# Global Trends and Motivation Toward the Adoption of TR-XLPE Cable

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**Abstract - Utility companies worldwide are striving to reduce the life cycle costs of their medium voltage distribution systems in response to economic and environmental drives. The use of tree retardant XLPE insulation has allowed utilities to achieve long cable service life under severe operating conditions. This has led to improved life cycle economics and has minimized social and environmental issues resulting from cable replacement activities.**

**This paper will discuss the multitude of accelerated cable aging tests, implications and current global trends for both the TR-XLPE and the Copolymer XLPE insulations. It will review the experience with TR-XLPE in North America, experience with Copolymer XLPE and TR-XLPE in Europe as well as the growing interest and usage of TR-XLPE in Asia. As the long life performance expectations for the MV underground cable system increase, motivation towards using TR-XLPE as the insulation of choice to achieve these objectives is increasing.**

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**Keywords - crosslinked polyethylene, tree-retardant XLPE, copolymer XLPE, accelerated wet cable tests**

## I. INTRODUCTION

Utility companies worldwide are striving to reduce the life cycle costs of their medium voltage distribution systems in response to economic and environmental drives. The use of tree retardant XLPE insulation has allowed utilities to achieve long service life under severe operating conditions. This has led to improved life cycle economics and has minimized social and environmental issues resulting from cable replacement activities.

When extruded cables with XLPE insulation started to replace the older paper cables in the early 1970's, there was an expectation that those cables would provide long life with no electrical property degradation. However, in the late 1970's, it was recognized that XLPE, as well as other polymers, undergo a degradation process, called water treeing, when exposed to moisture and an electrical stress. Two different approaches were used, at about the same time, to solve this problem. In North America, a novel additive formulation approach was used to impart water treeing resistance. The resulting product, called additive TR-XLPE or "TR-XLPE," was introduced in the early 1980's and has shown excellent field service performance. In Europe, blends of polyethylene with ethylene alkyl acrylate copolymers were used to impart resistance to water treeing degradation. This product, called "Copolymer XLPE", was also introduced in the early 1980's and has had excellent field service performance.

This paper will discuss the global experience with tree retardant XLPE cables in medium voltage cable systems. It will review the cable aging test results for both the TR-XLPE and the Copolymer XLPE products as well as review the experience with TR-XLPE in North America, experience with Copolymer XLPE and TR-XLPE in Europe, as well as the growing interest and usage of TR-XLPE in Asia.

### *A. Experience with TR-XLPE in North America*

Tree-retardant crosslinked polyethylene (TR-XLPE) was designed to overcome the water treeing deficiency of high molecular weight thermoplastic polyethylene and crosslinked polyethylene (XLPE). In addition to significantly retarding the growth of water trees, TR-XLPE was designed to maintain XLPE's high dielectric strength and low electrical loss. It was introduced in 1983 and in the ensuing 23 year time period, TR-XLPE has become the predominant insulation used for medium voltage underground distribution cables in North America. Over these years, laboratory testing has consistently demonstrated the excellent resistance of TR-XLPE against degradation in wet electrical aging. Accelerated cable testing methods have further proven the performance enhancement of TR-XLPE in wet environments, such that TR-XLPE performance remains a benchmark in the North American cable industry. Additionally, there have now been 23 years of experience with TR-XLPE insulated cables in North America with excellent field performance. Evaluations of field aged cable continue to support the performance advantages of TR-XLPE over other insulation compounds.

As a review, in the 1970's, unjacketed high molecular weight thermoplastic polyethylene and cross-linked polyethylene (XLPE) cables began failing prematurely with water treeing being associated with the cable failures.[1,], [2], [3] This experience identified a need for an improved XLPE insulation. In the 1970's, Union Carbide Corporation developed a laboratory test to characterize the initiation and growth of water trees in an insulation material.[4] This laboratory test provides the capability to characterize the influence of a material's formulation on its water tree resistance such that a novel additive was identified that provided significant water tree retardancy to XLPE, called TR-XLPE. Figure 1 highlights the water tree growth shapes of XLPE and TR-XLPE in the laboratory test after aging 90 days at room temperature with the microphotographs being taken at 40X magnification. Figure 2 highlights the length of the water trees grown in XLPE and TR-XLPE in this laboratory test with days of aging. This lab test has now been accepted by the industry and adopted as ASTM D6097-97. As demonstrated by the water tree shapes in Figure 1, the TR-XLPE grows smaller and constrained trees compared to conventional XLPE.

