

IEEE Recommended Practice for Testing of Electric Submersible Pump Cable

IEEE Industry Applications Society

Developed by the
Petroleum & Chemical Industry Committee

IEEE Std 1017.1™-2021
(Revision of IEEE Std 1017.1-2013)



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of the
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Approved 23 September 2021

IEEE SA Standards Board

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Abstract: Procedures and test voltage values for factory, acceptance, and maintenance testing of electric submersible pump (ESP) cable systems are presented. This recommended practice applies to cable systems rated 3 kV through 8 kV (phase to phase) and is intended only for this special-purpose cable. The intent is to provide uniform test procedures and guidelines for evaluation of the test results.

Keywords: cable ampacity, cable maintenance, cable testing, conductors, electric submersible pump (ESP), factory testing, field testing, IEEE 1017™, submersible pump cable

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Introduction

This introduction is not part of IEEE Std 1017.1–2021, IEEE Recommended Practice for Testing of Electric Submersible Pump Cable.

This document is part of the IEEE 1017 family of Electric Submersible Pump (ESP) documents. The IEEE 1017 family of documents originally included three recommended practices (RPs) including RP 1017 (now IEEE Std 1017.1™), RP 1018 (now IEEE Std 1017.2™ [B16]), and RP 1019 (now IEEE Std 1017.3™ [B17]).¹ These three RPs were the first standards sponsored by the Petroleum and Chemical Industry Committee of the IEEE Industry Applications Society.

Work began on the ESP standards in 1979. At that time, the typical life of ESP cables was significantly less than one year. Less than five vendors manufactured all ESP cable in the world. Each manufacturer used proprietary guidelines, as well as construction and performance requirements. After five years of work, the initial publication of RP 1017, RP 1018, and RP 1019 was completed in 1984. ANSI approval was obtained in 1985.

The original RPs focused on specifications for polypropylene cable (RP 1019). This was followed by the specifications for a relatively new insulation material EPDM (RP 1018). During this process, it became clear that a document outlining field testing of the cable was required. This grew into RP 1017. The voltage rating of the cables was limited to 3 kV and 5 kV. Testing was limited to dc hi-pot testing and a dc voltage withstand test.

Version 2 (1991) of RP 1018 and RP 1019 expanded with the addition of ampacity curves based on the Neher-McGrath method. The Neher-McGrath calculations were modified to make them specifically applicable to the downhole conditions experienced by the cables. No significant changes to the testing requirements contained in RP 1017 were made.

Version 3 of RP 1017 (2004) included the addition of general descriptions of new testing procedures including time domain reflectometers (TDRs), thumpers, bridge type fault locators, and dc burn in. Also included was a major improvement in the interpretation of dc hi-pot testing results, including methods for predicting failure of the cables without overstressing and destroying the insulation.

By the 2004 version, the cable types described in RP 1018 and RP 1019 included four types: round, round with lead sheath, flat and flat with lead sheath.

Prior to the 2004 version, all values in the ESP cable standards were based on the United States Customary System (USCS, or English Engineering Units). Due to increased globalization of IEEE standards, The IEEE Standards Association (SA) had a requirement that all published documents use SI units exclusively. The market for ESP cable standards deals almost exclusively in USCS units, so the drafts were rejected by the ballot groups. Members of the ballot group threatened to withhold approval of the IEEE RPs and move the work to other standards development organizations. This led the working group to petition the SA Standards Board (SASB) to include dual units, SI and USCS. The SASB approved the dual unit request and made a change to IEEE SA policy to allow dual units in all IEEE standards.

Version 4 (2013) of the RPs primarily involved editorial cleanup and verification of table values. Discussion began on advanced test methods, but these test methods were not included in this version. Discussions also began on inclusion of 8 kV rated cables.

The current version of the 1017 family of RPs (version 5) contains the most significant modifications to the RPs in their 40-year history. Version 5 includes greatly expanded content and a complete revamp of the group of RPs. The first major modification was renumbering of the RPs to emphasize the continuity of the standards as a group. RP 1017 became RP 1017.1, RP 1018 became RP 1017.2, and RP 1019 became RP 1017.3. All

¹The numbers in brackets correspond to those of the bibliography in Annex A.

three RPs were expanded to include 8 kV rated cable in addition to the 3 kV and 5 kV historic rated voltages. Additionally, cable sizes were expanded to include #3/0 AWG and #4/0 AWG.

RP 1017.1 was expanded to include all testing: factory, acceptance, and field testing. Additionally, advanced test methods including very low frequency tan-delta (VLF tan-delta) and partial discharge (PD) were included, along with interpretation guidance. Testing for surface feedthroughs and downhole connectors was added. New tests for qualification of encapsulating materials for non-lead metallic barrier cables with encapsulating jacket were also added.

RP 1017.2 and RP 1017.3 were modified to remove testing (pulled into RP 1017.1) and were expanded to include non-lead metallic barrier cables (sometimes called “tubing encapsulated power cable” or “TEPC”). The insulating and jacket material specifications were expanded to include reinforced high modulus materials. Finally, the Neher-McGrath curves were updated to correct an error and to make them more readable and usable.

This recommended practice, under the jurisdiction of the Petroleum and Chemical Industry Committee of the IEEE Industry Applications Society, may be used by anyone desiring to do so and is presented as minimum criteria for installation and field testing of this class of submersible cable. It is not intended to restrict innovation or to limit development of improvements in cable design. Every effort has been made to assure the accuracy and reliability of the data contained herein. However, the committee makes no representation, warranty, or guarantee in connection with the publication of this recommended practice and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use, for any conflict, or for the infringement of any patent resulting from the use of this recommended practice.

