

Case Study: Rejuvenation Fluid Injection Results from Duke Power's Little Rock Retail Tap Line, a 115 kV XLPE, Buried Transmission Circuit

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Abstract - In 1994, a Duke Power Company, 115 kV class, XLPE underground transmission cable failed. Failure analysis performed by Cable Technology Laboratories noted a low ac breakdown strength and suggested a high insulation moisture content as a likely reason. Duke Power opted to treat the remaining (un-failed) cables using CableCURE® life-extension, fluid injection technology. The treated cables remained in service for an additional 10 years after injection. Ultimately a termination failure led to the decision to remove them from service. This allowed an unprecedented opportunity to evaluate the responsiveness of solid dielectric, transmission cables to fluid treatment. Until now most of the 60,000,000 feet of injected cable has been in the distribution class of cables. The results of that evaluation, published in this paper, demonstrate treatment effectiveness on par with results obtained on distribution class cables.

Keywords - transmission cable, injection technology, CableCURE life extension technology

I. INTRODUCTION

Injection technology, otherwise known as cable insulation rejuvenation, is a well established option to cable replacement. Cable injection technology involves the injection of a diffusive, water-reactive material into the conductor core of a buried power cable insulated with solid dielectric materials. Once inside the cable, the fluid diffuses into the cable's insulation and chemically combines with the water content inevitably contained within. This process retards the growth of water trees – the primary cause of cable failure in aged solid dielectric cable – simultaneously increasing overall insulation breakdown strength.

Treated cables demonstrate long term survival rates on par with new cables. With application costs on the order of 1/3 the cost of cable replacement it is not surprising that injection technology has experienced remarkable market success. Most of this market growth, however, has been limited to medium voltage 'distribution class' cables. Solid dielectric cables that transmit power at voltage classes above 46 kV have construction details similar to distribution cables, however, questions have remained regarding the potential effectiveness of injection technology in light of the increased insulation thickness required by the higher voltages.

A cradle to grave study of one injection project performed at Duke Power on a 115 kV transmission class

cable helps to put an end to any question about the effectiveness of injection technology when applied to this class (transmission) of cable. In fact, on all measured parameters this cable demonstrated responsiveness to treatment as good as or better than typically seen on distribution cables.

II. BACKGROUND

The Little Rock Retail tap line is a segment of a double circuit line feeding a Duke Power retail substation which crosses the glide path of one of the Charlotte Douglas Airport Run-ways. The portion of the line that directly crosses the glide path was placed underground. It represents approximately 1,800 double circuit feet of 115 kV class 1,000 kcmil Al, XLPE insulated cable.

The original underground installation took place in 1979. The cables were direct buried in a flat configuration 12 inches on center. They were positioned in an envelope with controlled backfill one foot above and below the cables. Six phase conductors and one spare cable were installed.

The cable had a fabric separator tape, extruded conductor shield, 880 mils of XLPE insulation and an extruded insulation shield. A two inch wide semi-conducting rubberized fabric tape was applied over the insulation shield. The metallic shield consisted of a 1.5 inch-wide, 10 mils thick tinned copper tape applied helically. It also included 24 number 14 AWG tinned copper wires. A rubberized fabric separator/binder tape was applied over the wires, and the cable was finished with a 170 mil thick insulating PVC jacket.

In 1994, Duke incurred a cable failure on one of the two circuits. The cable was removed from service and sections of the cable were sent to Cable Technology Laboratories (CTL) for failure investigation and an evaluation of the dielectric strength of the cable that remained in service. It was noted that the cable adjacent to the failure "...had a very low ac voltage breakdown level." CTL suggested in their report that "the low breakdown strength was due to a high moisture level within the insulation." The average breakdown voltage was reported to be 278kV (316 V/mil) across 3 samples.

Duke Power decided to replace all three phase conductors in the failed circuit and investigate the possibility of injection for the remaining circuit. The new installation involved installing a duct bank for the failed circuit with sufficient conduit for installation of a new second circuit should the need arise in the future.

III. INITIAL INVESTIGATION OF INJECTION EFFICACY

After CTL's cable evaluation was performed, UtilX Corp. along with Dow Corning, set about to determine the possible value of chemically treating the remaining circuit rather than replacing them. Dow Corning is the patented provider of CableCURE fluids while UtilX Corp. is the provider of injection services using CableCURE fluids.

