Commissioning & Maintenance of Electrical Equipments (DI04009031)

GTU Course Presentation

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Lecture 1.1: Do's and Don'ts Regarding Safety in Substation/ Power Station Operators

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Introduction to Substation Safety

- Substations are critical nodes in power systems, operating at high voltages and carrying immense fault currents.
- Safety of operators and maintenance personnel is of paramount importance to prevent fatal electrical accidents.
- Key hazards include electrical shock, arc flash, and arc blast.
- Strict adherence to safety protocols minimizes risks and ensures continuous power supply.

Safety First

According to the Central Electricity Authority (CEA) Safety Regulations, safety is a mandatory legal requirement, not an optional practice.

The "Do's" of Substation Safety

- **Do** obtain a valid Permit-To-Work (PTW) before starting any maintenance.
- **Do** verify that the equipment is isolated, locked out, and tagged out (LOTO).
- **Do** use local earth discharges to completely discharge residual capacitive energy.
- **Do** maintain proper minimum working clearances based on the voltage level.
- **Do** inspect all Personal Protective Equipment (PPE) before use.

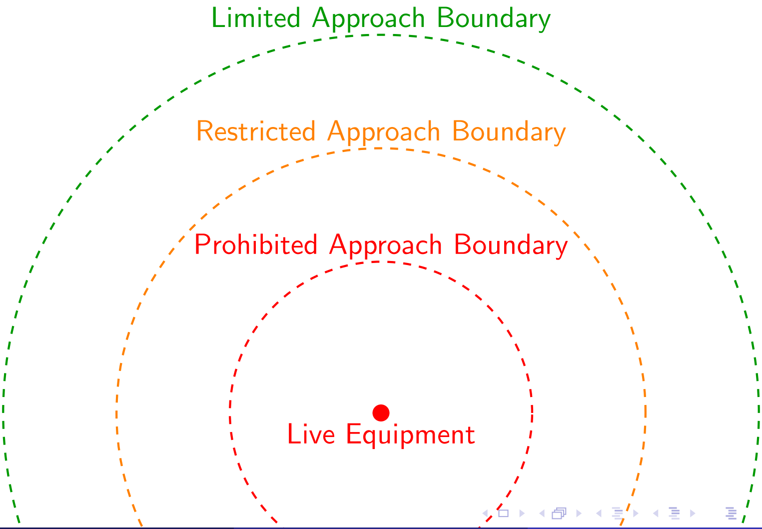
Personal Protective Equipment (PPE) Requirements

Proper PPE is the last line of defense for a power station operator.

Equipment	Purpose
Insulated Gloves	Protects against electrical shock (rated for voltage
Safety Helmet	Protection from falling objects and accidental con
Arc Flash Suit	Thermal protection from arc flash burns
Safety Shoes	Non-conductive soles to protect against step poten
Safety Goggles	Protects eyes from sparks and UV light during arc

Safety Clearance Zones

Maintaining physical distance is crucial. Below is a conceptual diagram of approach boundaries.



Standard Operating Procedures (SOPs)

Standard Operating Procedure (SOP)

A set of step-by-step instructions compiled by an organization to help workers carry out complex routine operations, aiming to achieve efficiency, quality output, and uniformity of performance while reducing miscommunication and failure to comply with safety regulations.

Execution Steps:

1. Identify the specific equipment and the work scope.
2. Read and understand the specific SOP for the task.
3. Conduct a tool-box talk with the team.
4. Execute switching sequences in the exact order specified.

Lecture 1.2: Do's and Don'ts Regarding Safety in Substation/ Power Station Operators

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The "Don'ts" of Substation Safety

- **Don't** bypass or override safety interlocks on switchgear.
- **Don't** assume a circuit is dead; always test for voltage before touching.
- **Don't** work without a standby person when performing critical operations.
- **Don't** wear loose clothing, metallic ornaments, or conductive jewelry in the yard.
- **Don't** rush through switching operations; follow the step-by-step procedure strictly.

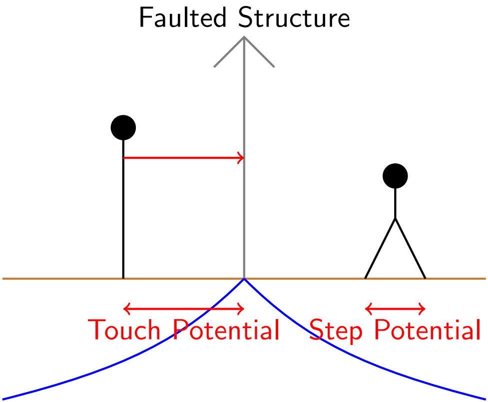
Hazards of Ignoring Safety Rules

Ignoring safety rules can lead to catastrophic consequences.

- **Electrocution:** Direct contact with live parts causes severe injury or death.
- **Arc Flash:** Short circuits through the air generating extreme heat (up to 35,000°F).
- **Equipment Damage:** Incorrect switching can destroy transformers or breakers.
- **System Outages:** Faults caused by human error can lead to widespread grid failure.

Understanding Step and Touch Potential

During a fault, current flows into the earth, creating a voltage gradient on the surface.



Lockout/Tagout (LOTO) Procedure

Lockout/Tagout (LOTO)

A safety procedure used in industry and research settings to ensure that dangerous machines are properly shut off and not able to be started up again prior to the completion of maintenance or repair work.

- **Lockout:** The placement of a lockout device on an energy isolating device, ensuring that the equipment cannot be operated.
- **Tagout:** The placement of a prominent warning device, such as a tag, to indicate that the equipment may not be operated.

Case Study: The Importance of Earthing

Accident Prevention

In a 2018 incident, a maintenance worker survived an accidental re-energization of a 33kV line because the line was properly locally earthed. The earth connection provided a low-impedance path for the fault current, tripping the upstream breaker instantly.

Lessons Learned:

- Never trust visual isolation alone.
- Always apply temporary local earths before touching conductors.
- Remove earths only after all personnel are clear and work is fully completed.

Lecture 1.3: Electrical Safety at the Time of Operation, Control, and Maintenance

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Safety During Operation and Control

- **Authorized Personnel Only:** Only certified operators should execute switching commands on SCADA or local control panels.
- **Sequence of Operation:** Always open the circuit breaker before opening an isolator. Isolators are off-load devices and cannot interrupt fault or load current.
- **Communication:** Use clear, standard, and repeated communication between the control room and field operators.
- **Alarms and Annunciations:** Never ignore control panel alarms. Investigate the root cause before resetting relays.

Safety During Maintenance

Maintenance activities expose personnel directly to the physical equipment, increasing risk.

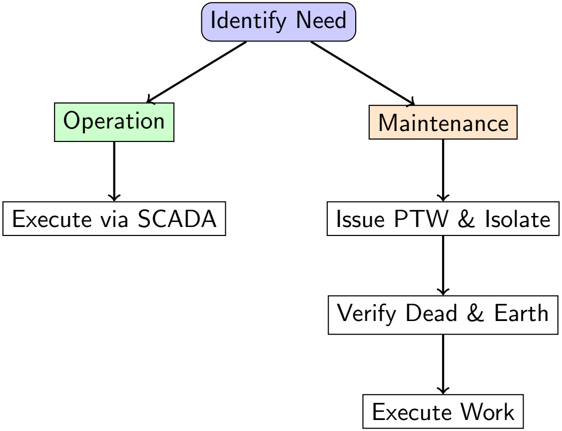
- **Pre-Maintenance Briefing:** Discuss the task, identify hazards, and assign roles.
- **Test Before Touch:** Use approved voltage detectors to ensure the system is de-energized.
- **Discharging:** Use earthing rods to discharge residual capacitive charge on long cables or transformers.
- **Barricading:** Physically barrier the safe working zone from adjacent live panels or bays.

Permit-To-Work (PTW) System

A formal, documented system to control high-risk activities.

PTW Phase	Action Required
Issue	Authorized person details the work, isolation points,
Receipt	Supervisor acknowledges understanding and takes res
Execution	Work is carried out within the defined boundaries an
Clearance	Tools removed, personnel cleared, earths removed.
Cancellation	System returned to the control engineer for re-energi

Operation vs. Maintenance Flow



Understanding Arc Flash Boundaries

Arc Flash Hazards

An arc flash is an explosive release of energy caused by an electrical arc. The energy released can cause severe burns, hearing damage, and blast injuries.

Key Boundaries:

- **Arc Flash Boundary:** Distance at which incident energy equals 1.2 cal/cm^2 (causes second-degree burn).
- **Limited Approach:** Unqualified persons must stay outside this boundary unless escorted.
- **Restricted Approach:** Only qualified persons with appropriate PPE can cross this line.

Lecture 1.4: Factors Affecting Life and Classification of Insulating Materials

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Introduction to Insulating Materials

- Insulating materials (dielectrics) are used to isolate conducting parts of electrical equipment from each other and from the ground.
- They prevent leakage currents and short circuits.
- The reliability and lifespan of electrical equipment (transformers, motors, cables) depend heavily on the integrity of their insulation.
- Insulation fails when it loses its dielectric strength due to various degrading factors.

Factors Affecting the Life of Insulating Materials

- **Thermal Stress:** High operating temperatures accelerate chemical degradation (oxidation, depolymerization).
- **Electrical Stress:** Overvoltages, switching surges, and partial discharges (corona) degrade insulation structurally.
- **Environmental Stress:** Moisture, dust, chemicals, and radiation reduce surface resistance and promote tracking.
- **Mechanical Stress:** Vibrations, thermal expansion/contraction, and electromagnetic forces cause physical cracking or abrasion.

Thermal Degradation

Thermal Degradation (Arrhenius Equation)

The rate of thermal degradation of an insulating material generally follows the Arrhenius equation. A common rule of thumb is that the life of insulation is halved for every 10°C rise in operating temperature above its rated limit.

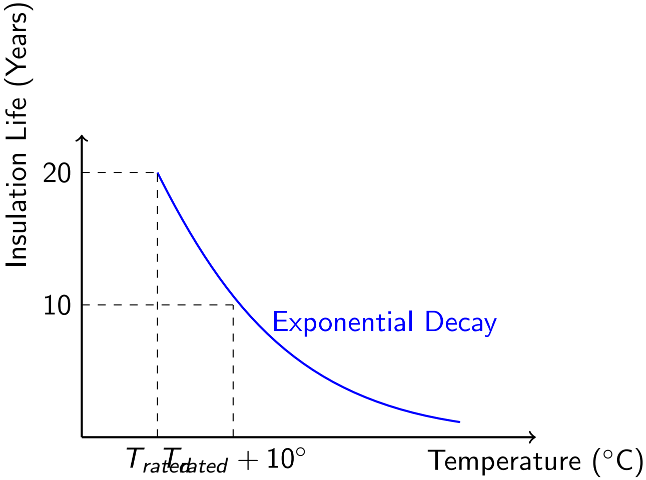
- For example, if a motor rated for Class B (130°C) operates continuously at 140°C, its expected insulation life of 20 years may reduce to just 10 years.

Classification of Insulating Materials (IS 1271)

Indian Standards (IS 1271) classify insulating materials based on their maximum continuous operating temperature.

Class	**Max Temp (°C)**	**Typical Materials**
Y	90	Unimpregnated paper, cotton, silk.
A	105	Impregnated paper, cotton, silk, enamel.
E	120	Polyurethane, epoxy resins.
B	130	Mica, glass fiber, asbestos with suitable
F	155	Mica, glass fiber with high-temp binders
H	180	Silicone elastomer, mica with silicone res
C	¿ 180	Teflon, pure mica, ceramics, glass, quart

Insulation Life vs. Temperature Curve



Lecture 1.5: Measuring Insulation Resistance

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Introduction to Insulation Resistance (IR)

- Insulation Resistance (IR) is the resistance offered by an insulating material to the flow of direct current.
- It is measured in Mega-ohms (MΩ) or Giga-ohms (GΩ).
- IR is not a constant value; it varies with temperature, moisture content, and the applied voltage duration.
- Measuring IR is the most common non-destructive diagnostic test for electrical equipment health.

