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Medium-Voltage Cable Acceptance Testing

U.S. practice (NETA ATS · IEEE 400.2) · Example: 2.5 MWac PV plant

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Abstract

This paper describes the acceptance testing of medium-voltage shielded power cables in a solar photovoltaic (PV) plant before first energization: visual and mechanical inspection, shield continuity, insulation resistance, and a withstand test with very low frequency (VLF) AC voltage, followed by a second insulation resistance reading. It follows ANSI/NETA ATS and IEEE Std 400.2.

The withstand test is the step that finds installation defects, which in new cable systems are concentrated in the terminations and splices made on site. For cables with extruded insulation, the acceptance test is made with sinusoidal VLF voltage at 0.1 Hz, at 21 kV rms for 15 kV class cable and 26 kV rms for 20 kV class cable, with a recommended duration of 60 minutes for new circuits. These voltages are from the 2013 edition of IEEE Std 400.2 and must be confirmed in the 2024 edition. The paper explains where these values come from, how the test is connected and what is recorded.

The method is illustrated with the medium-voltage collection and interconnection circuits of an anonymized 2.5 MWac PV plant in Brazil: three short underground circuits, with ten conductors to test, and one bare overhead span to which the cable withstand test does not apply. The example shows the test plan, not test results.

Keywords: medium-voltage cable, acceptance test, VLF, very low frequency, withstand test, insulation resistance, shield continuity, tan delta, IEEE 400.2, ANSI/NETA ATS, PV plant commissioning.

Notice – professional responsibility

Educational content. This paper describes a test method and illustrates it with an anonymized example. It is not a test procedure, specification or recommendation for any specific project.

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High-voltage testing is hazardous. The tests described here apply lethal voltage to cables that store charge. They must be performed only by qualified persons, under the safety program of the site, with the test voltages and durations approved in the project test procedure and accepted by the cable and accessory manufacturers.

No warranty. The information is provided as is. The test values quoted are those of the editions cited; the reader is responsible for verifying every value against the current editions and the project data.

1 Introduction and Scope

The medium-voltage cables of a PV plant carry its entire output. They are few, they are buried, and a failure takes the plant or a large block of it out of service for days. Factory tests show that the cable left the plant in good condition. They say nothing about what happened to it afterwards: pulling damage, a nicked insulation shield, a void in a field-made termination, moisture in a splice.

The acceptance test is the only check of the installed cable system as a whole before it is energized. It is test 8 and test 9 of the commissioning sequence described in the opening paper of this series, and it sits at the end of cold commissioning, just before the release for energization.

Scope: acceptance testing of new shielded medium-voltage cable systems, 5 kV to 35 kV class, with extruded insulation (XLPE, TR-XLPE or EPR), including their terminations and splices. Maintenance testing of aged cables, fault location, and the testing of unshielded cables, bus and switchgear are not covered.

Audience: commissioning engineers, testing technicians, EPC project managers and owner's engineers who specify, perform or review cable acceptance tests.

Normative basis: ANSI/NETA ATS for the list of inspections and tests, IEEE Std 400 and IEEE Std 400.2 for the field test methods and voltages. Section 3 lists each document and what it contributes.

2 Fundamentals

2.1 What each test shows

No single test characterizes a cable system. The acceptance sequence uses several, each answering a different question.

Test	Question it answers	What it does not show
Visual and mechanical inspection	Is the cable the one specified, installed without damage, correctly terminated and grounded?	Internal defects
Shield continuity	Is the metallic shield continuous from end to end?	Shield condition along the route
Insulation resistance	Is there gross contamination, moisture or a short to ground?	Whether the cable will withstand service voltage
VLF withstand	Does the cable system survive a voltage above service level for a set time?	How close a surviving defect is to failure
Tan delta (optional)	What is the overall condition of the insulation, as a baseline?	The location of a defect
Partial discharge (optional)	Is there a localized defect, and where?	Defects that do not discharge at the test voltage

Insulation resistance and withstand are often confused. A cable with a severe workmanship defect in a termination can show an insulation resistance of many gigohms. Insulation resistance is a screening test; the withstand test is the acceptance test.

2.2 Why very low frequency

A cable is a capacitor. At 60 Hz, the charging current of even a short medium-voltage cable requires a large and heavy test source. At 0.1 Hz the same cable draws 600 times less current, so the test set is portable.

Direct voltage needs even less power, and for decades it was the usual field test. Experience with extruded insulation changed that. A DC test stresses the insulation differently from service voltage and is less effective at finding the defects typical of extruded cable and its accessories, and DC testing of service-aged XLPE cable is associated with later failures in service. For new extruded cable, DC acceptance values are still published, but VLF AC is the method normally specified.

