CONDITION BASED MAINTENANCE STRATEGY TOOLS FOR POWER CABLE SYSTEMS

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ABSTRACT

Predictive maintenance programs are beneficial for improving the reliability of medium voltage cable systems. The condition of medium voltage electrical power cable systems must be established for the program to be successful. Assessing the condition of the cable system while it is energized and employing cable rehabilitation or replacement program based on the results will enable the asset manager to realize a reliable system operating in power and industrial companies. The cable treatment technology is based on a well proven silicone injection technology. The condition of medium voltage electrical power cable systems while it is energized and in service are presented. This paper describes the novel technologies used in condition assessment and life extension of medium voltage cables operating in electric power distribution and the results obtained from a few case studies.

INTRODUCTION

Power cables, being the critical component of an electrical distribution system must operate as long as possible within reliability and safety standards. Proper diagnostic testing is a vital part of the maintenance program in order to achieve this goal. The overall objective of diagnostic testing, of course, is to identify defects that result in a system failure and predict the time required for these defects to induce the failure in the cable system. The test should be economically justified and should not cause additional degradation to the system under test. Hence, testing performed at over-voltages is always of some concern and are avoided in the technology described herein.

In-situ testing of installed cable systems while at operating voltage in order to estimate future performance represents an advance in reliability improvement in cables operating in distribution systems. This advance is possible due to novel technology (CableWISE) developed a decade ago which utilizes advances in signal processing and interpretation. This technology is the most effective one of several diagnostic methods available today, as it provides early identification of weak components of the cable system while the system remains energized. This method can locate the degraded components of the system and determine the extent of the degradation. This is essential for maintaining system reliability. Cost savings can be realized by prioritizing the replacement of weak sections of a circuit and rehabilitating the aged extruded cables.

Not all degradation phenomena are associated with partial discharges (PD). In PILC cables for example, failures are commonly associated with moisture ingress, which normally can lead to a failure by a thermal runaway process. Moisture in PILC cables increases the dielectric losses resulting in localized heat generation that thermally degrades the paper insulation and normally leads rapidly to a cable failure. PD may only be present only at advanced stages of such degradation. Regardless, signals emanate from the cable system during service and can change nature of aging regardless of whether conventionally detectable PD occurs.

The majority of cable failures in an extruded cable system are related to water treeing, which lead to failure when they convert to electrical trees (Ref.1) Water treeing is a low level degradation which occurs because of combined effects of ac electric fields and aqueous salts from electrolyte filled voids connected by narrow paths through the amorphous regions (degraded regions) of the polymer. The field induced pressure forces hydrated ions into the polymer. Micro voids are formed through electrochemical reactions (bond scission through oxidation) and polymeric chain rearrangement in low density areas (amorphous). On the other hand electrical treeing is a high Level degradation growing from regions of enhanced (ac/dc) electrical stresses (i.e., metallic asperities, conductive and structural irregularities) typically within water trees in cable insulation. Electrical trees can also be formed as a result of partial discharges in large voids in cables, terminations and joints. Once a water tree is converted to an electrical tree, the time to failure normally is very short because the initiated electrical tree propagates rapidly through the already weakened dielectric. Thus, the only window for conventional PD detection is during the conversion process. Under normal operating conditions, such conversion is caused by prolonged activity in cavities created in the water trees and In situ technology can detect such activities. Figure1 is a summary of degradation sites that are possible
as an extruded cable system ages. In situ (CableWISE) technology can detect, locate, and assess the effects of these sites. Most of the sites can progress to electrical trees and eventual failure, if no action is taken to mitigate it.

IN SITU CABLE ASSESSMENT TECHNOLOGY

Data acquisition begins by placing an RF sensor over the exterior of an energized shielded cable. RF signals emitted by the cable system while in service are detected, amplified, and then recorded on a laptop computer for later transmission to be analyzed by the specialists. (Ref 3) The analysis involves reading the signals both in frequency and time domains. The frequency spectra are used to locate the deterioration which emits RF signals, and the time domain traces are then used to determine the significance of deterioration. The assessed condition of each cable component also depends on the type of cable insulation, influence of installation conditions, and previous condition assessments (when available). Improved data analysis software permits detection of minute signals with the help of correlation software such as Fast Fourier transform. The ratio between the main frequency and the first harmonic is also used to further identify signals of concern.

SEVERITY ASSESSMENT

From the data analyzed, the condition of the cable system between each set of sensors is determined by utilizing the signal magnitude, pulse repetition and phase angle. The cable system length is placed into one of five categories:

**Level 1:** The system is not degraded. No action needs to be taken.

**Level 2:** There is a small amount of aging-related signals. The probability of failure is very low. Retesting is recommended in four years. Proactive rejuvenation can be considered for extruded cables.

**Level 3:** The system is aging and has low probability of failure in two years. Retest the cable in two years. For extruded cables, proactive rejuvenation is recommended.

**Level 4:** The system has moderate probability of failure. It is recommended to replace the cable in 2 years. Further discussion is required to determine the viability of rejuvenation for extruded cables.

**Level 5:** The system has a high probability of failure within the next two years. Consider immediate replacement.

A review of historical CableWISE test data results has been performed by an independent research organization. Substantial data is available where such tested cables had remained energized and in service for many years after the testing was completed. This analysis has suggested that recommendations regarding future performance are justified as being reliably related to the probability of failure, rather than absolute values for any specific tested segment. It is also concluded that the analysis provides guidance on the accuracy of the diagnostic test method. This provides a new approach for guidance to the utilities regarding asset management decisions.

