Course 2:- Training Program Agenda

2-ELECTRICAL POWER SYSTEM STUDY & ANALYSIS-RMS DOMAIN

1. Introduction

The session will cover training in following power system analysis..

- Load Flow
- Time Domain Load Flow
- Contingency load flow analysis and Voltage Stability-PV & QV curve
- Short Circuit Studies
- Transient Stability-Large & Small Disturbance
- Motor Acceleration transient Studies
- Protection concepts and back protection current and time coordination
- EMTP basic concepts and studies
- Other Basic

Training will cover: -

- Types of software used for electrical network model and simulation of various system conditions and differences between RMS and phasor domain analysis software tool (ETAP PSSSE & DigSILENT PowerFactory) and EMTP instantaneous switching mode domain software tool (PSCAD) for capturing transient phenomena and the behavior of power electronic devices.
- Understanding of system component mathematical modeling and the data input requirements
- References & assumptions & tips for modeling in case of non-availability of input data for components.
- Classical theory and standards comparison
- Analysis & understanding of the expectations from a calculation or simulation.
- Correlation and double checking of results using Excel where possible (Excel calculation of some of the studies for comparison with RMS tool results.)
- PU concept and symmetrical components covering positive negative and zero sequence current voltage and impedance calculations.
- Equipment sizing & verification.
- Identifying and understanding the factors causing technical & operational limitations in the system.
- Case Studies
- Question & Answers
- Provision of several technical reference materials and notes (in soft files) covering various aspect of power systems

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2. Electrical Power System Component Modeling

- Busbar: - Nominal and off nominal voltage and initial voltage and voltage angle.
- Grid: - Equivalent system and its short circuit kA or MVA and equivalent X/R ratio.
- Two & Three Winding Transformers: - Rating, Voltage Ratio, Vector group, X/R ratio, manual off load tap changer and automatic voltage regulator/on load tap changer.
- System neutral earthing concepts modeling. System Earthing, NGT / NGR & Zig Zag Transformer, NGR sizing considerations, NGT sizing considerations, Voltage rating of the NGR/NGT, Parameters & Modelling inputs
- Loads: - Types Of Loads & their significance such as Constant Power Load, Constant Impedance Load
- Motor: - modeling motor as static constant power load and/or as a dynamic load.
- Motor dynamic modeling theory and model testing with technical data sheet by modeling details of motor torque, current and power factor versus slip, motor load torque versus slip and motor plus load inertia.
- Synchronous Machines: -Machine rating, Capability curve, active power injection, reactive power control, Sub transient Reactance, Transient Reactance, Synchronous impedance, Negative & Zero sequence reactance, Direct axis & Quadrature axis model representation along with their time constants. Terminal machine fault decrement, Active and reactive power out and stability and loss of synchronism. Control of active power and frequency, Control of reactive power and voltage. Machine inertia and inertia constant, Open and short-circuit characteristics of a synchronous machine, saturated and unsaturated value of synchronous reactance and short circuit ratio (SCR) of generators connected to transmission line or cable.
- Generator AVR/exciter & turbine-governor control system overview and standard IEEE model availability in various software's and their application and role in frequency and voltage control as well as generator active and reactive load power sharing
- Modelling Inputs Typical Synchronous Machine and its significance, Selection of various generator parameters, basic understanding of impedance parameter and time constants, power capability diagram. Generator load allocation.
- Understanding of swing or PQ or PV generation bus and their use
- Testing of load modeled

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- Harmonic Filters / PFIC: - Selection of tuning frequency for % reactor used with power factor improvement capacitors (PFIC)
- Shunt Reactor selection of location and capacity of shunt reactor for line capacitive charging MVAR to avoid delayed current zero (DCZ) on shunt compensated lines during switching.Rating, % reactance, Losses,
- Power factor improving shunt capacitors. Shunt Capacitor with series reactor selection for surge and harmonic suppression and for improving power factor to meet statutory requirements.
- Transmission Line Typical Parameters, Surge Impedance, need for Frequency dependent Model.Rating of line based on site ampacity evaluated thermal limit and maximum permissible power evacuation stability power angle, voltage drop limit. Modelling Parameters for Long, Medium, and short lines. Pi model and Double pi model of transmission lines, ABCD parameters concepts. Bergeron model and Frequency dependent models. Transmission Line Modelling (Assessment Of R, X & B constants, and ampacity),
- Cable typical parameters, Type of cables and their insulation, Surge Impedance, Frequency dependent Model. Rating of cable based on site ampacity evaluated thermal limit and maximum permissible power evacuation stability power angle, voltage drop limit, and short circuit withstand rating. Category A, B & C cables, earthed or unearthed grade cable voltage ratings. Modelling parameters for long, medium, and short length cables.
- Cable R, XL & susceptance compared to its overhead line value
- Circuit Breaker normal and short circuit ratings. Differences between LV & HV circuit breaker in terms of short circuit rating specification.
- Solar PV module & array & Wind turbine generation library and model
- Wind Turbine (Type-3 & 4), Rating, Active Power, Reactive power range, crowbar protection, fault injection capability. Modelling Inputs.
- Renewable generation inverters rating, DC to AC array rating, Maximum & European efficiency, Active Power, Reactive power range, fault injection capability, Curtailment of Power. Grid support capability including VRT, black start, voltage and frequency regulation, voltage droop control, grid forming and grid flowing control. Smart Inverters with volt-var control for local voltage control by reactive power absorption or injection with Q priority and P curtailment features to accommodate Q requirements. Capability curve and definition of reactive power limits (day time and night time) Mode of operation (Q mode, pf mode and Q(V) mode). Modelling Inputs

