DC Field Test for Medium-Voltage Cables: Why Can No One Agree?

C. David Mercier, *Member, IEEE,* and Sid Ticker, *Associate Member, IEEE*

***Abstract*— Industry standards for shielded medium-voltage cables (5–46 kV) have recently been revised, changing the dc test voltages for field tests and test durations and limiting tests to newly installed cables. The following industry groups' specifications and standards provide different guidelines for dc field tests for cross-linked polyethylene and ethylene propylene rubber insulated cables: IEEE, Insulated Cable Engineers Association (ICEA), and the Association of Edison Illuminating Companies (AEIC). These specifications and standards are discussed, showing the differences in the recommendations and why the differences exist. The conclusion provides a guide for dc field testing shielded medium-voltage cables based on these industry standards.**

***Index Terms*—DC field test voltages, medium-voltage cable.**

I. Introduction

FOR MANY YEARS, dc field tests have been used to test cables. The practice of dc testing extruded cables is carried over from paper-insulated oil-impregnated cables. Over the last 30 or so years, solid dielectric insulated cable has been required to be high-voltage dc tested in the factory. Field tests were performed for initial proof and maintenance testing. Initial tests after installation and prior to being energized were based on 80% of the manufacturer's factory test voltage. Maintenance tests were based on 60% of the manufacturer's factory test voltage. This is the basis for many current recommendations.

Over the years, many engineers have suspected that dc field tests may shorten the life expectancy of solid dielectric cables. It was perceived that dc tests caused damage to the cables. Many times, the cable would fail when reenergized, and it would not have failed if left untested. An Electric Power Research Institute (EPRI) study on cross-linked polyethylene (XLP) cables determined that dc maintenance testing on aged cables can damage the cable, resulting in premature cable failures [1].

DC high-voltage field testing of shielded medium-voltage cables is used extensively in the petrochemical industry. DC tests are used as an acceptance test during installation and as a maintenance test to improve the system reliability [2]. High-voltage dc testing is used to detect gross imperfections in cable. There are many standards and specifications available listing dc test voltages for testing cables after installation. Test voltages during installation are similar in these documents. The recommendations differ on tests made after installation and between the different insulation materials. The difference is based on the intended cable installation and the EPRI study on the effect of field testing XLP insulated cables. The study suggests that dc maintenance testing should be discontinued for XLP cables installed in wet locations.

Paper PID 98–08, presented at the 1997 IEEE Petroleum and Chemical Industry Technical Conference, Banff, Alta., Canada, September 15–17, and approved for publication in the IEEE Transactions on Industry Applications by the Petroleum and Chemical Industry Committee of the IEEE Industry Applications Society. Manuscript released for publication May 26, 1998.

The authors are with Southwire Company, Carrollton, GA 30119 USA.

Publisher Item Identifier S 0093-9994(98)08110-9.

TABLE I
DC Field Test Voltages and Test Duration (15-KV 133% Insulation Level)

Standard	Insulation	Acceptance	Maintenance
IEEE 400	EPR/XLP	56 kV / 15 Min.	46 kV 5-15 Min.
IEEE 576	EPR/XLP	65 kV / 15 Min.	
ICEA S-68-516	EPR	65 kV / 15 Min.	
ICEA S-66-524	XLP	65 kV / 15 Min.	
ICEA S-94-649	EPR/XLP	64 kV / 15 Min.	20 kV 5 Min.
AEIC CS6-96	EPR	64 kV / 5 Min.	51 kV 5 Min.
AEIC CS5-94	XLP	64 kV / 5 Min.	20 kV 5 Min.

For comparison of the different standards, 15-kV 133% insulation level test voltages are used in Table I. Tables are provided in the Appendix for 5–35-kV shielded power cables.

II. Industry Standards and Specifications

A. IEEE 400 [3]

The foreword of IEEE 400 [3] begins "... to say that there is a marked difference of opinion on the matter of cable testing would be a decided understatement." The foreword continues to point out that utilities tend to perform acceptance testing immediately after installation, while they do not favor maintenance testing after the cable has been in service, believing that such tests may shorten the life of the cable. Many industrial users, and a few utilities, perform both acceptance and maintenance testing, believing that such testing will contribute to improved service reliability.

