

IEEE Recommended Practice for Field Testing Electric Submersible Pump Cable

IEEE Industry Applications Society

Sponsored by the
Petroleum and Chemical Industry Committee

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USA

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IEEE Recommended Practice for Field Testing Electric Submersible Pump Cable

Sponsor

Petroleum and Chemical Industry Committee
of the
IEEE Industry Applications Society

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Abstract: Procedures and test voltage values for acceptance and maintenance testing of electric 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: cable ampacity, cable maintenance, cable testing, conductors, field testing, IEEE 1017™, submersible pump cable

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Introduction

This introduction is not part of IEEE Std 1017-2013, 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 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.

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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™¹; however, that document 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 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) because of its advantages over alternating current (ac). These advantages are as follows:

- 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

¹ Information on references can be found in Clause 2.

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

1.2 Scope

Procedures and test voltage values for 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 and 5 kV (phase to phase).

1.3 Purpose

The purpose of this recommended practice is as follows:

- a) Provide a guideline for performing leakage current test so it can be used as a cable quality tool
- b) Provide guidelines for evaluation of the test results
- c) Define terms that have a specific meaning to the recommended practice

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.

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.

NFPA 70®, National Electrical Code® (NEC®).^{2, 3}

3. Definitions

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³ NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA (<http://www.nfpa.org/>).

⁴ *IEEE Standards Dictionary Online* subscription is available at
http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html.

absorption current: Current resulting from 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. 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.

NOTE—Refer to Figure 1 for typical assembly.⁵

⁵ Notes in text, tables, and figures are given for information only, and do not contain requirements needed to implement the standard.

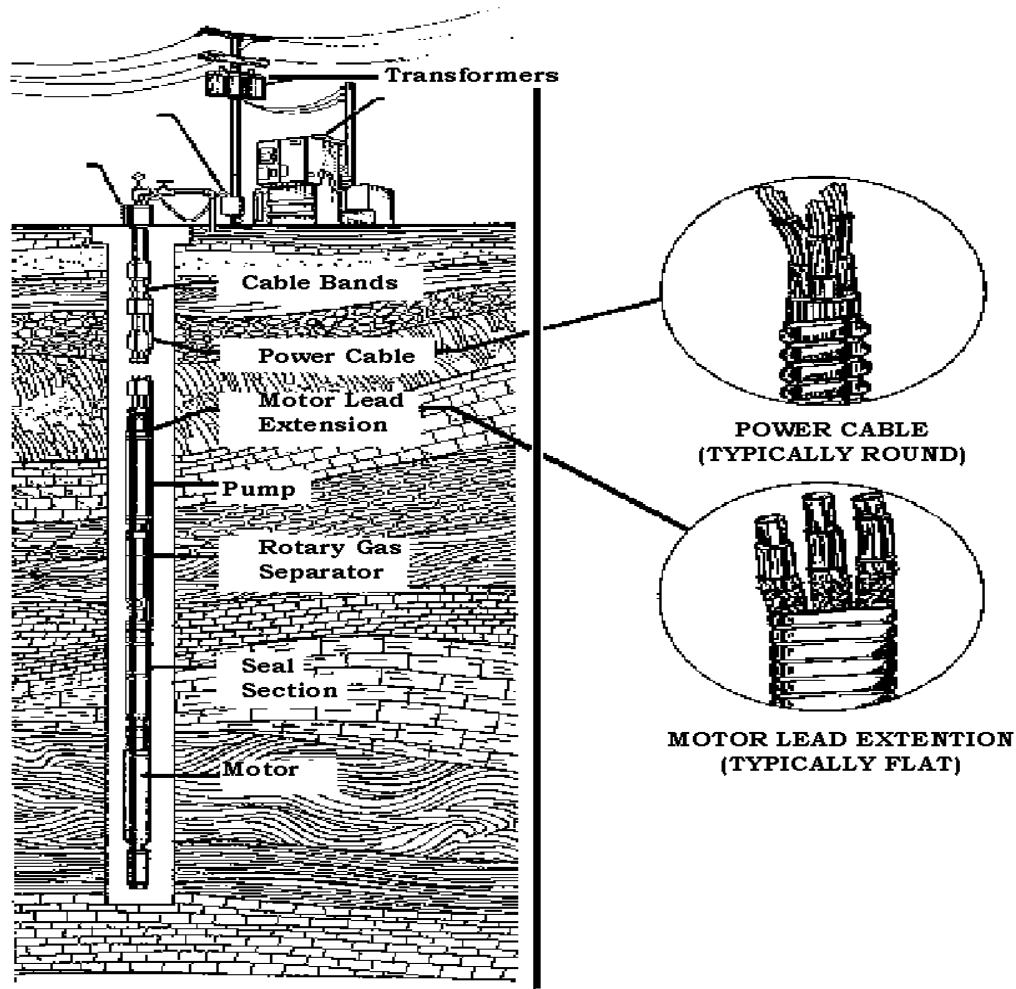


Figure 1—Typical ESP cable

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 test: This test is completed by the manufacturer at the 100% level. This voltage test is conducted phase to ground. Values are shown in Table 1.

Table 1—Test voltages for ESP cable

Cable rating (kV rms) (phase-to-phase)	Factory test voltage (kV dc) (phase-to-ground)	Factory test voltage (kV ac) (phase-to-ground)	Acceptance test voltage ^a (kV dc) (phase-to-ground)	Maintenance test voltage ^b (kV dc) (phase-to-ground)
3	27	9	22	11
5	35	13	28	14

^a Acceptance test is 80% of factory test.

