From: "Ben Lanz" <ben.lanz@imcorptech.com>
To: <nrcrep@nrc.gov>
Date: Fri, Sep 30, 2005 12:41 AM
Subject: Comments on NRC Generic Letter "Inaccessible or Underground Cable Failures That Disable Accident Mitigation Systems"

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To whom it may concern,

The attached document contains updated comments (as of 9/29/05) regarding the NRC Generic Letter found in the Federal Register / Vol. 70, No. 146 / Monday, August 1, 2005 / Notices pages 44127 - 44130

NRC Generic Letter is titled:

Proposed Generic Communication

Inaccessible or Underground Cable

Failures That Disable Accident

Mitigation Systems

In addition to the comments and example given in the attached MS Word document, I have attached a pdf document which outlines the justification for PD acceptance testing of all new installations, as it is only way to *assure cable system insulation reliability.*

If you have any questions about my comments, example or the justification document, please do not hesitate to contact me.

Kindest regards,

-Ben

Benjamin T. Lanz

Senior Application Engineer

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-----Original Message-----
From: Ben Lanz [mailto:ben.lanz@imcorptech.com]
Sent: Tuesday, August 16, 2005 8:50 AM
To: 'nrcrep@nrc.gov'
Cc: Thomas Koshy (TXK@nrc.gov)
Subject: Comments on NRC Generic Letter "Inaccessible or Underground Cable Failures That Disable Accident Mitigation Systems"

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If you have any questions about my comments I invite you to contact me directly.

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CC: "Thomas Koshy" <TXK@nrc.gov>

Shielded Extruded Power Cable Acceptance Testing

Definition
The definition of a shielded power cable acceptance test according to IEEE 400, the IEEE Standard *Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems,* is the following:

> A field test made after cable system installation, including terminations (see IEEE 48) and joints (see IEEE 404), but before the cable system is placed in normal service. The test is intended to further detect installation damage and to show any gross defects or errors in installation of other system components.

The Need for an Acceptance Test
IEEE 400 states that there is a need for an acceptance test. Although modern extruded power cables are thoroughly tested by the manufacturer with a calibrated 60Hz partial discharge (PD) test before shipment, some defects may not be detected. Damage to the cable may also occur during shipment, storage, or installation. In addition to cable defects, poor workmanship on installed accessories, such as joints and terminations, can give rise to additional defects. The goal of the acceptance test is to find these defects before the cable is place in service.

Historical Perspective
Traditionally, cable acceptance tests have been carried out by applying a direct current (DC) voltage to a cable at a specific voltage level and for a prescribed duration. The DC high potential withstand test, or HIPOT, was, and still is, a good choice of high potential withstand test for paper insulated lead covered (PILC) cables. The DC HIPOT is a good choice for PILC cables because PILC cables commonly fail by conduction which can be measured by a test in the form of power loss or 'leakage' current. In the 1960s the electric utility industry decided to embrace a new technology and adopt cables with extruded insulation. The extruded cable systems promised to be more economical, simpler to install, and have a relatively long service life (compared to PILC cables). What the electric utilities did not know is that extruded materials, such as cross linked polyethylene (XPLE) and ethylene propylene rubber (EPR), do not typically fail by conduction. They fail in the presence of an alternating current (AC) field through a mechanism associated with PD. This failure mechanism causes the insulation to be eroded over time until a fault channel bridges its entire thickness. Some extruded materials, such as XLPE, cannot tolerate continuous PD for very long. Other extruded materials, such as some formulations of EPR, can last years before failure, even when under continuous PD conditions. In the early days of extruded cable and accessory development, manufacturers understood the problem of PD and quickly switched the quality control test from traditional dielectric loss measurements, such as power factor and tangent delta, to a calibrated 60Hz PD test. A calibrated 60Hz PD test was not available outside the factory shielded test laboratories until the late 1990s due to high radio frequency (RF) noise in the environment where cables are installed. Today, calibrated 60Hz PD diagnostic tests comparable to the factory tests are readily available for field application.

