Medium-Voltage Underground Systems

Addressing issues affecting the quality and reliability of medium-voltage underground distribution

UL Solutions

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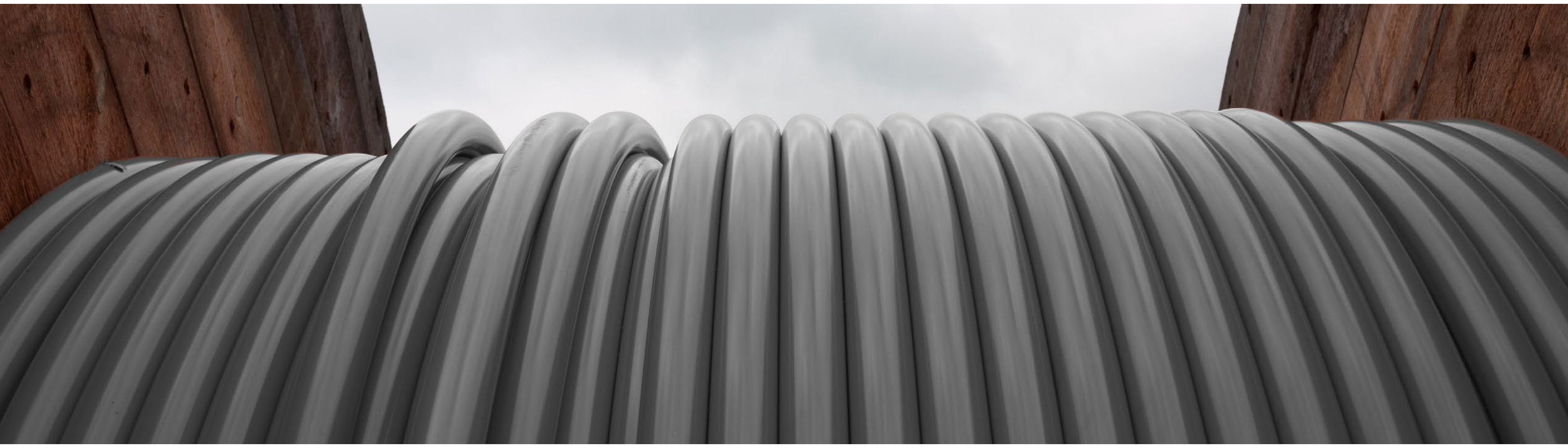
Executive summary

The quality of medium-voltage underground systems is critical to helping ensure the safe and reliable distribution of electrical power. We require reliable electricity in more facets of everyday life, all while drawing that electricity from increasingly diverse sources and locations. A variety of factors — including cables, connectors, joints and terminations — can compromise the quality of the cable system, potentially shortening the anticipated life and degrading reliability. The resulting downtime leads to lost revenue and costly repairs.

This white paper, prepared by UL Solutions experts, discusses the factors related to the failure of medium-voltage distribution components, including those involving production practices and procedures. The paper also outlines the steps that utilities and other industrial users of medium-voltage distribution products can take to monitor quality throughout the procurement process, helping reduce incidents of preventable failure. The white paper concludes by reviewing UL Solutions programs for medium-voltage distribution that can help to address these issues.

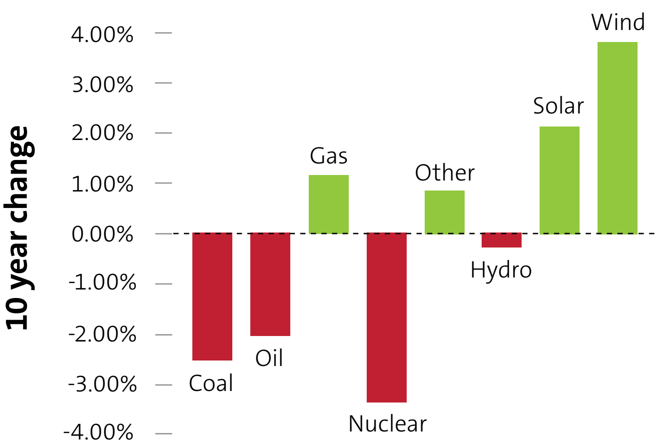
The use of medium-voltage distribution cable systems in infrastructure projects

