CABLE TESTING STANDARDS: OVERVIEW OF THE IEEE 400 BUNDLE

BY ALAN MARK FRANKS, AVO Training

Since its inception, IEEE — the world’s largest technical professional association and a major U.S. and global standards organization — has been responsible for literally hundreds of standards and updates that include power cable. The need for testing has existed since the first cables were installed in the 1800s, back when electricity first began influencing American lives.

Studies completed and published by the National Electric Energy Testing Research and Applications Center (NEETRAC) at Georgia Institute of Technology have indicated a significant reason for concern involving the integrity of U.S. power cable installations. Research further indicates that service-aged and new cable installations are subject to the same workmanship issues that cause more than 50 percent of U.S. cable outages, as illustrated in Figure 1. This is not only costly but also negatively affects system reliability.

With the previously mentioned issues in workmanship and the need to identify the status of service-aged cable systems, a new age of cable

Figure 1: North American Cable Outages by Equipment Type
testing is now providing solutions to complex cable problems and establishing baseline data for condition-based maintenance programs.

IEEE cable test standards have evolved with the science of cable and testing technologies that exist today. Tests are identified in major categories as either installation, acceptance, or maintenance in nature. Further, the tests can be withstand or diagnostic and used in combination depending on the user’s needs.

The current IEEE 400 Series of standards consists of five major standards known as the IEEE 400 Bundle. These comprehensive standards provide the guidance industry needs to address testing and evaluating of cable installations old and new. Much research has gone into the development of these standards.

What follows is an overview of the IEEE 400 Bundle of cable standards. A much more thorough examination is necessary specific to an organization’s needs for cable testing and evaluation of data derived from actual cable tests.

Figure 2: Time Domain Reflectometer (TDR)

Figure 3: Insulation Resistance Test

CABLE TESTING STANDARDS: IEEE 400 BUNDLE

The following IEEE standards (or their revisions) are included in the IEEE 400 Bundle. These standards outline current tests that are available and reported as in use in the cable industry.


This standard provides guidance on appropriate tests, including advantages and disadvantages. Field tests are identified as voltage withstand, dielectric response, partial discharge, time-domain reflectometry (Figure 2), and thermal infrared imaging.

For all types of tests, voltage levels and test duration should be consistent with the cable system characteristics. In shielded power cable system quality and reliability, these three aspects are important for field tests and results evaluation:

- A healthy (defect-free and/or non-aged) insulation can withstand a higher voltage stress level, whereas insulation that has aged and/or contains defects should have a lower withstand level (Figure 3).
A test shall be designed to prevent or minimize the shortening of service lifetime due to the field test. In the case of withstand tests, the impact on a defective insulation should be high enough to cause a breakdown or to exceed a critical level of a monitored property.

Voltage level and duration are important, inseparable elements of the on-test and after-test performance of the cable circuit. The recommended test voltages and durations for tests (given in IEEE 400 point documents) are based on extensive field testing and empirical data from experiments. Arbitrarily increasing voltage or extending the test duration from the recommended values can increase the probability of an early service failure.

IEEE 400.1™-2007, IEEE Guide for Field Testing of Laminated Dielectric, Shielded Power Cable Systems Rated 5 kV and Above with High Direct Current Voltage. This standard covers the application of high-voltage direct current (Hipot) as a means of acceptance and also as a diagnostic test. This type of test is recommended for laminated insulation. Cables in industry of this type are usually of the paper-insulated, lead-sheathed design. The dc high-potential (Hipot) test has long been an acceptable means of evaluating the condition of laminated insulation.

Note: IEEE 400 does not recommend the application of HVDC for evaluating extruded dielectric service-aged cable that has been in service for more than five years.

IEEE 400.2™-2013, IEEE Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF) (Less Than 1 Hz). This standard presents the test methods and voltages applied when performing withstand tests using the very low frequency test (Figure 4). Also discussed is the rationale for performing the VLF withstand versus the dc dielectric withstand for solid dielectric extruded insulation cables. Test method and test parameters are also presented for the VLF tan delta test. The following four paragraphs are excerpts from IEEE 400™ 2013 Introduction.

