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## **Power Cable Standards: Medium Voltage (North America)**

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Wissam Geahchan, P.Eng.

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Continuing Education and Development, Inc.

P: (877) 322-5800

[info@cedengineering.ca](mailto:info@cedengineering.ca)

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## 1.0 Context and Scope

This course provides a comprehensive overview and a comparative analysis of medium voltage (MV) cable standards, focusing on cables rated up to 46 kV and the critical role standards play in modern power systems.

Medium voltage cable standards are developed to ensure safety, reliability, quality, performance, and system compatibility, helping manufacturers, utilities, engineers, and specifiers achieve consistent and dependable results across a wide range of applications. Understanding these standards is essential for minimizing risk, ensuring regulatory compliance, and delivering long-term network performance.

MV cable standards are not static - they evolve over time in response to technological advancements, new scientific research, continuous improvement initiatives, and lessons learned from manufacturing and field experience. As materials, designs, and installation practices improve, standards are updated to reflect best practices and real-world performance expectations. Staying current with these changes allows professionals to make informed decisions and avoid costly mismatches between cable design, application, and operating conditions.

The course will review the primary medium voltage cable standards used in North America, examining their key design, construction, and testing requirements. Students will gain insight into how these standards address electrical, mechanical, and environmental performance, as well as how testing validates long-term reliability. The course will also take a deeper dive into selected design components to explain not just what the requirements are, but why they exist.

The course concludes with a clear comparison of the major standards, highlighting their key differences. A decision flow chart will also be provided to help determine which standard is most appropriate for a given application, enabling more confident specification, clearer communication with stakeholders, and better alignment between system requirements and cable design. The following standards are within the scope of this course:

1. **CSA C68.5** - Primary shielded and concentric neutral cable for distribution utilities
2. **CSA C68.10** - Shielded power cable for commercial and industrial applications, 5-46 kV
3. **ANSI/ICEA S-94-649** - Concentric Neutral Cables Rated 5 Through 46KV
4. **ANSI/ICEA S-97-682** - Utility Shielded Power Cables Rated 5 Through 46 kV
5. **ANSI/NEMA WC74 / ICEA S-93-639** - 5-46 kV Shielded Power Cable for Use in the Transmission and Distribution of Electric Energy
6. **ANSI/ICEA S-113-684** - Performance Based Standard for Electric Utility Extruded Dielectric Shielded Power Cables Rated 5 Through 46 KV
7. **UL 1072** - Standard for Medium-Voltage Power Cables
8. **AEIC CS8 Specification** – Specification for Extruded Dielectric Shielded Power Cables Rated 5 Through 46 kV (*optional specification*)

## 2.0 Key Medium Voltage Cable Standards

Standard	Voltage Range	Region	Scope
CSA C68.5	15 – 46 kV <15kV possible	Canada	Shielded power cables <b>for use by electric utilities.</b>
CSA C68.10 (Type MV68.10)	5 – 46 kV	Canada	Shielded power cables <b>for commercial / industrial</b> installations within scope of the CE Code.
ANSI/ICEA S-94-649	5 – 46 kV	US / Canada	Concentric neutral cables <b>for use by electric utilities.</b>
ANSI/ICEA S-97-682	5 – 46 kV	US / Canada	Shielded power cables <b>for use by electric utilities</b>
AEIC CS8	5 – 46 kV	US / Canada	<b>Supplementary specification</b> to ICEA S-94-649 and S-97-682
ANSI/ICEA S-113-684	5 – 46 kV	US / Canada	Shielded power cables <b>with reduced diameters for use by electric utilities</b>
ICEA S-93-639/ ANSI/NEMA WC74	5 – 46 kV	US / Canada	Shielded power cables <b>for commercial/industrial.</b>
UL 1072 (Types MV90/MV105)	2 – 35 kV	US	Shielded/Non-shielded cables <b>for commercial/industrial</b> installations within scope of the NEC

**Table 1 – Key North American MV Cable Standards and their Scope**

MV cables in North America are used across a wide range of applications where dependable power delivery is required at distribution-level voltages, typically up to 46 kV. Common applications include utility distribution networks, industrial facilities, commercial campuses, renewable energy projects, substations, and large infrastructure such as transit systems, airports, and data centers. MV cables are selected based on system voltage, load requirements, environmental conditions, and the applicable standards and codes, ensuring reliable performance over long service lives.

Typical installation methods for these types of cables include direct burial, duct or conduit systems, cable tray, and aerial or riser installations, depending on the application and environment.

**Direct burial installations** are often used in utility and industrial settings where cables are designed with robust jackets and moisture barriers to withstand soil conditions and mechanical stress. **Duct and conduit installations** - commonly found in urban areas, substations, and commercial facilities - provide added mechanical protection and allow for easier cable replacement or system expansion.

In industrial plants and substations, MV cables are frequently installed in **cable trays, trenches, or vaults**, where accessibility and heat dissipation are important considerations. These installations may require additional fire performance, chemical resistance, or sunlight resistance depending on the environment. For **vertical runs** in buildings or riser applications, cables must meet specific flame and smoke performance requirements as defined by applicable standards and electrical codes.

Permitted applications and installation methods in North America are governed by a combination of industry standards and electrical codes, such as those issued by the National Electrical Code (NEC), the Canadian Electrical Code (CE Code), ICEA, CSA, UL and IEEE. These codes, standards, publications and guides define acceptable installation practices, allowable environments, and performance requirements to ensure safety, reliability, and compliance.

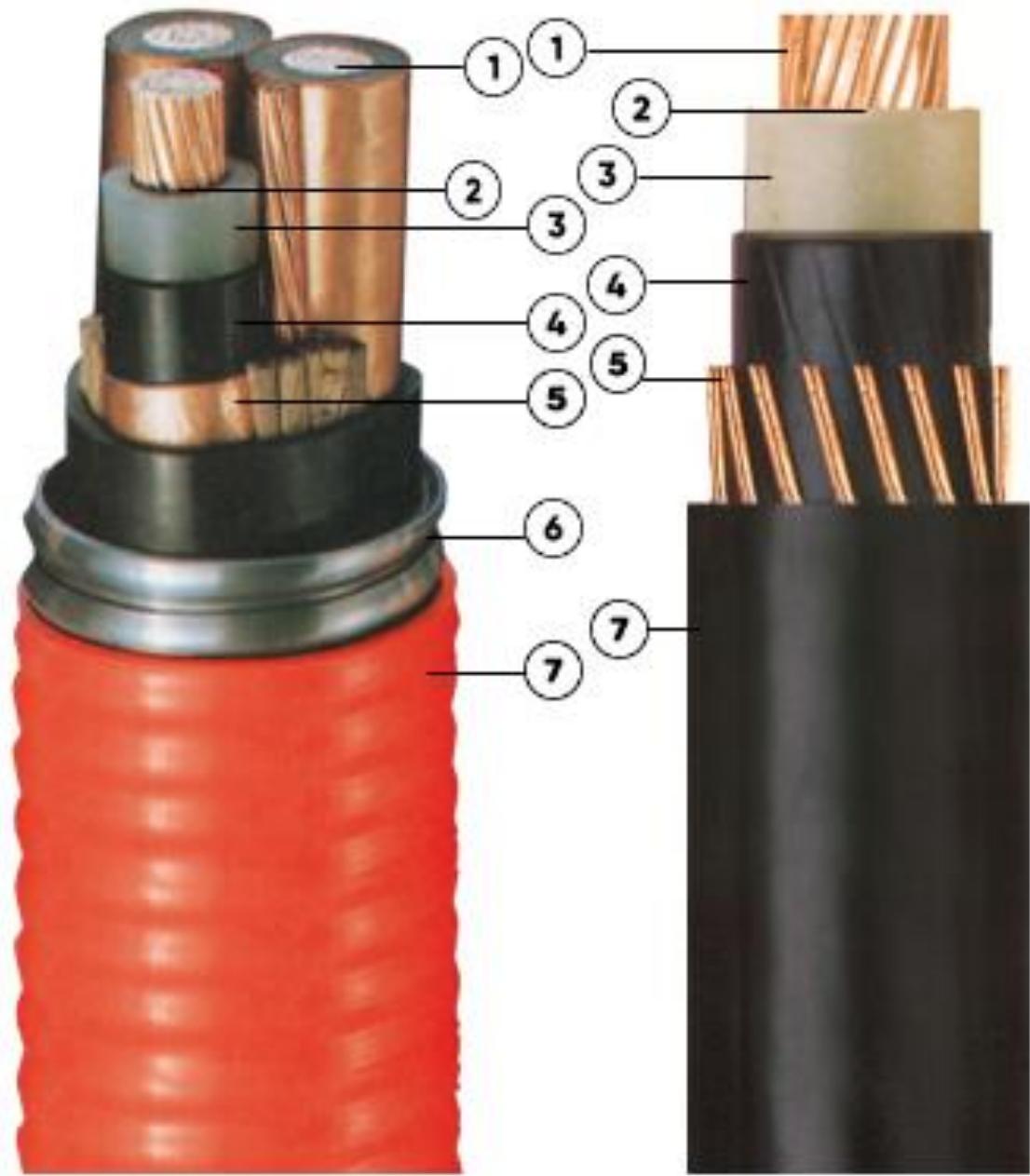
Understanding the standards that define medium voltage cables is critical to selecting the right cable for a specific application and installation method. While many MV cables may appear similar on the surface, the underlying standards determine key aspects such as insulation systems, jacket materials, allowable operating temperatures, grounding methods, flame performance, and testing requirements. These differences directly impact how a cable will perform in various environments, including direct burial, duct systems, tray installations, or indoor riser applications.

A solid understanding of applicable MV cable standards allows engineers, specifiers, and installers to match cable design to real-world operating conditions, reducing the risk of premature failure, non-compliance, or costly rework. Selecting a cable without fully considering the governing standard can lead to issues such as inadequate moisture protection, insufficient mechanical strength, or incompatibility with installation codes. By understanding how standards define construction and permitted uses, professionals can make informed decisions that enhance system reliability, safety, and long-term performance.

### 3.0 Basic Construction Requirements

#	Component	Function
1	<b>Conductor</b>	A wire or combination of wires designed to carry electric current. During installation, the conductor is typically a mechanical load-bearing component.
2	<b>Conductor shield</b>	A nonconducting or semi-conducting element in direct contact with the conductor acting as a stress control layer.
3	<b>Insulation</b>	Relied upon to electrically insulate the conductor and must be capable of withstanding the electrical stresses distributed across it when the conductor is energized.
4	<b>Insulation shield</b>	To confine the electric field to within the insulation and symmetrically distribute voltage stresses in the insulation.
5	<b>Metallic shield</b>	A non-magnetic metallic material serving as a current-carrying medium for charging and leakage currents while providing a solid ground plane. If large enough, it can also be used to carry neutral, unbalanced phase, and fault currents.
6	<b>Armour</b>	A metal sheath, tape, or wire providing mechanical protection.
7	<b>Jacket</b>	A covering that provides mechanical protection, chemical protection, sunlight resistance, moisture migration resistance, ion filtration, and corrosion resistance.

Table 2 – MV cable components and function. Refer to Figure 1.



**Figure 1** – Medium Voltage Cables: Armored (left) and Un-armored (right)

### 3.1 Conductor

The conductor is the core current-carrying element of a medium voltage cable, consisting of a single wire or a combination of stranded wires designed to efficiently transmit electrical energy. In North America, conductors are most commonly made from copper or aluminum, with stranding configurations selected to balance electrical performance, flexibility, and mechanical strength. The conductor size is determined by ampacity requirements, voltage drop considerations, and system operating conditions as defined by applicable standards and electrical codes. While this description may appear straightforward, the conductor is in fact one of the most carefully engineered components of a medium voltage cable, and its design has a direct and lasting impact on the cable's electrical performance, mechanical durability, installation behavior, and long-term reliability.

From an electrical perspective, the conductor must provide a low-resistance path for current flow while maintaining stability under both normal and abnormal operating conditions. The choice between copper and aluminum is influenced by conductivity, weight, cost, and installation considerations. Copper offers higher electrical conductivity, which allows for smaller conductor sizes at a given ampacity, and provides excellent mechanical strength and corrosion resistance. Aluminum, although less conductive, offers significant weight and cost advantages, making it particularly attractive for larger conductor sizes and long cable runs. When properly sized and installed, aluminum conductors perform reliably in medium voltage applications, provided that appropriate termination and connection practices are followed. The selection between these materials is therefore not merely a matter of preference, but a carefully evaluated decision based on system design, installation constraints, and lifecycle cost.

Stranding configuration further refines conductor performance. A solid conductor may be used in smaller sizes, but in medium voltage cables, stranded conductors are far more common due to their superior flexibility and handling characteristics. Stranding allows the conductor to bend more easily during installation, reducing the risk of mechanical damage and easing routing through ducts, conduits, or cable trays. At the same time, stranding improves resistance to fatigue caused by vibration or thermal expansion and contraction during service. The number of strands, their diameter, and their arrangement are all selected to meet specific performance objectives. Fine stranding increases flexibility, while coarser stranding improves mechanical strength and reduces manufacturing complexity. Engineers must balance these factors to produce a conductor that performs reliably throughout the cable service life.

The conductor size is determined primarily by ampacity, which represents the maximum continuous current the conductor can carry without exceeding its allowable temperature limit. Ampacity is influenced by conductor material, cross-sectional area, insulation type, installation environment, ambient temperature, and heat dissipation conditions. Electrical codes and industry standards provide tables and calculation methods to determine appropriate conductor sizes for specific applications, but designers must also consider voltage drop, short-circuit withstand capability, and system reliability. In medium voltage systems, short-circuit performance is particularly important, as fault currents can generate significant thermal and mechanical forces within the conductor. The conductor must be able to withstand these forces without melting,

deforming, or losing structural integrity. This requirement influences both the conductor cross-section and the stranding method.

Beyond its electrical function, the conductor also serves an important mechanical role, particularly during installation. Pulling tension, bending, and sidewall pressure are all applied directly to the conductor, making its construction and strength critical to preventing damage during installation. During a typical cable pull, the conductor experiences tensile forces that can be substantial, especially in long duct runs or vertical installations. If these forces exceed allowable limits, the conductor may stretch, distort, or suffer internal strand damage that is not immediately visible but can later lead to overheating or failure. Standards therefore define maximum allowable pulling tensions based on conductor material and cross-sectional area, and installation procedures are developed to ensure these limits are not exceeded.

Bending stresses are equally important. When a cable is routed around corners or into equipment terminations, the conductor must bend without kinking or cracking. Excessive bending can cause strand separation, deformation, or localized stress points that compromise electrical and mechanical performance. Minimum bend radius requirements are specified to ensure that the conductor maintains its geometry and internal integrity. These requirements are especially critical for medium voltage cables, where conductor deformation can affect the interface with the conductor shield and insulation, potentially leading to partial discharge or insulation breakdown over time.

Sidewall pressure, which occurs when a cable is pulled around a bend in a conduit or duct, also acts directly on the conductor. High sidewall pressure can flatten or distort the conductor, affecting strand alignment and compactness. This can result in uneven stress distribution and reduced electrical performance. Proper installation planning, including the use of suitable pulling equipment, lubricants, and routing layouts, is therefore essential to protect the conductor during installation. The conductor's design must anticipate these stresses and provide sufficient robustness to withstand them without permanent damage.

The conductor's surface condition and geometry also influence the performance of surrounding cable components. A smooth, round conductor minimizes electrical stress concentrations and supports proper interface with the conductor shield. Irregularities, sharp edges, or protruding strands can create localized electric field intensification, which increases the risk of partial discharge and long-term insulation degradation. For this reason, compacted or compressed strand designs are commonly used in medium voltage cables to improve electrical uniformity and overall cable reliability. Compaction reduces the air gaps between strands, producing a more uniform surface that improves contact with the conductor shield and enhances dielectric performance.

Compacted conductors also offer dimensional advantages. By reducing the overall diameter of the conductor, compaction allows for thinner insulation layers while maintaining required electrical clearances. This can result in smaller overall cable diameters, which improves handling, reduces material usage, and simplifies installation. In addition, compacted conductors improve strand stability, reducing the likelihood of strand movement under thermal cycling or

mechanical stress. This stability contributes to long-term reliability, particularly in applications where cables are subjected to frequent load variations.

The interaction between the conductor and the conductor shield is particularly important in medium voltage cables. The conductor shield, typically made of a semi-conductive polymer compound, is applied directly over the conductor to smooth the electric field and eliminate air gaps at the interface between the conductor and insulation. For this system to function correctly, the conductor surface must be uniform, clean, and properly shaped. Any irregularities in the conductor surface can compromise the effectiveness of the conductor shield, leading to localized electrical stress and potential insulation failure. This is another reason why conductor geometry and surface quality are treated as critical design parameters in medium voltage cable manufacturing.

Thermal performance is another key consideration in conductor design. As current flows through the conductor, resistive losses generate heat. This heat must be dissipated through the insulation and surrounding environment. The conductor's material, cross-sectional area, and strand configuration all influence how effectively heat is generated and transferred. A properly designed conductor ensures that operating temperatures remain within the limits of the insulation system, preserving both electrical performance and mechanical strength over time. Repeated thermal cycling can cause expansion and contraction of the conductor, which places additional stress on the insulation and shield layers. A well-designed stranded conductor accommodates this movement more effectively than a rigid structure, reducing the risk of long-term degradation.

In service, the conductor is also subjected to electromagnetic forces during fault conditions. When short-circuit currents flow, strong magnetic fields are generated that can cause the conductor to experience sudden mechanical forces. These forces can lead to strand displacement, deformation, or even rupture if the conductor is not designed to withstand them. Medium voltage cable standards therefore include short-circuit performance requirements that account for both thermal and mechanical effects. The conductor must be capable of withstanding these extreme conditions without losing its functional integrity.

The choice of conductor construction also affects termination and splicing practices. Proper termination requires that the conductor be clean, stable, and dimensionally consistent. Stranded conductors must be designed so that strands do not unravel or shift during stripping and preparation. Compact conductors, in particular, provide a stable structure that facilitates termination and improves contact with connectors and lugs. Poor conductor stability can lead to loose connections, increased resistance, overheating, and eventual failure at terminations, which are among the most common failure points in power cable systems.

Over the life of a medium voltage cable, the conductor remains the primary pathway for energy transmission, and any degradation in its performance directly affects system reliability. Corrosion, strand breakage, or deformation can increase resistance, generate heat, and accelerate insulation aging. For this reason, conductor material selection, stranding design, surface quality, and mechanical strength must all be carefully controlled during manufacturing. The conductor is not merely a passive element within the cable; it is an active structural and electrical component whose characteristics shape the behavior of the entire cable system.

### 3.2 Conductor Shield

The conductor shield is a nonconducting or semi-conducting layer applied directly over the conductor and functions as a stress control layer. Its primary purpose is to smooth out the electric field at the conductor surface, eliminating air gaps and irregularities that could lead to localized electrical stress and partial discharge. In medium voltage applications, this layer is critical to long-term insulation performance. While it is thin in comparison to other cable components, the conductor shield plays a disproportionately important role in ensuring electrical reliability, as it forms the transition zone between the metallic conductor and the solid insulation system.

At the microscopic level, the surface of a stranded conductor is not perfectly smooth. Even with compacted strands, small valleys, peaks, and interfaces exist between individual wires. If insulation were applied directly over this uneven surface without an intermediate layer, air pockets would remain trapped at the interface. These air pockets have much lower dielectric strength than solid insulation and would be exposed to concentrated electric fields during operation. Over time, these conditions can lead to partial discharge activity, which gradually erodes insulation material and ultimately causes premature failure. The conductor shield eliminates this problem by providing a uniform, intimate contact surface that bridges irregularities in the conductor and establishes a smooth electrical boundary for the insulation.

In modern medium voltage cables, conductor shields are typically made from extruded semi-conducting polymer compounds. These materials are formulated to possess controlled electrical resistivity, allowing them to distribute electric stress evenly without behaving as true conductors. The semi-conducting nature of the shield ensures that it remains essentially the same electrical potential as the conductor while preventing sharp voltage gradients at the interface. This controlled resistivity is essential, as material that is too conductive could interfere with insulation performance, while a material that is too resistive would fail to properly smooth the electric field. The balance achieved through careful compound formulation is therefore fundamental to the effectiveness of the conductor shield.