^b Maintenance test is 40% of factory test.

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.

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

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.

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 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. 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.

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: Phase-to-phase voltage of a three-phase system.

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

4. Safety

4.1 Description

Testing of cable systems using high-voltage dc 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 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.

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 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 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 dc 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

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 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 microamperes)
- Negative polarity to the cable conductor
- Minimum meter accuracy of 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 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.

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 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, 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)

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.

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.

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 Murray loop bridge.

5.4.4 High voltage fault burn

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

5.5 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.

6. DC high-pot test methods

6.1 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.
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.

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

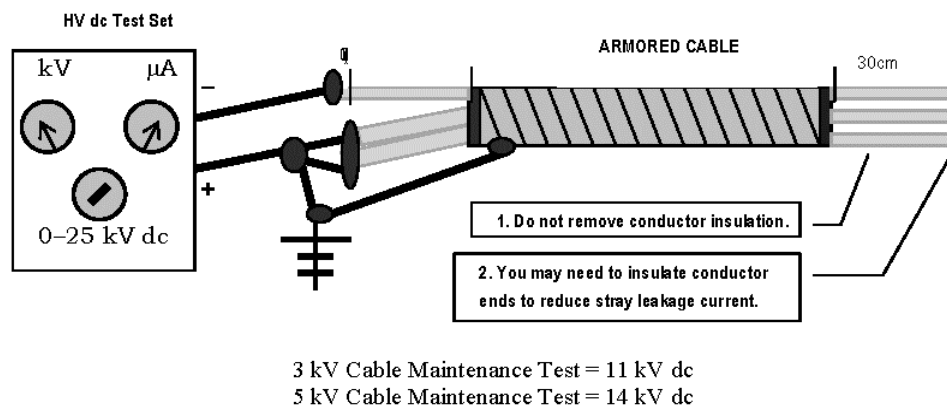


Figure 2—High voltage dc cable test conditions

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 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 5 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. [B5].

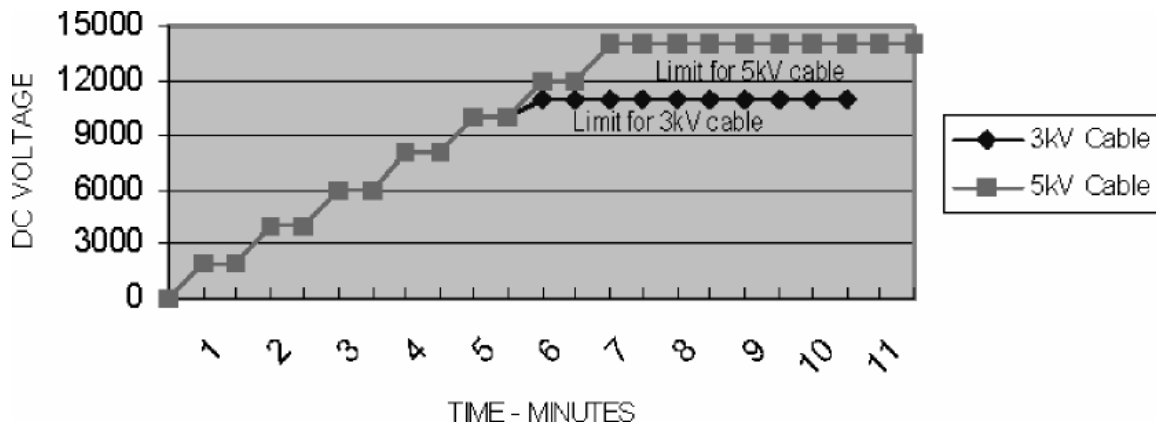


Figure 3—High voltage dc step test

At the completion of the test period, the 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 (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.

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.

7. Evaluation of dc high-pot test results

7.1 Current-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, only the conduction current is left, 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

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- μ A value on the low end of a 0- μ A to 100- μ A scale is not as accurate.

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. 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 and then stabilize as shown in Figure 4.