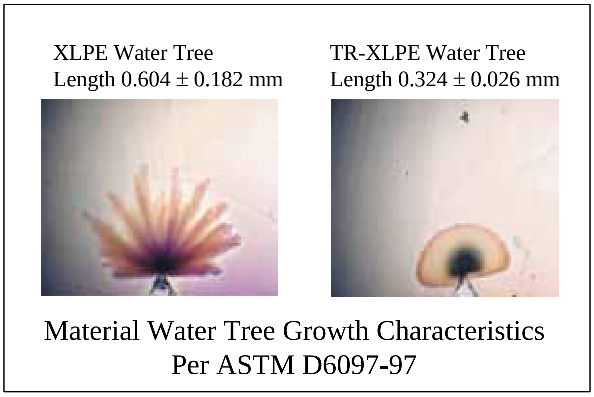



Figure 1 : Water Tree Growth Patterns in XLPE and TR-XLPE

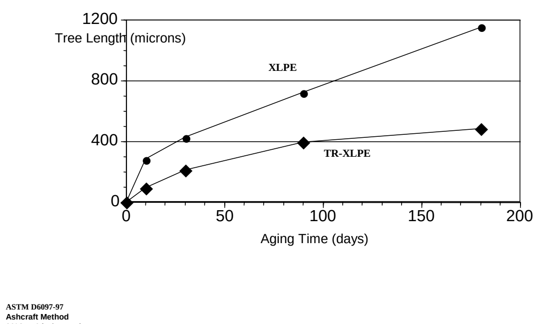



Figure 2 : Comparison of Water Tree Lengths in XLPE and TR-XLPE as a Function of Aging

Following the laboratory demonstration of improved water tree resistance, TR-XLPE demonstrated improved performance in the key North American wet accelerated cable electrical tests of the AEIC Accelerated Water Treeing Test (AWTT)[5] and the Accelerated Cable Life Test (ACLT)[6]. In the 1980's, TR-XLPE showed dramatic improvements over XLPE.[7] While material improvements over the years have improved the performance of both XLPE and TR-XLPE cables, recent tests continue to show the superiority of TR-XLPE with Figure 3 demonstrating the performance improvement obtained by TR-XLPE over XLPE in the 1990's North American AWTT test. In North America today, TR-XLPE has become the industry benchmark for AWTT performance and ACLT performance for long life cables.

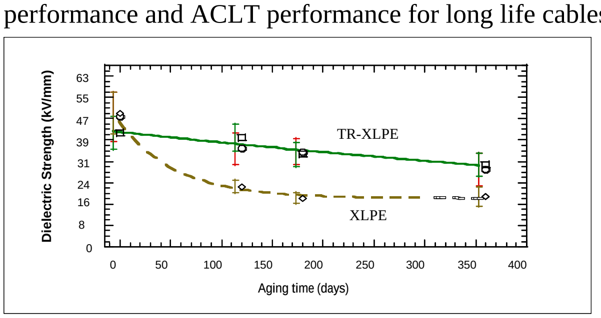



Figure 3 : Performance of TR-XLPE and XLPE in the AEIC AWTT Test in 1990's.

In addition to the improved performance of TR-XLPE in the ACLT and AWTT, other accelerated cable tests conducted in wet and high electrical stress conditions have also demonstrated the improved performance of TR-XLPE. In a cable aging program conducted by NEETRAC[8], TR-XLPE outperformed both XLPE and EPR insulated cables. In this test program, jacketed cable designs were used with water outside the cable but none in the conductor and the cables were operated under temperature conditions representative of feeder cable conditions. Figure 4 demonstrates the superior performance of the TR-XLPE insulated cable versus the XLPE and EPR insulated cables in that no cable failures occurred with the TR-XLPE after five years of aging.[3]

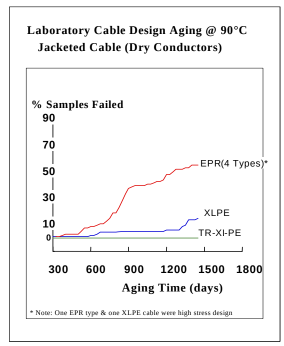



Figure 4 : NEETRAC Cable Aging Program Comparing the Performance of TR-XLPE, XLPE and EPR Insulated Cables

In recent years, two major studies have been conducted in which field aged cables were removed from service and their electrical performance characterized.[9], [10], [11] Figure 5 combines the data from these two studies using similar 35 kV cable design.[12], [13] Though we recognize these were different field installations, the results of the studies demonstrate the excellent stability of the materials in the field. In both field installations, there were no failures with the TR-XLPE cables. These studies demonstrate that TR-XLPE shows the highest level of dielectric strength after 17 years of field aging.