Contents

1. Overview.....	11
1.1 Background.....	11
1.2 Scope.....	12
1.3 Purpose.....	12
1.4 Word usage.....	12
2. Normative references.....	12
3. Definitions, acronyms, and abbreviations.....	13
3.1 Definitions.....	13
3.2 Acronyms and abbreviations.....	15
4. Safety.....	17
4.1 Description.....	17
4.2 Application.....	17
4.3 Procedures to secure cable test area.....	17
5. General considerations.....	18
5.1 Environmental influences.....	18
5.2 Cable storage.....	18
5.3 Equipment maintenance.....	18
5.4 Tests covered by the recommended practice.....	19
5.5 Additional test equipment.....	19
6. DC hi-pot test methods.....	20
6.1 Overview.....	20
6.2 Precautions.....	21
6.3 DC high potential tester (hi-pot).....	21
6.4 Equipment setup.....	21
6.5 Procedures.....	22
6.6 Evaluation of dc hi-pot test results.....	24
7. Conductor resistance and continuity tests.....	32
8. Finished armored cable factory tests.....	33
8.1 DC withstand test.....	33
8.2 AC withstand test.....	34
8.3 DC test conductance leakage readings.....	34
9. Mechanical integrity of armored cable.....	34
10. Mechanical/chemical testing of nonlead metallic barrier cables with encapsulating jacket.....	34
10.1 Cold bend.....	34
10.2 Abrasion resistance.....	35
10.3 Tear resistance.....	36
11. Effect of chemical exposure on tensile, yield, and elongation.....	38
11.1 Purpose.....	38
11.2 Test specimen.....	38
11.3 Alternative test specimen.....	38
11.4 Chemical exposure conditions.....	38
11.5 Chemical compatibility with well fluids (optional).....	41
11.6 Cold impact test.....	41
11.7 Stripability/removal.....	41

12. Partial discharge (PD) testing	41
12.1 Overview	41
12.2 Precautions	42
12.3 Procedures	42
12.4 Interpretation of results	44
13. Very low frequency/tan-delta (VLF/TD) testing	45
13.1 Overview	45
13.2 Precautions	45
13.3 VLF/Tan-delta test equipment	45
13.4 Equipment setup	46
13.5 Procedures	46
13.6 Evaluation of VLF-TD results	47
14. Testing of surface feedthroughs and connections	56
14.1 Description	56
14.2 Environment	56
14.3 Wellhead with pack-off (no connections at wellhead)	58
14.4 Wellhead with connections	58
14.5 Visual Inspection	59
14.6 Procedure for testing of potheads (motor connectors)	60
14.7 Testing of wellhead penetrators	61
Annex A (informative) Bibliography	64

IEEE Recommended Practice for ~~Field~~ Testing of Electric Submersible Pump Cable

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1. Overview

1.1 Background

Guidance for the ~~field and maintenance~~ testing of conventional power cable is available in IEEE Std 400™ series of guides¹; however, those documents are ~~that document is~~ not ~~an~~ applicable guides ~~guide~~ in assessing the condition of electric submersible pump (ESP) cable. By adopting some principles set forth in IEEE Std 400 series and applying others developed from field experience, this recommended practice for submersible cable testing will assist those persons with the responsibility of determining the dielectric condition of this type of cable.

This recommended practice proposes the use of direct current (dc) for hi-pot testing because of its advantages over rated condition alternating current (ac) voltage. These advantages are as follows:

¹~~Information on references can be found in Clause 2.~~

- a) Smaller test equipment may be used.
- b) It minimizes damage when a fault occurs, which aids in fault examination.
- c) Improved safety due to smaller charging current compared to conventional frequency testing.

Other forms of testing, such as partial discharge (PD), very low frequency tan-delta (VLFTD) offer similar safety benefits using ac current in different conditions. These tests provide significantly additional information to traditional hi-pot tests and are addressed in this recommended practice as well.

This recommended practice is for cables without a connecting motor-lead extension cable or surface connecting cable, and it is primarily for armored cables; however, unarmored cables can be tested by submersing them in water.

This document does recommend dc and ac leakage testing at the factory after assembly of the cable prior to final shipment. This document ~~practice~~ does not require that testing be performed, either at the time of installation or periodically thereafter, for acceptance or maintenance. It sets forth the consensus of currently known good practice in testing methods, with interpretation of results.

1.2 Scope

Procedures and test voltage values for factory, acceptance and maintenance testing of ESP cable systems are presented. Installation and handling practices are also covered. This procedure applies to cable systems rated 3 kV through 8 ~~and 5~~ kV (phase to phase).

1.3 Purpose

The purpose of this recommended practice is as follows:

- a) Provide a guideline for performing ESP ~~leakage current test so it can be used as a~~ cable factory, acceptance and maintenance tests. ~~quality tool~~

- b) Provide guidelines for evaluation [and interpretation](#) of the test results.
- c) Define terms that have a specific meaning to the recommended practice.

1.4 Word usage

[The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted \(shall equals is required to\).](#)^{2,3}

[The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required \(should equals is recommended that\).](#)

[The word *may* is used to indicate a course of action permissible within the limits of the standard \(may equals is permitted to\).](#)

[The word *can* is used for statements of possibility and capability, whether material, physical, or causal \(can equals is able to\).](#)

2. Normative references

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 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.

[ANSI/ICEA T-24-380, Standard for Partial Discharge Test Procedures.](#)⁴

²[The use of the word *must* is deprecated and cannot be used when stating mandatory requirements, *must* is used only to describe unavoidable situations.](#)

³[The use of *will* is deprecated and cannot be used when stating mandatory requirements, *will* is only used in statements of fact.](#)

⁴[ANSI publications are available from the American National Standards Institute \(<https://www.ansi.org/>\). ICEA publications are available from the Insulated Cable Engineers Association \(<https://www.icea.org/>\).](#)

~~API RP 11S6, Recommended Practice for Testing of Electric Submersible Pump Cable Systems.~~

API RP 500, Recommended Practice for Classification of Locations for Electrical Installation at Petroleum

Facilities Classified as Class I, Division 1, and Division 2.⁵

API RP 505, Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Zone 0, Zone 1 and Zone 2.

ASTM D471, Standard Test Method for Rubber Property — Effect of Liquids.⁶

ASTM D638, Standard Test Method for Tensile Properties of Plastics.

ASTM D1938. Standard Test Method for Tear-Propagation Resistance (Trouser Tear) of Plastic Film and Thin Sheeting by a Single-Tear Method.

ICEA S-96-659, Standard for Nonshielded Cables Rated 2001-5000 V For Use In The Distribution Of Electrical Energy.

IEC 60079-10-1, Explosive Atmospheres—Part 10-1: Classification of Areas—Explosive Gas Atmospheres.⁷

UL 719, Standard for Nonmetallic Sheathed Cable.⁸

UL 2556, Standard for Safety Wire and Cable Test Methods.

