



IEEE Guide for Accelerated Aging Tests for Medium-Voltage (5 kV–35 kV) Extruded Electric Power Cables Using Water-Filled Tanks

IEEE Power Engineering Society

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Insulated Conductors Committee



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**Insulated Conductors Committee
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IEEE Power Engineering Society**

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Abstract: Accelerated aging tests on extruded medium-voltage cables using water-filled tanks are addressed. Information on the equipment, cable samples, test conditions, and measurements to perform the aging tests is provided. Techniques on how to analyze the test data are also included. The implementation of this guide will allow a better description of the test data obtained by different laboratories.

Keywords: accelerated aging test, accelerated cable life test (ACLT), cross-linked polyethylene (XLPE), ethylene propylene rubber (EPR), medium-voltage cable, tank structure, temperature measurement and profile, test conditions, water-filled tanks

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Introduction

This introduction is not part of IEEE Std 1407-2007, IEEE Guide for Accelerated Aging Tests for Medium-Voltage (5 kV–35 kV) Extruded Electric Power Cables Using Water-Filled Tanks.

This guide addresses accelerated aging tests of extruded medium-voltage cables using water-filled tanks. Information is provided on the equipment, cable samples, test conditions, and measurements to perform the accelerated aging tests. The guide identifies the critical test parameters and describes techniques for their measurement and control. The implementation of the techniques will allow test data obtained by different laboratories at different times to be better compared. Specific test values (e.g., voltage) are given in this guide, and the range in test values (e.g., maximum temperature) are more limited than stated in the previous version of this guide.

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1. Overview

The insulations commonly used in extruded medium-voltage power cables are cross-linked polyethylene (XLPE), tree- retardant XLPE (TRXLPE), and ethylene propylene rubber (EPR). These materials are known to gradually deteriorate with time due to the synergistic action of moisture and electrical stress. This degradation, often referred to as water treeing, causes a reduction in the breakdown voltage and an increase in the dielectric loss. The degradation can be so severe that failures can occur in service at operating stresses. The mechanisms of moisture-induced degradation have been studied extensively and it is believed known that several mechanisms are occurring. ~~A thorough knowledge of the degradation mechanisms allows optimum choices of test parameters to be made; this results in an accelerated aging test that evaluates the long-term performance of a cable in the absence of scattered defects. Although there is not a complete understanding of the mechanisms of moisture-induced degradation, the urgency to develop an aging test has resulted in the proposal of several accelerated aging tests for materials and cables (Banks, et al., [B4],[†] Bartnikas, Densley, and Eichhorn [B5], Bartnikas, et al., [B6], Mashikian, et al., [B21], Schroth, et al., [B24], Steenish and Faremo [B26]).~~ Several accelerated aging tests have been developed to evaluate the long term performance of cables (Banks, Faremo, Steennis [B4],¹ Bartnikas, Densley, Eichhorn [B5], Bartnikas et al. [B6], Mashikian et al., [B20], Schroth, Kalkner, Fredrich [B25], Steennis and Faremo [B27]). The tests may be either fixed time, where the cables are aged for a fixed time and then subjected to one or more diagnostic tests to assess the cable condition, or a time-to-failure test. A problem inherent in all accelerated aging tests is the choice of test parameters in the test itself. These should contain the deterioration factors causing service aging and not introduce aging mechanisms that do not occur in service. The diagnostic test must measure a property representative of service aging. Research has shown that the most important parameters in tests to evaluate moisture-induced degradation are electrical stress, temperature, water characteristics, and time.

Two accelerated aging tests have evolved in North America. One accelerated aging test that has evolved in North America into, a Qualification test, is the accelerated water treeing test (AWTT) in which lengths of cables are aged in water-Filled pipes for 4, 6, and 12 months and then subjected to a step ac breakdown (ACBD) test, the diagnostic test (AEIC CS5/ANSI/ICEA S-94, AEIC S6-96). An alternative -649 and ANSI/ICEA S-97-682²). The other is a test has emerged where cables are aged in water-filled tanks, either for a Fixed time or to failure in water-Filled tanks, i.e., an accelerated cable life test (ACLT) (Lyle [B18], Walton, Smith, Thue [B32]). The time-to-failure test has the advantage of involving the whole aging process, initiation, growth, and Final failure. The main disadvantage is that the test duration is unknown and there can be considerable time between the First and the last failure. Several laboratories have performed and are now performing tank-type tests accelerated aging tests in tanks (both time-to-failure tests in which the samples are aged to failure and aging tests in which the samples are aged for fixed time periods followed by a diagnostic test such as a step ACBD test) using different aging conditions of voltage, temperature, water characteristics, etc. This makes a direct comparison of the data between laboratories very Difficult. The situation is further complicated because the methods of measuring some of the critical parameters differ Significantly. As a result, apparently similar test conditions can, in fact, be entirely different in two separate test arrangements. An example of this ambiguity is the temperature measurement. Although a nominal temperature of 90 °C is sometimes used as the maximum temperature during temperature cycling, the precise location where this temperature is measured may vary. It may be measured in the length of the cable outside the water or in the length of cable immersed in the water. If the water temperature is not controlled, however, the temperature of the immersed cable will depend upon the following:

- Tank size
- Tank shape and material
- Volume of water
- Number of cables in the tank
- Whether the tank is thermally insulated, etc.