IEEE Standard 400 tests are "go, no-go" tests. The system is required to withstand the specified voltage for the specified time duration. This test will normally reveal gross imperfections due to improper field handling, such as excessive bending or airgaps between the insulation and shield interfaces. While performing a high-voltage dc test, it is common to monitor insulation leakage current and/or insulation resistance. The guide notes that a decrease in current with time is generally a practical criterion for acceptance. Also noted is the practice of recording the insulation resistance values when performing maintenance tests. Comparing insulation resistance readings of the cable to previous test readings is useful for maintenance testing. Minimum acceptable leakage current levels should not be specified, due to the many factors which can affect the output current.

1) Acceptance Test: The test voltages listed in IEEE 400 are based on the circuit's basic impulse level (BIL) rather than on the type and thickness of the insulation. Because IEEE 400 bases test voltages on the circuit voltage, dc test voltages for 133% insulation levels are not provided. Other specifications are based on insulation thicknesses; therefore, these specifications include dc test voltages for 133% insulation levels.

2) Maintenance Test: Maintenance test durations allow times from 5 to 15 min to allow the charging current to reach steady state on long circuits. It is noted throughout the guide that dc testing may be detrimental to cables that have been subjected to long periods of exposure to moisture. The ac breakdown voltage may be well above the ac operating stress. If the cable is exposed to high dc stress levels, the useful service life may be reduced. Whenever practical, seek consensus with the cable manufacturer on suitable test levels.

B. AEIC

Both AEIC CS5 [4] and CS6 [5] specifications state that "DC test voltages are applied to discover gross problems such as improperly installed accessories or mechanical damage. DC testing is not expected to reveal deterioration due to aging in service."

1) During Installation: Insulated cables covered by AEIC CS5 and CS6 specifications provide information for tests during and after installation. A dc test may be made at any time during the installation for a duration of 5 min. An after service test, for a duration of 5 min, can be made after the cable has been completely installed and placed in service any time within the first five years of service. The during installation voltage is based on 80% of factory dc test voltages. The AEIC has removed requirements for dc factory tests. Experience has shown that the ac factory test detects the same imperfections as a dc factory test and will also detect imperfections a dc test cannot detect.

2) After Installation: After installation tests in AEIC CS5 and CS6 for insulated cables are different. The test voltages for ethylene propylene rubber (EPR) insulated cables in CS6 are 65% of factory dc test voltages. CS5 test voltages for XLP insulated cables is 25% of factory dc test voltages. For a 15-kV 133% insulated cable, the test voltage for during installation is 64 kV. The after installation test for EPR insulated cables is 51 and 20 kV for XLP insulated cables. AEIC CS5 adds an additional statement in the after installation instructions stating, "...after that time, dc testing is not recommended."

The basis for this difference in CS5 is based on the following statement in CS5:

> There is some evidence that dc testing of aged cross-linked polyethylene cables can lead to early cable failures. Information on this subject is available in EPRI project report TR-101245, "Effect of DC Testing on Extruded Cross-Linked Polyethylene Insulated Cables."

C. ICEA

Both ICEA S-68-516 [6] and S-66-524 [7] state "...if voltage tests are made after installation, they shall be made immediately." The test is a dc voltage with a duration of 15 min. There is no reference to any type of maintenance test. These standards are intended to be used in many types of installations; therefore, they must be general and cannot address problems unique to specific installations.

The ICEA has prepared a new standard on medium-voltage concentric neutral underground cable [8]. Underground utility products are unique, allowing this standard to address issues specific to cables installed in underground conduit or directly buried. This standard follows the recommended voltages of AEIC CS5 for XLP insulated cables. It does differ in the test duration. It specifies 5 min during installation, 15 min after installation and before the cable is placed in regular service, and 5 min in service. The same test voltage is used for EPR and XLP insulated cable for the first five years, unlike AEIC CS6, which has higher values for EPR. The ICEA wanted consistent values for XLP and EPR; therefore, because there is no test data showing that EPR is not damaged at the higher test voltage, it was decided to stay with the lower test voltages.

