EPR-Based URD Insulation: "A Question of Confidence"

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Operations and engineering personnel from the largest utilities down to the most modest co-ops are concerned about the possibility of failure of miles of medium voltage (15-35 kV) underground residential distribution (URD) power cable buried within their service areas. More specifically, utility engineers and management alike are beginning to worry about the cable specification decisions that were made years ago and the consequences of cable failure and subsequent replacement.

Appropriately, there is industry-wide concern regarding cable life and related performance. Insulation compound manufacturers, cable producers, utilities, as well as research organizations, such as the Electric Power Research Institute, are attempting to better understand the broad issue of cable failure and the array of satellite issues that either contribute to or retard cable failure.

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The Factors

Interpreting cable failure, or the broader issue of the total life-cycle cost of cable, can be accomplished from several different perspectives. The result is that the list of costs that accrue from cable failure far outstrip the cost of the cable itself. Even so, the origin of this debate necessarily returns to the performance of the cable itself and the combination of the three primary factors that contribute to cable failure: heat, moisture, and electrical stresses.

These three factors degrade URD cable by producing the phenomenon known as electrochemical treeing—microscopic dendritic cracks in cable insulation that lead to loss of insulation properties and eventual cable failure.

Of course, heat is generated in cables under normal service conditions and that high temperatures can be reached during overloading. Unfortunately, overloading is not uncommon today. Explosive growth in populated and industrial areas will perpetuate overloading and the subsequent heat generation. Although managing the effects of moisture on URD cable also is mandatory, it takes a higher priority in the rainy parts of the world. In the United States, the "moisture concern" areas include the Northeast, Southeast, and Northwest. The last factor contributing to cable failure—electrical stresses—varies in its intensity according to levels regulated by the controlling utility. Severe electrical stresses also can be caused by switching surges and lightning impulses.

The Choices

Today, utilities have two choices in insulation materials to protect the miles of URD cable they bury each year. They are cross-linked polyethylene (XLPE) and varieties of ethylene-propylene rubber (EPR).

Comparisons of accumulated electrical and performance data [1] between XLPE insulated cables and EPR insulated cables suggest that the performance of EPR insulated cables extends cable life. Recognizing that overloading is a real problem at many utilities, two studies [2] were completed ten years ago that evaluated the physical and electrical properties of the most popular insulations. The evaluations were carried out from room temperature to above the rated overload temperature of 130°C.

The electrical properties of EPR are stable over the entire temperature range. Whereas the electrical loss characteristics of EPR are somewhat higher than those of XLPE at temperatures below its crystalline melting point (approximately 90°C), the onset of crystalline melting in XLPE produces a drop in dielectric breakdown strength and an increase in ac loss characteristics; XLPE is inferior to EPR at these elevated temperatures. Similar effects were noted in key physical properties measured at these elevated temperatures. Examples include elastic modulus and creep in both tension and compression. Additional laboratory testing results are shown in Table I.

The modulus values at higher temperatures show how dependent XLPE is on crystallinity for its strength. At the emergency overload temperature (130°C), XLPE weakens considerably and becomes prone to deformation. The poorer deformation resistance of XLPE is a concern in applications where it is used with premolded splices or

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TABLE I.
EPR VS. XLPE—PHYSICAL PROPERTIES
(Properties as 1.2 mm insulation on No. 12 AWG wire.)

	EPR (60 phr Clay) Semicrystalline	XLPE
At 22°C:		
Tensile strength, MPa	12.4	16.7
Elongation at breakdown, %	320	500
100% modulus, MPa	4.7	7.9
At 90°C		
100% modulus, MPa	1.8	3.4
At 130°C		
100% modulus, MPa	1.5	0.2
Heat distortion, % (molded slab)	8	20
Tensile strength, % at 22°C after 100% elongation	5	43

elbows. This characteristic deformation also is an expression of the lower cross-link density of XLPE compared with EPR.

