Conference Record of the 2004 IEEE International Symposium on Electrical Insulation, Indianapolis, IN USA, 19-22 September 2004

Service Aged Medium Voltage Cables – A Critical Review Of Polyethylene Insulated Cables

Arthur V. Pack, Jr., PE
Vice President Engineering
The Okonite Company
102 Hilltop Road
Ramsey, NJ 07446
(210) 825-0300
pack@okonite.com

***Abstract*: Utility organizations have major investments in underground distribution facilities to provide electrical service to their customers. Medium voltage cable is a major component of these distribution facilities. Over the years since residential subdivisions have been served with underground electric systems, there have been many insulations sold to the utilities. There has now been sufficient time for these cables to have aged naturally and data is becoming available to evaluate each of these insulations.**

This paper will describe the various polyethylene insulations that have been available over the past 35 years and give the actual performance of these materials. The data indicates service life estimation among these insulations. A follow up paper will provide the same critical analysis of the various ethylene propylene rubber insulations that have been used over the same period.

INTRODUCTION

As part of a comprehensive asset management program, a large investor owned utility has been removing medium voltage distribution cables from service and subjecting them to AC breakdown tests [1]. The goal is to assess the condition of the medium voltage distribution cable plant. The cables were randomly removed from disparate parts of the service territory and include both jacketed and unjacketed cables. Two different voltage classes of cables were taken with no preponderance given to either type. However, one characteristic that the samples have in common is that they are those cables that have not previously failed in service. The breakdown test methodology is the AEIC high voltage time test.

Since the sample consists only of cables that had not failed in service, they are the best cables from the population, the survivors. There is no knowledge of how many sections of cable have previously failed so the population cannot be properly related to the sample. Therefore, we were not able to utilize any of the common statistical methodologies. The sample of cables being tested is not representative of the population of all cables of that type.

As a result of this, a visual way of displaying the ACBD results was chosen. A scattergram is used to depict the location and dispersion of the test data. What is obvious in looking at the data this way is that in general, the best cable remaining from each vintage of cable gets weaker each year. There also appears to be a threshold below which very few cables survive in service.

HMWPE

The AC breakdown data for high molecular weight polyethylene is displayed in Figure 1. This scattergram clearly shows a pattern of decreasing dielectric strength with the service age of the cable. It also shows that very few AC breakdowns occur with values lower than 7 kV/mm.

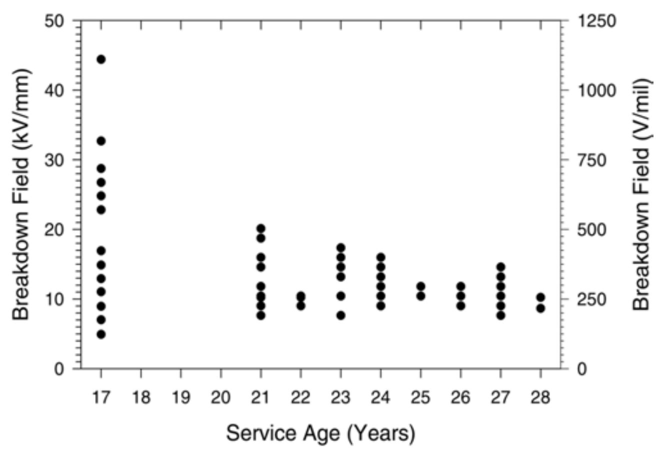

Figure 1 – Scattergram of AC breakdown values of High Molecular Weight Polyethylene cables.

This sample consists of 264 individual pieces of cable, 15 m long each. The effective test length is approximately 9 m with 3m at each end of the sample for terminations. In some instances, more than one sample was taken from a piece of cable removed from the field. Naturally, we would expect to get different AC breakdown values for each such piece. The lowest service age is 17 years because the utility stopped purchasing HMWPE 17 years before the project was initiated.

XLPE

Similarly, Figure 2 shows a scattergram of AC breakdown values from samples of XLPE cable that were removed from service in the same manner as the HMWPE cables. This group consisted of 250 samples of cable.

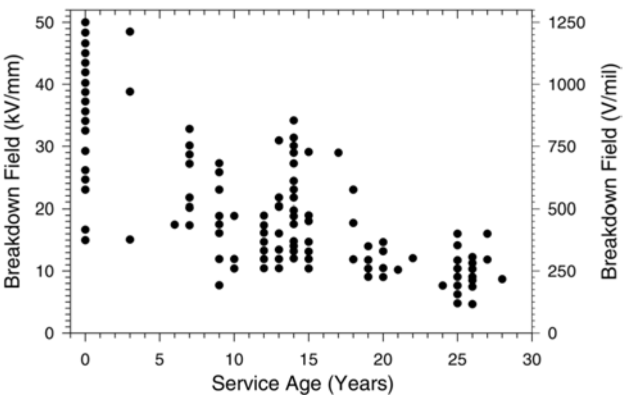

Figure 2 – Scattergram of AC breakdown values for cross-linked polyethylene cable samples.