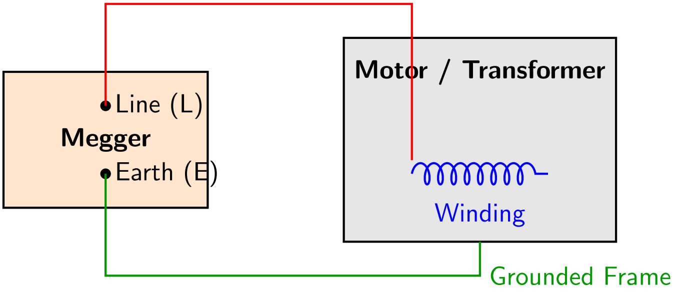
Method I: The Megger Test

A Megger (Insulation Tester) applies a high DC voltage across the insulation and measures the small leakage current to calculate resistance ($R = V/I$).

Equipment Voltage Rating	Megger DC Test Voltage
Up to 415 V (Low Voltage)	500 V DC
415 V to 1000 V	1000 V DC
1.1 kV to 3.3 kV	2500 V DC
3.3 kV to 33 kV and above	5000 V DC / 10000 V DC

Note: The Megger reading is typically taken after 1 minute of voltage application.

Megger Connection Diagram



Method II: Polarization Index (PI)

Polarization Index (PI)

PI is the ratio of insulation resistance measured at 10 minutes to the insulation resistance measured at 1 minute.

$$\text{PI} = \frac{\text{IR at 10 minutes}}{\text{IR at 1 minute}}$$

- A good insulation system shows an increase in resistance over time as polarization currents decay.
- **PI < 1.0:** Dangerous (Insulation is highly contaminated/wet)
- **PI 1.0 - 1.5:** Poor
- **PI 1.5 - 2.0:** Fair
- **PI > 2.0:** Good (Standard for most high voltage motors/transformers)

Method III: Dielectric Absorption Ratio (DAR)

Dielectric Absorption Ratio

Similar to PI, but conducted over a shorter time frame, typically used for smaller equipment where the polarization current decays rapidly.

$$\text{DAR} = \frac{\text{IR at 60 seconds}}{\text{IR at 30 seconds}}$$

(Sometimes defined as 60s / 15s depending on standards).

Evaluation Criteria:

- **DAR $<$ 1.25:** Poor (needs investigation/drying)
- **DAR 1.25 - 1.6:** Acceptable
- **DAR $>$ 1.6:** Excellent

Lecture 1.6: Reconditioning of Insulation and Drying Out Procedures

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Why is Reconditioning Needed?

Moisture Ingress

Insulating materials like paper, cotton, and pressboard are highly hygroscopic. They absorb moisture from the atmosphere during storage, prolonged shutdown, or due to breather failures in transformers.

- Moisture drastically reduces dielectric strength and Insulation Resistance (IR).
- It accelerates thermal aging and can lead to immediate electrical breakdown upon energization.
- When IR/PI/DAR values fall below acceptable limits, the equipment must not be energized.
- The process of removing this moisture to restore insulation health is called **Drying Out** or **Reconditioning**.

Drying Out Procedures

Drying involves applying heat to drive out moisture, often combined with vacuum to lower the boiling point of water.

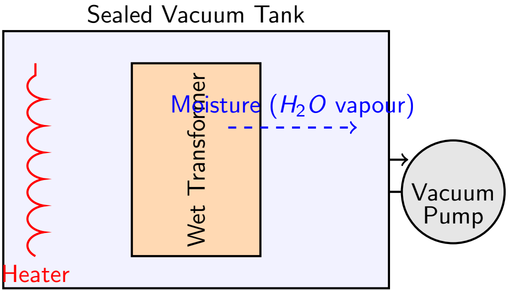
Common Methods:

1. **External Heating:** Using halogen lamps, space heaters, or hot air blowers (suitable for small motors or open windings).
2. **Internal Heating (Short Circuit Method):** Passing a low AC or DC current through the windings to generate I^2R heat internally.
3. **Vacuum Drying:** Placing the equipment in a vacuum chamber while heating it. Highly effective for large power transformers.

Comparison of Drying Methods

Method	Speed	Application	Precautions
External Heat	Slow	Small machines, surface moisture	Avoid localized hot spots (e.g., placing lamp too close).
Internal Heat	Moderate	Medium transformers, motors	Monitor current and temperature continuously; avoid exceeding class temp.
Vacuum Drying	Very Fast	EHV transformers, severe moisture	Expensive setup; requires robust tank to withstand vacuum pressure.

Conceptual Vacuum Drying Process



Monitoring the Drying Process

- Drying must be closely monitored to prevent damage to the insulation from overheating.
- Temperature must be kept well below the maximum rated temperature of the insulation class (e.g., around 80-90°C for transformers).
- Measure the IR periodically (e.g., every 2 hours) during the drying process.
- **Completion criteria:** The IR value will initially drop as temperature rises, then slowly rise as moisture leaves, and finally flatten out. When the IR is high and constant for several hours, drying is complete.

Lecture 1.7: Insulating Oil: Properties and Causes of Deterioration

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Introduction to Insulating Oil

- Mineral insulating oil is extensively used in transformers, circuit breakers, and oil-filled cables.
- It serves two primary functions:
    1. **Insulation:** Provides high dielectric strength between live parts and the grounded tank.
    2. **Cooling:** Acts as a heat transfer medium, absorbing heat from the core and windings and dissipating it through radiators.
- It is typically a highly refined mineral oil (naphthenic or paraffinic base).

Key Properties of Insulating Oil

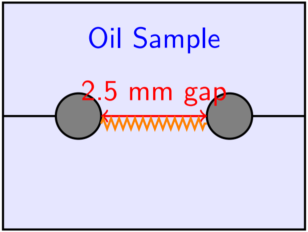
- **Electrical Properties:**
  - **Breakdown Voltage (BDV):** The voltage at which the oil fails as an insulator. High BDV indicates clean, dry oil.
  - **Dielectric Dissipation Factor (Tan δ):** Measures dielectric loss; indicates contamination.
- **Physical/Chemical Properties:**
  - **Flash Point:** The temperature at which oil vapors ignite momentarily. Must be high ($> 140°C$) to prevent fire hazards.
  - **Viscosity:** Must be low to allow efficient natural or forced circulation for cooling.
  - **Acidity / Neutralization Number:** Measures acidic byproducts of oxidation.

Standard Values for Transformer Oil (IS 335)

Property	Standard Requirement (New Oil)
Breakdown Voltage (BDV)	$\geq$ 30 kV (rms) for 2.5 mm gap
Water Content (Moisture)	$\leq$ 50 ppm (parts per million)
Flash Point	$\geq$ 140°C
Kinematic Viscosity at 27°C	$\leq$ 27 cSt
Dielectric Dissipation Factor	$\leq$ 0.002 at 90°C

BDV Test Setup

A sample of oil is placed in a test cell containing two spherical or mushroom-shaped electrodes spaced exactly 2.5 mm apart. An AC voltage is applied and increased at a rate of 2 kV/s until an arc occurs. The average of 5 to 6 breakdowns is taken as the BDV.



Causes of Oil Deterioration

- **Moisture:** Water enters via faulty breathers or degraded gaskets. Even small amounts (ppm) severely reduce BDV.
- **Oxidation and Sludge:** Under heat and in the presence of oxygen, oil oxidizes. Copper acts as a catalyst. This produces acids and solid sludge.
- **Sludge accumulation:** Coats the core and windings, drastically reducing cooling efficiency and causing overheating.
- **Solid Impurities:** Cellulose fibers from degrading paper insulation float in the oil, aligning under electric fields and causing flashovers.

Lecture 2.1: Requirements of Foundation for Static and Rotating Electrical Machinery

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What is a Foundation?

A foundation is a structural base that supports machinery and transfers its load safely into the ground. It ensures stability, structural integrity, and minimal vibration transfer.

Key Purposes of Foundations:

- Support the static weight of the equipment.
- Absorb dynamic loads and vibrations (especially in rotating machines).
- Maintain perfect alignment over long operational periods.
- Prevent settlement of the soil underneath.

Types of Machinery

Electrical machinery is broadly classified into two types regarding foundation needs:

Type	Characteristics
Static Machinery	E.g., Transformers, Switchgears. Imposes mainly static loads. Minimal vibrations.
Rotating Machinery	E.g., Motors, Generators. Imposes static weight plus dynamic forces (unbalanced centrifugal forces, torque pulsations).

Foundation Material Properties

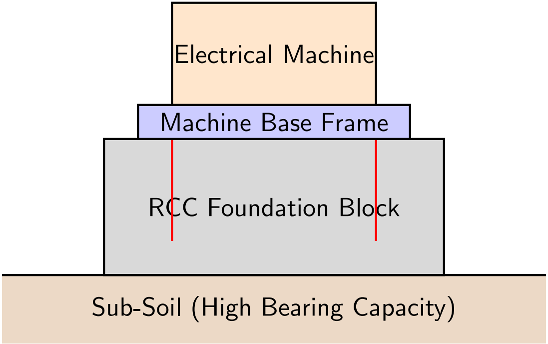
Common Materials:

- **Concrete:** The most common material due to its compressive strength and mass (damps vibrations). Typically Reinforced Cement Concrete (RCC) is used.
- **Steel Skids:** Used for smaller or temporary installations.

Soil Bearing Capacity (SBC)

The maximum contact pressure that the soil can withstand without failure. The foundation area must be designed such that the total pressure is well below the SBC.

Block Diagram of a Typical Foundation



General Requirements of Foundation

1. **Mass:** The mass of the foundation should be 2.5 to 3 times the mass of the rotating machine to absorb vibrations effectively.
2. **Rigidity:** Must be rigid enough to prevent distortion of the machine frame.
3. **Center of Gravity:** The combined CG of the machine and foundation should be as low as possible and pass through the center of the base area.
4. **Isolation:** Should be isolated from surrounding building structures to prevent transmission of vibrations.

Lecture 2.2: Specific Requirements for Static vs Rotating Machinery

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Foundation for Static Machinery (Transformers)

Static machines like Power Transformers require simple foundation designs.

Key Aspects for Static Machine Foundations

- **Load Bearing:** Must support the heavy static weight of the core, windings, tank, and oil.
- **Oil Soak Pits:** Large transformers require an oil soak pit (catch basin) around/under the foundation with crushed rocks to prevent fire hazards in case of oil leakage.
- **Rails:** Foundations for very large transformers often have rails embedded in the concrete to facilitate rolling the unit into place.

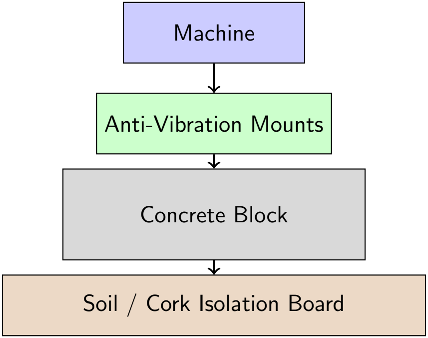
Foundation for Rotating Machinery (Motors/Generators)

Rotating machines produce complex dynamic loads.

Design Considerations:

- **Dynamic Forces:** Foundation must withstand unbalanced forces operating at rotational frequency.
- **Resonance Avoidance:** Natural frequency of the foundation must NOT match the operating speed of the machine (avoid $f_{natural} \approx f_{operating}$).
- **Grouting:** Critical for filling the gap between the machine baseplate and the concrete foundation, ensuring uniform load distribution.

Vibration Isolation Techniques



Materials used for isolation: Cork, Rubber pads, Steel springs, Glass fiber.

Foundation Bolts and Grouting

Component	Function
Anchor Bolts	Also called foundation bolts. They secure the equipment firmly to the foundation block. Can be cast-in-place or post-installed.
Grout	A fluid mixture of cement, sand, and water (or epoxy) poured between the concrete base and metal skid. It hardens to provide a continuous, high-strength support.

Lecture 2.3: Concept of Levelling and Aligning

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Introduction to Levelling

Levelling

Levelling is the process of adjusting the equipment base so that it sits perfectly horizontal (parallel to the earth's surface).

Why is Levelling Important?

- Prevents unequal distribution of oil in bearings.
- Ensures uniform loading on the foundation.
- Prevents lateral forces on structural components that were designed for vertical loads only.
- It is a prerequisite for proper alignment.

Alignment

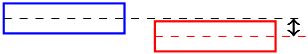
Alignment is the process of making the centerlines of two coupled shafts perfectly collinear (forming a single straight line) under normal operating conditions.

Objectives of Shaft Alignment:

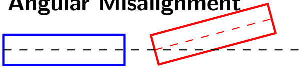
- Increase operating lifespan of bearings, seals, and couplings.
- Minimize power loss and improve efficiency.
- Reduce vibration levels and noise.
- Minimize shaft bending and fatigue failures.

