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DRAFT IEEE Recommended Practice for Field Testing Electric Submersible Pump Cable

Sponsor

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of the
IEEE Industry Applications Society

Abstract: Procedures and test voltage values for acceptance and maintenance testing of electrical submersible pump (ESP) cable systems are presented. This recommended practice applies to cable systems rated 3 kV and 5 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: conductors, cable ampacity, cable testing, field testing, and submersible pump cable.

Introduction

(This introduction is not a part of Draft IEEE P1017 IEEE Recommended Practice for Field Testing Electric Submersible Pump Cable.)

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 construction 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 specification 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 document.
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Marcus O. Durham, *Chair* Thomson H. Wallace, *Secretary*

David Anderson	Robert Lannom	Rodney Story
Gordon Baker	Howard Oswald	
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1. Introduction

1.1 Background.

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

This recommended practice proposes the use of dc because of its advantages over ac. These advantages are as follows:

(1) Smaller test equipment may be used
(2) Minimizes damage, which aids in fault examination

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 recommended 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 presently known good practice in testing methods, with interpretation of results.

1.2 Purpose.

The purpose of this recommended practice is as follows:

(1) Provide a guideline for performing leakage current so it can be used as a cable quality tool
(2) To provide guidelines for evaluation of the test results
(3) To define terms that have a specific meaning to the guide

1.3 Scope.

This document presents procedures and test voltage values for acceptance and maintenance testing of ESP cable systems. This procedure applies to cable systems rated 3 kV and 5 kV (phase to phase).

2. References

This recommended practice should be used in conjunction with the following publications. If the following publications are superseded by an approved revision, the revision should apply.

API RP 11S4, Recommended Practice for Electric Submersible Pump Installation, 2nd Edition, May 1986. [1]

API RP 11S5, Recommended Practice for Application of Electric Submersible Pump Cable System

API RP 11S6, Recommended Practice for Testing of Electric Submersible Pump Cable System

IEEE Std 400, IEEE Guide for Making High-Direct-Voltage Tests on Power Cable Systems in the Field (ANSI).[2]

IEEE Std 1018, IEEE Recommended Practice for Specifying Electric Submersible Pump Cable—Ethylene-Propylene Rubber Insulation (ANSI).

IEEE Std 1019, IEEE Recommended Practice for Specifying Electric Submersible Pump Cable—Polypropylene Insulation (ANSI).

NFPA 70, National Electrical Code (ANSI)[3]

3. Definitions

For the purposes of this standard, the following terms and definitions apply. IEEE Std 100-1996, The IEEE Standard Dictionary of Electrical and Electronic Terms, Sixth Edition, should be referenced for terms not defined in this subclause.

3.1 Basic

3.1.1 electric submersible pumps (ESP).: Equipment that refers to deep-well electric submersible pumps as commonly used to lift fluids from subsurface formations. Refer to Figure 1 for typical assembly.

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1 API publications are available from the Publications Section, American Petroleum Institute, 1200 L Street NW, Washington, DC 20005, USA.

2 IEEE publications are available from the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

3 NFPA publications are available from the National Fire Protection Association, One Batterymarch Park, Quincy, MA, 02269, USA.

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

3.2 Cable

3.2.1 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.

3.2.2 Motor lead extension cable: Three-conductor cable normally designed with a high temperature/high dielectric insulation to allow the smallest cable possible. This cable runs from above the pump to the motor including motor connecting plug.

3.2.3 Surface connection cable: Power cable connecting the ESP cable to surface equipment. Sometimes referred to as a “surface cable.”

3.3 Current

3.3.1 Absorption current: Current resulting from charge absorbed in the dielectric as a result of polarization.

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

3.3.3 Leakage current (conductance): Current resulting from leakage through the cable insulating medium and over surfaces of cable connections and terminations. This leakage current is measured using a test set equipped with an accurate microamp meter. Corona discharge from external energized elements will also be indicated as leakage current.

3.4 Electrical Tests

3.4.1 AC test: AC tests are performed by the manufacturer as a pass/fail test to insure the electrical integrity of the cable.

3.4.2 Acceptance test: Acceptance testing is intended to detect damage prior to the initial installation of new cable. These tests are normally performed by the user or his designated representative using DC voltage at 80% of the factory test voltage.

3.4.3 DC test: DC testing is performed by the manufacturer to insure 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.

3.4.4 Factory test: This test is completed by the manufacture at the 100% level as indicated in Table 1. This voltage test is conducted phase to ground.

3.4.5 Insulation resistance: The opposition to current flow through the insulation is referred to as insulation resistance (IR).

3.4.6 Insulation resistance test: 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. A megohmmeter is used to perform this test.

3.4.7 Maintenance test: This test is made after removing the cable from a well and is normally performed by the user or his designated representative using DC voltage at 40% of the factory test voltage. It is intended to detect the deterioration of the cable insulation and to determine suitability for reuse. Maintenance testing is sometimes referred to as proof testing.

