

Course 1 :- Training Program Agenda
Electrical power system component modelling and control basics
(Precursor course to RMS based power system studies course with
ETAP or PSSE or Dig Silent Power Factory Computational Tools).

Contents:

- **Overview.**
 - Electrical power system Introduction, Changes influencing generation and transmission, operation of generators, Energy conversion basics, Renewable energy sources, Energy storage, Transmission and Distribution systems and Utilization, Environmental aspects of electrical energy.
 - Per-unit system & Basic network theory.
 - Magnetic circuits and flux calculations: MMF, Flux, permeability, reluctance, Ferromagnetic materials, B vs H loop, hysteresis, Eddy current losses.
 - Forces on rotating current loop placed in magnetic field
 - Concept of Lorentz force and Fleming's left hand rule, Faraday's induced voltage law and Fleming's Right Hand rule.
 - In motor on each segment of the current carrying loop (armature in rotor) in a stationary magnetic field (field in stator) resulting in torque causing rotation of armature rotor with visualisation of field current and force direction using Fleming's Left Hand rule.
 - Basics of machines covering transformer, induction machine, dc machine and synchronous machines, each of which have both operation as generator and motor. Understanding similarity between transformer and induction machine and that between dc and synchronous machine.
- **Circuit & Power System Components.**
 - Basics of power system short circuit. Transients in R-L circuits covering DC and AC source and fault in an AC circuit. Short circuit in an unloaded synchronous generator. Symmetrical fault in power system. Calculation of fault current using impedance diagram. Circuit breaker selection. Unsymmetrical faults covering single-line to ground (LG) fault, line-to-line (LL) fault, double-line to-ground fault (LLG), Fault current computation using sequence networks.
 - Basic understanding of components of power system. Per Unit representation and modelling of transmission line, synchronous machine, induction motor and transformer for computational analysis.
 - Three-phase systems.
 - Active and reactive power, power transfer and reactive power, harmonics in three-phase systems.

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- **Transmission Line Model & Performance Analysis.**
 - Transmission line series and shunt model parameters of transmission lines.
 - Phase and sequence (positive, negative and zero sequence) modelling of three-phase overhead. Equations of overhead power line parameters of impedances and susceptance
 - Series parameter covering line resistance, inductance of a straight conductor, single phase and three phase single circuit and double lines (with and without earth wires) with symmetrical & asymmetrical spacing, transposed line, bundled and composite conductor.
 - Line Shunt parameters covering capacitance of a straight conductor, single phase line and three-phase line. Effect of earth on the calculation capacitance. Magnetic and electrostatic induction and corona.
 - ABCD parameters, short line approximation, medium line approximation and π T representation. Long line model equivalent representation. Voltage and current characteristics of an SMIB system, Midpoint voltage and current of loaded lines. Power in a lossless line. PV & QV voltage stability assessment.
- **DC motors**
 - DC machines as generator and motor, Concept of machine as energy conversion device where for motors, the electrical input is converted to mechanical output via the intermediate magnetic field circuit.
 - DC machine brief on its stator field winding, that generates the magnetic field, and rotor with current carrying armature, split ring commutator rotating with armature winding loops and stationary brushes
 - Concept of Lorentz force (in dc motor) on each segment of the current carrying loop (armature in rotor) in a stationary magnetic field (field in stator)
 - Concept of Faraday's law for induction of voltage and current (in dc generator) in a rotating armature conductor due to changing magnetic flux caused by rotational sweep of armature (by mechanical power) cutting the stationary magnetic field in stator/
 - Types of dc motors covering separately excited dc motor, shunt dc motor series dc motor compounded dc motor and permanent-magnet dc
 - The magnetisation curve of a dc machine
 - The torque and emf equation of each type of dc motor (separately excited dc motor, shunt dc motor series dc motor compounded dc motor and permanent-magnet dc) and their terminal characteristics from equations of each motor torque and emf as function of field flux and armature current and speed.
 - Typical speed-torque and speed-current and torque-current characteristic of a series, shunt and other dc motor.
 - Power Flow in an Induction Motor after accounting for stator full load and no-load electrical losses and rotor electrical losses plus windage and friction mechanical losses and derivation of equivalent circuit of a dc motor.