CASE HISTORIES

Case History A: The assessment levels discussed above were used while evaluating cable systems in a major Western Utility in US and serve as an example of how to apply the predictive technology. Overall, the analysis allowed this utility to evaluate the potential of utilizing this predictive condition assessment technology (CableWISE) as part of the overall cable replacement program. This utility monitors and maintains records on their system; the dedicated action to assess the predictive technology provided cost savings and avoided customer complaints. Removing located weakened sections via a planned program and avoiding intentional application of external stresses after predictions have been made has paid dividends. (Ref 5)
Case History B: An in depth analysis of the results was done on the results of diagnostic tests performed in the year 2000 on over 22 miles of distribution feeder cables. The field performance over a 7 year time horizon was examined. The tested cables were under continuous operation after the diagnostic testing was completed. The projections show that of the cables that 'should have failed', the actual failures were low; for cables projected to not fail, the accuracy was very high. The overall accuracy for cable segments and accessories analyzed separately was 98%. (Ref 8)

Field Tests After Condition Assessment

IN Situ condition assessment testing (CableWISE) of installed cable systems involves attaching signal-detecting sensors at selected locations while the cable remains energized and in service. The signals are recorded and later processed to provide an assessment of each component of the cable system (joints, terminations, transformers, etc.)

Experience gained by applying this technique shows that it is essential that users, as a minimum, (a) maintain good records, and (b) appropriately monitor the tested cable systems. In addition, (c) it is essential that the user not perform any voluntary testing activities that can influence the predictions made by CableWISE technology. Therefore certain actions that the user can take to assure reliable operation of their cable system after CableWISE testing include the following: monitoring future behavior, not applying over-voltage stresses, and performing further online test(s) on weakened systems in accordance with the recommendations.

Whenever an over-voltage is applied to an extruded cable system, electrons may induce discharges (leading to an immediately observable event) or become trapped in the insulation (leading to a potentially latent problem). While the goal in imparting an over-voltage is to induce failure during the test, the fact is that electrons that can be trapped and released after the diagnostic testing process is completed may cause premature failure at a later time. Failure at a later time can result simply from continued aging under normal load cycling of the cable system, after ‘aging’ has been accelerated by voluntarily applying the over-voltage. (This phenomenon can not be accounted for the prediction which focuses solely on the normal load cycle aging process without externally-applied overstress.) Hence a voluntary over-voltage application may cause an incipient fault to become a more significant defect that could lead to premature failure.

The user must assure that a sustained or repeated over-voltage is not applied to the cable system after CableWISE testing, or else those voltages will allow further accelerated aging and/or water tree growth, and ‘skew’ the projections. Some of the field procedures using overvoltage are discussed below.

Thumping is a fault locating procedure that applies a current impulse to reduce high fault impedance by flashing over the fault. No specification or standard exists for test procedures, and therefore, no generally accepted thumping repetition rate methodology is available for users to apply. Thumping also strains the core and coil of transformers, and contacts of switchgear attached to the cable circuit. It is the CableWISE position that any excessive thumping can lead to electron trapping, and should be avoided for long cable lengths. Failures should be located by radar, or arc- reflection radar methods to avoid the stress to the un-failed region that is not removed.

A dc HiPot test also applies a stress to the cable that can lead to electron trapping or flashover. Space charge that develops around a defect can actually shield (protect) the region possessing the defect. dc testing intended as a tool to intentionally induce failure of a CableWISE tested cable system, will, unfortunately, have a negative impact on the system, even if a failure is not induced. The harmful effect of dc is related to the degree of degradation (defects) already present in the cable, which for XLPE, may or may not be related to the age of the cable system. This is documented in the technical literature. DC testing should be avoided (Ref2).

Very low Frequency testing, (VLF) intended as a substitute for dc, is also applied at an over-voltage; it is not a predictive test and therefore has a different objective from a CableWISE In situ test. As with dc, it should not be applied after an online test for the same reasons. Furthermore, VLF testing is reported to be effective for ‘weeding out’ cables with a few but large defects, but not effective for cables that possess many small defects (which CableWISE testing can locate). Hence VLF, while potentially avoiding the problems with dc, and still applying an over-voltage, may not even locate an incipient problem. Regardless, since VLF applies an over-voltage, the reasons for not applying VLF after CableWISE testing are the same as explained for dc.

In conclusion, voluntary over-voltages should not be applied to systems previously subjected to Insitu CableWISE testing designed to estimate future performance.

EXTRUDED CABLE LIFE EXTENSION

The technologies used to extend the life of extruded cables have been in use since mid 1980’s. Initially nitrogen was flowed through the strands to dry the cable core and keep the water out, but it was expensive and high maintenance was required to continuously feed the nitrogen to the cable. As research findings showed (Ref.1) that Acetophenone, a byproduct of cross linking process, improved the water tree retardancy in XLPE insulation. Acetophenone was then injected into the strands in the field instead of nitrogen
500 utilities worldwide have utilized CableCURE million feet of underground distribution cables. More than 70 breakdowns have been employed on more than 70 regions. Hence the overall process involves a monomeric starting material that reacts with water and itself, leading to fewer, if any, outages due to dielectric breakdown. The main benefit of CableCURE cable rejuvenation is that it significantly extends the economically useful lifespan of an underground power distribution cable, deferring by decades the cost of cable replacement. A significant improvement in cable system reliability is achieved thus leading to fewer, if any, outages due to dielectric breakdown.

This technology has been employed on more than 70 million feet of underground distribution cables. More than 500 utilities worldwide have utilized CableCURE technology to improve system reliability. Over 99% of those cables remain in failure-free service today.

**SUMMARY**

Asset managers in electric utilities and industrial plants can use novel technologies to improve the reliability of their electrical distribution system. Cost savings can be realized by making proper engineering judgements based on in situ cable system condition assessment (CableWISE) and by increasing the remaining life of the aged extruded cables by fluid injection (CableCURE). These two technologies have been in use for many years with proven success in the field.

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