3.5 Voltage

3.5.1 Rated voltage: The rated voltage is expressed in terms of phase-to-phase voltage of a three-phase system.

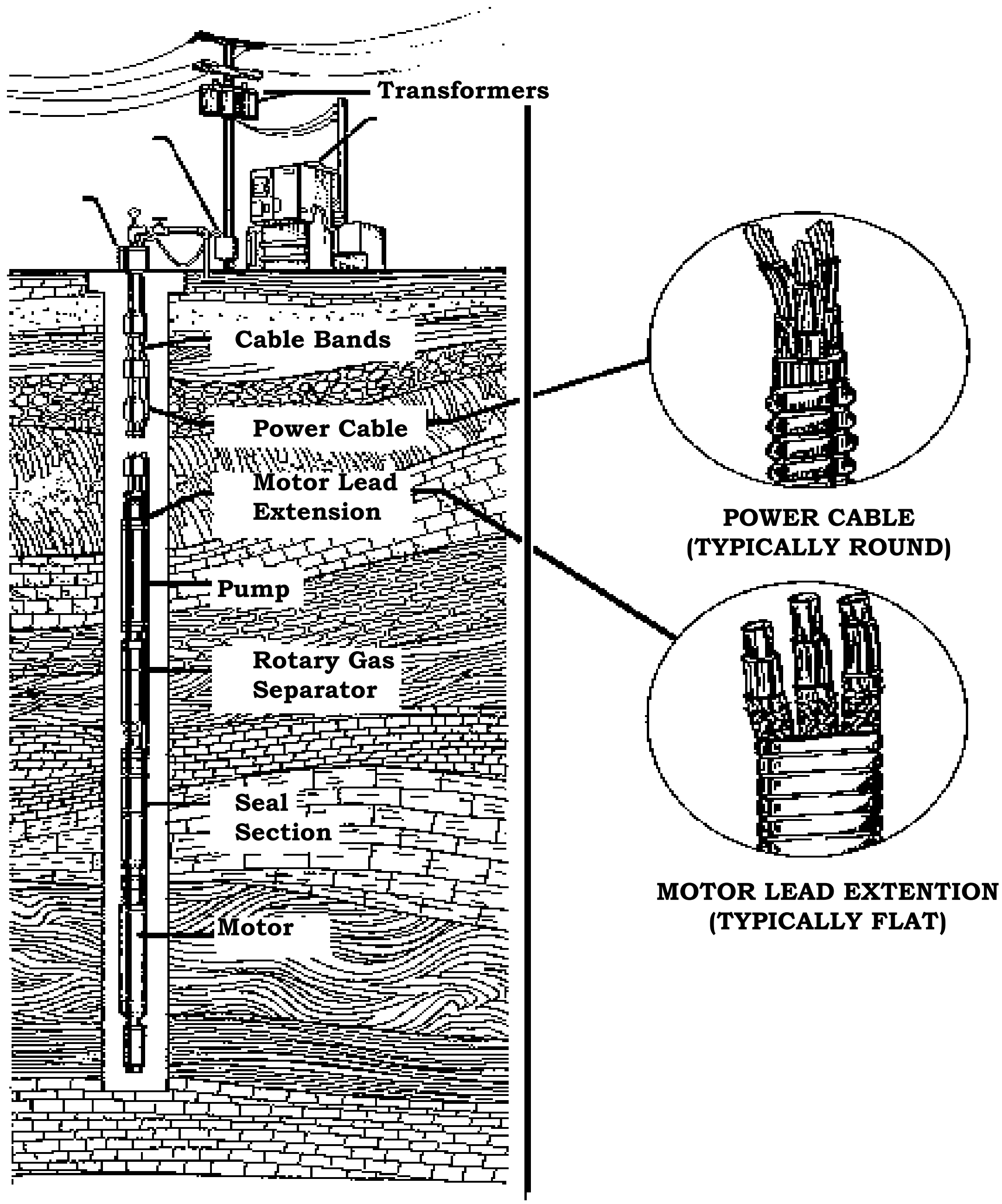


Figure 1--Typical electrical submersible pump cable

4.0 Safety

4.1 Description

Testing of cable systems using high voltage direct current (DC) testing involves all of the hazards normally associated with working on energized circuits and several unique hazards that should be addressed.

4.2 Application

Cables that are tested using dc voltage 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 dc testing that is not properly grounded following the test can have dangerous charge buildup. Proper grounding procedures shall be followed to eliminate personnel hazards.

4.3 Procedures to Secure Cable and 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 insure equipment is in working order and grounding system is functional. It is recommended that a strobe light be incorporated into the unit to indicate that the system has been energized.

Cable circuits normally 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 to ensure 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 as well as 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. A grounded connection should be applied to each conductor, the armor, and all non-energized metallic parts in the vicinity. The only time a ground connection should be removed is when applying test voltage to that insulated conductor.

When dc 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 re-attached to the conductor. The ground should be applied long enough to completely discharge the cable. This requirement may be up to four times the duration of the applied voltage. Otherwise there is danger of electrical shock even without an applied voltage.

Additional precautions should be followed after completing tests with voltages greater than 5 kVdc. Connect all conductors and the armor (group tie) to ground (normally the steel reel).

5. General Considerations

5.1 Environmental Influences

5.1.1 Temperature.

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 a chance 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 meters (3280 feet), additional insulation of the cable ends is required to withstand the prescribed test voltages. Wind can cause erroneous current reading. Consequently, all of these factors should be considered when conducting cable tests.

5.1.3 Oilwell Liquids and Gases.

Well liquids and gases are entrained in ESP cables that have been applied in service. The presence of these materials will increase the leakage current and decrease the insulation resistance. The entrained gas may ignite during high-voltage testing. This is due to the temperature rise in the well. Consequently, caution should be exercised when performing cable high-voltage tests.

The cable will continue to degas over a period of several days. Depending on specific well conditions, acceptable test value may be achievable in as little as 12 hours after being pulled from a well.

5.2 Test Equipment

5.2.1 DC High Potential Tester (hi-pot).

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 microamps)
- Negative polarity to the cable conductor
- Meter accuracy at least 2% full scale
- A ground position for discharging the cable

5.2.2 Insulation Resistance 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 lower 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 drop off significantly due to the increase in well temperature.

5.3 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 microamp 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, this current should be measured and subtracted from the test-current readings.

