Much has been said about the aging condition of power cable installations in the United States. Cables can be categorized as service-aged solid dielectric, service-aged laminated (PILC), or cables of more recent design and installation. Much has been learned about the causes of cable outages, and recent studies indicate that even with design issues in early cables, the major cause of these outages can be related to poor quality during the installation process, either in cable installation, termination, or splicing.

The National Electric Energy Testing Research & Applications Center (NEETRAC) documents that approximately 50 percent of cable outages can be directly attributed to poor workmanship during cable installation, splicing, and terminating. As a result of the failure analysis studies conducted by NEETRAC, it can be concluded that there is a significant connection between cable outages and a lack of training in cable installation, splicing, and terminating of medium-voltage cables. As well-stated in “Cable Accessory Failure Analysis presented at the NEETRAC Fall 2010 ICC Educational Session: “All evidence points to improved training as the single most cost-effective means of improving system reliability.” Figure 1 represents the process of improving system reliability through failure analysis, training, and skill certification.

**FAILRE ANALYSIS**

First, consider the issue of failure analysis. A process of root cause should be employed to all cable outages to determine the primary cause of failure. If the failure is due to a product quality issue, the manufacturer is likely involved, and these types of issues normally include a significant timeline. Redirection in purchasing and product approvals may be necessary to offset any further outages due to the use of the product.

More often, the root cause can be identified as a workmanship issue, either in cable installation, splicing, or termination. Often, imminent cable failure is due to tracking caused by inadequate preparation and cleaning during the splicing process. This is one of the many common modes of failure experienced by utilities today.

**Figure 1: Improving Cable System Reliability**

*Tracking leads to imminent cable failure and is caused by inadequate preparation and cleaning during the splicing process.*
Another example of improper cable preparation is where tool settings were not adequate for the semi-con stripping process, which will certainly result in failure.

In many cases, the results of improper cable installation appear make it somewhat difficult to get to the bottom of what actually caused the initial failure. With these issues in mind, it is imperative that a comprehensive cable failure analysis program be in place to determine root cause, thus ensuring that costly failures can be eliminated.

Handling, preparation, splicing, and terminating are imparted to the worker. This is a craftsmanship issue that requires a detailed understanding of medium-voltage cable construction as well as the use of proper procedures and tools. Historically, these craft skills were taught in an on-the-job (OJT) fashion with apprentices working under the watchful eyes of skilled craftsmen who had years of cable experience. These mentors grew up in the early stages of the cable industry and acquired their skills over a significant timeline that coincided with the boom of the power cable industry. As Baby Boomers are leaving the workplace, so are most of these mentors and, along with them, many years of cable splicing and terminating craft skills.

OJT training philosophies need to be supplemented with more formal training with finite objectives and proctored labs where workers not only learn the technologies, but also the craft skills necessary to perform medium-voltage cable work. The implementation of formal cable training greatly reduces the time it would take to gain this experience on the job. By implementing formal training, the quality of instruction can be monitored to ensure that all trainees get the same information and apply the knowledge in controlled lab exercises proctored by experienced instructors; this ensures that the mentorship is complete. The impact of high-quality training where workers demonstrate the learned skills has a definite impact on the future quality of maintenance and new installation work.

Training can be outlined in four basic areas of craftsmanship:
- Cable installation and handling
- Cable preparation and tools
- Cable splicing
- Cable termination

CABLE INSTALLATION AND HANDLING
Many cable failures occur because of mishandling the cable during installation. Issues such as exceeding the bending radius, excessive tension, excessive side-wall pressure, cuts, abrasion, and damage to jacket etc. can lead to cable failure. Much of this damage goes unrecognized as many current acceptance testing methods will not identify the damage unless it is catastrophic in nature. In
short, these damages go un-noticed — sometimes for years — and ultimately lead to failure and a premature shortening of cable life.

Cable handling, specifications, rigging, application of lubricants, conduit fill, etc. are necessary components of training that installers need to ensure proper installation of medium-voltage cables. It often takes a significant amount of equipment and rigging to install power cables.