The extrusion process used to apply the conductor shield is closely coordinated with the insulation extrusion in modern cable manufacturing. In many medium voltage cable designs, the conductor shield, insulation, and insulation shield are applied in a single, continuous triple-extrusion process. This ensures that all three layers are applied under controlled conditions, with clean interfaces and consistent bonding. The bonding between the conductor shield and the insulation is particularly important. A fully bonded interface prevents the formation of micro-voids or delamination over time, both of which could serve as initiation points for partial discharge. Bonded systems also maintain mechanical stability during thermal cycling, as the layers expand and contract together rather than separating.

Material compatibility between the conductor shield and the insulation is another critical design consideration. The polymers used in both layers must adhere well to one another and exhibit similar thermal and mechanical behavior. If the materials expand or contract at significantly different rates, stress can develop at the interface, potentially leading to separation or cracking. Standards therefore specify requirements for adhesion, thermal aging performance, and chemical compatibility to ensure that the conductor shield and insulation function as a unified system

throughout the cable's service life. This compatibility is not accidental but the result of extensive material development, testing, and qualifications.

The electrical properties of the conductor shield are also carefully controlled. Its volume resistivity must remain within a specified range over the expected operating temperature range of the cable. If resistivity increases excessively at low temperatures, the shield may lose its ability to equalize electric stress effectively. If resistivity decreases too much at high temperatures, unwanted current flow could occur within the shield layer. Both conditions can compromise electrical performance. For this reason, conductor shield compounds are tested for resistivity stability, aging behavior, and resistance to environmental factors such as moisture and heat.

From a mechanical perspective, the conductor shield must maintain intimate contact with both the conductor and the insulation while accommodating the movements caused by thermal expansion, contraction, and mechanical bending. During cable operation, load changes cause the conductor to heat and cool, resulting in repeated dimensional changes. The conductor shield must flex with these movements without cracking, separating, or losing adhesion. A well-designed shield layer therefore contributes not only to electrical performance but also to the long-term mechanical stability of the cable system.

During installation and termination, the conductor shield must be cleanly removable without damaging the underlying insulation. Proper strippability is essential to ensure high-quality terminations and splices. At terminations, the conductor shield is removed in a controlled manner to allow stress control components in accessories to function correctly. If the shield is difficult to remove, installers may inadvertently nick, gouge, or tear the insulation, creating defects that can lead to partial discharge or breakdown. Conversely, if the shield peels too easily or separates unevenly, it may leave behind residues or irregular edges that interfere with stress grading at the termination. Therefore, conductor shield compounds are engineered to provide a precise balance between adhesion to the insulation and ease of removal.

The quality of conductor shield removal has a direct impact on the reliability of cable accessories. Terminations and splices rely on smooth, defect-free insulation surfaces to properly distribute electrical stress. Any imperfections introduced during shield removal can act as stress concentration points. These defects may not cause immediate failure, but under operating voltage and environmental conditions, they can gradually initiate partial discharge activity that leads to insulation degradation. For this reason, installation training, proper tools, and strict workmanship standards are essential when handling conductor shields in medium voltage cable systems.

Poorly designed or improperly removed conductor shields can compromise electrical stress control at accessories, increasing the risk of failure. In many field investigations of medium voltage cable failures, defects associated with the conductor shield interface are frequently identified as contributing factors. These may include improper bonding, contamination, irregular stripping, or damage to the insulation during shield removal. Such issues highlight the importance of viewing the conductor shield not as a minor layer, but as a critical functional component that demands the same level of attention as the conductor and insulation.

The conductor shield also plays a role in the overall cleanliness of the insulation system. Because it is applied directly over the conductor, it acts as a barrier that prevents contaminants from the conductor's surface from migrating into the insulation. This is particularly important in manufacturing environments, where even small particles of metal, dust, or moisture can significantly reduce dielectric strength. By encapsulating the conductor in a controlled, uniform layer, the conductor shield helps maintain the purity and integrity of the insulation interface.

Over the service life of a medium voltage cable, the conductor shield remains electrically and mechanically active. It continuously manages electric stress, accommodates thermal cycling, and supports the stability of the insulation system. Unlike outer layers that primarily provide mechanical or environmental protection, the conductor shield operates at the core of the cable's electrical function. Its failure or degradation directly affects insulation performance and can rapidly lead to cable failure. This is why conductor shield materials and designs are subject to rigorous qualification testing, including electrical, thermal, mechanical, and aging evaluations.

### 3.3 Insulation

The insulation is relied upon to electrically isolate the energized conductor from ground and adjacent phases while withstanding the electrical stresses imposed during operation. In medium voltage cables, insulation materials such as cross-linked polyethylene (XLPE) or ethylene propylene rubber (EPR) are commonly used due to their strong dielectric properties and thermal stability. Insulation thickness and material selection are governed by voltage rating, system grounding method, and applicable standards.

When energized, voltage stress is distributed radially across the insulation, making uniform material quality essential. Standards require rigorous electrical and physical testing to verify that insulation can withstand normal operating voltage, overvoltage, and transient conditions throughout its expected service life. Factors such as temperature rating, aging performance, and resistance to electrical treeing are all considered in insulation design.

Insulation performance is also closely tied to manufacturing quality and installation practices. Contamination, moisture ingress, or mechanical damage can significantly reduce dielectric strength. Understanding insulation requirements and limitations is essential to selecting a cable that will perform reliably in its intended application and environment.

It is worthwhile reviewing the concept of “**DISCHARGE RESISTANT**” or “**DISCHARGE FREE**” cable designs.

Industry standards such as ICEA S-94-649 and AEIC CS8 recognize two fundamental design concepts for extruded, solid-dielectric medium voltage cables: **Discharge Resistant (DR)** and **Discharge Free (DF)**. While both approaches aim to ensure reliable long-term performance, they are based on different philosophies regarding partial discharge behavior within the insulation system.

Partial discharge (PD) occurs when voids or imperfections exist within a solid dielectric and the local electric field becomes high enough to ionize the air or gas trapped inside those voids. This

ionization results in small, localized electrical breakdowns that do not completely bridge the insulation but generate repetitive discharge pulses. Over time, these partial discharge events can erode insulation material, initiate electrical treeing, and ultimately lead to premature insulation failure.

Most solid dielectric insulation systems are susceptible to degradation when exposed to sustained partial discharge activity. The repeated electrical stress and localized heating caused by PD gradually weaken the insulation structure, reducing its dielectric strength and long-term reliability. As a result, controlling partial discharge is a critical consideration in medium voltage cable design, manufacturing, and testing.

Some dielectric materials, however, are relatively insensitive to partial discharge activity and can continue to withstand operating voltage even in the presence of PD. This characteristic is known as partial discharge resistance, and it reflects the ability of an insulation system to tolerate void-related discharge activity without experiencing rapid degradation or failure.

The **Discharge Free** concept is based on the premise that new cables should exhibit extremely low or undetectable levels of partial discharge. In practice, however, the industry acknowledges that it is not possible to reliably demonstrate that a new cable is completely free of partial discharge. Although modern manufacturing processes have significantly reduced apparent PD activity compared to earlier designs, the presence of very small voids or imperfections cannot be entirely eliminated.

For this reason, industry standards define a pass/fail criterion of 5 picocoulombs (pC) for factory partial discharge testing of Discharge Free cables. To put this into perspective, a single 5-pC discharge signal would require multiple voids—such as several 10-mil voids, numerous 5-mil voids, or a large number of 1-mil voids—discharging simultaneously. This illustrates how extremely small and difficult-to-detect imperfections can contribute to measurable PD activity.

Recognizing that no cable can be guaranteed to be completely free of partial discharge, some manufacturers choose to employ the **Discharge Resistant** design concept. This approach focuses on using insulation materials that can withstand the presence of partial discharge without experiencing unacceptable degradation. Rather than attempting to eliminate all PD activity, the DR concept emphasizes material robustness and long-term reliability under realistic operating conditions.

As a result of this different design philosophy, Discharge Resistant cables are subject to different factory testing requirements as defined by ICEA and AEIC standards. While many electrical, mechanical, and physical tests are common to both DR and DF cables, one key difference is that Discharge Resistant cables are not required to undergo factory partial discharge testing on each production length.

Instead, the insulation material used in Discharge Resistant cables must be periodically tested, typically on a monthly basis, for partial discharge resistance in accordance with applicable ICEA and AEIC requirements. This material-level testing verifies that the insulation can withstand sustained voltage in the presence of PD activity. The differences in testing philosophy reflect the

underlying distinction between the two design concepts and help users select the approach best suited to their application and reliability expectations.

### **3.4 Insulation Shield**

The insulation shield is designed to confine the electric field within the insulation and ensure that voltage stresses are symmetrically distributed. This layer typically consists of an extruded semi-conducting material applied over the insulation and serves as the outer boundary of the cable's electrical system. By creating a controlled and uniform electric field, the insulation shield helps prevent localized stress concentrations that could lead to insulation failure. Although it is not directly involved in current conduction, its influence on electrical performance is fundamental, because it defines how the electric field behaves within the insulation and how that field transitions to the grounded components of the cable system.

In a medium voltage cable, the electric field does not simply radiate uniformly from the conductor outward. Without proper control, variations in insulation thickness, material imperfections, or geometric irregularities could cause the electric field to intensify in certain areas. These localized stress points accelerate electrical aging and can initiate partial discharge, which gradually erodes the insulation. The insulation shield prevents this by establishing a smooth, equipotential surface around the insulation. This ensures that the electric field lines remain evenly distributed across the insulation thickness, allowing the insulation material to perform as intended over long periods of service.

The insulation shield is typically made from a semi-conducting polymer compound similar in nature to the conductor shield but formulated specifically for its location and function. Its resistivity is carefully controlled so that it can maintain a stable electrical potential while still allowing grounding through the metallic shield that surrounds it. If the resistivity were too high, the layer would not properly equalize the electric field. If it were too low, it could carry excessive current and generate unwanted heating. Achieving this balance is critical to ensuring that the insulation shield performs effectively across the full operating temperature range of the cable.

In medium voltage cables, the insulation shield works in conjunction with the conductor shield to form a fully shielded insulation system. The conductor shield defines the inner electrical boundary of the insulation, while the insulation shield defines the outer boundary. Together, they create a controlled electrical environment in which the insulation is subjected to predictable, uniform stresses. This arrangement minimizes partial discharge activity and significantly improves long-term reliability, particularly in higher voltage applications and in grounded systems where stable electric field control is essential. Without this fully shielded system, medium voltage cables would be far more vulnerable to premature insulation degradation and unpredictable failure behavior.

The effectiveness of the insulation shield also depends on its continuity and uniformity. The layer must be free from gaps, thin spots, or discontinuities that could disrupt the electric field. Even small imperfections can create localized stress concentrations that undermine the benefits of shielding. For this reason, insulation shields are typically applied using precision extrusion

processes that ensure consistent thickness and smooth surface finish. Manufacturing controls focus on maintaining stable extrusion conditions, clean material handling, and proper bonding between the insulation and the insulation shield. Bonding is especially important because a bonded interface prevents the formation of micro-voids that could otherwise become sites for partial discharge.

Compatibility between the insulation shield and the underlying insulation material is another critical factor. Both layers must adhere well and exhibit similar thermal and mechanical behavior. During operation, the cable is subjected to thermal cycling as load conditions change. The insulation expands and contracts, and the insulation shield must move with it without separating, cracking, or losing adhesion. If the two layers behave differently, mechanical stresses can develop at the interface, leading to delamination or cracking that compromises electrical performance. Standards therefore specify material compatibility requirements, aging performance limits, and adhesion characteristics to ensure long-term stability.

The insulation shield also plays an essential role in grounding. In a typical medium voltage cable, the insulation shield is in contact with a metallic shield, such as copper tape or wire, which is connected to ground. This arrangement ensures that the outer boundary of the insulation remains at ground potential. By maintaining a defined and stable reference potential, the insulation shield allows the electric field to be fully contained within the insulation. This is particularly important in grounded systems, where predictable field distribution is necessary for both safety and performance. Effective grounding through the insulation shield also ensures that fault currents are safely conducted away from the insulation system, reducing the risk of thermal or electrical damage.

From a system perspective, the insulation shield contributes to both electrical reliability and personnel safety. By controlling the electric field and maintaining grounding continuity, it reduces the likelihood of surface discharges, tracking, or unexpected voltage gradients on the cable surface. This helps protect not only the cable itself but also the surrounding equipment and personnel who may come into contact with cable accessories or terminations. In this sense, the insulation shield is a key element in maintaining a safe and predictable operating environment for medium voltage systems.

Like the conductor shield, the insulation shield must be properly removed during splicing and termination. Clean, damage-free removal is critical to maintaining electrical stress control at accessories. During termination preparation, the insulation shield is stripped back to expose a defined length of insulation. This exposed insulation then interfaces with stress control components in terminations or splices, which are designed to gradually redistribute the electric field and prevent stress concentrations. If the insulation shield is removed unevenly, or if the insulation surface is damaged during removal, the effectiveness of these stress control components is compromised.

Improper handling or removal of the insulation shield can result in uneven electric fields and reduced accessory performance. Small nicks, cuts, or gouges in the insulation surface may not be visible once the termination is completed, but they can become points of electrical stress under operating voltage. Over time, these defects may initiate partial discharge, leading to insulation

erosion and eventual failure. Residual semi-conducting material left on the insulation surface can also interfere with proper stress control, as it may alter the intended electrical field distribution. For these reasons, precise workmanship, proper tools, and strict installation procedures are essential when dealing with insulation shields.

The design of the insulation shield compound directly influences how easily and cleanly it can be removed. The compound must adhere sufficiently to the insulation to maintain a stable bonded interface during service, yet allow controlled separation during stripping. Achieving this balance is a significant materials engineering challenge. If adhesion is too strong, installers may struggle to remove the shield without damaging the insulation. If adhesion is too weak, the shield may separate prematurely or leave irregular surfaces. Modern compound formulations and extrusion techniques are therefore carefully optimized to meet both service performance and installation requirements.

The insulation shield also contributes to the overall cleanliness and integrity of the insulation system. By forming a protective outer layer over the insulation, it helps shield the insulation from contamination during manufacturing, handling, and installation. Contaminants such as dust, moisture, or metallic particles can significantly reduce dielectric strength if they reach the insulation surface. The insulation shield acts as a controlled barrier that preserves the insulation's electrical properties until the cable is prepared for termination or splicing.

Over the life of a medium voltage cable, the insulation shield remains continuously active in managing electric stress and maintaining grounding stability. It must withstand thermal aging, mechanical movement, and environmental influences without losing its electrical or mechanical properties. Unlike outer jackets or armor layers, which primarily provide environmental and mechanical protection, the insulation shield operates directly within the cable's electrical system. Any degradation in this layer has immediate consequences for insulation performance and system reliability.

Field experience has shown that many medium voltage cable failures can be traced to issues associated with the insulation shield interface, particularly at terminations and splices. These issues often arise not from inherent material defects, but from improper installation practices or inadequate surface preparation. This highlights the importance of viewing the insulation shield not as a secondary layer, but as a critical functional component whose performance depends equally on design, manufacturing quality, and workmanship in the field.

### 3.5 Metallic Shield

The metallic shield is a non-magnetic metallic component that provides a solid ground plane and a controlled path for charging and leakage currents. Common forms include copper tape (**Figure 2**), copper wire shields, or concentric neutral wires (**Figure 3**). By grounding the cable system, the metallic shield enhances safety and reduces external electric fields around the cable.

In addition to carrying charging and leakage currents, the metallic shield may be sized to carry neutral, unbalanced phase, and ground fault currents. When designed for this purpose, standards

specify minimum cross-sectional area and continuity requirements to ensure the shield can safely withstand thermal and mechanical stresses during fault conditions.

The metallic shield also plays a role in system protection and diagnostics. Proper grounding allows protective devices to operate effectively during faults and can assist in locating cable damage. Understanding metallic shield design is essential for coordinating cable selection with system grounding and protection schemes.

See **Table 3** for the various metallic shield types and materials that are recognized in the medium voltage cable standards within the scope of this document.



**Figure 2** – Longitudinally applied and corrugated copper tape

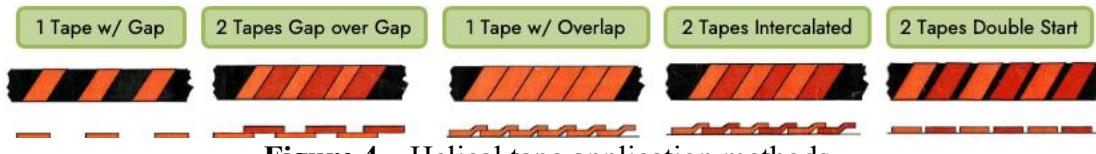


**Figure 3** – Concentric neutral wires

	<b>Concentric Neutral</b>	<b>Tape</b>	<b>Wire</b>	<b>Braid</b>	<b>Metal Sheath</b>
<b>Types</b>	<b>Round wires</b> Flat straps	Helical <b>Longitudinal and Corrugated</b>	Wrapped metal wires	<b>Smooth</b> Welded & Corrugated <b>Extruded &amp; Corrugated</b>	
<b>Materials</b>	Copper Tin-coated copper			Aluminum Aluminum alloy Lead Copper Bronze	

**Table 3** – Metallic shield types and materials

There are various methods of helical tape application including 1 tape with gap, 2 tapes gap over gap, 1 tape with overlap, 2 tapes intercalated, and 2 tapes double start. See **Figure 4**.



**Figure 4** – Helical tape application methods

Longitudinally applied and corrugated copper tape (LACT) consists of a copper tape/strip longitudinally placed along the medium voltage cable core, corrugated using a corrugator, and then formed around the core and glued. See **Figure 5**.

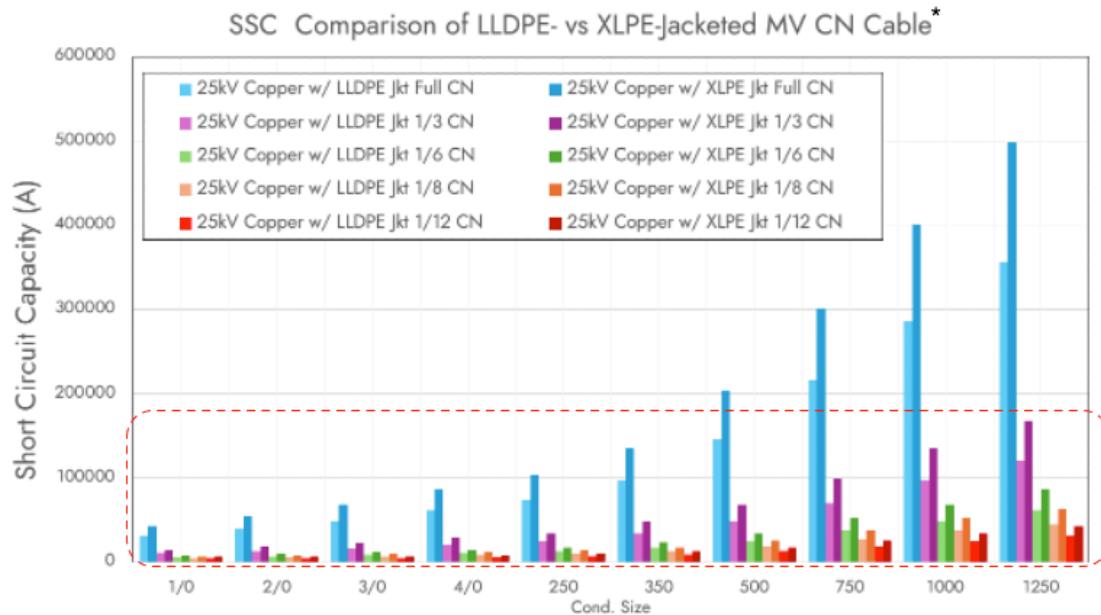


**Figure 5** – Copper LACT

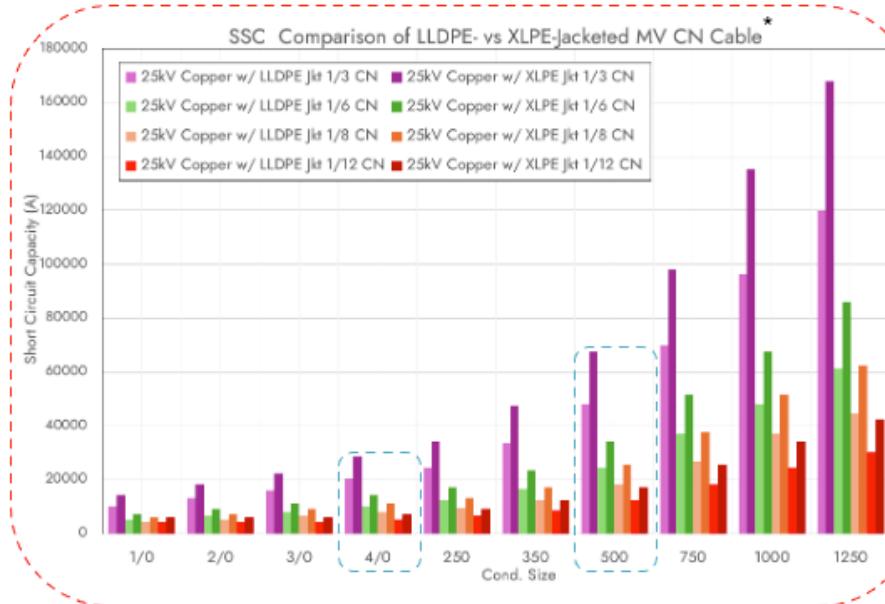
Requirements for copper tape metallic shielding include quality of application, thicknesses, corrugation lay factor, and % overlap/gap.