This guide directly addresses tank-type accelerated aging tests. Accelerated aging test parameters are presented which that, if reported, will allow test data obtained by different laboratories at different times to be better compared.

This guide will:

- Identify the critical test parameters and techniques for their measurement and control.
- Review the levels of the test parameters, such as voltage (V), temperature (T), etc. It is not the intention of this guide to recommend Specific test values.
- Identify the test parameters to be included in reports, etc.
- The following will be discussed:
- Test specimens
- Prior tests and preconditioning of specimens
- Test structure
- Temperature
- Water
- Voltage
- Failures
- Abnormalities
- Diagnostics
- Data analysis
- Final report

It must be pointed out that some parameters are interrelated so that a change in one will have an effect on others (i.e., as already mentioned, the size of the tank could influence the temperature of the cable immersed in a tank without water temperature control).

1.1 Scope

This guide provides information on the equipment, cable specimens, test conditions, and measurements to perform accelerated aging tests on medium-voltage cables using water-Filled tanks, whether the test be a time-to-failure test or a test in which samples are aged for fixed times followed by a diagnostic test such as a step ACBD test. The guide identifies the critical test parameters and describes techniques for their measurement and control. The implementation of the techniques will facilitate a comparison of data obtained by different laboratories.

2. Normative references

~~This guide shall be used in conjunction with the following publications. When the following publications are superseded by an approved revision, the revision shall apply~~

~~The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in the text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.~~

~~AEIC CS5-94~~, CS8-07, Specification for ~~Cross-Linked Polyethylene Insulated~~ Extruded Dielectric Shielded Power Cables Rated 5 through 46 kV.³

~~AEIC CS6-96, Specifications for Ethylene Propylene Rubber Insulated Shielded Power Cables Rated~~
ANSI/ICEA S-94-649, Standard for Concentric Neutral Cables Rated 5 through 46 kV.^{4,5}

ANSI/ICEA S-97-682, Standard for Utility Shielded Power Cables Rated 5 through 69 46 kV. ICEA T-24-380,
Guide for Partial-Discharge Test Procedure.⁶

3. Definitions ~~abbreviations, and acronyms~~

For the purposes of this document, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms* [B13] should be referenced for terms not defined in this clause.

3.1 Definitions

3.1.1 abnormality: Any deviation from the preestablished test conditions, including the tolerance limits, that may affect the outcome of the test.

3.1.2 air failure: A failure in the cable above the waterline but below the termination.

3.1.3 termination failure: A failure in the portion of the cable that does not have a metallic shield covering.

3.1.4 water failure: A failure in the active, shielded cable length that is below the waterline and that did not occur as a result of mechanical damage.

3.1.5 waterline failure: A failure at the interface between air and the tank water to include the distance of the total water line variation.

3.2 Abbreviations and acronyms

ACLT	accelerated cable life test
AWTT	accelerated water treeing test
DSC	differential scanning calorimetry
EPR	ethylene propylene rubber
GMTF	geometric mean time to failure
~~I~~	~~conductor current~~
Mle	maximum likelihood estimators
PD	partial discharge
PL	polymer or polymer-lined
R	conductor resistance
SS	stainless steel
$\tan \delta$	loss tangent (dissipation factor) of insulation
T/C	thermocouple
THD	total harmonic distortion
TRXLPE	tree retardant cross-linked polyethylene
V_0	line to ground voltage
VLF	very low frequency
ω	$2\pi f$ where f is the frequency in Hz of applied voltage
XLPE	cross-linked polyethylene

[ACBD](#) [ac breakdown](#)

3 AEIC publications are available from the Association of Edison Illuminating Companies, 600 N. 18th Street, P. O. Box 2641, Birmingham, AL 35291-0992, USA (<http://www.aeic.org/>). AEIC publications are also available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112-5704, USA (<http://global.ihs.com/>).

⁴ [ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA \(<http://www.ansi.org/>\).](#)

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⁶ See Footnote 5.

4. Cable materials and design considerations

An accelerated aging test in a water-filled tank, whether a time-to-failure test or a fixed aging time test followed by diagnostic testing such as a step ACBD test, imposes a complex combination of electrical, thermal, and mechanical stresses on a cable during the aging test program. Since these stresses are applied to a manufactured cable that, at a minimum, must be a cable core composed of an unfilled conductor (conductor without strand-filling material to block the ingress of moisture or water), conductor shield, insulation, insulation shield (and metallic shield), the test inherently evaluates these individual materials as well as the overall cable structure. The synergistic effects between the various materials are important. Insulation/shield interface characteristics, variable thermal expansion characteristics, volatile diffusion rates, ionic contamination, manufacturing process, and many other factors provide for a complex, dynamic system that is more than a simple sum of the individual parts.