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- **Synchronous Generator Overview Performance Analysis & Model**
 - Basics understanding of synchronous machines, induction machine, equivalent circuit under balanced short-circuit conditions, synchronous generators in parallel, the operation of a generator on an infinite busbar, Basics of synchronous generator and model and study of steady state performance cylindrical and salient pole synchronous generators and automatic voltage regulators (AVRs),
 - Generator P & Q expressions and Voltage vector diagram, Generator Power Capability Diagram Assessment, Generator PQ capability chart with limits related to stator & rotor current limit, Prime mover power limit, Theoretical stability and load angle limit, continuously acting AVR limit and manual operation limit. Generator behaviour during faults/transients,
 - Power versus angle chart of cylindrical and salient pole generator
 - Generator ratings and reactance, generator excitation and power system stabilisers.
 - Generator Sub transient, transient and steady state reactance variation, during sudden fault or transients, due to associated sudden changes in path and pattern of stator and rotor of current and the associated reduction in the flux into field core resulting in increased reluctance in flux path and reduced flux through rotor and reduced initial inductance. The flux path changes after initial redistribution and inductance increases.
 - Generator performance analysis parameters and data sheet
 - Generator rated and transient current withstand capability covering voltage a frequency operating range capability, continuous and overload capability, short time or occasional overload capability, continuous and short time I^2t capability for unbalanced system operation, generator short time field forcing current capability and ceiling exciter voltage and response time and over speed capability,
 - Synchronous Machine Model & Performance Analysis covering model data related to synchronous machine reactance's, typical transformer Impedances and equivalent circuit determination of induction and synchronous machine.
 - Classified into three broad categories based on the generator excitation power source covering DC excitation systems, AC excitation systems, Brushless excitation system and static excitation systems
 - Generator neutral earthing based on generator stator to core arcing fault current core damage with respect to the extent of damage withstand of current as current versus time curve for minimum damage, bearable damage and severe damage.

- **Per unit analysis**
 - Per-unit analysis of power systems, Single-phase systems, change of base quantities, Three-phase systems, mutually coupled systems having different operating voltages

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- **3 phase induction motor model**
 - Overview of 3 phase induction motor. Wound rotor and Squirrel-cage rotor type motors.
 - Theory and principle of operation of three phase induction motor. Basics of production of a Rotating magnetic field and the Concept of 'Slip' and development of induced torque in induction motor.
 - Analysis of induction motor. Different forms of squirrel-cage rotor bars including deep bar, double bar, T bar and integrally cast double bar.
 - Power Flow in an Induction Motor after accounting for stator full load and no-load electrical losses and rotor electrical losses plus windage and friction mechanical losses
 - Phasor diagram, Torque, slip, and rotor impedance equations and derivation of the stator equivalent circuit, rotor equivalent circuit and stator-referred rotor equivalent circuit derivation.
 - Expression for torque and power. Starting or lock rotor torque and maximum Torque
 - Motor speed-torque Characteristics. Applied voltage and rotor resistance effect on the speed-torque characteristics of an Induction Motor
 - Service factor, efficiency and power factor, Rating, Full-load current, Torques and starting current
 - Over view of motor torque based on NEMA torque classifications as Design A, B, C & D.
 - Electrical motor torque versus speed and mechanical load torque versus speed and the motor as well as load rotor inertia and their effect on startup time of motor and pump from zero to full load torque without stalling.
 - Start of induction motor including star delta start, auto transformer start, soft electronically volt control stat, VFD start by ramping frequency keeping V/f constant throughout motor star.
 - Regenerative braking, plugging and dynamic braking.
 - Transients fault back feed from motor during source side bus fault.