- STATCOM & SVC Rating, Reactive power range, voltage control capability, Possibility of active harmonic filtering, Voltage dependency of the output Modelling Inputs

3. **Software types and simulation architecture and user interface covering: -**
   - Creation of One-Line Diagram,
   - Libraries (data and interface). Examples for creating library of typical cable, motor, motor load, HV CB, LV CB, harmonics load etc.
   - selection of project standard and changing settings of load and generation category and project titles.
   - Understanding Use of 3-Dimensional Database in ETAP using single file for changing data, switching circuits off and changing view of SLD
     - Presentation and use of different SLD for different studies
     - Configuration related to different operating status of various switching devices.
     - Changing data using revision to conduct what if analysis with different component parameters,
     - Report Manager,
     - Scenario Wizard,

4. **Load Flow Studies & Analysis Covering: -**
   - Theory & background
   - Excel hand calculation of a branch load flow exercise using classical theory for comparison with ETAP.
   - PU concept and ABCD parameters for quick Excel/hand calculation of load flow voltage drop, power flow losses and bus angles assessment
   - Understanding of driving parameters, iteration selection, % bus loading category and generation loading category selection for load flow run
   - Setting of Load flow alerts and alarm in reports.
   - Case Study SLD with creation of various cases, configurations, and parameter changes
   - Case study to include typical multi voltage level substation with load variations and varying system circuit operating conditions.
     - Peak Load
     - Average Load
     - Minimum Load

- Analysis of system bus % voltage, voltage angle, branch real and reactive power losses, source end power factor under varying source voltage conditions.
- Analysis of load flow summary of overall system losses, generation and loads etc.
- Power factor improvement capacitor connection and modeling of 6 % or 7 % or 14 % series reactor with capacitor to form detuned filters for power factor improvement.
- Study of Capacitor kvar variation with voltage.
- Use of ETAP scenario wizard for setting up case studies for easy case study run and reporting
- Cases for load sharing between generators and grid under varying load conditions covering PV (voltage control), PQ (Mvar control) & V, delta (Swing) bus mode selection of generators and sources.
- Load flow example to model motor load list with continuous, intermittent and stand by loads along with transformer sizing.
- One of the software will be used to create scenarios' simulations calculation and analysis and summarising mitigation requirement
- Need for time varying load flow to study impact on system under load and generation variation.

5. **Short Circuit Studies & Analysis Covering: -**
   - Theory & background
   - Excel calculation of a typical model of ac and dc fault current decrement based on standard tested CB both for LV & HV.
   - Importance of system component X/R ratio for peak making fault calculation and for assessment of dc component at fault break.
   - Switchgear/CB Duty calculation using ETAP to compare system peak making, symmetrical and asymmetrical break short circuit current with corresponding rated CB duty parameters.
   - Understanding differences in HV CB standard IEC 62227 (previously IEC 60056) & LV CB standard IEC 60947 and the short circuit calculation standard IEC 60909
   - Understanding generating sources with and without AC fault decay. Differences in grid and generator in terms AC fault decay
   - Motor Model review for checking motor contribution to fault.
   - Brief comparison of fault calculation based on classical theory and IEC 60909 standard.
   - Impedance correction factor for generators and transformers to take pre-fault load effects in fault current.

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- Assessment of HV Switchgear / CB duty in terms of peak making rating, symmetrical and asymmetrical break rating, % dc component at break and 1 or 3 second withstand.
- Assessment of LV Switchgear / CB duty in terms of Icu, Icm, Ics, Icw which are related to reference short circuit ultimate current, peak making rating, symmetrical and asymmetrical rating, % dc component at break and 1 or 3 second withstand.
- Use of C factor as per IEC 60909 and understanding the variations in fault due to effect transformer taps.
- Understanding use of Method A or B or C for calculation of peak making short circuit current.
- LLG, LG, LL short circuit calculation with assessment of sequence voltage and currents i.e. positive sequence, negative sequence and zero sequence fault values of current and voltage.
- Understanding of driving parameters, motor status selection for short circuit run
- Setting of short circuit alerts and alarm in reports.
- Case Study SLD creation with creation of various cases, configurations and parameter changes
- Analysis of system bus LLL, LLG, and LL fault results
- Brief Comparison of IEC & IEEE standards.
- Case study runs with IEC 61363 used as standard in shipping applications.