Medium-voltage underground cable systems — including cables, connectors, joints and terminations — represent an essential element in maintaining and expanding the capabilities of the global energy infrastructure. Operating at voltages ranging from 2,000 to 46,000 volts, a wide range of applications use medium-voltage systems, including utilities, offshore, manufacturing, interconnections and renewables. Future investments in power transmission and distribution systems are expected to result from the increased demand for power.



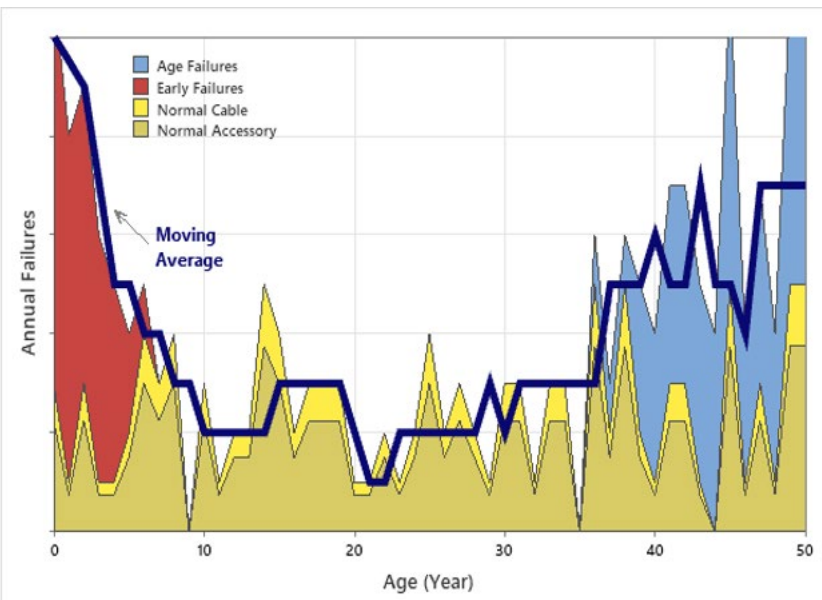
This increase will likely exceed the sustained 6% growth (green bars of the chart exceed the red bars) seen in the last 10 years.[1] The growth will drive increased demand within the medium-voltage space in the years ahead. Such demand will see the expansion of the existing, well-established, but aging, grid, together with the connection of new energy resources and conversion from overhead to underground distribution to improve reliability. In a recent survey,[2] the aging legacy grid, renewables and upgrades currently represent utility engineers' first-, second- and fourth-largest concerns.

At the same time, the growing reliance on the use of medium-voltage systems presents a number of challenges related to cable system failures. In the legacy grid, the average age of underground systems is between 30 and 35 years,[3] while the user community's expected life span typically varies between 30 and 40 years. The new underground installations essential for distributed energy resources (DER), such as solar and wind, along with grid reliability improvements, will see cable systems experiencing changing operational profiles and challenges we have yet to discover. One result of these new DER facilities is legacy generation plant retirement (see the 10 year reduction in coal powered generation – left red bar). This means that the existing infrastructure will not likely share the same real estate with the new resources, thereby driving the distribution grid's expansion in different locations. In fact, much of the DER will connect directly to the distribution grid.



Moreover, the supply chain base for cable system components will change with the expansion of existing suppliers and new entrants, yet a wide range of issues, such as load profiles, installation conditions and initial quality, will still significantly impact the installed systems' actual life span and the ways in which they are qualified.

Regardless of the cause, failure contributes to significant increases in utility companies' spending on maintenance. This spend draws on both the operational funds and the scarce engineering manhour resources of a utility. The U.S. Energy Information Agency (EIA) reports that the U.S. utility industry's spending on operations and maintenance now exceeds $13 billion (USD) annually, an increase of nearly 400% in 20 years.[4] However, failures lead to more than just costly and time-consuming repairs for utility companies and temporary inconveniences for customers. When they result in sustained power outages, failures can have widespread impacts on safety and impose significant economic and societal costs on the affected communities.