In order to study the potential efficacy of the injection technology, a section of the cable, as described above, was injected with restoration fluid. The complete cable was then maintained in 68 degree centigrade water for 30 days in order to accelerate the fluid diffusion into the cable's insulation. After this conditioning period the cable was cut into three 34 foot sections. AC voltage withstand testing was performed on each section and compared to the values obtained for the untreated cable. In all three cases the voltage was first raised to an equivalent of 100 V/mil and maintained at that level for 10 minutes. The voltage was then stepped in increments equivalent to 23V/mil (20 kV) every ten minutes until reaching 348kV (395 V/mil). Terminal flashovers at this level required a voltage reduction to 308kV (350 V/mil) where the cables were maintained in each case at that level for 13 hours, after which the test was discontinued. As a result of the voltage limitation it was not possible to break down the cable and hence to obtain an understanding of the full improvement of the cable's performance.

In addition to the ac breakdown testing, a 3 inch long piece of the treated cable was sent to Dow Corning for fluid penetration analysis. The Cable was sectioned into 8 wedge shaped pieces each of which was microtomed to 250 μ m thick. These sections were analyzed by infrared microscopy in order to analyze the depth to which fluid had penetrated the cable's insulation as a result of the accelerated diffusion scheme. Measurements were taken sequentially from just beyond the conductor shield to the outer diameter of the cable. Treatment profiles showed complete penetration through the cable with remarkable radial symmetry.

This culmination of data was sufficient to convince all parties to move forward with a cable treatment option as opposed to cable replacement. 1,800 circuit feet of cable (7,200 cable ft.) were injected in 1995. This included 3 phases and a spare cable. These cables remained in service until 2004. In 2004 UtilX was informed that a termination failure had occurred, and a decision had been made to reroute a new circuit through the duct bank which had been constructed after the original failure in 1994. Duke Power made the abandoned 3 phase circuit available for follow up research. The spare cable remains energized and underground for future research.

IV ANALYSIS RESULTS

An engineer from UtilX recovered 5, 40 foot sections of the cable and shipped them to CTL for a final evaluation. The cable was tested for insulation tensile strength, dimensional coherency, shield stripping strength, dissipation factor, volume resistivity of extruded shields, ac voltage breakdown, water tree presence, and partial discharge detection.

The insulation tensile strength and ultimate elongation of the insulation was performed in accordance with ICEA S-108-720-2004. Table 1 shows the values obtained as well as the standards for new cables. In all cases, the values were high and well above minimum standards.

TABLE 1: INSULATION TENSILE STRENGTH AND ULTIMATE ELONGATION

Specimen Number	Outer Part of Insulation Wall		Inner Part of Insulation Wall	
	Tensile Strength (psi)	Ultimate Elongation (%)	Tensile Strength (psi)	Ultimate Elongation (%)
1	3260	475	2480	350
2	3070	475	2830	450
3	2730	450	2160	400
4	2860	450	2720	450
5	3400	500	2330	400
6	3300	525	2660	450
Average Value	3110	480	2530	415
ICEA S-108-720-2004 Requirement *	Minimum 1800	Minimum 250	Minimum 1800	Minimum 250

* For new XLPE insulation

Dimensional analysis demonstrated that the cable components had proper dimensions as required by AEIC CS7-82. The table of dimensions has not been placed in this report.

No value was reported for insulation stripping strength. It was noted, however that the cable's extruded insulation shield was firmly bonded to the cable's insulation such that they could not be separated from each other.

Dissipation factors were obtained. Unfortunately this information was not gathered for the pre-injected cable. In addition, it should be noted that correlation data between dissipation factor ($\tan \delta$) values of virgin XLPE and XLPE that contains injection fluids has yet to be established. None the less, the dissipation factors reported were well below AEIC CS7-82 maximum limits. They demonstrated little to no voltage dependence when tested across three voltage levels (10 kV, 40kV and 66kV), and they compared well to virgin insulation (See Table 2).