5.4 Special Fault Locating Test Equipment.

5.4.1 Time Domain Reflectometer (TDR).

TDRs use high-frequency pulses to detect anomalies in the cable. A TDR sends a pulse down the cable, and the reflective signal is measured. This measurement indicates where the fault should be located. The TDR requires interpretation from an experienced operator.

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

5.4.2 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 actually 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.

5.4.3 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-resistance fault is present, this device may not be effective. This test device is also referred to as a Murry loop.

5.4.4 DC Burn.

A dc voltage (5 to 10 kV) is applied to a faulted cable. The voltage is allowed to remain until the fault becomes obvious.

5.5 Equipment Maintenance.

To ensure accuracy of cable tests, periodic maintenance tests and calibrations should be performed on the test equipment. These should follow 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 (NIST).

6. DC Hi-Pot Test Methods

6.1 Precautions.

Barriers, enclosures, or watchmen should be used to 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).

CAUTION

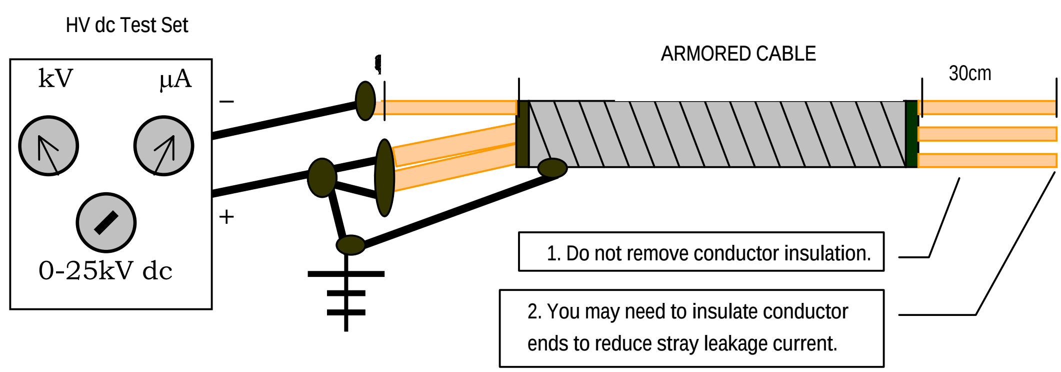
Distances for personnel safety will be significantly greater. Users should comply with all applicable safety codes.

To improve accuracy of the test it is desirable to reduce corona leakage current at the bare metal extremities of cable by covering these with plastic bags, RTV silicone or electrical putty 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.

6.2 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 Fig 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 non-residue approved solvent to minimize stray current and prevent flashover.



3kV Cable Maintenance Test = 11kV dc
5kV Cable Maintenance Test = 14kV dc

Figure 2 – High voltage dc cable test conditions

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

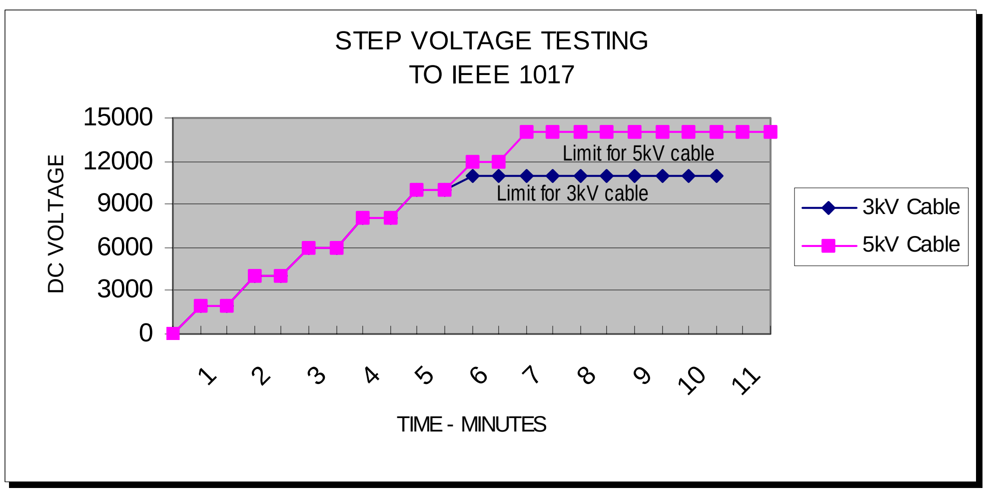
Before applying the test voltage, the cable should be allowed to cool to ambient surface temperature. The voltage may be increased continuously or in steps to the maximum test value. If increased continuously, the rate should be approximately 1kV per second. This prevents impulse stresses on the insulation. 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 (1 minute minimum) before taking a current reading. Apply voltage slowly to prevent an off-scale meter indication.

Maximum test voltage should be maintained for 5 minutes. Conductance leakage should be noted at 1-minute intervals for 5 minutes and after the maximum test voltage has been reached. Figure 3 depicts a typical step voltage test sequence for maintenance testing. Tables 2 thru 5 indicate the recommended maximum study-state leakage current. These values are based on theory developed in an IEEE paper by Durham, et al [1].

At the completion of the test period, voltage should gradually be reduced to zero. After the voltage is reduced, the conductor should be solidly grounded. The ground lead should be attached to the conductor under test for sufficient time to allow the conductor to discharge.

The test may be conducted dry or wet on armored cable. However, on unarmored cable the entire assembly must be submerged.

A minimum of three steps should be used.