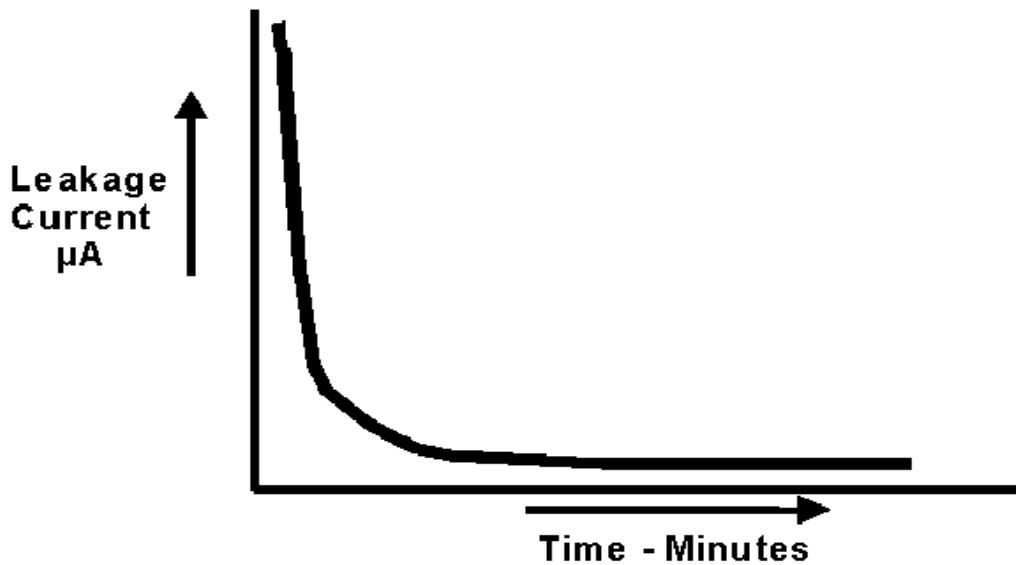


Figure 4—Leakage current in good cable

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

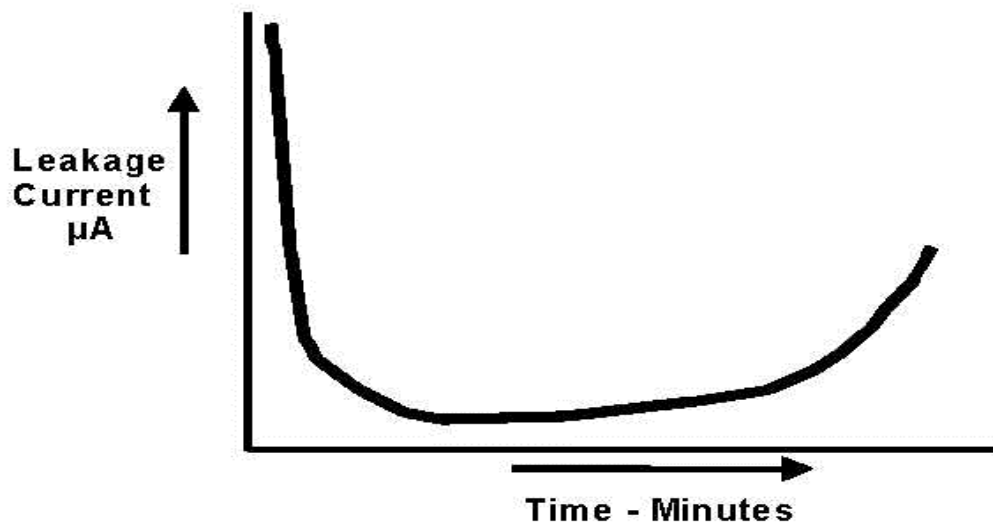


Figure 5—Leakage current in bad cable

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 does

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, Table 2 through Table 10 provide a set of values for polypropylene and EPDM cables. API RP 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 it. When interpreting rubber products, a large variation may be seen from one vendor to the next because of the special compound ingredients used for the unique formulations.

Table 2—Polypropylene acceptance testing (3-kV rated)

Values for 1.91-mm (75-mil) insulation thickness 3-kV polypropylene					
Conductor	Conductor diameter	Insulation minimum point	Calculated insulation diameter	IR value 1 km (kft)	DC leakage 1 km (kft)
Trade size	mm (in)	mm (in)	mm (in)	MΩ	μA/kV
10 mm ² (Solid)	3.57 (0.140)	1.73 (0.068)	7.03 (0.276)	3 588 (11 791)	0.28 (0.08)
6 Awg (Solid)	4.11 (0.162)	1.73 (0.068)	7.57 (0.298)	3 234 (10 588)	0.31 (0.09)
16 mm ² (Solid)	4.51 (0.178)	1.73 (0.068)	7.97 (0.314)	3 015 (9 860)	0.33 (0.10)
4 Awg (Solid)	5.19 (0.204)	1.73 (0.068)	8.65 (0.340)	2 705 (8 874)	0.37 (0.11)
4 Awg (Standard 7 Wire)	5.89 (0.232)	1.73 (0.068)	9.35 (0.358)	2 447 (8 014)	0.41 (0.12)
4 Awg (Compact 7 Wire)	5.41 (0.213)	1.73 (0.068)	8.87 (0.349)	2 618 (8 578)	0.38 (0.12)
25 mm ² (Solid)	5.64 (0.222)	1.73 (0.068)	9.10 (0.358)	2 533 (8 301)	0.39 (0.12)
2 Awg (Solid)	6.54 (0.258)	1.73 (0.068)	10.00 (0.394)	2 248 (7 355)	0.44 (0.14)
2 Awg (Standard 7 Wire)	7.42 (0.292)	1.73 (0.068)	10.88 (0.428)	2 027 (6 642)	0.49 (0.15)
2 Awg (Compact 7 Wire)	6.81 (0.268)	1.73 (0.068)	10.27 (0.404)	2 175 (7 130)	0.46 (0.14)
1 Awg (Solid)	7.35 (0.289)	1.73 (0.068)	10.81 (0.425)	2 043 (6 700)	0.49 (0.15)
1 Awg (Standard 7 Wire)	8.33 (0.328)	1.73 (0.068)	11.79 (0.464)	1839 (6 026)	0.54 (0.17)
1 Awg (Compact 7 Wire)	7.57 (0.298)	1.73 (0.068)	11.03 (0.434)	1993 (6 531)	0.50 (0.15)
1/0 Awg (Standard 7 Wire)	9.35 (0.368)	1.73 (0.068)	12.81 (0.504)	1667 (5 463)	0.60 (0.18)
1/0 Awg (Compact 7 Wire)	8.56 (0.337)	1.73 (0.068)	12.02 (0.473)	1797 (5 889)	0.56 (0.17)
2/0 Awg (Standard 7 Wire)	10.52 (0.414)	1.73 (0.068)	13.98 (0.550)	1506 (4 934)	0.66 (0.20)

