# Recommended Practice for Testing of Electric Submersible Pump Cable Systems

API RECOMMENDED PRACTICE 11S6
FIRST EDITION, DECEMBER 1, 1995

American Petroleum Institute

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**Exploration and Production Department**

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## Foreword

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# Recommended Practice for Testing of Electric Submersible Pump Cable Systems

## 1 Scope

### 1.1 GENERAL

This recommended practice covers testing of Electric Submersible Pump Cable Systems. Cable testing, in general, can be broken into two basic categories: Factory Testing and Field Testing. This recommended practice only addresses procedures for Field Testing.

Factory Tests provide assurance that the finished product meets the anticipated performance criteria for the intended application. All the tests involved are used to detect gross cable defects in materials and workmanship. Typical tests on new cable include ac, dc, IR and Conductor Resistance, and are covered under such standards as IEEE 400, IEEE 1017, IEEE 1018, and IEEE 1019.

One consideration of any testing is that an electrical failure may not occur on a damaged cable during the actual test since testing is done under controlled conditions relative to oil well conditions. A more costly failure may then occur with the damaged cable downhole. Testing is simply an indicator of the insulation at that time. It is not a guarantee of future performance.

The test procedures and values outlined in this document are based upon accepted practices. Nevertheless, engineering judgment should be used to determine values and procedures applicable in specific situations.

### 1.2 ORGANIZATION

This recommended practice addresses field testing of electric submersible pump cable systems. It is organized into three major topic categories. The first category provides general definitions and overview of terms, safety considerations, and cable system preparation guidelines (Sections 2–6). The second category identifies various situations under which testing is performed (Sections 7–10). The third category identifies test methods and procedures (Sections 11–14).

### 1.3 JURISDICTION

This document covers generally accepted practices for submersible cable systems. All applicable local, state, and national codes and regulations should be followed for each installation.

## 2 Definitions

### 2.1 AC TESTS

AC Tests are tests performed by the manufacturer to determine cable insulation integrity. The applied ac voltage is used as a pass/fail test. AC tests have seldom been performed in the field. (See Section 13.)

### 2.2 ACCEPTANCE TESTING

Acceptance testing is performed by the user upon receipt of new cable and connection devices to confirm that no damage occurred during shipping and handling. (See Section 7.)

### 2.3 CONDUCTOR RESISTANCE

Conductor Resistance is that property of the conductor that resists the flow of electrons (direct current). It is affected by conductor cross-sectional area, conductor length, conductor material, and conductor temperature.

### 2.4 CONNECTORS

Connectors are attachments for electrically conducting power through the wellhead and downhole packer. These devices consist of two separable components which complete the electrical circuit when mated.

### 2.5 DC TESTS

DC Tests are tests performed by the manufacturer or user to determine insulation integrity. The applied dc voltage may be used as a pass/fail test. The leakage current of the applied voltage may be used as a comparative measure of cable system quality. (See Section 12.)

### 2.6 DIAGNOSTIC TESTING

Diagnostic Testing is performed to locate faults, determine the cause of failure, and evaluate the condition of used cable after faults have been located and repaired. These tests may also be used to help determine suitability for reuse. (See Section 10.)

### 2.7 GROUNDING STICK (DISCHARGE RESISTOR)

A grounding stick should be used to discharge a cable after testing. A grounding stick is an assembly with a resistance not less than 10,000 ohm/kV of test voltage.

### 2.8 HIGH POTENTIAL (HI-POT) TESTS

High potential insulation tests are intended to provide nondestructive ac or dc strength testing of insulation. A dc test is considered high potential when it is conducted at a voltage level two times the insulation rating plus 1000 volts or more. An ac test is considered high potential when it is conducted at a voltage level greater than 1.2 times the insulation rating.

The tests may be leakage current tests or voltage withstand tests. Direct current high potential tests are widely used for acceptance and maintenance (proof) testing.

### 2.9 INSULATION CONDUCTANCE

Insulation conductance is equivalent to the reciprocal of insulation resistance. It is usually measured in units of µa/1000 V/1000 ft.

### 2.10 INSULATION IMPEDANCE

Insulation impedance is an electrical measurement of the opposition to the flow of alternating current through the insulation. Impedance includes resistance and alternating current effects. Changes in impedance may be caused by imperfections in or deformations of the insulation.

### 2.11 INSULATION RESISTANCE

Insulation Resistance (IR) is a property of the insulation that opposes the flow of direct current through the insulation. (See Section 11.)

### 2.12 IR TESTS

IR Tests are conducted by impressing a dc voltage across the insulation. This will produce a leakage current through the insulation. The ratio of impressed voltage to leakage current is insulation resistance. This test uses a megohmmeter. (See Section 11.)

### 2.13 LEAKAGE CURRENT

Leakage Current is the current reading resulting from conduction through an insulating medium or over surfaces such as terminations. This current is usually measured in microamps.

### 2.14 IN-SITU TESTING

In-Situ Testing consists of tests made during and after installation of the cable in the well. It is intended to detect deterioration of the cable system to determine suitability for start-up or continued operation. (See Section 9.)

### 2.15 MEGOHMMETER TESTS

Megohmmeter Tests are insulation resistance tests conducted at an impressed dc voltage of 5000 V or less. (See Section 11.)

### 2.16 PENETRATORS

Penetrators (feed-through mandrels) are pressure/fluid barriers around electrical conductors. The electrical connection may be by connectors or cable leads.

### 2.17 POTHEADS

Potheads are electrical connectors to the motor which isolate the motor oil from the well fluid. A motor lead extension (MLE) is a short length of flat cable connected to the pothead for splicing to the main power cable.

### 2.18 POWER FACTOR

Power factor is the ratio of power-producing current in a circuit to the total current in that circuit. A definition of power factor for purely sinusoidal waveforms is the ratio of kw or working power to the total kVa or apparent power.

### 2.19 MAINTENANCE TESTING

Maintenance (Proof) Testing consists of high voltage tests made on a used cable system prior to installation or reinstallation in a well. (See Section 8.)

### 2.20 TIME DOMAIN REFLECTOMETER (TDR)

The Time Domain Reflectometer (TDR) is a test device that applies a voltage pulse to a cable length. The signal will be reflected from locations where the impedance makes a notable change because of irregularities in the insulation. (See 14.3.)

## 3 Insulation Properties

### 3.1 DESCRIPTION

Insulation is the material around a conductor which isolates the conductor, prevents electrical breakdown, and allows the conductor to transport electrical energy to a specific location. Material properties influence the effectiveness of the insulation.

### 3.2 APPLICATION

Integrity of the insulation is determined by high voltage testing and insulation resistance testing.

Two IEEE recommended practices (1018 and 1019) identify the criteria for specifying cable. IEEE 1017 recommends the dc high voltage requirements shown in Table 1 when testing cable.

These criteria can provide an indication of insulation integrity, but do not define cable performance during use. Performance is the relationship between integrity and time.

Insulation resistance is related to the dimensions of the material. Characteristic material properties are included in the bulk resistivity factor (insulation resistance constant), K.

Because cable insulation is essentially a tube around a wire, the resistance reduces to a ratio of the overall diameter, $D$, and the conductor diameter, $d$.

$$R = K \log D/d$$

Typical resistance constants for high quality electrical insulation have been determined by the power cable industry. These are based on years of experience at high voltage levels. For example, the minimum acceptable bulk resistivity factor of ethylene propylene diene monomers (EPDM) insulation for use at service levels up to 138,000 Vac is 20,000 megohm-kilofeet for new insulation. The polyethylene value is 50,000 megohms-kilofeet. Many submersible cables use a polypropylene (poly) insulation. For our purposes, the same value of 50,000 megohm-kilofeet will be used for polypropylene.

Insulation that has been environmentally exposed will have values that are significantly lower than these new insulation resistance constants. Lower resistance values on used cable may still represent suitable insulation for submersible pump application.

A method is proposed to develop criteria for comparing cable characteristics. These are based on the acceptance and maintenance criteria of Table 1. To allow for the reduced characteristics of insulation during Acceptance and Maintenance Tests, the K factor should be adjusted as shown in Table 2. These numbers are the recommended minimum values for insulation resistance.