Maintenance voltage for 3kV cable is 11kVdc, voltage for 5kv cable is 14kVdc

Figure 3 – High voltage dc step test

Recommended test voltages for ESP cable are shown in Table 1. When, in the opinion of the user, it is necessary to use more stringent maintenance test voltages, a higher level should be determined in consultation with the suppliers of the cable. When considering these higher voltages, the user should be aware of the insulation damage resulting from unduly high-voltage stresses.

Table 1--Test voltages for ESP cable

Cable dating (kV rms.) (phase-to-phase)	Factory test voltage (kV)	Acceptance † test voltage (kV)	Maintenance ‡ test voltage (kV)
3	27	22	11
5	35	28	14

All tests are dc, conductor to ground for 5 minutes
† Acceptance test is 80% of factory test.
‡ Maintenance test is 40% of factory test.

Table 2-1--Polypropylene acceptance testing

Values for 1.91 mm (75 mil) insulation thickness 3kV polypropylene					
Conductor	Conductor dia.	Insulation min. point	Calculated insul. dia.	IR value, 1 km (1 kft)	dc leakage, 1 km (1 kft)
Size	mm (inches)	mm (inches)	mm (inches)	MΩ	µA/kV
$10mm^2$	3.56 (0.140)	1.73 (0.068)	7.01 (0.276)	3,594 (11,791)	0.28 (0.08)
6 AWG	4.11 (0.162)	1.73 (0.068)	7.57 (0.298)	3,227 (10,588)	0.31 (0.09)
$16mm^2$	4.52 (0.178)	1.73 (0.068)	8.01 (0.314)	3,005 (9,860)	0.33 (0.10)
4 AWG	5.18 (0.204)	1.73 (0.068)	8.66 (0.341)	2,694 (8,840)	0.37 (0.11)
$25mm^2$	6.55 (0.258)	1.73 (0.068)	10.01 (0.394)	2,241 (7,355)	0.45 (0.14)
2 AWG	7.42 (0.292)	1.73 (0.068)	10.87 (0.428)	2,025 (6,642)	0.49 (0.15)
1 AWG	8.43 (0.332)	1.73 (0.068)	11.89 (0.468)	1,818 (5,964)	0.55 (0.17)
1/0 AWG	9.35 (0.368)	1.73 (0.068)	12.80 (0.504)	1,664 (5,458)	0.60 (0.18)
2/0 AWG	10.52 (0.414)	1.73 (0.068)	14.00 (0.551)	1,504 (4,934)	0.67 (0.20)

Table 2-2--Polypropylene acceptance testing

Values for 2.29 mm (90mil) insulation thickness 5kV polypropylene					
Conductor	Conductor dia.	Insulation min. point	Calculated insul. dia.	IR value, 1 km (1 kft)	Dc leakage, 1 km (1 kft)
Size	mm (inches)	mm (inches)	mm (inches)	MΩ	µA/kV
$10mm^2$	3.56 (0.140)	2.06 (0.081)	7.01 (0.302)	4,071 (13,355)	0.25 (0.08)
6 AWG	4.11 (0.162)	2.06 (0.081)	7.57 (0.324)	3,670 (12,041)	0.27 (0.08)
$16mm^2$	4.52 (0.178)	2.06 (0.081)	8.01 (0.340)	3,427 (11,242)	0.29 (0.09)
4 AWG	5.18 (0.204)	2.06 (0.081)	8.66 (0.367)	3,095 (10,154)	0.32 (0.10)
$25mm^2$	6.55 (0.258)	2.06 (0.081)	10.01 (0.420)	2,580 (8,465)	0.39 (0.12)
2 AWG	7.42 (0.292)	2.06 (0.081)	10.87 (0.454)	2,337 (7,667)	0.43 (0.13)
1 AWG	8.43 (0.332)	2.06 (0.081)	11.89 (0.494)	1,104 (6,903)	0.48 (0.14)
1/0 AWG	9.35 (0.368)	2.06 (0.081)	12.80 (0.530)	1,900 (6,235)	0.53 (0.15)
2/0 AWG	10.52 (0.414)	2.06 (0.081)	14.00 (0.576)	1,749 (5,737)	0.57 (0.17)

Table 3-1--Polypropylene maintenance testing

Values for 1.91 mm (75mil) insulation thickness 3kV polypropylene					
Conductor	Conductor dia.	Insulation min. point	Calculated insul. dia.	IR value, 1 km (1 kft)	dc leakage, 1 km (1 kft)
Size	mm (inches)	mm (inches)	mm (inches)	MΩ	μA/kV
$10mm^2$	3.56 (0.140)	1.73 (0.068)	7.01 (0.276)	1,797 (5,896)	0.56 (0.17)
6 AWG	4.11 (0.162)	1.73 (0.068)	7.57 (0.298)	1,614 (5,294)	0.62 (0.19)
$16mm^2$	4.52 (0.178)	1.73 (0.068)	8.01 (0.314)	1,503 (4,930)	0.67 (0.20)
4 AWG	5.18 (0.204)	1.73 (0.068)	8.66 (0.341)	1,352 (4,437)	0.74 (0.23)
$25mm^2$	6.55 (0.258)	1.73 (0.068)	10.01 (0.394)	1,121 (3,678)	0.89 (0.27)
2 AWG	7.42 (0.292)	1.73 (0.068)	10.87 (0.428)	1,012 (3,321)	0.99 (0.30)
1 AWG	8.43 (0.332)	1.73 (0.068)	11.89 (0.468)	909 (2,982)	1.10 (0.34)
1/0 AWG	9.35 (0.368)	1.73 (0.068)	12.80 (0.504)	832 (2,729)	1.20 (0.37)
2/0 AWG	10.52 (0.414)	1.73 (0.068)	14.00 (0.551)	752 (2,467)	1.33 (0.41)