An accelerated aging test in a water-filled tank, whether a time-to-failure test or a fixed aging time test followed by diagnostic testing, can also be used to evaluate more than just the cable core. Since utilities now commonly employ moisture blocked conductors, overall jackets, and a variety of different radial and longitudinal moisture barriers, it is sometimes useful to test complete cable designs. Under these conditions the entire cable design structure is evaluated, including the cable core materials, all moisture barriers jackets, etc. Once again, the many synergistic interactions between all the cable components ultimately dictate the performance of the overall cable design.

In this respect, an accelerated aging test in a water-filled tank can be considered both a *cable core* performance test and a *cable design* performance test. For purposes of this discussion, when a cable core test is performed, the test cable consists only of the minimum components required to make up a shielded cable design. When a cable design test is performed, the test cable contains all of the components that the cable would have if placed in service on an electric utility system.

4.1 Cable core test

This is by far the most common use of the accelerated aging test in a water-filled tank to date. When conducting the cable core performance test, four different aspects of a cable design are addressed.

The first component evaluated is the insulation. It is the component that has to withstand the applied voltage, and for this test, it is not protected from moisture ingress, a key aspect of the aging process for many extruded dielectric insulation materials.

The second component considered to have an important effect on cable performance is the conductor shield. The conductor shield primarily controls the smoothness of the conductor shield/insulation interface, a high stress region of the design that is critical to achieving acceptable cable performance. Conductor shield cleanliness is also very important. Some ionic contaminants, which come primarily from the carbon black used to make the conductor shield conductive, can migrate into the insulation, enhancing sites for water tree initiation and growth.

The third aspect is the insulation shield. Like the conductor shield, the insulation shield controls the smoothness of the insulation/insulation shield interface. It also contains carbon black. However, because the voltage stress at the insulation/insulation shield interface is lower than that at the conductor shield/insulation interface, the impact of the insulation shield on cable performance is considered to be less significant than the conductor shield.

The fourth factor in a cable core evaluation test is the manufacturing process used to make the cable. This includes a multitude of factors including the curing process, extruder and die design and their condition, line speed, and the cooling process. Among other things, these processes affect void size and density, insulation morphological characteristics, and residual mechanical stresses in the insulation.

In summary, a cable core material test is generally considered to be a test of the materials used to make up the core. However, it is also a test of the process used to manufacture the cable and an evaluation of the synergistic interplay between all of these items. Items evaluated in a cable core accelerated aging test in a water-filled tank are listed as follows:

- a) Insulation
- b) Conductor shield
- c) Insulation shield
- d) Manufacturing processes
- e) Synergistic effects between all preceding items

The relative ranking of the listed items is arguable, but the cable core performance test, by its very nature, evaluates all of these components.

4.2 Cable design test

While the accelerated aging test in a water-filled tank is primarily used to evaluate cable cores, it is occasionally used to evaluate complete cable designs. Since complete cable designs often employ some type of moisture blocking component(s), they generally age more slowly than cables in a cable core test. The accelerated aging test in a water-filled tank is ideally suited for evaluating these cables because the test generally runs for extended periods of time, often several years.

A complete cable design normally incorporates a cable core plus a moisture-blocked conductor and a jacket. It may also employ the use of additional moisture barriers including water swellable tapes, hydrophilic or hygroscopic powders, and/or metal laminates. How all of these design characteristics combine to influence performance is extraordinarily complex. The cable core continues to be the most important portion of the cable structure. However, once moisture ingress to the core structure is reduced or eliminated by one or more of the components that make up the cable design, then the dynamics of the aging process can change significantly. For example, if moisture is no longer present at the conductor, the role of the conductor shield material may not be as pronounced as it would be if moisture were present. The same is true for the insulation material. For cable designs that provide for a complete hermetic seal, insulation characteristics such as water tree resistance may no longer be important.

Because it could take several years before specimens in a cable design test fail, it may be appropriate to remove specimens from the aging test periodically and conduct diagnostic tests such as ACBD and water tree counts. This is particularly useful for test programs conducted for the purpose of comparing different cable designs. Once a comparative performance trend is established, the test can be terminated without having to age the test specimens to failure.

Whether conducting a cable core test or a cable design test, it is important to know that the accelerated aging test in a water-filled tank does much more than evaluate the performance of one aspect of a cable construction. All of the cable components—from the conductor shield to the jacket—are inexorably linked. This means that performance data should not be associated with one component, but rather with the entire cable construction.