Stranded wire will have more insulation in contact with the wire than a solid conductor. This greater contact surface causes a proportional increase in the area. However, this small difference in area will have only a small effect on insulation resistance.

A larger size wire will have a greater area. An increase in area causes a decrease in the resistance of the insulation.

Tables 3 and 4 show the impact of the wire configuration. The bulk resistivity factor for new cable is used to determine the minimum insulation resistance ($R$) and corresponding leakage conductance ($G$) for cables with nominal 75 and 90 mil insulation thickness. The minimum thickness ($t$) for Nominal 75 mil insulation is 68 mils. The minimum thickness ($t$) for Nominal 90 mil insulation is 81 mils. The overall diameter ($D$) is calculated.

$$D = d + 2t$$

As an example, the minimum overall diameter for #1 AWG Solid (75 mil nominal) is: 425 (289 + 68 +68). Minimum values are used in the table to obtain worst-case conditions.

The insulation resistance and conductance are calculated in Tables 5-8 for field cable test conditions. The acceptance values are given in Tables 5 and 6, while the maintenance values are shown in Tables 7 and 8.

## 3.3 LIMITATIONS

These tables are to be used as a guide only. Field experience should be used based on actual well conditions. There are many cables throughout the world running with readings deviating from the tabulated values. For example, one organization uses a single value such as 0.2µa/kV/1000 ft for all cable sizes and materials.

At this point there is little or no data correlating the widely used insulation resistance (megohm) test with actual dielectric strength of the cable. As a result, if IR is the only criteria used, cable may be scrapped prematurely before all its useful life has been exhausted.

In an attempt to compare the relative condition of the three phase conductors in a single cable, some testers have proposed a 3:1 ratio of values between phases. If all the insulation resistance readings are above the minimum allowable reading in the tables, then the 3:1 ratio does not apply. If one of the resistance readings for a phase is under the minimum allowed in the tables, it is suggested that the cable be checked using a high voltage step test as specified in IEEE 1017.

Table 1—High-Voltage Testing Requirements

| (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|
| Thickness (mils) | Rating (kV) | Factory, 100% (kVdc) | Acceptance, 80% (kVdc) | Maintenance, 40% (kVdc) |
| 75 | 3 | 27 | 22 | 11 |
| 90 | 5 | 35 | 28 | 14 |

Table 2—K factors (megohm-kft) for Polypropylene and Thermoset (EPDM)

| (1) | (2) | (3) | (4) |
|---|---|---|---|
| Type | Factory, 100% (K) | Acceptance, 80% (K) | Maintenance, 40% (K) |
| Polypropylene | 50,000 | 40,000 | 20,000 |
| Thermoset (EPDM) | 20,000 | 16,000 | 8,000 |

## Table 3—Polypropylene Factory Cable Testing at 100% K (50,000) (See Note)

| (1) Wire Size, n-str | (2) Wire Diameter, *d* (mils) | (3) 75 mil Resistance (megohms-kft) | (4) 75 mil Conductance (μa/kV/kft) | (5) 90 mil Resistance, (megohms-kft) | (6) 90 mil Conductance (μa/kV/kft) |
|---|---|---|---|---|---|
| 6-1 | 162 | 13235 | 0.08 | 15051 | 0.07 |
| 4-1 | 204 | 11092 | 0.09 | 12693 | 0.08 |
| 4-7 | 232 | 10018 | 0.10 | 11500 | 0.08 |
| 2-1 | 258 | 9194 | 0.11 | 10581 | 0.09 |
| 2-7 | 292 | 8303 | 0.12 | 9584 | 0.10 |
| 1-1 | 289 | 8375 | 0.12 | 9664 | 0.10 |
| 1-7 | 328 | 7532 | 0.13 | 8716 | 0.11 |

Note: See limitations (refer to 3.3).

## Table 4—Thermoset-EPDM Factory Cable Testing at 100% K (20,000) (See Note)

| (1) Wire Size, n-str | (2) Wire Diameter, *d* (mils) | (3) 75 mil Resistance (megohms-kft) | (4) 75 mil Conductance (μa/kV/kft) | (5) 90 mil Resistance, (megohms-kft) | (6) 90 mil Conductance (μa/kV/kft) |
|---|---|---|---|---|---|
| 6-1 | 162 | 5294 | 0.19 | 6021 | 0.17 |
| 4-1 | 204 | 4437 | 0.23 | 5077 | 0.20 |
| 4-7 | 232 | 4007 | 0.25 | 4600 | 0.22 |
| 2-1 | 258 | 3678 | 0.27 | 4233 | 0.24 |
| 2-7 | 292 | 3321 | 0.30 | 3833 | 0.26 |
| 1-1 | 289 | 3350 | 0.30 | 3866 | 0.26 |
| 1-7 | 328 | 3013 | 0.34 | 3486 | 0.29 |

Note: See limitations (refer to 3.3).

## Table 5—Polypropylene Acceptance Cable Testing at 80% K (40,000) (See Note)

| (1) Wire Size, n-str | (2) Wire Diameter, *d* (mils) | (3) 75 mil Resistance (megohms-kft) | (4) 75 mil Conductance (μa/kV/kft) | (5) 90 mil Resistance, (megohms-kft) | (6) 90 mil Conductance (μa/kV/kft) |
|---|---|---|---|---|---|
| 6-1 | 162 | 10588 | 0.09 | 12041 | 0.08 |
| 4-1 | 204 | 8874 | 0.11 | 10154 | 0.10 |
| 4-7 | 232 | 8014 | 0.12 | 9200 | 0.11 |
| 2-1 | 258 | 7355 | 0.14 | 8465 | 0.12 |
| 2-7 | 292 | 6642 | 0.15 | 7667 | 0.13 |
| 1-1 | 289 | 6700 | 0.15 | 7731 | 0.13 |
| 1-7 | 328 | 6026 | 0.17 | 6973 | 0.14 |

Note: See limitations (refer to 3.3).

## Table 6—Thermoset (EPDM) Acceptance Cable Testing at 80% K (16,000) (See Note)

| (1) Wire Size, n-str | (2) Wire Diameter, *d* (mils) | (3) 75 mil Resistance (megohms-kft) | (4) 75 mil Conductance (μa/kV/kft) | (5) 90 mil Resistance, (megohms-kft) | (6) 90 mil Conductance (μa/kV/kft) |
|---|---|---|---|---|---|
| 6-1 | 162 | 4235 | 0.23 | 4816 | 0.21 |
| 4-1 | 204 | 3550 | 0.28 | 4062 | 0.25 |
| 4-7 | 232 | 3206 | 0.31 | 3680 | 0.27 |
| 2-1 | 258 | 2942 | 0.34 | 3386 | 0.30 |
| 2-7 | 292 | 2657 | 0.38 | 3067 | 0.33 |
| 1-1 | 289 | 2680 | 0.37 | 3092 | 0.32 |
| 1-7 | 328 | 2410 | 0.41 | 2789 | 0.36 |

Note: See limitations (refer to 3.3).

Table 7—Polypropylene Maintenance Cable Testing at 40% K (20,000)
(See Note)

| (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|
| Wire Size, n-str | Wire Diameter, *d* (mils) | 75 mil Resistance (megohms-kft) | 75 mil Conductance (μa/kV/kft) | 90 mil Resistance, (megohms-kft) | 90 mil Conductance (μa/kV/kft) |
| 6-1 | 162 | 5294 | 0.19 | 6021 | 0.17 |
| 4-1 | 204 | 4437 | 0.23 | 5077 | 0.20 |
| 4-7 | 232 | 4007 | 0.25 | 4600 | 0.22 |
| 2-1 | 258 | 3678 | 0.27 | 4233 | 0.24 |
| 2-7 | 292 | 3321 | 0.30 | 3833 | 0.26 |
| 1-1 | 289 | 3350 | 0.30 | 3866 | 0.26 |
| 1-7 | 328 | 3013 | 0.33 | 3486 | 0.29 |

Note: See limitations (refer to 3.3).