Metallic shields, particularly concentric neutral wires, are commonly able to handle a certain amount of short circuit current and so it is worthwhile discussing how concentric neutral sizing affects the short circuit capacity (SCC) of the metallic shield. See **Figures 6, 7, and 8** comparing SCC for 25 kV copper concentric neutral cables with an LLDPE jacket and an XLPE jacket and the brief discussion that follows.

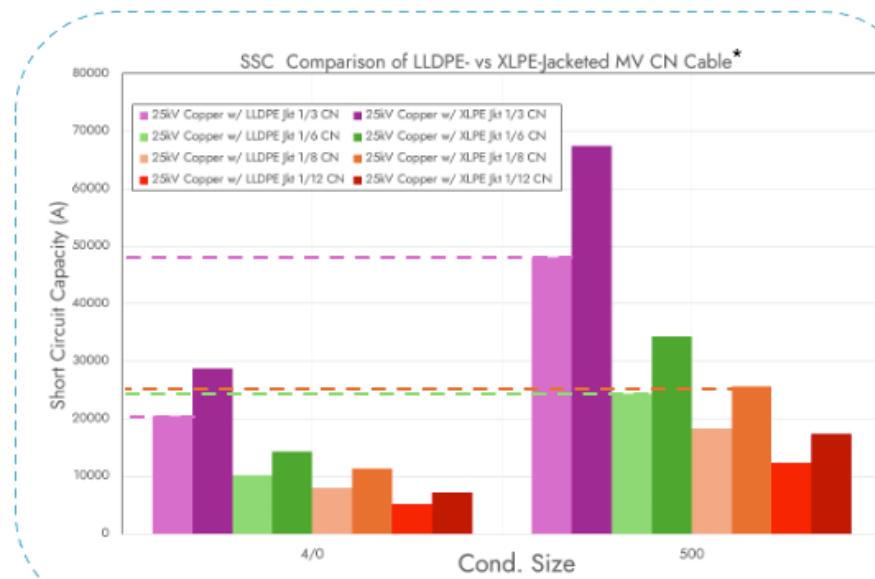
\* Note: These short circuit values assume a short circuit duration of 3 cycles and adiabatic heat generation (i.e. a conservative calculation).



**Figure 6 – SSC for 25kV Cu CN cables with LLDPE and XLPE jackets**



**Figure 7 – SSC for 25kV Cu CN cables with LLDPE and XLPE jackets (a closer look)**



**Figure 8** – SSC for 25kV Cu CN cables with LLDPE and XLPE jackets (an even closer look)

Understanding the relationship between conductor and concentric neutral size, jacket material types, and fault-clearing requirements **can help reduce cost** while maintaining performance and compliance. For example, where a 1/3 CN is required for a 4/0 AWG Copper 25kV cable w/ an LLDPE jacket, a 1/3 CN may be oversized for a 500 kcmil sized cable with an XLPE jacket.

### 3.6 Armour

Armour is a metallic protective layer applied over medium voltage cable constructions to safeguard the internal components from mechanical damage and environmental hazards encountered during handling, installation, and service. In many applications, particularly where cables are installed directly in the ground, routed through industrial facilities, or exposed to heavy equipment, vibration, or potential impact, the risk of physical damage is significant. Armour provides a robust barrier that reduces the likelihood of crushing, abrasion, penetration, or deformation reaching the insulation system or conductor, thereby preserving both electrical performance and long-term reliability.

The specific form of armour can vary widely depending on regional practices, governing standards, and application requirements. It may consist of helically applied steel or aluminum wires, interlocked metallic tapes, corrugated metal sheaths, or combinations of these constructions. Each type offers different balances of flexibility, mechanical strength, weight, corrosion resistance, and ease of installation. For example, wire armour generally provides excellent tensile strength and impact resistance, making it suitable for direct burial and heavy-duty industrial applications, while tape or corrugated sheath constructions may offer improved coverage and moisture protection with different bending characteristics. The selection of armour type is therefore not arbitrary but is closely tied to the expected mechanical stresses, environmental exposure, and installation method of the cable.

One of the most important functions of armour is protection against external forces during installation. Medium voltage cables are often pulled through ducts, trenches, or conduits, where they may encounter sharp edges, debris, or uneven surfaces. Armour acts as a sacrificial layer that absorbs abrasion and impact, preventing damage to the underlying insulation or shields. During pulling, the armour can also contribute to the overall tensile strength of the cable, helping it withstand the longitudinal forces applied by pulling equipment. This is particularly valuable in long or complex pulls where frictional forces can be substantial. However, it is important to recognize that not all armour constructions are designed to carry the full pulling load, and installation practices must always follow the manufacturer's recommendations and applicable standards to avoid overstressing the cable.

In addition to mechanical protection, armour can play a role in the electrical and grounding performance of the cable system. When properly bonded and grounded, metallic armour may serve as a supplementary path for fault current or induced currents, enhancing system safety and improving electromagnetic compatibility. This function, however, depends heavily on the material, cross-sectional area, continuity, and bonding method of the armour. In many designs, armour is not intended to carry significant fault current unless it is specifically sized and integrated into the grounding system for that purpose. Relying on armour for fault current without proper design can lead to overheating, mechanical damage, or failure during fault conditions. For this reason, standards carefully define acceptable armour materials, minimum coverage, and performance criteria to ensure that the armour performs its intended function without introducing new risks.

Corrosion resistance is another critical consideration in armour selection. In underground or coastal environments, moisture, salts, and chemicals can aggressively attack metallic components. Steel armour may require galvanization, coatings, or protective bedding layers to prevent corrosion over the cable's service life, while aluminum-based armours may offer improved corrosion resistance in certain soils and atmospheres. In some cases, additional outer jackets or serving layers are applied over the armour to further isolate it from the environment. The long-term integrity of the armour is essential, because once corrosion compromises the metallic layer, both mechanical protection and any intended electrical function may be reduced or lost.

The presence of armour also affects the cable's overall geometry, weight, and flexibility. Armoured cables are heavier and stiffer than their non-armoured counterparts, which has direct implications for handling and installation. Larger bending radii are typically required to avoid kinking or deforming the armour, and additional care must be taken when routing the cable around corners or through confined spaces. Improper bending can cause the armour to separate, buckle, or dig into underlying layers, potentially damaging the insulation or shields. Installation crews must therefore be trained to recognize the specific handling requirements of armoured cables and to use appropriate equipment such as rollers, guides, and tension control devices.

From a system design perspective, armour is not always necessary, and its inclusion should be based on a clear understanding of the installation environment and risk profile. In ducted installations with well-controlled conditions, non-armoured cables may perform perfectly well when combined with appropriate protective conduits. In contrast, in direct burial installations or

in areas with high mechanical risk, armour can significantly extend cable life and reduce the likelihood of costly failures. Over-specifying armour can increase material and installation costs and make handling more difficult, while under-specifying it can expose the cable to unacceptable risk. Achieving the right balance requires close collaboration between designers, manufacturers, and installers.

Armour also influences maintenance and fault location practices. In some cases, the presence of armour can make access to the underlying cable layers more complex during repairs or terminations, requiring specialized tools and techniques. On the other hand, the mechanical robustness provided by armour may reduce the frequency of damage-related faults, lowering long-term maintenance costs. Understanding how the armour interacts with the outer jacket, shielding system, and grounding arrangement is essential to ensure that repairs and modifications can be performed safely and effectively.

Another important aspect of armour design is its interaction with the insulation shielding system and metallic shield or concentric neutral. Care must be taken to prevent unintended electrical contact or abrasion between layers, which could compromise the insulation system or introduce circulating currents. Bedding layers or separator tapes are often used between the insulation shield and the armour to maintain proper spacing, prevent mechanical damage, and ensure electrical isolation where required. These seemingly minor details play a major role in the overall reliability of the cable system.

From a safety standpoint, armour provides not only protection to the cable but also to personnel. By reducing the likelihood of insulation damage and conductor exposure, armour lowers the risk of electric shock and fire. In certain industrial or hazardous locations, the presence of armour may be required by code or regulation to meet safety objectives. In these cases, armour is not merely an optional enhancement but an essential component of compliance and risk management.

The standards governing medium voltage cables carefully define armour types, materials, coverage, and performance requirements to ensure consistency and reliability across manufacturers and applications. These standards reflect decades of industry experience and testing, capturing best practices that help prevent common failure modes. By adhering to these requirements, manufacturers can produce armoured cables that perform predictably under mechanical, electrical, and environmental stresses, while users can have confidence in the suitability of the product for its intended application.

See **Table 4** for the different types and materials defined for use as armour in the medium voltage cable standards within the scope of this document.

	<b>Metal Sheath</b>	<b>Wire</b>	<b>Tape</b>
<b>Types</b>	<b>Extruded smooth</b> <b>Extruded corrugated</b>	Round	<b>Flat</b> <b>Welded &amp; Corrugated</b> <b>Interlocked</b>
<b>Materials</b>	<b>Aluminum</b> <b>Lead</b>	<b>Galvanized steel</b> Copper	<b>Steel</b> Aluminum <b>Copper</b> Bronze <b>Other non-magnetic materials like brass, cupro-nickel and zinc</b>

**Table 4** – Different armour types and materials

See **Figures 9, 10, 11** and **12** for examples of the different armour types.



**Figure 9** - Interlocked



**Figure 10** – Welded and Corrugated



**Figure 11** – Flat steel tape



**Figure 12** – Galvanized steel armour

### 3.7 Jacket

The jacket is the outermost protective layer of a medium voltage cable and serves as the first line of defense between the cable and its surrounding environment. While the internal layers of a cable are primarily responsible for electrical performance, the jacket is responsible for preserving the integrity of those layers by shielding them from mechanical damage, environmental exposure, and chemical attack. Without a properly designed and selected jacket, even the most carefully engineered conductor, insulation, and shielding system can experience premature degradation, leading to reduced service life and increased risk of failure.

From a mechanical standpoint, the jacket protects the cable against abrasion, impact, and general handling damage. During installation, cables are often pulled across rough surfaces, around rollers, through conduits, or across trench bottoms where stones, concrete, or metal edges may be present. The jacket absorbs these mechanical stresses and prevents them from being transferred directly to the insulation system or metallic components beneath. Even minor surface damage to the insulation can compromise dielectric strength, so the jacket's role in preventing such damage is fundamental to overall cable reliability.

In addition to mechanical protection, the jacket acts as a barrier against environmental contaminants. Many installation environments expose cables to oils, fuels, solvents, acids, alkalis, or industrial chemicals that can attack polymeric materials. A properly selected jacket material resists swelling, cracking, or softening when exposed to these substances, preserving both its own integrity and the protection it provides to underlying layers. In industrial plants, refineries, mining operations, and transportation facilities, this chemical resistance is often one of the most critical jacket performance requirements.

Moisture protection is another essential function of the jacket. Although the insulation system itself is designed to withstand electric stress, prolonged exposure to moisture can lead to insulation aging, water treeing, and corrosion of metallic components. The jacket helps limit the ingress of moisture into the cable structure and reduces the rate at which water can migrate along the cable. In direct burial applications, where the cable is in constant contact with soil and groundwater, this function becomes particularly important. In such environments, the jacket must maintain its integrity over decades while exposed to varying temperatures, soil chemistry, and mechanical pressures.

Sunlight resistance is a key requirement for cables installed outdoors or on exposed structures. Ultraviolet radiation can degrade many polymer materials over time, leading to embrittlement, cracking, and loss of mechanical strength. Jacket compounds intended for outdoor use are therefore formulated with stabilizers that protect against UV radiation and ozone. Standards define test methods and acceptance criteria to ensure that jacket materials maintain their performance after prolonged exposure to sunlight. Without this protection, the jacket could fail long before the electrical components of the cable reach the end of their expected service life.

In some applications, particularly where metallic components such as armour or concentric neutrals are present, the jacket must also provide ion filtration or corrosion protection. Certain soil conditions contain ions that can accelerate corrosion of metals. A properly designed jacket can act as a barrier that reduces the movement of these ions toward the metallic layers, thereby slowing corrosion processes and extending the life of the cable. This function is especially important in aggressive soils, coastal regions, and industrial sites where chemical contamination may be present.

Standards play a critical role in defining jacket material requirements and performance expectations. Properties such as minimum thickness, tensile strength, elongation at break, tear resistance, and resistance to environmental stress cracking are carefully specified to ensure consistent and predictable performance. Thickness requirements ensure that the jacket can withstand expected mechanical wear, while tensile strength and elongation requirements ensure

that the material can stretch and recover without cracking during installation and service. Environmental stress cracking resistance ensures that the jacket will not develop premature cracks when exposed to combined mechanical stress and chemical or environmental influences.

The jacket also contributes to the overall electrical safety of the cable system. Although it is not part of the primary insulation system, the jacket provides an additional layer of separation between energized components and the surrounding environment. In the event of damage to internal layers, the jacket may help delay or prevent direct exposure, providing an added margin of safety for personnel and equipment. This secondary protective role reinforces the importance of selecting jacket materials that maintain their integrity throughout the cable's service life.

Fire performance is another critical consideration, particularly in indoor installations, cable trays, tunnels, and confined spaces. In these environments, the behavior of the jacket material in a fire can significantly affect overall system safety. Some applications require jackets with enhanced flame resistance, low smoke generation, or halogen-free characteristics to reduce toxic gas emissions during combustion. Standards and codes define specific fire performance tests and classifications that jacket materials must meet for certain installation types. Selecting the appropriate jacket for these environments helps protect not only the cable system but also the safety of occupants and emergency responders.

The jacket also influences installation practices and handling procedures. Different jacket materials exhibit different coefficients of friction, stiffness, and surface hardness, all of which affect pulling tension and ease of routing. A jacket with high friction may increase pulling forces, potentially stressing the conductor or armour, while a very soft jacket may be more susceptible to damage from sharp edges. Installers must understand these characteristics to choose appropriate lubricants, pulling methods, and protective measures. Proper training and awareness help ensure that the jacket performs its protective role rather than becoming a source of vulnerability.

From a system design perspective, jacket selection represents a balance between performance, durability, cost, and regulatory compliance. A jacket that exceeds all possible requirements may provide excellent protection but at a higher material and installation cost, while a minimally compliant jacket may reduce initial cost but increase long-term risk. Engineers must consider the full lifecycle of the cable, including installation, operation, maintenance, and eventual replacement, when selecting jacket materials and constructions. This lifecycle perspective often reveals that investing in a higher-performance jacket can reduce total ownership cost by minimizing failures and maintenance.

The jacket also plays a role in identification and traceability. Color coding, printed legends, and surface markings are typically applied to the jacket to indicate voltage rating, conductor size, manufacturer, and applicable standards. These markings assist installers, inspectors, and maintenance personnel in correctly identifying the cable and verifying its suitability for a given application. The jacket material must therefore be compatible with printing and marking methods that remain legible throughout the cable's service life.

In modern medium voltage cable systems, the jacket is no longer viewed as a simple protective coating but as an integrated component of the overall cable design. Its interaction with armour, metallic shields, and bedding layers must be carefully managed to prevent abrasion, chemical incompatibility, or unintended electrical effects. Separator tapes, bonding layers, or specialized compounds may be used to ensure that each layer performs its intended function without compromising the others. These design details reflect the high level of engineering that goes into producing reliable medium voltage cables.

Thermoplastic	LDPE	Low-Density Polyethylene
	LLDPE	Linear Low-Density Polyethylene
	MDPE	Medium-Density Polyethylene
	HDPE	High-Density Polyethylene
	PVC	Polyvinyl Chloride
	PP	Polypropylene
	CPE-TP	Chlorinated Polyethylene, Thermoplastic
	SCPE	Thermoplastic Elastomer
	LSHF	Semi-conducting Polyethylene
Thermoset	LSHF	Limited-Smoke Halogen Free
	CSPE	Chloro-sulfonated Polyethylene (Hypalon)
	CPE-XL	Chlorinated Polyethylene, Thermoset
	CR	Neoprene
	NBR/PVC	Nitrile-butadiene/Polyvinyl Chloride
	XLPE	Cross-linked Polyethylene

**Table 5** – Different jacket materials

Polyethylene variants (LDPE, LLDPE, MDPE, HDPE) generally offer excellent water resistance and low-temperature performance (down to -40 °C), but they lack flame and fire resistance and have high smoke/toxicity levels. PVC is cost-effective and provides fair flame retardance but can have a high toxicity. Polypropylene (PP) stands out for its wide temperature range (-40 °C to +105 °C) and excellent chemical resistance,. Thermoplastic elastomers (TPE) and chlorinated polyethylene/semiconducting PE combine good flexibility with strong resistance to chemicals, UV, and water, making them versatile for harsh environments; however, they come at medium cost and moderate toxicity level. Low Smoke Halogen Free (LSHF) materials excel in flame retardance, fire resistance, and very low toxicity, making them ideal for safety-critical applications, though their low-temperature performance is only fair compared to polyethylene options.

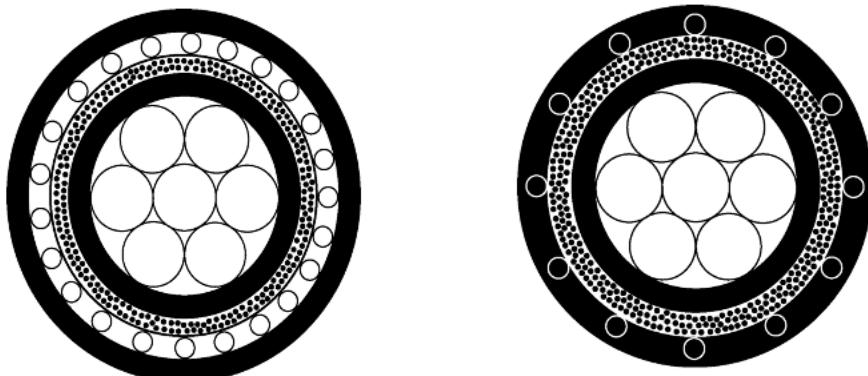
Materials like CSPE and CPE (thermoset) offer excellent toughness, chemical resistance, and water resistance, with wide temperature ranges (-40 °C to +105 °C) and strong low-temperature performance. They also provide good flame and fire resistance with moderate smoke/toxicity, making them suitable for demanding environments. Neoprene is more balanced, with good flexibility and water resistance but only fair flame/fire resistance and moderate low-temp capability (-20 °C). NBR/PVC blends excel in oil resistance and water resistance but have limited flexibility and fair low-temperature performance (-30 °C). XLPE stands out for toughness

and low-temperature capability (-40 °C) but lacks flexibility and flame/fire resistance, with low smoke/toxicity.

Overall, thermoplastic jackets are ideal for cold and cost-sensitive applications, while thermoset jackets provide durability and safety for demanding conditions.

A jacket is optional for concentric neutral power cables. An un-jacketed medium voltage cable typically employs tin-coated copper concentric neutral wires (Cu-Sn).

Jackets can be applied either overlaid or encapsulating. See **Figure 13**. Cables with overlay jackets typically come with a separator tape that is applied over the metallic shield to prevent fall in. Encapsulating jackets, on the other hand, have the jacketing material extruded to fill void spaces around the metallic shield. Cables with an overlay jacket are more flexible than those with encapsulating jackets, however they are less water-tight.