It is for these reasons, that the quality and reliability of both legacy (age-based failures) and new installations (early failures) have become a critical consideration for users. As part of that effort, the medium-voltage community is increasingly tasked with helping to manage and renew the aging system, reduce the rate of early failures and increase mid-life reliability. This means addressing both ends of the "bathtub" aging curve: reduce new component failures (red area of the figure) and increase the life of the legacy grid (blue area). Both of these activities need to occur as the sector grows and evolves.

Failure of components in the underground system is probabilistic and naturally varies year over year. Consequently, determining when components start to age and when they have reached the end of their life can prove a considerable challenge.

Some causes of underground failures

In-service failures of medium-voltage underground systems stem from several sources. Accessories, such as elbows, joints and terminations, account for most reported failures,[5] adding up to almost twice the number of cable failures. In general, the causes of underground failures fall into one of three categories:

Issues related to construction and design

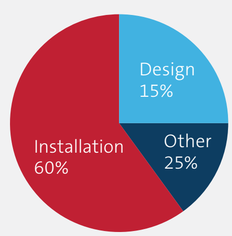
The currently available medium-voltage components incorporate many significant technological advances compared with earlier versions. Good examples of advances in design include factory-tested accessories, jackets for cables and joints and conductor water blocking.

At the same time, the cables, joints and terminations installed today represent only a portion of the complete grid, with the legacy grid forming the largest and oldest portion. It is important to recognize that this composite grid involves complex interactions among various materials, components and manufacturers. Therefore, testing new components alone cannot assure continued performance.

In some cases, type testing on new designs or material combinations to historical paradigms may not be sufficient to identify challenges that become apparent in industrial deployment. These potential challenges can eventually lead to premature failure, ultimately leaving the user with additional activities to regain the required performance.

Installation problems

Medium-voltage distribution applications vary considerably in terms of their technical requirements. However, they all require that the system be assembled in the field from highly engineered components, such as accessories and cables, in many different terrains. The issues around the assembly remain the most significant challenge for both new and legacy installations.



Product selection and procurement protocols generally do not suffice to ensure reliable operation on their own. The ease of installation and component interoperability needs emphasizing. In parallel, they also require robust test and diagnostic techniques to identify field problems and provide feedback to reduce their occurrence in the future. Failure to do so can result in newly installed cables suffering electrical overheating or degradation leading to premature failure.

Aging

One of the major advantages of underground cable systems is that they are relatively immune from environmental factors such as storms, wind and other extreme weather events. However, underground installation means that observing the system's aging can prove difficult. This is even more difficult, given that the components last a long time, so failures start to accumulate with little in the way of warning.

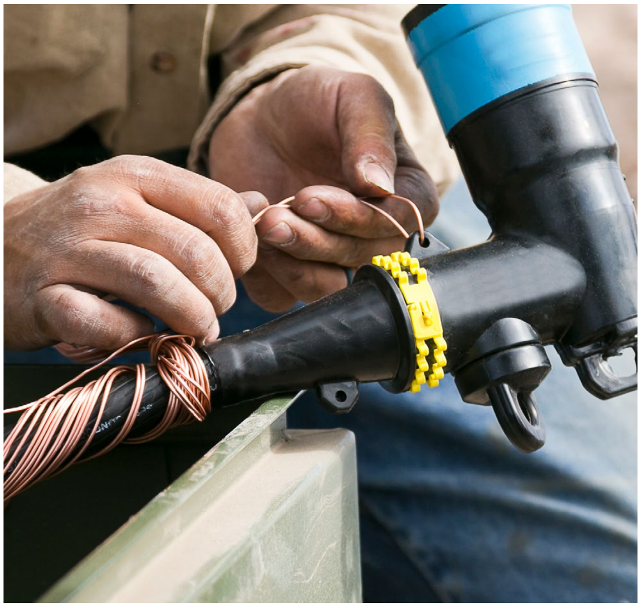
DER technologies that cause the grid to operate in modes not previously experienced also provide complications that exacerbate aging. As an example, the existing system does not experience the large swing in loading and heating caused at night with solar generation.

