THE DEVELOPMENT AND IMPACT OF AN EFFECTIVE CABLE TESTING PROGRAM AT PPL UTILITIES INC.

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Abstract

This Paper presents the chronological development of an effective cable-testing program at PPL. It covers such topics as a general overview of the medium voltage distribution system and the reasons it became necessary to develop a program.

The paper will discuss the three types of tests currently being used in implementing the testing:

1. *TDR (Time Domain Reflectometry) and it's use in identifying neutral problems.*
2. *Power factor testing – it's strengths and limitation.*
3. *CDA (Complex Discharge Analysis) and it's usefulness in locating specific cable problems.*

The paper will also discuss the statistical data we have compiled to support continuing and expanding our cable test program.

A Chronological Overview

PPL Utilities serves about 1.3 million customers across a 10,000 square mile area.

As was the case for most electrical utilities in the U.S. prior to 1960, nearly all of our 12.47 kV distribution system was overhead. After 1960 we started installing 15 kV rated cross-linked polyethylene (XLP) with a concentric neutral. The earliest installations were contained in a flexible polyethylene conduit. In 1970 the conduit was eliminated and the cable was direct buried. At the time this was considered to be an effective cost savings measure.

As neutral problems became an obvious result of a direct burial installation, in 1981 we began to purchase and install cable having an outer jacket intended to protect the neutral.

In 1995 we decided to buy cable having strand-filled conductors and to install them in flexible polyethylene conduit.
We presently have about a cable plant containing about 18 million feet of buried cable. About ½ of this has a concentric neutral and was installed without the benefit of any conduit.

Current Conditions

Over the past several years our failure rate has began to accelerate in XLPE cable. Field investigation indicates there are several basic reasons for this change.

The most obvious reason is neutral deterioration. This is primarily due to soil and ground water condition. Neutral deterioration results in stray and fluctuating voltages. This condition eventually can result in insulation failure due to the uneven electrical stresses caused by a resulting nonconcentric or nonexistent neutral.

Cables are failing because of water treeing that can develop into electrical trees, a growing problem in 1960's, 1970's and early 1980's vintage cables.

Electrical treeing is occurring in cable insulation due to physical damage or impurities that probably entered the insulation at the time it was extruded.

Insulation breakdown also is happening when water and other contaminants enter accessories such as splices and terminations. This can result in insulation failure as well.

III Problems - III Solutions

At PPL we quickly concluded that there was no single test method that could identify the many mechanisms of cable failures. We began to seek solutions for the three basic problems that resulted in the in service cable failures.
Simply stated the three areas of concern are:

1. Neutral Deterioration
2. Electrical Treeing
3. Water treeing

The three problems had three solutions:
1. Time Domain Reflectometry
2. Partial Discharge testing
3. Power Factor Tipup Tests

Time Domain Reflectometry

Simply stated T.D.R. testing sends a pulse down the cable, if a change in impedance is encountered its result, with the equipment we are using, is shown as a trace on a display screen as a negative or a positive change in magnitude. The greater the change in impedance the greater the magnitude of the change. Positive deflections are a result of increases in impedance and negative deflections are a result of a decrease.

A completely open neutral will result in the same size deflection as a cable end conversely a neutral that has only a few strands of the overall conductor deteriorated or broken will appear as a small change in the wave form.

We can also successfully see splices (a positive followed by a negative deflection), T-connections or anything else that results in a change of impedance. We can even see areas where the exposed neutral wires have been pulled to one side of the center conductor and are still in tact since this affects the orientation of the neutral with respect to the center conductor.

As is the case with any test equipment that uses measurable pulses traveling along a conductor of uniform design, if we know the velocity of propagation of the insulating medium we can calculate the length of the conductor. Conversely if we know the length it's simple to establish the velocity of propagation of the cable type. At PPL we found it much more practical to carefully measure several lengths of cable of the types on our distribution system to establish an accurate V.O.P. We found that construction prints to be approximations of the actual lengths that could not be depended upon to locate discontinuities or anomalies in the neutral conductors since the overall length was not properly established.

We adopted a ranking system that has served well to categorize the sererity of an anomaly. This chart illustrates the various levels of compromised neutral.

