
Professional Certificate in High Voltage Engineering

High voltage equipment and testing

Arc Flash – A high-energy release of light and heat caused by a low-impedance fault through an arc. Related terms: Arc fault, incident energy, flash protection. An arc flash can occur when a conductive path is established between phases or between a phase and ground, releasing temperatures up to 20 000 °C. In high-voltage substations, arc-flash studies are used to determine safe working distances and required personal protective equipment. Challenges include accurate modeling of arc impedance, variability of fault location, and ensuring that protective relays coordinate to limit fault duration.

Arc Resistance – The resistance offered by an arc column to the flow of current, typically expressed in ohms. Related terms: Arc voltage, arc impedance, fault current. Arc resistance influences the magnitude of the arc voltage for a given fault current and therefore affects the energy released during an arc flash. For example, a high-arc-resistance fault may produce a lower fault current but a longer arc duration. Determining arc resistance accurately requires high-speed measurements and consideration of plasma temperature and gas composition.

AC Breakdown Voltage – The minimum alternating-current voltage at which an insulating material experiences electrical breakdown under specified test conditions. Related terms: Dielectric strength, impulse breakdown, test voltage. AC breakdown testing is commonly performed on transformer windings, cable insulation, and printed circuit boards to verify that they can withstand service voltages plus a safety margin. Practical application includes selecting appropriate insulation thickness for a 33 kV distribution line. A key challenge is the frequency dependence of breakdown characteristics, which can lead to over-estimation of performance if only low-frequency tests are used.

Basic Insulation Level (BIL) – The level of insulation designed to withstand standard lightning impulse voltages without failure. Related terms: Insulation coordination, impulse test, surge arrester. BIL values are expressed in kilovolts (e.g., 100 kV BIL) and guide the selection of equipment such as circuit breakers and bushings. In practice, a 115 kV substation transformer may be specified with a 125 kV BIL to provide margin against severe lightning strikes. The main challenge is reconciling BIL with other design constraints such as size, weight, and cost.

Corona Discharge – A localized, non-uniform ionization of the surrounding air that occurs when the electric field exceeds the corona onset value but is insufficient to cause a complete breakdown. Related terms: Partial discharge, surface discharge, corona loss. Corona is commonly observed on high-voltage conductors with sharp points or edges, resulting in audible noise, ozone generation, and energy loss. Engineers use corona rings or smooth conductors to mitigate the effect. A practical example is the installation of corona-suppression grading rings on a 500 kV transmission line. Challenges include detecting low-level corona in the presence of background noise and quantifying its contribution to overall system losses.

Dielectric Strength – The maximum electric field that an insulating material can sustain without breakdown.

Related terms: Breakdown voltage, insulation resistance, partial discharge. Dielectric strength is measured in kilovolts per millimeter (kV/mm) and varies with temperature, humidity, and material composition. For instance, epoxy resin used in transformer windings typically exhibits a dielectric strength of 15–20 kV/mm. Designers must consider derating factors for long-term reliability. A recurring challenge is the degradation of dielectric strength over time due to thermal aging and moisture ingress.

Dielectric Loss – Energy dissipated as heat in an insulating material when it is subjected to an alternating electric field. Related terms: Loss tangent, $\tan \delta$, insulation heating. Dielectric loss is expressed as a percentage or as a loss tangent ($\tan \delta$) and increases with frequency and temperature. In high-voltage cable testing, a low loss tangent (e.g., $\tan \delta = 0.001$) indicates good insulation quality. Practical applications include selecting low-loss insulation for high-frequency HVDC converters. The main challenge is separating true dielectric loss from measurement errors caused by stray capacitance.

Electrostatic Discharge (ESD) – A sudden flow of static electricity between two objects at different potentials, often triggered by contact or a close approach. Related terms: Charge accumulation, surface charge, spark discharge. In high-voltage laboratories, ESD can damage sensitive measurement equipment and cause premature insulation failure. Anti-static flooring and grounding straps are practical measures to control ESD. Challenges include controlling charge buildup on insulated tools and ensuring that personnel follow strict grounding procedures.

Earthing (Grounding) – The intentional connection of electrical equipment to the earth to provide a low-impedance path for fault currents. Related terms: Earth fault, ground resistance, protective earthing. Proper earthing limits touch voltage during a fault and facilitates the operation of protective devices. A common practice is the installation of a ground grid beneath a substation, with a target earth resistance below 1 Ω . The difficulty lies in achieving low resistance in high-resistivity soils and maintaining the integrity of the earthing system over the equipment's lifetime.