**Figure 13** – Overlay (left) and Encapsulating (right) jacket application

Red stripes are optional feature for jackets on medium voltage cables. See **Figure 14**.

When provided, the three stripes shall be extruded into the jacket to a specified depth. The stripe material must be durable and compatible. The total width cannot exceed 50% of the outer circumference of the jacket. The stripes must be sunlight resistant.



**Figure 14** – Jacket with 3 red stripes

### 3.8 Summary

The following table (**Table 6**) lists the basic construction requirements defined in the medium voltage cable standard within the scope of this document.

Component	CSA C68.5	CSA C68.10	ICEA S-94-649	ICEA S-97-682	AEIC CS8	ICEA S-113-684	ICEA S-93-639	UL 1072
Conductor Type	Cu/Al/ Cu-Sn	Cu/Al/ Cu-Sn	Cu/Al/ Cu-Sn	Cu/Al/ Cu-Sn	Cu/Al/ Cu-Sn	Cu/Al/ Cu-Sn	Cu/Al/ Cu-Sn	Cu/Al/ Cu-Sn
Conductor Water-blocking	Optional							
Insulation Materials	TRXLPE/ EPR	XLPE/ TRXLPE/ EPR	XLPE/ TRXLPE/ EAM/EPR	XLPE/ TRXLPE/ EAM/ EPR	XLPE/ TRXLPE/ EPR	Thermoset material	XLPE/ TRXLPE/ E/ EPR	XLPE/ EP/ DREP/ EPCV
Metallic Shielding	Concentric Neutral		Concentric Neutral		Concentric Neutral	Concentric Neutral		
	Tape(s)	Tape(s)		Tape(s)	Tape(s)	Tape(s)	Tape(s)	Tape(s)
		Tape + Wire					Tape + Wire	
		Wire Shield		Wire Shield	Wire Shield	Wire Shield	Wire Shield / Straps	Wire Shield / Straps
		Braid				Braid		Braid
	Lead Sheath	Lead Sheath		Lead Sheath	Metal Sheath	Metal Sheath	Metal Sheath	Metal Sheath
Metallic shield Water-blocking	Optional LWB	Optional LWB	Optional LWB	Optional LWB	Optional LWB or Radial	Optional LWB or Radial	None	None
Armour	None	Sheath Flat tape Interlock Wire	None	None	None	None	Sheath Flat tape Interlock Wire	Sheath Interlock Wire
Jackets	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3 red stripes	Optional	-	Optional	Optional	Optional	Optional	-	-

Table 6 – Basic construction requirements

## **4.0 Testing Requirements**

Medium voltage cables are fundamental components of modern power distribution systems, and their performance directly influences system safety, reliability, and operational continuity. Because these cables operate at elevated voltage levels and are often expected to perform for decades in demanding environments, their design and manufacture are governed by strict requirements. Factory testing plays a central role in ensuring that medium voltage cables meet these requirements before they are released for installation and service. Through a structured program of qualification and production testing, manufacturers verify that cable designs, materials, and processes consistently produce products that conform to applicable North American standards.

Factory testing begins with the understanding that a medium voltage cable is not a single material or component, but a complex system made up of conductors, semi-conducting layers, insulation, metallic shields, armor, and protective jackets. Each of these elements must perform its intended function while also interacting correctly with adjacent components. Testing at the factory level is designed to confirm that the cable system, as a whole, can withstand the electrical, mechanical, thermal, and environmental stresses it will encounter during its service life. Without this verification, even small defects or inconsistencies introduced during manufacturing could lead to premature failures once the cable is energized.

Qualification testing is typically performed to demonstrate that a new cable design is suitable for production and meets the performance expectations established by industry standards. These tests are often more extensive than routine production tests and may include long-duration electrical testing, thermal cycling, and aging evaluations. Qualification testing validates material selections, insulation systems, and construction details, providing confidence that the design will perform reliably under normal and abnormal operating conditions. Once a design has been qualified, ongoing production testing ensures that each manufactured length maintains that same level of quality and compliance.

Physical and mechanical testing is an essential part of factory verification because medium voltage cables are subjected to significant mechanical stresses from the moment they are manufactured. During production, cables are handled, wound onto reels, transported, and ultimately installed using pulling equipment that applies tension and bending forces. Factory tests confirm that conductors, insulation, shields, and jackets possess the necessary strength, flexibility, and dimensional consistency to withstand these stresses without damage. Measurements of conductor diameter, insulation thickness, shield coverage, and jacket thickness help ensure uniformity and compliance with specified tolerances, which directly affects electrical performance and long-term durability.

Mechanical performance of polymeric materials used in insulation and jackets is also closely evaluated. Tensile strength and elongation tests verify that materials can stretch and recover without tearing or cracking, an important characteristic during installation and thermal expansion in service. Deformation and hot-set tests help confirm that insulation will maintain its shape and thickness when subjected to elevated temperatures and mechanical load. Strippability tests assess how easily semi-conducting shields can be removed without damaging the insulation, which is

critical for achieving reliable splices and terminations. Together, these tests ensure that the cable can be handled, installed, and accessorized without compromising performance.

Electrical testing is at the core of factory quality assurance for medium voltage cables. Since the primary function of the cable is to safely transmit electrical energy, the integrity of the insulation system is of paramount importance. Electrical tests are designed to identify defects that could result in breakdown, partial discharge activity, or accelerated aging once the cable is energized. One of the most common factory electrical tests is the AC voltage withstand test, which subjects the cable to a specified voltage level for a defined period of time. Successfully passing this test demonstrates that the insulation system can withstand electrical stress beyond normal operating conditions without failure.

Additional electrical measurements are often performed to verify conductor and shield performance. DC resistance testing confirms that the conductor meets resistance requirements and that there are no discontinuities or manufacturing defects. Insulation resistance testing provides an indication of insulation quality and cleanliness, helping to detect contamination or moisture intrusion. For shielded cables, continuity and resistance checks of metallic shields ensure that grounding paths are intact and capable of performing their intended function.

Partial discharge considerations are also addressed during factory testing, depending on the cable design concept and the applicable standard. Some cable designs are subject to factory partial discharge testing with defined acceptance criteria, while others rely on material-level testing to demonstrate resistance to partial discharge activity. In both cases, the intent is to ensure that the insulation system will not experience rapid degradation due to localized electrical discharges during normal service. Factory testing establishes a controlled environment in which these electrical characteristics can be evaluated consistently and repeatably.

Environmental and chemical resistance testing further supports the long-term reliability of medium voltage cables. Many installations expose cables to moisture, heat, cold, sunlight, and a wide range of chemicals found in soil, industrial facilities, or underground vaults. Factory tests simulate these conditions to verify that insulation and jacket materials retain their mechanical and electrical properties over time. Heat aging tests evaluate how materials respond to prolonged exposure to elevated temperatures, while cold bend and cold impact tests confirm that materials remain flexible and resistant to cracking at low temperatures.

Chemical resistance testing evaluates the ability of jacket and insulation materials to withstand exposure to oils, fuels, acids, alkalis, and other substances without swelling, cracking, or loss of strength. Water absorption and moisture penetration tests help confirm that the cable design limits moisture ingress, which is critical for maintaining dielectric performance over the life of the cable. For outdoor applications, sunlight and ultraviolet resistance testing ensures that jacket materials will not degrade when exposed to long-term solar radiation. These tests collectively verify that the cable can perform reliably in the environments for which it is intended.

Factory testing requirements are defined and enforced through recognized North American standards such as those published by ICEA, AEIC, IEEE, and CSA, and are referenced by installation codes and utility specifications. These standards establish not only which tests are

required, but also the test methods, acceptance criteria, and frequency at which tests must be performed. Some tests are conducted on every production length to ensure baseline safety and quality, while others are performed periodically or during design qualification to confirm ongoing compliance. This structured approach allows manufacturers to maintain consistent quality while giving users confidence in the performance of the product they are specifying and installing.

Understanding factory testing is essential for anyone involved in the design, specification, manufacture, or application of medium voltage cables. Factory tests provide the first and most critical verification that a cable meets its intended performance requirements and complies with applicable standards. They ensure that the cable leaving the manufacturing facility is capable of withstanding the electrical, mechanical, and environmental demands it will face in service. This foundation of testing and compliance sets the stage for proper installation and long-term reliability, forming a critical link between cable design, manufacturing quality, and system performance.

## **4.1 Physical/Mechanical Tests**

Physical and mechanical testing plays a critical role in ensuring the safety, reliability, and long-term performance of power cables. Power cables are not simple conductors; they are complex assemblies composed of conductors, insulation, shields, metallic armour, and outer jackets. Each component is designed to withstand a combination of electrical, thermal, and mechanical stresses throughout the cable's service life. While electrical testing ensures that cables can carry current and withstand voltage stresses, physical and mechanical testing evaluates how well cables can endure the real-world conditions they encounter during manufacturing, installation, and operation. Without rigorous physical and mechanical testing, even the best-designed cables could fail prematurely, resulting in service interruptions, costly repairs, or safety hazards.

The mechanical stresses encountered by power cables are numerous and often unavoidable. During installation, cables are subjected to pulling tension, bending around corners, compression from rollers or trench surfaces, and torsion when wound on drums or reels. Each of these forces can strain the conductor, insulation, and shielding layers, and if the materials or construction are inadequate, damage can occur. Pulling a cable beyond its designed tensile limits can stretch the conductor, crack insulation, or delaminate shielding layers, compromising both mechanical integrity and electrical performance. Mechanical testing, such as tensile strength measurements, bend tests, and elongation assessments, ensures that cables can tolerate these installation stresses without sustaining damage. By confirming the limits of flexibility and pulling strength, manufacturers provide installers with the confidence to handle the cable safely while minimizing the risk of damage during routing, trenching, or duct installation.

Bending and flexibility are particularly important aspects of mechanical performance, as cables must often negotiate tight spaces, corners, or complex routing pathways. Excessive bending can cause kinking, conductor strand breakage, or microcracks in insulation, all of which can lead to partial discharge activity or long-term degradation. Mechanical testing includes minimum bend radius assessments and repeated bending cycles, which simulate the stresses encountered in installation and operation. These tests ensure that the cable can flex as needed while maintaining

its structural integrity and electrical performance. They also help establish installation guidelines, such as minimum bend radii and handling procedures, which are critical for avoiding damage during deployment.

Impact resistance is another vital component of physical testing. In both industrial and utility applications, cables may be exposed to accidental impacts from tools, machinery, or construction activities. Armour, insulation, and jackets are all tested to ensure they can absorb shocks without cracking, splitting, or exposing conductors. Testing methods often involve dropping weights or applying sudden forces to simulate real-world impact scenarios. Understanding how a cable responds to such stresses allows engineers to design appropriate protective layers and to select the correct cable type for specific environments. For example, cables intended for underground installation in areas with heavy equipment traffic require higher impact resistance than those placed in protected indoor conduits.

Compression and crush tests are similarly essential, particularly for cables that will be buried or laid under heavy loads. Soil pressure, traffic loads, or stacked materials can exert significant forces on buried cables, and inadequate resistance can lead to insulation deformation or conductor damage. Mechanical testing ensures that both the insulation system and metallic components can withstand these forces without permanent deformation or loss of performance. Armour and bedding layers are often tested as part of this process to verify that the combination of materials provides the intended mechanical protection.

Torsion and cyclic loading tests further contribute to understanding a cable's mechanical resilience. In service, cables may experience twisting forces during installation or thermal expansion and contraction cycles during operation. Repeated loading can create fatigue in conductors, insulation, and shields, leading to micro-cracks, delamination, or reduced mechanical strength over time. Cyclic testing simulates these conditions by subjecting cables to repeated flexing, twisting, or compression, helping manufacturers and engineers identify potential failure modes before the cable is placed in service. This kind of testing ensures that the cable will maintain its performance throughout its expected lifespan, even under fluctuating environmental and operational conditions.

Environmental factors often amplify the mechanical stresses on power cables. Temperature variations cause thermal expansion and contraction in conductors, insulation, and shields, generating internal mechanical stresses. Exposure to moisture, chemicals, or UV radiation can degrade polymeric materials, making them more brittle and susceptible to mechanical failure. Physical and mechanical testing frequently includes accelerated aging protocols to evaluate how materials perform under combined thermal, chemical, and mechanical stresses. By assessing mechanical performance in these conditions, engineers can verify that cable materials and constructions are suitable for the environments in which they will be installed, whether in underground, industrial, marine, or outdoor applications.

The importance of physical and mechanical testing also extends to safety considerations. Power cables carry high voltages and currents, and any mechanical failure that exposes conductors or damages insulation can result in electric shock, fires, or catastrophic system failures. By ensuring that cables can withstand bending, tension, crushing, and impact, mechanical testing reduces the

risk of these hazards. Proper testing provides both designers and installers with the confidence that the cable will maintain its integrity under normal and extreme handling conditions, contributing directly to operational safety.

In addition to installation and operational reliability, mechanical testing supports quality control during manufacturing. During production, cables must maintain consistent dimensions, material properties, and construction standards. Dimensional checks, elongation tests, and mechanical strength measurements detect deviations or defects in raw materials, compounding, extrusion, or stranding processes. Early detection of anomalies prevents defective cables from reaching the field, reducing waste and ensuring that every installed cable meets the required mechanical performance standards.

Mechanical testing is also critical for standard compliance and certification. Cables must be tested to demonstrate compliance with standards before they can be certified for use. Understanding the testing protocols and performance criteria ensures that cables meet regulatory and safety expectations, and it allows engineers to specify the right cable types for particular projects or environmental conditions.

Another dimension of mechanical testing is its role in predicting long-term reliability. Medium voltage cables are expected to operate for decades under varying electrical and environmental conditions. Mechanical failures often manifest gradually, beginning with minor cracks, strand separations, or delamination that progress over time. By simulating installation stresses, thermal cycling, and environmental conditions in a controlled testing environment, manufacturers and engineers can evaluate how the cable will perform over its expected service life. This predictive capability is crucial for asset owners seeking to minimize unplanned outages and lifecycle costs, as it ensures that cables are robust enough to survive the stresses of real-world operation without premature failure.

The following table (**Table 7**) provides a comparative analysis of the various physical and mechanical testing requirements in the medium voltage cable standards within the scope of this course.

Physical / Mechanical Test	CSA C68.5	CSA C68.10	ICEA S-94-649	ICEA S-97-682	AEIC CS8	ICEA S-113-684	ICEA S-93-639	UL 1072
Dimensional measurements	✓	✓	✓	✓	✓	✓	✓	✓
Aged/unaged Tensile & Elongation	✓	✓	✓	✓	✓	✓	✓	✓
Air oven aging	✓	✓	✓	✓	✓	✓	✓	✓
Voids, protrusions,	✓	✓	✓	✓	✓	✓	✗	✗

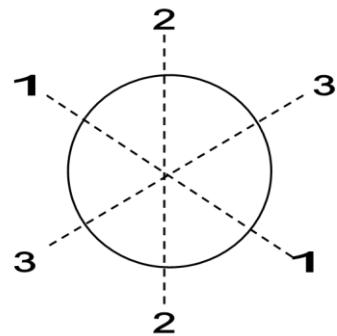
convolutions, contaminants & irregularities								
Wafer boil	✓	✓	✓	✓	✓	✓	✓	✗
Hot creep/set	✓	✓	✓	✓	✓	✓	✓	✓
Shrinkback (XLPE/TRXLPE only)	✓	✓	✓	✓	✓	✓	✗	✗
Insulation eccentricity	✓	✓	✓	✓	✓	✓	✗	✗
Indent (under concentric neutral)	✓	✗	✓	✗	✓	✗	✗	✗
Removability/Adhesion (insulation shield)	✓	✓	✓	✓	✓	✓	✓	✓
Corrugation lay factor	✗	✗	✗	✓	✓	✓	✗	✗
Deformation	✓	✓	✓	✓	✓	✓	✓	(insul + jkt)
Cold impact (-25, -40, -45, -50)	✓	✓	✗	✗	✗	✗	✗	✓ (-40)
Cold bend + PD	✓	✓	✗	✗	✗	✗	✗	✗
Cold bend	✗	✗	(jacket)	(jacket)	(jacket)	(jacket)	✓	✓ (-35)
Tightness of jacket (PE overlay)	✗	✓	✗	✓	✓	✓	✓	✗
Heat shock	✓	(PVC)	(PVC)	(PVC)	(PVC)	(PVC)	✓	(PVC /TPE)
Water in conductor / under jacket	✓	✓	✓	✓	✓	✓	✓	✗

Longitudinal water penetration (optional)	✓	✓	✓	✓	✓	✓	✓ conductor	✗
Flexibility of armour	✗	✓	✗	✗	✗	✗	✓	✓
Tightness of armour	✗	✗	✗	✗	✗	✗	✗	✓
Tension of interlocked armour	✗	✗	✗	✗	✗	✗	✗	✓
Zinc Coating (galv steel armor)	✗	✓	✗	✗	✗	✗	✓	✓
Compatibility of optional WB components	✓	✓	✓	✓	✓	✓	✓	✓ (SB only)
Connectability (for blocked strand conductor)	✓ (optional)	✗	✗	✗	✗	✗	✗	✗
Brittleness	✓	✓	✓	✓	✓	✓	✓	✓
Thermomechanical qualification	✓	✗	✓ (optional)	✓ (optional)	✓ (opt.)	✓ (optional)	✗	✗
Duct pulling	✗	✗	✗	✗	✗	✓	✗	✗
Durability of ink	✗	✗	✗	✗	✗	✗	✗	✓
Tree Count Test (for engineering info only)	✗	✗	✗	✗	✓	✗	✗	✗

Table 7 – Physical / Mechanical Tests

#### 4.1.1 Dimensional Measurements

Dimensional measurements verify that all cable components—conductor, insulation, shields, and jackets—meet the specified tolerances for diameter, wall thickness, and overall geometry. Accurate dimensions are critical for ensuring proper electrical performance, mechanical fit, and compatibility with accessories such as terminations and splices. Variations outside acceptable limits can lead to uneven stress distribution, partial discharge activity, or difficulties during installation. Dimensional checks are typically conducted using precision calipers, micrometers, or automated measurement systems, and are performed on both raw materials and finished cables to ensure consistent quality throughout production.



**Figure 15** – Conductor diameter measurement method using caliper



**Figure 16** – Scale for weight measurement

#### 4.1.2 Aged/Unaged Tensile & Elongation

Tensile strength and elongation tests assess the mechanical robustness of insulation, jackets, and shielding materials. Testing both aged and unaged samples provides insight into how materials will perform immediately after manufacturing and after exposure to thermal or environmental stress. High tensile strength ensures the cable can withstand installation forces such as pulling and bending, while sufficient elongation allows the cable to flex without cracking. For aged samples, reductions in these properties can indicate potential long-term degradation, highlighting the importance of selecting materials that retain mechanical integrity over the cable's service life.



**Figure 17** – “Dog-bone” prep



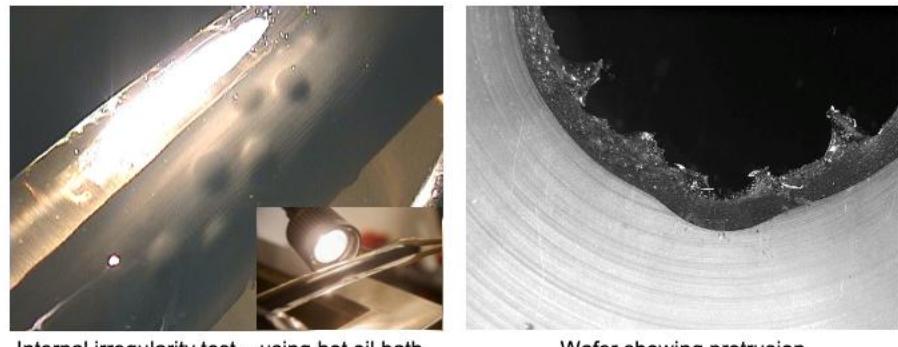
**Figure 18** – Universal testing machine used for tensile and elongation testing

#### 4.1.3 Air Oven Aging

Air oven aging simulates long-term thermal exposure by subjecting insulation and jacket materials to elevated temperatures over a defined period. This test evaluates how heat affects mechanical properties such as tensile strength, elongation, and flexibility. The purpose is to ensure that the cable can withstand continuous operation under elevated conductor temperatures without premature insulation or jacket failure. By accelerating the aging process in a controlled environment, manufacturers can predict the cable's long-term performance and identify materials that maintain stability and reliability under thermal stress.