Table 8—Thermoset (EPDM) Maintenance Cable Testing at 40% K (8,000)
(See Note)

| (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|
| Wire Size, n-str | Wire Diameter, *d* (mils) | 75 mil Resistance (megohms-kft) | 75 mil Conductance (μa/kV/kft) | 90 mil Resistance, (megohms-kft) | 90 mil Conductance (μa/kV/kft) |
| 6-1 | 162 | 2118 | 0.47 | 2408 | 0.42 |
| 4-1 | 204 | 1775 | 0.56 | 2031 | 0.49 |
| 4-7 | 232 | 1603 | 0.62 | 1840 | 0.54 |
| 2-1 | 258 | 1471 | 0.68 | 1693 | 0.59 |
| 2-7 | 292 | 1328 | 0.75 | 1533 | 0.65 |
| 1-1 | 289 | 1340 | 0.75 | 1546 | 0.65 |
| 1-7 | 328 | 1205 | 0.83 | 1395 | 0.72 |

Note: See limitations (refer to 3.3).

For short lengths, IR testing will require a megohmmeter that has an expanded range. One scale should be at least 20,000 megohms.

### 3.4 PROCEDURE

All cable tests should be conducted using the procedures in Section 11 and Section 12.

The K factors are based on a temperature of 60° F (15.6° C). Temperature correction factors should be used to correct field measurements to 60° F values.

Different insulation materials exhibit different temperature coefficient factors. Although there are test methods in use to establish the temperature coefficient factors, most electrical grade insulations have a coefficient of 1.03.

Table 9 (from ICEA Pub. No. S-66-524 / NEMA WC 7) provides the correction factor for a coefficient of 1.03. For temperatures that are not on the table, the temperature correction factor can be calculated from the following relationship:

Correction Factor = 1.03 exp (Test Temperature – 60° F)

Corrected leakage current values may have an error associated with them since the temperature correction factor derived from IR measurements, may be different than a factor derived from high-voltage dc leakage measurements.

The table is applied differently for a resistance (megohm) and conductance (leakage a/kV) readings. Two examples illustrate the calculations.

a. Example 1:

Resistance reading = 200 megohm

Cable temperature = 200° F

Table correction = 63.0

Temp. corrected megohm = 200 × 63
= 12,600 megohms

Length = 5,000 ft

Corrected resistance = 12,600 × 5kft
= 63,000 megohms-kft

Compare the corrected resistance with the table value using the appropriate wire size. In general, the cable is acceptable if the corrected resistance is equal to or greater than the table value.

Table 9—Temperature Correction Factor—Insulation (1.03)

| (1) | (2) | (3) | (4) |
|---|---|---|---|
| Temperature (°F) | *Tcf* | Temperature (°F) | *Tcf* |
| 60 | 1.00 | 215 | 97.67 |
| 65 | 1.16 | 220 | 113.23 |
| 70 | 1.34 | 225 | 131.26 |
| 75 | 1.56 | 230 | 152.17 |
| 80 | 1.81 | 235 | 176.41 |
| 85 | 2.09 | 240 | 204.50 |
| 90 | 2.43 | 245 | 237.08 |
| 95 | 2.81 | 250 | 274.84 |
| 100 | 3.26 | 255 | 318.61 |
| 105 | 3.78 | 260 | 369.36 |
| 110 | 4.38 | 265 | 428.18 |
| 115 | 5.08 | 270 | 496.38 |
| 120 | 5.89 | 275 | 575.44 |
| 125 | 6.83 | 280 | 667.10 |
| 130 | 7.92 | 285 | 773.35 |
| 135 | 9.18 | 290 | 896.52 |
| 140 | 10.64 | 295 | 1039.32 |
| 145 | 12.34 | 300 | 1204.85 |
| 150 | 14.30 | 305 | 1396.75 |
| 155 | 16.58 | 310 | 1619.22 |
| 160 | 19.22 | 315 | 1877.12 |
| 165 | 22.28 | 320 | 2176.10 |
| 170 | 25.83 | 325 | 2522.69 |
| 175 | 29.94 | 330 | 2924.49 |
| 180 | 34.71 | 335 | 3390.29 |
| 185 | 40.24 | 340 | 3930.27 |
| 190 | 46.65 | 345 | 4556.27 |
| 200 | 62.69 | 350 | 5281.96 |
| 205 | 72.68 | 355 | 6123.24 |
| 210 | 84.25 | 360 | 7098.51 |

b. Example 2:

Conductance reading = 0.5μa/kV

Cable temperature = 100° F

Table correction = 3.26

Temp. corrected μa/kV = 0.5μa/kV/3.26

= 0.153μa/kV

Length = 5000 ft

Corrected conductance = 0.153μa/kV/5kft

= 0.031μa/kV/kft

Compare the corrected conductance with the appropriate table value. In general, the cable is acceptable if the corrected conductance is equal to or less than the table value.

# 4 Safety

## 4.1 DESCRIPTION

High direct-voltage testing of cable systems involves all of the hazards normally associated with working on energized circuits, as well as several unique hazards that should be addressed.

## 4.2 APPLICATION

Cables can hold a dc electrical charge for long periods of time after voltage has been removed. Electrical charge is maintained because of high capacitance and dielectric absorption characteristics of the insulation. For this reason proper grounding procedures should be followed to eliminate personnel hazards.

Furthermore, cable subjected to high-voltage dc testing that is not properly grounded following the test can have dangerous charge buildup. This buildup is a characteristic of all insulating materials.

## 4.3 PROCEDURES

Cable circuits will normally have one or more ends remote from the location of the test equipment and test operator. These ends should be cleared and guarded to ensure the safety of personnel. Reliable voice communication should be established between all such locations and the test operator.

All ends as well as all connecting leads of components being tested require guarding from accidental contact by such means as barriers, enclosures, or a watchman at all points. The ends require separation from all elements not to be subjected to test and by a distance of not less than 6 in.

All components require de-energizing before starting any work. A grounded connection should be applied to each conductor, the armor, and all nonenergized metallic parts in the vicinity. The only time a ground connection should be removed is when test voltage is being applied to that conductor.

When dc voltages are applied to the cable, a residual charge will remain in the insulation. After it is tested, each conductor should be discharged with a grounding stick. Then a grounded connection should be re-attached to the conductor. The ground should be applied long enough to completely discharge the cable. This 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.

# 5 Visual Inspection

## 5.1 DESCRIPTION

This procedure involves the visual inspection of a cable system prior to and following electrical testing. The procedure is appropriate for all tests covered in the recommended practice. As part of the procedure, the cable will be spooled to another reel. Then the cable should be re-spooled in its original armor direction.

## 5.2 APPLICATION

The first application is to detect physical damage or deterioration that requires corrective action before electrical testing. A second application is to determine the cause of changes in electrical properties identified during testing.

## 5.3 LIMITATIONS

Since visual inspections are very subjective, this procedure is dependent on the experience, training, and knowledge of the technician.

Visual examination on its own does not eliminate the need for electrical tests. However, it may reveal defects that cause scrapping or repairing of a section of cable prior to electrical tests.

If the armor is intact, inspection during spooling will only show the condition of the armor along the length of the cable. Other cable components may be examined at the end of the cable.

In some areas, inspections are performed but repairs are not normally undertaken because of severe well conditions or high operating costs.

The following procedure gives general items for consideration during inspection. For detailed methodology refer to manufacturers or repair facilities.

## 5.4 PROCEDURE

An initial visual inspection is made to evaluate the overall condition of the cable. Spool through the cable looking for obvious physical damage or deterioration. A decision is made to either scrap a portion of the cable or make further tests and repairs. If the decision is to repair, damaged areas should be prepared so that electrical tests can be performed.

### 5.4.1 Armor

The basic function of the armor is for mechanical protection and containment of the underlying materials. If the armor is crushed, it should be removed so that the jacket can be inspected. If the armor is separated, it should be repaired. All armor will have some degree of corrosion. The percentage of material loss and the time it was in the hole can be used to estimate the remaining useful life.

### 5.4.2 Jacket

The function and importance of the jacket (filler) varies with the cable design. If the jacket is damaged it should be removed so that the insulation can be inspected. Hardening (embrittlement) may cause the jacket to crack during installation or removal of the cable. However, hardening will not be found from electrical tests unless there is a break in the insulation. Softening and swelling can affect the life of the cable.