Types of Misalignment

Parallel (Offset) Misalignment



Angular Misalignment



Procedure for Levelling

Basic Procedure:

1. Clean the foundation and machine base thoroughly.
2. Place the machine on the foundation over steel wedges or levelling shims/jacks.
3. Place a precision Spirit Level or Laser Level on machined reference surfaces of the equipment (like shaft journals or milled base pads).
4. Adjust the wedges or jacks to bring the bubble of the spirit level to the dead center.
5. Check levelling in both longitudinal (lengthwise) and transverse (crosswise) directions.
6. Tighten anchor bolts gradually and re-check level, as tightening may distort the frame.

Lecture 2.4: Alignment of Direct Coupled Drive & Effects of Misalignment

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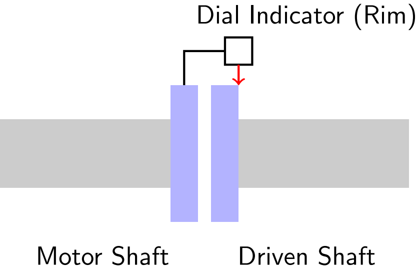
Alignment Methods

Depending on the accuracy required, different tools and methods are used for alignment:

- **Straightedge and Feeler Gauge:** Quick but least accurate. Uses a metal straightedge across coupling halves and feeler gauges between faces.
- **Dial Indicators (Rim and Face method):** Very common. Uses precision dial gauges to measure parallel (rim) and angular (face) deviations.
- **Laser Alignment System:** Highly accurate, modern, and automated. Emits laser beams between brackets on shafts and computes exact shim requirements.

Dial Indicator Setup (Concept)



Note: The dial indicator rotates with the shaft to measure concentricity.

Procedure for Alignment

1. **Pre-alignment Checks:** Ensure soft foot (uneven seating of machine feet) is corrected.
2. **Mounting Tools:** Install dial gauges or laser heads.
3. **Measurement:** Rotate shafts together and record readings at 0, 90, 180, and 270 degrees.
4. **Calculation:** Determine vertical and horizontal corrections.
5. **Correction:** Add or remove precision stainless steel shims under the movable machine's feet. Move horizontally using jacking bolts.
6. **Verification:** Re-measure to ensure alignment is within tolerance.

Effects of Misalignment

Consequences of Poor Alignment

Misalignment generates reaction forces within the coupling that transfer to the shafts, bearings, and seals.

Major Effects:

- Premature bearing failure (due to excessive axial/radial loads).
- Accelerated wear on coupling elements (elastomers or gear teeth).
- High vibration levels and noise.
- Shaft fatigue cracking or complete breakage.
- Premature seal failure, leading to fluid leakage.
- Increased energy consumption (due to mechanical friction).

Lecture 2.5: Installation Procedure of Power Transformer as per I.S.

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Introduction to Transformer Installation

The installation of a Power Transformer must be carried out carefully according to Indian Standards (like IS: 10028 - Code of practice for selection, installation, and maintenance of transformers).

General Precautions:

- Transformer must be handled in an upright position.
- Lifting should only be done using the designated lifting lugs on the tank.
- The installation area must have adequate ventilation and safety clearances.

Pre-Installation Checks

Before placing the transformer on the foundation:

- **Visual Inspection:** Check for physical damage during transit, oil leaks, and integrity of bushings.
- **Foundation Readiness:** Verify foundation dimensions, levelling, and oil soak pit condition.
- **Nitrogen Gas Pressure:** For large transformers shipped without oil, verify positive nitrogen gas pressure is maintained to prevent moisture ingress.
- **Insulation Resistance (Megger):** Check IR values of core-to-ground and between windings.

Installation Steps

1. **Positioning:** Move the transformer onto the foundation plinth using rollers, cranes, or skids. Lock the wheels securely.
2. **Assembly of Accessories:**
    - Mount the radiators/cooling tubes.
    - Install the Conservator tank and Buchholz relay (ensuring 3 to 7 degrees upward slope towards the conservator).
    - Install the breathers, temperature indicators, and explosion vent.
3. **Bushing Installation:** Carefully install HV and LV bushings and connect internal leads.

Oil Filling and Final Checks

Oil Filtration and Filling

Transformer oil must be tested for Dielectric Strength (BDV) and moisture content. It is filtered in a streamline filter machine and filled into the transformer under vacuum to avoid trapping air bubbles.

Final Pre-Commissioning Tests:

- Oil BDV test (> 50 kV typical for new oil).
- Winding resistance measurement.
- Transformer Turns Ratio (TTR) test.
- Vector group verification.
- Earth resistance measurement of the neutral and body grounding.

Lecture 2.6: Installation Procedure of Rotating Electrical Machines (Induction Motor & Alternator)

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Pre-Installation Requirements

Installing rotating machines (like 3-phase induction motors or alternators) strictly follows standards (e.g., IS 900 for induction motors).

Site Preparation:

- Location must be clean, dry, and well-ventilated.
- Allow sufficient space for rotor removal and maintenance access.
- Ambient temperature should normally not exceed 40°C.

Initial Checks:

- Verify nameplate details against supply voltage and load requirements.
- Rotate shaft by hand to ensure free movement (no binding or abnormal noise).
- Measure insulation resistance using a Megger (minimum 1 $M\Omega$ for LV motors).

Mounting and Levelling

1. **Base Plate / Skid:** Place the motor/alternator on the prepared foundation block or steel skid.
2. **Levelling:** Use shims and spirit levels on the shaft and machined pads to ensure perfectly horizontal mounting.
3. **Soft Foot Check:** Ensure all four feet rest solidly on the base. If one foot is loose, it causes casing distortion when tightened. Correct by adding shims.
4. **Bolting:** Lightly snug the foundation bolts. Do not fully tighten until alignment is complete.

Alignment and Coupling

Aspect	Requirement
Coupling Fit	Half-couplings should be heated in an oil bath or induction heater for interference fit onto the shaft. Never use a hammer.
Alignment	Perform precise alignment (laser or dial gauge) to match motor shaft with the driven equipment (pump, fan) or prime mover (turbine, engine).
Grouting	After alignment, grout the baseplate to the concrete. Wait for curing before final tightening of anchor bolts.

Electrical Connections & Earthing

Electrical Safety and Connections

- Connect power cables to the terminal box according to Star or Delta configuration as required.
- Ensure proper lugging and crimping. Loose connections cause localized heating.
- **Earthing:** Two distinct and separate solid earth connections must be made to the motor/alternator frame body as per IE Rules.

Final Run: Check direction of rotation before coupling (bump test). Run uncoupled to check for vibrations and bearing temperature.

Lecture 2.7: Installation Procedure of Switchgear as per I.S.

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Introduction to Switchgear Installation

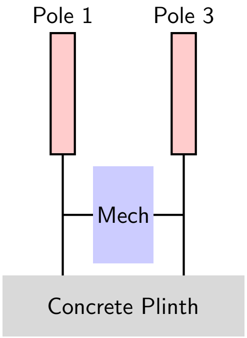
Switchgear encompasses Circuit Breakers (CB), Isolators, and Control Panels. Proper installation is critical for system protection and personnel safety (IS 8623 / IS 3427).

Handling and Storage:

- Switchgear panels are tall and have a high center of gravity. Transport upright using cranes or pallet jacks.
- Store indoors in a dry environment. Use space heaters if condensation is a risk.

1. **Base Channel:** Install base channels (ISMC) leveled accurately on the floor trench. Max deviation typically < 1 mm per meter.
2. **Panel Erection:**
   - Move panels over the base channel.
   - Bolt adjacent panel sections together loosely.
   - Align the front faces and bolt firmly.
3. **Busbar Connections:** Connect main busbars between transport sections. Ensure contact surfaces are clean and smeared with contact grease. Use torque wrenches for tightening hardware.
4. **Earthing:** Connect the main earth bus at the bottom of the panels to the station earth grid.

Outdoor Circuit Breaker & Isolator Installation



Outdoor structures (SF6 CBs, VCBs) require erection of galvanized steel support structures, mounting of pole units, and mechanical linkages to the drive mechanism.

Final Checks for Switchgear

Pre-commissioning Tests

- **Mechanical Operation:** Rack the breaker IN and OUT (Test/Service positions) multiple times. Manually operate charging springs and trip linkages.
- **Contact Resistance:** Measure micro-ohms across closed breaker contacts.
- **Timing Test:** Measure closing, opening, and Close-Open (CO) times of all three poles to ensure simultaneity.
- **Insulation Test:** Megger the busbars and breaker poles (Pole-to-Pole and Pole-to-Earth).

Lecture 2.8: Devices and Tools Required for Installation of Electrical Equipment

GTU Course Presentation

Mechanical Handling Tools

Installing heavy electrical equipment requires specialized lifting and moving tools.

- **Cranes and Hoists:** EOT (Electric Overhead Traveling) cranes, mobile cranes, and chain pulley blocks for lifting transformers and heavy motors.
- **Slings and Shackles:** Wire rope slings, nylon web slings, and D-shackles to secure the load to the crane hook.
- **Hydraulic Jacks:** Used for lifting heavy machinery a few inches for levelling or placing rollers.
- **Crowbars and Rollers:** Steel pipes used as rollers to manually move machinery over short, flat distances.

Measuring and Levelling Tools

Precision is critical during installation.

Tool	Application
Precision Spirit Level	Checking horizontal and vertical levels of bases and shafts. Sensitivity is often up to 0.02mm/m.
Dial Indicator	Measuring runout, concentricity, and shaft alignment down to 0.01mm.
Feeler Gauge	Checking air gaps in motors and clearances between coupling faces.
Micrometer / Vernier	Measuring shaft diameters and shim thicknesses accurately.

Electrical and Hand Tools

Common Hand & Assembly Tools

- **Spanners & Sockets:** Open-end, ring spanners, and socket sets for tightening nuts and bolts.
- **Torque Wrench:** Critical for tightening electrical busbar connections and foundation bolts to a specific, manufacturer-specified torque value.
- **Crimping Tool:** Hydraulic or manual tools for attaching copper/aluminum lugs to cable ends.
- **Hammers & Mallets:** Nylon or copper/brass mallets for gentle tapping without damaging machined surfaces.

Testing Devices

Before finalizing the installation, basic testing devices are required:

- **Insulation Resistance Tester (Megger):** Usually 500V, 1000V, or 5000V devices to check insulation integrity of cables, transformers, and motors.
- **Multimeter:** For checking continuity, voltage, and resistance.
- **Earth Tester:** To measure the resistance of the earth pit and grid connections.
- **Phase Sequence Meter:** To verify the correct phase sequence (RYB) of the incoming supply before connecting to a motor.

Lecture 2.9: Concept of Maintenance, Types of Maintenance

GTU Course Presentation

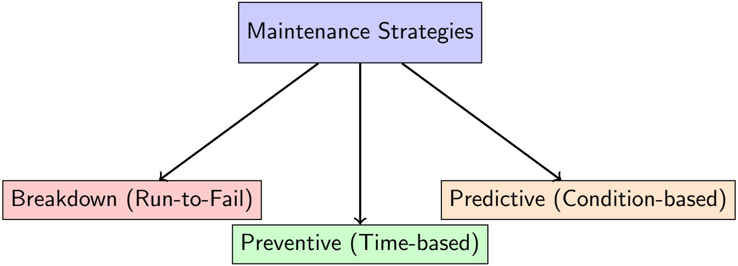
Concept of Maintenance

Maintenance

Maintenance encompasses all activities intended to keep an equipment in, or restore it to, a state in which it can perform its required function safely and reliably.

Objectives of Maintenance:

- Maximize equipment availability and reliability.
- Extend the useful life of the asset.
- Ensure safety of personnel and property.
- Optimize operational efficiency and reduce energy losses.
- Minimize total cost of ownership.


Maintenance Strategies
Breakdown (Run-to-Fail)
Preventive (Time-based)
Predictive (Condition-based)

1. Breakdown (Reactive) Maintenance

Also known as "Run-to-Failure" or Corrective maintenance.

- **Concept:** No action is taken until the equipment actually fails.
- **When to use:** Only for cheap, non-critical items where replacement is easy and failure does not affect production or safety (e.g., a light bulb).
- **Disadvantages:**
  - Unplanned downtime.
  - Secondary damage to other components.
  - High overtime labor and emergency spare parts costs.