Table 3-2--Polypropylene maintenance testing

Values for 2.29 mm (90mil) insulation thickness 5kV polypropylene					
Conductor	Conductor dia.	Insulation min. point	Calculated insul. dia.	IR value, 1 km (1 kft)	Dc leakage, 1 km (1 kft)
Size	mm (inches)	mm (inches)	mm (inches)	MΩ	μA/kV
$10mm^2$	3.56 (0.140)	2.06 (0.081)	7.01 (0.302)	2,035 (6,678)	0.49 (0.15)
6AWG	4.11 (0.162)	2.06 (0.081)	7.57 (0.324)	1,835 (6,020)	0.55 (0.17)
$16mm^2$	4.52 (0.178)	2.06 (0.081)	8.01 (0.340)	1,713 (5,621)	0.58 (0.18)
4 AWG	5.18 (0.204)	2.06 (0.081)	8.66 (0.367)	1,548 (5,077)	0.65 (0.20)
$25mm^2$	6.55 (0.258)	2.06 (0.081)	10.01 (0.420)	1,290 (4,232)	0.78 (0.24)
2 AWG	7.42 (0.292)	2.06 (0.081)	10.87 (0.454)	1,168 (3,834)	0.86 (0.26)
1 AWG	8.43 (0.332)	2.06 (0.081)	11.89 (0.494)	1,052 (3,452)	0.95 (0.29)
1/0 AWG	9.35 (0.368)	2.06 (0.081)	12.80 (0.530)	950 (3,118)	1.05 (0.32)
2/0 AWG	10.52 (0.414)	2.06 (0.081)	14.00 (0.576)	874 (2,868)	1.14 (0.35)

Table 4-1--EPDM acceptance testing

Values for 1.91 mm (75mil) insulation thickness 3kV EPDM					
Conductor	Conductor dia.	Insulation min. point	Calculated insul. dia.	IR value, 1 km (1 kft)	dc leakage, 1 km (1 kft)
Size	mm (inches)	mm (inches)	mm (inches)	MΩ	μA/kV
$10mm^2$	3.56 (0.140)	1.73 (0.068)	7.01 (0.276)	1,438 (4,717)	0.69 (0.21)
6 AWG	4.11 (0.162)	1.73 (0.068)	7.57 (0.298)	1,291 (4,235)	0.78 (0.24)
$16mm^2$	4.52 (0.178)	1.73 (0.068)	8.01 (0.314)	1,202 (3,944)	0.83 (0.25)
4 AWG	5.18 (0.204)	1.73 (0.068)	8.66 (0.341)	1,082 (3,550)	0.92 (0.28)
$25mm^2$	6.55 (0.258)	1.73 (0.068)	10.01 (0.394)	897 (2,942)	1.12 (0.34)
2 AWG	7.42 (0.292)	1.73 (0.068)	10.87 (0.428)	810 (2,657)	1.24 (0.38)
1 AWG	8.43 (0.332)	1.73 (0.068)	11.89 (0.468)	727 (2,386)	1.38 (0.42)
1/0 AWG	9.35 (0.368)	1.73 (0.068)	12.80 (0.504)	666 (2,186)	1.50 (0.46)
2/0 AWG	10.52 (0.414)	1.73 (0.068)	14.00 (0.551)	602 (1,974)	1.66 (0.51)

Table 4-2--EPDM acceptance testing

Values for 2.29 mm (90mil) insulation thickness 5kV EPDM					
Conductor	Conductor Dia.	Insulation Min. Point	Calculated Insul. Dia.	IR Value, 1 km (1 kft)	dc leakage, 1 km (1 kft)
Size	mm (inches)	mm (inches)	mm (inches)	MΩ	μA/kV
$10mm^2$	3.56 (0.140)	2.06 (0.081)	7.01 (0.302)	1,628 (5,342)	0.61 (0.19)
6 AWG	4.11 (0.162)	2.06 (0.081)	7.57 (0.324)	1,468 (4,817)	0.68 (0.21)
$16mm^2$	4.52 (0.178)	2.06 (0.081)	8.01 (0.340)	1,370 (4,497)	0.73 (0.22)
4 AWG	5.18 (0.204)	2.06 (0.081)	8.66 (0.367)	1,238 (4,062)	0.81 (0.25)
$25mm^2$	6.55 (0.258)	2.06 (0.081)	10.01 (0.420)	1,032 (3,386)	0.97 (0.30)
2 AWG	7.42 (0.292)	2.06 (0.081)	10.87 (0.454)	935 (3,066)	1.07 (0.33)
1 AWG	8.43 (0.332)	2.06 (0.081)	11.89 (0.494)	842 (2,762)	1.19 (0.36)
1/0 AWG	9.35 (0.368)	2.06 (0.081)	12.80 (0.530)	773 (2,562)	1.29 (0.39)
2/0 AWG	10.52 (0.414)	2.06 (0.081)	14.00 (0.576)	699 (2,294)	1.43 (0.44)