### 5.4.3 Insulation Coverings

Insulation coverings (braids, tapes, extrusions) have the function of containing and protecting the underlying insulation. This layer may not be repairable. Damage to or hardening of this layer may require scrapping this section of cable. Discoloration is generally an indication of exposure to elevated temperature or certain well contaminants. It does not necessarily indicate that the material has deteriorated.

Lead sheath is a metallic insulation covering particularly used in $H_2S$, gaseous, and high temperature wells. The lead may develop pin holes, splits, and embrittlement. If these occur, the function of the lead is compromised. This section of cable should be removed to restore the covering integrity.

### 5.4.4 Insulation

Insulation is the component that determines whether a cable will pass an electrical test. If it has been damaged, it must be repaired. Hardening, softening, or swelling of this layer may require scrapping this section of cable. Softening of thermoplastics may cause the conductors to float toward the middle of the cable. This will necessitate scrapping that portion of the cable.

Insulation materials may act as a molecular sieve. This permits certain hydrocarbons to migrate through the insulation layers to the conductor surface. The polymers may also change characteristics. This gooey material may make it very difficult to install a successful splice or connection.

Discoloration may be an indication that the insulation has been exposed to elevated temperature or certain well contaminants. It does not necessarily indicate that the material has deteriorated. However, if dc tests give a high leakage conductance, discoloration may indicate a loss of insulation properties.

Polymeric materials such as Kapton may be used under the insulation and over the conductor. These should be treated the same as the insulation coverings described above.

### 5.4.5 Conductors

Conductors are used to carry the electrical current. Cable sections with damaged conductors should be removed. Damage may be in the form of a cut, nick, break, or stretch.

### 5.4.6 Motor Lead Extension/Pothead

Motor lead extensions and potheads are in the most difficult application in the well. Their size and materials are restricted. Because of the mechanical stress and high temperature location, it has been general practice that these items are not reused.

If the decision is made to reuse the components, the cable portion should be inspected as described above. The pothead should be inspected to assure that there is a good mechanical connection between the armor and the pothead housing. If there is any damage to the pins or insulation the pothead should be replaced. If the pins are misaligned, the pothead should be replaced. O-rings should not be reused.

### 5.4.7 Connecting Devices

The cable portion should be inspected as described above. The shell should be inspected to assure that there is a good mechanical connection between the armor and the housing. If there is any damage to the pins or if the pins are misaligned, the device should be replaced. Sealing surfaces should be mechanically sound and clean. Bonded rubber surfaces should be intact. Keyways and threads should be checked for proper fit.

Devices that are certified by a nationally recognized testing laboratory may not be modified without voiding the certification.

# 6 Cable System Preparation

## 6.1 DESCRIPTION

This procedure involves the cleaning and preparation of a cable system for electrical testing. The procedure is appropriate for all tests covered in this recommended practice.

As part of the procedure, the cable may be spooled to another reel and inspected for physical damage.

## 6.2 APPLICATION

Rigorous application of this procedure becomes more important as the voltage level increases.

## 6.3 LIMITATIONS

Cable ends, connectors, penetrators, and potheads should be prepared so that there is no leak-over or arcing during test. If this procedure is not followed, the test results will be inconsistent and damage to insulation integrity may occur.

## 6.4 PROCEDURE

Before testing, the cable system should be allowed to reach room temperature and be de-gassed.

A continuity check should be made to assure that all connecting device housings form a continuous path with the armor.

A continuity check should be made on each conductor to assure there are no breaks in the wire or connecting device.

A conductor resistance check may be made on each phase wire. A sensitive ohmmeter or bridge is necessary for this test. By proper interpretation of the readings, weak splices or other conductor imperfections may be identified. The resistance for typical conductor sizes are shown in Table 10. The readings for each of the three conductors should not differ by more than 2% and should be within 5% of the table values.

### 6.4.1 Cable With Connecting Devices

Cable with connecting devices should be prepared as follows.

Penetrators (feed-through mandrels), potheads, and other pressure/fluid barriers should be pressure tested prior to electrical testing. Potheads are generally tested near 30 psi differential pressure. In some areas, potheads are also vacuum tested.

The connecting device should be thoroughly cleaned with nonconductive solvents and completely dried. Shrink sleeves, oil and other test insulators should be kept completely clean prior to use.

*Warning: If all contaminants are not removed, arcing will occur resulting in damage to the insulation integrity.*

After cleaning, the electrical contacts should be isolated and have adequate electrical insulation to prevent arc-over during testing. This may consist of an insulated connector, close-fitting insulating sleeves or extension pins, or high quality insulating oil.

Table 10—Resistance of Typical Conductor Sizes

| (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|
| | | | Maximum Ohms/1000 ft at 77° F (25° C) | |
| AWG Size | Number of Strands | Nominal Diameter (mils) | Bare Copper | Coated Copper |
| 6 | 1 | 162 | 0.419 | 0.431 |
| 4 | 1 | 204 | 0.263 | 0.271 |
| 2 | 7 | 292 | 0.169 | 0.175 |
| 1 | 7 or 19 | 328 | 0.134 | 0.139 |

The preferred choice for connectors and penetrators is to use the insulated mating connector.

Electrical contacts on a male connecting device can be isolated using high dielectric, nonadhering, preshrunk sleeves as shown in Figure 1. Heat should not be applied to form shrink sleeves on the contact to be tested since the required heat may exceed the temperature rating of the insulating material. The required fit depends on the type of connecting device being tested. Devices having short male contacts require a close fit. The fit of insulated female and long male contacts tend to be less critical. In all cases, it is recommended that the insulating sleeves fit flush with the bottom of the connecting device and extend at least 1 in. past the end of the contact (see Figure 2).

Electrical contacts on female connecting devices can be isolated with insulated extension pins (Figure 3). The pins provide clearance to safely connect the test leads. The ends of the extension pins need to be rounded (Figure 3) so that connecting devices using contact springs are not damaged. The OD of the extension pin conductor needs to be matched to the type of connector being tested. It is recommended that a section of high dielectric shrink sleeve be used to enhance the insulated section of the extension pins.

Alternatively, a molded test plug may be used to fit over the contacts of a pothead (see Figure 4). The plug should be kept clean from all contaminants.

Using another technique, potheads may be submerged into clean electrical grade oil. Caution should be used to prevent contaminating the oil with well fluids or other materials that may be on the pothead and cable.

### 6.4.2 Cable Without Connecting Devices

Cable ends without connecting devices should be prepared as follows.

Remove the armor and all other materials that cover the insulation. Materials removed include jacket, braid, tape, and lead. Only insulation materials should remain. At least 8 in. of insulation materials should be exposed on both ends of the cable.

The insulation surfaces should be thoroughly cleaned with non-conductive solvents and completely dried. Shrink sleeves, oil and other test insulators should be kept completely clean prior to use.

*Warning: If all contaminants are not removed, arcing will occur resulting in damage to the insulation integrity.*

At the end of the cable where the test lead is to be connected, remove at least 1/2 in. of insulation from the end of each conductor. Separate the test conductor as far from the other conductors as possible. Ensure that the bare conductor end is not closer than 6 in. to another conductor end or ground.

On the opposite end of the cable, apply a corona guard such as silicone cement, electrical putty, or plastic bags. Separate the conductor being tested as far from the other conductors as possible. Ensure that the conductor end is not closer than 6 in. to another conductor end or ground.