Figure 4: Performing VLF Withstand and Tan Delta Tests

Ideally, field withstand testing of cable systems would be done using the same power frequency as would normally be applied to the cable under operating conditions, but at higher test voltage. However, because of the inherent capacitance of long runs of medium-/high-voltage concentric shielded cable, the excessive charging current is beyond the limits of normally available power sources and test equipment found in the field, except costly ac resonant test systems.

High-voltage dc testing would eliminate the charging current issue associated with ac tests, but would not subject the cable system to the voltage stress distribution that it is exposed to under normal operating conditions. Furthermore, there are significant negative issues affecting the integrity of aged cross-linked polyethylene (XLPE) cable after it is exposed to high-voltage dc tests and then placed back into service. There is also the unknown influence of elevated dc voltage on other extruded cables such as mineral-filled EPR. In addition, dc is not effective in detecting many
forms of gross defects that may be present in a cable system that will otherwise be detected by VLF or at operating frequency.

When required to perform field testing on long lengths of medium-/high-voltage cable with an alternating current source, an alternative to applying power frequency is very low frequency (VLF, 0.01 to 1 Hz). The charging current at a very low frequency of 0.1 Hz is only 1/500 or 1/600 of that at 50 Hz or 60 Hz respectively so that significantly smaller and more portable VLF power sources have the capability to test cable systems of relatively long lengths.

This guide provides a definition of VLF, a description of the wave-shapes and their magnitudes and frequencies that can be applied as a source for overvoltage field testing, the issues with different wave shapes, the duration of testing, and what diagnostic information can be learned when these VLF voltages are applied.

Applicable test procedures and test values for withstand and maintenance testing are contained in the ANSI/NETA MTS, Standard for Maintenance Testing Specifications, and ANSI/NETA ATS, Standard for Acceptance Testing Specifications.

IEEE 400-3™-2006, IEEE Guide for Partial Discharge Testing of Shielded Power Cable Systems in a Field Environment. This standard provides background information on partial discharge detection and location (Figure 5). PD detection and location is applicable to laminated and solid dielectric cables. Guidance is provided involving interpretation of PD data. The following excerpts are taken from the IEEE 400.3™-2006 standard:
“PDs are small electric sparks or discharges that occur in defects in the insulation, or at interfaces or surfaces, or between a conductor and a floating metal component (not connected electrically to the high-voltage conductor nor to the ground conductor), or between floating metal components if the electric field is high enough to cause ionization of the gaseous medium in which the components are located. The discharges do not bridge the insulation between conductors, and the defects may be entirely within the insulation, along interfaces between insulating materials (e.g., at accessories), or along surfaces (terminations or potheads).

Partial discharge characteristics depend on the type, size, and location of the defects, insulating material, applied voltage, and cable temperature, and they vary with time. The damage caused by PD depends on several factors and can range from negligible to causing failure within days to years.

Advances in digital (electrical) measurement technology, both in the time and frequency domains, have improved the sensitivity of PD measurements. This has led to an increasing number of PD measurements on cable systems, particularly on medium-voltage systems. The purpose of such measurements is to assess the current condition of a cable circuit. At the current state-of-the-art, very good cables and very bad cables can generally be identified.

It is the remaining life of the cables between these two extremes that cannot be predicted with great accuracy. As well, this technology cannot determine with complete confidence that a specific cable is in very good condition with essentially no probability of failure in the near future, as failure can be caused by phenomena that do not generate PD. However, the PD measurement can, at times, predict with a high level of confidence that a given cable is in very poor condition and is likely to fail in the near future.”

IEEE 400-4™-2015, IEEE Guide for Field Testing of Shielded Power Cable Systems Rated SKV and Above with Damped Alternating Current (DAC) Voltage. This latest IEEE standard provides a description of the methods and practices used in the application of damped alternating current voltages for field testing of shielded power-cable systems (Figure 6). DAC voltage testing is one of the alternative methods of ac voltage testing and is applicable for a broad range of medium-voltage, high-voltage, and extra-high-voltage cables. As the DAC test procedure has been used for several years for diagnostic, maintenance, and acceptance (commissioning) tests, it provides a method of evaluation of the insulation condition and helps fit the need for more complete information on the condition of cable systems. This guide addresses DAC voltage testing in the frequency range from 20 Hz to 500 Hz.