Table 3— Polypropylene acceptance testing (5-kV rated)

Values for 2.29-mm (90-mil) insulation thickness 5-kV polypropylene					
Conductor	Conductor diameter	Insulation minimum point	Calculated insulation diameter	IR value 1 km (kft)	DC leakage 1 km (kft)
Trade size	mm (in)	mm (in)	mm (in)	MΩ	μA/kV
10 mm ² (Solid)	3.57 (0.140)	2.06 (0.081)	7.69 (0.302)	4 063 (13 355)	0.25 (0.07)
6 Awg (Solid)	4.11 (0.162)	2.06 (0.081)	8.23 (0.324)	3 677 (12 041)	0.27 (0.08)
16 mm ² (Solid)	4.51 (0.178)	2.06 (0.081)	8.63 (0.340)	3 436 (11 242)	0.29 (0.09)
4 Awg (Solid)	5.19 (0.204)	2.06 (0.081)	9.31 (0.366)	3 094 (10 154)	0.32 (0.10)
4 Awg (Standard 7 Wire)	5.89 (0.232)	2.06 (0.081)	10.01 (0.394)	2 808 (9 200)	0.36 (0.11)
4 Awg (Compact 7 Wire)	5.41 (0.213)	2.06 (0.081)	9.53 (0.375)	2 998 (9 826)	0.33 (0.10)
25 mm ² (Solid)	5.64 (0.222)	2.06 (0.081)	9.76 (0.384)	2 904 (9 519)	0.34 (0.11)
2 Awg (Solid)	6.54 (0.258)	2.06 (0.081)	10.66 (0.420)	2 587 (8 465)	0.39 (0.12)
2 Awg (Standard 7 Wire)	7.42 (0.292)	2.06 (0.081)	11.54 (0.454)	2 338 (7 667)	0.43 (0.13)
2 Awg (Compact 7 Wire)	6.81 (0.268)	2.06 (0.081)	10.93 (0.430)	2 505 (8 213)	0.40 (0.12)
1 Awg (Solid)	7.35 (0.289)	2.06 (0.081)	11.47 (0.451)	2 356 (7 731)	0.42 (0.13)
1 Awg (Standard 7 Wire)	8.33 (0.328)	2.06 (0.081)	12.45 (0.490)	2 128 (6 973)	0.47 (0.14)
1 Awg (Compact 7 Wire)	7.57 (0.298)	2.06 (0.081)	11.69 (0.460)	2 301 (7 542)	0.43 (0.13)
1/0 Awg (Standard 7 Wire)	9.35 (0.368)	2.06 (0.081)	13.47 (0.530)	1933 (6 337)	0.52 (0.16)
1/0 Awg (Compact 7 Wire)	8.56 (0.337)	2.06 (0.081)	12.68 (0.499)	2 081 (6 819)	0.48 (0.15)
2/0 Awg (Standard 7 Wire)	10.52 (0.414)	2.06 (0.081)	14.64 (0.576)	1750 (5 737)	0.57 (0.17)

Table 4—Polypropylene maintenance testing (3-kV rated)

Values for 1.91-mm (75-mil) insulation thickness 3-kV polypropylene					
Conductor	Conductor diameter	Insulation minimum point	Calculated insulation diameter	IR value 1 km (kft)	DC leakage 1 km (kft)
Trade size	mm (in)	mm (in)	mm (in)	MΩ	μA/kV
10 mm ² (Solid)	3.57 (0.140)	1.73 (0.068)	7.03 (0.276)	1794 (5 896)	0.56 (0.17)
6 Awg (Solid)	4.11 (0.162)	1.73 (0.068)	7.57 (0.298)	1617 (5 294)	0.62 (0.19)
16 mm ² (Solid)	4.51 (0.178)	1.73 (0.068)	7.97 (0.314)	1507 (4 930)	0.66 (0.20)
4 Awg (Solid)	5.19 (0.204)	1.73 (0.068)	8.65 (0.340)	1352 (4 437)	0.74 (0.23)
4 Awg (Standard 7 Wire)	5.89 (0.232)	1.73 (0.068)	9.35 (0.368)	1223 (4 007)	0.82 (0.25)
4 Awg (Compact 7 Wire)	5.41 (0.213)	1.73 (0.068)	8.87 (0.349)	1309 (4 289)	0.76 (0.23)
25 mm ² (Solid)	5.64 (0.222)	1.73 (0.068)	9.10 (0.358)	1267 (4 151)	0.79 (0.24)
2 Awg (Solid)	6.54 (0.258)	1.73 (0.068)	10.00 (0.394)	1124 (3 678)	0.89 (0.27)
2 Awg (Standard 7 Wire)	7.42 (0.292)	1.73 (0.068)	10.88 (0.428)	1013 (3 321)	0.99 (0.30)
2 Awg (Compact 7 Wire)	6.81 (0.268)	1.73 (0.068)	10.27 (0.404)	1088 (3 565)	0.92 (0.28)
1 Awg (Solid)	7.35 (0.289)	1.73 (0.068)	10.81 (0.425)	1021 (3 350)	0.98 (0.30)
1 Awg (Standard 7 Wire)	8.33 (0.328)	1.73 (0.068)	11.79 (0.464)	920 (3 013)	1.09 (0.33)
1 Awg (Compact 7 Wire)	7.57 (0.298)	1.73 (0.068)	11.03 (0.434)	997 (3 265)	1.00 (0.31)
1/0 Awg (Standard 7 Wire)	9.35 (0.368)	1.73 (0.068)	12.81 (0.504)	834 (2 732)	1.20 (0.37)
1/0 Awg (Compact 7 Wire)	8.56 (0.337)	1.73 (0.068)	12.02 (0.473)	899 (2 945)	1.11 (0.34)
2/0 Awg (Standard 7 Wire)	10.52 (0.414)	1.73 (0.068)	13.98 (0.550)	753 (2 467)	1.33 (0.41)