⁵API publications are available from the American Petroleum Institute (<https://www.api.org/>).

⁶ASTM publications are available from ASTM (<https://www.astm.org>).

⁷IEC publications are available from the International Electrotechnical Commission (<https://www.iec.ch>) and the American National Standards Institute (<https://www.ansi.org/>).

⁸UL publications are available from Underwriters Laboratories (<https://www.ul.com/>).

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.^{9 4}

absorption current: A Current resulting from molecular polarizing and electron drift, which decays with time of voltage application at a decreasing rate from a comparatively high initial value to nearly zero, and depends on the type and condition of the insulation system ~~charge absorbed into the dielectric as a result of polarization.~~

ac test: This test is performed by the manufacturer at power frequency as a pass/fail test to help verify the electrical integrity of the cable.

acceptance test: This test is intended to help detect damage before the initial installation of new cable and includes only the cable itself and excludes terminations, penetrations, motor leads, etc.:- These tests are normally performed by the user or the designated representative using dc voltage at 80% of the factory test voltage.

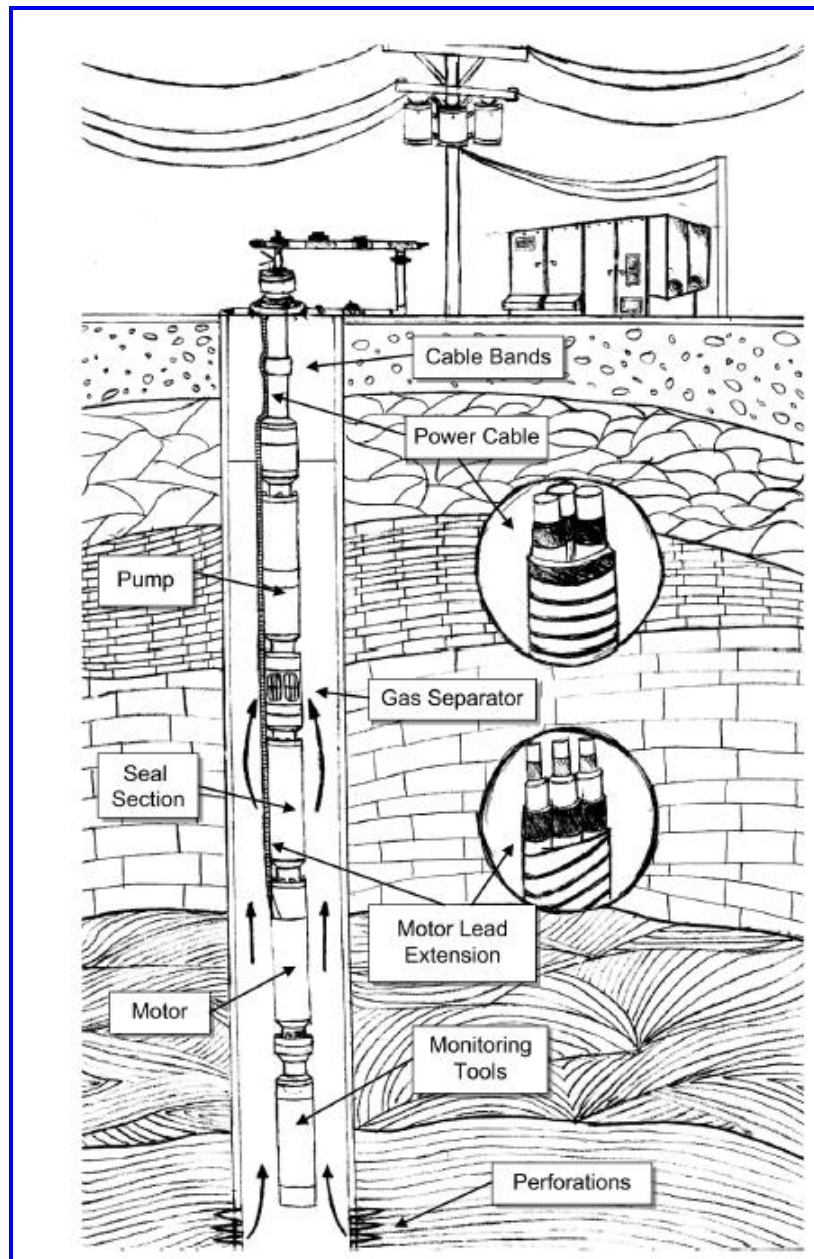
capacitance current: Current required to charge the capacitor formed by the dielectric of the cable under test.

dc test: This test is performed by the manufacturer to help verify the electrical integrity of the cable. The conductance leakage current is used as a comparative measurement, and the dc voltage can be used as a pass/_fail test.

electric submersible pumps (ESPs): Equipment that refers to electric-driven, deep-well centrifugal pumps as commonly used to lift fluids from subsurface formations.