DC HIPOT per IEEE 400
The DC HIPOT withstand test no longer fulfills IEEE 400's definition of an acceptance test. IEEE 400, section 4.2, states:

> Furthermore, from the work of Bach [Bach, R., et al, "Voltage Tests to Assess Medium Voltage Cable Systems," Elektrizitaetswirtschaft, Jg. 92, H. 17/18. pp 1076-1080, 1993.], we know that even massive insulation defects in extruded dielectric insulation cannot be detected with dc at the recommended voltage levels.

If the purpose of an acceptance test, according to the definition above, is to "show any gross defects or errors in installation of other system components," then the DC HIPOT not suitable for extruded cable installations.

Recommended replacement for the DC HIPOT

IEEE 400 section 7.4 states:

> If the cable system can be tested in the field to show that its partial discharge level is comparable with that obtained in the factory tests on the cable and accessories, it is the most convincing evidence that the cable system is in excellent condition.

According to IEEE 400 "the most convincing evidence that the cable system is in excellent condition" is a test which can best replicate the factory test.

Acceptance Testing at Facility A

The Present Situation

Facility A is currently involved in a massive effort to improve the reliability of the medium voltage underground network. Although Facility A designs the cable systems in-house, most of the cable installations are performed by contractors. Contractors are required to have qualified personnel to install the cable and accessories. Facility A requires that the contractor perform a DC HIPOT as an acceptance test and provide a one year warranty on their workmanship.

Concerns

There are several concerns with Facility A's present cable installation standard.

The installation contractor:	Facility A:
• Claims to have qualified splicer personnel	• Facility A does not have a way to verify the skills of the contactor's splicers
• Uses a DC HIPOT acceptance test	• According to IEEE 400 the DC HIPOT not a suitable acceptance test for extruded cable installations.
• Installs and tests the cable system	• This creates a conflict of interest. Quality control needs to be independent of the installer's bias
• Offers a one year warranty	• According to an EPRI cable accessory research report (EPRI Accessories Project 0420002) even gross workmanship defects in modern accessories can last for years under severe PD conditions. Workmanship defects are very likely to outlast the contractor's one year warranty.

Recommendation

With the concerns listed above, Facility A needs an acceptance test which:

- is supported by the latest IEEE standards
- is independent of the installation contractor
- proves the contractors' qualifications
- can accurately detect and locate workmanship and factory defects
- can replicate manufacturers' calibrated 60Hz PD test
- assures that the cable system will operate reliably for 10 years or more
- can be economically justified

Conceptual Economic Justification for Calibrated 60Hz PD Acceptance Testing

In order to demonstrate the economic viability of the proposed acceptance test, a simple economic study has been prepared comparing DC HIPOT testing with subsequent failures versus PD acceptance testing with no failures. This study shows that Facility A can not afford to ignore PD acceptance testing as part of its cable installation program. Facility A has had ___ failures after installation since _____. The typical cost of a fault is $________ including fault location man-hours, excavation man-hours, materials, repair man-hours, and the loss of revenue due to the down time.