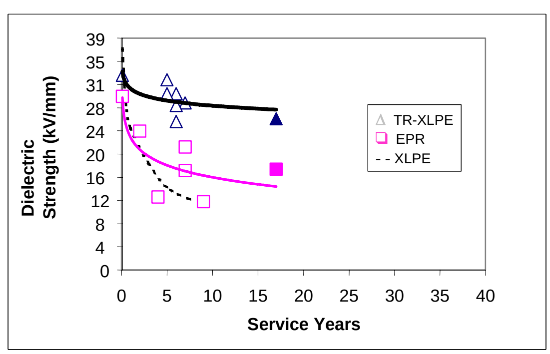



Figure 5 : Dielectric Strength of Field Aged 35 kV Cables

Cable field experience after 23 years continues to support the performance advantages of TR-XLPE. Over the past 23 years, the demonstrated performance of TR-XLPE insulated cables has met the initial design expectations such that projections are being made in North America for TR-XLPE cable life well in excess of 40 years. [14], [15]

*B. Experience with TR-XLPE in Europe*

In Europe, a different approach than in North America was used. Emphasis was placed on cleanliness and retention of electrical breakdown test after aging in water. Researchers found that blends of the polyethylene resin used in XLPE with copolymers, based on ethylene alkyl acrylate copolymers, resulted in improved resistance to electrical breakdown after aging in water under electrical stress. The resulting product, called "Copolymer XLPE" or sometimes just "Copolymer insulation" was introduced in the early 1980's and has also had excellent field service performance for MV cables. A review paper, summarizing the 20 year history with the product and the key performance advantages over standard XLPE, was presented at the 2003 Jicable conference.[16]

Similar to North America, long term wet aging tests were developed to confirm the improved resistance to degradation of copolymer XLPE, which later became specifications for performance cable systems in many European countries. The best known was the German VDE two year aging test, which was a basis for the recently harmonized CENELEC test.[17] Typical results for the Copolymer XLPE compared to the standard XLPE and to EPR are shown in Figure 6, from a presentation at the 2001 T&D conference [18]

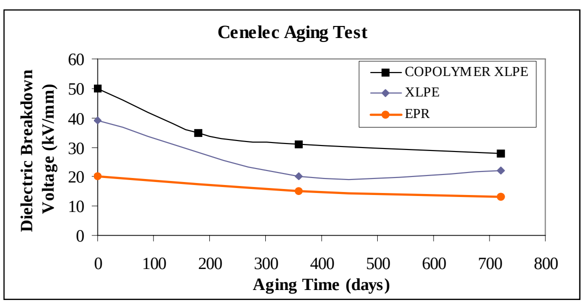



Figure 6 : CENELEC Test Results for Cables with XLPE, Copolymer, and EPR Insulations.

The TR-XLPE technology used in North America was also evaluated in Europe starting in the late 1980's with good results. Long term aging tests showed comparable or better performance when compared to the copolymer XLPE.[19] However, the lack of local production was a logistical barrier for the TR-XLPE product. A few years ago, production of TR-XLPE was started in Europe. Long term cable aging tests following the CENELEC protocol have been conducted at several test facilities. Results from the tests confirmed the excellent retention of dielectric strength after water exposure under these conditions for the TR-XLPE when compared to XLPE as well as to the Copolymer XLPE standard in Europe. Results after 1 year of aging are shown in Figure 7 [20].

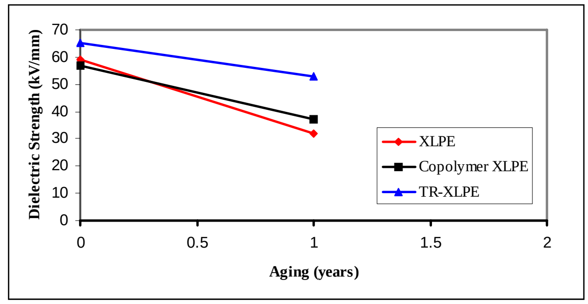



Figure 7 : A comparison of XLPE, Copolymer and Additive TR-XLPE type insulation after 1 year in CENELEC long term test.

The use of tree retardant insulation in Europe is well established, primarily with the copolymer XLPE system and more recently with the TR-XLPE system as well. Recently, Italy, which used predominantly EPR insulated cables for MV, has converted completely to the use of tree retardant insulations. Several Eastern European countries are also recognizing the importance of using tree retardant insulations for long life cables and are adopting CENELEC based specifications. In Russia, a comparative aging test of TR-XLPE, Copolymer XLPE and an XLPE control has been initiated by the Russian Cable R&D Institute (VNIIKP) with the intent of developing specifications for performance extruded cable systems.

In the Middle East and Africa, TR-XLPE has been evaluated and approved in several countries such as Saudi Arabia, Israel, the UAE and South Africa.

*C. Experience with TR-XLPE in Asia*

Historically, in Asia there has not been a uniform emphasis on the long term performance of MV cables such that there were no performance specifications to ensure long life cables. As the performance results of the tree retardant XLPE insulations being used in North America and Europe have been consistently demonstrated, several Asian countries began adopting performance specifications for their cables. One of the first countries was the Philippines, where the largest utility, Meralco, instituted a cable specification requiring TR-XLPE insulation in the early 1990's. Several years later, the Korean utility KEPCO also instituted a cable aging test protocol and a specification which requires TR-XLPE insulation[21].