- **Power System Stability**
 - Basics of electrical power system stability. Basics of equation of motion of a rotating machine. Steady-state stability, Transient stability and stability basics equations, Power-Angle relationship, Swing equation and Equal area Criterion. Dynamic or small-signal stability, Stability of loads leading to voltage collapse. Improvement of system stability.

- **Power System Analysis**
 - Basics of load flow and short circuit. Load flow iteration methods. Short circuit calculation standard, symmetrical components, System neutral earthing and earth fault, Interference with Communication Circuits–Electromagnetic Compatibility (EMC)

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- **HVDC**
 - Basics of direct-current transmission, current source and voltage source converters, semiconductor valves for HVDC converters both current source converter HVDC and voltage source converter HVDC.

- **Over voltage & Insulation Requirements.**
 - Overvoltage's and insulation requirements, Generation of overvoltage's, Protection against overvoltage's, Insulation coordination, Propagation of surges, Determination of system voltages produced by travelling surges, Electromagnetic transient program (EMTP).

- **Control System Basics**
 - Basics of negative feedback control system covering control stability analysis using Routh-Hurwitz criteria and Root Locus method, Steady state error assessment and step response analysis.
 - Compensators based on root locus design cover gain or P compensator, PID, PI, PD compensator/controller design as well as Phase Lead Phase Lag Compensator design.
 - Laplace transformer and s domain transfer function block diagram develop from time domain equations covering 1st order differential, 2nd order differential, Pid, Lead Lag & wash out filter transfer functions and their step response tests.
 - Control system frequency response analysis with Bode & Polar plot & Nyquist plot to assess relative stability using gain and phase margins, Nyquist stability criterion. Closed loop frequency response and design.
 - Control system application based on pole placement and optimum control design.

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- **Power System Control Basics**
 - Control of voltage and reactive power, generation and absorption of reactive power Relation between voltage, power, and reactive power, Methods of voltage control by injection of reactive power, tap-changing transformers, phase-shift transformer. Voltage collapse, voltage control in distribution networks, long lines, general system considerations
 - Control of power and frequency, Introduction to turbine governor, control loops. Division of load between generators, power-frequency characteristic of an interconnected system, system connected by lines of relatively small capacity.
 - Power system control basics, Basic generator control loops, Load frequency control model related to Prime mover, turbine and governor, generator and exciter/AVR and load
 - Voltage and reactive power control modelling covering Generator model, Exciter, AVR and Amplifier model. Excitation system stabiliser based on rate feedback and PID controls.
 - Automatic generation control in single and multiarea system and Tie line bias control.

- **Power System Operation Economics**
 - Fundamentals of the economics of operation and planning of electricity systems, economic operation of generation systems, Basics of generation system planning, economic operation and planning of transmission and distribution systems and of transmission system planning, Transmission & distribution network security considerations and drivers for change

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- **Power electronic SWPWM, SVPWM, current hysteresis switching converter model**
 - Overview of power electronic converters (including half bridge/ full bridge and 3 phase circuit operation and filters) and their components including electronic switching and storage devices like inductor and capacitor. Operation and characteristics of switching devices covering power diode, power bipolar junction transistor, thyristor or SCR, MOSFET & IGBT, dc-dc buck, boost & buck boost converters ac-dc rectifiers, dc link/bus and dc link energy storage passive devices L and C, and dc-ac inverters.
 - Current conducting and voltage blocking V-I characterisers 4 quadrant operation regimes of electronic switches ie diode, thyristor, Power BJT. MOSFET, IGBT and composite switches with antiparallel or anti series diodes. L, C, LC, and LCL filter design overview
 - Basics of control blocks of voltage source converter (VSC or VSI) and current source converters (CSC or CSI)
 - Study of Full-Bridge (H-Bridge) Inverter, Neutral Point Clamped (NPC) Diode Inverter, and Flying Capacitor Inverter circuits for converter dc to ac 3 phase output voltages. Advantages and Disadvantages of each with H-bridges being complex, NPC inverters requiring many diodes for higher levels, and flying capacitor inverters being susceptible to capacitor failure.
 - Basics of pulse width modulation (PWM), Sine-triangle-comparison based PWM, Space vector-based PWM. Details of Basics of sine triangle pulse width modulation (SPWM) to generate pulsed DC converter outputs that mimics the input ac reference signal (called modulating or reference signal) having an amplitude modulating index m_a (usually kept < 1) for comparison with the high frequency triangular carrier wave to achieve desired scanning steps for deriving dc pluses at inverter output.
 - DC to DC converter building block overview and modelling for open loop and closed loop control of output voltage based on varying Duty factory with switching pulse derived using carrier wave of high frequency for comparison with reference signal with amplitude modulation index.
 - Full bridge inverter model controlled by a set of square wave inputs to simulate and observe Fourier series and Total Harmonic Distortion (THD) of the output voltage and current.
 - Over view of open loop and closed loop dq voltage and current feedback outer and inner controllers and Phase Lock Loop (PLL) for generation of switching device gate pulses required for grid following PV & WTG & BESS inverter active and reactive current output to grid (based on active and reactive power set points control derived based on PV MPPT or manually derived values.)