Table 5—Polypropylene maintenance testing (5-kV rated)

Values for 2.29-mm (90-mil) insulation thickness 5 kV polypropylene					
Conductor	Conductor diameter	Insulation minimum point	Calculated insulation diameter	IR value 1 km (kft)	DC leakage 1 km (kft)
Trade size	mm (in)	mm (in)	mm (in)	MΩ	μA/kV
10 mm ² (Solid)	3.57 (0.140)	2.06 (0.081)	7.69 (0.302)	2 032 (6 678)	0.49 (0.15)
6 Awg (Solid)	4.11 (0.162)	2.06 (0.081)	8.23 (0.324)	1838 (6 021)	0.54 (0.17)
16 mm ² (Solid)	4.51 (0.178)	2.06 (0.081)	8.63 (0.340)	1718 (5 621)	0.58 (0.18)
4 Awg (Solid)	5.19 (0.204)	2.06 (0.081)	9.31 (0.366)	1547 (5 077)	0.65 (0.20)
4 Awg (Standard 7 Wire)	5.89 (0.232)	2.06 (0.081)	10.01 (0.394)	1404 (4 600)	0.71 (0.22)
4 Awg (Compact 7 Wire)	5.41 (0.213)	2.06 (0.081)	9.53 (0.375)	1499 (4 913)	0.67 (0.20)
25 mm ² (Solid)	5.64 (0.222)	2.06 (0.081)	9.76 (0.384)	1452 (4 760)	0.69 (0.21)
2 Awg (Solid)	6.54 (0.258)	2.06 (0.081)	10.66 (0.420)	1293 (4 233)	0.77 (0.24)
2 Awg (Standard 7 Wire)	7.42 (0.292)	2.06 (0.081)	11.54 (0.454)	1169 (3 833)	0.86 (0.26)
2 Awg (Compact 7 Wire)	6.81 (0.268)	2.06 (0.081)	10.93 (0.430)	1253 (4 107)	0.80 (0.24)
1 Awg (Solid)	7.35 (0.289)	2.06 (0.081)	11.47 (0.451)	1178 (3 866)	0.85 (0.26)
1 Awg (Standard 7 Wire)	8.33 (0.328)	2.06 (0.081)	12.45 (0.490)	1064 (3 486)	0.94 (0.29)
1 Awg (Compact 7 Wire)	7.57 (0.298)	2.06 (0.081)	11.69 (0.460)	1150 (3 771)	0.87 (0.27)
1/0 Awg (Standard 7 Wire)	9.35 (0.368)	2.06 (0.081)	13.47 (0.530)	967 (3 169)	1.03 (0.32)
1/0 Awg (Compact 7 Wire)	8.56 (0.337)	2.06 (0.081)	12.68 (0.499)	1040 (3 409)	0.96 (0.29)
2/0 Awg (Standard 7 Wire)	10.52 (0.414)	2.06 (0.081)	14.64 (0.576)	875 (2 868)	1.14 (0.35)

Table 6— Ethylene-propylene diene monomer (EPDM) acceptance testing (3-kV rated)

Values for 1.91-mm (75-mil) insulation thickness 3-kV EPDM					
Conductor	Conductor diameter	Insulation minimum point	Calculated insulation diameter	IR value 1 km (kft)	DC leakage 1 km (kft)
Trade size	mm (in)	mm (in)	(in)	MΩ	μA/kV
10 mm ² (Solid)	3.57 (0.140)	1.73 (0.068)	7.03 (0.276)	1436 (4 716)	0.70 (0.42)
6 Awg (Solid)	4.11 (0.162)	1.73 (0.068)	7.57 (0.298)	1294 (4 235)	0.77 (0.47)
16 mm ² (Solid)	4.51 (0.178)	1.73 (0.068)	7.97 (0.314)	1207 (3 944)	0.83 (0.51)
4 Awg (Solid)	5.19 (0.204)	1.73 (0.068)	8.65 (0.340)	1083 (3 550)	0.92 (0.56)
4 Awg (Standard 7 Wire)	5.89 (0.232)	1.73 (0.068)	9.35 (0.368)	979 (3 206)	1.02 (0.62)
4 Awg (Compact 7 Wire)	5.41 (0.213)	1.73 (0.068)	8.87 (0.349)	1048 (3 431)	0.95 (0.58)
25 mm ² (Solid)	5.64 (0.222)	1.73 (0.068)	9.10 (0.358)	1014 (3 320)	0.99 (0.60)
2 Awg (Solid)	6.54 (0.258)	1.73 (0.068)	10.00 (0.394)	900 (2 942)	1.11 (0.68)
2 Awg (Standard 7 Wire)	7.42 (0.292)	1.73 (0.068)	10.88 (0.428)	811 (2 657)	1.23 (0.75)
2 Awg (Compact 7 Wire)	6.81 (0.268)	1.73 (0.068)	10.27 (0.404)	871 (2 852)	1.15 (0.70)
1 Awg (Solid)	7.35 (0.289)	1.73 (0.068)	10.81 (0.425)	818 (2 680)	1.22 (0.75)
1 Awg (Standard 7 Wire)	8.33 (0.328)	1.73 (0.068)	11.79 (0.464)	736 (2 410)	1.36 (0.83)
1 Awg (Compact 7 Wire)	7.57 (0.298)	1.73 (0.068)	11.03 (0.434)	798 (2 612)	1.25 (0.77)
1/0 Awg (Standard 7 Wire)	9.35 (0.368)	1.73 (0.068)	12.81 (0.504)	667 (2 185)	1.50 (0.92)
1/0 Awg (Compact 7 Wire)	8.56 (0.337)	1.73 (0.068)	12.02 (0.473)	719 (2 356)	1.39 (0.85)
2/0 Awg (Standard 7 Wire)	10.52 (0.414)	1.73 (0.068)	13.98 (0.550)	603 (1 974)	1.66 (1.01)