The specification process can address many of the known issues, including activities that relate known multifactor aging test protocols to the known issues observed in the field. Experience within the engineering sector and follow-up on service failures are powerful ways to strengthen the relationships between laboratory and field experience.

In many cases, increasing awareness, implementing stronger process controls and ensuring that the specifications for system components are up to date and appropriate can reduce the risk of failures attributable to these causes. However, even the most robust protocols may not prove sufficient to identify the real-world variations and anomalies in a supplier's production processes. Thus, as component consistency is a major end-user requirement, the current protocols will likely need augmentation with this improved understanding of the users' needs. This trend is apparent in the recent improvements made to the Association of Edison Illuminating Companies (AEIC) cable specifications focusing on consistency.

Production factors affecting medium-voltage underground components' reliability

Medium-voltage distribution components differ from most equipment, products and materials used in infrastructure operations. Although the system itself is assembled in the field, components such as cables, connectors, joints and terminations are produced in continuous manufacturing processes rather than assembled from many separate components. Cable accessories are generally injection molded, and cables are extruded in very long lengths, each integrating the essential conductor, shielding and insulation elements into a finished product. This approach, often replicated on many lines within a factory site, enables manufacturers to efficiently produce finished components that meet specifications and the users' desire for consistency.

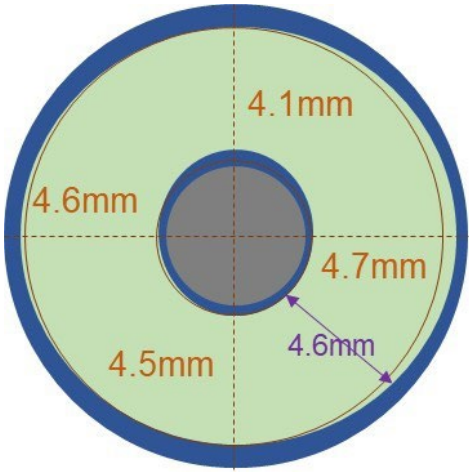


The challenge is that achieving consistent output quality from continuous flow processes requires robust technology, constant monitoring and correction of process variables such as speed and pressure, and production-related factors like temperature, damage, conditioning and contaminants.

If not tightly controlled, deviations in any of these variables can increase the risk of life-limiting defects in finished products — defects that may go undetected during normal production testing and commissioning. In addition to potential problems with continuous production equipment, human interactions may also compound the issues. Production workers who are insufficiently experienced or improperly trained in cable production can negate expansions and output increases. Seemingly minor human errors, such as failing to clean tools, pulling extruded cable along a rough surface, failing to pay attention during forklift activities or accidentally inflicting minor nicks can occur without notice, resulting in undetected flaws or defects.

Further, inadequate testing facilities and equipment, as well as processes developed without sufficient understanding of the user's goals, can miss obvious cable defects and even introduce new ones. In some cases, problems with faulty manufacturing equipment go unrecognized and remain unaddressed for many orders because testing did not catch the issues.