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- **Power electronic SWPWM, SVPWM, current hysteresis switching converter model (continued)**
 - Grid follower inverter (PV or WTG or BESS) model in closed loop with power plant controller, voltage ride through and current limit controller for simulation and study of dynamic grid code compliance studies
 - Closed loop Voltage source converter model for PQ mitigation FACTS devices with power and dq quantity closed control system for simulation of
 - Voltage or reactive power control distribution static compensator D-STATCOM
 - Voltage or reactive power control distribution static compensator SVC with reactor and capacitor
 - Voltage balancing and Active Harmonic mitigating active harmonic filter
 - Voltage sag or swell mitigation series FACTS dynamic voltage restorer (DVR),
 - 3rd harmonic and DC offset mitigation in nonlinear loads with Zig Zag transformer mode and simulation
 - Variable frequency drive with motor dynamic modelling
- **Variable Frequency Drive - Speed Control of Induction Motor**
 - Overview of dc motor speed control and dc motor design that it achieves by perpendicular alignment of current carrying armature conductors and stator magnetic field
 - Basics of dc motor being easiest for speed control because of its torque being cross product of magnetic field density and armature current ($F=B \times l = BI \times \sin(\text{angle between field and current})$) and the motor design that has the orthogonality between them that maximises dc motor torque per given field and armature current.
 - The concept thus of decoupling nature of flux and current in dc motor thereby achieving torque by either varying armature current by maintaining flux constant or vice versa.
 - Overview of V/f Control (Scalar Control) technique of VFD for motor speed control based on changing frequency for speed change by maintaining constant ratio of V/f to keep the motor's magnetic flux constant & stable. Discussion of Scalar control VFD's merits/demerits, limitations and type of mechanical loads that the scalar technique can be applied.