Table 7— Ethylene-propylene diene monomer (EPDM) acceptance testing (5-kV rated)

Values for 2.29-mm (90-mil) insulation thickness 5-kV EPDM					
Conductor	Conductor diameter	Insulation minimum point	Calculated insulation diameter	IR value 1 km (kft)	DC leakage 1 km (kft)
Trade size	mm (in)	mm (in)	mm (in)	MΩ	μA/kV
10 mm ² (Solid)	3.57 (0.140)	2.06 (0.081)	7.69 (0.302)	1626 (5 342)	0.61 (0.19)
6 Awg (Solid)	4.11 (0.162)	2.06 (0.081)	8.23 (0.324)	1472 (4 816)	0.68 (0.21)
16 mm ² (Solid)	4.51 (0.178)	2.06 (0.081)	8.63 (0.340)	1375 (4 497)	0.73 (0.22)
4 Awg (Solid)	5.19 (0.204)	2.06 (0.081)	9.31 (0.366)	1238 (4 062)	0.81 (0.25)
4 Awg (Standard 7 Wire)	5.89 (0.232)	2.06 (0.081)	10.01 (0.394)	1124 (3 680)	0.89 (0.27)
4 Awg (Compact 7 Wire)	5.41 (0.213)	2.06 (0.081)	9.53 (0.375)	1200 (3 930)	0.83 (0.25)
25 mm ² (Solid)	5.64 (0.222)	2.06 (0.081)	9.76 (0.384)	1162 (3 808)	0.86 (0.26)
2 Awg (Solid)	6.54 (0.258)	2.06 (0.081)	10.66 (0.420)	1035 (3 386)	0.97 (0.30)
2 Awg (Standard 7 Wire)	7.42 (0.292)	2.06 (0.081)	11.54 (0.454)	936 (3 067)	1.07 (0.33)
2 Awg (Compact 7 Wire)	6.81 (0.268)	2.06 (0.081)	10.93 (0.430)	1003 (3 285)	1.00 (0.30)
1 Awg (Solid)	7.35 (0.289)	2.06 (0.081)	11.47 (0.451)	943 (3 092)	1.06 (0.32)
1 Awg (Standard 7 Wire)	8.33 (0.328)	2.06 (0.081)	12.45 (0.490)	852 (2 789)	1.17 (0.36)
1 Awg (Compact 7 Wire)	7.57 (0.298)	2.06 (0.081)	11.69 (0.460)	921 (3 017)	1.09 (0.33)
1/0 Awg (Standard 7 Wire)	9.35 (0.368)	2.06 (0.081)	13.47 (0.530)	774 (2 535)	1.29 (0.39)
1/0 Awg (Compact 7 Wire)	8.56 (0.337)	2.06 (0.081)	12.68 (0.499)	833 (2 728)	1.20 (0.37)
2/0 Awg (Standard 7 Wire)	10.52 (0.414)	2.06 (0.081)	14.64 (0.576)	700 (2 295)	1.43 (0.44)

Table 8— Ethylene-propylene diene monomer (EPDM) maintenance testing (3-kV rated)