Ease of installation is another important consideration in choosing cable. EPR is much more flexible than XLPE over a wide range of temperatures, having a modulus at 100 percent extension only 60 percent as large as XLPE's. Greater flexibility in a wide range of climates means it can be installed easily and cost-effectively with smooth, reliable splices and terminations. These advantages are very important in areas where cable must be installed in extremely cold weather.

Thermal Conductivity and Thermal Expansion

In the wire and cable industry, insulations with the highest thermal conductivity—the capacity of a material to conduct heat—are preferred. Samples of commercial XLPE and a compound of EPR were compared at 90 and 130°C. The results are shown in Table II. It is apparent that the mineral fillers used with EPR play an important role in improving heat conductivity. This means that the insulations of EPR are 30 percent more efficient than the XLPE in dissipating heat, particularly at the emergency overload temperature.

Thermal expansion characteristics of URD cable also can contribute to cable failure. Whereas the thermal expansion characteristics of XLPE may not be a problem at normal operating temperatures, the substantial increase in dimensions at overload conditions frequently leads to problems. The dramatic change in expansion characteristics exhibited by XLPE, particularly in the temperature range near the transition point shown in Fig. 1, can lead to increases in dimension at overload conditions that cause great pressure on the insulation shield, whether extruded or metallic. That pressure can cause a subsequent separation or void to form between the insulation and the insulation shield. The void will lead to cable degradation and failure when the insulation is susceptible to corona.

TABLE II.
THERMAL CONDUCTIVITY

	EPR Semicrystalline	XLPE
W/m-°C		
At 90°C	0.268	0.226
At 130°C	0.264	0.205

At any points of physical discontinuity along a cable, such as splices, terminals, grounds, and clamps, the higher expansion of XLPE when subject to high thermal cycles may cause distortion, material migrations, and voids. Differences in thermal expansion characteristics between XLPE and EPR also can cause failures to occur at the junction of the two types of insulation that are normally in contact in joints, splices, and elbows [3]. Most joints, splices, and elbows are made of EPR. The differing coefficients of thermal expansion of XLPE and EPR may result in the formation of air gaps at the junction of the two insulations. This air gap may produce corona discharges and eventually result in a cable failure.

ACLT Data

In a more recent test sponsored by the Du Pont Company for insulations based on its "Nordel"® hydrocarbon rubber, URD power cables with insulation based on Nordel have been exposed to sophisticated accelerated cable life testing (ACLT). Commercial cable samples with insulation based on XLPE and tree-retardant (TR)-XLPE also were included in the ACLT (Fig. 2).

Results from the ACLT, which still was operational as of July 1, 1988, indicate that cables with insulation based on EPR, made with Nordel, have lasted ten times longer than those with XLPE-based insulation and three-and-one-half

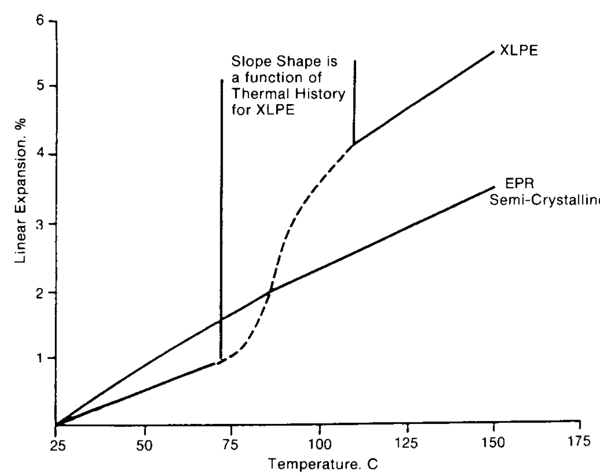

Fig. 1. Thermal expansion/contraction.

Fig. 2. The Du Pont Company is spearheading the industry's newest ACLT for URD cable. The cables, some with insulation based on Du Pont "Nordel"® hydrocarbon rubber, are energized with 35 kV and 250 A in a cycle schedule of 8 hr on and 16 hr off while immersed in a controlled, deionized water-bath. The test measures the retention of dielectric strength as the cable specimens undergo accelerated thermal, mechanical, and electrical stress conditions.

times longer than cables with insulation based on TR-XLPE. The cables with XLPE-based insulation showed a mean failure time of 53 days. The cables with TR-XLPE-based insulation showed a mean failure time of 161 days. As of July 1, none of the 24 cable samples with insulation based on Nordel had failed; that represents 571 days of successful operation in this ACLT environment.