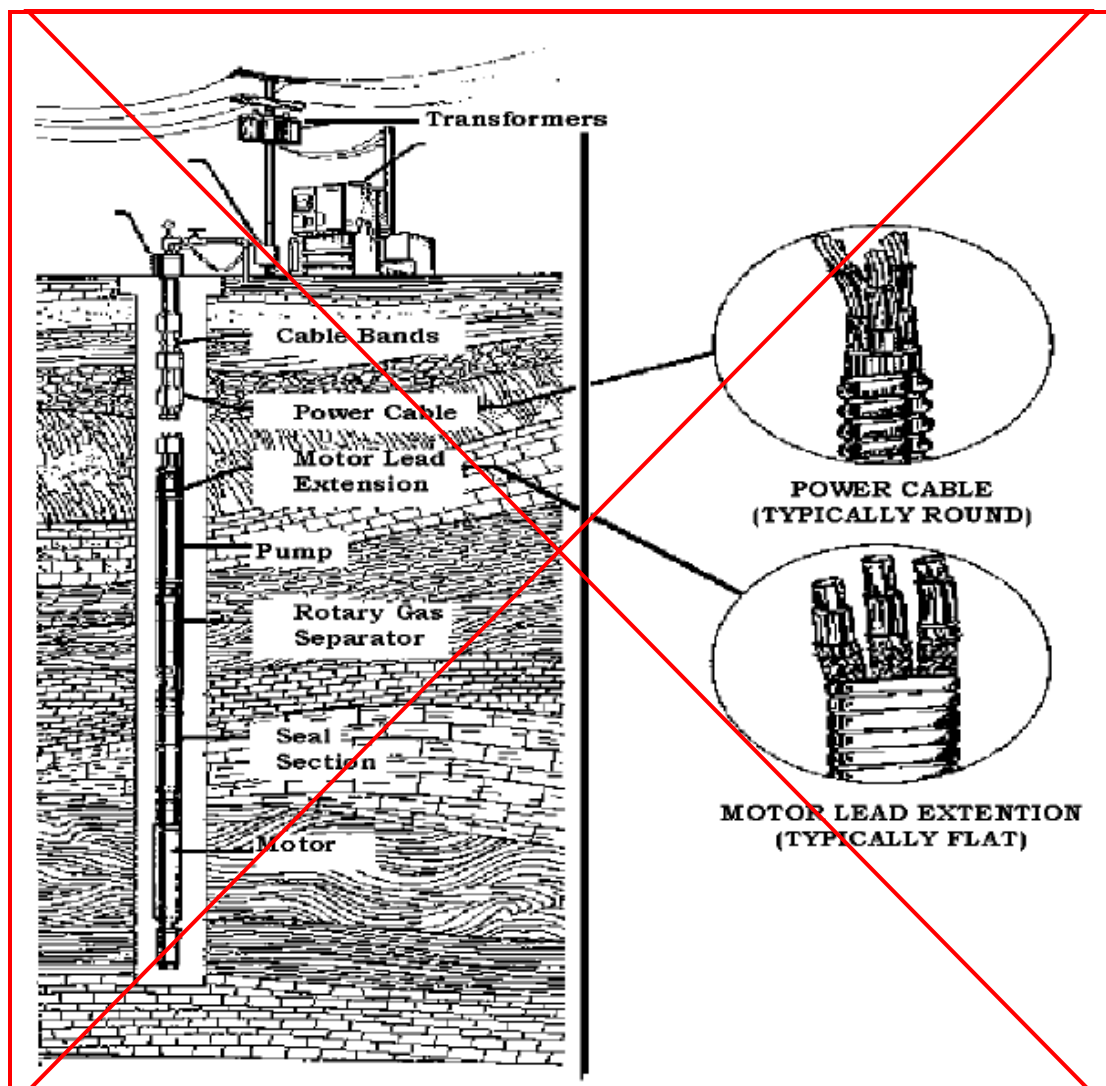
^{9 4} *IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. An IEEE account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page ~~subscription is available at~~ http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html.

NOTE—Refer to Figure 1 for typical assembly.^{10 5}



(New)

^{10 5} Notes in text, tables, and figures of a standard are given for information only, and do not contain requirements needed to implement this the standard.



(Deleted)

Figure 1—Typical ESP cable

ESP cable: Three-conductor power cable is installed in the well for the purpose of transmitting power from the surface to the motor or motor-lead extension cable.

factory leakage current test: This test is completed by the manufacturer at ~~the~~ 100% of the factory test voltage level. This voltage test is conducted phase to ground. Factory tests may be conducted either at the manufacturing facility or at other manufacture's regional locations prior to delivery of the cable to the customer.

NOTE—The factory test voltage level is ~~Values are~~ shown in Table 1.

feedthrough/penetrator: A pressure blocking device that breaks the downhole cable from the surface conditions such that there is no continuous gas leakage pathway between the well internal and surface conditions. Penetrator systems utilize a separable surface connector and may or may not have a lower connector system.

field: This term or the term “in the field” may include cable not yet installed or cable that has been removed from its operating environment.

imbalance: Voltage and current in three phase system normally are equal but with slight changes in impedance in each phase, these can vary slightly from nominal values. Imbalance is the difference in voltage and current between the three phases of a cable system due to the impedance differences.

insulation resistance (IR): The opposition to current flow through the insulation.

insulation resistance test: The ratio of applied direct voltage to measured leakage current where the current measurement is taken at time t , specified from the start of voltage application ~~By impressing a dc voltage across the insulation, a leakage current will be produced through the insulation. The ratio of voltage to current is the insulation resistance of the cable.~~

leakage current (conductance): Current resulting from leakage through the cable insulating layer(s) and over surfaces of cable connections and terminations. This leakage current is measured using a test set equipped with an accurate microampere meter. Corona discharge from external energized element is included in this value.

maintenance leakage current test: This test is conducted after removing the cable from a well and is normally performed by the user or the designated representative using dc voltage at 40% of the factory test voltage level. It is intended to detect the deterioration of the cable insulation and to help determine suitability for reuse. It is also sometimes referred to as proof testing.

NOTE—The factory test voltage level is shown in Table 1.

motor-lead extension cable (MLE): Three-conductor cable typically designed with a high-temperature/-high dielectric insulation to allow for the smallest cable profile possible. This cable runs from above the pump to the motor and includes the motor connecting plug (Pothead).

rated voltage: The Phase-to-phase voltage to which operating and performance characteristics are defined of a three-phase system.

surface connecting cable: Power cable from wellhead to surface equipment.

system test: A field test made during or after installation or connection of motor, terminations, motor leads, penetrations, etc. but before the cable system is placed in normal service. The test is intended to detect installation damage and to show any gross defects or errors in installation of other system components.

tan-delta mean: The mean of all tan-delta values (minimum six values) obtained during measurement at a given voltage level.

tan-delta standard deviation: The standard deviation of all tan-delta values (minimum six values) obtained at a given voltage level.

tan-delta tip-up: The difference between the tan-delta mean at the $1.5'U_o$ voltage level and the tan-delta mean at the $0.5'U_o$ voltage level.