Proposed Acceptance Testing Standard

100010 – Extruded 15kV Class Cable Acceptance Testing

A. Partial discharge testing for new and existing Power Cables, Joints and Terminations
   a. Definition – Partial Discharge (PD) is an electrical discharge that does not completely bridge the space between two electrodes. When a power cable is placed under electric stress of sufficient strength, partial discharge may occur at localized defect sites. These defect sites are caused by workmanship errors and/or aging and are aggravated by power system voltage transients. Defects can be found in joints, terminations, and cable insulation.
   b. Testing Qualifications
      i. Testing Contractor shall be independent of the supplier, manufacturer and installing contractor of the cable system.
      ii. Testing Contractor shall have been regularly engaged in the electrical partial discharge testing of power cables and appurtenances for a minimum of 5 years.
      iii. Test instruments shall be calibrated in accordance with NETA, IEEE, ICEA, or other nationally recognized organizations and standards.
      iv. Services shall be provided by a certified engineering technician to perform the actual testing. Written technician's certifications shall be provided upon request.
   c. Testing Criteria
      i. Disconnect and test each cable (out of service) using external, variable voltage power frequency source.
      ii. Diagnostic testing shall include the following four steps:
         1. Map the cable using a Low Voltage TDR (time-domain reflectometry) to locate joints, terminations and cable anomalies
         2. Sensitivity calibration to match cable factory test conditions with discharge output in the 5 -50 picoCoulomb (pC) range for extruded cable, and at least 50-100pC for accessories.
         3. Diagnostic Stress test with time varying excitation voltage applied.
         4. Data analysis, interpretation and recommendations to include locations of partial discharges.
      iii. Maximum test voltage used shall be 1.5-3.0 times the operating voltage (Uo) of the cable (line–to-ground) depending on the cable's voltage class. An example for 15kV class new extruded cable would be to record response data at 1.0, 1.3, 1.5, 2.0, 2.5, and 3Uo levels.
      iv. Provide summarized reports showing cable length, locations of joints, terminations, and defect sites, PD inception voltage levels, and recommendations for future action.
   d. Frequency of Application
      i. New cable should be tested after installation is completed and before energizing the circuit with network power. If the quality of shipping and handling is questionable, an onsite test of the cable on the factory reel is recommended. The test is recommended to be repeated every 10 years until the cable is 20 years old.
      ii. Significantly aged cable, 20 years or greater, should be tested every 5 years.
   e. General Recommendations for Extruded 15kV Class Cable Systems

i.	IEEE 48 Terminations	No PD less than 5pC to 1.5Uo
ii.	IEEE 404 Joints	No PD less than 3pC to 1.5Uo
iii.	IEEE 386 Separable Connectors	No PD less than 3pC to 1.3Uo
iv.	ICEA S-94-649 MV Extruded Cable	No PD less than 5pC to 4Uo

References

IEEE 400 *IEEE Standard Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems*

Medium Voltage Cable Standard
ICEA S-94-649
Cable Manufactures' Standard for Medium Voltage Extruded Cable
ICEA S-94-649 Extruded cables shall not have a PD magnitude less than 5pC with a PDEV below $4U_0$
(section 4.3.2.1 and Table 4-7)

IEEE 404 -Joints
IEEE Standard for Extruded and Laminated Dielectric Shielded Cable Joints Rated 2.5kV to 500kV
Joints shall not have less than 3pC at $1.5U_0$ (section 7.4.1 and Table 1)

IEEE 48 -Terminations
IEEE Standard Test Procedures and Requirements for Alternating-Current Cable Terminations 2.5 kV Through 765 kV
Terminations shall not have less than 5pC at $1.5U_0$
(section 8.4.1.5 and Table 2)

IEEE 386 –Separable Connectors
IEEE Standard for Separable Insulated Connector Systems for Power Distribution Systems Above 600 V
Separable connectors shall not have less than 3pC at 1.3Uo
(section 7.4 and Table 1)

NRC Generic Letter about Cable Monitoring
updated 9/29/05

NRC must be congratulated for recognizing the importance of periodic monitoring of the condition of certain nuclear plant cables.

IMCORP Recommendation
As a provider of testing services for such cable systems (Re: The Oconee Nuclear Plant), we wish to provide the following guidelines which may help nuclear plant owners/operators in facilitating the performance of meaningful monitoring tests:

