample and hold devices – Sampling theorem and data reconstruction – Frequency domain characteristics of zero order hold.

**UNIT-II:****z-transformations**

z-Transforms – Theorems – Finding inverse z-transforms – Formulation of difference equations and solving – Block diagram representation – Pulse transfer functions and finding open loop and closed loop responses.

**UNIT-III:****State space analysis and the concepts of Controllability and observability**

State space representation of discrete time systems – State transition matrix and methods of evaluation – Discretization of continuous – Time state equations – Concepts of controllability and observability – Tests(without proof).

**UNIT – IV:****Stability analysis**

Mapping between the s-Plane and the z-Plane – Primary strips and Complementary strips – Stability criterion – Modified Routh’s stability criterion and Jury’s stability test.

**UNIT – V:****Design of discrete-time control systems by conventional methods**

Transient and steady state specifications – Design using frequency response in the w-plane for lag and lead compensators – Root locus technique in the z-plane.

## **UNIT – VI:**

### **State feedback controllers:**

Design of state feedback controller through pole placement – Necessary and sufficient conditions – Ackerman's formula.

### **Learning outcomes:**

- The students learn the advantages of discrete time control systems and the “know how” of various associated accessories.
- The learner understand z-transformations and their role in the mathematical analysis of different systems (like Laplace transforms in analog systems).
- The stability criterion for digital systems and methods adopted for testing the same are explained.
- Finally, the conventional and state space methods of design are also introduced.

### **Text Book:**

1. Discrete-Time Control systems – K. Ogata, Pearson Education/PHI, 2nd Edition.
2. Digital Control and State Variable Methods by M.Gopal, TMH, 4<sup>th</sup> Edition.

### **Reference Books:**

1. Digital Control Systems, Kuo, Oxford University Press, 2nd Edition, 2003.

**H.V.D.C. TRANSMISSION****Preamble:**

This subject deals with the importance of HVDC transmission, analysis of HVDC converters, Faults and protections, Harmonics and Filters. It also deals with Reactive power control and Power factor improvements of the system.

**Learning Objectives:**

- To Understand basic concepts of HVDC Transmission.
- To analyze the converter configuration.
- To Know the control of converter and HVDC Transmission.
- To Understand the significance of reactive power control and AC/Dc load flow.
- To Know different converter faults, protection and effect of harmonics.
- To leave low pass and high pass filters.

**UNIT – I****Basic Concepts**

Economics & Terminal equipment of HVDC transmission systems: Types of HVDC Links – Apparatus required for HVDC Systems – Comparison of AC & DC Transmission, Application of DC Transmission System – Planning & Modern trends in D.C. Transmission.

**UNIT – II****Analysis of HVDC Converters**

Choice of converter configuration – analysis of Graetz – characteristics of 6 pulse & 12 pulse converters – Cases of two 3 phase converters in star – star mode – their performance.

**UNIT – III****Converter & HVDC System Control**

Principal of DC Link Control – Converters Control Characteristics – Firing angle control – Current and extinction angle control – Effect of source inductance on the system - Starting and stopping of DC link - Power Control.

**UNIT-IV****Reactive Power Control in HVDC**

Reactive Power Requirements in steady state-Conventional control strategies-Alternate control strategies-sources of reactive power-AC Filters – shunt capacitors-synchronous condensers.

**Power Flow Analysis In AC/DC Systems**

Modelling of DC Links-DC Network-DC Converter-Controller Equations-Solution of DC loadflow –solution of AC-DC Power flow-Simultaneous method-Sequential method.

**UNIT-V****Converter Fault & Protection**

Converter faults – protection against over current and over voltage in converter station – surge arresters –smoothing reactors – DC breakers –Audible noise-space charge field-corona effects on DC lines-Radio interference.

**Harmonics**

Generation of Harmonics –Characteristics harmonics, calculation of AC Harmonics, Non-Characteristics harmonics, adverse effects of harmonics – Calculation of voltage & Current harmonics – Effect of Pulse number on harmonics.

## **UNIT-VI**

### **Filters**

Types of AC filters, Design of Single tuned filters – Design of High pass filters.