2. Routine & Preventive Maintenance

Routine Maintenance: Day-to-day minor tasks such as cleaning, visual inspection, tightening loose bolts, and minor lubrication.

Preventive Maintenance (PM)

Planned, scheduled maintenance activities performed at regular intervals (time-based or cycle-based) designed to prevent wear and tear from leading to failure. *Examples:* Changing oil every 6 months, overhauling a motor every 3 years.

Advantages of PM:

- Reduces sudden breakdowns.
- Planned resource allocation.
- Increases safety.

Drawback: Might replace parts that still have remaining useful life.

Lecture 2.10: Preventive Maintenance - Procedure for Developing Maintenance Schedules

GTU Course Presentation

What is a Maintenance Schedule?

Maintenance Schedule

A comprehensive document that outlines exactly WHAT maintenance tasks need to be done, WHO will do them, and WHEN (frequency) they must be executed for a specific piece of equipment.

A good schedule translates maintenance strategies into actionable plans.

Procedure for Developing a PM Schedule

Step 1: Inventory and Criticality Analysis

- List all electrical assets (motors, transformers, panels).
- Rank them by criticality (High/Medium/Low) based on production impact and safety risk.

Step 2: Collect Manufacturer Data

- Refer to OEM (Original Equipment Manufacturer) manuals.
- OEMs provide baseline recommendations for daily, monthly, and yearly checks.

Procedure for Developing a PM Schedule (Cont.)

Step 3: Define Maintenance Tasks Determine specific actions. Examples:

Task Type	Example
Inspection	Check for oil leaks on transformer.
Servicing	Greasing motor bearings.
Testing	Megger testing cables.
Calibration	Calibrating protection relays.

Step 4: Determine Frequency Establish how often each task is done (Daily, Weekly, Monthly, Quarterly, Annually, Turnaround).

Implementation and Continuous Improvement

Step 5: Resource Planning

- Identify tools, spare parts, and manpower skill levels required for each task.
- Schedule tasks using a CMMS (Computerized Maintenance Management System).

Step 6: Review and Refine (Feedback Loop)

A PM schedule is not static. If a motor fails between annual PMs, the frequency might need to be increased to semi-annually. Conversely, if parts are always perfectly fine during PM, the interval can be safely extended.

Lecture 2.11: Factors Affecting Preventive Maintenance Schedules

GTU Course Presentation

Introduction

OEM manuals provide a baseline for maintenance intervals. However, in reality, identical motors might require vastly different PM schedules depending on where and how they are used. Several critical factors dictate whether PM frequencies should be increased or decreased.

1. Environmental Conditions

The physical environment heavily impacts equipment deterioration.

- **Temperature & Humidity:** High ambient temperatures degrade insulation faster (the 10°C rule halves insulation life). High humidity causes corrosion and moisture absorption.
- **Dust and Dirt:** Cement plants or mining environments clog cooling fins and air filters, requiring more frequent cleaning.
- **Corrosive Atmospheres:** Chemical plants or coastal areas (salt spray) accelerate rust and terminal oxidation.

2. Operational and Load Conditions

Factor	Impact on Schedule
Duty Cycle	A motor running 24/7 requires more frequent lubrication than a motor running 8 hours a day.
Loading	Equipment constantly operating near its maximum rated capacity stresses electrical and mechanical parts faster.
Start/Stops	Frequent starting of heavy loads causes high starting currents (thermal stress) and mechanical shocks.

3. Equipment Age and History

Bathtub Curve Concept

Equipment failure rates are high initially (infant mortality), low during normal life, and increase as the equipment ages (wear-out phase).

- **Age:** Older equipment nearing the end of its design life requires more frequent inspections (e.g., checking for insulation brittleness).
- **Failure History:** If historical data shows frequent specific failures (e.g., repeated bearing issues), PM frequency for that specific component must be tightened.

Lecture 2.12: Maintenance Schedules of Electrical Equipment as per IS

GTU Course Presentation

Maintenance of Power Transformers (IS 10028)

- **Hourly/Daily:** Check oil level in conservator, winding/oil temperatures, and inspect for oil leaks. Check silica gel color (blue/orange is good, pink/white needs replacing).
- **Monthly:** Check oil level in bushings. Clean breather.
- **Half-Yearly:** Test oil Dielectric Strength (BDV).
- **Yearly:** Test insulation resistance (Megger). Check earth resistance. Calibrate temperature indicators. Test Buchholz relay operation.

Maintenance of 3-Phase Induction Motors

Frequency	Maintenance Activity
Daily	Check for abnormal noise/vibration. Monitor body and bearing temperatures. Ensure cooling fins are clean.
Monthly	Check foundation bolts for tightness. Check belt tension/coupling.
Half-Yearly	Grease bearings (do not over-grease). Check terminal box connections for tightness.
Yearly	Measure Insulation Resistance. Check alignment. Overhaul if vibration levels indicate bearing wear.

Maintenance of Circuit Breakers & Batteries

Circuit Breakers (e.g., VCB/SF6):

- **Quarterly:** Clean insulators. Check gas pressure (for SF6). Check mechanism lubrication.
- **Yearly:** Measure contact resistance (micro-ohm meter). Perform timing test. Test protective relay trip circuits.

Lead-Acid Batteries (Substation DC Supply)

- **Weekly:** Check electrolyte level and top up with distilled water.
- **Monthly:** Measure specific gravity and cell voltages. Clean terminals and apply petroleum jelly to prevent sulfation.

Maintenance of Solar and Wind Plants

Solar PV Plants:

- **Frequent:** Cleaning solar panels (dust drastically reduces output).
- **Quarterly:** Check DC string box connections, inverter cooling fans, and MC4 connectors. Inspect for hot spots using a thermal camera.

Wind Power Plants:

- **Mechanical:** Pitch and yaw mechanism lubrication, gear-box oil sampling.
- **Electrical:** Generator slip-ring and carbon brush inspection (monthly). Bolt torque checking on tower segments (yearly).

Lecture 3.1: Importance of Commissioning of Transformer

GTU Course Presentation

Introduction to Commissioning

Commissioning

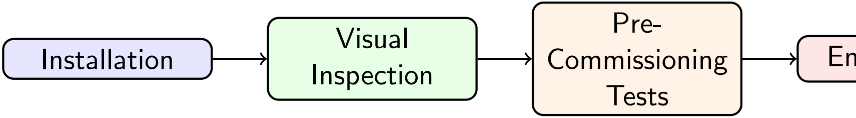
Commissioning of a transformer is a series of tests and verifications conducted after installation to ensure that it has not been damaged during transit and complies with operational specifications.

- Bridges the gap between installation and operation.
- Ensures the safety of personnel and equipment.
- Establishes baseline data for future maintenance and condition monitoring.

Why is Commissioning Important?

- **Verification of Specifications:** Confirms that the transformer meets the design and manufacturing specifications.
- **Detection of Transit Damage:** Identifies hidden faults (e.g., shifted core, broken connections) that occurred during transportation.
- **Safety Assurance:** Minimizes the risk of catastrophic failure upon energization, which could lead to fire or explosion.
- **Warranty Validation:** Mandatory requirement by manufacturers to validate equipment warranties.

Commissioning Workflow



The sequence highlights that rigorous testing is a prerequisite before exposing the transformer to the grid voltage.

Common Faults Detected During Commissioning

Test/Inspection	Potential Fault Detected
Visual Inspection	Oil leaks, physical damage, missing accessorie
Insulation Resistance	Moisture ingress, deteriorated insulation
Winding Resistance	Loose connections, broken strands
Voltage Ratio	Turns ratio mismatch, tap changer issues

Conclusion of Lecture

Key Takeaway

Never skip or rush the commissioning process. The cost of a failed transformer far outweighs the time and resources spent on comprehensive pre-commissioning checks.

- Establish standard operating procedures (SOPs).
- Use calibrated testing equipment.
- Document all findings meticulously for lifecycle management.

Lecture 3.2: Importance of Commissioning of Transformer (Continued)

GTU Course Presentation

Impact of Poor Commissioning

- **Premature Failure:** Unidentified minor faults can escalate into major breakdowns under load conditions.
- **Operational Downtime:** Unexpected outages lead to significant financial losses and reduced grid reliability.
- **Safety Hazards:** Inadequate earthing or insulation failure can cause fatal accidents for substation personnel.

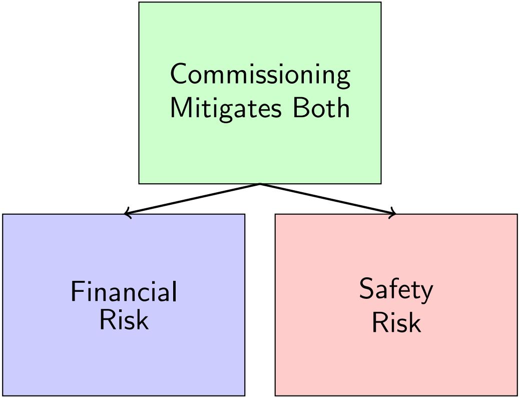
Regulatory and Standards Compliance

Standards

Commissioning must align with national and international standards such as IS 10028, IEC 60076, and IEEE C57.12.90.

- **IS 10028:** Code of practice for selection, installation, and maintenance of transformers.
- Compliance ensures legal protection and adherence to best engineering practices.
- Utilities and regulatory bodies mandate commissioning reports before final approval.

Risk Management Perspective



Economic Justification

Parameter	**Impact of Commissioning**
Lifespan	Extends useful life by identifying early-stage defects.
Maintenance Costs	Reduces reactive maintenance; enables predictive maintenance.
Insurance	Lower premiums due to documented risk mitigation.

Summary of Importance

- Commissioning is not just a formality but a critical engineering milestone.
- It requires skilled personnel, proper planning, and exact execution.
- The generated data forms the "birth certificate" of the transformer's operational life.

Lecture 3.3: Difference Between Type Test, Routine Test and Special Test

GTU Course Presentation

Classification of Transformer Tests

Test Categories

Transformer tests are broadly categorized based on their purpose: verifying design (Type Tests), ensuring manufacturing quality (Routine Tests), and addressing specific operational requirements (Special Tests).

- As per IEC 60076 and IS 2026.
- Tests are conducted at the manufacturer's premises before dispatch.

Routine Tests

- **Purpose:** Conducted on *every single unit* manufactured to verify its performance against the specified ratings.
- **Nature:** Basic quality control checks.
- **Examples:**
  - Measurement of Winding Resistance.
  - Measurement of Voltage Ratio and Vector Group.
  - Measurement of Impedance Voltage / Short Circuit Impedance.
  - Measurement of No-Load Loss and Current.
  - Dielectric tests (Separate source voltage withstand).

Type Tests

- **Purpose:** Conducted on *one unit of a specific design* to verify that the design meets the specifications and can withstand operational stresses.
- **Nature:** Destructive or highly stressful tests; expensive and time-consuming.
- **Examples:**
    - Temperature Rise Test.
    - Lightning Impulse Test.
- **Note:** Once a design passes type tests, subsequent identical units do not undergo these tests unless specified by the purchaser.

Special Tests

- **Purpose:** Conducted as per customer request or to verify specific performance characteristics under unique conditions.
- **Examples:**
  - Short-Circuit Withstand Test (often considered a special or type test).
  - Measurement of Zero-Sequence Impedance.
  - Measurement of Acoustic Noise Level.
  - Measurement of Harmonics of the no-load current.

Comparison Overview

Feature	Routine Test	Type Test	Special Tes
Frequency	Every Unit	One per Design	As Requeste
Purpose	Quality Control	Design Validation	Specific Info
Cost	Low	High	Varies
Stress Level	Normal	High/Extreme	Moderate to H

Lecture 3.4: Detailed Examples of Routine, Type, and Special Tests

GTU Course Presentation

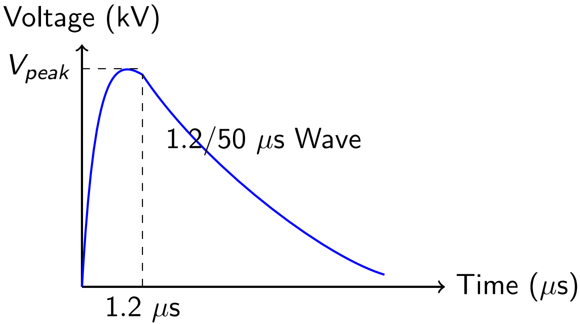
Deep Dive: Temperature Rise Test (Type Test)

- **Objective:** To check if the temperature rise of the oil and windings exceeds the specified limits when operated at full load.
- **Procedure:**
  - Short-circuit one winding.
  - Apply voltage to the other winding to circulate full load current.
  - Monitor oil temperature until it stabilizes (gradient $\leq 1^{\circ}$C per hour).
- **Significance:** Validates the cooling system design.