SEVERITY OF DAMAGE

LEVEL	%CHANGE	CHARACTERISTIC
1	0 TO 25%	Difficult to see
2	25 TO 50%	Smaller than a splice
3	50 TO 75%	Larger than a splice
4	75 TO 100%	Larger than the end

Experience with this test method has also shown that on occasion the test must be performed from both ends of a cable to accurately determine the condition of the neutral. Another parameter that can need to be changed is the width of the pulse. The need to vary or effect both changes in technique is usually due to several areas of questionable neutral resulting in sharp attenuation of the signal.
Please examine the graphics associated with this test method for a better understanding of the test significance and

problems that can be encountered in diagnosing the waveforms.

Power Factor Testing

Power factor tests are performed at 2, 7 and 10KV. This is done to establish the “Tip-up”. This relationship is established between the 2 and 10Kv readings. The 7 kV reading is taken to give the field tester a sense of what the power factor is near operating voltage as our distribution system operates at 12.47 kV. The readings at reduced voltages are converted to equivalent 10 kV readings so a direct comparison can be made.

Typically good power factors range between 0.01% and about 0.1%.
%Power factor should not increase with voltage. Slight increases are acceptable but anything in, at or in excess of 0.04% should be considered abnormally high and probably shows the presence of water trees. Sometimes a negative tip-up will be measured. Typically this is indicative of contaminated terminators or splices and an investigation should be made to determine their cause.

Power factor is a very useful tool in determining the overall quality of a cable system but it doesn’t give any indication of exactly where a problem might be.

Partial Discharge Testing

There are several approaches to partial discharge testing in the field. The system we chose to use is called Complex Discharge Analysis (CDA). The CDA system charges a cable system at a rate of 0.1 Hertz. When the desired voltage level is reached the source is disconnected from the test specimen and the charged cable is discharged. A circuit designed to approximate a sinusoidal shape is used to discharge at a frequency of 40 to about 70 Hertz. Due to the presence of inductors in the discharge circuit the resulting wave form has a “ringing” effect that causes the wave to repeat itself but at an ever diminishing voltage level.

The partial discharge is induced to occur in the cable by the discharge portion of the waveform. The majority of PD will occur when the voltage crosses the X-axis or at about 0.00 volts as this is the part of a sinusoidal waveform where the rate of change is the greatest.

Locating the source of partial discharge is very important otherwise spot repairs cannot be made and as in the power factor test you are left with knowing a problem exists but not where it is located.

Similar time domain principals are applied in this test method as in the TDR method of cable neutral analysis. This is accomplished by knowing the velocity of a pulse and also knowing the range of time it should take for the pulse to reflect off the remote cable end or any anomaly existing within its length. You still need to know the VOP or an accurate cable length to accurately establish the source of PD.

This method of PD testing has the advantages of a DC hi-pot without the disadvantages. The DC hi-pot tester is considerably less expensive, requires less space and has less weight because it does not require a large transformer to produce AC power. The major disadvantage of DC testing of XLPE cables is the tendency to charge and polarize the water trees. This changes the water trees into electrical trees over time and weakens the cable considerably usually leading to premature insulation failure. DC testing requires time to determine insulation quality as it waits for the charging of the cable to take place so that the remaining losses are primarily the leakage component of the current and judgements as to insulation suitability are based on that figure. Allowing this amount of time is what results in insulation degradation, converting water trees to electrical and severely compromising the service life. When a CDA wave form is applied to a cable the rate of rise of voltage is comparatively slow, This is similar to a DC test set but the application time of the voltage is 0.1 Hertz about 10 seconds, not enough time to cause the breakdown phenomenon that the DC testing causes while minimizing the weight and size of the test unit. Much the same as the DC units

does since an actual repeating AC wave is not being produced.
Another advantage to the CDA test method only requires the individual application of several half cycles unlike some AC partial discharge test equipment that requires the operator to spot partial discharge in “real time”. This method can result in hundreds or thousands of cycles at a given test voltage before the presence or absence of PD can be determined. If electrical treeing is already present or if water treeing on a significant scale is present the result is unnecessary insulation weakening by virtue of the amount of time the voltage must be applied to make a judgement as to the cables fitness for service.

Using CDA the events occurring in the half wave are captured digitally and examined as waveforms after the actual test has been applied.

In the past one of the biggest problems in field testing for PD was the inability to eliminate sources of interference that could overshadow the Pd coming from the cable itself. Cables have a tendency to act as antennas particularly when it comes to AM radio stations. Am radio can be a real problem as it resides in the frequency spectrum that encompasses the PD. This problem has been addressed by introducing a complex filtering system accompanied by a Fast Fourier transform display designed to recognize and eliminate the AM radio that can cause false PD to appear.