The guide presents the practices and procedures for testing and diagnosis of shielded power-cable systems rated 5 kV and above using DAC voltages. It applies to all types of power-cable systems intended for the transmission or distribution of electric power. The tabulated test levels assume that the cable systems have an effectively grounded neutral system or a grounded metallic shield.

The purpose of the guide is to provide uniform practices and procedures for performing DAC voltage off-line tests on installed shielded power-cable systems in the field and to provide guidelines for evaluation of test results. Certain test parameters and procedures require further study and clarification; this guide provides a starting point that can be grown and improved.
with time as more experience is gathered from the field and analyzed.

Sinusoidal damped ac voltage testing, also known as oscillating wave testing, was introduced at the end of the 1980s as an alternative to dc test voltages. As a consequence of experiences in onsite ac testing on one hand and the technological progress in power electronics and advanced signal processing on the other hand, DAC testing has been used since the end of the 1990s. Some countries are currently using DAC for onsite testing with PD measurements and dissipation factor estimation for condition assessment of all types of power cable systems.

DAC voltages are generated by charging the test object to a predetermined voltage level and then discharging its capacitance through a suitable inductance. During the charging stage, the capacitance of the test object is subjected to a continuously increasing voltage at a rate dependent on the test-object capacitance and the current rating of the power supply. During the discharging stage, a DAC at a frequency dependent on the test-object capacitance and the inductance is present.

Most DAC applications are based on the combination of voltage withstand and advanced diagnostic measurements, i.e., partial discharges and dissipation factor.

**SUMMARY**

The IEEE 400 Standards identify three major areas of field testing: installation, acceptance, and maintenance testing. Field tests are identified as either withstand or diagnostic in nature. Power cable testing technologies are not static. Enhancements in electronics and software will continue, thus improving capabilities in predicting cable maintenance needs and proving new installations to ensure conditions do not exist that lead to premature failure of the cable system.

As technologies are developed, standards organizations such as IEEE will continue to set new goals for testing and maintaining power cable systems.

Depending on the installation, cable age, and end-user service requirements, testing is sometimes complex. Many cable installations are critical components of electrical systems, and outages lead to costly downtime, lost production, and reliability. The type of tests used for a cable installation may vary depending on the objectives of the owner, e.g., type of data required and for what purpose.

Ultimately, what can be expected for the future of power cable in the U.S. is higher quality installations, improved reliability, and reductions in costly cable-related power outages.

**REFERENCES**

IEEE 400 Bundle Series

Dean Williams. “Cable Accessory Failure Analysis.” NEETRAC, ICC Education Session, October 6-20, 2010

Alan Mark Franks is a Senior Safety Specialist at AVO Training Institute. He has over 48 years in the electrical utility industry with an extensive background in electrical safety and power distribution. Mark was instrumental in developing the pre-OSHA Electrical Safety Audit for industry and the conducting of on-site audits of facilities, installation of electrical equipment and systems, safety procedures, and training records and programs, all based on OSHA and NFPA regulations and other industry consensus standards. He has been an authorized OSHA Instructor for all general industry and construction regulations. Mark is a certified fiber optic technician, certified fiber optic instructor (#839), and a member-in-good-standing of the Fiber Optic Association. He participates in numerous associations including NFPA 70E 2000 alternate committee member, International Association of Electrical Inspectors, American Society of Safety Engineers, National Cable Splicer Certification Board, and American Society for Testing and Materials. Mark has provided electrical safety training and performed electrical mine-safety audits for general industry, utilities, and mines both underground and surface. He has instructed all aspects of power cable splicing, termination, testing, and fault location for 25 years and has been instrumental in developing the AVO Training Institute Cable Technician Certification Program.