#### 4.1.4 Voids, Protrusions, Convolutions, Contaminants & Irregularities

Inspection for voids, protrusions, convolutions, and other irregularities ensures that insulation and shield layers are continuous and free from defects that could compromise electrical performance. Voids or inclusions in insulation can concentrate electric fields and initiate partial discharge activity, leading to accelerated aging or premature failure. Surface protrusions or contaminants may affect shield adhesion and jacket integrity. This testing is typically performed visually, with magnification, or using specialized detection equipment, and is essential for maintaining high manufacturing quality and cable reliability.



Internal irregularity test – using hot oil bath

Wafer showing protrusion

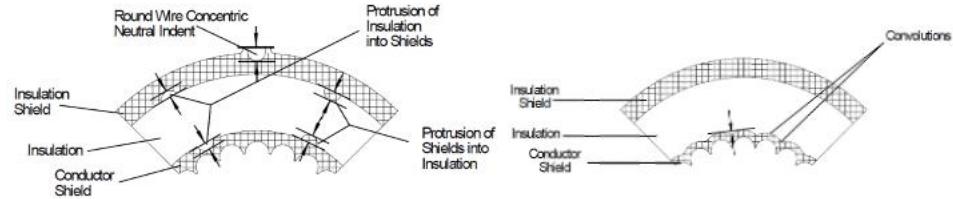


Figure 19 – Internal irregularity testing

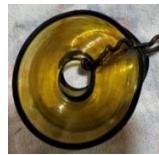
This test is also known as the “amber, agglomerate, gel, contaminant, protrusion, convolution and void test”

#### 4.1.5 Wafer Boil

The wafer boil test evaluates the effectiveness of crosslinking by checking if thermoset conductor/insulation shields dissolve or crack after extrusion. Wafers are immersed in a boiling solvent for 5 hours and then removed and examined for shield/insulation interface continuity. This test is particularly important for verifying that insulation shields and jackets will remain intact under thermal and moisture stress, which can be encountered during field installation or service in wet environments.



Figure 20 – Wafer boil test setup



**Figure 21** – Wafer post-immersion

#### 4.1.6 Hot Creep/Set

Hot creep and hot set tests assess the ability of insulation materials to maintain their shape under thermal and mechanical stress. It consists of an elongation test in an oven, followed by a hot creep set test. Excessive deformation can compromise electrical stress distribution and dimensional stability, potentially leading to partial discharge or reduced dielectric performance. This test helps ensure that the insulation system maintains structural integrity and long-term reliability under operating conditions.



**Figure 22** – “Dog-bone” specimen in oven attached to supporting apparatus with weight

#### 4.1.7 Shrinkback (XLPE/TRXLPE only)

Shrinkback testing evaluates the dimensional recovery of cross-linked polyethylene (XLPE or TRXLPE) insulation after heating. Materials are expected to retain their shape without excessive contraction that could expose the conductor or create gaps with the insulation shield. Proper shrinkback behavior ensures mechanical and electrical integrity, especially during installation or thermal cycling. This test is particularly important for XLPE-based cables, where cross-linking introduces residual stresses that may affect dimensional stability.

A cable sample undergoes a cycle of heating and cooling before shrinkback is measured.



**Figure 23** – Example of shrinkback

#### 4.1.8 Insulation Eccentricity

Insulation eccentricity measures the uniformity of the insulation layer around the conductor. Uneven insulation thickness can lead to localized electric field concentrations, increasing the risk of partial discharge and reducing the cable's dielectric strength. By verifying insulation symmetry, manufacturers ensure consistent electrical performance and reliability, particularly under high-voltage stress conditions. This measurement is critical for both concentric neutral and shielded designs, where uniform insulation is essential for proper stress control.

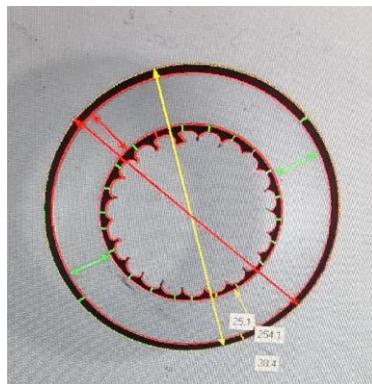


Figure 24 – Optical device for measuring shrinkback

#### 4.1.9 Indent (Under Concentric Neutral)

Indentation testing evaluates the ability of the insulation shield to withstand the mechanical presence of concentric neutral wires without damage. The concentric neutral can exert localized pressure, and excessive indentation may compromise the insulation shield or create voids that encourage partial discharge. This test ensures the cable maintains proper electrical stress distribution while accommodating mechanical features of utility cable designs.

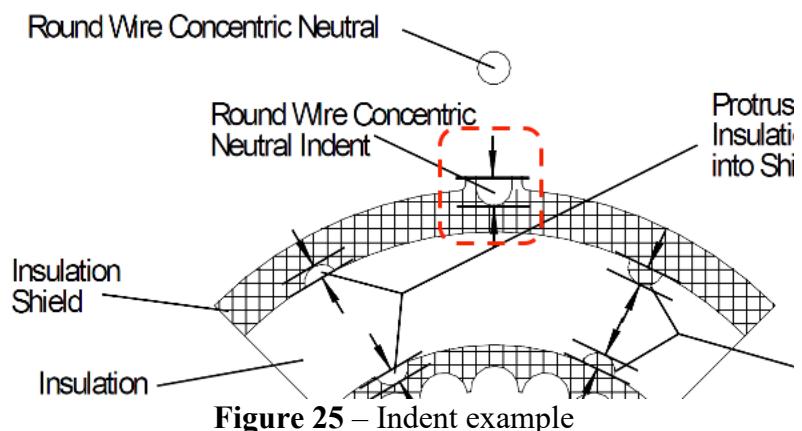


Figure 25 – Indent example

#### 4.1.10 Removability/Adhesion (Insulation Shield)

This test evaluates how easily the insulation shield can be removed from the insulation layer without damaging the underlying material. Proper removability is critical during cable termination and splicing, where technicians need to strip the insulation shield cleanly to install accessories. Excessive adhesion can result in insulation damage, while insufficient adhesion can allow delamination or voids, which may promote partial discharge. This test ensures a balance between secure bonding during service and practical handling during installation.

The insulation shield must be readily removable, and the required tension must be within the limits specified in the relevant standard.

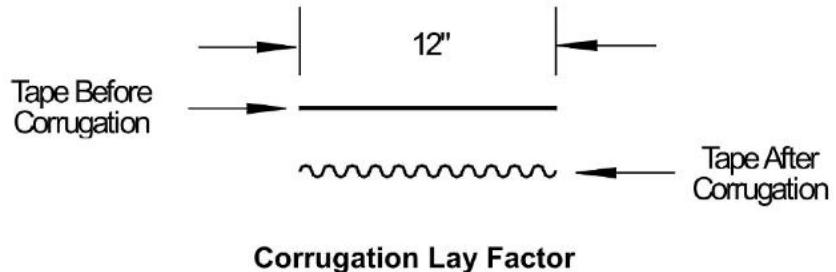


**Figure 26 – Example stripability results**

#### 4.1.11 Corrugation Lay Factor

For cables with corrugated metallic shields or conductors, the corrugation lay factor measures the spacing and pitch of the corrugations. Proper lay ensures mechanical flexibility while maintaining uniform stress distribution along the shield or conductor. Deviations can lead to uneven mechanical load transfer, excessive bending stress, or difficulty in installation. Verifying this parameter ensures both mechanical integrity and consistent electrical performance of the cable system.

Corrugation should produce a lay factor not less than 115% on the cable after jacketing.



$$CLF = W_{AC} \div W_{BC}$$

Where:

$CLF$  = Corrugation Lay Factor

$W_{AC}$  = Weight of tape after corrugation

$W_{BC}$  = Weight of tape prior to corrugation

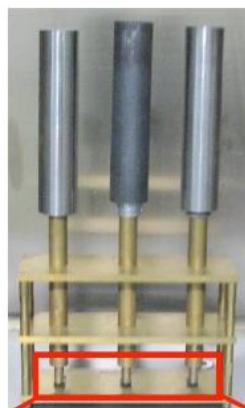


**Figure 27** – Measuring and calculating corrugation lay factor

#### 4.1.12 Deformation

Deformation testing evaluates the cable's ability to resist permanent shape changes when subjected to mechanical forces such as compression or bending. Excessive deformation can compromise insulation thickness, shield continuity, and overall dimensional integrity, affecting both electrical and mechanical performance. This test simulates handling, pulling, or stacking forces during manufacturing, transport, or installation, ensuring the cable maintains reliability under real-world stresses.

Percent (%) deformation is calculated using initial and final thickness after testing under a specified load.



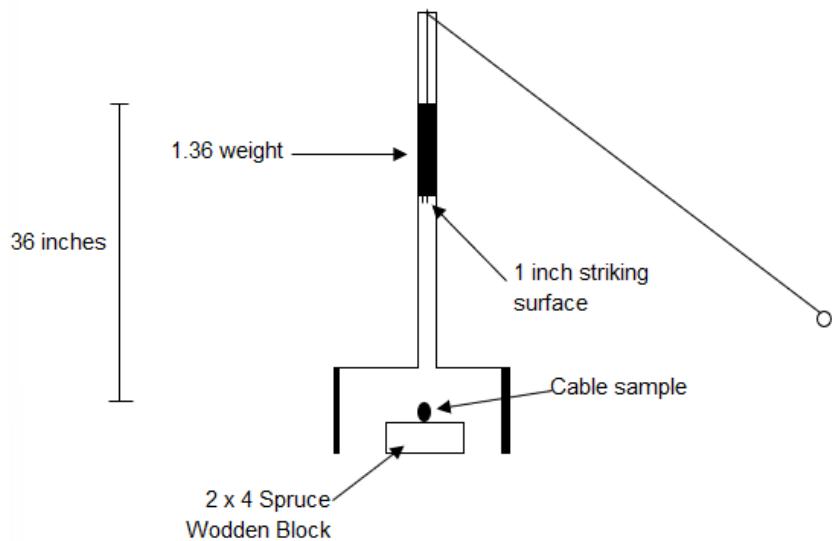
**Figure 28** – Deformation test set up

#### 4.1.13 Cold Impact

Cold impact tests assess how insulation, shields, and jackets behave when struck or impacted at low temperatures. Cables installed outdoors or in unheated spaces may experience brittle behavior if materials are not resilient to cold. The test simulates handling, dropping, or accidental impacts during installation. Passing this test ensures that the cable can withstand mechanical shocks in cold conditions without cracking, delamination, or other structural failures.

10 finished cable samples are conditioned at the specified cold temperature rating for a specified time.

**Typical passing criteria:** Not more than 2 out of 10 specimens tested can show cracks or rupture when subjected to an impact of  $12\text{ J}$ .



**Figure 29** – Cold impact test set up



**Figure 30** – Example cold chamber

#### 4.1.14 Cold Bend + Partial Discharge (PD)

This combined test evaluates cable performance under low-temperature bending while simultaneously monitoring for partial discharge activity. Bending a cable at low temperatures can introduce micro-cracks or stress concentrations, which may lead to PD if the insulation is

weak. This test ensures that insulation systems remain mechanically flexible and electrically stable under challenging conditions, providing confidence in long-term reliability.



**Figure 31** – Example tool for performing bend test (reel or mandrel)

#### **4.1.15 Tightness of Jacket (PE Overlay)**

For cables with overlay polyethylene (PE) jackets, jacket tightness tests verify proper adhesion and coverage over insulation and shielding layers. A tight jacket prevents moisture ingress, protects against mechanical damage, and ensures consistent electrical performance. Loose jackets can lead to delamination, water penetration, and premature failure, so this test ensures the jacket maintains both mechanical and environmental integrity.

#### **4.1.16 Heat Shock**

Heat shock testing evaluates the cable's ability to withstand sudden and extreme temperature increases without cracking, deforming, or delaminating. Samples are rapidly heated to high temperatures, simulating thermal spikes that may occur during short circuits, overloads, or manufacturing anomalies. Passing this test demonstrates that insulation and jackets can tolerate extreme thermal events without compromising electrical or mechanical performance.

A sample is wound tightly around a mandrel of a certain diameter, held firmly in place, and subjected to a specified temperature and time.

**Typical passing criteria:** no visible cracks or ruptures in the jacket

#### **4.1.17 Water in Conductor / Under Jacket**

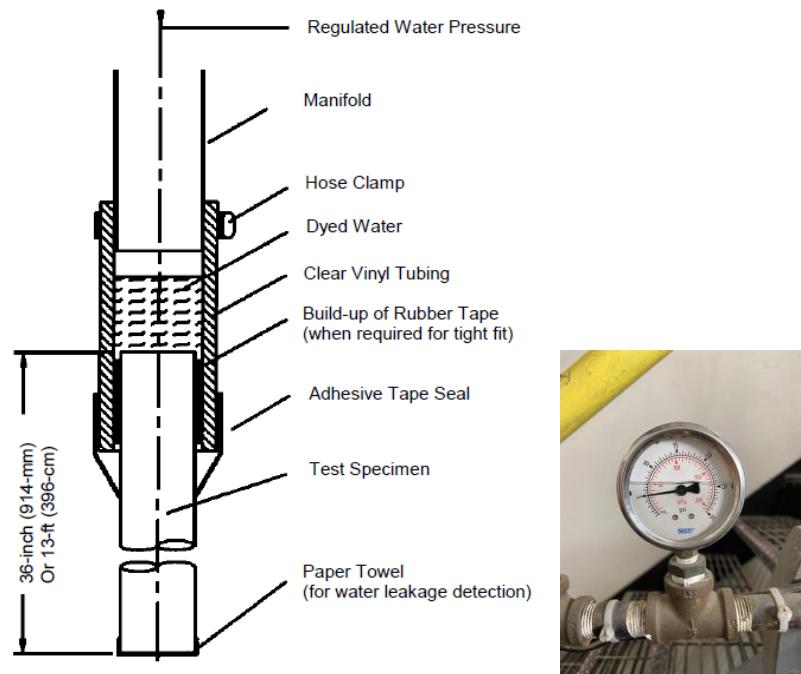
This test detects moisture penetration into the conductor or under the jacket. Water ingress can drastically reduce insulation resistance, promote corrosion of metallic components, and accelerate aging mechanisms such as treeing. The test ensures that manufacturing processes—such as extrusion and jacketing—produce a watertight cable capable of long-term service in moist or wet environments.

#### **4.1.18 Longitudinal Water Penetration (Optional)**

This optional test evaluates a cable's ability to resist water traveling along its length, simulating situations where water could enter the cable end or a damaged jacket. Preventing longitudinal water migration is critical for underground or direct-buried installations, where water

accumulation can compromise insulation and lead to early failures. Testing ensures proper sealing of insulation and jacket systems.

The procedures for this test are defined in ICEA T-34-664 (under jacket) and ICEA T-31-610 (for conductor).



**Figure 32** – Typical test equipment and test setup



**Figure 33** – Prepared sample



**Figure 34** – A passing result

#### **4.1.19 Flexibility of Armour**

Armour flexibility tests confirm that metallic protective layers, such as interlocked or corrugated steel, can bend without cracking, deforming, or losing continuity. Flexible armour facilitates installation through conduits, across trays, and around bends without compromising mechanical protection. Adequate flexibility ensures the cable can be handled safely while maintaining durability in service.

#### **4.1.20 Tightness of Armour**

Tightness testing ensures that the armour fits snugly around the insulation and shield layers, providing effective mechanical protection. Loose armour can shift, leaving areas exposed to mechanical damage, while overly tight armour may induce stress on insulation. Proper tightness balances protection with insulation safety and allows for thermal expansion during operation.

#### **4.1.21 Tension of Interlocked Armour**

This test evaluates the mechanical integrity of interlocked armour under axial tension, simulating pulling forces during installation. Proper tension ensures that armour maintains protective coverage without excessive deformation or separation. Failing this test can indicate potential installation problems or reduced mechanical reliability in the field.

#### **4.1.22 Zinc Coating (Galvanized Steel Armour)**

Zinc coating tests verify the thickness and uniformity of galvanization on steel armour, which protects against corrosion in moist or aggressive environments. Adequate zinc coverage prolongs the service life of the armour, ensuring continued mechanical protection and electrical safety. This is especially critical for buried or outdoor installations where corrosion risk is high.

The zinc coating must remain adherent when the wire is wrapped around a cylindrical mandrel of a specified diameter at a specified rate.

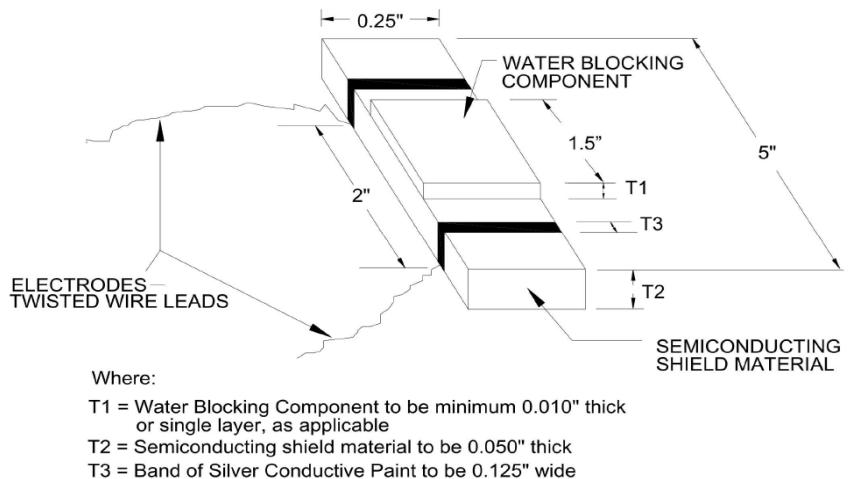
The zinc coating shall not flake nor be removable from the wire by rubbing with the fingers.



**Figure 35 – Galvanized steel wire**

#### 4.1.23 Compatibility of Optional WB Components

This test evaluates the compatibility of optional water-blocking (WB) components with insulation, shields, and jackets (any material with which it makes contact). Incompatible materials can cause swelling, chemical degradation, or reduced adhesion, undermining both mechanical and electrical performance. Verifying compatibility ensures that optional features enhance, rather than compromise, cable reliability.



**Figure 36** – Example test specimen setup

#### 4.1.24 Connectability (Blocked Strand Conductor)

This test ensures that there is no deterioration in connection performance between blocked conductors and a connector. It is important because it ensures resistance and temperature stability between a water-blocked conductor and a connector.

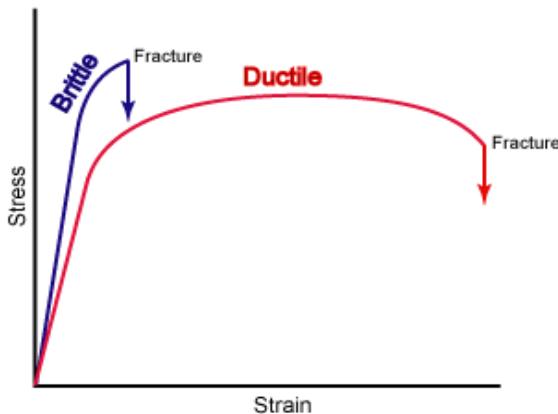
The purpose of this test is to give reasonable assurance that connectors will perform in a satisfactory manner. The procedure is defined in ANSI C119.4.

#### 4.1.25 Brittleness

Brittleness testing measures the tendency of insulation or jacket materials to crack under mechanical stress, particularly at low temperatures or after aging. Flexible and ductile materials are less prone to cracking during handling, installation, or operation, reducing the risk of premature failure and partial discharge initiation.

Brittleness testing determines the lowest temperature at which a material does not exhibit brittle failure

The test method is defined in ASTM D746.



**Figure 37 – Stress-strain graph**

#### 4.1.26 Thermomechanical Qualification

Thermomechanical qualification evaluates cable performance under combined thermal and mechanical stresses, simulating real-world operating conditions such as load cycles and temperature fluctuations. Passing this test demonstrates that insulation and shielding maintain dimensional stability, electrical integrity, and mechanical strength under service stresses.