Electric Field Stress – The distribution of electric field intensity within an insulating system under operating voltage. Related terms: Field grading, stress cone, dielectric stress. Uniform field stress reduces the risk of localized breakdown. Designers often employ stress-relief cones at conductor terminations to spread the field. For example, a 400 kV circuit breaker may incorporate a 30° stress cone to limit the peak field to below 30 kV/cm. Challenges include accurate finite-element modeling of complex geometries and accounting for material non-linearity.

Electric Power Transformer (EHV) – A transformer designed to operate at extra-high voltages (typically ≥ 230 kV). Related terms: Oil-immersed transformer, core loss, tap changer. EHV transformers step up or step down voltage for transmission networks and must withstand high mechanical and electrical stresses. Practical considerations include selecting a suitable cooling system (e.g., ONAN) and ensuring adequate insulation coordination with a BIL of 250 kV. A recurring challenge is the detection of incipient faults such as inter-turn faults through dissolved-gas analysis and partial-discharge monitoring.

Electric Surge Arrester – A device that protects equipment from transient over-voltages by diverting surge currents to ground. Related terms: Metal-oxide varistor (MOV), spark gap, voltage clamping. Surge arresters are rated by their nominal discharge voltage (NDV) and maximum continuous operating voltage (MCOV).

For a 220 kV line, a 270 kV NDV arrester may be installed. Practical application includes protecting substation busbars and transmission line terminations. Challenges involve ensuring that the arrester's energy rating matches the expected surge energy and that the grounding network can safely dissipate the diverted current.

Electro-Mechanical Relay – A switching device that uses an electromagnetic coil to open or close contacts in response to an electrical signal. Related terms: Protection relay, contact rating, coil voltage. In high-voltage protection schemes, electro-mechanical relays provide isolation and are often used as backup to digital relays. For example, a 125 kV circuit breaker may be equipped with a 500 A auxiliary relay for tripping. The main challenges are contact wear, coil insulation degradation, and the need for periodic calibration.

Flashover – A type of electrical discharge that jumps across an insulating surface, often following a breakdown along the surface rather than through the bulk material. Related terms: Surface discharge, tracking, arc flash. Flashover is a common failure mode in outdoor insulators exposed to pollution and moisture. A practical mitigation technique is the application of hydrophobic silicone coatings on polymer insulators. Detecting flashover involves visual inspection and infrared thermography. The challenge is that flashover can progress rapidly, causing extensive damage before protective devices operate.

High-Voltage Test Transformer (HVT) – A transformer used to step up voltage for testing insulation of equipment under controlled conditions. Related terms: Step-up transformer, voltage ratio, test set. HVTs are rated for specific test voltages (e.g., 1 MV) and are equipped with built-in voltage dividers for accurate measurement. They are essential for performing AC withstand, impulse, and partial-discharge tests on cables, switchgear, and transformers. Practical challenges include ensuring that the HVT's own insulation does not limit the test voltage and managing the large capacitive currents that arise during testing.

Impulse Voltage Test – A test that applies a high-amplitude, short-duration voltage waveform to evaluate insulation strength against lightning-type surges. Related terms: Lightning impulse, switching impulse, surge test. The standard IEC 60060-2 defines wave shapes such as 1.2/50 Ms for lightning impulse. For a 110 kV cable, a typical impulse test might use a 150 kV peak voltage. Practical applications include verifying the BIL of equipment before commissioning. Challenges include generating repeatable waveforms, handling the large discharge currents, and protecting test personnel from hazardous potentials.

Insulation Coordination – The systematic selection of insulation levels and protective device settings to ensure that equipment can survive over-voltages while the system clears faults quickly. Related terms: BIL, MCOV, protective relaying. Coordination studies balance the insulation strength of cables, transformers, and switchgear against the clearing times of circuit breakers. For example, a 33 kV distribution line may be coordinated with a 70 kV BIL transformer and a 1 s tripping time for a 5 kA fault. The main difficulty lies in accounting for varying fault currents, temperature effects, and aging of insulation.