D. IEEE 576 [11]

IEEE Standard 576 [11] includes recommendations on high-voltage dc testing. Recommendations are limited to installation proof testing. Voltage levels are provided to be used after installation and before being energized. The test values are in line with other industry standards. IEEE 576 includes discussion of insulation leakage current, including how to interpret the test results.

The test should be run for 15 min. Generally, the voltage is applied and leakage current is recorded after 15, 30, 45, and 60 s and at 1-min intervals thereafter.

Considerable experience is needed to properly interpret dc test results. The shape of the leakage current curves is one of the most important things to watch. In general, the leakage current will start at a relatively high value and drop off rapidly, becoming constant at a lower value. The fact that the current becomes stable and levels off is more important than the actual magnitude of the leakage current. If the current does not drop or, if after dropping, it begins to rise again, a strong indication of trouble on the circuit is evident. The test can be stopped at this point before a failure or it can be continued until the cable fails. After failure, the weak spot can be located and repaired.

III. Effects of DC Testing on Extruded XLP Insulated Cables

Reference [1] is cited by AEIC and ICEA standards for utility concentric neutral cables designed primarily for underground installations. The reduction of the dc test voltage for maintenance testing is based on this project. The initial project was limited to XLP cables aged under wet conditions, which is typical of utility distribution circuits. It does not include cables

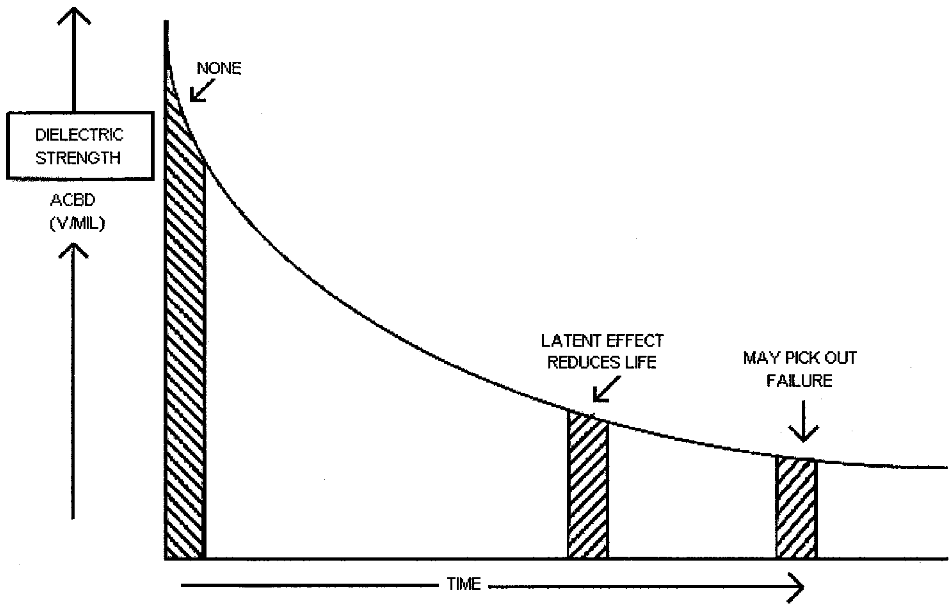

Fig. 1. DC effect on cable life.

aged in a dry environment. This report is applicable only to XLP cables in wet environments. An additional test program was recommended to test the effect of dc tests on aging EPR insulated cables, but was stopped due to lack of funds.

A hypothesis is suggested to explain the effect of dc testing on XLP insulated cables. It states that "...the effect of dc, if any, will depend upon the dielectric strength of the cable after aging, at the time of dc application." This hypothesis is illustrated in Fig. 1.

The following recommendations are made by this EPRI report to utility companies for 15-kV 100% insulation level XLP cable.

1) It is recommended not to do dc acceptance (proof or maintenance) testing at 40 kV on XLP insulated cables that have failed once in service and then are spliced. It is advisable not to do dc testing periodically at the level of 40 kV on aged (heavily treed) XLP insulated cables.
2) DC testing can be performed on a newly manufactured cable at the factory at 70 kV in order to detect any gross imperfections in the cable construction.
3) DC testing can be done at 55 kV in the field on a new cable prior to energizing, when aged cable is not spliced in the system.
4) These recommendations apply only to XLP insulated cables that are aged and/or have water trees grown in the insulation from operating in a wet environment.