The results of the test method can be viewed as a combination of several applications of a specific voltage that results in a “Map” showing the frequency and intensity of PD along the cable length. The results can also be looked at as individual “Shots” and each PD event can be viewed and examined for authenticity.

SPENDING $$$ THAT MAKE SENSE

After developing some degree of expertise in the use and interpretation of the three methods of cable testing PPL launched a test program. Our cables were prioritized according to criteria such as cables with prior failures and cables considered more critical for varying reasons such as the number of customers served or the number of failures on a circuit.

We were targeting cables that had been previously judged unreliable. This conclusion was usually based on the fact that failures had occurred in the cables or the cables were in the same subdivision, installed at the same time and frequently of the same manufacturer as others that had failed in service.

After a year we compiled our cost savings compared to wholesale replacement in the trouble areas. The results were gratifying. We found that 65% of the cables we had intended to replace didn’t need any attention. About 15% required treating with a compound that displaces moisture and they would then be considered suitable for service and only about 20% of the cable we had targeted for replacement really needed to be replaced.
Simply stated our test program had saved $1,383,000, after expenses, in cable replacement costs in a one-year period.

Conclusion

In short we have an effective tool for the identification of Pd as it exists in buried distribution cables on medium voltage power systems. We also have good systems of identifying neutral problems on jacketed and unjacketed cables as well as identifying the phenomenon of water treeing before it become electrical trees that can lead to
In-service failures.

REFERENCES

/1/ TDR use in Neutral Corrosion Detection and Slice Identification, Keith Lanan, UTILX CORP., May 24, 1999.

/2/ Chapter 5 CC-502b, I, TDR, Utilx Corp.

/3/ A-C Dielectric-Loss, Power-factor and Capacitance as Applied to Insulation Systems of High Voltage Power Apparatus in the Field, (A Review), Part I and Part II, 1991

/4/ Complex Discharge Analyzing (CDA)-an alternative procedure for diagnostic tests on HV power apparatus of extremely high capacity. ISH Gnoz (1995).

/5/ Power Factor Test-Data reference Book, Doble Engineering Company, 1974.

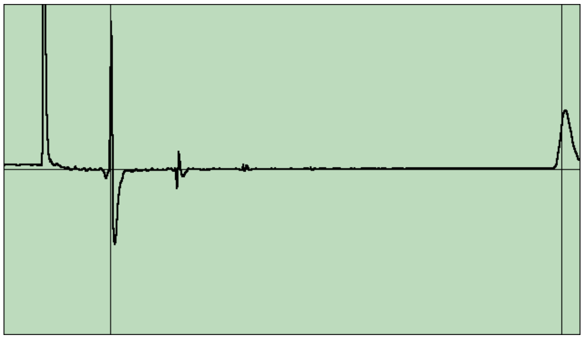
/6/ Recent Developments for Recognition of Partial Discharge (PD) in Power Cable after Installation. First International Conference on Electrical Energy, Damascus (1995)

/7/ IEC 270 (1981 and Draft Sept. 1995)

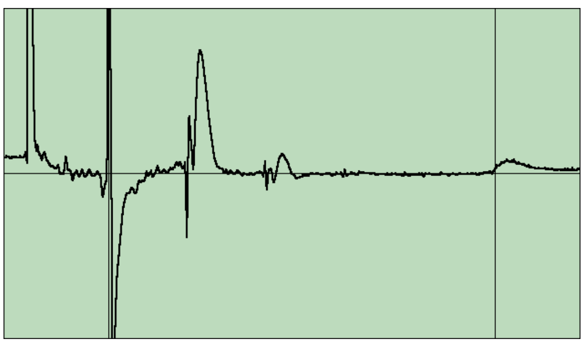
/8/ IEEE Guide 400-3 (Draft November, 1999) Partial Discharge Testing of Power Cables in a Field Environment.

/9/ Users Manual, CDA Partial Discharge Diagnosis System for computer aided detection and location of PD faults in Medium Voltage Power Cables, Lemke Diagnostics GmbH, August 1999.