TABLE 2: DISSIPATION FACTOR

Applied Voltage (kV)	Dissipation Factor (tan δ)		
	Sample 1	Sample 2	Virgin XLPE Insulation
10	240 x 10 ⁻⁶	360 x 10 ⁻⁶	~200 x 10 ⁻⁶
40	230 x 10 ⁻⁶	360 x 10 ⁻⁶	~200 x 10 ⁻⁶
66	240 x 10 ⁻⁶	370 x 10 ⁻⁶	~200 x 10 ⁻⁶
AEIC CS7-82 Specification Limit*	<5000 x 10 ⁻⁶	<5000 x 10 ⁻⁶	<5000 x 10 ⁻⁶

* For new cable

Of particular interest is the volume resistivity measurements of the conductor and insulation shields. Because the injection fluid is itself a dielectric material, there may be some concern that their values may be adversely affected by the injection. The measured values of the treated cable are noted to be well within AEIC specified limits (See Table 3).

Table 3: VOLUME RESISTIVITIES OF EXTRUDED SHIELDS (REPRESENTATIVE SAMPLE)

	Measured	AEIC CS7-82 Spec. Limit
Resistivity of Conductor Shield at 90°C (ohm-m)	68	max. 1000
Resistivity of Conductor Shield at 130°C (ohm-m)	19	max. 1000
Resistivity of Insulation Shield at 90°C (ohm-m)	23	max. 500
Resistivity of Insulation Shield at 110°C (ohm-m)	28	max. 500

The data that is most relevant towards providing an overall assessment of the effectiveness of the injection is the ac voltage breakdown information. See Table 4. Four of the 5 samples were subjected to a complete ac voltage breakdown test. One of the 5 samples was damaged in termination preparation and failed as a result of that damage. Each of the remaining 4 cables was subjected to the maximum voltage available for the test (440kV) achieving a nominal stress of 500V/mil. None of the cables failed under this maximum available voltage stress level. It is worth noting that after 10 years of life after injection and a total operational lifespan of 25 years this cable demonstrated an ac breakdown strength approaching a new cable value of approximately 700 V/mil.

TABLE 4: AC VOLTAGE BREAKDOWN

Applied Voltage, kV	Voltage Stress (V/mil)	Time Under Test (minutes)				
		Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
88	100	10	10	10	10	10
123	140	10	10	10	10	10
158	180	10	10	10	10	10
194	220	10	10	10	10	10
230	260	10	10	10	10	10
265	300	10	10	10	10	10
300	340	10	10	10	10	10
335	380	10	10	10	8**	10
370	420	10	10	10		10
405	460	10	10	10		10
440	500	7*	7*	6*		9*

* No breakdown. Maximum possible voltage reached. Test interrupted due to numerous flashovers.

** Failure located at cable insulation, inadvertent cut made during cable preparation for tests.

Finally, infrared microscopy was employed to analyze the diffusion distribution of CableCURE fluid in the cable insulation (Figure 1). The demonstrated concentration and distribution pattern is extremely good. The fluid concentration contained in the cable’s insulation is nearly exactly at the target levels. More remarkable is that the distribution of the fluid was also nearly perfect with close to steady concentration values from the inner diameter all the way out to its outer diameter.

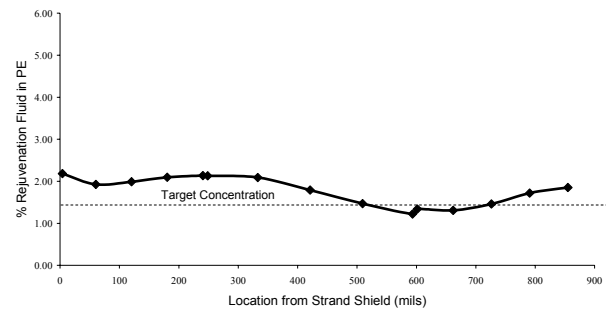


Figure 1: % CableCURE/XL to Polyethylene vs. Position from I.D. to O.D.

V. CONCLUSION

Although a significant amount of transmission cable footage has been injected with rejuvenation fluid over the last decade, the amount of footage is small compared to the footage of distribution-class cable that has been injected. As a result, it has not been possible before now to publish real world results on the effectiveness of treatment on this class of cable. The results published in this report agree well with injection results of the well studied distribution cables. Transmission cables can clearly be benefited by injection technology in the same proven way as distribution class cables.



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