Deep Dive: Lightning Impulse Test (Type Test)

- **Objective:** To verify the insulation's ability to withstand transient overvoltages (lightning strikes).
- **Waveform:** Standard 1.2/50 μs impulse wave.
- **Sequence:**
  - One reduced full wave (approx. 50%).
  - One full wave (100%).
  - One chopped wave (if specified).
- **Analysis:** Comparing voltage and current oscillograms of reduced and full waves for discrepancies indicating insulation failure.

Impulse Waveform Characteristics



Deep Dive: Measurement of Zero Sequence Impedance (Special Test)

- **Objective:** To determine the zero-sequence impedance for earth fault protection settings.
- **Applicability:** Three-phase transformers, especially star-connected with neutral brought out.
- **Method:**
  - Three line terminals are shorted together.
  - A single-phase voltage is applied between the shorted terminals and the neutral.
- $Z_0 = \frac{3 \times V}{I}$, where I is the total current and V is applied voltage.

Summary of Test Differences

Key Distinction

Routine tests ensure the transformer was built correctly. Type tests ensure the transformer was designed correctly. Special tests provide additional operational parameters.

- Manufacturers provide Test Certificates detailing routine test results for every unit.
- Purchasers must explicitly request and often pay extra for Type and Special tests if not standard for the design.

Lecture 3.5: Pre-Commissioning Checks- Significance and Procedure

GTU Course Presentation

What are Pre-Commissioning Checks?

Pre-Commissioning

Pre-commissioning involves a series of physical inspections and preliminary electrical tests performed on-site before the transformer is energized.

- Follows mechanical installation and oil filling.
- Precedes formal commissioning tests.
- Focuses on visual readiness, mechanical integrity, and basic safety.

Visual and Mechanical Inspections

- **Oil Level Check:** Ensure oil in the conservator tank is at the correct level (corresponding to ambient temperature).
- **Silica Gel Breather:** Check the color of the silica gel. It should be blue (if standard) or orange (if eco-friendly), not pink/white (indicating moisture).
- **Valves and Leaks:** Verify all valves are in correct position (open/close) and check for any oil seepage around gaskets and radiators.
- **Earthing Connections:** Confirm double earthing of the transformer tank and neutral earthing (if applicable).

Significance of Standard Reference Values

- **Baseline Comparison:** Field test results must be compared against the Manufacturer's Factory Acceptance Test (FAT) report.
- **Acceptable Deviation:**
  - Voltage Ratio: $\pm 0.5\%$.
  - Winding Resistance: Within $1 - 2\%$ of factory values (after temperature correction).
- Significant deviations indicate damage during transit or installation errors.

Pre-Commissioning Flowchart

1. Visual & Mechanical Check

↓

2. Oil BDV & Moisture Test

↓

3. Insulation Resistance (Megger)

↓

4. Ratio & Resistance Test

Transformer Oil Preparation

Oil Quality

Transformer oil must be filtered and tested on-site before energization, regardless of factory tests.

- **Breakdown Voltage (BDV):** Should generally be > 60 kV for new oil.
- **Moisture Content (PPM):** Should be kept strictly below $10 - 15$ ppm.
- Oil filtration removes dissolved gases and moisture accumulated during transit.

Lecture 3.6: Insulation Resistance Measurement (IR and PI)

GTU Course Presentation

Insulation Resistance (IR) Test

- **Objective:** To measure the resistance of the insulation to assess its condition (dryness and cleanliness).
- **Equipment:** Insulation Tester (Megger). Typically 500V or 1000V for control wiring; 2.5kV or 5kV for main windings.
- **Procedure:** Measure resistance between:
  - HV winding and LV winding.
  - HV winding and Earth (Tank).
  - LV winding and Earth (Tank).

Polarization Index (PI)

Polarization Index

PI is the ratio of the Insulation Resistance measured at 10 minutes to the IR measured at 1 minute.

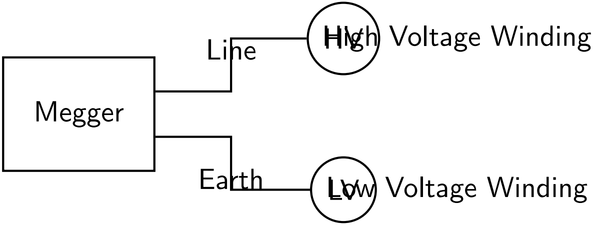
$$PI = \frac{IR_{10\ min}}{IR_{1\ min}}$$

- **Significance:** Evaluates the presence of moisture and contamination. PI is less sensitive to temperature variations than absolute IR values.
- **Reference Values:**
  - < 1.0: Dangerous
  - $1.0 - 1.5$: Poor
  - $1.5 - 2.0$: Fair
  - $2.0 - 4.0$: Good
  - > 4.0: Excellent

Testing Control Wiring and Auxiliary Circuits

- **Cooling System Motors:** IR of fan and pump motors should be checked. Minimum acceptable value is typically 1 MΩ at 500V DC.
- **Control Circuit wiring:** Ensures marshaling box wiring has no earth faults.
- **Tap Changer Motor:** Motor and control circuitry of the OLTC (On-Load Tap Changer) must be meggered before operation.
- **Caution:** Disconnect sensitive electronic relays (like AVRs) before applying Megger voltage to control wiring.

IR Measurement Circuit



Factors Affecting IR Values

Factor	Effect on IR Value
Temperature	IR roughly halves for every 10°C rise in temperature. Must correct values to standard 20°C.
Moisture	Significant drop in IR value. Decreases PI.
Dirt/Contamination	Creates surface leakage paths, reducing apparent IR.

Lecture 3.7: Polarity and Vector Group Test

GTU Course Presentation

Importance of Polarity

Polarity

Polarity identifies the relative phase relationship between the primary and secondary induced voltages in a transformer.

- Essential for **parallel operation** of transformers.
- Incorrect polarity results in a dead short circuit when transformers are paralleled.
- Determines correct connections for protection relays (e.g., differential protection).

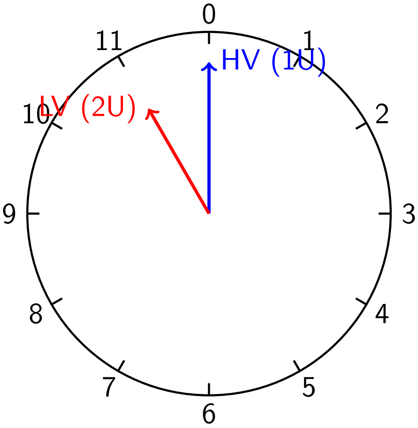
Polarity Test Method (AC Method)

- **Setup:** Connect one high voltage terminal (e.g., 1U) to the corresponding low voltage terminal (e.g., 2U).
- Apply a low AC voltage across the HV terminals (1U and 1V).
- Measure the voltage across the HV terminals (V_1), LV terminals (V_2), and between the unconnected terminals (1V and 2V, let's call it V_3).
- **Subtractive Polarity (Standard):** $V_3 < V_1$.
- **Additive Polarity:** $V_3 > V_1$.

Understanding Vector Groups

- Indicates the winding connections (Star, Delta, Zig-zag) and the phase displacement between HV and LV sides.
- Standard nomenclature: e.g., **Dyn11**.
  - **D**: HV winding is Delta connected.
  - **y**: LV winding is Star (wye) connected.
  - **n**: LV neutral brought out.
  - **11**: Phase shift is $11 \times 30^\circ = 330^\circ$ (LV leads HV by 30°).

Vector Group Test (Dyn11 Example)



For Dyn11, LV phasor is at the 11 o'clock position relative to the HV phasor at 12 o'clock.

Procedure for Vector Group Test

- Connect 1U to 2U.
- Apply three-phase balanced low voltage to HV terminals (1U, 1V, 1W).
- Measure voltages between various terminals: (1V-2V), (1V-2W), (1W-2V), (1W-2W).
- Check predefined voltage conditions based on the vector group.
- *Example for Dyn11:* V_{1V-2V} must equal V_{1V-2W}, and $V_{1W-2W} < V_{1W-2V}$.

Lecture 3.8: Ratio Test on All Taps

GTU Course Presentation

Purpose of the Ratio Test

- **Objective:** To verify that the turns ratio of the transformer matches the design specification, ensuring the correct output voltage.
- Formula:

$$\text{Voltage Ratio} = \frac{V_{HV}}{V_{LV}} \approx \frac{N_{HV}}{N_{LV}}$$

- It detects shorted turns, open circuits, or incorrect connections within the windings.

Testing on All Taps

Why All Taps?

Transformers have tap changers (OLTC or OCTC) to regulate voltage. Testing on a single tap is insufficient because a fault may exist on a specific tap winding or contact.

- Validates the mechanical and electrical integrity of the tap changer mechanism.
- Ensures the voltage varies sequentially and correctly as the tap position changes.

Transformer Turns Ratio (TTR) Meter

- Modern testing is done using a digital **TTR Meter**.
- **Operation:** It applies a known low AC voltage to the primary and measures the induced voltage on the secondary.
- Automatically calculates the ratio and the phase angle deviation.
- Extremely accurate, avoiding reading errors of analog voltmeters.

Acceptance Criteria

Parameter	Limit
Calculated vs Measured Ratio	Must be within $\pm 0.5\%$
Phase Angle Deviation	Typically less than 0.1 degree
Excitation Current	Recorded by TTR, should be very lo

If error $> 0.5\%$, it indicates:

- Shorted turns (which also cause high excitation current).
- Tap changer contact issue.

Procedure

1. Isolate the transformer completely.
2. Connect TTR 'H' leads to High Voltage terminals and 'X' leads to Low Voltage terminals.
3. Select Phase (e.g., A phase to A phase).
4. Keep Tap changer at Tap 1. Run test. Record Ratio, Error %, and Current.
5. Change tap to Tap 2. Repeat test.
6. Continue until all tap positions (e.g., 1 to 17) are tested for all three phases.

Lecture 3.9: Magnetizing Current Test

GTU Course Presentation

What is Magnetizing Current?

Magnetizing Current

The current drawn by the primary winding of a transformer when it is energized at rated voltage and frequency, with the secondary open-circuited (no-load condition).

- Primarily consists of the current needed to establish the magnetic flux in the core.
- A very small percentage of the full-load current (typically 0.5% to 2%).

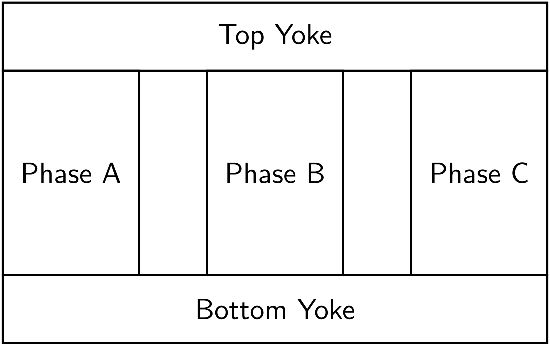
Objective of the Test at Commissioning

- **Locate Core Defects:** Identifies shifts in the core structure that may have happened during transport.
- **Identify Shorted Turns:** A shorted turn acts like a heavily loaded secondary, drawing massive excitation current.
- **Check Magnetic Circuit Health:** Identifies issues with core joints or insulation between core laminations.

Procedure

- Normally conducted at low voltage (e.g., 415V AC) from the LV side (or HV side depending on convenience, typically HV for safety if LV is low).
- Keep the other winding strictly open-circuited.
- Apply 3-phase voltage and measure the current in each phase using an ammeter or clamp meter.

Expected Pattern in 3-Phase Core Type



- Due to magnetic reluctance, the path for the center limb (Phase B) is shorter than for the outer limbs (Phases A and C).
- Therefore, **Current in Phase A** $\approx$ **Current in Phase C**.
- **Current in Phase B** $<$ **Current in Phase A/C**.

Analysis of Results

Observation	**Diagnosis**
$I_a \approx I_c$, $I_b < I_a$	Normal Core Condition.
Extremely high current in one phase	Inter-turn short circuit in that
Unbalanced current pattern	Core joint displaced or loose.