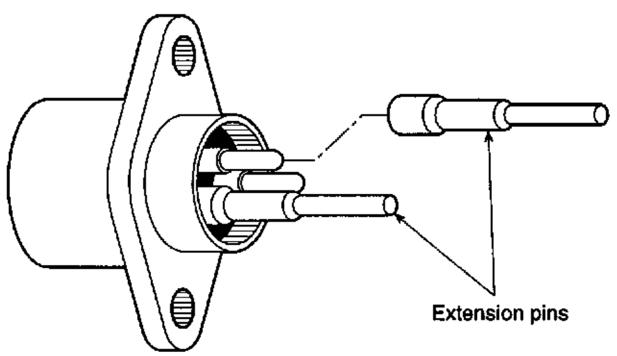



Figure 1—Cable with Male Connecting Device Isolated with High-Dielectic, Nonadhering, Preshrunk Sleeves

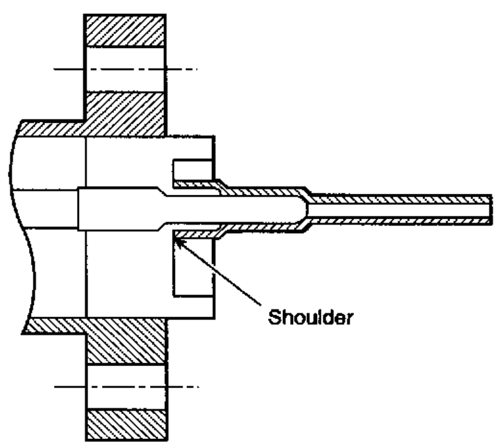



Figure 2—Positioning of High-Dielectic, Nonadhering, Preshrunk Sleeve on Male Connector

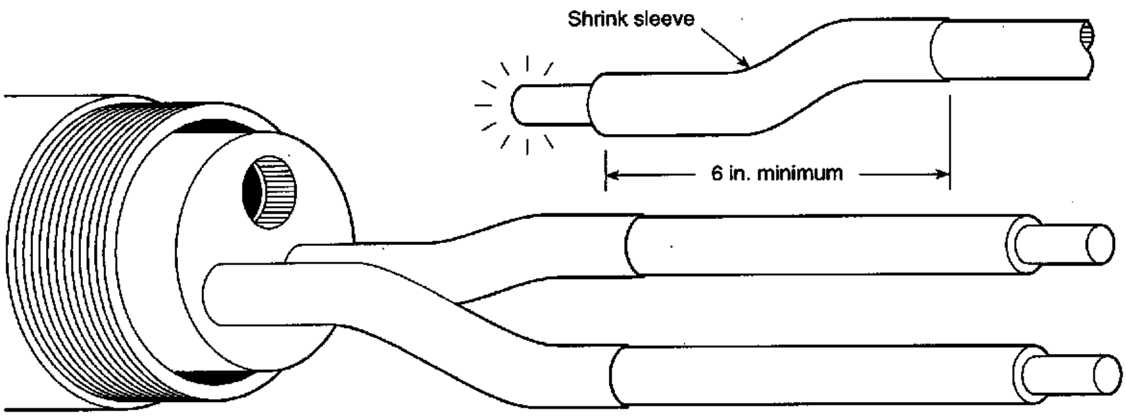



Figure 3—Cable with Female Connecting Device Isolated with Insulated Extension Pins

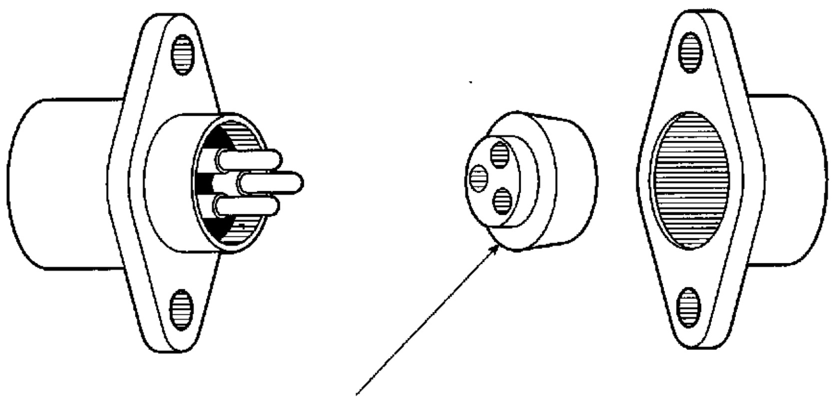



Figure 4—Positioning of a Molded Test Plug over the Contacts of a Pothead

# 7 Acceptance Testing

## 7.1 DESCRIPTION

Acceptance testing may be performed by the user upon receipt of new cable systems from the manufacturer. The purpose is to confirm that the cable system has not been damaged during shipping or handling, and to reveal any gross manufacturing defects. The test may also be performed on the cable system prior to installation in the well, if the unused cable system has been stored.

## 7.2 APPLICATION

Acceptance testing consists of an insulation resistance (IR) Test (Section 11) followed by a dc high potential test as defined in Section 12.

## 7.3 LIMITATIONS

An acceptance test is performed on unused cable. Tests on used cable systems are performed at lower voltages and fall under the categories of maintenance (proof), in-situ, or diagnostic testing.

# 8 Maintenance (Proof) Testing

## 8.1 DESCRIPTION

Maintenance (proof) testing consists of high voltage tests made on used cable systems prior to installation in a well. The purpose of maintenance testing is to confirm that the cable is acceptable for reuse.

## 8.2 APPLICATION

Maintenance testing should be performed every time a cable is pulled or repaired, or has been in storage prior to reuse.

Maintenance testing consists of an Insulation Resistance (IR) Test (Section 11) followed by a dc high potential test (Section 12). The maximum test voltage for dc maintenance testing is less than the original acceptance testing level.

## 8.3 LIMITATIONS

A cable deteriorates when installed in a well due to environmental effects and handling. Because of this change in cable characteristics, high voltage test levels should be adjusted.

The minimum dc test level for determining cable performance should be the maintenance test value. The maximum dc test level should not exceed the acceptance test value.

Actual field experience should be used to determine the appropriate test level for a particular application. Prolonged or repeated application of high voltages should be avoided.

# 9 In-Situ Testing

## 9.1 DESCRIPTION

In-situ testing consists of low energy tests made during and after installation of the cable system in the well. These tests are intended to evaluate the in-situ condition of the electrical system in a non-destructive manner. Because low energy levels are used, these tests will generally only reveal gross defects in the overall integrity of the electrical system elements including connectors, penetrators, cable, pothead and motor. Testers include megohmmeters (Section 12), volt-ohmmeters, and time domain reflectometers (Section 14).

## 9.2 APPLICATION

In-situ testing generally consists of system IR readings. IR tests are usually performed with a megohmmeter. Because IR readings are temperature dependent, resistance usually drops rapidly in a nonlinear manner as cable is lowered into the well.

A sudden and unanticipated drop in IR readings or low "as landed" readings may indicate system problems. Based on previous experience, it may be necessary to pull the unit and rectify the defect. However, industry experience has shown that the ESP may start and run with IR readings lower than 1 megohm.

A volt-ohmmeter may be used to confirm continuity of the conductor and motor circuit.

Another method of in-situ testing uses a time domain reflectometer (TDR). TDRs have been used extensively in other industries. However, this industry has had only limited success with the technology. The main advantage of a TDR is its ability to identify the depth of a gross cable defect.

## 9.3 LIMITATIONS

The interpretation of in-situ test readings is extremely dependent on comparison with historic data in a specific field or well.

Some of the variables that impact IR readings include: surface temperature, bottom hole temperature, cable type, depth, pressure, fluid level, well fluids, gasses, previous exposure of the cable, termination preparation, humidity, test voltage and test procedure. Because of all the variables involved, IR readings are seldom repeatable. However, used in the context of experience they can be important indicators of changes in the system.

TDRs respond to changes in the impedance of the cable. TDR signal loss depends on the insulation material and is greater in cables which have absorbed well fluids. A reduction in reflected signal makes it difficult to interpret the readings.

# 10 Diagnostic (Fault) Testing

## 10.1 DESCRIPTION

Diagnostic (fault) testing is performed to locate faults in a cable system.

## 10.2 APPLICATION

Diagnostic testing is performed after a cable system has failed an acceptance, maintenance (proof) test or in-situ test.

Several test methods are used (Section 14). Diagnostic test methods to locate a fault are listed in order of increasing destructive capability: physical inspection, IR tests, time domain reflectometer tests, high voltage Murry loop (bridge fault locator) tests, dc high potential tests, and evaluation with a capacitive discharge instrument (thumper).

Murry loop tests, dc high potential tests, and evaluations using capacitive discharge instruments are only performed after all equipment has been disconnected from the cable.