The results look similar to Figure 1 for HMWPE in that the cables, which had been in service the longest, tend to have the lowest AC breakdown strength. There are also very few AC breakdown values below 7 kV/mm.

As mentioned earlier, it was impossible to conduct a rigorous statistical analysis of these two sets of data because of the nature of the data sets. Each AC breakdown value was taken from a sample of cable that had not failed in service. The number of HMWPE cables in the HMWPE population and number of XLPE cables in the XLPE population are not known because the number of failed cables is not known. With no knowledge of how representative the data is of the population, no statistical methodologies could be used. What is known is that the highest AC breakdown value observed for each vintage of cable represents the best cable that has survived in service.

However, an interesting exercise is the superposition of the XLPE data on the HMWPE data. When we do this, the results are shown in Figure 3.

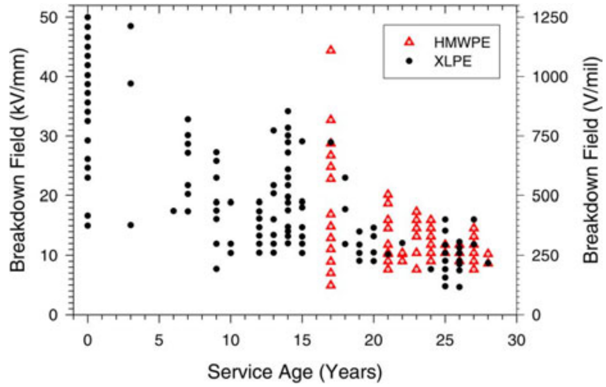

Figure 3 – Combined scattergram of AC breakdown values for HMWPE and XLPE cable samples.

It is obvious that the two sets of data merge and appear confined to an envelope defined by the highest AC breakdown values and what appears to be the threshold of 7 kV/mm as the low limit.

The evolution of polyethylene based cable insulation went from HMWPE to XLPE to gain the higher thermal capacity of a thermoset material (XLPE) over a thermoplastic material (HMWPE). It was readily accepted that the XLPE insulation was superior and in general, the XLPE insulated cables lasted longer in service than the HMWPE cables. However, this data shows that the surviving HMWPE cables are at least as good, if not better than the surviving XLPE cables. This result was unexpected.

TRXLPE

A similar analysis was conducted with samples of cable insulated with TRXLPE, which were also removed from service, and the results reported in the literature [2], [3]. However, here there is a significant difference. This population had not suffered any in service failures, so we are able to state that the lowest AC breakdown for each vintage of cable represents the worst cables of that vintage. Naturally, the highest AC breakdown levels reported were the best for cables of that vintage.

Comparison of the TRXLPE data with the source references will show a difference in the unaged AC breakdown levels [5]. This is due to the fact that TRXLPE cable, when new and still impregnated with the by-products of cross-linking (primarily acetophenone) will breakdown thermally instead of electrically [4]. These thermal breakdowns are lower than electrical breakdowns and cannot be properly compared to aged cables that break down electrically. This has led to confusion over the retained dielectric strength of TRXLPE cable. Therefore we have used AC breakdown data from tests conducted at the Okonite Cable Evaluation and Development Laboratory where the by-products of cross-linking were driven out of the cable by thorough preconditioning. The scattergram obtained is depicted in Figure 4.

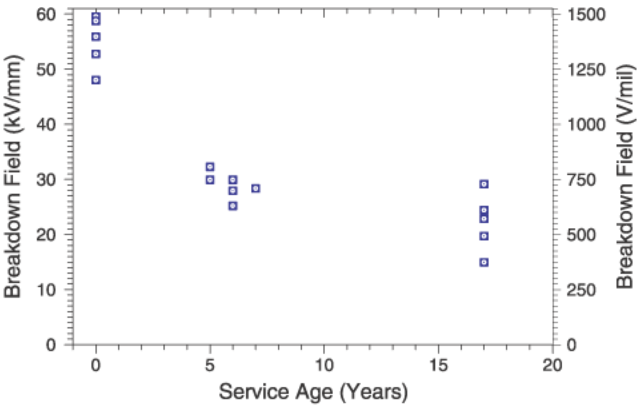

Figure 4 – Scattergram of AC breakdown values for Tree Retardant Crosslinked Polyethylene cable samples.

Again, it is apparent that the AC breakdown strength gets lower as the cables age. With no in service cable failures having been reported yet, we do not know if the 7 kV/mil threshold exists.

COMPOSITE AC BREAKDOWN ANALYSIS

The most striking visual correlations are apparent when the previous three scattergrams are plotted on a common set of axes. Certainly, the HMWPE and XLPE are virtually indistinguishable.