Insulation Monitoring Device (IMD) – A system that continuously measures the insulation resistance of ungrounded (IT) networks to detect deterioration. Related terms: Earth fault detection, resistive leakage, protective earth. IMDs inject a low-level DC voltage and monitor the resulting current to calculate insulation resistance. In a hospital's IT power system, an IMD may trigger an alarm when resistance falls below 10 M Ω . Practical challenges include maintaining measurement accuracy in the presence of harmonic distortion and

ensuring that the injected signal does not interfere with sensitive loads.

Insulation Resistance (IR) – The resistance offered by an insulating material to the flow of DC current, typically measured in megohms. Related terms: Megohmmeter, leakage current, dielectric loss. High IR values indicate good insulation condition, while low values may signal moisture ingress or aging. For a 10 kV cable, an IR above 1 M Ω is generally acceptable. Practical applications include routine maintenance testing of switchgear and cables. Challenges arise from temperature dependence (IR decreases with temperature) and the need for proper test lead selection to avoid parallel leakage paths.

Lightning Impulse Test – A specific impulse test that simulates the wave shape of a natural lightning strike, commonly using a 1.2/50 Ms front-time/rear-time waveform. Related terms: Impulse voltage, surge arrester, BIL. The test is performed on equipment such as insulators and bushings to verify their ability to endure high-energy transients. For a 220 kV substation busbar, the test voltage may be set to 350 kV. The main challenges involve generating sufficient energy, controlling the rise time, and protecting the test environment from electromagnetic interference.

Magnetizing Current – The component of current required to establish the magnetic flux in the core of a transformer under no-load conditions. Related terms: No-load loss, core loss, excitation current.

Magnetizing current is typically a small percentage (1–5 %) of rated current and appears as a lagging reactive component. In a 500 MVA, 400 kV transformer, the magnetizing current may be about 2 % of rated current, equating to 10 kA reactive. Accurate measurement is important for diagnosing core saturation and for determining transformer impedance during fault studies. Challenges include separating magnetizing current from harmonic distortion caused by nearby non-linear loads.

Megohmmeter (Megger) – An instrument used to apply a high DC voltage (typically 500V to 5 kV) and measure the resulting leakage current to calculate insulation resistance. Related terms: Insulation resistance, test voltage, IEC 60270. Meggers are portable and commonly used for field testing of switchgear, cables, and motor windings. For a 33 kV cable, a 2.5 kV test voltage may be applied for 60 seconds. Practical challenges include ensuring that test leads are clean, that the equipment under test is de-energized, and that the test does not cause insulation breakdown due to excessive voltage.

Partial Discharge (PD) – A localized dielectric breakdown that does not completely bridge the insulation, often occurring at voids, inclusions, or interfaces. Related terms: Discharge inception voltage, PD magnitude, PD detection. Partial discharge is a key indicator of insulation degradation and is monitored using acoustic, electromagnetic, or electrical methods. In a 110 kV cable, PD activity may be detected at a voltage of 70 % of the rated voltage, indicating early aging. Practical application includes condition monitoring of transformers and GIS. The main challenges are distinguishing genuine PD signals from external noise and correlating PD magnitude with remaining life.

Partial-Discharge Measurement (PDM) – The process of detecting, quantifying, and locating partial discharge events in high-voltage equipment. Related terms: PD sensor, PD magnitude (pC), PD pattern analysis. PDM techniques include the use of high-frequency current transformers (HFCT), ultrasonic probes, and optical detection. For a GIS module, a PD magnitude of 10 pC may be considered the detection limit of most commercial systems. Practical challenges involve calibrating sensors, dealing with electromagnetic

interference, and interpreting PD patterns to identify specific defect types.

Phase-to-Ground Fault – A fault condition where one phase conductor makes unintended contact with earth, creating a low-impedance path for fault current. Related terms: Earth fault, fault current, protective relaying. Phase-to-ground faults are the most common type of fault in distribution networks and often result in high fault currents due to the low earth impedance. Protective devices such as earth-fault relays are set to trip within a few cycles. For a 11 kV feeder, the fault current may reach 10 kA. Challenges include accurately measuring the zero-sequence currents and ensuring that the earthing system can safely carry the fault current without excessive touch voltage.

Potential Divider – A resistive network used to scale down a high voltage to a measurable level for instrumentation. Related terms: Voltage divider, scaling factor, high-voltage probe. In a 1 MV impulse test, a potential divider with a ratio of 1000:1 Allows a 1 kV reading on the instrument. Practical considerations include the need for high-precision resistors, temperature stability, and shielding against corona. The main challenge is maintaining linearity over the full test voltage range and preventing the divider itself from becoming a source of partial discharge.