Important

The exact values will be much lower than factory tests because the test is done at reduced voltage (e.g., 415V instead of 11kV). The *pattern* is what matters.

Lecture 3.10: Magnetic Balance Test (For 3 Phase Transformer)

GTU Course Presentation

Purpose of Magnetic Balance Test

- **Objective:** To confirm that the magnetic circuit of a 3-phase transformer is balanced and intact.
- It is a simple, low-voltage test used exclusively for three-phase core-type transformers.
- Effectively detects inter-turn short circuits and major core displacement.
- Does NOT apply to shell-type or single-phase transformer banks.

Underlying Principle

- When a single-phase voltage is applied across one phase of the primary winding, it induces magnetic flux in that limb.
- This flux travels through the yoke and splits to return via the other two limbs.
- Because the flux splits, it induces voltages in the other two phase windings.
- The sum of the voltages induced in the other two phases should equal the applied voltage.

Testing Procedure

1. Keep the secondary winding completely open.
2. Apply a single-phase AC voltage (e.g., 230V) across Phase U (between 1U and 1N, or 1U and 1V for Delta).
3. Measure the voltage across Phase V and Phase W.
4. Repeat by applying voltage to Phase V, then Phase W.

Expected Results (Star Winding Example)

Let applied voltage be V.

Apply Voltage	Measure U-N	Measure V-N	Measure
U-N	V (e.g., 230V)	$\approx 50 - 80\%$ of V	$\approx 20 - 5$
V-N (Center)	$\approx 50\%$ of V	V (e.g., 230V)	$\approx 50\%$
W-N	$\approx 20 - 50\%$ of V	$\approx 50 - 80\%$ of V	V (e.g.,

Key Equation for Validation:

- When voltage V_{UN} is applied: $V_{UN} \approx V_{VN} + V_{WN}$
- When voltage V_{VN} is applied: $V_{VN} \approx V_{UN} + V_{WN}$

Interpretation of Anomalies

Diagnostic value

If the sum of induced voltages does not approximately equal the applied voltage, or if the symmetrical pattern is broken, there is a fault.

- **Near Zero Voltage Induced:** Suggests a severe shorted turn in the limb where no voltage is appearing.
- **Significant Imbalance:** Suggests core damage, shifted laminations, or poor core joints.

Lecture 4.1: Pre-Commissioning Inspection Checks for Rotating Machines

GTU Course Presentation

Introduction to Pre-Commissioning

Pre-Commissioning Inspection

A series of visual and mechanical checks performed on rotating machines (synchronous, induction, DC) before applying any electrical power. It ensures the machine is mechanically intact and correctly installed.

- Prevents catastrophic failures upon initial startup.
- Verifies alignment, lubrication, and cooling systems.
- Confirms that all nameplate specifications match the design requirements.

Visual Inspection Checks

Key Areas of Inspection

Visual checks are the first line of defense against installation errors.

- **Foundation and Mounting:** Ensure foundation bolts are tightened to the required torque. Check for any cracks in the concrete bed.
- **Nameplate Verification:** Cross-verify rated voltage, current, speed, and power factor with the electrical panel ratings.
- **Terminal Box:** Inspect for clean connections, proper lug sizes, and adequate clearance between phases.

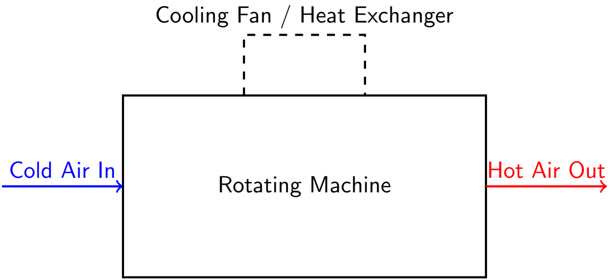
Mechanical Checks and Alignment

Parameter	Check/Tolerance
Shaft Alignment	Dial indicator / Laser alignment within 0.05 m
Air Gap	Uniformity within 10% of average gap
Rotor Free Rotation	Hand-barring without binding or scraping

Table: Typical Mechanical Inspection Parameters

- **Bearings & Lubrication:** Check oil level in sight glass, verify correct grease type for anti-friction bearings.
- **Coupling:** Inspect coupling halves, insert keys properly, and check for coupling guards.

Cooling and Ventilation System Checks



- Ensure air intake and exhaust vents are free of obstruction.
- Verify the direction of rotation of external cooling fans (TEFC motors).
- For water-cooled machines, check water pressure, flow rate, and pipe connections for leaks.

Documentation and Clearances

- **Work Permits:** Ensure proper Lockout/Tagout (LOTO) procedures were followed during installation.
- **Clearances:** Minimum safety clearances around the machine must be maintained as per standards (e.g., IEEE/IEC).
- **Sign-off:** Completion of the mechanical completion certificate before proceeding to electrical testing.

Lecture 4.2: Pre-Start Tests on Rotating Machines

GTU Course Presentation

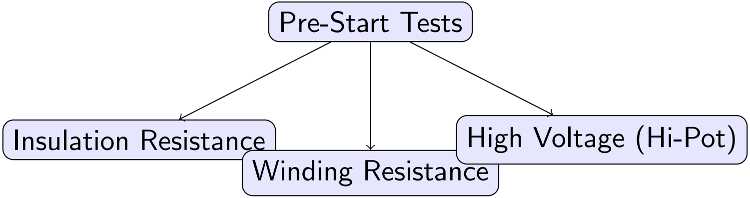
Overview of Pre-Start Tests

Pre-Start Testing

A set of electrical and mechanical tests conducted after visual inspections but before energizing the machine with full operational voltage.

- Establishes a baseline for future maintenance.
- Ensures the electrical integrity of windings, cables, and protection circuits.
- Mitigates the risk of short-circuits or earth faults on initial power-up.

Hierarchy of Pre-Start Tests



- Tests must be performed in a logical sequence.
- If Insulation Resistance fails, High Voltage tests **must not** be conducted.

Preparation for Electrical Testing

Safety First

All rotating parts must be stationary. The machine must be completely isolated from the supply grid.

- **Disconnection:** Remove external cables from the motor terminal box to isolate the motor from the switchgear.
- **Discharging:** Ground all windings before and after tests to remove capacitive charge.
- **Environmental Check:** Record ambient temperature and humidity, as they affect test readings.

Phase Sequence and Polarity Checks

- **Phase Sequence:** Verify the incoming supply phase sequence (R-Y-B) matches the motor terminals to ensure correct direction of rotation.
- **Polarity Test:** For DC machines and synchronous machine field windings, verify the correct polarity of poles.
- **CT/PT Checks:** If current transformers or potential transformers are embedded in the motor, test their continuity and ratio.

Earth and Grounding Verification

Grounding Component	Acceptable Resistance
Motor Body to Main Earth Grid	$< 1.0\,\Omega$
Terminal Box Earth Stud	$< 0.5\,\Omega$
Bearing Insulation (if applicable)	$> 1\,\mathrm{M}\Omega$

Table: Grounding and Earthing Checks

- Proper grounding ensures personnel safety in case of a fault.
- Large motors may have insulated bearings to prevent destructive shaft currents; these must be tested.

Lecture 4.3: Winding Resistance Measurement

GTU Course Presentation

Purpose of Winding Resistance Measurement

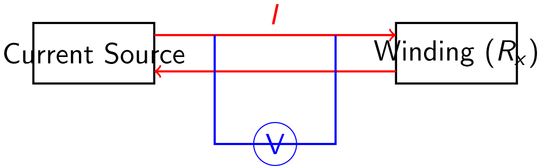
Winding Resistance

The DC resistance of the machine's stator and rotor (if accessible) windings. It is a fundamental indicator of the condition of the copper conductors and internal connections.

- **Objective 1:** Calculate I^2R copper losses.
- **Objective 2:** Check for loose internal connections, broken strands, or shorted turns.
- **Objective 3:** Serve as a baseline for future temperature-rise calculations.

Measurement Method: Kelvin Double Bridge

For very low resistances (typical in large machine windings), a simple multimeter is inaccurate. The Kelvin Double Bridge or Micro-Ohmmeter is used.



Voltage Drop measured inside current leads

4-Wire Method

By using separate current injection and voltage measurement leads, contact resistance and lead resistance are eliminated.

Procedure and Precautions

- **Temperature Stabilization:** The motor must be at ambient temperature (cold state) before measurement.
- **Current Limit:** Test current should not exceed $10 - 15\%$ of the rated current to prevent heating the winding during the test.
- **Discharge:** Highly inductive windings take time to charge and discharge. Always allow the reading to stabilize and discharge completely after testing.

Evaluating Results

The measured resistance is temperature-dependent and must be corrected to a standard reference temperature (usually 75°C or 20°C).

$$R_s = R_t \frac{T_s + k}{T_t + k}$$

Where:

- R_s, R_t = Resistance at standard and test temperatures.
- T_s, T_t = Standard and test temperatures in °C.
- k = Temperature coefficient constant (234.5 for Copper, 225 for Aluminum).

Acceptance Criteria

Condition	**Acceptance Standard**
Phase-to-Phase Balance	Difference between phases $\leq 1\%$ (for AC
Comparison with Factory	Within $\pm 5\%$ of manufacturer's test data

Table: Winding Resistance Tolerance

- A significant imbalance indicates a partial short circuit, a wrong number of turns, or high-resistance terminal connections.

Lecture 4.4: Insulation Resistance Measurement of Windings

GTU Course Presentation

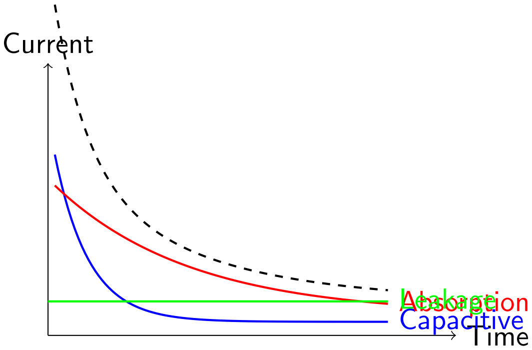
Basics of Insulation Resistance (IR)

Insulation Resistance

The measure of opposition provided by the winding insulation to the flow of direct current. It indicates the presence of moisture, dirt, or degradation in the insulation.

- Commonly measured using a Megger (Megohmmeter).
- It is a non-destructive DC test.
- The total current has three components: Capacitive charging current, Dielectric absorption current, and Leakage current.

Components of Test Current



- **Leakage Current** is constant and flows through defects. If IR is low, leakage current is high.

Test Procedure and Voltage Levels

Machine Rated Voltage	**DC Test Voltage**
$<$ 1000V	500V DC
1000V – 2500V	500V – 1000V DC
2501V – 5000V	1000V – 2500V DC
$>$ 5000V	2500V – 5000V DC

Table: Recommended IR Test Voltages (IEEE 43)

- Connect Megger positive to winding, negative to ground.
- Read resistance value after 1 minute of applied voltage.

Polarization Index (PI)

Polarization Index

The ratio of the Insulation Resistance measured at 10 minutes to the IR measured at 1 minute.

$$\mathrm{PI} = \frac{\text{IR at 10 minutes}}{\text{IR at 1 minute}}$$

- Evaluates the health and dryness of the insulation independent of temperature.
- **PI** < 1.0: Dangerous (Wet/Contaminated).
- **PI** $1.0 - 1.5$: Poor.
- **PI** $2.0 - 4.0$: Good (Acceptable for most Class B/F motors).

Temperature Correction of IR

- Insulation resistance halves for roughly every 10°C increase in temperature.
- Formula for correction to 40°C:

$$R_{40} = R_T \times K_T$$

  where K_T is the temperature correction multiplier.
- Minimum acceptable R_{40} (IEEE standard):

$$\mathrm{IR}_{\mathrm{min}} = \mathrm{kV} + 1 \text{ (in M}\Omega\text{)}$$

  (e.g., for a 4.16 kV motor, minimum IR is 5.16 MΩ).

Lecture 4.5: High Voltage Tests (Power Frequency)

GTU Course Presentation

Introduction to High Voltage (HV) Tests

High Voltage (Hi-Pot) Test

An overvoltage test applied to machine windings to verify the dielectric strength of the insulation under stress. It is a **Go/No-Go** test.

- Ensures the insulation can withstand transient overvoltages during operation.
- **Prerequisite:** IR test and Polarization Index must be acceptable. Never perform HV testing on wet or poor insulation!
- Primarily applied to medium/high voltage machines (> 1 kV).