3.2 Acronyms and abbreviations

ac alternating current

ASD adjustable speed drive

AWG American wire gauge

c ampacity coefficient

CEV corona extinction voltage

CIV corona inception voltage

dc direct current

dV/dt change in voltage divided by change in time

EPDM ethylene propylene diene monomer

EPR ethylene-propylene rubber: used as a generic term to define EPM or EPDM insulation

ESP electric submersible pump

kVA kilovolt-amperes

kW kilowatt

MLE motor lead extension cable

PD partial discharge

PE polyethylene thermoplastic

PMM permanent magnet motor

PP polypropylene thermoplastic

PWM pulse width modulated

TDR time domain reflectometry

THD total harmonic distortion

U_o rated voltage

V_o operating voltage

VSD variable speed drive

VFD variable frequency drive

VLF very low frequency (for the purpose of this guide 0.01 Hz to 1.0 Hz)

VLF-DF very low frequency—dissipation factor

VLF-DS very low frequency—dielectric spectroscopy

VLF-DTD very low frequency—differential dissipation factor (delta tan-delta)

VLF-LC very low frequency—leakage current

VLF-LCH very low frequency—loss current harmonics

VLF-PD very low frequency—partial discharge

VLF-PDEV very low frequency partial discharge extinction voltage

VLF-PDIV very low frequency partial discharge inception voltage

VLF-TD very low frequency dissipation factor (tan-delta)

Cable names may include multiletter description based on cable construction from copper conductor to outer armor. First letter is usually vendor name, second is insulation (e.g., E for EPDM or P for polypropylene). Next is jacket (e.g., L for lead or N for Nitrile). Last is three-conductor type (e.g., F for flat or R for round).

4. Safety

4.1 Description

Testing of cable systems using high-voltage ~~de~~ testing involves all hazards that are normally associated with working on energized circuits and several unique hazards that should be addressed.

4.2 Application

Cables subjected to high-voltage testing can hold an electrical charge for long periods of time after voltage has been removed. This electrical charge is maintained because of the high capacitance and dielectric absorption characteristics of the insulation. This buildup of an electrical charge is characteristic of all insulating materials.

WARNING

Cable subjected to high-voltage testing that is not properly grounded after the test can have dangerous charge buildup. Proper grounding procedures shall be followed to [reduce](#) ~~eliminate~~ personnel hazards.

4.3 Procedures to secure cable test area

Cable testing is best performed in a designated area designed for the sole purpose of inspecting and testing of cable. Equipment should be maintained, calibrated, and checked at regular intervals to help verify that equipment is in working order and that the grounding system is functional. It is recommended that a warning light be incorporated into the test setup to indicate that the system has been energized.

[All safety or personal protective equipment \(PPE\) should be inspected to verify that the ratings exceed the test voltages.](#)

Cable circuits often have one or more ends that are remote from the location of the test equipment and test operator. These ends should be cleared and guarded for the safety of personnel. Voice communication should be established between all such locations and the test operator. Before a cable is energized, make sure the area is clear of personnel.

All ends and all connecting leads of components being tested require guarding from accidental contact by such means as rope barriers, enclosures, or a watchman at all hidden points. The ends require separation from all elements not to be subjected to test by a distance of not less than 15 cm (5.9 in).

All components should be de-energized before starting any work. Cable may become electrically charged by induced voltages. A grounded connection should be applied to each conductor, the armor, and all non-energized metallic parts in the vicinity prior to physical contact. The only time a ground connection should be removed is when applying test voltage to that insulated conductor.

When ~~de~~ voltages are applied to the cable, it is common for a residual charge to remain in the insulation. After the cable is tested, each conductor should be discharged to ground. A grounded connection should be reattached to the conductor. The ground should be applied long enough to completely discharge the cable, or at least two times the duration of the voltage test. Otherwise, there is danger of electrical shock.

Additional precautions should be followed after completing tests with ~~de~~ voltages greater than 5 kV. Connect all conductors and the armor (group tie) to an effective ground.

5. General considerations

5.1 Environmental influences

5.1.1 Temperature and trapped gases

Rapid decompression of the cable can cause damage as gas bubbles expand inside the cable. As a result, cable pull speeds should be held to levels which allow trapped gasses to dissipate without causing cable damage.

The dielectric strength of cable insulation is reduced at elevated temperatures. Therefore, surface cable tests should be conducted after the cable has cooled to surface ambient temperature and the cable has had sufficient time to degas.

5.1.2 Environmental conditions

High humidity and conditions favoring condensation on exposed surfaces can affect test results to a marked degree. Contamination can greatly increase conduction current and increase the potential for flashover. Relative air density affects the measurement of test voltage and may cause a flashover at the termination. At elevations higher than 1000 m (3280 ft), additional insulation of the cable ends is required to withstand the prescribed test voltages. Wind can cause erroneous current readings by preventing the accumulation of space charges at bare energized terminals resulting in increased corona. Consequently, all of these factors should be considered when conducting cable tests.

5.2 Cable storage

Where possible, cable reels are to be stored indoors on a hard, dry surface to help prevent deterioration of the reels, possible ingress of moisture into the cables, and to protect the cables from extremely low temperatures prior to installation. Cable reels should not be stored on their sides. This practice can potentially cause snags when cable is being deployed from the reel. Cables should be stored at temperatures between $-50\text{ }^{\circ}\text{C}$ and $+75\text{ }^{\circ}\text{C}$.

Cable reels stored outdoors should be supported off the ground and covered with a suitable weatherproof material. The reel supports should be at least twice the width of the reel flange, long enough to provide adequate load bearing surface (to prevent sinking), and high enough to prevent the reel from sitting in free standing water in the event of heavy rainfall. All reel supports must be positioned under each reel flange, and to prevent free rolling each reel should be chocked between the reel flange and the support at opposite sides of the flange.

All cable reels should be stored in such a manner allowing easy access for lifting and moving, away from construction activities, falling or lying objects, sources of high heat, open flames, chemicals or petroleum products, etc. that may come in contact with the cable and cause damage.

The use of fencing or other barriers to protect cables and reels against damage by vehicles or other equipment moving about the storage area is highly recommended.

If the factory-applied endcaps are removed for any reason, the exposed cable ends should be re-sealed using properly applied weatherproof endcaps or by taping the ends with a tape/mastic designed specifically to prevent the entrance of moisture into the cable. Tapes such as PVC or duct tape are not suitable for preventing the entrance of moisture. Loose cable ends on the reels should be securely re-fastened to the reel flange and should not be allowed to lie on the ground.