Tests include:

1. Heat cycling
2. PD tests before/after heat cycling
3. Tan  $\delta$  before/after heat cycling
4. Jacket Examination
5. Component dimensions before/after heat cycling

#### 4.1.27 Duct Pulling

Duct pulling tests simulate the installation of cables through conduits, assessing tensile strength, elongation, and flexibility under pulling forces. This test ensures that the cable can be safely installed without insulation damage, shield disruption, or armour deformation, which could compromise long-term reliability.

If a cable uses a jacket material and/or thicknesses that are not covered by ICEA standards, a purchaser may request a duct pulling qualification test.

This test is conducted to establish that the cable design will not be damaged when pulled through a conduit in a way that generally represents pulling conditions in service

The test method is defined in ICEA S-113-684.

#### 4.1.28 Durability of ink

Ink durability testing verifies that markings on the cable jacket, such as voltage rating, manufacturer, and standard references, remain legible over the cable's expected service life. Clear and durable markings are essential for field identification, inspection, and maintenance.

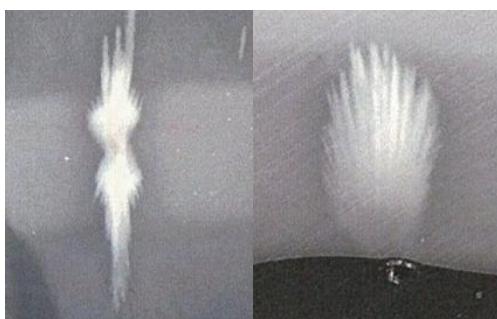
A specimen is taken from a finished cable and conditioned in an air oven and rubbed repeatedly with a felt-faced weight.

#### 4.1.29 Tree Count Test (for engineering information only)

Tree count tests quantify the amount and density of water or electrical trees in insulation, typically after accelerated water tree testing. While not typically used for pass/fail purposes, this information helps engineers assess material performance, predict long-term reliability, and compare insulation systems for design and selection purposes.

Electrochemical degradation initiated by a combination of electric field, moisture and ionic impurities.

There are 2 main types of trees – (1) Vented and (2) Bowtie. Vented trees grow from shield interfaces and Bowtie trees grow from water-filled voids or contaminants. See **Figure 38**.



**Figure 38** – Bowtie tree (left) and Vented tree (right)

### 4.2 Electrical Tests

Electrical testing is one of the most critical aspects of ensuring that power cables will perform reliably and safely throughout their service life. While physical and mechanical tests confirm that a cable can withstand installation and environmental stresses, electrical testing directly evaluates the cable's ability to carry current, maintain insulation integrity, and endure the electrical stresses associated with normal operation and fault conditions. Power cables are complex systems composed of conductors, insulation, shields, armour, and jackets, and their electrical performance depends on the proper design, material selection, and manufacturing quality of each layer. Without thorough electrical testing, there is no assurance that a cable will function as intended under the high voltages and currents encountered in medium and high voltage power distribution networks.

The primary purpose of electrical testing is to verify the dielectric integrity of the insulation system. Insulation is the critical barrier that prevents the flow of current between conductors and between the conductor and ground. Any compromise in the insulation, whether caused by material defects, voids, or contamination, can lead to localized electrical stress, partial discharge, or catastrophic failure. Electrical testing subjects the cable to controlled voltage conditions that simulate real-world operation or exceed normal operating stresses to confirm that the insulation can withstand the demands of the system. This includes both direct current (DC) and alternating current (AC) tests, as well as impulse voltage tests in some cases, each designed to evaluate specific aspects of insulation performance under different stress conditions. By performing these tests during manufacturing and before installation, manufacturers and end users can identify potential weaknesses before they lead to field failures.

One of the most widely used electrical tests is the high-voltage AC or DC test, which applies a voltage higher than the cable's rated operating voltage to ensure the insulation can withstand overvoltages without breakdown. This type of testing confirms that the insulation system is free from defects that could initiate partial discharge or failure. Partial discharge is a localized dielectric breakdown within voids, inclusions, or imperfections in the insulation, which does not immediately bridge the conductor and ground but gradually erodes the insulation over time. High-voltage testing, along with partial discharge measurement, provides confidence that the cable has no hidden weaknesses that could compromise long-term reliability. These tests are especially important for medium and high voltage cables, where failure consequences can be severe and costly.

Insulation resistance testing is another essential electrical evaluation. This test measures the resistance of the insulation system to current leakage and verifies that it remains high enough to prevent unintended current flow. Low insulation resistance can indicate moisture ingress, contamination, or deterioration of the insulation material. By conducting insulation resistance tests, manufacturers and installers can confirm that cables meet defined performance thresholds and will maintain safe electrical separation during operation. Insulation resistance testing is often repeated periodically as part of preventive maintenance programs to monitor insulation health over time.

Conductor resistance and continuity measurements are also vital components of electrical testing. These tests confirm that the conductor is continuous and that its resistance matches expected values for its material, size, and length. Any deviations could indicate manufacturing defects, poor stranding, or damage during handling. Ensuring proper conductor performance is crucial, as high resistance or broken strands can lead to overheating, energy loss, and reduced current-carrying capacity. Electrical testing at this stage helps verify that the cable's fundamental function—efficient energy transmission—is uncompromised.

Electrical testing is particularly important in verifying the performance of shielding systems. Medium voltage cables often include both conductor and insulation shields designed to control the electric field within the insulation and provide a uniform grounding path. Proper bonding, continuity, and resistivity of these shields must be confirmed to prevent localized electrical stress, reduce partial discharge activity, and maintain long-term reliability. Electrical tests ensure that the shields are continuous, properly connected to ground, and free from defects that could

compromise their function. In this way, electrical testing supports not only the primary insulation but also the ancillary components critical to overall cable performance.

Another key reason electrical testing is indispensable is that it simulates real-world fault conditions and system stresses. During operation, cables may experience transient overvoltages, switching surges, or short-circuit currents. Electrical testing protocols often include overvoltage withstand tests, impulse voltage tests, and fault current simulations to confirm that the cable can survive these abnormal but realistic conditions without damage. By verifying that the cable can tolerate temporary electrical stresses beyond its normal operating range, manufacturers provide assurance that the cable will not fail prematurely under adverse conditions, protecting both the system and personnel.

Electrical testing also plays a crucial role in quality control and standard compliance. Manufacturers must demonstrate compliance with these standards to achieve certification and ensure that the cable is suitable for the intended market or project. Understanding these standards and performing the associated tests is essential for engineers and asset owners to verify that the cable will meet regulatory, safety, and performance expectations. Electrical testing is not just a formality; it is a guarantee that the cable has been produced and validated according to recognized best practices.

Field experience consistently demonstrates that electrical failures in power cables are often linked to manufacturing defects or material inconsistencies that could have been detected through proper electrical testing. Defects such as voids in insulation, improper shielding, inadequate bonding, or contaminant inclusion can all lead to partial discharge, insulation breakdown, or even catastrophic failure. Detecting these issues in the factory, before the cable is installed in a live system, prevents costly outages, equipment damage, and safety incidents. Electrical testing therefore serves as a critical safeguard that protects both capital investment and system reliability.

Electrical testing also informs maintenance and asset management strategies. By establishing baseline electrical performance parameters during manufacturing and installation, utility operators can monitor changes over time to detect early signs of degradation. Techniques such as partial discharge monitoring, insulation resistance measurements, and periodic withstand testing provide insights into the health of the cable system, enabling proactive maintenance and life-extension programs. In this sense, electrical testing is not only a tool for quality assurance but also a critical component of ongoing asset management.

Finally, electrical testing reinforces the interdependence of design, materials, and installation practices. A cable that passes mechanical testing but fails electrical testing indicates potential problems in conductor continuity, insulation uniformity, or shield bonding. This feedback loop allows manufacturers to adjust material selection, production processes, and quality control procedures to prevent recurrence. For installers and engineers, understanding the electrical performance limits of the cable informs proper handling, pulling tension, termination practices, and system integration. Electrical testing thus underpins the entire lifecycle of power cables, from production to installation to decades of reliable service.

The following table (**Table 8**) provides a comparative analysis of the various electrical testing requirements in the medium voltage cable standards within the scope of this course.

Electrical Test*	CSA C68.5	CSA C68.10	ICEA S-94-649	ICEA S-97-682	AEIC CS8	ICEA S-113-684	ICEA S-93-639	UL 1072
DC resistance	✓	✓	✓	✓	✓	✓	✓	✓
Volume resistivity	✓	✓	✓	✓	✓	✓	✓	✓
Insulation resistance	✓	✓	✓	✓	✓	✓	✓	✓
Spark test (non-conducting jacket)	✓	✓	✓	✓	✓	✓	✓	✓
Radial resistivity (for semicon jacket/covering only)	✓	✓	✓	✓	✓	✓	✗	✗
AC withstand	✓	✓	✓	✓	✓	✓	✓	✓
Partial discharge (PD)	✓	✓	✓	✓	✓	✓	✓	✓
CV extrusion qualification	✓ (monthly)	✓	✓ (monthly)	✓ (monthly)	✓ (monthly)	✓ (monthly)	✗	✗
High Voltage Time Test (HVTT)	✓	✗	✓	✓	✓	✓	✗	✗
Hot impulse	✓	✗	✓	✓	✓	✓	✗	✗
Accelerated Water Tree Test (AWTT)	✓	✗	✓	✓	✓	✓	✗	✗
Dielectric constant & dissip/power factor	✓	✓	✓	✓	✓	✓	✓	✓
Resistance stability	✓	✓	✓	✓	✓	✓	✗	✗
Dry electrical test	✓	✓	✓	✓	✓	✓	✓	✓
Dissipation factor characterization	✓	✓	✓	✓	✓	✓	✗	✗
Accelerated water absorption	✗	✓	✓	✓	✓	✓	✓	✓

Table 8 – Electrical Tests

#### 4.2.1 DC resistance

DC resistance testing measures the electrical resistance of the conductor under direct current. This test ensures that the conductor meets specified material and dimensional requirements, confirming uniformity, proper stranding, and the absence of manufacturing defects such as voids, cracks, or discontinuities. Accurate conductor resistance is critical for predicting voltage drop, power loss, and heating under load. High or inconsistent resistance can indicate potential problems that reduce cable efficiency and long-term reliability.

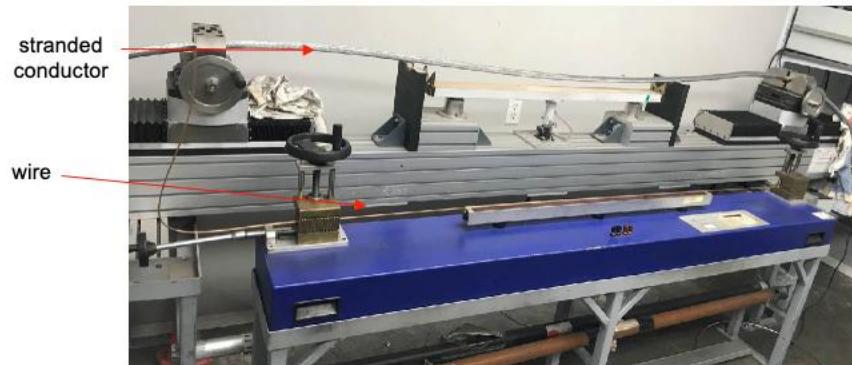


Figure 39 – Resistance bridge

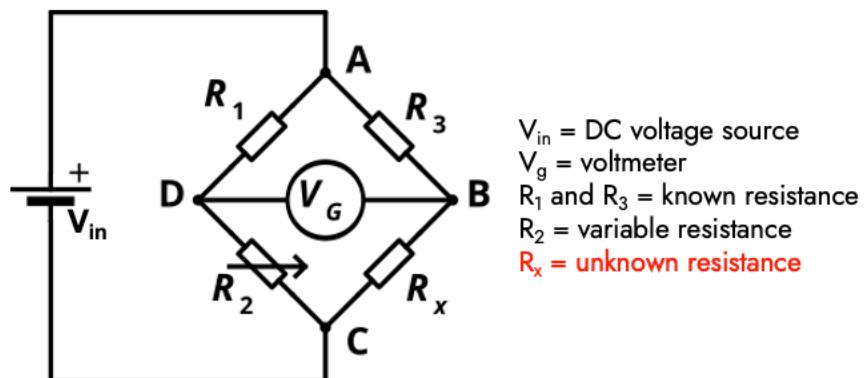


Figure 40 – Wheatstone bridge circuit

#### 4.2.2 Volume resistivity

Volume resistivity evaluates the ability of insulating materials to resist the flow of electrical current through their bulk. High resistivity ensures that the insulation effectively prevents leakage currents and maintains dielectric integrity over time. This test is essential for confirming the quality and uniformity of insulation compounds, particularly in extruded dielectric cables, and helps predict long-term performance under thermal and electrical stress.

This test method is defined in ICEA T-35-425.

**Conductor shield**

$$\rho = \frac{0.4R(D^2 - d^2)}{1000L}$$

$\rho$  = volume resistivity ( $\Omega\text{m}$ )  
 $R$  = measured resistance ( $\Omega$ )  
 $D$  = diameter over conductor stress control layer, mm  
 $d$  = diameter over conductor, mm  
 $L$  = distance between potential electrodes, mm



**Insulation shield**

$$\rho = \frac{0.8R(D^2 - d^2)}{1000L}$$

$\rho$  = volume resistivity ( $\Omega\text{m}$ )  
 $R$  = measured resistance ( $\Omega$ )  
 $D$  = diameter over insulation shield layer, mm  
 $d$  = diameter over insulation, mm  
 $L$  = distance between potential electrodes, mm



**Figure 41** – Volume resistivity measurement and calculation.

#### 4.2.3 Insulation resistance

Insulation resistance testing assesses the resistance between the conductor and the metallic shield or ground. It is a measure of insulation quality and cleanliness, revealing potential moisture contamination, voids, or chemical degradation. High insulation resistance indicates robust electrical separation, reducing the risk of leakage currents, dielectric breakdown, and premature failure. This test is fundamental for both factory acceptance and ongoing quality assurance.

Test methods defined in: ANSI/ICEA T-27-581 / NEMA WC23053 and CSA C22.2 No. 2556 / UL 2556 / NMX-J-556-ANCE.



**Figure 42** – Tools for insulation resistance measurement

#### 4.2.4 Spark test

The spark test applies a high-voltage, low-current signal to detect pinholes, voids, or thin spots in non-conducting jackets. This test ensures the outer jacket provides continuous mechanical and environmental protection, preventing moisture ingress, chemical attack, or physical damage that could compromise the insulation. Detecting flaws before installation is critical to maintaining cable longevity and safety.

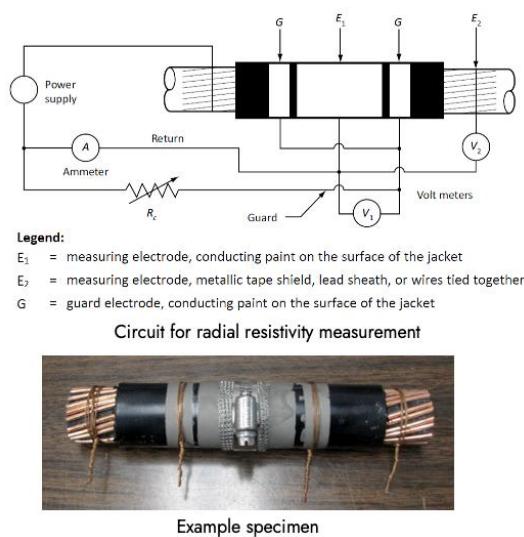
This test is also known as the “jacket integrity test”. *Semi-conducting jackets* may only be inspected using optical devices and/or visually.



Figure 43 – Spark tester (open)

#### 4.2.5 Radial resistivity (for semiconducting jacket/covering only)

Radial resistivity measures the resistance across the thickness of semi-conductive layers such as insulation shields. It ensures that the semi-conductive material effectively distributes the electric field around the conductor, preventing localized stress concentrations that can lead to partial discharge or premature insulation failure. Proper radial resistivity is essential for consistent electrical stress control within medium voltage cables.



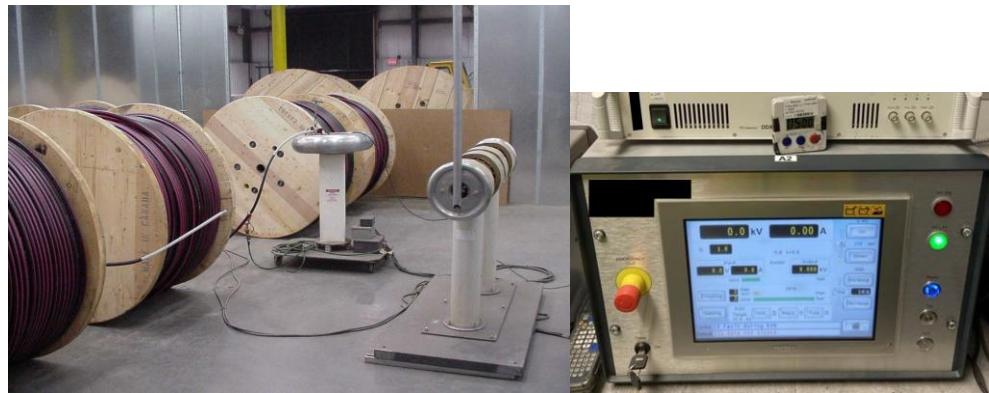
Example specimen

Figure 44 – Example specimen for radial resistivity test

#### 4.2.6 AC withstand

The AC withstand test subjects the cable to an alternating current voltage higher than its normal operating voltage for a specified duration. This evaluates the insulation system's ability to endure electrical stress without breakdown. Successful AC withstand testing verifies that the cable can safely handle overvoltage, transients, and temporary surges during operation, providing assurance of long-term dielectric performance.

AC withstand test procedures and voltages are specified in the relevant standard



**Figure 45** – Example test set up for AC withstand test

#### 4.2.7 Partial Discharge (PD)

Partial discharge testing identifies small electrical discharges within voids, imperfections, or interfaces in the insulation. These micro-discharges can gradually degrade insulation, leading to premature failure. Factory PD testing ensures that the cable is free from manufacturing defects that could initiate or accelerate PD activity. Monitoring PD during qualification and production helps maintain high reliability and long service life.

A partial discharge is a localized electrical discharge that occurs under high voltage stress. Partial discharge level shall not exceed 5 pC at the specified AC test voltage. The types of partial discharge are:

1. Internal PD (within the insulation)
2. Surface PD (tracking across the insulation)
3. Corona PD (from an electrode into gas)

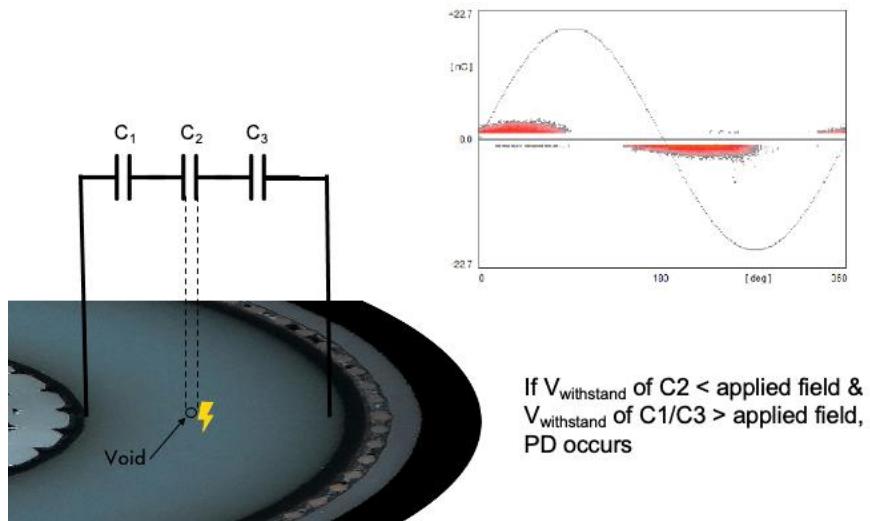


Figure 46 – Example PD measurement

#### 4.2.8 CV extrusion qualification

Continuous Vulcanization (CV) extrusion qualification evaluates the consistency and quality of extruded insulation. By measuring capacitance changes with applied voltage, this test detects variations in insulation thickness, density, or uniformity. CV extrusion qualification is typically a monthly test that ensures that the extruded dielectric material meets design specifications, providing predictable electrical performance and reducing the risk of early-life failures.