IV. Conclusion

A. Acceptance Testing

Acceptance testing of insulated cables during or immediately after installation utilizing high-voltage dc tests does not damage the cable insulation. High-voltage dc tests are limiting, revealing severe problems, such as damaged cable or improperly installed accessories. The differences in test voltages are not substantial. Up to 5-kV differences between specifications and standards are due to differences in rounding when determining the test voltage. IEEE 400 test voltages do not provide values for 133% insulation levels. It is recommended that the acceptance test voltage be based on the insulation level. Acceptance test voltages should be based on insulation levels given in IEEE 576.

A 5-min duration for a "go, no-go" test duration is all that is needed. A test duration up 15 min will not damage the insulation. The 15-min duration is needed when measuring leakage current or insulation resistance.

B. Maintenance Testing

It has been shown in a well-controlled test program conducted over a period of ten years that service failures in extruded cables could be greatly decreased with maintenance tests performed in 1–3-year intervals [9]. Maintenance tests increases the reliability of the electrical system [10]. The concern and area of great debate is: "What dc voltage is high enough to detect weak points in the cable circuit without causing an ac failure when the circuit is placed back into service?" There are not any clear answers to this question today. The critical areas in deciding dc test values are: "What type of environment was the cable exposed to during service, what type of insulation material is used, and how long has the cable been in service?"

If the service environment is dry, there is not any evidence that dc tests are harmful to the insulation. If it is a high moisture environment (wet environment), length of service and insulation type need to be considered.

1) Service Less than Five Years: If the cable has been in service less than five years, the cable has not aged enough to be harmed by a dc test using voltages specified for maintenance testing. Recommended test voltages for EPR and XLP are different, based on service environment.

TABLE II
IEEE 400 FIELD TEST VOLTAGES

System Voltage (kV)	Acceptance Test Voltage (kV dc)	Maintenance Test Voltage (kV dc)
5	28	23
8	36	29
15	56	46
25	75	61
28	85	68
35	100	95

TABLE III
AEIC CS5 XLP FIELD TEST VOLTAGES

System Voltage (kV)	Insulation Thickness 100% / 133% (mils)	Maintenance Test Voltage 100% / 133% (kV dc)*
5	90 / 115	9 / 11
8	115 / 140	11 / 14
15	175 / 220	18 / 20
25	260 / 320	25 / 30
28	280 / 345	26 / 31
35	345 / 420	31 / 39

*First five years

TABLE IV
AEIC CS6 EPR FIELD TEST VOLTAGES

System Voltage (kV)	Insulation Thickness 100% / 133% (kV dc)	Acceptance Test Voltage 100% / 133% (kV dc)	Maintenance Test Voltage 100% / 133% (kV dc)*
5	90 / 115	28 / 36	22 / 29
8	115 / 140	36 / 44	29 / 35
15	175 / 220	56 / 64	45 / 51
25	260 / 320	80 / 96	64 / 77
28	280 / 345	84 / 100	67 / 80
35	345 / 420	100 / 124	80 / 99

*First five years

XLP insulations can be harmed by dc test voltages if the insulation has been in a wet environment and begun to age due to electrochemical treeing. The voltages need to be reduced to those provided by ANSI/ICEA S-94-649-1997 or AEIC CS5-94. EPR is not as susceptible to electrochemical treeing and, therefore, may be tested at the higher voltages shown in IEEE 400 and AEIC CS-6-95.

2) Service More than Five Years: If the cable has been in service more than five years in a dry environment, there is no evidence that dc tests are harmful.

If the cable has been in service in a wet environment, the cable manufacture needs to be consulted to determine acceptable voltage levels. If the insulation is XLP, the recommendation will most likely be to test at your own risk. If the insulation is EPR, there is not any evidence showing high-voltage dc tests harmful to the insulation. An argument can be made that no study exists showing that high-voltage dc tests are not harmful.

Without a consensus of opinion, standards are including references to studies, so that the user can evaluate whether dc testing will be harmful on their system.

High-voltage dc field tests continue to be useful tests to check systems before they are placed into service. When used as maintenance tests, the possibilities of damage to cable should be considered.