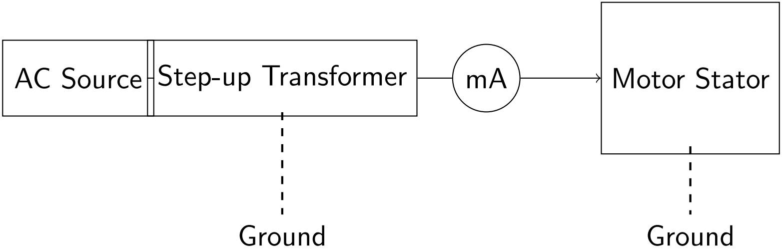
Test Standard and Voltage Levels

- Standard practice dictates testing each phase separately while grounding the other two phases.
- The magnitude of the test voltage for new machines is typically:

$$V_{\text{test}} = 2 \times E + 1000 \text{ Volts}$$

  where E is the rated line-to-line voltage of the machine.
- For used or reconditioned machines, the test voltage is often reduced to 60-80% of the new machine test value to prevent accidental breakdown.

Test Setup Diagram



Leakage Current Monitoring

The AC High Voltage test stresses the insulation by simulating actual operating AC conditions. A sudden spike in leakage current indicates a breakdown.

Procedure and Safety

Step	Action
1. Isolate	Disconnect all electronics, RTDs, and surge arreste
2. Ramp-up	Increase voltage gradually (e.g., 500V/sec).
3. Hold	Maintain full test voltage for **1 minute**.
4. Ramp-down	Decrease voltage slowly to zero.
5. Discharge	Ground the tested phase to bleed off capacitive cha

Table: HV Test Procedure Steps

Interpreting the Results

- **Pass:** The insulation withstands the voltage for 1 minute without any disruptive discharge (flashover or puncture).
- **Fail:** An abrupt increase in leakage current leading to the tripping of the HV test kit. The winding has suffered a dielectric breakdown.
- **Warning:** Corona discharge (hissing sound, bluish glow) may occur at terminals; ensure adequate clearance before testing.

Lecture 4.6: Trial Start

GTU Course Presentation

What is a Trial Start?

Trial Start (Bump Test)

A momentary energization of the rotating machine (often uncoupled from the load) to verify correct electrical connections and rotational direction.

- Validates phase sequence matches desired mechanical rotation.
- Ensures no binding or scraping occurs when magnetic flux is established.
- The motor is energized just long enough to begin rotation, then immediately de-energized.

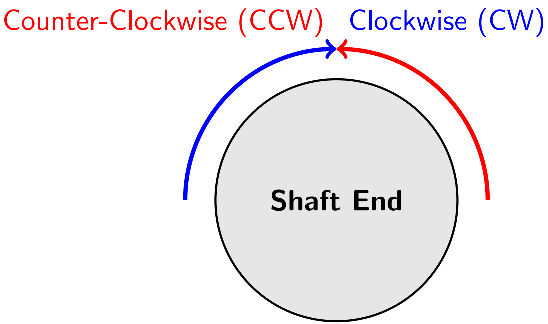
Prerequisites for Trial Start

Checklist before Bumping

A trial start must only be performed after all static electrical tests are successfully completed.

- IR, PI, and Winding Resistance tests passed.
- Machine is completely assembled, with coupling guards in place (if coupled).
- Proper lubrication is applied to bearings.
- Protection relays (Overcurrent, Earth Fault) are set to minimum settings.

Direction of Rotation Check



- Standard direction is usually facing the non-drive end (NDE) or drive end (DE) depending on the standard. Always clarify the reference point!
- If rotation is incorrect: swap any two phases (e.g., R and Y) at the motor terminal box or switchgear.

Observation During Trial Start

- **Acoustic Noise:** Listen for abnormal rubbing, grinding, or magnetic hum.
- **Visual Inspection:** Watch for excessive arcing at brushes (DC machines/Slip ring motors) or sparks from the terminal box.
- **Starting Current (Inrush):** Observe the ammeter needle; it should swing up (6-8 times rated current) and drop down as speed increases. If it stays high, immediately trip the breaker.

Safety and Documentation

- Personnel must stand clear of the coupling and shaft during the bump test.
- Have an operator ready at the Emergency Stop (E-Stop) pushbutton.
- Record the observed direction of rotation and sign off the trial start protocol.

Lecture 4.7: No Load Test

GTU Course Presentation

Purpose of the No Load Test

No Load Test (Uncoupled Run)

Running the machine continuously without any mechanical load connected to the shaft at rated voltage and frequency.

- Determines core losses and friction/windage losses.
- Evaluates the steady-state mechanical behavior (vibration, bearing temperature).
- Measures no-load current and power factor.

Operating Conditions and Duration

- The machine is typically run uncoupled.
- **Duration:** Run until bearing temperatures stabilize (change of less than $1 - 2^{\circ}C$ per hour). For large motors, this can take 2 to 4 hours.
- Parameters must be logged every 15-30 minutes.

Parameters Monitored

Electrical Parameters	**Mechanical Parameters**
Voltage (V_r, V_y, V_b)	Bearing Temperature (DE & NDE)
Current (I_r, I_y, I_b)	Vibration (Velocity / Displacement)
Power input (kW)	Stator Winding Temperature (RTDs)
Power Factor	Cooling air/water temp (In/Out)

Table: No Load Run Log Sheet

No-Load Current

For induction motors, no-load current is typically 25% to 40% of full load current due to the large magnetizing component required to cross the air gap.

Acceptance Criteria

- **Current Balance:** Phase currents should be balanced within 5%. Unbalance can indicate turn-to-turn shorts or unbalanced supply voltage.
- **Temperatures:** Bearing temperatures should remain below the manufacturer's alarm limits (e.g., anti-friction bearings $< 90^\circ$C, sleeve bearings $< 80^\circ$C).
- **Vibrations:** Must remain within ISO 10816 standards (e.g., < 2.8 mm/s RMS for rigid mounts).

Separation of Losses (Induction Motor)

$$P_0 = \sqrt{3} V_0 I_0 \cos\phi_0$$
$$\downarrow$$
$$P_0 = P_{\text{core}} + P_{\text{friction\&windage}} + P_{\text{stator } I^2R}$$

- At no load, rotor current is negligible, so rotor copper loss is ignored.
- Stator copper loss ($3I_0^2R_s$) is calculated using measured stator resistance.
- Remaining power represents constant losses (Core + F&W).

Lecture 4.8: Vibration Measurement & Troubleshooting

GTU Course Presentation

Vibration

The oscillating motion of a machine component about its equilibrium position. In motors, excessive vibration causes premature bearing failure and insulation degradation.

- Measured at bearing housings in three axes: Horizontal (H), Vertical (V), and Axial (A).
- Measured units: Displacement (microns peak-to-peak), Velocity (mm/s RMS), or Acceleration (g).

Vibration Measurement Standard (ISO 10816)

Machine Class	Good (mm/s RMS)	Unacceptable
Class I (Small Motors)	< 0.71	> 4.5
Class II (Medium < 75kW)	< 1.12	> 7.1
Class III (Large rigid base)	< 1.8	> 11.2
Class IV (Large soft base)	< 2.8	> 18.0

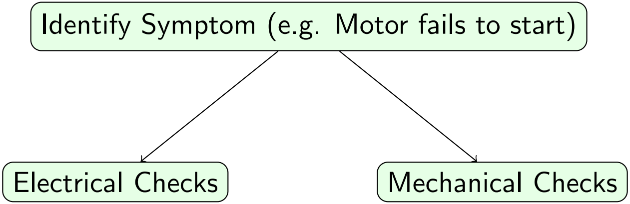
Table: ISO 10816 Vibration Severity Chart

- Velocity is the most common parameter for assessing overall machine health.

Common Causes of Vibration

- **Mechanical Unbalance:** Heavy spot on the rotor. Dominant frequency is $1\times$ RPM.
- **Misalignment:** Shafts are not co-linear. Dominant frequencies at $1\times$ and $2\times$ RPM, especially high in the axial direction.
- **Mechanical Looseness:** Loose foundation bolts. Shows multiples of RPM $(1\times, 2\times, 3\times)$.
- **Bearing Defects:** Pitting on races or rolling elements. Generate high-frequency noise.

Troubleshooting Methodology



- **Electrical:** Check supply voltage, fuses, contactor, and thermal overload relay. Measure winding resistance and IR.
- **Mechanical:** Try hand-barring the shaft. Check for jammed loads or seized bearings.

Common Faults and Remedies (Induction Motors)

Fault	Possible Cause	Remedy
Motor overheats	Overload, Blocked ventilation, Low voltage	Reduce load, clean fins, check supply voltage.
High hum / noise	Single phasing (lost phase), Loose laminations	Check supply fuses, tighten core bolts.
Trips on Earth Fault	Insulation failure, moisture	Clean/dry windings, revarnish, replace cable.

Table: Basic Troubleshooting Matrix

Lecture 5.1: Pre-Commissioning Checks of Switchgear

GTU Course Presentation

Pre-Commissioning Checks of Switchgear

- Pre-commissioning checks ensure that the switchgear is installed correctly, free of damage, and safe to energize.
- **Importance:** Prevents catastrophic failures upon first energization.
- **Scope:** Includes physical inspection, mechanical operation checks, and basic electrical tests.

Pre-Commissioning

The phase of verifying that all equipment has been installed in accordance with the design specifications and is ready for functional testing.

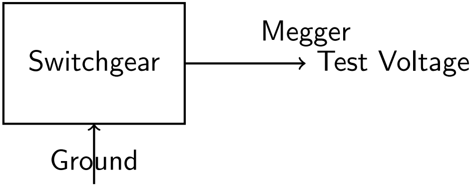
Visual Inspection (Nameplate, Interlocks)

- **Nameplate Verification:** Check rating parameters (Voltage, Current, Short-circuit rating) against design.
- **Physical Condition:** Inspect for transit damage, loose connections, or missing components.
- **Interlocks Check:** Verify mechanical interlocks (e.g., preventing rack-in when breaker is closed).

Component	**Check Point**
Enclosure	Scratches, dents, proper earthing
Busbars	Tightness (torque check), color coding
Interlocks	Smooth operation, correct blocking logic

Insulation Resistance (IR) Measurement

- Also known as Megger testing.
- Measures the insulation resistance between phases and phase-to-earth.
- **Acceptance Criteria:** Usually $\geq$ 1000 MΩ for HV switchgear, typically applying 1kV to 5kV DC.



IR Test Procedure

Procedure Highlights

1. Ensure equipment is de-energized and grounded before testing.
2. Connect Megger leads between Phase and Ground (or Phase to Phase).
3. Apply test voltage (e.g., 500V for LV, 5kV for MV).
4. Record reading after 1 minute.
5. Discharge the equipment after the test.

Lecture 5.2: Contact Resistance and Functional Tests

GTU Course Presentation

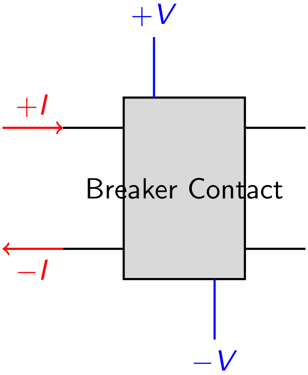
Contact Resistance Test of CBs and Isolators

- **Purpose:** Ensures that the main contacts of circuit breakers and isolators have minimal resistance to prevent overheating.
- **Method:** Four-wire (Kelvin) method using a Micro-ohmmeter (CRM - Contact Resistance Meter).
- **Test Current:** Normally 100A or more DC is injected.

Standard Values

Typical contact resistance for MV/HV breakers is in the range of 10 to 50 micro-ohms ($\mu\Omega$).

Four-Wire Resistance Measurement



- $R = \frac{V}{I}$ (calculates resistance bypassing lead resistance).

CT, PT, and Relay Connections Verification

- **Polarity Test:** Ensures directional relays operate correctly.
- **Ratio Test:** Verifies the turns ratio of CTs and PTs.
- **Secondary Injection Test:** Injects current/voltage directly into relays to confirm settings and tripping logic.