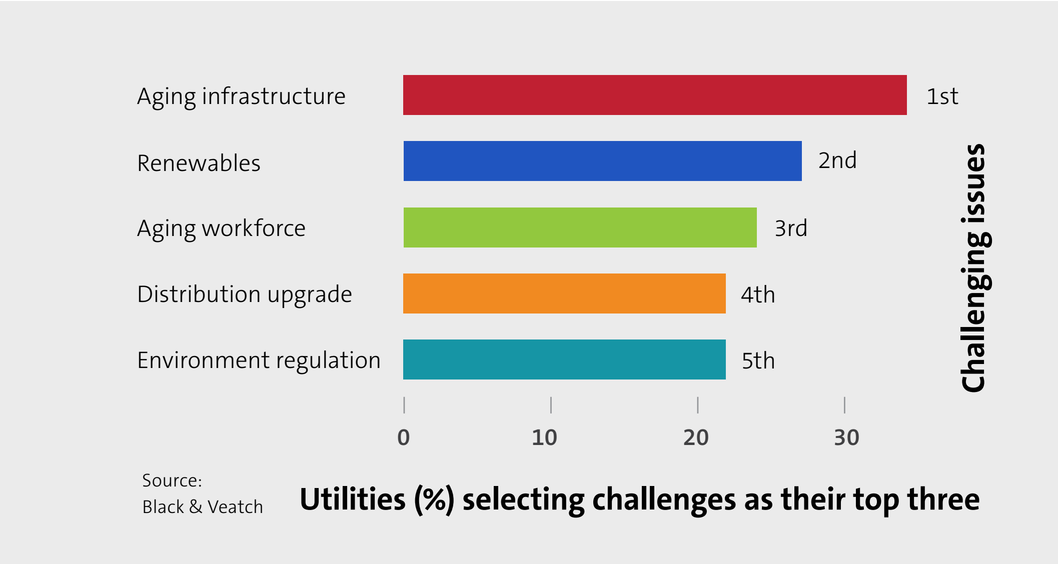
These shortcomings in the production sphere result in an increased risk of installing medium-voltage distribution components that contain stress-enhancing and life-limiting defects. These defects may go unnoticed for years before leading to a fault well before the expected service life is reached, requiring the repair or replacement of the defective system ahead of any planned infrastructure upgrade schedule, and the user must bear the costs.



Other issues

Lastly, several issues not related to design or production can impact medium-voltage distribution cables' quality and long-term reliability performance.

Technical standards for various geographical markets differ in approach and scope. Thus, a document developed in the industrial space will likely not include many of the elements considered important in the utility space. Moreover, North American and European markets seek to include requirements intended to promote longevity, such as long-term wet testing and water barriers, as well as compatibility with accessories, including defined dimensions. Additionally, they require activities that identify and address product defects before shipment. Requirements of seemingly comparable standards may differ in subtle but significant ways, ultimately leaving it to the purchaser to determine whether a given standard's requirements satisfactorily address their specific quality and reliability concerns.



Another issue involves the challenges of increasingly global supply chains. To meet the distribution grid's continued expansion, medium-voltage distribution components are sourced from producers with manufacturing operations and subcontractors worldwide. Although global supply chains offer many benefits, manufacturing performance standards can vary widely, creating the potential for significant variations in what is ostensibly the same product. This can result in missing the paramount end-user goal of consistency.

Rigorous supplier quality programs and audit protocols can help address this problem, but such programs can prove difficult and time-consuming to implement, especially with an increasingly limited workforce being pulled in many directions.

A final issue reflects the reduced availability of requisite technical knowledge and expertise related to cable accessories, cable, and installation technologies in general. The energy industry faces a growing gap in critical skills.[2] The number of new workers entering the industry falls short of the number of workers leaving. The departure of experienced workers exacerbates the problems associated with the aging legacy grid.

Also, upgrading and integrating renewables brings many new challenges. As a result, fewer utility industry professionals possess the diverse technical knowledge necessary to support distribution expansion. In the end, this gap is likely to exacerbate the impact of any substandard or defective medium-voltage distribution components more than recent experience may lead us to think.

Ensuring medium-voltage underground systems' quality and reliability

In this context, the effort to address design, installation, aging and other issues related to medium-voltage distribution cables' quality and reliability presents a critical challenge to the utility industry and other industrial users. At the same time, those who buy medium-voltage cables can take action to help ensure the overall quality of their purchases and reduce the incidence of premature cable failures. These actions include:

Vendor qualification assessments

Users can implement vendor quality assessment programs to help ensure that accessory and cable manufacturers and producers are — and remain — sufficiently qualified to deliver consistent products that meet requirements and the specifications of their intended application. Such a program includes reviews of the qualification tests and regular in-person assessments of the facilities and technologies used to provide the components.