Values for 1.91-mm (75-mil) insulation thickness 3-kV EPDM					
Conductor	Conductor diameter	Insulation minimum point	Calculated insulation diameter	IR value 1 km (kft)	DC leakage 1 km (kft)
Trade size	mm (in)	mm (in)	(in)	MΩ	μA/kV
10 mm ² (Solid)	3.57 (0.140)	1.73 (0.068)	7.03 (0.276)	718 (2 358)	1.39 (0.42)
6 Awg (Solid)	4.11 (0.162)	1.73 (0.068)	7.57 (0.298)	647 (2 118)	1.55 (0.47)
16 mm ² (Solid)	4.51 (0.178)	1.73 (0.068)	7.97 (0.314)	603 (1972)	1.66 (0.51)
4 Awg (Solid)	5.19 (0.204)	1.73 (0.068)	8.65 (0.340)	541 (1775)	1.85 (0.56)
4 Awg (Standard 7 Wire)	5.89 (0.232)	1.73 (0.068)	9.35 (0.368)	490 (1603)	2.04 (0.62)
4 Awg (Compact 7 Wire)	5.41 (0.213)	1.73 (0.068)	8.87 (0.349)	524 (1716)	1.91 (0.58)
25 mm ² (Solid)	5.64 (0.222)	1.73 (0.068)	9.10 (0.358)	507 (1660)	1.97 (0.60)
2 Awg (Solid)	6.54 (0.258)	1.73 (0.068)	10.00 (0.394)	450 (1471)	2.22 (0.68)
2 Awg (Standard 7 Wire)	7.42 (0.292)	1.73 (0.068)	10.88 (0.428)	406 (1328)	2.47 (0.75)
2 Awg (Compact 7 Wire)	6.81 (0.268)	1.73 (0.068)	10.27 (0.404)	435 (1426)	2.30 (0.70)
1 Awg (Solid)	7.35 (0.289)	1.73 (0.068)	10.81 (0.425)	409 (1340)	2.45 (0.75)
1 Awg (Standard 7 Wire)	8.33 (0.328)	1.73 (0.068)	11.79 (0.464)	368 (1205)	2.72 (0.83)
1 Awg (Compact 7 Wire)	7.57 (0.298)	1.73 (0.068)	11.03 (0.434)	399 (1306)	2.51 (0.77)
1/0 Awg (Standard 7 Wire)	9.35 (0.368)	1.73 (0.068)	12.81 (0.504)	334 (1093)	3.00 (0.92)
1/0 Awg (Compact 7 Wire)	8.56 (0.337)	1.73 (0.068)	12.02 (0.473)	360 (1178)	2.78 (0.85)
2/0 Awg (Standard 7 Wire)	10.52 (0.414)	1.73 (0.068)	13.98 (0.550)	301 (987)	3.32 (1.01)

Table 9— Ethylene-propylene diene monomer (EPDM) maintenance testing (5-kV rated)

Values for 2.29-mm (90-mil) insulation thickness 5-kV EPDM					
Conductor	Conductor diameter	Insulation minimum point	Calculated insulation diameter	IR value 1 km (kft)	DC leakage 1 km (kft)
Trade size	mm (in)	mm (in)	mm (in)	MΩ	μA/kV
10 mm ² (Solid)	3.57 (0.140)	2.06 (0.081)	7.69 (0.302)	813 (2671)	1.23 (0.37)
6 Awg (Solid)	4.11 (0.162)	2.06 (0.081)	8.23 (0.324)	736 (2408)	1.36 (0.42)
16 mm ² (Solid)	4.51 (0.178)	2.06 (0.081)	8.63 (0.340)	688 (2248)	1.45 (0.44)
4 Awg (Solid)	5.19 (0.204)	2.06 (0.081)	9.31 (0.366)	619 (2031)	1.61 (0.49)
4 Awg (Standard 7 Wire)	5.89 (0.232)	2.06 (0.081)	10.01 (0.394)	562 (1840)	1.78 (0.54)
4 Awg (Compact 7 Wire)	5.41 (0.213)	2.06 (0.081)	9.53 (0.375)	600 (1965)	1.67 (0.51)
25 mm ² (Solid)	5.64 (0.222)	2.06 (0.081)	9.76 (0.384)	581 (1904)	1.72 (0.53)
2 Awg (Solid)	6.54 (0.258)	2.06 (0.081)	10.66 (0.420)	518 (1693)	1.93 (0.59)
2 Awg (Standard 7 Wire)	7.42 (0.292)	2.06 (0.081)	11.54 (0.454)	468 (1533)	2.14 (0.65)
2 Awg (Compact 7 Wire)	6.81 (0.268)	2.06 (0.081)	10.93 (0.430)	501 (1643)	1.99 (0.61)
1 Awg (Solid)	7.35 (0.289)	2.06 (0.081)	11.47 (0.451)	472 (1546)	2.12 (0.65)
1 Awg (Standard 7 Wire)	8.33 (0.328)	2.06 (0.081)	12.45 (0.490)	426 (1394)	2.35 (0.72)
1 Awg (Compact 7 Wire)	7.57 (0.298)	2.06 (0.081)	11.69 (0.460)	460 (1508)	2.17 (0.66)
1/0 Awg (Standard 7 Wire)	9.35 (0.368)	2.06 (0.081)	13.47 (0.530)	387 (1268)	2.58 (0.79)
1/0 Awg (Compact 7 Wire)	8.56 (0.337)	2.06 (0.081)	12.68 (0.499)	416 (1364)	2.40 (0.73)
2/0 Awg (Standard 7 Wire)	10.52 (0.414)	2.06 (0.081)	14.64 (0.576)	350 (1147)	2.86 (0.87)

Table 10—Temperature-correction factors (TCFs)*

Test temperature	Insulation resistance TCF multiplier	DC leakage current TCF multiplier
10 °C (50 °F)	0.750	1.33
15 °C (59 °F)	0.970	1.03
20 °C (68 °F)	1.27	0.787
25 °C (77 °F)	1.66	0.602
30 °C (86 °F)	2.20	0.455
35 °C (95 °F)	2.81	0.356
NOTE—These factors apply to Table 2 through Table 9.		

Create a graph of current in microampere versus potential in kilovolts. On the graph, plot the slope of the acceptable dc leakage current. Then plot the microampere conductance at each test voltage. The measured current curve should be completely below the acceptable leakage current line. The equations for conducting the tests have been developed by Durham et al. [B4].

