EE103:

Power System Control & Stability
Training Description:

The robustness of a power system is measured by the ability of the system to operate in a state of equilibrium under normal and perturbed conditions. Power system stability deals with the study of the behavior of power systems under conditions such as sudden changes in load or generation or short circuits on transmission lines.

A power system is said to be stable if the interconnected generating units remain in synchronism. The ability of a power system to maintain stability depends to a large extent on the controls available on the system to damp the electromechanical oscillations. Hence, the study and design of controls are very important. Of all the complex phenomena on power systems, power system stability is the most intricate to understand and challenging to analyze. Electric power systems of the 21st century present an even more formidable challenge as they are forced to operate closer to their stability limits.

This intensive training course is concerned with understanding, modelling, analyzing, and mitigating power system stability and control problems. Such problems constitute very important considerations in the planning, design, and operation of modern power systems.

The complexity of power systems is continually increasing because of the growth in interconnections and use of new technologies. At the same time, financial and regulatory constraints have forced utilities to operate the systems nearly at stability limits. These two factors have created new types of stability problems. Greater reliance is, therefore, being placed on the use of special control aids to enhance system security, facilitate economic design, and provide greater flexibility of system operation. In addition, advances in computer technology, numerical analysis, control theory, and equipment modelling have contributed to the development of improved analytical tools and better system-design procedures. The primary motivation for this course is to describe these new developments and to provide a comprehensive treatment of the subject.

The course is intended to meet the needs of practicing engineers associated with the electric utility industry as well as those of graduate students and researchers. The course will provide the necessary fundamentals, explaining the practical aspects, and giving an integrated treatment of the latest developments in modeling techniques and analytical tools.

Training Objectives:

By the end of the training, participants will be able to:

✓ Apply and gain an in-depth knowledge on power system control and stability
✓ Discuss the basic concepts, definitions, classification of stability and historical review of stability problems
✓ Recognize synchronous machine theory and modeling, physical description and mathematical description of a synchronous machine
✓ Describe the dq0 transformation, per unit representation, equivalent circuits for direct and quadrature and steady-state analysis
✓ Identify electrical transient performance characteristics, magnetic saturation and equations of motion
Differentiate synchronous machine parameters, operational parameters, standard parameters, frequency-response characteristics and determination of synchronous machine parameters

Explain synchronous machine representation in stability studies, simplifications essential for large-scale studies, neglect of stator pψ terms and neglecting the effect of speed variations on stator voltages

Illustrate simplified model with amortisseurs neglected and constant flux linkage model

Recognize reactive capability limits, AC transmission, transmission lines, transformers, transfer of power between active sources, power flow analysis, power system loads, basic load-modelling concepts, modeling of induction motors, acquisition of load-model parameters and excitation systems

Enumerate the elements and the various types of excitation systems

Carry out dynamic performance measures, control and protective functions, excitation systems and field testing for model development and verification

Training Designed for:

This course is intended for electrical managers, engineers, planners, supervisors and other technical staff involved in the stability and control of electrical power systems.

Training Program:

**DAY ONE:**

- **PRE-TEST**
- **Introduction to the Power System Stability Problem**
- **Basic Concepts & Definitions**
  - Power Versus Angle Relationship, The Stability Phenomena
  - Voltage Stability & Voltage Collapse, Mid-Term & Long-Term Stability
- **Classification of Stability**
- **Historical Review of Stability Problems**
- **Synchronous Machine Theory & Modelling**
- **Physical Description**
  - Armature & Field Structure, Machines with Multiple Pole Pairs
  - MMF Waveforms, Rotating Magnetic Field, Direct & Quadrature Axes
- **Mathematical Description of a Synchronous Machine**
  - Review of Magnetic Circuit Equations Single Excited Circuit
  - Coupled Circuits, Basic Equations of a Synchronous Machine
  - Stator Circuit Equations, Stator Self-Inductances, Stator Mutual Inductances
  - Mutual Inductance Between Stator & Rotor Windings, Rotor Circuit Equations
- **The dq0 transformation**
  - Stator Flux Linkages in dq0 Components, Rotor Flux Linkages in dq0 Components
  - Stator Voltage Equations in dq0 Components, Electrical Power & Torque
  - Physical Interpretation of dq0 Transformation
**DAY TWO:**

- **Per Unit Representation**
  - Per Unit System for the Stator Quantities
  - Per Unit Stator Voltage Equations, Per Unit Rotor Voltage Equations
  - Stator Flux Linkage Equations, Rotor Flux Linkage Equations
  - Per Unit System for the Rotor, Per Unit Power & Torque, Summary of per Unit Equations
  - Complete Set of Electrical Equations in Per Unit, Per Unit Reactances