Field oversight and asset management

To help ensure the quality of the installed system, users should require commissioning tests before systems go into service. This is because the most effective time to correct any installation issues is while the installation crews are still on site and before any premature failures can impact the System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI). In a modern distribution grid, testing new components also requires assessing the legacy grid to which the new components connect. Upgrades and new resources can only realize their full value if all of these parts operate together.

Workforce training

Utilities and manufacturers alike recognize that a growing talent gap hampers the grid's growth. Addressing the gap in technical information among workers in the industry today presents a challenge that requires a commitment to provide sufficient education and training opportunities. A higher level of workforce knowledge and expertise will offset the investment to initiate and deliver such training, resulting in more efficient resolutions for issues and a reduction in the deployment of systems likely to fail prematurely. Investments in workforce training can also have the added benefit of increasing overall employee engagement and productivity.

Ongoing review and testing

Distribution components must undergo routine sample inspection to the relevant national and international standards to ensure conformity with specifications. However, the conformity approach does not always deliver the consistency and longevity users require of their new installations. Quality management teams should track and analyze the available data to proactively identify potential inconsistencies and problems. The analysis can help ensure that the appropriate testing guides corrective actions. This oversight enables close collaboration that offers optimal reliability and the lowest total cost for the system.

By taking these actions, utility companies and other industrial users of medium-voltage distribution systems can improve profitability by helping to reduce the incidence of premature failures and the need for repairs and unplanned maintenance on installed components.

UL Solutions' approach to medium-voltage quality and reliability

Consistency and quality cannot be inspected into an installation at the end of the process; the design and manufacturing process must include it right from the start. UL Solutions understands this.

As a global safety science leader with expertise in testing, certifying and inspecting wire and cable products, UL Solutions experts are developing specialized programs to provide utilities and other industrial cable customers with risk mitigation regarding their components' quality and reliability.

Our medium-voltage audit and inspection programs focus on manufacturing processes and techniques specific to medium-voltage distribution requirements. Our global network of experienced auditors and inspectors facilitates the monitoring and evaluation of supply chain facilities and technologies, regardless of their location.

Field Test and Asset Management programs help ensure that the resources devoted to expanding and upgrading the distribution grid provide stakeholders with optimal value. We do this by working with the end user to verify new installations' required performance with an understanding of existing grid components' capabilities.

The distribution grid is changing and expanding. Knowledge is the key enabler for all involved in these activities. UL Solutions expertise, insight and global reach provide a fast and effective way to expand and strengthen the knowledge capability in light of workforce changes at stakeholders and in the face of an evolving grid architecture.

Summary and conclusion

The consistency, quality and reliability of medium-voltage distribution are of vital interest to the utility industry and other industrial entities since defective products can result in premature failure with significant consequences. Yet, producing consistent, high-quality medium-voltage components that meet buyers' needs can prove challenging, and the increased pace with which the grid is changing and declining knowledge resources don't make it any easier. Therefore, to maintain the distribution grid's usual performance, purchasers need to fill this void with new programs and initiatives.

Experts at UL Solutions are developing programs for asset management, field testing, quality and qualification designed to meet the needs of users and manufacturers alike. We aim to help stakeholders work together to ensure that the distribution grid delivers increasing value to society in the coming decades.

Learn more at UL.com/mvhv.

Endnotes

1. UL analysis of data from the BP Energy Review 2021
2. Black & Veatch 2020 Strategic Report: Repowering the Power Industry
3. UL analysis with input from BP, OCEI & Roland Berger
4. Based on data from the U.S. Energy Information Administration, as reported in “Utilities Continue to Increase Spending on Transmission Infrastructure,” a posting on the website of the energy collective, Jan., 16, 2018. Web. 16 April 2018. http://www.theenergycollective.com/todayinenergy/2423726/utilities-continue-increase-spending-transmission-infrastructure.
5. Long Life XLPE Insulated Power Cables Edited by OCEI 2021, Chapter 5

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