Example

Assume: #2 Awg (33.6 mm²), EPDM insulation, 2.3-mm (90-mil) thickness

From Table 6: 1.07 $\mu\text{A/kV/1 km}$ (0.33 $\mu\text{A/kV/1 kft}$) = the maximum allowed leakage.

If we assume a length of 2000 m (6562 ft) 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 kilovolt/kilometer (kilovolt/kilofoot), the leakage for the cable is 0.375 $\mu\text{A/kV/1 km}$ (0.11 $\mu\text{A/kV/1 kft}$).

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

Next plot the measured microamperes versus the impressed kilovolts as shown in Figure 6 (values shown in Table 11). For acceptable performance, all values must be below the leakage current line.

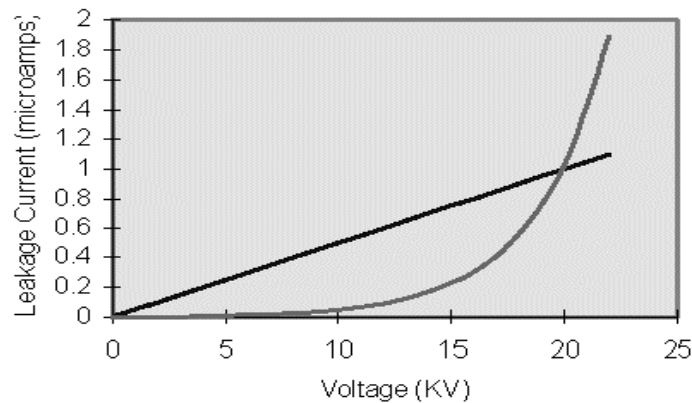


Figure 6—Leakage current limit and test curves

Table 11—Test data used for example

Segment	Impressed kilovolts	Maximum allowed microamperes	Measured microamperes on 2 km (6.26 kft)
0	0.0	0.00	0.00
1	2.3	2.50	1.06
2	4.7	5.00	2.50
3	7.0	7.49	4.35
4	9.3	10.00	6.23
5	11.7	12.50	8.65
6	14.0	15.00	10.50
NOTE—Readings have been rounded.			

7.3 Dielectric failure

If at any time during the test a sudden 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 a reapplication of voltage. Once a dielectric failure occurs, the failed portion of the cable should be removed from service. 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 can be an 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 the appropriate values from Table 2 to Table 10 in this recommended practice.

Historically, a 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 a 3-to-1 ratio as a pass/fail criteria. The appropriate criteria are the leakage values shown in Table 2 through Table 10 regardless of the ratio. Leakage current ratios that change significantly from historical values may indicate damage.

If leakage currents are high, further investigation and testing is necessary to determine whether the cable has a high-resistance fault or deteriorating cable dielectric.

8. 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. Mechanical integrity

The primary component providing 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. 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

- a) An ignitable vapor is present and
- b) 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:

- a) The presence of other ignition sources
- b) Electrical equipment type
- c) 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 require 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 National Electrical Code® (NEC®) (NFPA 70®)^{6,7}, 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 Class I, Division 1. The connectors, cable, and raceways for these systems must be approved by an NRTL.

The downhole equipment should not be considered classified under NEC requirements. The environment in which this equipment operates is not conducive to explosive ignition primarily due to a lack of oxygen. In addition, there are no occupancy concerns for the downhole environment.

10.4 Visual Inspection

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

10.5 Test procedures for surface equipment

10.5.1 Unclassified feedthroughs procedure

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

10.5.2 Division 2 connection procedure

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

10.5.3 Division 1 connection procedure

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

⁶ National Electrical Code and NEC are both registered trademarks of the National Fire Protection Association, Inc.

⁷ NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA (<http://www.nfpa.org/>).

Annex A

(informative)

Bibliography

Bibliographical references are resources that provide additional or helpful material but do not need to be understood or used to implement this standard. Reference to these resources is made for informational use only.

- [B1] API RP 11S3, Recommended Practice for Electric Submersible Pump Installations.⁸
- [B2] API RP 11S4, Recommended Practice for Sizing and Selection of Electric Submersible Pump Installation.
- [B3] API RP 11S5, Recommended Practice for Application of Electric Submersible Pump Cable Systems, 1st ed.
- [B4] Durham, M. O., R. A. Durham, and D. Anderson, “What are standardized equations for acceptance of hi-pot tests and for voltage drop?” in *45th Annual IEEE Industry Applications Society Petroleum and Chemical Industry Committee Conference*, Indianapolis, IN, pp. 281–287, Sept. 1998.
- [B5] Durham, M. O., D. H. Neuroth, K. Ashenayi, and T. Wallace, “Field test technology relationships to cable quality,” *IEEE Transactions on Industry Applications*, vol. 31, no.6, pp. 1381–1389, Nov./Dec. 1995.
- [B6] IEEE Std 400™, IEEE Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems Rated 5 kV and Above.^{9, 10}
- [B7] IEEE Std 1018™, IEEE Recommended Practice for Specifying Electric Submersible Pump Cable—Ethylene-Propylene Rubber Insulation.
- [B8] IEEE Std 1019™, IEEE Recommended Practice for Specifying Electric Submersible Pump Cable—Polypropylene Insulation.

⁸ API publications are available from the Publications Section, American Petroleum Institute, 1200 L Street NW, Washington, DC, USA (<http://www.api.org/>).

⁹ The IEEE standards or products referred to in this clause are trademarks of the Institute of Electrical and Electronics Engineers, Inc.

¹⁰ IEEE publications are available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>).