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- **Variable Frequency Drive - Speed Control of Induction Motor (continued)**
 - Basic concept of dc motor field and current orthogonality as applied to vector control of VFD (or field orient control of VFD) for ac induction motor, where ac motor field producing current vector and torque producing current vectors are aligned orthogonally in the rotating d q axis to achieve decoupling of flux producing current and torque producing current vectors for simplifying and achieving fast and precise control of torque and speed of ac induction motor just as that can be achieved with dc motor
 - Overview of Vector Control (Field-Oriented Control - FOC) technique of VFD for motor speed control based on decoupling by achieving orthogonality, as in dc motor, of the motor's current into two components (one for flux production and one for torque production) that is achieved by using Park transformation to analyse motor currents in a d q axis rotating reference frame.
 - Over view of Direct Torque Control (DTC) of motor's electromagnetic torque and flux by manipulating the voltage and frequency without the decoupling of current components required in FOC. Merits and demerits of DTC over FOC vector control where DTC offers faster, more direct control strategy than vector control that can be applied for demanding applications requiring very high dynamic performance.
 - Transfer function closed loop control system block diagram for V/f scalar, Vector control (FOC) and DTC control VFD techniques.
 - Challenges with VFD applications covering electrical noise such as harmonic, including high frequency noise, harmonic generation, harmonic calculation, harmonic management, special cable requirements, VFD cable installation and termination requirements
 - The variable frequency drives with various configuration such as six pulse drive, 12 pulse drive, 18 pulse drive, Active front end, Pulse width modulation. The higher pulses do not generate lower harmonic orders.
 - Understanding harmonic noise management (to meet the regulatory body requirements) that includes use of low pass power system filter, band pass power system filter, hybrid power system filter, active power system filter and combinations thereof.
 - Generation of EMI & need to study up to 100th harmonic for Study of Active Front End (AFE) PWM rectifier VFD. VFD motor cable type and maximum length issues arise from voltage doubling due to voltage reflections of PWM switching frequencies and from increased electromagnetic interference (EMI) (EMI) caused by long cables demanding need for use of shielded motor cables, output filters, such as load reactors or more complex LC filters, for longer runs.
 - Understanding need for VFD cable with drain wires and shielding due to VFD generated voltage spikes and current imbalance for which VFD cable needs proper insulation rating, drain wires, and foil/braid shielding for EMI reduction.
 - Issues with VFD motor bearing current due to high-frequency current through motor bearings caused by the common-mode voltage (CMV) and high-frequency pulse-width modulation (PWM). Need for insulated bearings or a shaft grounding ring to provide a safe path for the current to earth, bypassing the bearings.

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Renewable Power Inverter Based Generation

- Three-phase voltage-source converters. Basic operation and control of voltage source converters. Current capability of converter insulated gate bipolar transistor (IGBT) switches.
- Types of wind turbine generator technologies. Type1 fixed-speed and Type2 variable slip wind turbine induction generators and their Modelling and analysis of short-circuit current contribution
- Overview of Type 3 variable-speed wind turbine doubly fed induction generators (DFIG), Basic operation principle, Rotor protection. Passive and active crowbar protection dc chopper protection General model of doubly fed induction generators (DFIG). DFIG steady-state equivalent circuit, DFIG natural stator and rotor short-circuit currents under constantan excitation DFIG stator and rotor short-circuit currents under crow bar action, DFIG short-circuit currents with dc chopper control, DFIG short-circuit currents with rotor converter control
- Type 4 variable-speed inverter interfaced wind turbine generators, generators. The modelling and analysis of the short-circuit contribution of Type 4 variable-speed WTG converter interfaced generators is presented in Section 6.11.
- Type 5 variable-speed wind turbines synchronous generators
- Other technologies such as grid-connected BESS, distributed energy resources, HVDC systems and variable-speed pump storage hydropower plants interfaced to the ac grid through voltage-source inverters
- Solar photo voltaic (PV) generators and connection to the ac grid
- Solar PV applications, Solar PV generator components, Solar PV voltage-source inverters, Grid connection of solar PV power plant and short-circuit current contribution of solar PV inverters
- Modelling and analysis of grid-connected voltage-source inverters. Basics of inverter model based on Park transformation of stationary three-phase RYB reference frame to the rotating dq reference frame, Phase-locked loop, inverter inner current control loop, Inverter outer control loops and inverse park transformation with short-circuit current contribution of voltage-source inverters based on frozen controls
- Grid code requirements for dynamic reactive current injection from inverters to stay connected without tripping to satisfy grid code by high voltage, low-voltage fault and high voltage ride-through features provided in the grid connected inverter control.