- **Equivalent Circuits for Direct & Quadrature Axes**

- **Steady-State Analysis**
  - Voltage, Current, & Flux Linkage Relationships
  - Field Current, Phasor Representation, Rotor Angle
  - Procedure for Computing Steady-State Values

- **Electrical Transient Performance Characteristics**
  - Short-circuit Current in a Simple RL Circuit
  - Three-phase Short-circuit at the Terminals of a Synchronous Machine
  - Elimination of DC Offset in Short-Circuit Current

- **Magnetic Saturation**
  - Open-circuit & Short-circuit Characteristics
  - Representation of Saturation in Stability Studies
  - Improved Modelling of Saturation, Use of Potier Reactance

- **Equations of Motion**
  - Review of Mechanics of Motion, Swing Equation, Per Unit Moment of Inertia
  - Mechanical Starting Time, Calculation of Inertia Constant
  - Calculation of H from Moment of Inertia in MKS Units
  - Calculation of H from WR2 in English Units, Typical Values of H
  - Representation in System Studies

- **Synchronous Machine Parameters**

- **Operational Parameters**

- **Standard Parameters**
  - Parameters Based on Classical Definitions, Accurate Expressions for Standard Parameters
  - Parameters Including Unequal Mutual Effects, Parameters of Salient Pole Machines
  - Typical Values of Standard Parameters

**DAY THREE:**

- **Frequency-response Characteristics**
  - Armature Time Constant

- **Determination of Synchronous Machine Parameters**
  - Enhanced Short-Circuit Tests, Decrement Tests
  - Frequency-Response Tests (Standstill Frequency Response (SSFR), Open-Circuit Frequency Response (OCFR), On-Line Frequency Response (OLFR))
  - Calculation of Machine Parameters from Design Data

- **Synchronous Machine Representation in Stability Studies**

- **Simplifications Essential for Large-scale Studies**
Neglect of Stator $\Psi$ Terms

Neglecting the Effect of Speed Variations on Stator Voltages

- Relationship between Per Unit $P_e$ & $T_e$

Simplified Model with Amortisseurs Neglected

- Alternative form of Machine Equations, Phasor Diagram for Transient Conditions

Constant Flux Linkage Model

- Classical Model
- Constant Flux Linkage Model Including the Effects of Subtransient Circuits
- Summary of Simple Models for Different Time Frames

Reactive Capability Limits

- Reactive Capability Curves, Armature Current Limit, Field Current Limit
- End Region Heating Limit, V Curves and Compounding Curves

**DAY FOUR:**

- AC Transmission

  - Transmission Lines
    - Electrical Characteristics (Overhead Lines, Underground Cables)
    - Performance Equations, Natural or Surge Impedance Loading
    - Equivalent Circuit of a Transmission Line, Nominal $\pi$ Equivalent Circuit
    - Classification of Line Length, Typical Parameters (Overhead Lines, Underground Cables)
    - Performance Requirements of Power Transmission Lines
    - Voltage & Current Profile Under No-Load (Receiving End Open-Circuited, Line Connected to Sources at both Ends)
    - Voltage-Power Characteristics [4,10] (Radial Line with Fixed Sending End Voltage, Line Connected to Sources at Both Ends)
    - Power Transfer & Stability Considerations, Reactive Power Requirements
    - Effect of Line Loss On V-P and Q-P Characteristics, Thermal Limits
    - Loadability Characteristics, Effect of Using Bundled Conductors

- Transformers
  - Representation of Two-Winding Transformers (Basic Equivalent Circuit in Physical Units, Per Unit Equivalent Circuit, Standard Equivalent Circuit, Equivalent $\pi$ Circuit Representation, Consideration of Three-Phase Transformer Connections)
  - Example of Modelling Two-Winding Transformers
  - Representation of Three-Winding Transformers (Example of Modelling Three-Winding Transformers)
  - ULTC Data, H-L Branch, L-T Branch
  - Phase-Shifting Transformers (Example of Modelling a Phase-Shifting Transformer)