More extensive diagnostic tests to determine the cause of a failure are normally performed by the manufacturer or an independent laboratory. These tests are usually beyond the scope of what can be done in the field.

### 10.3 LIMITATIONS

Diagnostic tests should be run in the order of least destructive tests first. It is important that these tests be performed by qualified and trained personnel.

Capacitive discharge tests are destructive. DC high potential tests may be destructive, particularly when the energy discharge is high. The damage may be so extensive that the original fault cannot be analyzed.

Leakage current (insulation conductance) and insulation resistance test results are highly dependent on the length of time between cable removal from the well and testing. Readings will improve as the cable cools, dries out, and degasses.

## 11 Insulation Resistance (Megohmmeter) Tests

### 11.1 DESCRIPTION

Cable system insulation resistance (IR) is measured with a dc megohmmeter which is a device that measures extremely high resistance values. The test equipment is generally compact, inexpensive and widely used by cable manufacturers and operators.

IR testing can be used as a quality check on the insulation of a cable system and to determine catastrophic faults and gross defects in used cable.

### 11.2 APPLICATION

IR tests are performed as part of acceptance, maintenance (proof) and diagnostic (fault) testing.

Insulation resistance testing requires precautions for worker safety. The equipment should be operated in a manner consistent with manufacturer instructions.

Insulation resistance is measured at ambient conditions. The measured IR depends on a number of factors including: temperature, cable construction, cable length, conductor size, cable voltage rating (insulation wall thickness), previous exposure of the cable, termination preparation, humidity, test voltage and test procedure.

For cables being tested while installed in the well, the IR values are lower because of additional variables including: bottom hole temperature, well fluids, and exposure time. Other ESP system components such as motors, connectors, penetrators, and splices also reduce IR readings.

Acceptance tests require temperature correction factors to convert IR readings to a common temperature of 60° F (15.6° C). Temperature correction tables may be obtained from the cable manufacturer for that specific design being tested.

Acceptable insulation resistance values should be calculated using the methods described in Section 3.

The insulation resistance values shown in the tables of Section 3 are normalized to megohm-kft at 1000 Vdc. Because the cable insulation can be modeled as an infinite number of parallel resistors, the megohm reading will decrease as the cable length increases. Therefore the measured resistance (megohmmeter reading) is multiplied by the length of the cable (in kilofeet) to obtain a value that compares with the normalized thresholds given in the table.

### 11.3 LIMITATIONS

Cable insulation material will affect the IR reading. Polypropylene has a much higher insulation resistance at room temperature than EPDM rubber.

Environmental factors also affect IR readings. Elevated temperature reduces IR readings. Humidity in the air or moisture in the cable can lower IR readings by a factor of 1000 or more.

Insulation resistance testing is often done during ESP installation. When the cable is lowered into the well, the readings will decrease as well temperature increases. A sharp drop in the IR reading will often occur when the cable reaches the fluid level.

Well liquids and gasses permeate cable insulation and jacket materials. This results in lower IR values in the well. After the cable is removed from the well, these liquids and gasses begin to leave the cable and IR readings should improve. This venting process may take several days, and even longer for deteriorated lead sheathed cables.

Megohmmeter test voltages vary from 1000 Vdc to 5000 Vdc depending on the model. Comparison of values obtained at different test voltage levels is difficult. Therefore most tests are performed at 1000 Vdc. While higher voltages may locate sites with weak or severely damaged insulation, higher test voltages should not be used as a substitute for dc high potential tests (see Section 12).

Installations that have downhole sensors connected to the cable system may present limitations on IR test voltage levels. *Contact the manufacturer for acceptable voltage levels.*

### 11.4 TEST PROCEDURE

Follow the safety procedures described in Section 4, cable preparation procedures described in Section 6, and equipment manufacturer's instructions.

The test should be made using a megohmmeter with a dc source rated at 1000 v.

A test should be made between each pair of phase conductors. A test is also conducted between each phase conductor and the armor, with the ground lead connected to the armor. Most instruments use the negative lead for ground.

A group-tie test may be used to simulate a motor connected to the cable. The three conductors are connected (terminated) together at one end. Then the IR tests are conducted. The values obtained from the group-tie test will typically be lower than test values obtained under similar test conditions with the conductors unterminated.

The cable is energized until the reading stabilizes. The value should be recorded at the end of this time.

During the electrical test procedure, precautions should be taken to prevent contact with energized surfaces.

When dc voltages are applied to the cable, a residual charge will remain in the insulation. Each conductor should be grounded after it is tested. The ground should be applied long enough to completely discharge the cable. This may be up to four times the duration of the applied voltage. Otherwise there is danger of electrical shock even without an applied voltage.

## 12 DC High Potential Tests

### 12.1 DESCRIPTION

This section refers to dc high potential testing of ESP cable and attachments for quality assurance. Attachments include motor leads, potheads, pigtails, penetrators, connectors, splices, and any other mechanism that may be connected to the cable. Motors and most downhole sensors are specifically excluded from high potential tests.

Even though ESP cable is used with an applied ac potential, the test equipment for dc testing is smaller, less expensive, and considered safer than comparable ac test equipment.

DC high potential testers measure the microamp leakage current value for the cable under test. The particular value of leakage current measured will depend on a number of factors including: insulation material, applied voltage, cable length, temperature, humidity and end terminations. Maximum acceptable leakage current criteria are typically based on experience.

### 12.2 APPLICATION

The level of dc high potential voltage is different for each category of testing. Test voltages for factory, acceptance and maintenance (proof) testing are given in Table 11. To reduce the stress applied to the insulation and the potential for cable damage, and to allow for changes in conditions, Acceptance and maintenance test voltage levels are typically less than factory test levels. These values are based upon phase-to-ground readings.

The test voltage levels in Table 11 are based on IEEE standard 1017. These are for pass-fail (no-go) type tests. For information on step testing, refer to IEEE STD-1017.

The maintenance test voltage levels in Table 11 are minimum values. The acceptance test voltage levels are maximum values in the field.

Acceptable leakage current values should be calculated using the methods described in Section 3.

The leakage conductance values in the tables of Section 3 are normalized to microamperes per kilovolt per kilofoot. Because the cable insulation can be modeled as an infinite number of parallel resistors, the microampere reading will increase as the cable length increases. Therefore the measured leakage current (microamperes) is divided by the test voltage (in kilovolts) and divided by the length of the cable (in kilofeet) to obtain a value that compares with the normalized thresholds given in the tables.

For connectors, penetrators, potheads, and cable assemblies with these attachments use the test voltages shown in Table 12.

### 12.3 LIMITATIONS

Inaccurate readings may be made when the cable under test has short (less than 8 in.) and/or unclean end terminations. The bulk of the measured leakage current would then occur on the ends due to low surface resistivity. End effects also play an important role in evaluating the quality of motor lead extension (MLE) insulation because of the short cable lengths involved.

High temperature and humidity can also lead to inaccurate estimation of cable insulation quality. One high-voltage test equipment manufacturer has suggested a "baggie" test where plastic bags are placed over the exposed end terminations. The air inside the bag is ionized during testing creating

Table 11—DC Test Voltages (kV) for ESP Cable

| (1) | (2) | (3) | (4) |
|---|---|---|---|
| Cable Rating ac $\phi$-$\phi$ | Factory Test Voltage | Acceptance Test Voltage | Maintenance Test Voltage |
| 3 | 27 | 22 | 11 |
| 5 | 35 | 28 | 14 |

Table 12—DC Test Voltages (kV) for Connectors, Penetrators, and Potheads

| (1) | (2) | (3) |
|---|---|---|
| Cable Rating ac $\phi$-$\phi$ | Acceptance Test Voltage | Maintenance Test Voltage |
| 3 | 18 | 11 |
| 5 | 24 | 14 |

an end-shielding system which minimizes end leakage, particularly under high humidity conditions.

Well liquids and gasses permeate cable polymeric materials during service downhole resulting in fluctuating leakage current values when the cable is first tested on the surface. Once these fluids have been released stable readings may be taken of the ESP cable.