The ongoing test is being conducted at CPI Laboratories, Scottsville, Texas. Test samples are full-size 15-kV-rated cable with 0.175 in. of insulation.

Both power cable manufacturers and utility companies alike are becoming increasingly interested in the results of ACLTs because they provide clues as to when power cables may fail in the field and require costly replacement. Results from the tests indicate a cable's ability to withstand electrical, thermal, and environmental stresses it will encounter over many years in a utility's power distribution system. Cable failure times are recorded. After all cables of a specific design have failed under these accelerated testing conditions, a statistical mean time to failure for that design is calculated. Valuable information can be collected faster than monitoring the performance of cables in use beneath the ground. At the same time, utilities and industry associations are monitoring installed cables so that performance data from the ACLT and field installations may be correlated.

The Debate

Although there are issues concerning the degree of correlation of ACLTs versus in-ground testing, it has been demonstrated that, regardless of current test methodology, EPR consistently outperforms XLPE and TR-XLPE. Hence, the reason for increasing concern in the utility industry.

When electrochemical treeing of URD cable with insulation based on XLPE became an issue with utilities, TR-XLPE was developed. It was a relatively simple matter for utilities to justify a switch from XLPE to TR-XLPE. They found that electrical properties were reasonably similar and the initial cost increase was very minor. It seemed like cheap insurance.

However, now that strong evidence is accumulating regarding the level of ac breakdown in XLPE and TR-XLPE during a variety of ACLTs and related tests, utility managers and engineers are wary about the miles of XLPE and TR-XLPE buried in a variety of strategic urban areas. The fact that the industry has not yet quantified an "in-ground" correlation for ACLTs simply exacerbates the utilities' uncertainty. The fact remains that utilities have installed a much larger amount of XLPE and TR-XLPE cable than EPR cable for URD application.

The effect of URD cable failure is immense because the cost of digging up cable and replacing it is tremendous. Then, there are related maintenance and legal costs that may accrue after the initial failure. All of these costs add up to well over the usual 10 to 15 percent higher price of EPR cable installations.

It is an established fact that EPR cable is used extensively in industrial environments; EPR cable dominates with 90 percent of that market. The reason for this is that plant engineers have a "keep-it-running-no-matter-what" responsibility when it comes to supplying the plant with electric power. Also, the flexibility of EPR cable is important in industry because industrial plants are forever tapping off a line, inserting a splice, and constantly changing the distribution pattern of power within buildings.

Although the manipulation of URD cable in nonindustrial environments is minimal, the performance and reliability demanded by industry are characteristics that should be encouraged for nonindustry applications. At this time, the best way to perpetuate that trend is to specify EPR cable.

Conclusion

Ethylene-propylene rubber (EPR) has performance characteristics that permit power cables to be used successfully under conditions of electrical stress, heat, and moisture, which have produced increasingly higher rates of failure in cables with other insulating polymers. These characteristics of properly compounded EPR, combined with the increased cable flexibility and ease of termination, are receiving more attention from electric utilities concerned with the failure rates experienced with polyethylene and cross-linked polyethylene.

Laboratory tests show that EPR is uniquely resistant to both initiation and growth of electrochemical and electrical trees even without the use of tree-retardant additives, the use of metallic moisture barriers, or strand-filled compounds. This resistance to treeing contributes to excellent EPR cable performance in water- and cyclic-load aging of full-sized underground residential distribution cables.

Furthermore, the outstanding performance in accelerated cable life tests (ACLTs) of cables insulated with EPR-based compounds is undeniable. Regardless of the debate over correlating ACLT and in-ground testing data, results from ACLTs are of great interest to utility personnel and will continue to influence the way power companies gauge cable life expectancy and associated costs.

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