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- **Renewable Power Inverter Based Generation (continued)**
 - Dynamic reactive current control and short-circuit current contribution of voltage-source inverters during balanced and unbalanced voltage dips. Short-circuit current contribution with Inverter model in positive-sequence synchronous reference frames model)
 - Sequence network representation of voltage-source inverters during balanced And unbalanced short-circuit faults
 - Short-circuit currents in ac grids containing mixed synchronous generators and inverters
 - Background of Grid-forming (GFM) voltage-source inverters. Evolution GFM inverter due to challenges faced with grid-following (GFL) voltage-source inverters. Control structure of grid-forming inverters
 - Grid-forming (GFM) virtual synchronous machine (VSM) inverters that have features of real synchronous machines with representation rotor swing dynamics for inertial response and electrical damping as well as other synchronous generator sub functionalities including, virtual governor-turbine model virtual field or internal voltage model
 - Model of grid-forming (GFM) VSM inverters using P-frequency & Q-voltage droop control
 - 3 phase and 2 phase short-circuit current contribution of grid-forming (GFM) inverters. Over-current limitation strategies of grid-forming inverters
 - Symmetrical components sequence equivalent circuits of 'grid-forming' inverters
- **AC & DC UPS**
 - Overview of ac & dc uninterrupted power systems (ups)
 - Single and dual redundant ac and dc ups supply system description with detailed SLD covering protection control, alarms, and indication
 - Static AC ups system to serve critical AC loads. Operation of UPS in normal mode, upset mode and bypass mode
 - Common static ups system configurations covering offline ups or standby power systems, online protection ups or line interactive ups, double conversion ups (on-line).
 - Major components of UPS systems covering ac to dc rectifier or battery charger, dc link L or C, dc to ac inverter, battery, and manual/auto static transfer switch
 - Operation of d.c. supply UPS systems serving critical dc load. Major components characteristics. Controlled rectifiers, un-controlled rectifiers. Understanding float or boost charging. Recharge cycle for discharged battery
 - Understanding UPS performance relevant to power quality in terms of voltage regulation, Frequency control, and surge protection

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- **AC & DC UPS (continued)**
 - Theory, Application, Design Features, Constructional Features, Installation Requirements. Tests of battery. components of battery, AMPERE - HOUR CAPACITY, Specific gravity of acid during charge/discharge and Voltage per cell (VPC), maximum and end cell voltage.
 - TYPE of battery such as vent type Lead Acid (vented Plante and Tubular type), Absorbent glass mat (AGM) and Gel type Valve regulated (VRLA) type, Alkaline & Ni-CD and Li-ion Type
 - Basics of battery charger. Boost or fast charge after battery discharge and Float (trickle) charge the battery to compensate for the internal discharges and keep the battery fully charged as long as s AC power is available.
 - DC system fault calculations covering fault current from DC battery based on number of battery cells, cell resistance and external wire resistance
 - Battery care and ventilation and enclosure or in rooms
 - Rotary UPS system configurations covering Inertia-driven ride-through system with a synchronous motor, Inertia-driven ride-through system with an induction motor and an eddy current clutch. Battery supported Motor Generator (M-G) set, Rotary systems with a transfer switch to a bypass source. Paralleling redundant rotary systems
 - Estimation of dc loads for battery sizing covering loads for Up to one minute related to Closing and tripping of Circuit breakers, starting current of automatically started DC motors, Solenoid valves for isolation, safety relief etc., In rush currents of vital controls, instrumentation, communication system etc and longer-term loads upto 2 to 10 hours related DC motors drives, Uninterrupted Power Supply (UPS) loads, Vital controls, instrumentation, Supervisory systems, annunciation etc., Communication systems, plant emergency lighting, Indicating lamps, annunciation, etc on control panels and switchgear, emergency lights in control room and other vital places and Plant communication system

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- **Power/ Voltage Quality**
 - Occurrence and causes, mainly due to power electronics in network, of harmonics, inter harmonics, voltage fluctuation, flicker, voltage unbalance and their effects. Computation of harmonic distort, flicker Pst that need to be below acceptable levels as per various IEC and IEEE standards.
 - Modelling, computations and field measurement of harmonics, inter harmonics, harmonic resonance, voltage fluctuation, flicker, voltage unbalance for ensuring computability with standards to assess counter measurements to mitigate the PQ issues.
 - Countermeasures to mitigate the power and voltage quality measures by Consumer-related measures, Filter circuits, Dynamic reactive power compensation such as STATCOM, DVR and SVC, Symmetrical connections, Active filters, High-performance batteries, Superconductive magnetic energy storage