#### **Learning Outcomes:**

The Student shall be able to

- Learn different types of HVDC levels and basic concepts
- Know the operation of converters
- Acquire control concept of reactive power control and AC/DC load flow.
- Understand converter faults, protection and harmonic effects
- Design low pass and high pass filters

#### **Text Books:**

1. HVDC Power Transmission Systems: Technology and system Interactions – by K.R.Padiyar, New Age International (P) Limited, and Publishers.
2. HVDC Transmission by S.Kamakshaiah and V.Kamaraju-Tata McGraw-Hill

#### **Reference Books:**

1. HVDC Transmission – J.Arrillaga.
2. Direct Current Transmission – by E.W.Kimbark, John Wiley & Sons.
3. Power Transmission by Direct Current – by E.Uhlmann, B.S.Publications.

**ELECTRICAL DISTRIBUTION SYSTEMS****Preamble:**

This subject deals with the general concept of distribution system, substations and feeders as well as discusses distribution system analysis, protection and coordination, voltage control and power factor improvement.

**Learning Objectives**

- To study different factors of Distribution system.
- To study and design the substations and distribution systems.
- To study the concepts of voltage drop and power loss.
- To study the distribution system protection and its coordination.
- To study the effect of compensation for power factor improvement.
- To study the effect of voltage control on distribution system.

**UNIT – I:****General Concepts**

Introduction to distribution systems, Load modeling and characteristics – Coincidence factor – Contribution factor loss factor – Relationship between the load factor and loss factor – Classification of loads (Residential, commercial, Agricultural and Industrial).

**UNIT – II:****Substations**

Location of substations: Rating of distribution substation – Service area with 'n' primary feeders – Benefits and methods of optimal location of substations..

**Distribution Feeders**

Design Considerations of distribution feeders: Radial and loop types of primary feeders – Voltage levels – Feeder loading – Basic design practice of the secondary distribution system.

**UNIT – III:****System Analysis**

Voltage drop and power-loss calculations: Derivation for voltage drop and power loss in lines – Uniformly distributed loads and non-uniformly distributed loads – Numerical problems - Three phase balanced primary lines.

**UNIT – IV:****Protection**

Objectives of distribution system protection – Types of common faults and procedure for fault calculations for distribution system – Protective devices: Principle of operation of fuses – Circuit reclosures – Line sectionalizes and circuit breakers.

**Coordination**

Coordination of protective devices: General coordination procedure – Various types of coordinated operation of protective devices - Residual Current Circuit Breaker

**UNIT – V:****Compensation for Power Factor Improvement**

Capacitive compensation for powerfactor control – Different types of power capacitors – shunt and series capacitors – Effect of shunt capacitors (Fixed and switched) – Power factor correction – Capacitor allocation – Economic justification – Procedure to determine the best capacitor location – Numerical problems.

## **UNIT – VI:**

### **Voltage Control**

Voltage Control: Equipment for voltage control – Effect of series capacitors – Effect of AVB/AVR – Line drop compensation – Numerical problems.

### **Learning Outcomes:**

- Able to understand various factors of distribution system.
- Able to design the substation and feeders.
- Able to determine the voltage drop and power loss
- Able to understand the protection and its coordination.
- Able to understand the effect of compensation for p.f improvement.
- Able to understand the effect of voltage control.

### **Text Book:**

1. “Electric Power Distribution system, Engineering” – by TuranGonen, McGraw–hill Book Company.

### **Reference Books:**

1. Electrical Distribution Systems by Dale R.Patrick and Stephen W.Fardo, CRC press
2. Electric Power Distribution – by A.S. Pabla, Tata McGraw–hill Publishing company, 4<sup>th</sup> edition, 1997.
3. Electrical Power Distribution Systems by V.Kamaraju, Right Publishers.

## **HIGH VOLTAGE ENGINEERING (ELECTIVE – III)**

### **Preamble:**

With the growth of power, HV power transmission has become an important subject. The performance of generating equipment requires knowledge of different phenomena occurring at higher voltage. Thus evaluations of various insulating materials are required for protection of HV equipments. Keeping this in view the course is designed to understand various phenomena related to breakdown study and withstand characteristics of insulating materials. The course also describes the generation and measurement of DC, AC and Impulse voltages as well various testing techniques.

### **Learning Objectives:**

- To understand electric field distribution and computation in different configuration of electrode systems.
- To understand HV breakdown phenomena in gases, liquids and solids dielectrics.
- To acquaint with the generating principle of operation and design of HVDC, AC and Impulse voltages and currents.
- To understand various techniques of AC, DC and Impulse measurement of high voltages and currents.
- To understand the insulating characteristics of dielectric materials.
- To understand the various testing techniques of HV equipments.