Protection Relay – An electronic or electromechanical device that monitors electrical quantities and initiates the operation of circuit breakers when abnormal conditions are detected. Related terms: Over-current relay, distance relay, differential relay. Modern high-voltage protection relays are digital, supporting communication protocols such as IEC 61850. For a 220 kV line, a distance relay may be set to trip at 80 % of the nominal impedance. Practical challenges include setting appropriate pickup values to avoid nuisance trips while ensuring fast fault clearance, and managing the cybersecurity of network-connected relays.

Resistive Leakage – The continuous flow of current through an insulating material due to its finite resistance, often influenced by moisture or contamination. Related terms: Insulation resistance, leakage current, dielectric loss. In a high-voltage cable, resistive leakage may be on the order of a few microamperes per kilometer under normal conditions. Excessive leakage can indicate insulation deterioration. Practical methods for detection include DC insulation resistance testing and monitoring of protective earth currents. Challenges involve differentiating resistive leakage from capacitive charging currents during transient tests.

Series Capacitor – A high-voltage capacitor connected in series with a transmission line to improve voltage regulation and increase power transfer capability. Related terms: Series compensation, FACTS, capacitor bank. Series capacitors offset the inductive reactance of long lines, effectively raising the transmission line's power-transfer limit. For a 400 kV, 500 km line, a 200 MVAR series capacitor may be installed. Practical challenges include controlling over-voltage during switching, managing the resonant interaction with line inductance, and protecting the capacitor from fault currents using protective devices such as series-resistor switches.

Surge Impedance Loading (SIL) – The loading level at which the reactive power generated by line capacitance equals the reactive power consumed by line inductance, resulting in a purely resistive line. Related terms: Capacitive loading, inductive loading, line compensation. SIL provides a useful reference for determining the need for series compensation. For a 345 kV, 300 km line, the SIL may be approximately 1 GW. Practical application includes planning the operating point of a transmission corridor to avoid

excessive voltage rise. The challenge lies in accurately modeling the line parameters and accounting for temperature-dependent changes in reactance.

Switchgear – Assemblies of electrical disconnectors, circuit breakers, protective relays, and associated control equipment used to control, protect, and isolate electrical circuits. Related terms: Circuit breaker, disconnect switch, GIS. High-voltage switchgear may be air-insulated (AIS) or gas-insulated (GIS) and is rated for specific voltage classes such as 115 kV, 230 kV, or 500 kV. Practical considerations include selecting appropriate breaking capacity, ensuring adequate clearance for flashover, and providing remote operation via SCADA. Challenges include maintaining reliable operation in harsh environments, managing oil or SF₆ handling, and conducting regular testing without disrupting service.

Test Cell – A dedicated enclosure that houses high-voltage test equipment, providing controlled environmental conditions and safety isolation. Related terms: Test fixture, high-voltage laboratory, shielding. Test cells are used for AC withstand, impulse, and partial-discharge testing of equipment such as cables and transformers. For a 1 MV impulse test, the cell must be equipped with grounded shielding walls and interlocks to prevent accidental exposure. Practical challenges include ensuring that the cell's own insulation does not limit the test voltage, managing the acoustic noise from impulse generators, and complying with safety standards such as IEC 60270.

Test Fixture – A mechanical and electrical assembly that holds the device under test (DUT) securely while providing the necessary connections for high-voltage testing. Related terms: Test cell, test lead, mounting bracket. Fixtures must be designed to minimize stress concentrations and avoid introducing additional discharge points. For a 33 kV cable sample, a coaxial fixture provides uniform field distribution and reduces edge effects. Practical challenges include accommodating different equipment geometries, ensuring repeatable positioning for comparative testing, and providing adequate insulation to prevent inadvertent arcing.

Test Lead – A high-voltage cable or probe used to connect the test equipment to the DUT, designed to have low capacitance and high insulation strength. Related terms: Test fixture, voltage divider, shielding. Test leads for impulse testing are often rated for 1 MV and have a capacitance of 30–50 pF/m to limit charging currents. Proper handling and storage are essential to avoid damage to the insulation. Practical challenges include managing the inductive and capacitive effects that can distort the test waveform, and ensuring that the leads are kept away from conductive surfaces that could cause premature breakdown.