6. **Transient Stability will cover.**
   - Introduction to Transients & fundamentals on power system dynamics and stability as well as induction and synchronous machine dynamics.
   - Power System Transient Stability Overview
   - Introduction to Exciter & Governor Block Diagrams
   - Overview on Laplace Transform, Transfer Function, Control System Modeling & Analysis
   - Generator AVR/Exciter & Turbine Governor & their application and role in frequency and voltage control as well as generator active and reactive load power sharing
   - Network and load modeling, steady-state and transient-state stability limits, simulation of system disturbances and actions, effects of system parameters, common transient stability studies such as critical fault clearing time, critical islanding time, protective device settings, bus transfer by checking bus voltage / Hz vector difference, load shedding using frequency relay, etc.

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- Voltage & Frequency Recovery & Machine Rotor Angle Instability Analysis Studies Associated with Large Disturbance As Well As Small Disturbance Stability.
- Power System Stabilizer for Small Disturbance Stability
- Synchronous Generator Technical Operating Aspects & Equations
- Under/Over Voltage and Under/Over frequency relay setting from transient simulation responses.
- Induction and synchronous motor dynamic topics cover modelling, Dynamic Motor Modeling, Motor Reacceleration Transients After Faults
- Overview on Synchronous Motor Dynamic Modelling & Impact on Transient Studies
- Typical Generator & Motor Transient Examples
- Use of UDM module modelling concepts & features& examples if it is available or a demo can be given including Controller Dynamic Parameter Estimation
- Voltage stability analysis
- Hands-on exercises using ETAP.

7. **Motor Starting Studies & Analysis Covering: -**
   - Grid and Generator Modelling of source fault impedance.
   - Modeling motor using ETAP parameter estimation and load model along with combined inertia.
   - Motor Equivalent Circuit & driven load model testing in ETAP
   - DOL & other assisted start case studies in ETAP using both transient and motor acceleration modules.
8. **Renewable Generation Based Dynamic Studies**
   - Basics aspects of control System & control loops
   - Control of active power and frequency
   - Control of reactive power and voltage
   - Synchronous generator, AVR/exciter, turbine governor & PSS control system
   - Overview of grid forming & grid following VSC inverter control structure, grid forming virtual synchronous machine (VSM) inverters, grid forming inverters using P-f & Q-V droop control.
   - LVRT, HVRT, Fault ride through Studies
   - Frequency Ride through
   - Voltage & frequency regulation
   - Ramp control

9. **Protection systems and component and unit zone protection & concepts**
   - General Protection
   - Transformer protection
   - Motor protection bus protection line distance protection
   - Typical unit protection and equipment protection settings basics
   - Instrument Transformers CT Types, Standard specifications for metering / protection class CT.
   - Equivalent circuit of CT, Selection & Sizing of CT from view point of ratio, error, composite error, saturation factor, knee point voltage, magnetizing current, CT secondary burden etc.
   - Relationship between ALF and connected burden for protection class CTs
   - CT requirements for various protections.
   - CT AC & DC Saturation during symmetrical steady state and transient symmetrical and asymmetrical short circuit and CT sizing to account for saturation
   - Class 5P & Class X/PS CTs – Requirement / Specifications.
   - CT Polarity, Choice of 1A and 5A. CT secondary rating
   - VT Types, Standard specifications for metering / protection class /VT.
   - Significance of Voltage Factor (V.F.) for VTs
   - Type of VT connections (Star, V and Open Delta)
   - High & Low CT ratio Excel CT sizing calculations.
   - Review of CT & VT international standards.
10. **Back Up Time Coordinated Protective Device Time & Current Coordination Using Graphical Technique**
   - Relay coordination basics and differences in definite time, extremely inverse, very inverse and standard inverse relay curves and their use and curve placement in ETAP Star view.
   - Principle of coordination of non-unit O/C & E/F relays and releases in a example system with multi circuits.
   - Coordination in Time Current Curve (TCC) Plot of a simple example circuit
   - Sequence of operation check of set relays for various location and times of fault
   - Radial with single direction fault current & Loop system with multi direction fault current
   - Need for directional OC
   - Generator voltage restraint or voltage control OC relay coordination
   - Evaluation of Multistage under voltage and under frequency load shedding principles

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- Creating case study with different system elements with their CTs and relays
- Setting a series of radial circuit connected relays fed from upstream source by coordination in ETAP including systems and relays associated with: -
    - Motors
    - Transformers
    - Generators with 51 V relays
    - Cables
- Protection operating sequence check in ETAP
- Checking of relay operation in multi-source fed loop or parallel circuits using operating sequence check in ETAP
- Case studies for understanding use and coordination with: -
    - LV CB series trip LSIG release and fuses
    - User defined curves related to peak load demand profile, shift factors for various elements, thermal curve, generator fault decrement.
- Various interface features that can be used

11. Brief Review of Other aspects Modules

- As per time availability

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