In China, electric utilities are experiencing large growth in their underground cable networks and are beginning to focus on improving the life and reliability of medium voltage cables. In order to assess the performance improvement with TR-XLPE insulation for the PRC utilities, The Dow Chemical Company and Wuhan High Voltage Research Institute (WHVRI) have jointly developed and sponsored a cable testing program with PRC cable designs. The test program, based on the North American AWTT protocol, included three different cables: one with local PRC XLPE insulation and semicon shields; one with North America XLPE insulation and semicon shields; and one with North America TR-XLPE insulation and semicon shields.

Results from this cable aging test program show the clear performance superiority of TR-XLPE cables and the test program clearly differentiates between the performance of TR-XLPE, XLPE, and local XLPE materials[22]. Furthermore, the test protocol lends itself to being the format for a useful qualification and screening test for PRC utilities. The results after one year of aging provide a clear indication of the longer life expectancy of cables made with TR-XLPE insulation. The key data, showing the improved retention of dielectric strength and reduction in bow tie tree counts achieved with TR-XLPE over XLPE are shown in Figures 8 and 9, respectively.[22]

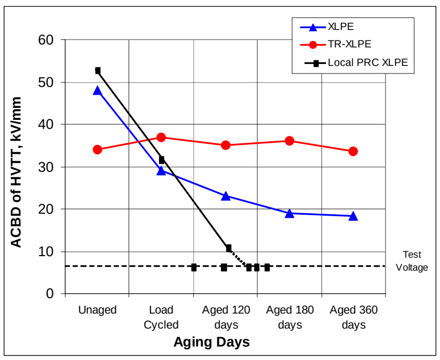
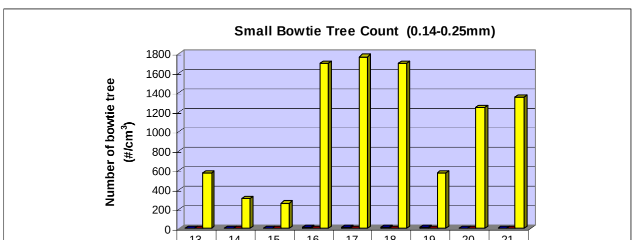



Figure 8 : AC breakdown values from High Voltage Time Test




| | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|
| XLPE | 5 | 7 | 2 | 12 | 13 | 13 | 10 | 4 | 2 |
| TR-XLPE | 0 | 0 | 0 | 1 | 3 | 5 | 0 | 2 | 0 |
| Local PRC XLPE | 569 | 308 | 261 | 1703 | 1771 | 1698 | 575 | 1252 | 1357 |

Figure 9 : Small Bowtie Tree (0.14～0.25mm) counts after 120 days (13,14,15), 180 days (16,17,18), and 360 (19,20,21)Days

The results from this study were published at Wire China 2004. A summary was also presented at the Fall 2004 ICC meeting[22]. As a result of these tests, Wuhan is considering developing performance protocols consisting of longer term wet aging for recommendation to PRC utilities.

## II. CONCLUSIONS

In the late 1970's, it was recognized that XLPE, as well as other polymers, undergo a degradation process, called water treeing, when exposed to moisture and an electrical stress enhancement. North America and Europe used different approaches to solve this problem. In North America, additive based "TR-XLPE" was introduced in the early 1980's and has shown excellent field service performance. Multiple accelerated wet electrical tests have consistently demonstrated the improved retention of dielectric strength achievable with TR-XLPE over other insulation materials. These tests have led to TR-XLPE being the predominant insulation used for medium voltage underground distribution cables in North America. In Europe, "Copolymer XLPE" was introduced in the early 1980's and has also had excellent field service performance for medium voltage cables. The TR-XLPE technology used in North America has been shown to have comparable or better performance than copolymer XLPE in European standard tests such that the growth of TR-XLPE insulation is expected in Europe. In Asia, the expectation for improved cable life and reliability has led to significant interest in TR-XLPE to achieve these expectations. Usage of TR-XLPE in Asia is growing as performance-based tests have been implemented. As the long life performance expectations for medium voltage underground cable systems increase, there is an increasing motivation to use TR-XLPE as the insulation of choice to achieve these objectives.

## III. ACKNOWLEDGEMENTS

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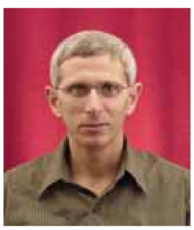

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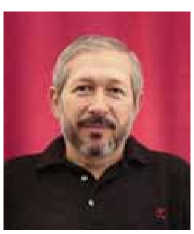

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