5.3 Equipment maintenance

For accuracy of cable tests, periodic maintenance tests and calibrations should be performed on the test equipment. These procedures should follow the manufacturers' recommended practices. A label showing the latest calibration date should be affixed to the instrument. For some applications, it may be desirable to use outside certifications traceable to the National Institute of Standards and Technology or other recognized testing agencies or bureaus.

5.4 Tests covered by the recommended practice

This recommended practice covers equipment and procedures for the following tests:

- DC hi-pot (dc leakage)
- DC withstand
- AC withstand
- Conductor resistivity and continuity
- Mechanical integrity inspection
- Partial discharge (PD)
- Very low frequency (VLF)/Tan-delta (TD)
- Wellhead penetrator/Pothead dc hi-pot (dc leakage)
- Qualification testing for encapsulating materials

5.5 Additional test equipment

[In addition to the tests covered in this document, additional test equipment is available. A brief description of various test equipment follows.](#)

5.5.1 Insulation resistance (IR) meter

Resistance-measuring instruments by themselves are not recommended for testing the reliability of ESP cable. The output voltage is insufficient to establish a conductive path across insulation defects and will only indicate gross defects.

Insulation resistance measurements are used as the cable is being lowered into the well. These readings provide an indication to the systems reliability. As the unit is lowered into the well, IR can be expected to gradually drop off due to the increase in well temperature.

[Insulation resistance measurements can be used as a go/no-go indicator prior to other tests discussed in this document.](#)

~~5.4 Special fault locating test equipment~~

5.5.2 Time-domain reflectometer (TDR)

~~Time-domain reflectometers (TDRs)~~ use high-frequency pulses to detect anomalies in the cable. A TDR sends a pulse down the cable, and then the reflective signal is measured. This measurement indicates where the fault should be located. The TDR requires interpretation from an experienced operator. [Because of the high inductance in spooled cable, TDR sometimes is ineffective in locating a fault when cable is on the reel, particularly in lead jacketed cable. In these cases, bridge-type fault location can be more effective.](#)

Communication-type TDRs are designed for low-voltage cable and will not detect minor faults in high-voltage insulation. The power-type TDRs impress a larger voltage on the cable to overcome insulation resistance before the impulse is applied and measured.

In some installations it is helpful to capture a TDR “fingerprint” once the cable is landed. This is then used as a baseline for comparison purposes after a fault is identified in the downhole equipment. It is important to note that the fingerprint should be updated each time the string is removed from the well and re-run. For example, the addition of a packer requires, in most instances, a packer penetrator be added to the cable string. This changes the characteristics of the cable string, and a new baseline fingerprint should be captured.

5.5.3 Bridge-type fault locator

A bridge-type fault locator uses a balancing bridge in conjunction with high dc voltage to measure conductor impedance (distance) to a fault. This is one of the least destructive types of fault-locating equipment, and it is ~~relatively~~ effective. However, if a high-~~impedance~~ ~~resistance~~ fault is present, this device may not be effective. This test device is also referred to as a Murray loop bridge.

5.5.4 Thumper

A high-voltage capacitive discharge is applied to a cable when using a thumper. It is sometimes used to break down conductor insulation to locate a fault. However, this approach creates extreme stress on the cable insulation. If improperly used, it can create faults in otherwise good cable. This method is normally not recommended for testing cable and should only be used by experienced personnel for isolating the fault location. Additional safety considerations may be required.

It should be noted that the use of the thumper can destroy evidence of the failure mechanism as the insulation is burned away. This may prevent forensic analysis and accuracy of fault identification and may lead to repeated failures.

5.5.5 High-voltage fault burn

Either ac or dc voltage (generally 5 kV ~~to~~ 10 kV) is applied to a faulted cable. The voltage is allowed to remain until the fault location becomes obvious.

It should be noted that a fault burn can destroy evidence of the failure mechanism as the insulation is burned away. This may prevent forensic analysis and accuracy of fault identification and may lead to repeated failures.

6. DC ~~hi~~ **high**-pot test methods

6.1 Overview

Direct current (dc) high potential testing has been used for decades as a means to detect gross damage or significant weakness in dielectric materials. It is highly adaptable to field testing, as the required equipment is lightweight and portable. The test consists of the application of a high-voltage dc voltage between the conductor and a grounded external plane for a duration of time (typically 5 min or more). Leakage current measurements taken from the test may be used to determine the basic strength of the dielectric system and the overall insulation resistance (IR). This test is not likely to uncover more subtle conditions such as voids in the insulation, minor damage, or the presence of water treeing. In addition, leakage current values at a specific voltage can be subject to variances due to humidity, as well as the preparation method and physical orientation of the cable ends. These values are also highly dependent on the temperature of the cable at the time of the test. These factors should be taken into consideration when interpreting the results.

Although IEEE Std 400.1TM [B12] is not an applicable guide in assessing the condition of electric submersible pump (ESP) cable, by adopting some principles set forth in IEEE Std 400.1 and applying others developed from field experience, this recommended practice will assist those persons with the responsibility of determining the dielectric condition of this type of cable.

Unless otherwise noted, electrical tests described in ANSI/NEMA WC71/ICEA S-96-659, *Part 7 Testing and*

Test Methods should be performed per that standard.¹¹

¹¹Information on references can be found in Clause 2.

6.2 Precautions

Barriers, enclosures, or watchmen should be used to help prevent anyone from coming into accidental contact with the cable during testing. The ends require separation from all elements not subject to test by distances not less than 15 cm (5.9 in).

WARNING

Distances for personnel safety will be significantly greater [than 15 cm \(5.9 in\)](#). Users shall comply with all applicable safety codes.

To improve the accuracy of the test, it is desirable to reduce corona leakage current at the bare metal extremities of the cable by covering these with plastic bags, silicone sealant, electrical putty, or immersing in electrical grade oil to reduce stress concentrations.

Environmental conditions as outlined in 5.1.2 can cause erroneous meter readings. In addition, conducting cable tests when there is high humidity, when it is snowing or raining, or when actual precipitation is present on cable surfaces can be hazardous to equipment and personnel due to the likely chance of flashover.