DC voltage tests at levels exceeding those given in Table 11 cause a voltage stress on the cable insulation which may weaken the insulation depending on its condition. Power industry experience has shown this stress effect is cumulative. However, the benefits derived from testing at voltage levels above the minimum recommended maintenance testing levels may surpass the risks involved, particularly for newer cables.

Typical ESP power cable has an insulation thickness that is adequate to withstand the acceptance test voltages in Table 11 without significant loss in cable life. This may not be true in pothead and motor lead extensions where the insulation wall thickness is constrained by pump and well casing clearance. Extreme caution should be taken when testing these components to avoid failure during test or worse, preconditioning these components to fail while downhole. The end user should exercise care in choosing acceptance voltage levels after contacting component manufacturers for recommendations.

It is general practice not to reuse potheads and motor lead extensions after use in a well. Because of the space constraints and temperature at the location where these are applied there is a probability of damage and deterioration.

Molded rubber connectors and cable components should not be reused unless they have been properly cleaned, inspected, and tested.

*CAUTION: Proper preparation of the ends of connectors, penetrators, and potheads is crucial to their surviving high voltage tests. The ends should be prepared as identified in Section 6. If the ends are not properly prepared arcing will occur and create a carbon path. This will permanently damage the connection device.*

Installations that have downhole sensors connected to the cable system may present limitations on test voltage levels. *Contact the manufacturer for acceptable voltage levels.*

### 12.4 TEST PROCEDURE

Follow the safety procedures described in Section 4, cable preparation procedures described in Section 6, and equipment manufacturer's instructions.

The test should be made with an direct current from a source of ample capacity so that the specified test voltage level can be maintained.

The procedure involves testing one conductor at a time while the other two conductors, along with the armor and any other metallic components, are connected to ground. The high voltage lead is connected to the conductor under test.

Most hi-pot testers use the negative lead because negative charge injects electrons into the insulation which effectively builds a shield around the conductor. A positive charge will increase the electric field stress on the insulation which may result in premature failure after ac power has been reapplied. Under field test conditions, use of a positive lead should not result in pre-stress failure if proper grounding procedure is used (see Section 4).

Conductors not being tested, armor, connection device housings, and any other metallic components, should be connected to ground. The ground lead from the test set should be connected to the local ground. The test lead is then connected to the bare conductor of the phase being tested.

The test voltage should be applied gradually, within the limits of the equipment, until the desired test voltage is reached (see Tables 11 and 12). The total time taken to reach the specified test level should not take less than 10 sec. This prevents impulse stresses on the insulation.

The charging current limit of the test equipment should not be exceeded while the voltage is being increased. The test voltage should be maintained at the specified test voltage for 5 minutes. After the test has been completed, the applied voltage should be reduced to zero.

When dc voltages are applied to the cable, a residual charge will remain in the insulation. Each conductor should be grounded after it is tested. The ground should be applied long enough to completely discharge the cable. This may be up to four times the duration of the applied voltage. Otherwise there is danger of electrical shock even without an applied voltage.

Repeat the above test procedure for the other two conductors that were previously connected to ground. Remember to ground the conductor after each test to ensure that the cable is de-energized.

The described test may be conducted in air or with the cable submerged in water. Submergence will provide an additional path and may identify defects otherwise not observed.

## 13 AC Testing

### 13.1 DESCRIPTION

AC high potential testing is a factory test that is not performed in the field. The following information is provided to aid understanding of how and why the test is performed.

### 13.2 APPLICATION

Electric submersible pump cables are designed for ac operation. Therefore ac tests are used to establish the integrity of the cable string. Because they employ a different type of signal, ac tests may find defects that are not identified with dc tests.

Factory ac testing is generally done twice during the cable manufacturing process — as an interim test and again as a final test. AC test voltage requirements are much lower than dc test voltages. Factory test voltages are provided in Table 13. A 50 or 60 Hz power source is used.

AC testing does not polarize the insulation material as does dc testing. AC testing is more discernible in detecting faults than dc testing. This is partially due to the higher level of electrical stress imposed on the cable by the ac voltage. Given adequate time, the ac test voltage will burn through weak or faulted insulation. Higher dc test voltages are required to detect the same problem.

Under dc testing the insulation in the cable acts like a resistor. Under ac testing the insulation in the cable acts likes a capacitor.

Unlike dc testing, after the ac testing is completed and the applied voltage has been drained to zero, there is no residual charge left in the cable. With ac testing it is not necessary to guard against a build up of charge in the cable once the testing is completed.

Care and attention to detail is still required in preparing the cable termination ends. At the test voltages outlined in this document, there is no substantial difference in the type of termination required for either ac or dc testing. With ac testing, cable end losses are not significant for long lengths of cable. In dc testing cable end losses can be very substantial and will give erroneous readings.

In addition to measuring leakage current, an ac test set can be used to measure the capacitance and power factor of the insulation.

### 13.3 LIMITATIONS

The power (kVa reactive power) requirements for an ac voltage test are much higher than for a dc voltage test (typically 25,000 times more power is required). An ac adjustable transformer is physically larger and more expensive than a dc test unit. Because of the size and weight of the equipment, it is more difficult to transport.

The power requirements for the ac test unit are based on the required charging current and test voltage for the cable. For example, to test a 6000 ft length of 3ϕ #1 AWG EPR / EPR round cable at 5200 V, the reactive power to conduct the test would be over 5 kVa. This is based on a cable capacitance of 0.07 µf per 1000 ft at 60 Hz.

Conversely, for the same cable subjected to dc testing, the kva rating for the test set would be primarily based on the leakage current requirements. For this cable, the test set would require a rating of 0.0002 kVa. (Based on a leakage current of 10µa for the cable when tested at 15,000 Vdc. )

Table 13—AC Voltage Tests

| (1)<br>Voltage Rating of Cable, Phase to Phase (V) | (2)<br>Factory Test AC Voltage, 5-min Duration (V) |
|---|---|
| 3000 | 9,000 |
| 4000 | 11,500 |
| 5000 | 13,000 |

When ac or dc voltage potential is applied to the cable, an electrical stress is imposed on the insulation. This electrical stress is highest in regions close to the conductor and gradually diminishes the further the distance is from the conductor.

Conductor geometry (stranded versus solid) and scrapes or grooves in the copper's surface results in a higher concentration of electrical stress. The increased electrical stress concentration over these areas may cause a premature weakening or even failure of the insulation due to the ac testing.

Gas infusion into the cable insulation may result in the formation of micro voids (tiny bubbles) in the insulation itself. Upon application of a high ac test voltage the gas inside the void may start to discharge and arc. This corona discharge can lead to physical degradation of the insulation which will lead to electrical failure.

Should a failure occur, the alternating current from a conventional (nonresonant) test set will blow a larger hole at the location of the fault. This may eliminate the possibility of identifying the cause of the cable fault. In addition, the arcing from the ac fault may damage the adjacent insulated conductors.

Extended time periods of high voltage ac testing has been reported to weaken the electrical strength of polypropylene insulation. This may lead to a lower insulation breakdown voltage.

## 14 Fault Location Tests

### 14.1 MURRY LOOP (BRIDGE FAULT LOCATOR) TESTS

#### 14.1.1 Description

The Murry loop is an electrical current bridge used for the rapid location of faults in single or multi-conductor cables. The tests described, use a high voltage Murry loop instrument.

### 14.1.2 Application

The Murry loop is a nondestructive method of locating faults that have been identified by other tests. Compared to other fault-locating equipment, the device is portable and inexpensive.

A high voltage dc is applied to the cable. The device uses a balance bridge to determine the relative location of the fault.

### 14.1.3 Limitations

The Murry loop technique requires a conducting carbon path at the fault site. The carbon path becomes part of the detection circuit. It may be necessary to increase the burn voltage control to form a carbon path at the fault. The Murry loop will not work with an open conductor, a direct short, or multiple faults on the conductors under test.

The Murry loop can only be used after the equipment is removed from the well.

### 14.1.4 Procedure

The Murry loop utilizes a high voltage dc source during measurements and all precautions for worker safety (Section 4) should be considered. The test equipment should be used according to manufacturer recommendations. The cable should be prepared as described in Section 6.