Table 5-1--EPDM maintenance testing

Values for 1.91 mm (75mil) insulation thickness 3kV EPDM					
Conductor	Conductor dia.	Insulation min. point	Calculated insul. dia.	IR value, 1 km (1 kft)	dc leakage, 1 km (1 kft)
Size	mm (inches)	mm (inches)	Mm (inches)	MΩ	μA/kV
$10mm^2$	3.56 (0.140)	1.73 (0.068)	7.01 (0.276)	719 (2,358)	1.39 (0.42)
6 AWG	4.11 (0.162)	1.73 (0.068)	7.57 (0.298)	645 (2,118)	1.55 (0.47)
$16mm^2$	4.52 (0.178)	1.73 (0.068)	8.01 (0.314)	601 (1,972)	1.66 (0.51)
4 AWG	5.18 (0.204)	1.73 (0.068)	8.66 (0.341)	541 (1,775)	1.86 (0.56)
$25mm^2$	6.55 (0.258)	1.73 (0.068)	10.01 (0.394)	448 (1,471)	2.23 (0.68)
2 AWG	7.42 (0.292)	1.73 (0.068)	10.87 (0.428)	405 (1,328)	2.47 (0.75)
1 AWG	8.43 (0.332)	1.73 (0.068)	11.89 (0.468)	361 (1,185)	2.77 (0.84)
1/0 AWG	9.35 (0.368)	1.73 (0.068)	12.80 (0.504)	333 (1,092)	3.00 (0.92)
2/0 AWG	10.52 (0.414)	1.73 (0.068)	14.00 (0.551)	301 (987)	3.33 (1.02)

Table 5-2--EPDM maintenance testing

Values for 2.29 mm (90mil) insulation thickness 5kV EPDM					
Conductor	Conductor dia.	Insulation min. point	Calculated insul. dia.	IR value, 1 km (1 kft)	Dc leakage, 1 km (1 kft)
Size	mm (inches)	mm (inches)	mm (inches)	MΩ	μA/kV
$10mm^2$	3.56 (0.140)	2.06 (0.081)	7.01 (0.302)	814 (2,671)	1.23 (0.37)
6 AWG	4.11 (0.162)	2.06 (0.081)	7.57 (0.324)	734 (2,408)	1.36 (0.42)
$16mm^2$	4.52 (0.178)	2.06 (0.081)	8.01 (0.340)	685 (2,248)	1.46 (0.45)
4 AWG	5.18 (0.204)	2.06 (0.081)	8.66 (0.367)	619 (2,031)	1.62 (0.49)
$25mm^2$	6.55 (0.258)	2.06 (0.081)	10.01 (0.420)	516 (1,693)	1.94 (0.59)
2 AWG	7.42 (0.292)	2.06 (0.081)	10.87 (0.454)	467 (1,533)	2.14 (0.65)
1 AWG	8.43 (0.332)	2.06 (0.081)	11.89 (0.494)	421 (1,381)	2.38 (0.72)
1/0 AWG	9.35 (0.368)	2.06 (0.081)	12.80 (0.530)	386 (1,268)	2.59 (0.79)
2/0 AWG	10.52 (0.414)	2.06 (0.081)	14.00 (0.576)	350 (1,147)	2.86 (0.87)

Table 6--Temperature correction factors

Test temperature	Insulation resistance TCF multiplier	DC leakage current TCF multiplier
10 °C (50 °F)	0.75	1.36
15 °C (59 °F)	0.97	1.03
20 °C (68 °F)	1.27	0.78
25 °C (77 °F)	1.66	.060
30 °C (86 °F)	2.20	0.46
35 °C (95 °F)	2.81	0.36

These factors apply to tables 2-1 through 5-2.

7.0 Evaluation of dc Hipot Test Results

7.1Current-Time Relationship.

The current indication will momentarily increase for each voltage increment due to the charging of the capacitance and the dielectric absorption characteristics of the cable. Both of these decay: the first, in a few seconds; the latter, more slowly. Ultimately, this leaves only the conduction current, including any external surface leakage or corona leakage currents. The time required to reach steady state current depends on the insulation temperature, the material, and the cable geometry whether it is flat or round.

7.2 Interpretation.

Considerable experience is needed to properly interpret dc test results. A significant factor is the change of leakage current with time. In general, the current will start relatively high and decline rapidly and should then become constant at some lower value. The fact that the current becomes constant is more important than the actual magnitude. If the leakage current starts to rise, it is a strong indication that trouble exists. It is usually the practice to continue the test for as long as the leakage current continues to rise, until dielectric failure occurs.

The leakage current curves are based on reaching and remaining at a constant voltage. At this voltage, the leakage current in a good cable will decrease rapidly then stabilize as shown in Figure 4.

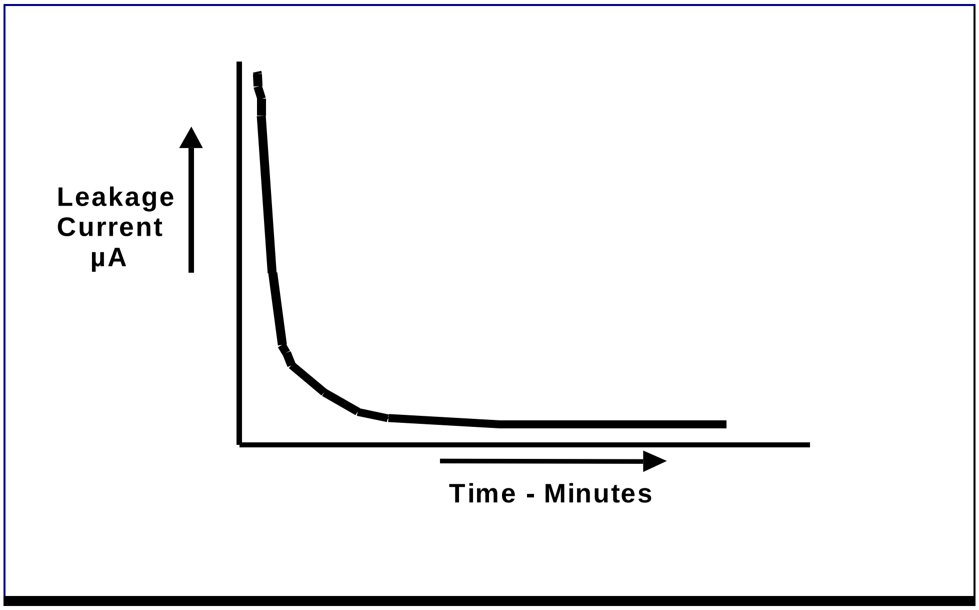


Figure 4—Leakage current in good cable

Deteriorating insulation quality may be observed in Figure 5 where the leakage current begins to rise as the time increases.