### **UNIT-I:**

#### **Introduction to High Voltage Technology**

Electric Field Stresses – Uniform and non-uniform field configuration of electrodes – Estimation and control of electric Stress – Numerical methods for electric field computation.

### **UNIT-II:**

#### **Break down phenomenon in gaseous, liquid and solid insulation**

Gases as insulating media – Collision process – Ionization process – Townsend's criteria of breakdown in gases – Paschen's law – Liquid as Insulator – Pure and commercial liquids – Breakdown in pure and commercial liquid – Intrinsic breakdown – Electromechanical breakdown – Thermal breakdown – Breakdown of solid dielectrics, composite dielectrics used in practice.

### **UNIT-III:**

#### **Generation of High voltages and High currents**

Generation of high DC voltages – Generation of high alternating voltages – Generation of impulse voltages and currents – Tripping and control of impulse generators.

### **UNIT-IV:**

#### **Measurement of high voltages and High currents**

Measurement of high AC, DC and Impulse voltages – Voltages and measurement of high currents – Direct, alternating and Impulse.

## **UNIT–V:**

### **Non-destructive testing of material and electrical apparatus**

Measurement of DC resistivity – Measurement of dielectric constant and loss factor – Partial discharge measurements.

## **UNIT–VI:**

### **High voltage testing of electrical apparatus**

Testing of insulators and bushings – Testing of isolators and circuit breakers – Testing of cables – Testing of transformers – Testing of surge arresters – Radio interference measurements.

### **Learning Outcomes:**

- To be acquainted with the performance of high voltages with regard to different configurations of electrode systems.
- To be able to understand theory of breakdown and withstand phenomena of all types of dielectric materials.
- To acquaint with the techniques of generation of AC,DC and Impulse voltages.
- To be able to apply knowledge for measurement of high voltage and high current AC,DC and Impulse.
- To be in a position to measure dielectric property of material used for HV equipment.
- To know the techniques of testing various equipment's used in HV engineering.

### **Text Books:**

1. High Voltage Engineering: Fundamentals by E.Kuffel, W.S.Zaengl, J.Kuffel by Elsevier, 2<sup>nd</sup> Edition.
2. High Voltage Engineering and Technology by Ryan, IET Publishers.

### **Reference Books:**

1. High Voltage Engineering by M.S.Naidu and V. Kamaraju – TMH Publications, 3rd Edition
2. High Voltage Engineering by C.L.Wadhwa, New Age International (P) Limited, 1997.
3. High Voltage Insulation Engineering by RavindraArora, Wolfgang Mosch, New Age International (P)Limited,1995.



## **FLEXIBLE ALTERNATING CURRENT TRANSMISSION SYSTEMS**

### **Preamble:**

Flexible Alternating Current Transmission System controllers have become a part of modern power system. It is important for the student to understand the principle of operation of series and shunt compensators by using power electronics. As the heart of many power electronic controllers is a voltage source converter (VSC), the student should be acquainted with the operation and control of VSC. Two modern power electronic controllers are also introduced.

### **Learning Objectives:**

- To learn the basics of power flow control in transmission lines using FACTS controllers
- To explain operation and control of voltage source converter.
- To understand compensation methods to improve stability and reduce power oscillations of a power system.
- To learn the method of shunt compensation using static VAR compensators.
- To learn the methods of compensation using series compensators
- To explain operation of Unified Power Flow Controller (UPFC).

### **Unit-I:**

#### **Introduction to FACTS**

Power flow in an AC System – Loading capability limits – Dynamic stability considerations – Importance of controllable parameters – Basic types of FACTS controllers – Benefits from FACTS controllers – Requirements and characteristics of high power devices – Voltage and current rating – Losses and speed of switching – Parameter trade-off devices.

### **Unit-II:**

#### **Voltage source and Current source converters**

Concept of voltage source converter(VSC) – Single phase bridge converter – Square-wave voltage harmonics for a single-phase bridge converter – Three-phase full wave bridge converter– Three-phase current source converter – Comparison of current source converter with voltage source converter.

### **Unit-III:**

#### **Shunt Compensators-1**

Objectives of shunt compensation – Mid-point voltage regulation for line segmentation – End of line voltage support to prevent voltage instability – Improvement of transient stability – Power oscillation damping.