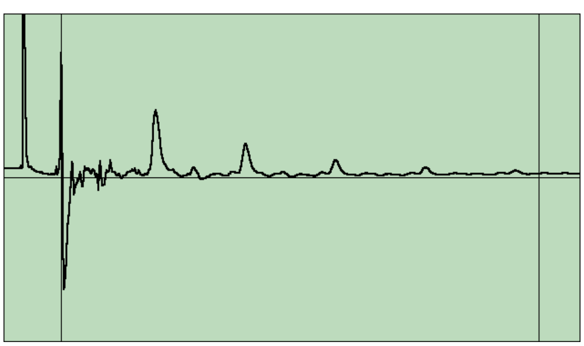
TDR TRACES SHOWING VARIOUS CONDITIONS COMMANLY ENCOUNTERED



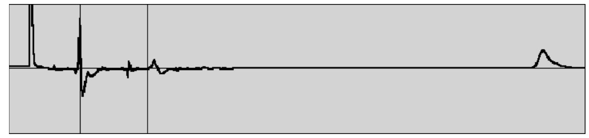
AT THE EXTREME LEFT OF THE WAVE FORM IS THE INITIAL PULSE. AT THE FIRST CURSOR IS THE REFLECTION OF THE END OF THE TEST CABLE. THE NEXT EVENT TO THE RIGHT IS A REFLECTION OF THE TEST CABLE END AS IS THE NEXT VERY SMALL EVENT. AT THE EXTREMEM RIGHT THE END REFLECTION IS VERY CLEAR.



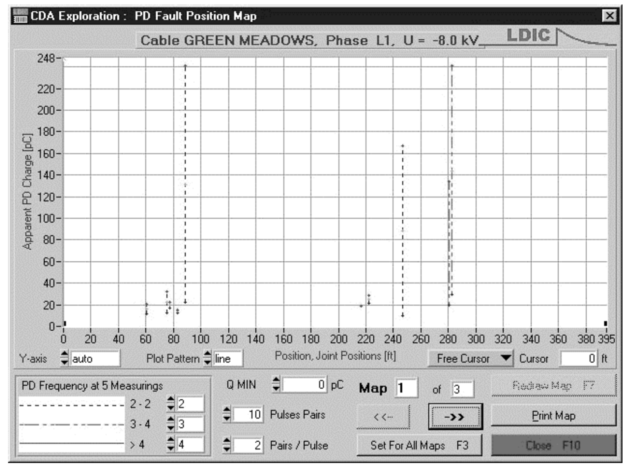
THE LARGEST EVENT ON THIS TRACE IS A HIGH LEVEL AREA OF NEUTRAL DETERIORATION. THE END REFLECTION CAN BE SEEN AT THE SECOND CURSOR. NOTE THE SIGNIFICANT REDUCTION IN MAGNITUDE.



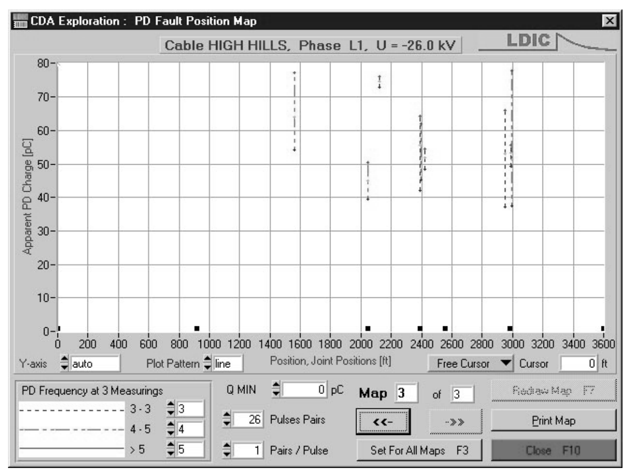
THIS TRACE SHOWS SEVERAL AREAS OF MAJOR DETERIORATION AND GENERAL DETERIORATION OVER THE ENTIRE LENGTH OF THE CABLE. THE SECOND CURSOR IS AT THE END OF THE CABLE. ATTENUATION IS SO HIGH THE END REFLECTION CAN'T BE SEEN.



THE SECOND EVENT FROM THE LEFT OF THE CURSOR IS A SPLICE.



THIS MAP SHOWS SEVERAL AREAS OF PD CAUSED BY DEGREDATION OF THE SEMI-CON JACKET.



THIS MAP SHOWS SEVERAL AREAS OF PD EMINATING FROM SPLICES.