Cable handling and installation take on significant meaning when considering an installation that requires a high level of craftsmanship. A cable failure in this type of installation could potentially cause catastrophic damage to other feeders in the same vault. Every aspect of the need for a quality cable installation is apparent.

CABLE PREPARATION AND TOOLS
A large number of cable outages can readily be attributed to how the cables were prepared for splicing or terminating. Most cable manufacturers do not provide explicit instructions on how to prepare the cable; rather, the instructions specify the dimensions required in the preparation. Most manufacturers have a disclaimer that reads as follows: “Prepare cables according to acceptable industry practices.” Therein lies the ambiguity, as no specific guidelines are provided as to methods or tooling other than tool manufacturers’ instructions on how to use their specific tools.

Procedures vary widely in the U.S. and, in many cases, there are no specific requirements. Most splices and terminations come in kit form today, and the assumption is that all the instructions needed are in the kit. This is a fallacy, as there are no specific instructions on cable prepping procedures and techniques, not to mention appropriate tools. Everyone would agree that the tool illustrated on the left in Figure 2 would not be appropriate for cable preparation. On the other hand, some may believe that the tool on the right in Figure 2 would be an appropriate tool for preparing a cable. Box cutters and other razor-blade knives have contributed significantly to cable failures in the U.S. One could argue that in the hands of a well-trained splicer, the box cutter would work. The better argument is that the appropriate tool is one manufactured for cable prepping, and that is the tool that should be in the hands of a well-trained splicer.

There are many tools available for any cable splicing or terminating project. Cable tool selection is a responsibility of the end user and should be based on reliability, ease of use, and repeatability of the task being performed. Adjustment and maintenance of the tool is as important as the tool itself. Keep in mind that improper use of the tool or a maladjusted tool could prove detrimental.
The use of appropriate tools alone does not ensure quality. Training in cable construction, dimensions, materials, care, and use of appropriate tools, along with environmental controls, are needed to equip the worker with the skills to complete a quality splice or termination.

**CABLE SPLICING**

Let’s consider the technologies available today to splice medium-voltage cables. The major technologies employ products of tape, heat-shrink, molded, cold-shrink, resin, and a specialized group of products for paper-insulated lead cable splicing. Technologies are also available where the outside diameter of cable is a significant issue or where flexibility is needed, such as cables for dredge or mining operations. All of these products require special skills for the splice to meet the quality standards required for the installation.

There are literally hundreds of individual products and kits that cover the scope of medium-voltage cable splicing. Mastering the technologies required to move efficiently within the medium-voltage cable field requires a solid base of cable understanding. The use of specialized tools, attention to detail, preciseness, and other skills are required to perform quality splicing with the array of cable and ancillary products available today. The following introduces examples of several technologies used in industrial and utility cable systems with comments identifying certain skills needed to perform quality work.

**Tape Splice**

Tape splices can be completed in various levels of voltage and configurations. Instructions are normally very detailed, and several different types of tapes are used to complete the splice. Tapes can be ordered in kit or bulk quantities depending on the end user’s needs. These types of splices define the craft skills needed to perform medium-voltage cable splicing. Properly completed, this type of splicing will perform well for many years.

The use of appropriate tools alone does not ensure quality. Training is needed.

Some of the critical points that must be employed by the splicer include:

- Cable prepping dimensions are critical.
- Cable must be kept extremely clean and splicer cannot handle insulation surfaces.
- Proper tape must be used to replace cable construction.
- Thickness of materials is critical, especially the insulation layers.
- All tapes are assembled in a half-lapping process that has to be learned.

15 kV cable being spliced using the straight tape splice method.
Tension and tape elongation is critical for proper performance of the splice.
Moisture proofing, grounding, shielding, rejacketing are all part of the technology.
The variables in maintaining tension, precise interpretation of instructions, and the time it takes to assemble this type of splice make this technology somewhat difficult to master.