1. Withstand voltage tests at any frequency (dc, 0.1Hz or 60Hz), which do not require that *continuous cable response be monitored during the test, should not be allowed, as the test could* introduce defects that may not grow fast enough to produce failure during the test. Failure may occur later on during normal service. We have performed controlled tests on cables subjected to withstand tests and determined, by measuring partial discharge prior to and following the test, that new defects had been created by the withstand test.
2. Global condition assessment tests, such as dissipation factor tests, polarization/relaxation tests, or dielectric spectroscopy may be useful in assessing the overall dielectric properties of the cable. However, these tests alone will miss discrete defects, such as electrical trees, responsible for most ultimate cable failures. Results obtained from these global condition assessment tests could sometimes vary widely during successive tests, with the duration of test voltage application or the condition of the cable terminations. They are ineffective in assessing the condition of the cable system accessories, such as joints and terminations.
3. Partial discharge tests have been shown to be very effective in revealing the sites of potential future failures. In order to conduct a meaningful and predictive test, the following conditions must be fulfilled:
    a. The test sensitivity must be very high (5-20 picocoulomb, pC, detection range is highly desirable). One of the most important factors affecting this sensitivity is the type and condition of the outer metal shield of the cable. Experience indicates that lapped copper tape shielding is prone to get corroded or develop high electrical resistance between overlapping layers. This, in turn, significantly attenuates the partial discharge signal propagating from the discharge site to the measuring instrument, thus yielding an insensitive test. We recommend that nuclear plant medium voltage cables be constructed with concentric neutral shielding wires or, preferably, flat straps. Sensitivity assessment prior to test voltage application is a MUST.
    b. The test must be conducted at an elevated voltage, preferably in the 2.0-2.5 times operating voltage level. However, the dwell time at voltages above operating level should be limited to just 5-10 seconds to prevent any undue further deterioration. This recommended voltage range is necessary to (i) simulate overvoltage transients that may occur on the system and (ii) provide the voltage level necessary to initiate partial discharge at defect sites.
    c. The test system must be robust against any noise that tends to mask partial discharge signals. Effective noise mitigation systems are required to ensure effective test sensitivity.
    d. Data interpretation must be based on standards (e.g. IEEE, ICEA), proven experience and a database covering significant cable lengths.

International Cable Testing Standards
There is industry wide consensus on the need to standardize on a thorough cable test. One of the foremost authorities on cable testing is the IEEE 400 standard *Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems.* In section 7.4, the document states that "perhaps the most significant factory test made on the insulation of full reels of extruded cable is the partial discharge test." The standard continues by stating that "if the cable system can be tested in the field to show that its partial discharge level is comparable with that obtained in the factory tests on the cable and accessories, it is the most convincing evidence that the cable system is in excellent condition." The factory test described in the IEEE 400 standard is a 60Hz off-line partial discharge test with calibrated sensitivity

(according to ICEA T 24380 –cable manufacturer's cable test calibration standard). The IMCORP test conforms to the standard's recommendations and repeat the manufacturer's test as closely as possible in the field by providing a 60Hz, sensitivity calibrated, partial discharge test. Repeating the manufacturer's test in the field is the only way that factory test baseline data can be compared with factory test results and thus, clearly determine a cable system's reliability. The IEEE 400 standard's recommendation cannot be met with any other type of test including the following:

- Low voltage tests
  1. Time Domain Reflectometry (TDR)
  2. Characterization tests used for noise mitigation
- Voltage withstand
  1. DC
  2. AC power frequency
  3. Low frequency AC (VLF)
- General condition assessment
  1. Tangent Delta
  2. Dielectric Spectroscopy
  3. Relaxation voltage or current
  4. Simple insulation resistance
- Partial Discharge
  1. On-line partial discharge test techniques
  2. Off-line partial discharge test techniques which
     a. are not calibrated for sensitivity
     b. use voltage sources other than continuous power frequency

As an example of how industry standards can be used, we will look to the example given by the NRC's Generic Letter "Inaccessible or Underground Cable Failures That Disable Accident Mitigation." IMCORP provided cable reliability consulting and testing services for Duke Power at their Oconee nuclear plant which was mentioned in the letter.