6.3 DC high potential tester (hi-pot)

[Selection of the hi-pot tester should be based on the following:](#)

~~Equipment should provide~~

- The maximum voltage required
- Means of increasing voltage continuously or in small steps from zero to the maximum limit
- Output voltage regulation
- Filtered dc voltage output

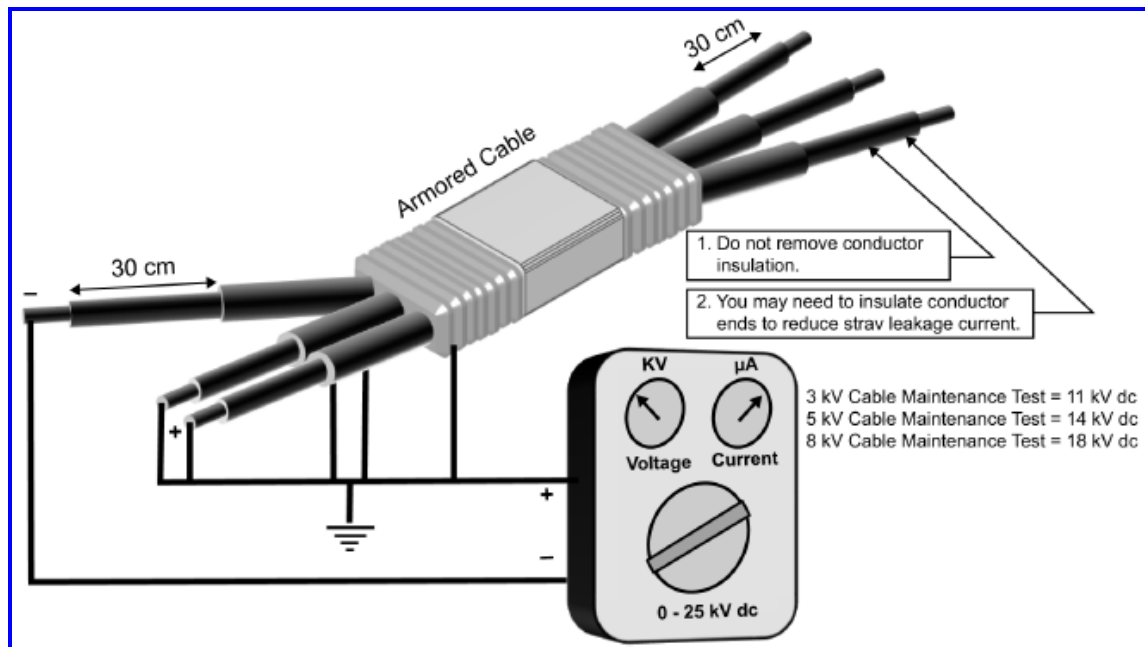
- Voltage and current indicators (current indicator should read in microamperes)
- Negative polarity to the cable conductor
- Minimum meter accuracy of 2% full scale
- A ground position for discharging the cable

6.4 Equipment setup

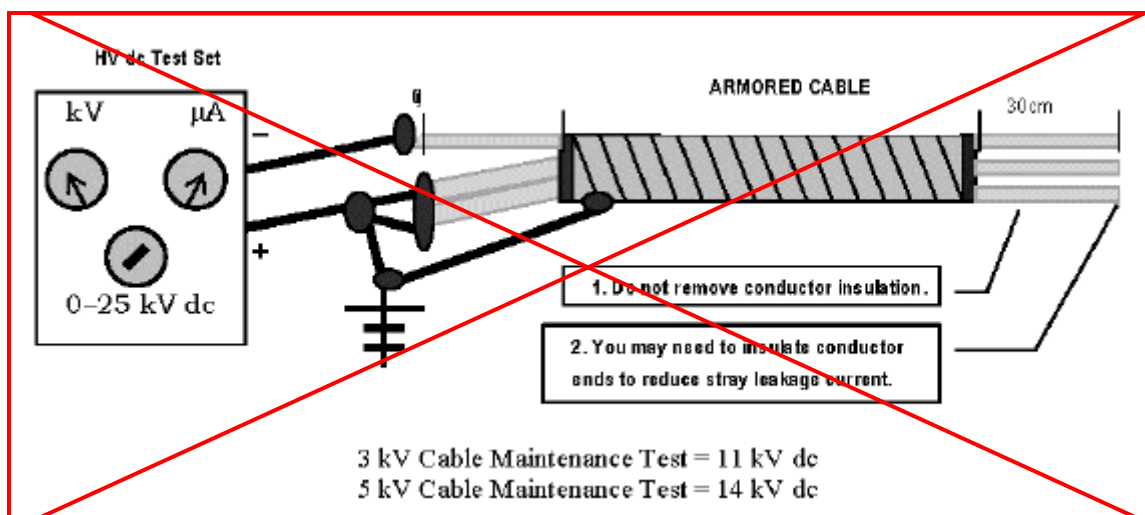
Check the operation of the test set in accordance with the manufacturers' recommendations. The equipment leakage current indication can be checked by connecting a short piece of small uninsulated wire to the test lead. Raise the voltage until corona is heard on the ends of the wire, and check for a current reading on the microampere meter. Then isolate the test lead and cover with plastic material, if necessary, to reduce corona. Raise the voltage to the test value. If leakage current in the test equipment is substantial, [test leads should be checked for damage and cleanliness. If substantial leakage current remains,](#) this current should be measured and subtracted from the test-current readings.

6.5 Procedures

Remove approximately 30 cm (12 in) of armor and outer coverings from each cable end to expose clean insulation. Then separate and spread phase conductors as shown in Figure 2. Remove approximately 2.5 cm (1 in) of insulation from phase conductors at the test set end, and buff the exposed metallic conductors. Clean the exposed insulation with a clean cloth and/or a nonresidue-approved solvent to help minimize stray current and help prevent flashover.