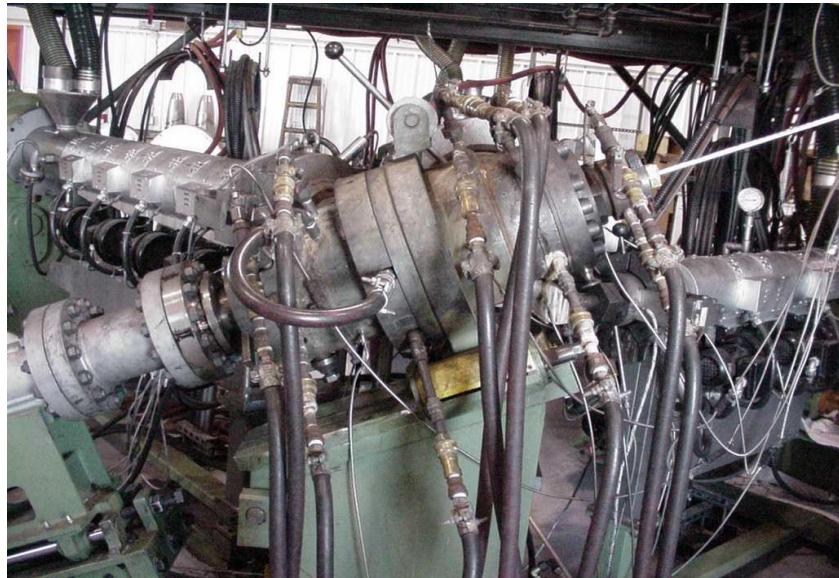


Figure 47 – Example extrusion head (triple head)

#### **4.2.9 High voltage time test (HVTT)**

The high voltage time test subjects cables to elevated voltage for extended durations to simulate long-term electrical stress. It verifies that insulation can sustain operational voltages and temporary overvoltage without breakdown. HVTT is particularly useful for qualification of new cable designs, ensuring that insulation materials and construction methods provide durable dielectric strength over decades of service.

#### **4.2.10 Hot impulse**

Hot impulse testing applies fast, high-voltage impulses to simulate transient overvoltage, such as lightning strikes or switching surges. This test ensures that the insulation system can withstand short-duration voltage spikes without breakdown. Passing hot impulse testing is crucial for utility and industrial applications where transient voltages are common and can compromise cable reliability if the insulation is inadequate.

#### **4.2.11 Accelerated Water Tree Test (AWTT)**

The AWTT evaluates the insulation's resistance to water tree formation, a common degradation mechanism in polymeric materials subjected to electrical stress and moisture. By accelerating water tree growth under controlled conditions, this test predicts long-term insulation performance in wet or direct-buried environments. AWTT ensures that the cable can maintain dielectric integrity over its expected service life, reducing the risk of premature failure due to moisture-related deterioration.

This test is a key part of cable core qualification.

Samples are aged for 120, 180, and 360 days and then go through HVTT / physical measurements. Only a 120-day test is required for cable core *manufacturing* qualification.

#### **4.2.12 Dielectric constant and Dissipation/Power Factor**

Measuring the dielectric constant and dissipation factor (or power factor) characterizes insulation quality by quantifying energy losses within the dielectric material. A low and stable dissipation factor indicates uniform, defect-free insulation with minimal leakage currents. These measurements are important for predicting long-term electrical performance, efficiency, and temperature rise under operational loads.

Dielectric constant is a measure of how well a material can store electrical energy when subjected to an electric field (aka relative permittivity).

Dissipation factor (Tan Delta) is an electrical measurement of energy loss and is the ratio of resistive current to capacitive current.

Power factor (Sin Delta) is also an electrical measurement of energy loss and is the ratio of real power to apparent power.

#### 4.2.13 Resistance Stability

Resistance stability testing evaluates whether insulation and shielding materials maintain consistent electrical resistance under thermal and mechanical stress. Stable resistance ensures predictable dielectric behavior, minimizes leakage currents, and prevents hotspots that could accelerate aging. This test is critical for assessing long-term reliability, particularly in industrial and utility applications with fluctuating environmental conditions.

#### 4.2.14 Dry electrical test

Dry electrical testing applies high voltage in a dry environment to confirm the dielectric strength of insulation without the influence of moisture. This test is a baseline assessment of insulation quality, ensuring that the cable can withstand normal and temporary overvoltage during operation. Passing this test indicates proper manufacturing quality and material consistency.

This test is a key part of cable qualification.

Samples of cable are current loaded at their emergency temperature rating for a minimum of 3 weeks while **capacitance and dissipation factor** are measured and monitored. After current loading test is complete, PD level is measured and reported.

#### 4.2.15 Dissipation Factor Characterization

Dissipation factor characterization measures energy losses in insulation over a range of frequencies and temperatures. It provides insight into material quality, aging behavior, and dielectric stability. This information is critical for design verification and comparing insulation formulations, ensuring that cables maintain reliable electrical performance under varying operating conditions.

A *lower dissipation factor* indicates better insulation quality and lower heat generation. A *higher or increasing dissipation factor* indicates degradation, moisture ingress, contamination, or aging.

#### 4.2.16 Accelerated Water Absorption

This test evaluates the insulation and jacket's susceptibility to moisture uptake under accelerated conditions. Water absorption can degrade electrical properties, promote corrosion, and reduce service life. By simulating worst-case exposure, this test ensures that the cable design provides adequate moisture resistance, which is especially important for direct-buried, underground, or high-humidity installations.

### 4.3 Environmental / Chemical Resistance Tests

Environmental and chemical resistance testing is a critical aspect of ensuring that power cables maintain their performance, safety, and longevity in real-world conditions. While mechanical and electrical testing confirm that a cable can withstand physical handling and electrical stresses, environmental and chemical resistance testing evaluates how the materials and construction of the cable perform under the harsh external factors that they encounter throughout their service life. Medium voltage cables are often installed in environments that expose them to moisture, extreme temperatures, ultraviolet radiation, aggressive chemicals, oils, gases, and corrosive substances. These conditions can degrade polymeric insulation, jackets, shields, and even metallic components if the materials are not carefully selected and validated. Environmental and chemical testing ensures that cables retain their functional integrity under these challenging conditions and prevents premature failure that could lead to outages, safety hazards, or costly replacements.

One of the primary purposes of environmental testing is to simulate long-term exposure to natural elements such as sunlight, heat, cold, and humidity. Ultraviolet radiation from sunlight can cause polymer degradation in jackets and insulation, leading to embrittlement, cracking, or loss of flexibility over time. High temperatures, whether from ambient conditions or conductor heating under load, can accelerate chemical aging in insulation and jacket materials, reducing tensile strength, elongation, and mechanical resilience. Cold temperatures can cause polymers to become brittle, increasing susceptibility to cracking during handling or thermal contraction. Humidity and moisture, particularly in buried or outdoor installations, can penetrate into cable layers, promoting water treeing in insulation, corrosion of metallic components, and deterioration of polymeric materials. Environmental testing exposes cables to controlled cycles of these stressors to evaluate material durability, predict service life, and confirm that the cable is suitable for its intended installation environment.

Chemical resistance testing complements environmental testing by evaluating how cables respond to exposure to oils, fuels, acids, alkalis, solvents, and other substances commonly encountered in industrial or underground settings. Many cable installations are located near machinery, pipelines, chemical plants, refineries, or transportation networks, where accidental spills or continuous exposure to corrosive substances are possible. Insulation, shielding, and jackets must resist chemical attack to prevent swelling, softening, cracking, or delamination, which could compromise dielectric strength or mechanical protection. Testing involves immersion or surface exposure of cable materials to specific chemicals for defined durations, followed by evaluation of physical properties such as tensile strength, elongation, hardness, and insulation resistance. These tests confirm that materials will retain their protective properties under realistic chemical exposure scenarios.

Combined environmental and chemical stresses often exacerbate cable degradation, making integrated testing essential. For example, exposure to moisture and heat in the presence of corrosive ions can accelerate corrosion of metallic armour, shields, or conductors. Similarly, UV radiation combined with acidic rainfall or industrial pollutants can hasten jacket embrittlement or cracking. Accelerated aging tests simulate decades of service exposure within a controlled laboratory setting, allowing manufacturers and engineers to understand how materials will

behave over the cable's intended lifespan. By reproducing these complex stressors, testing helps identify weaknesses, optimize material formulations, and validate cable designs for reliability in real-world conditions.

Environmental and chemical resistance testing also supports safety and compliance objectives. Many regions and applications impose strict requirements for cable performance under adverse conditions. For instance, buried cables in aggressive soils must demonstrate resistance to moisture ingress, chemical attack, and corrosion, while cables installed outdoors must meet UV and ozone resistance requirements. Fire performance in combination with environmental exposure may also be specified for indoor installations. Compliance with these standards is verified through systematic testing, which ensures that the cable will perform safely even in challenging environments. Understanding the results of these tests allows engineers to select the correct cable type for each specific application and to anticipate maintenance requirements over the cable's service life.

Chemical resistance testing is particularly important for the integrity of insulation and jacket materials. Polymers are susceptible to degradation when exposed to hydrocarbons, oils, solvents, or industrial chemicals, which can alter mechanical properties and reduce electrical insulation capability. For example, swelling of insulation or jacket compounds due to chemical exposure can lead to partial discharge, reduced dielectric strength, or mechanical delamination between layers. By subjecting materials to controlled chemical exposure, testing identifies compounds that are vulnerable and confirms that formulations meet the necessary performance criteria. This ensures that cables maintain both electrical and mechanical integrity in chemically aggressive environments.

Another critical aspect of environmental and chemical testing is the verification of long-term resistance to moisture and water ingress. Water treeing, a phenomenon where microscopic channels form within insulation due to prolonged moisture exposure under electrical stress, is a leading cause of medium voltage cable failures. Testing for water absorption, permeability, and resistance to hydrostatic pressure ensures that insulation systems, jackets, and protective layers can resist water penetration and maintain dielectric performance over decades. In addition, metallic components such as armour, conductor strands, or shields are often subjected to salt, acid, or soil chemistry tests to ensure corrosion resistance, which is critical for both mechanical protection and grounding performance.

These tests also provide valuable feedback for cable design and material selection. By understanding how specific polymers, metallic alloys, and construction methods respond to environmental and chemical stressors, manufacturers can optimize cable formulations, layering, and protective systems. For instance, an outer jacket may be compounded with UV stabilizers, antioxidants, and chemical-resistant additives to ensure durability, while insulation compounds can be designed for moisture resistance and thermal stability. Testing validates these design choices, ensuring that they translate into practical, long-lasting performance in the field.

Environmental and chemical resistance testing also informs maintenance and life-cycle management strategies. By predicting how materials will degrade under specific environmental conditions, engineers can anticipate inspection intervals, identify potential weak points, and

develop preventive maintenance plans. For utilities and industrial operators, this predictive insight helps reduce unplanned outages, extend cable service life, and optimize total lifecycle cost. In high-stakes applications, such as critical industrial processes, substations, or high-reliability utility networks, understanding environmental and chemical vulnerabilities is essential to maintain continuous operation and prevent safety incidents.

Ultimately, environmental and chemical resistance testing ensures that medium voltage cables are not only designed for electrical and mechanical performance but also for the real-world conditions in which they must operate. These tests provide assurance that cables will maintain insulation integrity, mechanical strength, and protective functions when exposed to heat, cold, moisture, sunlight, chemicals, or corrosive soils. By incorporating this testing into design, manufacturing, and quality assurance, manufacturers deliver cables that are durable, safe, and reliable. For engineers, installers, and asset owners, understanding these test results allows informed decisions about cable selection, installation practices, and maintenance programs, ensuring long-term operational confidence and minimizing the risk of failure in challenging environments.

The following table (**Table 9**) provides a comparative analysis of the various environmental and chemical resistance testing requirements in the medium voltage cable standards within the scope of this course.

Env/Chemical Resistance Test*	CSA C68.5	CSA C68.10	ICEA S-94-649	ICEA S-97-682	AEIC CS8	ICEA S-113-684	ICEA S-93-639	UL 1072
Weather/UV resistance (720h/1000h UV)	✓ (1000h)	✓ (1000h)	✓ (Mandatory: PVC, CPE, TPE Optional: others) (720h)	✓ (Mandatory: PVC, CPE, TPE Optional: others) (720h)	✓ (Mandatory: PVC, CPE, TPE Optional: others) (720h)	✓ (720h)	✓ (720h)	✓ Optional (720h)
Carbon black content (jacket)	✓	✓	✓	✓	✓	✓	✗	✗
Absorption coefficient	✗	✗	✓	✓	✓	✓	✓	✗
Environmental stress cracking	✓	✓	✓	✓	✓	✓	✓	✓
Oil resistance / immersion	✓ (PVC)	✓	✓ (PVC, CPE + TPE)	✓ (PVC, CPE + TPE)	✓ (PVC, CPE + TPE)	✓ (PVC, CPE + TPE)	✓	✓
Flame – vertical (optional)	✓	✓	✗	✗	✗	✓	✓	✓
Limited smoke (optional)	✗	✓	✗	✗	✗	✓	✓	✓
Acid gas evolution (HAL-FREE only)	✗	✓	✗	✗	✗	✓	✓	✗
Halogen content (HAL-FREE only)	✗	✓	✗	✗	✗	✓	✓	✗

Table 9 – Environmental and Chemical Resistance Tests

#### 4.3.1 Weather/UV resistance (720h/1000h UV)

Weather and ultraviolet (UV) resistance tests evaluate the durability of cable jackets when exposed to prolonged sunlight and environmental conditions. Samples are subjected to controlled UV light exposure for 720 or 1,000 hours to simulate long-term outdoor conditions. This testing ensures that the jacket maintains mechanical integrity, flexibility, and chemical stability, preventing cracking, embrittlement, or surface degradation. Such performance is critical for above-ground installations, exposed conduits, and any cable subjected to direct sunlight, ensuring longevity and protection of underlying insulation.

#### 4.3.2 Carbon black content

The carbon black content test measures the concentration of carbon black within a polyethylene or other polymeric jacket. Carbon black serves as a UV stabilizer and enhances resistance to

weathering, thermal degradation, and oxidation. Verifying proper carbon black content ensures that the jacket will resist ultraviolet damage, maintain mechanical properties over time, and provide a consistent level of protection for the insulation. This test is particularly important for outdoor or exposed installations where UV degradation can compromise cable reliability.

#### 4.3.3 Absorption coefficient

The absorption coefficient test evaluates the jacket or insulation material's ability to resist moisture absorption. Materials that absorb excessive moisture can suffer from reduced dielectric strength, accelerated aging, and loss of mechanical performance. This test is particularly critical for direct-buried or wet-location cables, where prolonged exposure to water or high humidity can impact long-term reliability. Properly formulated materials with low absorption coefficients ensure that the cable maintains insulation integrity and prevents premature failure.

#### 4.3.4 Environmental stress cracking

Environmental stress cracking (ESC) tests assess a polymer's susceptibility to cracking under the combined effects of mechanical stress and exposure to chemicals or environmental conditions. Jackets or insulation may be subjected to tensile stress while exposed to environmental agents, revealing weaknesses that could lead to cracking or failure. ESC testing ensures that materials can withstand field stresses, chemical exposure, and long-term mechanical loading without developing cracks that compromise protection or insulation performance.

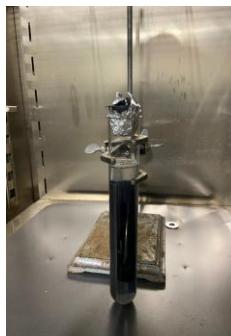


Figure 48 – ESC setup

#### 4.3.5 Oil resistance / immersion

Oil resistance testing evaluates a cable jacket's ability to withstand exposure to oils, lubricants, and hydrocarbons without degradation. Samples may be immersed in oil at elevated temperatures for specified durations to simulate accidental spills or industrial environments. This testing ensures that the jacket maintains mechanical strength, flexibility, and chemical integrity, preventing swelling, softening, or embrittlement that could compromise cable reliability. Oil-resistant jackets are particularly important in industrial facilities, substations, or areas with heavy machinery.

Test specimens are immersed in IRM 902 oil at a specified temperature for a specified time. Then, tensile and elongation properties are measured and compared with original properties.



Figure 49 – Oven (left) and oil (right) for oil immersion test

#### 4.3.6 Flame – vertical (optional)

Vertical flame testing assesses the jacket's flammability and its ability to limit flame propagation along the cable surface. This test simulates fire scenarios in installations where cables are in close proximity, such as conduits, trays, or risers. Passing the flame test ensures that the cable contributes minimally to fire spread, enhancing safety for personnel and property. While optional for some specifications, flame resistance is a critical requirement in high-risk installations or where local regulations mandate fire-retardant performance.

FT1/VW1 – Vertical Flame Test (Heat input 1700 BTU/h)

FT4/IEEE 1202/UL1685 – Vertical Tray Flame Test (Heat input 70,000 BTU/h)

ICEA T-30-520 – Vertical Tray Flame Test (Heat input 70,000 BTU/h)

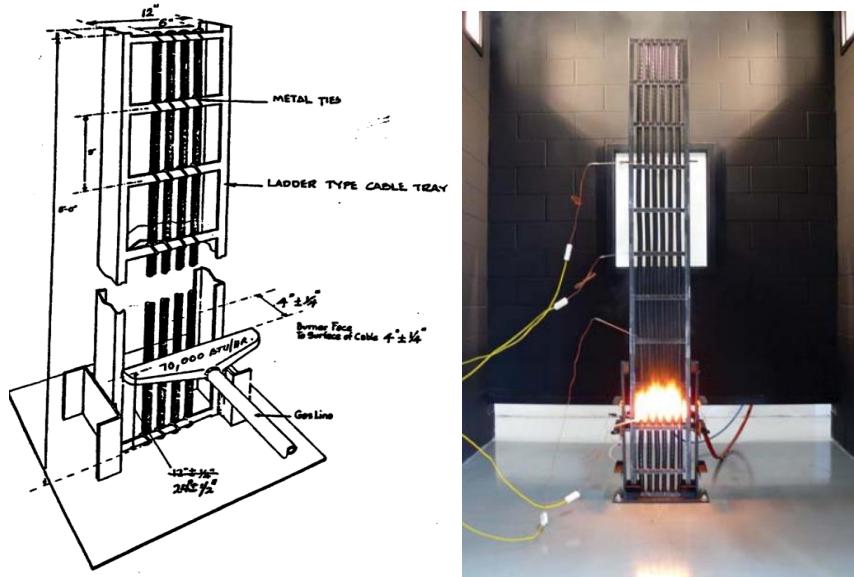


Figure 50 – Vertical tray flame test set up

#### 4.3.7 Limited smoke (optional)

Limited smoke testing evaluates a jacket's ability to produce minimal smoke when exposed to fire or high heat. In enclosed spaces or buildings, excessive smoke can hinder evacuation, reduce visibility, and pose a greater hazard than flames alone. Materials that meet limited smoke requirements improve safety during fire incidents, particularly in public buildings, tunnels, or industrial facilities. This test complements flame-resistance testing and is essential for environments with strict safety and fire codes.

Medium voltage cables with a limited smoke (ST1) designation have a low smoke release rate (SRR). Two (2) test methods are defined in UL/CSA 2556 – (1) Vertical Tray and (2) FT4.

##### 1. Method 1: Vertical Tray

- a. Duration: 20 mins
- b. Smoke release: 95 m<sup>2</sup>
- c. Peak release rate: 0.025 m<sup>2</sup>/s

##### 2. Method 2: FT4

- a. Duration: 20 mins
- b. Smoke release: 150 m<sup>2</sup>
- c. Peak release rate: 0.4 m<sup>2</sup>/s

where

$$SRR = \frac{(OD \times M_1)}{0.4064}$$

SRR = smoke release rate, m<sup>2</sup>/s

OD = optical density

M<sub>1</sub> = volumetric flow rate, m<sup>3</sup>/s, in the exhaust duct, referred to 298K

0.4064 = path length in the duct, m

#### 4.3.8 Acid gas evolution (HAL-FREE only)

Acid gas evolution testing determines whether halogen-free (HAL-FREE) jackets or insulation release corrosive gases, expressed as hydrogen chloride %, during combustion. The presence of acid gases can corrode metallic components, damage nearby equipment, and pose health risks to personnel. HAL-FREE materials are designed to minimize acid gas emission, and testing ensures compliance with environmental and safety standards for industrial and public installations.