Heat-Shrink Splice
Modern material science should be credited for the development of various types of heat-shrink materials. These products are available in multiple voltage levels and numerous cable configurations. Since these products use heat from a torch for assembly, a multitude of precautions and safety procedures must be implemented by the splicer. Confined space work, flames, hazardous location work, and the general requirements for using flames are skills required of the splicer.

Cold-Shrink Splice
Cold-shrink splice products have entered the product market and are being extensively used in the wind power sector. These splices are normally used on large-conductor, jacketed concentric cables and can present some difficulty in installation in direct-bury trench installations due to the environment. As mentioned previously, prepping, dimensions, assembly, and clean insulation surfaces are critical to the reliability of all splices. Since many of these splices are at the 35 kV level, environmental issues during construction are main contributors to failure.

Molded Splice
Molded products have increased in use due to the ease in assembly these products provide and are the product of choice for underground residential cable installation. These products come in all medium-voltage ranges and can be slip on, bolt on, or a combination of technologies to accommodate the splicing configuration desired. The cable prepping and adherence to specific dimensions are critical for this type of product. The tracking surfaces provided by these splices are usually short, requiring the surface to be extremely clean during installation.

Resin Splice
Resin splices are not the most common type of splice used in the U.S. but do have an application. Assembly, prepping, sealing, and mixing the compounds become critical issues for the assembly of this type of splice. Many failures occur when voids are left in the filling process, producing partial discharges that ultimately lead to failure.
Splicing PILC cable should only be undertaken by techs with significant training and experience with this technology, which is cable splicing in a totally different dimension. Probably the oldest splicing technology in the U.S., it is considered a craft of its own. The largest myth today is that lead cable is gone; there are many miles of lead cable in large metro installations. The main issue today is finding techs who have the experience to splice the cable in the numerous configurations required. With companies transitioning from lead to other cable insulations such as poly or EPR, additional technical issues present themselves. All manner of mistakes can be made that would affect the integrity of the splice, not to mention the safety issues with handling molten lead. Significant tooling and knowledge are required.

CABLE TERMINATIONS
Terminating medium-voltage cables presents similar technical issues as performing cable splicing. The same cable prepping, cleaning, assembly, and connecting technologies are present and require a skilled tech. As can be expected, there are fewer cable termination failures in the U.S. than failures in cable splices. This is due to the environmental issues, difficulty in assembly, and numerous opportunities for error that present themselves during the splicing operation. With that said, a termination being installed outdoors in inclement weather may also present the same difficulties.

What follows are examples of similar products for terminating medium-voltage cables. The most common failure point in cable terminations is the failure to control the electrical stresses created by terminating the insulation shielding. Moisture seals are necessary for terminations installed in outdoor applications or in environments where contaminants might enter the termination.

**Taped Terminations**
Taped terminations require a significant amount of time like hand-taped splices. A taped termination, thought of as half of a splice, requires specific dimensions for tape thicknesses to form a stress-relief cone. The electrical stress must be controlled to ensure there is no excessive electrical stress on the insulation at the point of termination of the insulation shielding. This construction results in the creation of a geometric stress cone as illustrated in Figure 3.

**Heat Shrink Termination**
Terminations made of high-performance heat-shrink materials (Figure 4) are currently available for all medium-voltage cables. As in heat-shrink splices, care in the use of torches must be exercised. One of the significant issues using a torch is that the...
Technician must ensure the entire termination body has been sufficiently shrunk, and there are no voids in the termination.

**Cold-Shrink Termination**

The advent of cold-shrink products that can withstand severe environmental and electrical conditions along with ease of construction have enhanced their use in the utility market. As with all previously described methods, the cold-shrink terminations must be installed with precision and adherence to approved cable preparation techniques.

**Molded Terminations**

Molded and modular terminations are used in a variety of applications including utility, industrial, and commercial. The terminations are designed to address a host of installation configurations and equipment specific termination requirements. Most of the failure issues with molded products are a result of prepping mistakes and a lack of clean assembly coupled with issues in torque and connector crimping. Cable alignment and external physical stress also contribute to failure.