- Transfer of Power Between Active Sources

- Power-Flow Analysis
  - Bus Classification, Representation of Network Elements, Network Equations
  - Nonlinear Power-Flow Equations, Gauss-Seidel Method
  - Newton-Raphson (N-R) Method, Application of the N-R Method to Power-Flow Solution
  - Sensitivity Analysis Using the Jacobian, Fast Decoupled Load-Flow (FDLF) Methods
  - Comparison of the Power-Flow Solution Methods
- Sparsity-Oriented Triangular Factorization, Network Reduction
- **Power System Loads**
- **Basic Load-modelling Concepts**
  - Static Load Models, Dynamic Load Models
  - Thermastically Controlled Loads, Discharge Lighting Loads
- **Modelling of Induction Motors**
  - Equations of an Induction Machine, Basic Equations of an Induction Machine
  - The d-q Transformation, Basic Machine Equations in d-q Reference Frame
  - Electrical Power & Torque, Acceleration Equation
  - Steady-state Characteristics, Equivalent Circuit
  - Torque-slip Characteristic, Effect of Rotor Resistance on Efficiency
  - Alternative Rotor Constructions, Representation of Saturation
  - Per Unit Representation, Representation in Stability Studies
  - Simplified Induction Machine Model, Induction Motor Parameters
- **Simulators (Hands-on Practical Sessions)**
  - Practical sessions will be organized during the course for participants to practice the theory learnt. Participants will be provided with an opportunity to carryout various exercises using our state-of-the-art simulators “Power World” and “ETAP software”

**DAY FIVE:**
- **Acquisition of Load-Model Parameters**
  - Two Basic Approaches to the Determination of System-Load Characteristics (Measurement-based Approach, Component-based Approach)
  - Measurement-Based Approach, Steady State Load-Frequency Characteristics
  - Dynamic Load-Voltage Characteristics, Component-Based Approach
  - Sample Load Characteristics (Component Static Characteristics, Load Class Static Characteristics, Dynamic Characteristics)
- **Excitation Systems**
  - Generator Considerations, Power System Considerations
- **Elements of an Excitation System**
  - Exciter, Regulator, Terminal Voltage Transducer & Load Compensator
  - Power System Stabilizer, Limiters and Protective Circuits
- **Types of Excitation Systems**
  - DC Excitation Systems
  - Field Flashing for Static Exciters, Recent Developments & Future Trend
- **Dynamic Performance Measures**
- Small-Signal Performance Measures

❖ Control & Protective Functions
- AC & DC Regulators, Excitation System Stabilizing Circuits
- Power System Stabilizer (PSS), Load Compensation
- Underexcitation Limiter, Overexcitation Limiter
- Volts-Per-Hertz Limiter and Protection, Field-Shorting Circuits

❖ Modelling of Excitation Systems
- Per Unit System, Specification of Temperature
- Type AC4A Exciter Model, Type ST1A Exciter Model
- Type ST2A Exciter Model, Modelling of Limiters
- Underexcitation Limiter (V/Hz Limiter, Field-Current or Overexcitation Limiter)

❖ Field Testing for Model Development & Verification
❖ Course Conclusion
❖ POST-TEST and EVALUATION

Training Requirement:

“Hand’s on practical sessions, equipment and software will be applied during the course if required and as per the client’s request.”

Practical sessions will be organized during the course for participants to practice the theory learnt. Participants will be provided with an opportunity to carry out various exercises using our state-of-the-art simulators “Power World” and “ETAP software”.

Please note that the above topics can be amended as per client’s learning needs and objectives. Further, it should be forwarded to us a month prior to the course dates.

Training Methodology:

This interactive training course includes the following training methodologies as a percentage of the total tuition hours:
- 30% Lectures, Concepts, Role Play
- 70% Workshops & Work Presentations, Techniques, Based on Case Studies & Practical Exercises, Software & General Discussions
- Pre and Post Test

Training Certificate(s):

Internationally recognized certificate(s) will be issued to each participant who completed the course.
Training Fees:

As per the course location - This rate includes participant’s manual, hand-outs, buffet lunch, coffee/tea on arrival, morning & afternoon of each day.

Note: The 5% VAT (Value Added Tax), will be effective starting 01st of January 2018 as per the new regulation from the UAE Government. The VAT applies for all quotation both for local and abroad.

Training Timings:

Daily Timings:
- 07:45 - 08:00  Morning Coffee / Tea
- 08:00 - 10:00  First Session
- 10:00 - 10:20  Recess (Coffee/Tea/Snacks)
- 10:20 - 12:20  Second Session
- 12:20 - 13:30  Recess (Prayer Break & Lunch)
- 13:30 - 15:00  Last Session

For training registrations or in-house enquiries, please contact:
Aisha Relativo: aisha@cmc-me.com
Tel.: +971 2 665 3945 or +971 2 643 6653 | Mob.: +971 52 2954615
Training & Career Development Department