### **Unit-IV:**

#### **Shunt Compensators-2**

Thyristor Switched Capacitor(TSC)–Thyristor Switched Capacitor – Thyristor Switched Reactor (TSC–TCR). Static VAR compensator(SVC) and Static Compensator(STATCOM): The regulation and slope transfer function and dynamic performance – Transient stability enhancement and power oscillation damping– Operating point control and summary of compensation control.

**Unit V:****Series Compensators**

Static series compensators: Concept of series capacitive compensation – Improvement of transient stability – Power oscillation damping – Functional requirements. GTO thyristor controlled Series Capacitor (GSC) – Thyristor Switched Series Capacitor (TSSC) and Thyristor Controlled Series Capacitor (TCSC).

**Unit–VI:****Combined Controllers**

Schematic and basic operating principles of Unified Power Flow Controller (UPFC).– Application on transmission lines.

**Learning Outcomes:**

The student should be able to

- Understand power flow control in transmission lines using FACTS controllers.
- Explain operation and control of voltage source converter.
- Analyze compensation methods to improve stability and reduce power oscillations in the transmission lines.
- Explain the method of shunt compensation using static VAR compensators.
- Understand the methods of compensations using series compensators.
- Explain operation of Unified Power Flow Controller (UPFC).

**Text Books:**

1. “Understanding FACTS” N.G.Hingorani and L.Guygi, IEEE Press.Indian Edition is available:—Standard Publications, 2001.

**Reference Books:**

1. “Flexible ac transmission system (FACTS)” Edited by Yong Hue Song and Allan T Johns, Institution of Electrical Engineers, London.
2. Thyristor-based FACTS Controllers for Electrical Transmission Systems, by R.MohanMathur and Rajiv k.Varma, Wiley

## **POWER SYSTEM REFORMS (Elective III)**

### **Preamble:**

This course introduces the concepts and issues of power system reforms and aims at computation of Available Transfer Capability (ATC), Congestion Management, Electricity Pricing, Ancillary services Management and Power system operation in competitive environment

### **Learning Objectives:**

- To study fundamentals of power system deregulation and restructuring.
- To study available transfer capability.
- To study congestion management
- To study various electricity pricing methods.
- To study operation of power system in deregulated environment.
- To study importance of Ancillary services management.

### **UNIT-I**

#### **Over view of key issues in electric utilities**

Introduction – Restructuring models – Independent system operator (ISO) – Power Exchange – Market operations – Market Power – Standard cost – Transmission Pricing – Congestion Pricing – Management of Inter zonal/Intra zonal Congestion.

### **UNIT-II**

#### **Available Transfer Capability (ATC)**

Structure of OASIS – Processing of Information – Transfer capability on OASIS – Definitions Transfer Capability Issues – ATC – TTC – TRM – CBM calculations – Methodologies to calculate ATC.

### **UNIT-III**

#### **Congestion Management**

Introduction to congestion management – Methods to relieve congestion

### **UNIT-IV**

#### **Electricity Pricing:**

Introduction – Electricity price volatility electricity price indexes – Challenges to electricity pricing – Construction of forward price curves – Short-time price forecasting.

### **UNIT-V**

#### **Power system operation in competitive environment:**

Introduction – Operational planning activities of ISO – The ISO in pool markets – The ISO in bilateral markets – Operational planning activities of a GENCO.

### **UNIT-VI**

#### **Ancillary Services Management:**

Introduction – Reactive power as an ancillary service – A review – Synchronous generators as ancillary service providers.

**Learning Outcomes:**

- Will understand importance of power system deregulation and restructuring.
- Able to compute Available Transfer Capability.
- Will understand transmission congestion management.
- Able to compute electricity pricing in deregulated environment.
- Will be able to understand power system operation in deregulated environment.
- Will understand importance of ancillary services.

**Text Books:**

1. Kankar Bhattacharya, Math H.J. Boller, JaapE.Daalder, 'Operation of Restructured Power System' Kluwer Academic Publisher – 2001.
2. Mohammad Shahidehpour, and Muwaffaqalomoush, – “Restructured electrical Power systems” Marcel Dekker, Inc. 2001

**Reference Books:**

1. Loi Lei Lai; “Power system Restructuring and Deregulation”, Jhon Wiley & Sons Ltd., England.
2. Electrical Power Distribution Case studies from Distribution reform, upgrades and Management (DRUM) Program, by USAID/India, TMH