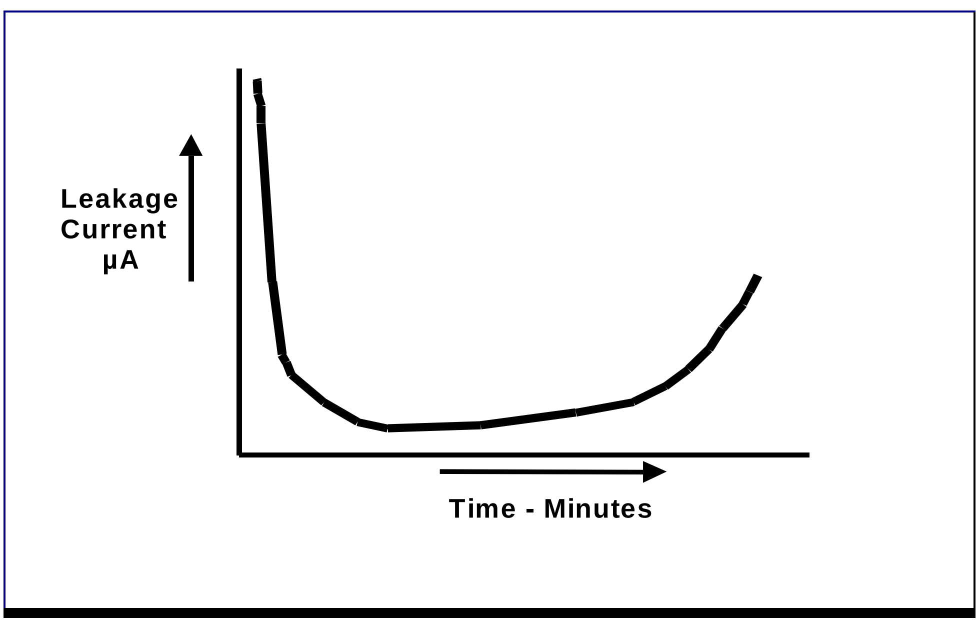


Figure 5—Leakage current in bad cable

Various insulating materials may have different leakage currents and still exhibit acceptable performance. For example, polypropylene insulated cable generally has much lower conductance leakage than EPDM rubber. Therefore, measuring higher leakage currents from one cable to the next may be the difference in materials and may not indicate deterioration in insulation.

To assist in the interpretation of leakage current, Tables 2 through 6 provide a set of values for polypropylene and EPDM cables. API 11S6 provides a very good explanation of the method used to calculate these tables. The values are to be used as a guide only and each operating area may wish to establish a set of values by cable type and well conditions that work for them. When interpreting rubber products a large variation may be seen from one vendor to the next. This is because of the special compound ingredients used for the unique formulations.

Step testing of cable requires more than the 3 to 6 steps to plot that is generated by the computer. Create a graph of microamp current versus kilovolt potential. On the graph, plot the slope of the acceptable dc leakage current. Then plot the microamp conductance at each of the test voltages. The measured current curve should be completely below the acceptable leakage current line. The equations for conducting the tests are developed in a paper “What are Standardized Equations for Acceptance of Hi-pot Tests and for Voltage Drop?” [B2].

EXAMPLE:

Assume: #2 AWG (33.6 mm^2), EPDM insulation, 2.3 mm (90 mil) thickness
From Table 4-2: 1.07 µA/kV/1km (0.33µA/kV/1kft) = the maximum allowed leakage

If we assume a length of 2000 meters(6562 feet) and the readings taken in the test data, then the plot would look like Figure-5.

If we divide the final reading in column 4 by the kV/km (kV/kft), the leakage for the cable is 0.375 µA per kV per 1km (0.11 µA per kV per 1 kft)

The first criterion is to determine the maximum leakage current permissible.

Next plot the measured µA verses the impressed kilovolts. All values must be below the leakage current line.

Table 7—Test data

Segment	Impressed kV	Maximum Allowed μA	Measured μA on 2 km (6.56 kft)
0	0	0	0
1	2.3	2.50	1.06
2	4.7	5.00	2.50
3	7.0	7.49	4.35
4	9.3	10.0	6.23
5	11.7	12.50	8.65
6	14.0	15.00	10.50

Readings have been rounded

Figure 6--Step test leakage current example

7.3 Dielectric Failure.

If at any time during the test a violent increase in leakage current occurs, failure or flashover has probably occurred in the cable. A failure can be confirmed by the inability of the cable to sustain the reapplication voltage. Once a dielectric failure occurs, the failure should be cut out. If a flashover occurs at the termination the termination should be repaired.

7.4 Current Comparison.

The comparison of the leakage currents of the three cable conductors is a useful indication of the insulation condition. However, no clear guidelines for such a comparison can be given. For large values of measured leakage current during maintenance testing, a potential problem is likely if the leakage current is greater than appropriate values from tables in this recommended practice.

Before leakage current was used as a measurement tool, 3 to 1 ratio was used to compare one phase with another phase regardless of the quantity of leakage. It is very difficult to compare conductor phases using 3 to 1 ratio as a pass/fail criteria. (Note that this ratio should be used with a great deal of discretion, particularly if microamp meter readings are less than 10 µA.)