![Figure 4: Heat Shrink Termination](image)

A three-phase cable installation using cold-shrink terminations requires great precision in installation.

![Figure 5: Paper-insulated lead cable terminations can use heat-shrink or cold-shrink technology.](image)

**Laminated Paper Insulated Lead Cable Terminations**

Previous methods of terminating PILC cables consisted primarily of the porcelain-insulated type (Figure 5). Today, PILC cables can be terminated by using modern technologies of heat-shrink or cold-shrink technology. Only well-experienced technicians should undertake the termination of PILC type cables.

**SKILL CERTIFICATION**

There are literally hundreds of examples of medium-voltage cable splicing and terminating that could illustrate different challenges to the cable splicer. The examples in this article promote the understanding of
the different skills a technician must have to perform reliable cable splices and terminations using an array of technologies. Key to the current status of cable splicing in the U.S. is the migration of experienced technicians away from the workforce, either by retirement or being promoted to supervisory-level positions of leadership that take them away from the everyday, on-the-job mentoring necessary to transfer the splicing and terminating skills needed in today’s cable environment.

Employers must consider either more formal apprentice programs with documented mentorship or formal training with clear objectives and proctored activities ensuring trainees demonstrate their skill. Either of these methods should lead to certifying of the employee’s skills and should include documented demonstration of successful splicing and terminating craftsmanship.

Further certifications or re-certification may be necessary based on evidence obtained through failure analysis as indicated in the model in Figure 1. Remember, you can only expect what you inspect. Many of the cable outages today could have been averted by simply having a quality inspection program in place to ensure installations were being completed within guidelines.

Project manning and time constraints on many installations create the “get in, get it done, and get out” philosophy, and cable terminations and splices are usually the last part of the installation. The sense of urgency of project completion can easily be directed at the cable splicer. A skilled, certified cable splicer understands that the quality of the cable installation is in his/her hands and will take all necessary steps to provide reliable terminations and splices that will last the duration of the cable’s life span.

CONCLUSION

To ensure a reliable cable installation, have competent personnel who are trained, have demonstrated splicing skills, and have attained a level of certification that will ensure a quality installation is achieved.

Cable prepping is the basis for all medium-voltage cable terminations and splices. Significant training in the use of special tools and materials with emphasis on following instructions is necessary.

Unlike the assembly of various products that require a more specialized understanding of the process, splices and terminations require the same basic skill in prepping medium-voltage cables. Failures in cable splices contribute to a large portion of cable outages in the U.S.

Validation of a cable splicer’s skill is necessary to ensure quality installations and a reliable cable future. Certification and recertification ensure that the splicer has demonstrated the requisite skills and is maintaining that skill level.

With the high-quality cable products on the market today, we must conclude that the future of cable reliability is in the hands of the cable splicer.

**ALAN MARK FRANKS** is a Senior Safety Specialist at AVO Training Institute. He has over 48 years in the electrical utility industry with an extensive background in electrical safety and power distribution. Mark was instrumental in developing the pre-OSHA Electrical Safety Audit for industry and the conducting of on-site audits of facilities, installation of electrical equipment and systems, safety procedures, and training records and programs, all based on OSHA and NFPA regulations and other industry consensus standards. He has been an authorized OSHA Instructor for all general industry and construction regulations. Mark is a certified fiber optic technician, certified fiber optic instructor (#839), and a member-in-good-standing of the Fiber Optic Association. He participates in numerous associations including NFPA 70E 2000 alternate committee member, International Association of Electrical Inspectors, American Society of Safety Engineers, National Cable Splicer Certification Board, and American Society for Testing and Materials. Mark has provided electrical safety training and performed electrical mine-safety audits for general industry, utilities, and mines both underground and surface. He has instructed all aspects of power cable splicing, termination, testing, and fault location for 25 years and has been instrumental in developing the AVO Training Institute Cable Technician Certification Program.