(New)



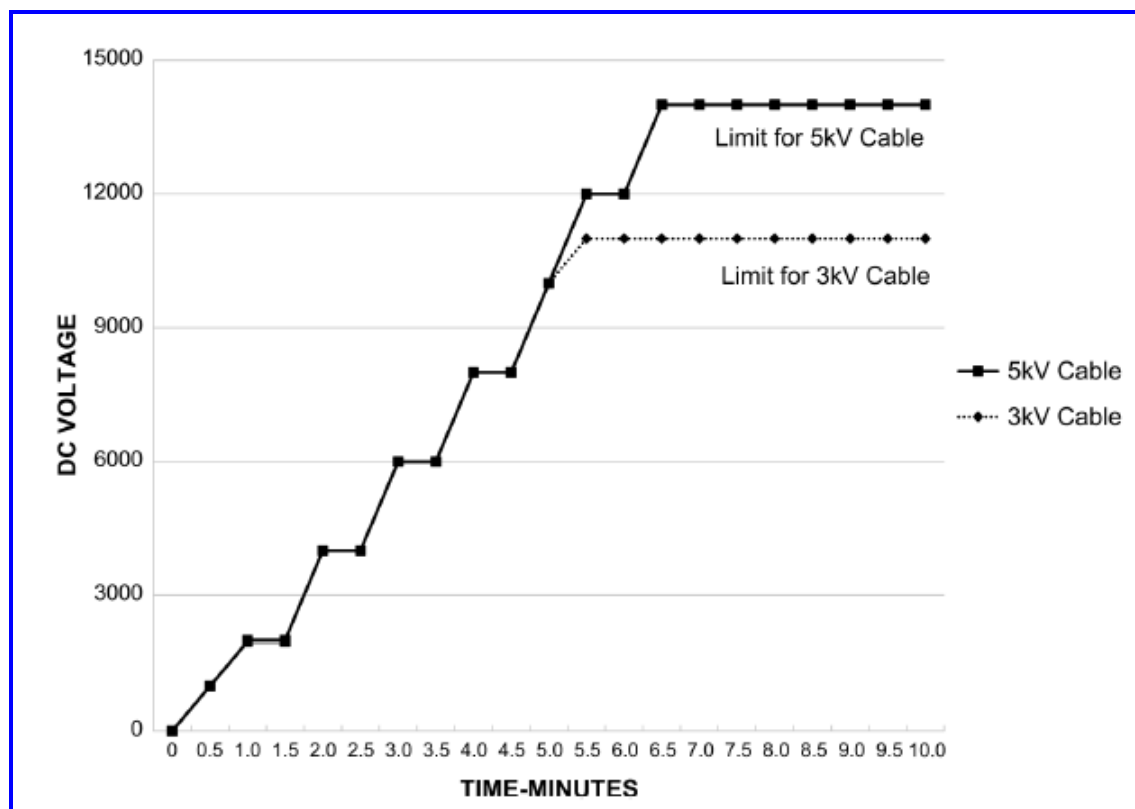
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Figure 2—High-voltage dc cable test conditions

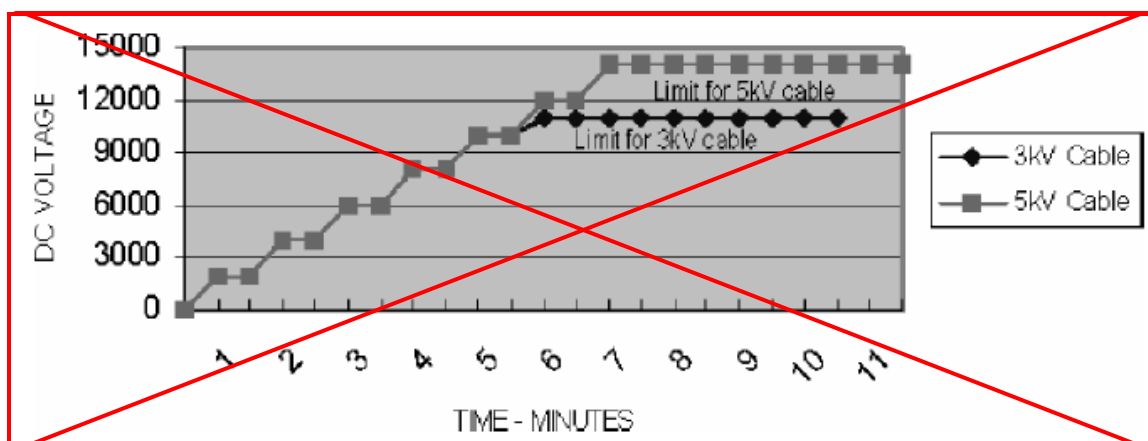
Each conductor should be tested separately with the remaining conductors, [armor](#), and [any lead jacket](#) grounded. The ground lead for the test set should also be connected to the power-source ground, supporting metallic structures, and the cable armor [and lead jacket](#).

Before applying the test voltage, the cable should be allowed to cool to ambient surface temperature. The voltage may be increased continuously or in steps to the maximum test value. If increased continuously, the rate should be approximately 1 kV/s. This rate helps avoid impulse stresses on the insulation. If the step method of voltage increase is employed, a minimum of three steps is desirable. Duration at each step should be long enough for the current to reach a steady value (a minimum of 1 min) before taking a current reading. Apply voltage slowly to prevent an off-scale meter indication.

Maximum test voltage should be maintained for a minimum of 5 min ~~minutes~~. Conductance leakage should be noted at 1 min intervals ~~for 5 min and after the maximum test voltage has been reached~~. Figure 3 depicts a typical step voltage test sequence for maintenance testing. Table 2 through Table 9 indicate the recommended maximum steady-state leakage current. These values are based on theory developed by Durham et al. [B10 B5].



(New)



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Figure 3—High-voltage dc step test

At the completion of the test period, the voltage can be reduced by returning the voltage control of the test equipment to zero. The voltage on the cable will discharge through the internal resistance of the test equipment. Normally this resistance has a very high ohmic value and the discharge time will be very long, especially for cables longer than a few hundred meters. A long discharge time may be impractical. Furthermore, directly grounding the cable with zero resistance while the voltage is at an elevated level can damage the cable. To discharge longer lengths of cable safely, separate grounding systems with built-in high-voltage discharge resistance designed to provide a time constant of several seconds or longer can be used. In all cases, discharge mechanisms should be designed to safely handle the test voltage and energy stored in the cable under test.

After the test voltage is reduced to a low level, the high-voltage conductor should be solidly grounded. The grounding provision used after a test should have no resistance included and be rated for the maximum fault current and fault duration of the system. The ground lead should be attached to the conductor under test for sufficient time to allow the conductor to discharge (a minimum of two times the length of the final voltage step).

The test may be conducted dry or wet on armored cable. However, on unarmored cable, the entire assembly must be submerged in a conductive solution (e.g., water or brine solution).