#### 4.3.9 Halogen content (HAL-FREE only)

Halogen content testing verifies that insulation or jackets labeled as halogen-free contain negligible amounts of chlorine, bromine, or other halogens. Low halogen content is important for reducing acid gas production during combustion, improving fire safety, and meeting environmental regulations. Ensuring compliance with halogen-free requirements protects both personnel and equipment and is increasingly specified in modern industrial and utility installations.

Halogens are typically used in jacket materials because they are typically very flame resistant. When burning, these materials will smoke heavily, limiting fresh air from reaching ignited material and form a char barrier, temporarily protecting unburnt material. However, while flame resistant, halogen-containing materials will eventually burn and can have a high toxicity risk.

Halogen content is determined using x-ray fluorescence or by chemical composition analysis of ingredients used. Each non-metallic component must have < 0.2% total halogen

## **5.0 Key Differences**

Understanding medium voltage cable standards is important because they provide the framework for design and performance expectations. Different standards may specify variations in conductor materials, insulation types, shielding requirements, armour constructions, jacket materials, and testing methodologies. These differences reflect the historical practices, environmental conditions, regulatory requirements, and technological developments in different regions or applications. Understanding these distinctions ensures that cables are selected not only to meet voltage and current requirements but also to satisfy long-term operational, mechanical, and environmental performance expectations.

Safety is another good reason to recognize the differences between cable standards. Medium voltage cables operate at voltages high enough to pose significant risk to personnel and equipment if improperly designed, installed, or tested. Standards define critical parameters such as dielectric strength, insulation testing, fault current withstand capability, and mechanical durability. Failure to comply with the appropriate standard for a given system or region can lead to catastrophic failures, including insulation breakdown, partial discharge activity, or conductor overheating, all of which can result in fires, equipment damage, or serious injury. By understanding the standards and their specific requirements, engineers and technicians can ensure that cables are installed in accordance with recognized safety practices and that they perform reliably under both normal and fault conditions.

Operational reliability and long-term performance are also heavily influenced by the standard under which a cable is manufactured. Medium voltage cables are subjected to complex electrical, thermal, and mechanical stresses during their service life. These stresses include continuous electrical loading, short-circuit events, thermal cycling, environmental exposure, and mechanical handling during installation. Different standards define how cables should be tested for these conditions, including conductor and insulation testing, partial discharge measurements, mechanical tensile tests, impact resistance, and long-term thermal aging. Selecting a cable according to a standard that has been validated for the intended operating conditions helps ensure that it will maintain its integrity and functionality over decades of service. Ignoring these distinctions or assuming that all medium voltage cables are equivalent can result in premature aging, unexpected failures, and costly downtime for maintenance or replacement.

Compatibility with system components and accessories is another critical consideration. Medium voltage cable standards often influence how cables interface with terminations, splices, switchgear, transformers, and protection devices. Standards dictate conductor dimensions, insulation thickness, shield properties, and mechanical characteristics, which directly affect how well a cable integrates with connectors, lugs, and stress control accessories. For instance, the bonding and grounding requirements for a conductor shield and insulation shield may differ depending on the standard, affecting how stress control components are applied during installation. Selecting a cable without understanding these nuances can lead to improper termination practices, inadequate stress control, and localized electric field concentrations that increase the likelihood of partial discharge or insulation breakdown. In this sense, knowledge of cable standards ensures that the entire system—cable, accessories, and equipment—works together as intended.

Economic factors also come into play. Selecting a cable according to the wrong standard can result in over-engineering or underperformance. Over-engineering may lead to unnecessarily thick insulation, excessively robust armour, or more expensive materials than required, increasing initial purchase and installation costs. Underperformance, on the other hand, exposes the system to premature failures, frequent maintenance, or even catastrophic damage that can result in far greater costs over the cable's lifecycle. By understanding the differences between standards, designers can choose the most cost-effective solution that meets electrical, mechanical, and environmental requirements without overpaying for features that are unnecessary for a specific installation scenario.

Environmental and regulatory compliance is another consideration. Medium voltage cables are installed in a wide variety of environments, from underground ducts and direct burial in soils to indoor cable trays, industrial plants, and outdoor installations exposed to UV radiation, moisture, or chemicals. Different standards account for these environmental factors differently, specifying parameters such as jacket and insulation materials, fire performance, UV resistance, chemical resistance, and corrosion protection for metallic components. Compliance with local codes and regulations often requires adherence to a particular standard, and using cables that do not meet the required standard may violate safety codes, result in failed inspections, or create liability concerns.

The testing and quality assurance processes associated with different standards are also significant. Standards define the tests that must be performed on conductors, insulation, shields, and jackets, including high-voltage tests, partial discharge measurements, mechanical integrity assessments, and environmental aging studies. These tests ensure that the cable will perform as expected under operational stresses. Different standards may set different voltage levels, durations, or tolerances for these tests. Engineers and quality assurance professionals must understand these differences to interpret test results accurately and to select cables that have been appropriately qualified for the intended service. Without this knowledge, there is a risk of assuming compliance where it does not exist, potentially compromising both performance and safety.

Globalization and international projects further highlight the importance of understanding medium voltage cable standards. Many modern infrastructure projects involve international suppliers, contractors, and clients. In these contexts, cables manufactured according to one regional standard may be used in an installation designed according to another. Misalignment of standards can lead to confusion over conductor sizing, insulation ratings, shielding practices, or mechanical properties, which can impact project timelines, installation quality, and long-term performance. By understanding the differences between standards, project managers and engineers can ensure compatibility, avoid costly redesigns or replacements, and maintain confidence that the system will function as intended.

## 5.1 CSA C68.5 vs CSA C68.10

**CSA C68.5** is for utility use with a concentric neutral and has AWTT requirements whereas **C68.10** is for industrial use.

**CSA C68.5** is primarily intended for utility distribution applications, where cables are typically installed in public right-of-ways, underground distribution networks, and other utility-owned systems. One defining characteristic of cables built to C68.5 is the use of a concentric neutral, which consists of helically applied neutral wires surrounding the insulation shield. This construction provides a reliable grounding path and allows the neutral to carry unbalanced load currents and ground-fault currents commonly encountered in utility systems. Because utility cables are expected to operate continuously and withstand a wide range of loading conditions over long service lives, C68.5 places a strong emphasis on long-term electrical and thermal performance.

A key requirement unique to CSA C68.5 is the inclusion of Accelerated Water Treeing Testing (AWTT). Water treeing is a long-term insulation degradation mechanism driven by moisture and electrical stress, particularly in underground utility installations where exposure to water is common. AWTT is used as a qualification test to demonstrate that the insulation system can resist the formation and growth of water trees over time. By requiring AWTT, C68.5 reflects the utility industry's need for insulation systems that can deliver decades of reliable service in wet and electrically stressed environments.

In contrast, **CSA C68.10** is intended primarily for industrial and commercial applications, where system configurations, grounding practices, and operating conditions differ from those of utility distribution networks. Cables built to C68.10 are typically used in industrial plants, large facilities, and private distribution systems, and they are not required to include a concentric neutral. Instead, grounding and fault-current return paths are often provided through separate conductors or system grounding schemes defined by the installation design and applicable electrical codes.

Because the expected installation environments and service conditions differ, C68.10 does not include AWTT requirements. Industrial systems are often installed in more controlled environments, such as conduits, cable trays, or vaults, where moisture exposure and long-term water ingress are less severe than in direct-buried utility installations. As a result, the standard places greater emphasis on meeting electrical, mechanical, and thermal performance requirements appropriate for industrial use rather than long-term water tree resistance.

## **5.2 CSA C68.10 vs UL 1072**

**CSA C68.10** and **UL 1072** are both standards that apply to industrial-use medium voltage cables, but they are written to align with different regulatory frameworks and installation codes in North America.

CSA C68.10 is for industrial use under the scope of the Canadian Electrical Code (CE Code) while UL 1072 is for industrial use under the scope of the National Electrical Code (NEC).

Cables manufactured to C68.10 are evaluated with the expectation that they will be installed in accordance with CE Code rules, which define acceptable grounding methods, installation practices, and application environments. As a result, the standard reflects Canadian regulatory requirements and installation philosophies commonly used in industrial facilities, commercial buildings, and private distribution systems.

In the United States, UL 1072 serves a similar role for industrial medium voltage cables, but it is written to support compliance with the National Electrical Code (NEC). UL 1072 establishes construction and performance requirements that allow cables to be listed for use under NEC rules. These requirements address insulation systems, shielding, jackets, and overall cable construction in a manner consistent with U.S. installation practices, grounding methods, and inspection expectations.

While CSA C68.10 and UL 1072 share similar objectives—ensuring safe and reliable performance of medium voltage cables in industrial applications—their requirements are shaped by the differences between the CE Code and the NEC. These differences may influence details such as marking, testing, grounding provisions, and acceptance by local authorities having jurisdiction. For projects that cross borders or involve multinational specifications, understanding the distinctions between these standards is critical to avoiding compliance issues and ensuring the selected cable is approved for installation in the intended jurisdiction.

Ultimately, selecting between CSA C68.10 and UL 1072 is not simply a technical decision, but also a code compliance decision. Specifying a cable that aligns with the governing electrical code ensures smoother approval, proper installation, and long-term regulatory compliance, reinforcing the importance of understanding how medium voltage cable standards interface with national electrical codes.

## **5.3 CSA vs ICEA**

CSA standards typically adapt **ICEA** requirements with Canadian-specific requirements such as like:

1. Cold Bend w/ PD
2. 1000 Hr UV Test
3. Mandatory thermomechanical test

CSA and ICEA standards for medium voltage cables are closely related, but they are developed to serve different regulatory and environmental contexts. In many cases, CSA standards build

upon the technical foundation established by ICEA, adapting those requirements to reflect Canadian installation practices, climate conditions, and code expectations. As a result, CSA standards often include additional or modified test requirements intended to address conditions that are more prevalent or more strictly regulated in Canada.

One key area where CSA standards expand on ICEA requirements is low-temperature performance. Cold bend testing with partial discharge (PD) measurement is a notable example. While ICEA standards address cold bend performance, CSA requirements combine mechanical bending at low temperatures with an electrical PD evaluation to ensure that insulation integrity is not compromised by cold-weather handling. This reflects the reality of Canadian installations, where medium voltage cables may be installed or moved at very low ambient temperatures, increasing the risk of insulation cracking or shield damage that could lead to partial discharge activity.

CSA standards also place greater emphasis on long-term outdoor exposure through requirements such as the 1,000-hour ultraviolet (UV) resistance test. This extended UV exposure test is intended to verify that cable jackets can withstand prolonged sunlight exposure without excessive degradation, cracking, or loss of mechanical properties. In comparison, ICEA standards typically require shorter UV exposure durations. The longer CSA requirement reflects Canadian expectations for durability in outdoor installations, where cables may be exposed to sunlight for extended periods before burial or in permanent above-ground applications.

Another important distinction is the inclusion of a mandatory thermomechanical test in CSA standards. This test evaluates the combined effects of thermal cycling and mechanical stress on the cable system, providing additional assurance that the cable can withstand repeated heating and cooling while under load. By requiring this test, CSA standards place added emphasis on long-term reliability and dimensional stability of the insulation and shield systems. While ICEA standards address thermal and mechanical performance separately, CSA's thermomechanical requirement represents a more conservative approach tailored to Canadian service conditions.

Overall, the relationship between CSA and ICEA standards can be viewed as one of adaptation rather than replacement. ICEA standards provide a widely recognized technical baseline for medium voltage cable design and testing, while CSA standards incorporate that baseline and layer in Canadian-specific requirements driven by climate, regulatory expectations, and installation practices. Understanding these differences helps specifiers and engineers determine which standard is most appropriate for their application and ensures that cables are selected with both performance and code compliance in mind.

## **5.4 UL vs ICEA**

**ICEA** focuses on construction and material properties, whereas **UL** is more focused on NEC compliance and product marking

ICEA standards are primarily focused on cable construction, materials, and performance requirements. They define how a medium voltage cable is built, including conductor construction, insulation systems, shielding methods, jacket materials, and dimensional

tolerances. ICEA documents also establish detailed electrical, mechanical, and environmental test requirements intended to verify long-term performance and reliability. Because of this emphasis, ICEA standards are commonly used by manufacturers and engineers as the technical baseline for cable design and qualification, regardless of where the cable will ultimately be installed.

In contrast, UL standards are developed with a strong emphasis on product safety certification and compliance with the National Electrical Code (NEC). UL evaluates whether a cable construction meets the safety and installation requirements referenced by the NEC, including flame performance, markings, and identification needed for field inspection and approval by authorities having jurisdiction. Rather than focusing deeply on material science or long-term performance mechanisms, UL standards concentrate on ensuring that products can be safely installed and clearly identified in accordance with U.S. electrical codes.

One of the most visible differences between ICEA and UL standards is the role of product listing and marking. UL standards specify how cables must be marked to indicate voltage rating, insulation type, temperature rating, and applicable listings, enabling inspectors and installers to quickly verify NEC compliance in the field. ICEA standards, on the other hand, do not provide listing or certification; they establish performance expectations but rely on other organizations, such as UL, to certify and label products for code acceptance.

In practice, ICEA and UL standards are complementary rather than competing. A medium voltage cable may be designed and tested to meet ICEA construction and performance requirements while also being evaluated and listed by UL to satisfy NEC compliance and marking requirements. Understanding the distinction between the two helps specifiers and engineers write clearer requirements, avoid confusion, and ensure that cables meet both technical performance expectations and regulatory approval requirements for their intended installation environment.

## **5.5 ICEA vs AEIC CS8**

**AEIC CS8 Specification** builds on existing **ICEA** utility cable standards with additional requirements including:

1. Tree Count Test after AWTT
2. Modified hot creep/set limits
3. Reduced de-gassing times
4. CTR reporting requirements

ICEA standards provide the foundational technical requirements for cable construction, materials, and baseline performance, while AEIC CS8 builds on that foundation to address the specific reliability expectations of electric utilities. Understanding how AEIC CS8 extends ICEA requirements is essential when specifying cables for utility distribution systems where long service life and proven field performance are critical.

ICEA utility cable standards establish the core design requirements for extruded dielectric cables, including conductor construction, insulation systems, shielding, jackets, and mandatory electrical and mechanical tests. These standards are widely used across North America and serve as the baseline reference for many other specifications. ICEA requirements are intended to ensure consistent manufacturing quality and acceptable performance under typical operating conditions, but they are written to be broadly applicable across a wide range of users and environments.

AEIC CS8, on the other hand, reflects the collective operating experience and reliability priorities of member utilities within the Association of Edison Illuminating Companies. As a result, the CS8 specification incorporates additional and more stringent requirements aimed at reducing long-term failure mechanisms commonly observed in underground distribution systems. Rather than redefining cable construction from scratch, AEIC CS8 enhances ICEA requirements to further validate insulation performance, manufacturing consistency, and long-term reliability.

One significant enhancement in AEIC CS8 is the requirement for a tree count test following Accelerated Water Treeing Testing (AWTT) *for engineering information only*. While ICEA standards require AWTT to evaluate resistance to water tree formation, AEIC CS8 goes a step further by requiring a quantitative assessment of water tree density after the test. This additional evaluation provides utilities with deeper insight into insulation quality and resistance to moisture-related degradation, allowing for more meaningful comparison between insulation systems and manufacturers.

AEIC CS8 also introduces modified hot creep and hot set limits compared to ICEA requirements. These tests evaluate the ability of insulation to maintain its dimensional stability under elevated temperature and mechanical load. By tightening or modifying acceptance limits, CS8 places greater emphasis on controlling insulation deformation, which can affect stress distribution and long-term electrical performance, particularly under sustained loading conditions typical of utility networks.

Another notable difference is AEIC CS8's allowance for reduced degassing times following insulation curing. Degassing removes crosslinking by-products that could negatively impact electrical performance if retained in the insulation. AEIC CS8 recognizes manufacturing process improvements that allow for shorter degassing periods while still maintaining acceptable performance, provided other qualification requirements are met. This approach balances manufacturing efficiency with performance assurance.

Finally, AEIC CS8 includes enhanced certified test report (CTR) reporting requirements, providing utilities with greater transparency. By requiring a more detailed reporting scheme, CS8 enables more informed evaluation of cable quality and long-term reliability expectations.

Overall, AEIC CS8 can be viewed as a utility-driven enhancement of ICEA standards rather than an alternative to them. ICEA establishes the baseline construction and performance framework, while AEIC CS8 adds targeted requirements based on utility operating experience and reliability goals.

## **5.6 ICEA S-113-684**

Unlike 649, 682, and 639, **ICEA S-113-684** is a performance-based standard permitting significant reduction of cable diameters, if so qualified.

ICEA standards for medium voltage cables are not all structured in the same way, and understanding these differences is important when evaluating cable designs and specifications. ICEA S-94-649, S-97-682, and S-96-639 are largely prescriptive standards, meaning they define specific construction details such as minimum insulation thicknesses, shielding requirements, and dimensional criteria based on voltage class and insulation type. These documents establish well-understood and conservative design rules intended to ensure consistent performance across a wide range of applications.

In contrast, ICEA S-113-684 represents a different philosophy. Rather than prescribing fixed construction dimensions, S-113-684 is a performance-based standard. It allows manufacturers greater flexibility in cable design, including the potential for significant reductions in overall cable diameter, provided the cable can successfully demonstrate equivalent or superior performance through qualification testing. This approach recognizes advancements in materials, manufacturing processes, and insulation technology that can achieve required electrical and mechanical performance without relying on traditional dimensional margins.

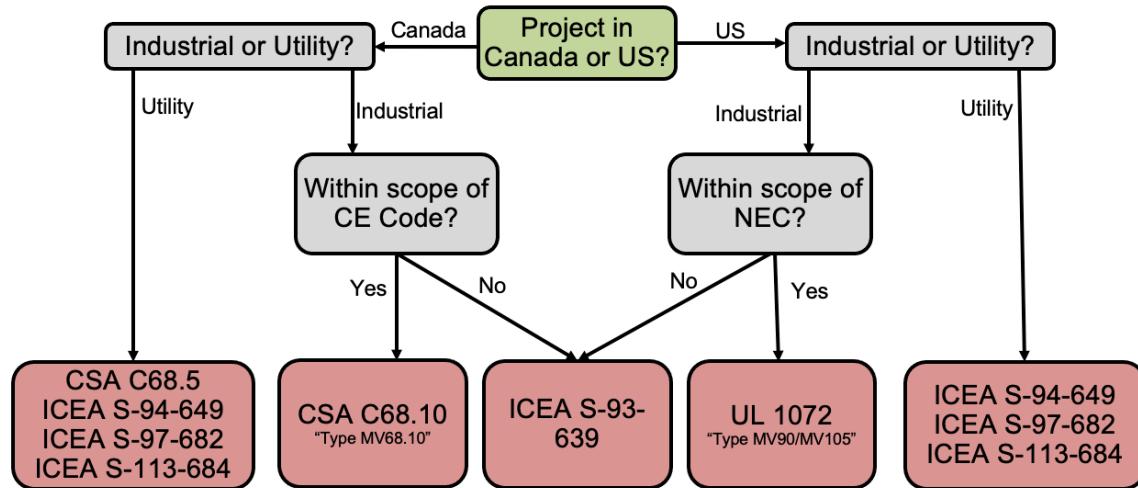
The performance-based nature of S-113-684 shifts the emphasis from “how the cable must be built” to “how the cable must perform.” To qualify for reduced dimensions, cables must undergo more comprehensive testing to prove that thinner insulation systems can withstand electrical stress, thermal loading, and long-term aging mechanisms such as partial discharge and water treeing. This ensures that reductions in diameter do not come at the expense of reliability or service life.

By permitting smaller cable diameters when properly qualified, ICEA S-113-684 offers practical benefits such as improved ampacity utilization, reduced material usage, lighter cable weight, and easier installation—particularly in conduit-constrained or retrofit applications. However, these benefits are balanced by the increased responsibility on manufacturers and specifiers to understand the qualification requirements and verify compliance.

Ultimately, ICEA S-113-684 does not replace prescriptive standards like 649, 682, or 639, but instead provides an alternative pathway for advanced cable designs. For applications where space constraints, installation efficiency, or material optimization are priorities, and where rigorous qualification can be demonstrated, S-113-684 offers a modern, performance-driven option within the ICEA standards framework.

## 6.0 Decision Tree

The following flowchart may help determine what standard to specify a cable to.



Note – It is worth mentioning that some applications may require compliance with multiple standards, which is possible when appropriately evaluated.

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