Test Set – An integrated system comprising a voltage source, measurement instruments, and control electronics used for high-voltage testing. Related terms: High-voltage generator, impedance matching, data acquisition. A typical test set for 500 kV equipment may include a step-up transformer, a 1 MV impulse generator, a partial-discharge detector, and a computer-based analysis platform. Practical considerations involve calibrating the voltage and current measurement channels, providing adequate safety interlocks, and ensuring that the set can handle the required test duration. Challenges include managing the large electromagnetic fields generated during testing and maintaining traceability to national standards.

Thermal Imaging (Infrared Thermography) – A non-contact technique that visualizes temperature distribution on equipment surfaces, helping to identify hot spots caused by abnormal current flow or poor

connections. Related terms: Hot-spot detection, infrared camera, fault location. In high-voltage substations, thermal imaging can detect overheating of busbars, bushings, and connections before catastrophic failure. For example, a temperature rise of 15 °C above ambient on a 220 kV busbar may indicate loose contact. Challenges include calibrating the camera for emissivity variations and interpreting temperature data in the presence of solar heating or wind.

Transformer Oil – A high-purity mineral oil used to insulate and cool power transformers and other high-voltage equipment. Related terms: Dielectric fluid, dissolved-gas analysis (DGA), oil filtration. Oil provides both electrical insulation (dielectric strength ≈ 30 kV/mm) and heat removal through natural or forced circulation. Practical maintenance includes periodic oil sampling for DGA to detect gases such as acetylene or ethylene, which indicate arcing. Challenges involve controlling oil moisture content, preventing oxidation, and managing the environmental impact of oil disposal.

Voltage Divider – A resistive or capacitive network that reduces a high voltage to a lower level suitable for measurement instruments. Related terms: Potential divider, scaling factor, high-voltage probe. Voltage dividers are calibrated to provide a known ratio, such as 1000:1, allowing a 1 MV test voltage to be measured as 1 kV. In high-frequency impulse testing, capacitive dividers are preferred due to lower inductance. Practical challenges include ensuring linearity across the entire voltage range, minimizing temperature drift, and protecting the divider from corona discharge.

Voltage Rating – The maximum continuous operating voltage for which a piece of equipment is designed and approved. Related terms: Nominal voltage, maximum system voltage, clearance. A 69 kV line, for instance, may have equipment rated for 75 kV to provide a safety margin. Voltage rating determines insulation thickness, clearance distances, and required protective devices. Practical application includes selecting appropriate switchgear for a new transmission line. A common challenge is reconciling the voltage rating with mechanical constraints, especially in compact GIS designs.

Voltage Stress – The electric field intensity experienced by an insulating material under operating conditions, expressed as volts per unit length. Related terms: Electric field stress, dielectric stress, stress grading. Excessive voltage stress can lead to premature breakdown or accelerated aging. Engineers use stress-grading techniques such as corona rings, grading foils, and field-shaping electrodes to distribute the field evenly. For a 500 kV cable termination, stress may be limited to 30 kV/cm to avoid partial discharge. Challenges include accurately modeling three-dimensional stress distributions and accounting for material non-linearity at high fields.

Winding Insulation – The insulating material that separates individual turns and layers of a transformer winding, typically consisting of paper, pressboard, or polymer films. Related terms: Turn-to-turn insulation, layer insulation, dielectric strength. Winding insulation must withstand the full operating voltage plus transient over-voltages without breakdown. For a 115 kV transformer, the inter-turn insulation may be rated at 15 kV per turn. Practical inspection methods include visual examination, tap testing, and partial-discharge monitoring. The primary challenges are detecting localized defects, managing moisture ingress, and ensuring long-term thermal stability.

Zero-Sequence Current – The component of current that is common to all three phases in a three-phase

system, typically associated with ground-fault conditions. Related terms: Ground fault, residual current, neutral current. Zero-sequence current flows through the neutral and earth conductors and is measured by ground-fault relays to detect phase-to-ground faults. In a 33 kV system, a ground-fault current of 8 kA may produce a zero-sequence current of the same magnitude. Practical challenges involve accurately measuring low-frequency zero-sequence currents in the presence of harmonic distortion and ensuring that the protective relay settings are coordinated with the system's earth impedance.