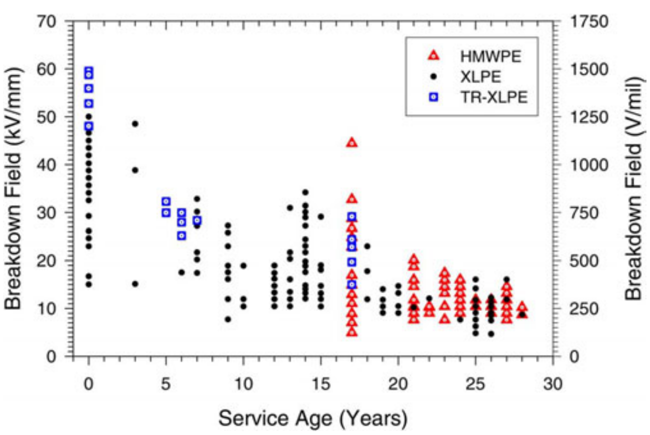

Figure 5 – Composite scattergram of AC breakdown values for HMWPE, XLPE and TRXLPE cables.

The TRXLPE data also fits into the envelope defined by the highest AC breakdown values for HMWPE and XLPE cables and the 7 kV/mm threshold. Since the service age of the TRXLPE samples are limited to 17 years, we will have to wait for the lowest AC breakdown values for each vintage to reach the 7 kV/mm threshold.

WEIBULL ANALYSIS OF TRXLPE

Since there have been no in service failures recorded for the TRXLPE cables in the 17 year period reported on, it is possible to subject the data to a statistical analysis. Figure 6 shows a Weibull probability plot of laboratory breakdown data of field-aged TRXLPE cable aged for various times using a 2-parameter Weibull distribution. Three age groups are displayed, one being the unaged samples, the next being the 5, 6 and 7 year data and the last being the 17 year data. The 5, 6 and 7 year data were accumulated as if it were 6 year data because of the closeness of the individual breakdowns.

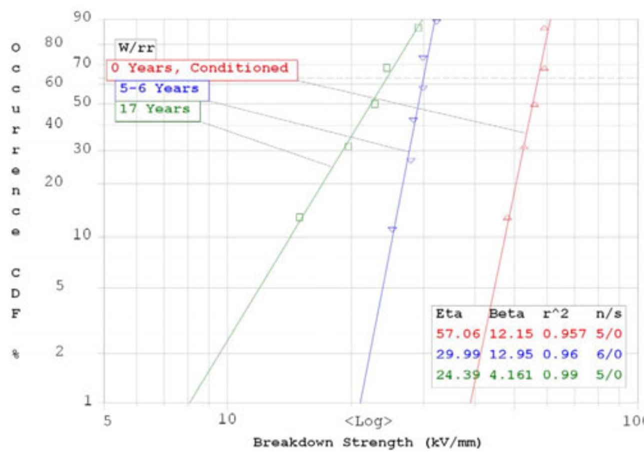

Figure 6 – Weibull plot of the TRXLPE AC breakdown values.

Even with such a small sample, the plot is compelling. There is some aging mechanism taking place in the TRXLPE cables. I hesitate to predict when service failures will commence, but indications are that there is no leveling off of the aging process.

CONCLUSIONS

This analysis strongly suggests that there is no significant difference between any of the three major generations of polyethylene insulation that have been in use for the last 35 years. Treeing (the common mode failure mechanism for HMWPE and XLPE) may also lead to an identical pattern for the TRXLPE cables. Even though the trees in TRXLPE look a little different from the trees in HMWPE and XLPE, it is known that the material does grow trees [6]. All that is needed is time.

It must be observed that the material used to manufacture the TRXLPE cables used in this sample (4202A) is not in general use at this time, and in fact may not even be commercially available. This would make the retrieval of samples of TRXLPE cable manufactured with 4202B the next obvious follow up

As more service aged samples of TRXLPE cable are made available and are given AC breakdown tests, the picture will become clearer.

ACKNOWLEDGEMENT

I gratefully acknowledge the authors cited in the references for their work in accumulating and presenting data in a manner that allows the comparisons made in this paper.

REFERENCES

1. Bialek, T. O. & Grzybowski, S. "Investigation of the Performance of Field Aged HMWPE and XLPE Cables", 2000 Conference on Electrical Insulation and Dielectric Phenomena, pg 760.

2. Katz, C. & Walker, M., "Evaluation of Service Aged 35kV TR-XLPE URD Cables", IEEE Transactions on Power Delivery, Vol. 13, No. 1, January 1998.

3. Person, T., Mendelsohn, A., Shattuck, G., Hartlein, R., "Evaluation of Tree Retardant XLPE (TR-XLPE) and EPR Insulated 35kV Cables After 17 Years of Field Service", JICABLE '03 – International Conference on Insulated Power Cables.

4. Szaniszlo, S., Kabelitems, No. 165, Union Carbide Corporation, December 1994.

5. Hartlein, R., Shattuck, B., Person, T., "Evaluation of 1985 Field Aged 35kV Cables", IEEE Insulated Conductor Committee, Minutes of the Fall 2002 Meeting, p. 140.

6. DiLorenzo, R., Krajick, F., Boss, S., Ronyello, J., Fridland, G., Pehlert, G., Dharmarajan, R., Annicelli, R., "Comparison of AC and Impulse Breakdown of Model EPR and TRXLPE Cables as a Function of Wet Electrical Aging", IEEE Insulated Conductor Committee, Minutes of The Spring 2002 Meeting, p.144.