TABLE V
IEEE 576 FIELD TEST VOLTAGES

System Voltage (kV)	Acceptance Test Voltage (kV dc)	
	100% Insulation Level	133% Insulation Level
5	25	35
8	35	45
15	55	65
25	80	95
28	85	100
35	100	125

TABLE VI
ICEA S-68-516 EPR AND ICEA S-66-524 XLP FIELD TEST VOLTAGES

System Voltage (kV)	Acceptance Test Voltage (kV dc)	
	100% Insulation Level	133% Insulation Level
5	25	25
8	35	35
15	55	65
25	80	100
28	85	—
35	100	—

APPENDIX

See Tables II–VI.

REFERENCES

[1] "Effect of DC testing on extruded cross-linked polyethylene insulated cables," Elect. Power Res. Inst., Palo Alto, CA, EPRI Project Rep. TR-101245, 1993.

[2] W. G. Morrison and R. J. Arhart, "Using new technology to improve reliability of an industrial cable distribution system," *IEEE Trans. Ind. Applicat.*, vol. 28, pp. 275–281, Mar./Apr. 1992.

[3] *IEEE Guide for Making High Direct-Voltage Tests on Power Cable Systems in the Field*, IEEE Standard 400-1991,

[4] *Specification for Cross-Linked Polyethylene Insulated, Shielded Power Cables Rated 5 through 46 kV*, AEIC CS5-94, 1994.

[5] *Specification for Ethylene Propylene Rubber Shielded Power Cables Rated 5-69 kV*, AEIC CS6-96, 1996.

[6] *Cross-Linked Thermosetting Polyethylene Insulated Wire and Cable for Transmission and Distribution of Electrical Energy*, ICEA S-66-524, 1988.

[7] *Ethylene-Propylene-Rubber-Insulated Wire and Cable for Transmission and Distribution of Electrical Energy*, ICEA S-68-516, 1988.

[8] *Standard on Concentric Neutral Cables Rated 5 through 46 kV*, ICEA S-94-649 Draft D, 1995.

[9] W. G. Morrison and R. H. Lee, "Testing of cable systems for improvement of reliability," in *Conf. Rec. Industrial and Commercial Power Systems Conf.*, Milwaukee, WI, Apr. 1972.

[10] *IEEE Recommended Practice for Reliable Industrial and Commercial Power Systems*, IEEE Standard 493-1990 (Gold Book).

[11] *IEEE Recommended Practice for Installation, Termination, and Testing of Insulated Powercable as Used in the Petroleum and Chemical Industry*, IEEE Standard 576, 1989.

C. David Mercier (S'85–M'85) received the Bachelor of Electrical Engineering degree from Auburn University, Auburn, AL, in 1984.

In 1985, he joined Southwire Company, Carrollton, GA, as a Sales Engineer. He is currently Applications Engineering Manager, involved with providing technical information involving applications, design, performance characteristics, and installation of overhead and underground wire and cable products. He is a Principal Member of National Electrical Code Panel 8 and an Alternate Member on Panel 6.

Mr. Mercier is a Member of the IEEE Power Engineering and IEEE Industry Applications Societies, the National Fire Protection Association, and International Association of Electrical Inspectors.

Sid Ticker (A'91) received the Applied Arts and Science Electrical Engineering degree from the New York Institute of Applied Arts and Sciences, New York, NY.

He began his career as a Military Instructor in the Microwave Radio School, Signal Corps, Fort Monmouth, NJ. In 1960, he joined Phelps Dodge Wire and Cable Company as a Senior Laboratory Technician in the area of UL and government/military specifications. In 1973, he became Quality Assurance Manager for Phelps Dodge Wire and Cable and was responsible for four manufacturing plants and providing technical assistance in the areas of installation, splicing, and terminations. In 1978, he became Assistant Plant Manager for Paper Insulated Cable Plant, Yonkers, NY, where he was responsible for operations and, in 1983, he became District Sales Manager, Direct Sales, New York, New Jersey, Pennsylvania, and Connecticut. In 1984, he joined Hi-Tech Cable, Starkville, MS, as an Applications Engineer and QA Manager. In 1989, he became Senior Applications Engineer with Southwire Company, Carrollton, GA, where he is responsible for providing technical support to sales and engineering.