In general, meter readings are more accurate above mid-scale because accuracy is normally a percentage of the full-scale reading. Therefore, when possible, select scales so that the readings are on the upper half of the meter. Trying to read a 2 µA value on the low end of a 0 to 100 µA scale is not accurate. When these low values are observed, it is difficult to compare performance between phases.

All cable insulation exhibits a negative temperature resistance coefficient. Increased temperature will, therefore, always result in increased leakage current.
As noted in section 5.1, testing under conditions of humidity, condensation, or actual precipitation on the cable surfaces can be hazardous. However, if testing must be done under these conditions, there may be an increase in the leakage current. Humidity also increases the corona discharge, which is indicated in the leakage current.

Wind prevents the accumulation of space charges at bare energized terminals. This results in an increase of corona. A plastic bag, RTV silicone or electrical putty retains this space charge in the presence of wind.

These factors should be considered when comparing and evaluating the apparent dielectric condition of the cable. If leakage currents appear to be high, then further investigation and testing is warranted to determine whether the cable has a high-resistance fault or deteriorating cable dielectric.

8.0 Conductor Resistivity and Continuity Tests

A test should be performed on all three-phase conductors to determine that their series resistance is balanced and that there are no breaks in any conductor. This test should be conducted by grounding all phase conductors at one end and measuring the resistance to ground of each conductor at the opposite end with an ohmmeter. These resistance values should be well balanced.

9.0 Mechanical Integrity

The primary component to assure mechanical integrity is the cable armor. Mechanical damage or discontinuities may indicate damage to the insulated conductor. Therefore, a thorough visual inspection is recommended.

The primary indications of mechanical damage are absence of armor, crimp marks, corrosion, and deformation. If these conditions are observed, the severity of the defect should be determined and, if necessary, corrected.

10.0 Testing of Surface Feedthroughs and Connections

10.1 Description.

The downhole cable must necessarily transition to a surface connection at some point. The type of transition depends on the installation configuration and area classification. The surface installation equipment is determined by the likelihood of an electrical failure occurring at the same time that, (1) an ignitable vapor is present and (2) the electrical failure will be the source of ignition.

At least three conditions reduce the likelihood of the electrical equipment being the cause of ignition: (1) other ignition sources must be present, (2) electrical equipment type, and (3) the presence and concentration of ignitable vapors in operating conditions.

The electrical configuration is not intended to control fugitive emissions. Refer to API RP 500 for details, there also may be state regulations that requires special consideration.

10.2 Wellhead with Feedthrough:

If there are no electrical connections, arcing contacts, or heat sources, then the electrical equipment will not be a source of ignition under normal operating conditions.

For these installations, the cable may be simply fed through the wellhead. The termination would be made in a vented junction box. The cable armor, wellhead, and vent box must be adequately grounded to the control panel grounding point. Bonding a copper wire of adequate size to the electrical components normally completes this circuit.

Although the area around the wellhead may be classified as Division 2, the cable is simply passing through the area. To make the area transition, appropriate seals and connections must be applied at the vented junction box.

10.3 Wellhead with Connections:

Some installations have a connection at the wellhead that may be a source of ignition. The equipment must have approval by a nationally recognized testing laboratory (NRTL).

Wellheads that are not enclosed in areas above ground grade are classified as Class I, Division 2. The connectors, cable and raceway for these systems must be approved for the area.

It is recognized under NFPA 70, Article 500-3 that there are connectors that have been used for many years without a problem. These connectors are not designed as load break devices and power must be de-energized before disconnecting the connector, therefore there is no source of ignition. This same criterion should apply for Feedthroughs at the wellhead.

Wellheads that are enclosed or in areas below ground grade are classified as a Class 1, Division 1 area. The connectors, cable and raceways for these systems must be approved by a NRTL.

10.4 Procedure:

The test procedure for surface equipment depends on the installation equipment.

10.4.1 Wellhead with Feedthrough.

The cable is tested as part of the downhole assembly as stated in this document.

10.4.2 Wellhead with Connections.

The components are prepared according to API 11S6 or the manufacturer procedures. The voltage tests are performed in the same manner as other components in this practice.

10.5 Visual Inspection:

The primary component to assure mechanical integrity is the cable armor. Mechanical damage or discontinuities may indicate damage to the insulated conductor. Therefore, a thorough visual inspection is recommended.

The primary component to assure mechanical integrity is the cable armor. Mechanical damage or discontinuities may indicate damage to the insulated conductor. Therefore, a thorough visual inspection is recommended.

10.6 Procedure:

The test procedure for surface equipment depends on the installation equipment.

10.6.1 Unclassified Feedthroughs.

The cable is tested as part of the downhole assembly as stated in this document.

10.6.2 Division 2 Connection.

The components are prepared according to API 11S6 or the manufacturer procedures. The voltage tests are performed in the same manner as other components in this practice.

10.6.3 Division 1 Connection.

The components are prepared according to API 11S6 or the manufacturer procedures. The voltage tests are performed in the same manner as other components in this practice.

Annex A

(informative)

Bibliography

[1] Durham, Marcus O., Neuroth, David H., Ashenayi, Kaveh, and Wallace,Thomson, "Field Test Technology Relationships to Cable Quality," , *IEEE Transactions on Industry Applications*, Vol. 31, No.6, Nov/Dec. 1995.

[2] Durham, Marcus O., Durham, Robert A., and Anderson, David "What are Standardized Equations for Acceptance of Hi-pot Tests and for Voltage Drop?", *Institute of Electrical And Electronics Engineers PCIC*, Institute of Electrical And Electronics Engineers PCIC, Indianapolis, September 1998.