Case Study

In mid to late 1990s, the Duke Power's Oconee nuclear power plant was preparing for operating license renewal. Duke performed many assessments of the plant so that the plant's operating license could be extended beyond the original 40 years for another 20 years. Among the assessments performed was a 60Hz off-line PD test to determine the reliability of several safety related cables. These cables were part of the backup power system of the nuclear plant form a hydroelectric dam (Keowee). In 1997, the first PD diagnostic test of 13.8 kV Keowee underground circuit was performed. This test showed no PD to 1.1Uo (1.1 times the line to ground voltage- 8kV). However, in 1999, subsequent tests to 2.0Uo revealed PD activity in 4 of the 6 cables at voltage levels ranging from 1.1Uo to 1.6Uo. Although Duke could not replace the cable immediately, due to their age and the very poor test results a decision was made to start the design process for a replacement. In order to monitor the cable, Duke instated an annual test program to monitor the rate the cable deterioration during the design and installation of replacement cables. In 2000, the 60Hz, off-line PD tests were performed once again. The test results were the same as the year before. The test results satisfied Duke that the defects were relatively stable and that there would be time to complete the installation of the replacement cables.

In order to assure that the replacement cables were built and installed correctly the Oconee team decided to use a standardize 60Hz, off-line PD test. In order to maintain the highest level of quality control, the cables were to be tested at the factory, after shipment while they were on the reels, installing the cable, and after final termination during a 72 hour limiting condition. The cables were tested at the cable manufacturer according to ICEA standard S-94-649 which requires that cables have less than 5pC of PD activity at 4Uo. Duke witnessed the test in the factory and the cables passed. In October 2001, the reels arrived at the Oconee site. On October 10, 2001, IMCORP tested all eleven reels. There were 3 reels of 5kV class cable at 5200 feet in length and 8 reels of 25kV class cable at 4700 feet in length. Once again the ICEA standard was used but an engineering compromise was reached to limit the maximum test voltage to 3Uo on the account of the rating of the cable terminations. The 5kV class cables were tested to 7.2kV (3Uo) with 5-10pC sensitivity and the 25kV class cables were tested to 24kV (3Uo) with better than 5pC sensitivity. All the cable tested to be free of partial discharge (PD) the 3Uo level. In one case the technicians had built one of the temporary terminations incorrectly. The IMCORP diagnostic system detected the defect and the termination was rebuilt and the cable tested to be free of partial discharge to 3.0Uo.

The cables were installed in the trench by late February 2002. The cables were installed as close to the final connection point as possible, but could not be connected right away due to an NRC 72 hour technical specification. On February 19th, IMCORP tested four 3 phase cables. The two 25kV class cables were 3900 feet in length and tested with a sensitivity better than 5pC. One of the 5kV cables was 4200 feet in length and was tested with a sensitivity between 5-10pC. The last cable was a short 5kV class jumper that was 23 feet in length and was tested with better than 5pC. The results of the IMCORP test found that the installation had not affected the integrity of the cable. All cables were found to be PD free to 3.0Uo. After these tests Duke Energy entered into a 72 hour limiting condition in which the old cables were deenergized and disconnected, and the new cables were pulled into final position and reterminated. With the same sensitivity, the IMCORP test was reapplied. The cable insulation was found to be PD free to 3.0Uo, but 5 of the 8 terminations were found to have PD activity greater than 5pC at 1.4Uo. This, however, was not considered to be consequential. IEEE 48, the termination manufacturer's standards, requires that a properly built termination have less than 5pC at 1.5Uo. By this standard the terminations were very nearly perfect. Duke was somewhat disappointed that the final terminations were not perfect. Both IMCORP and the termination manufacturer recommended that the terminations be given time to seat properly and perform a retest at a later date. Duke has scheduled a retest of these circuits every 5 years to monitor their reliability.

Conclusion

Duke is one of the few power generation companies to take advantage of the latest testing technology which can repeat the cable and accessory manufacturer test in the field. The NRC has demonstrated a serious comment to the reliability of inaccessible or underground cables. The Oconee nuclear team has demonstrated the feasibility of using IEEE 400's recommended practice of repeating the manufacturer's 60Hz off-line PD test. Now it is time for other plants to follow the example and prove the reliability of their inaccessible or underground cables.

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Creation Date:	Fri, Sep 30, 2005 12:40 AM
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