A fault site is located by connecting the appropriate circuit leads to the conductor being tested. This conductor should be connected to another conductor in the bridge path for comparison of the readings. A dc voltage is applied and a potentiometer is adjusted to obtain a null bridge reading. The location is determined by reading the potentiometer dial. The potentiometer value corresponds to a percentage of the total length of the cable. The test should be conducted from both ends of the cable to validate the location.

The basic circuit diagram (Figure 5) demonstrates the technique for locating a phase to armor fault. The device would be reconnected to locate a phase-to-phase fault.

## 14.2 CAPACITIVE DISCHARGE INSTRUMENT (THUMPER)

### 14.2.1 Description

A capacitive discharge instrument applies a high-voltage, high-current impulse to a faulted cable.

### 14.2.2 Application

Other test methods are used to initially determine if there is a fault in the cable. If the fault cannot be located by other methods, a capacitive discharge instrument can be used to apply high energy to the fault location. This energy enlarges the fault to the extent that it may be located by sound or sight.

A high-voltage capacitor is discharged into the cable. The repeated discharging of the capacitor provides a periodic pulsing of the faulted cable. *Manufacturers instructions and high voltage safety procedures (Section 4) should be followed.*

### 14.2.3 Limitations

This is a destructive procedure since the capacitive discharge instrument is a high energy device. The insulation will be destroyed in the area of the fault. This most likely will preclude any failure analysis.

### 14.2.4 Procedure

The procedure is performed with an alternating potential from a source of ample capacity so that there will be high energy arcing at the fault.

The procedure involves operating on one conductor at a time while the other two conductors, along with the armor and any other metallic components, are connected to the ground lead. The test lead is then connected to the bare conductor of the phase being evaluated.

The ground lead from the test set should be connected to the local ground.

Section 6 specifies techniques for preparing cable ends.

The instrument energy should be applied gradually until arcing is detected. After the fault has been located, the electrical energy should be removed immediately.

## 14.3 TIME DOMAIN REFLECTOMETER (TDR) TESTS

### 14.3.1 Description

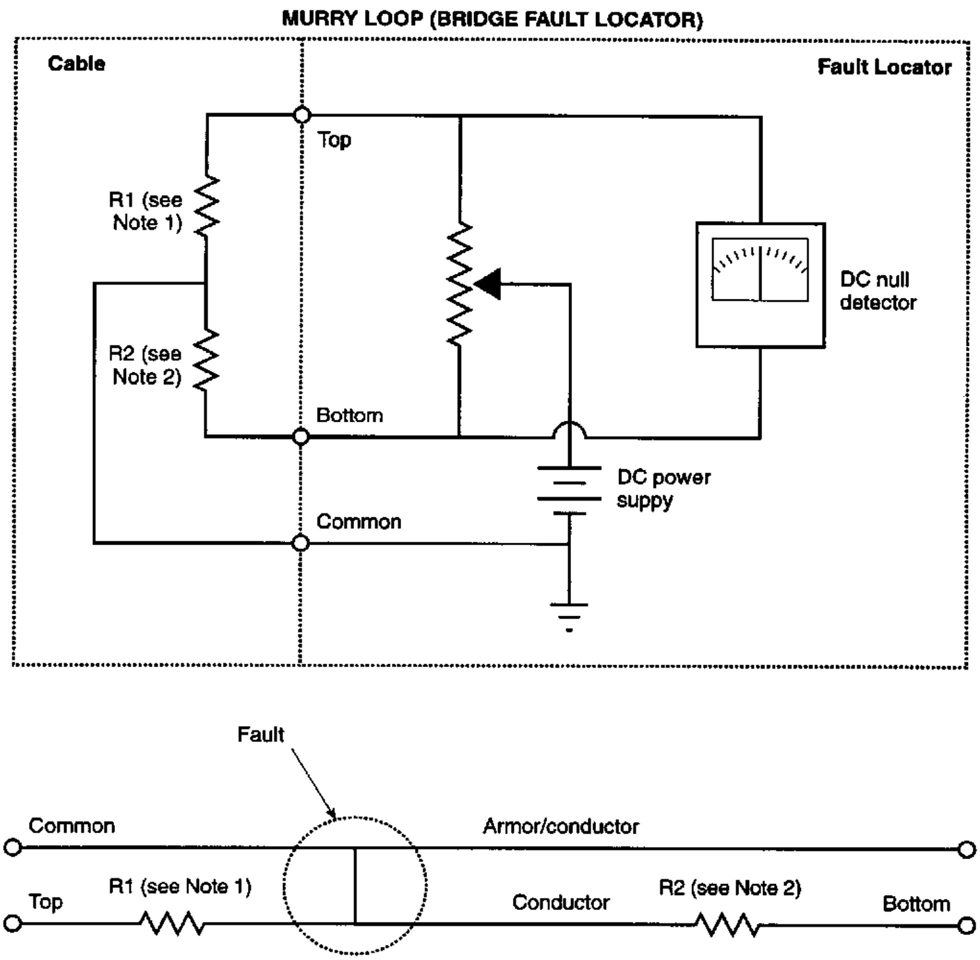
A time domain reflectometer is a device that applies an input voltage pulse on a length of cable and connected equipment. It records a reflection of the pulse in a manner similar to an acoustical well sounder. The shape, polarity, and displacement of the reflected pulse can be interpreted to locate substantial impedance changes in the system.

### 14.3.2 Application

A TDR is a nondestructive method of locating damaged areas in the cable system.

Cable has a characteristic impedance which is associated with the size of the conductors and the spacing between the conductors. The TDR reflection identifies changes from this characteristic. The changes may be caused by terminations, splices, crimping, banding, and electrical faults or other damage to the cable.

The TDR has traditionally been used with communication cables. Much of the data, experience, and information is associated with these type cables. Application on power cables




Notes:
1. R1 = Resistance of faulted connector from fault to top of cable.
2. R2 = Resistance of faulted connector from fault to bottom of cable.

Figure 5—Basic Circuit Diagram of a Phase to Armor Fault Location Test

requires different test techniques because cable configuration and insulation material properties affect the TDR readings.

The device permits identification of fault locations where there are large changes in insulation impedance. By identifying faults in the top portion of the cable the operator may eliminate the need to pull the entire tubing string.

### 14.3.3 Limitations

Application of TDRs to ESP cable requires a skilled operator to interpret the results.

Many types of TDRs are designed for use with communication cables. These TDRs do not possess enough energy in the pulse to be used with ESP cables.

Because of the number of reflections that may occur, it may be difficult to determine the importance of any single reflection. Hence, it is recommended to have an initial signature of the newly installed cable system. Subsequent tests are compared to this initial test. The signature includes a copy of the trace with notes about the meaning of each of the reflected pulses. In addition, the pulse duration, the amplitude of the pulse, and the velocity factor settings should be recorded.

The quality of the reflected signal depends on the insulation material, service history of the cable, and absorption of well fluids. These factors cause a reduction in reflected signal which makes it difficult to interpret TDR readings.

The TDR test will seldom find pinholes or small radial cracks in insulation, but only identifies changes in impedance. A very large impedance change may mask additional faults farther down the cable.

### 14.3.4 Test Procedures

Follow the safety procedures described in Section 4, cable preparations described in Section 6, and equipment manufacturer's instructions.

One of the insulation material properties that affects TDR readings is the impedance across the insulation. This impedance results in TDR pulse power losses which are considerably larger than found in communication cable. The test technique should be modified so the pulse amplitude is adequate to overcome these losses.

Another impact of these higher power losses is on the TDR pulse width. For submersible cables, a wider pulse may be required to overcome these losses. However, a wider pulse may cover up data from faults that are in close proximity. Consequently, the minimum width should be used that will provide a pulse reflection that has adequate amplitude and shape.

The insulation impedance also has an effect on the TDR measured velocity factor. Velocity factor is the ratio between the velocity of the pulse in the cable and what the velocity would be with air as insulation. The velocity factor will change as the insulation impedance changes. The impedance will change with temperature, pressure, fluid and time of exposure. Changes in the velocity factor may be used to determine deterioration of the insulation. An increase in the velocity factor will appear as a decrease in length of the cable on the TDR.

A known length of cable should be used to calibrate the TDR before testing.

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