Equipment	**Common Tests**
CT (Current Transformer)	Knee point voltage, Ratio, Polarity, IR
PT (Potential Transformer)	Ratio, Polarity, IR
Protection Relay	Pickup value, Trip timing

Functional Tests of Switchgear

- Functional tests simulate actual operating conditions without high voltage connected to the main bus.
- **Local/Remote Operation:** Verify breaker can be opened/closed from local panel and remote SCADA.
- **Trip Circuit Supervision (TCS):** Ensures trip coil health is continuously monitored.
- **Spring Charging Check:** Verify motor charges the closing spring within specified time (e.g., < 15 secs).

Lecture 5.3: Mechanical Operation and Integrity Tests

GTU Course Presentation

Mechanical Operation Test

- Assesses the mechanical robustness and smooth operation of the switchgear mechanisms.
- **Slow Closing/Opening:** Sometimes performed manually to verify alignment of contacts.
- **Multiple Operations:** Usually 5 to 10 close-open operations are performed to ensure consistency.
- Checks for proper latching, absence of binding, and free movement of the operating mechanism.

Mechanical Endurance

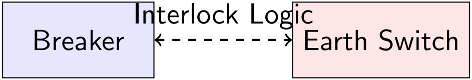
The ability of the switchgear to perform a specified number of operating cycles without mechanical failure or need for adjustment.

Protection Relay and Control Circuit Testing

- **Control Circuit Testing:** Applying control voltage (DC or AC) and operating switches to ensure the breaker responds correctly.
- **Relay Testing:** Utilizing secondary injection kits to simulate fault currents/voltages.
- **Checklists:**
  - Trip and close coil operational voltage range (e.g., $70\% - 110\%$ of rated DC).
  - Annunciation and alarms triggering correctly.

Interlock Verification (Electrical & Mechanical)

- **Mechanical Interlocks:** Physical barriers preventing unsafe operations (e.g., trying to rack-out a closed breaker).
- **Electrical Interlocks:** Logic wired in the control circuit (e.g., Earth switch cannot close if main bus is live).



SF_6 Gas / Vacuum Integrity Test

- **SF_6 Gas Test:**
  - Check gas pressure using gauges.
  - Dew point measurement to ensure moisture limits are not exceeded.
  - Gas leakage testing using a sniffer.
- **Vacuum Integrity Test (Vacuum Bottle Test):**
  - High voltage AC or DC is applied across open contacts.
  - Ensures the vacuum degree is sufficient to extinguish an arc.

Dielectric Strength

SF_6 gas has approximately 2.5 to 3 times the dielectric strength of air at the same pressure.

Lecture 5.4: HV Withstand and Partial Discharge Tests

GTU Course Presentation

On-Site Commissioning Tests of Switchgear

- After mechanical and functional checks, high voltage testing is the final step before putting equipment into service.
- Assures that insulation has not been compromised during transport and installation.
- Verifies clearances and the integrity of insulating materials (solid, liquid, or gas).

High-Voltage Withstand Test (As Per IS/IEC)

- Also known as Hi-Pot (High Potential) Test.
- **Procedure:** Apply a specific overvoltage (AC or DC) for a duration (usually 1 minute).
- **Criteria:** The equipment must withstand the voltage without breakdown or flashover.

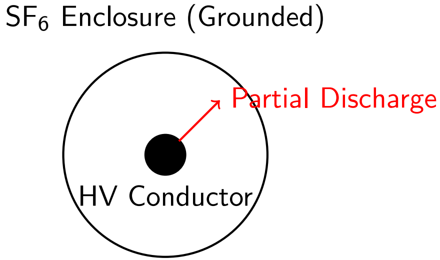
System Voltage	Typical AC Test Voltage (1 min)
11 kV	28 kV
33 kV	70 kV
132 kV	275 kV

Safety Warning

Strict boundary clearances and safety protocols must be observed during HV withstand tests.

Partial Discharge Test (For GIS)

- **Partial Discharge (PD):** Localized dielectric breakdown of a small portion of solid or fluid insulation.
- **Significance in GIS (Gas Insulated Switchgear):** Detects free-moving particles, sharp points, or voids in cast epoxy insulators.



PD Measurement Techniques

- **UHF (Ultra High Frequency) Method:** Uses sensors (antennae) embedded in GIS compartments to detect electromagnetic waves emitted by PD.
- **Acoustic Method:** Uses ultrasonic sensors attached to the outside of the GIS enclosure.
- **Acceptance Criteria:** Measured PD levels must be below a specified threshold (e.g., typically < 5 pC for factory tests, on-site limits vary by technique).

Lecture 5.5: Breaker Timing and Cable Inspections

GTU Course Presentation

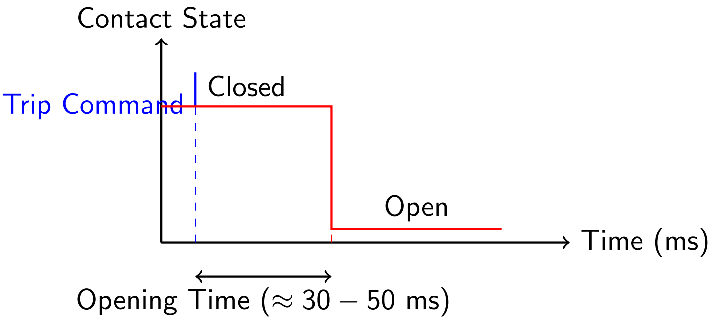
Breaker Timing Test

- Measures the operating times of the circuit breaker during closing and opening operations.
- **Parameters Measured:** Close time, Open time, Close-Open time, pole discrepancy.
- **Importance:** Ensures breaker clears faults within the time dictated by protection coordination.

Pole Discrepancy

The difference in closing or opening times between the three phases. Excessive discrepancy can cause unbalanced system voltages and currents.

Timing Measurement Graph



Pre-Commissioning Checks of Power Cable

- Ensuring power cables are properly laid and undamaged before electrical tests.
- Checks are critical for Medium Voltage (MV) and High Voltage (HV) cables where failures can be highly destructive.
- **Documents Verification:** Check cable schedules, routing diagrams, and test certificates from the factory.

Physical Inspection (Joints, Terminations, Bending)

- **Outer Sheath:** Inspect for cuts, abrasions, or chemical damage along the route.
- **Bending Radius:** Ensure the minimum bending radius is not violated (typically 12 to 15 times the cable diameter).
- **Joints and Terminations:** Verify that stress cones, lugs, and moisture seals are properly installed according to manufacturer instructions.
- **Cleating and Support:** Check for adequate physical support in trays or trenches.

Bending Radius Rule

Sharp bends cause severe mechanical stress, leading to localized failure of the cable insulation over time.

Lecture 5.6: Cable Resistance and Insulation Testing

GTU Course Presentation

Conductor Resistance & Continuity Test

- **Continuity Test:** Verifies that the conductor is intact from end to end using a simple multimeter.
- **Conductor Resistance:** Measured using a micro-ohmmeter or Kelvin bridge for precise DC resistance.
- Ensures that joints are properly crimped and there is no breakage of strands.

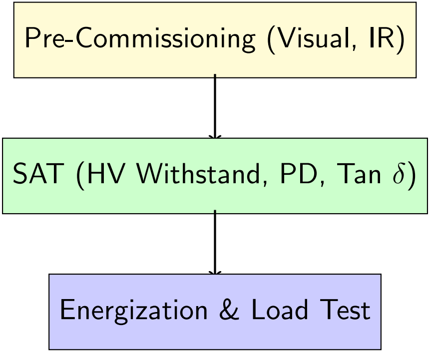
Test	**Instrument**
Basic Continuity	Digital Multimeter (buzzer)
Accurate Resistance	Micro-ohmmeter (CRM)

- Measures the resistance of the cable insulation between core and earth, and between cores (for multicore cables).
- Identifies moisture ingress, gross defects, or severe degradation before applying high voltage.
- **Voltage Applied:** Typically 1000V DC for LV cables, 5000V DC for MV/HV cables.

Polarization Index (PI)

$PI = \frac{IR \text{ at 10 min}}{IR \text{ at 1 min}}$. A PI value > 2.0 generally indicates healthy insulation.

- SAT forms the final stage of quality control on site.
- Validates that the installation process (pulling, bending, jointing) did not introduce defects.
- Includes advanced dielectric tests beyond simple Meggering.



High-Voltage Withstand Test (Cables)

- Applying an overvoltage to confirm insulation integrity.
- **VLF (Very Low Frequency) Testing:** Applying 0.1 Hz AC voltage.
  - Preferred over DC testing for XLPE cables because DC can cause space charge accumulation, leading to premature failure.
  - Requires much less power than 50 Hz AC testing for long cables due to capacitive charging current ($I = 2\pi fCV$).

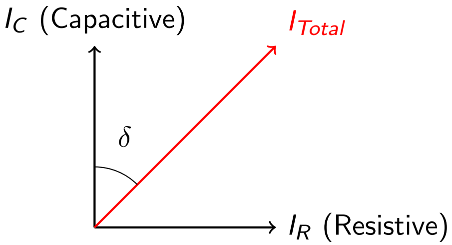
Lecture 5.7: Sheath Integrity and Dielectric Tests

GTU Course Presentation

Sheath Integrity Test

- **Objective:** To verify the condition of the anti-corrosion outer sheath of MV/HV cables.
- **Why it matters:** A damaged outer sheath allows moisture to penetrate, corroding the metallic screen and eventually causing insulation failure (water treeing).
- **Method:** Apply a DC voltage (e.g., 10 kV for 1 minute) between the metallic screen/sheath and the external ground.
- Leakage current is monitored; an unusually high current indicates sheath damage.

- **Tan δ (Dissipation Factor):** A diagnostic test to measure the overall dielectric losses in the cable insulation.
- As insulation deteriorates (due to water trees, thermal aging), the resistive leakage current increases relative to the capacitive current.



- $\tan\delta = \frac{I_R}{I_C}$. A higher $\tan\delta$ indicates degraded insulation.

Post-commissioning Checks

- Final verifications immediately before and right after applying system voltage.
- **Phasing Check:** Confirming phase sequence (R-Y-B) matches the grid using a high-voltage phasing stick.
- **Clearing the Area:** Removing all temporary grounds, tools, and non-essential personnel.

Safety First

Never assume a cable is dead until it is tested and grounded. Always follow Lockout-Tagout (LOTO) procedures.

Check	Purpose
Phase Sequence	Ensures motors rotate in correct direction
Phase Angle	Critical before closing a breaker tying two sourc
Voltage Magnitude	Prevents massive circulating currents

Lecture 5.8: Energization and Troubleshooting

GTU Course Presentation

Load Test Under Service Conditions

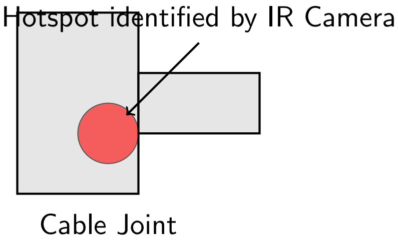
- **Initial Energization (Soak Test):** Equipment is energized at no-load for a period (e.g., 24 hours) to monitor for initial failures.
- **Load Testing:** Gradually applying load to the switchgear and cables.
- Monitoring meters (Voltmeter, Ammeter, MW, MVAR) to ensure readings correspond to expected values.

Soak Test

Energizing the electrical equipment at nominal system voltage without any load connected, to observe its behavior under steady electrical stress.

Temperature Monitoring During Energization

- **Thermography (IR Scanning):** Using infrared cameras to detect hot spots at joints, terminations, and contacts.
- **Causes of Hot Spots:** Loose connections, improper crimping, overloaded circuits.



Documentation of Test Results

- Detailed records of all pre-commissioning and commissioning tests are mandatory.
- **Baseline Data:** Serves as a reference for future maintenance and condition monitoring.
- **Handover Document:** A formal sign-off between the contractor and the client, indicating the system is safe to operate.

Document	**Content**
Test Reports	IR values, CRM values, Timing results
As-Built Drawings	Final wiring and routing post-modifications
O&M Manuals	Operating procedures and maintenance schedule

Faults and Troubleshooting

- **Breaker Fails to Close:** Check control voltage, spring charged status, mechanical interlocks, trip lockout relays.
- **High Contact Resistance:** Inspect for carbon deposits, lack of lubrication, or mechanical misalignment.
- **Cable Insulation Failure (Megger Fails):** Check for moisture at terminations, mechanical damage to the sheath, or tracking over insulators.

Troubleshooting Rule

Always start troubleshooting from the simplest possible cause (e.g., blown fuse in control circuit) before assuming major equipment failure.