2.3 Types of test and when they apply

IEEE Std 400.2 defines three test levels, in decreasing order of voltage:

- **Installation test:** after the cable is installed, before terminations and splices are made.
- **Acceptance test:** after the complete cable system is installed, with terminations and splices, before it is placed in service. This is the test of this paper.
- **Maintenance test:** during the service life, at a lower voltage.

The three levels are not interchangeable. Applying the acceptance level to an aged cable, or the maintenance level to a new one, defeats the purpose of the test.

2.4 Test voltages and duration

IEEE Std 400.2 was revised in 2024, and the 2024 edition is the current one. The table gives the withstand voltages of the 2013 edition for a sinusoidal waveform at 0.1 Hz, phase to ground. These are the values most widely reproduced in field procedures and test equipment documentation. The test procedure must take its values from the edition named in the contract.

VLF withstand voltages, sinusoidal waveform (IEEE Std 400.2-2013)

Cable rating, phase to phase (kV rms)	Installation (kV rms)	Acceptance (kV rms)	Acceptance (kV peak)	Maintenance (kV rms)
5	9	10	14	7
8	11	13	18	10
15	19	21	30	16
20	24	26	37	20
25	29	32	45	24
28	32	36	51	27
30	34	38	54	29

Cable rating, phase to phase (kV rms)	Installation (kV rms)	Acceptance (kV rms)	Acceptance (kV peak)	Maintenance (kV rms)
35	39	44	62	33

The values are for the sinusoidal waveform. The 2013 edition gave both rms and peak values; the 2024 edition states voltages in rms only and gives separate values for the cosine-rectangular waveform. The test report must state the waveform and the voltage basis; a 21 kV rms test and a 21 kV peak test are different tests.

The 2024 edition also extends the voltage range to 138 kV class cable, limits the monitored withstand test to tan delta and partial discharge, and calls for the voltage to be reduced gradually at the end of the test.

Duration. IEEE Std 400.2 recommends 60 minutes at 0.1 Hz for a new circuit or after a repair, and 30 minutes for an aged circuit. The 2013 edition allowed a shorter time, in the range of 15 to 30 minutes, only if a monitored property such as tan delta stayed stable for at least 15 minutes and no failure occurred. Many project specifications call for 30 minutes; the duration must be agreed in the test procedure before the campaign.

The voltage is not raised above the table value to shorten the test. Time at the specified voltage is what gives a defect the chance to fail during the test and not in service.

Limits. The test voltage must not exceed what the terminations, splices and any connected equipment are rated for. ANSI/NETA ATS-2025 publishes its own table of VLF acceptance values (Table 100.6.3) and tables for the other methods. Where the project specification cites NETA, the NETA table governs.

3 Standards and References Applicable (U.S. Market)

Document	What it provides for this test
ANSI/NETA ATS-2025	Inspection and test list for medium- and high-voltage cables. Tables 100.6 give acceptance test values by method: DC, VLF, damped AC, power-frequency AC, and tan delta test voltages and evaluation criteria. Appendix B gives guidance on choosing the test method.
IEEE Std 400-2023	Guide for field testing of shielded power cable systems rated 5 kV and above: overview of the methods, their advantages and limits, safety and test documentation.
IEEE Std 400.2-2024	Field testing with VLF voltage: withstand voltages and durations, tan delta and partial discharge measurement with a VLF source, and assessment criteria. Supersedes the 2013 edition.
IEEE Std 400.3	Partial discharge testing of shielded power cable systems in a field environment.

Document	What it provides for this test
ICEA S-94-649 and ICEA S-97-682	Cable construction standards for concentric neutral and for shielded utility cables rated 5 kV to 46 kV. Define the factory tests against which field values are limited.
IEEE Std 48 and IEEE Std 386	Terminations and separable connectors. Set the limits that the test voltage must not exceed.
NFPA 70 (NEC)	Installation requirements for medium-voltage conductors, including shield grounding and bending radius.
NFPA 70E and OSHA 29 CFR 1910.269	Safety of the test: qualified persons, test area guarding, grounding and discharge.

3.1 How to use these documents together

NETA ATS says which inspections and tests make up the acceptance of a cable, and gives the acceptance values. **IEEE Std 400.2** explains the VLF method in detail and is the source most test equipment and field procedures follow. **The cable and accessory manufacturers** set the upper limit: no field test voltage should exceed what they accept for their product.

The project test procedure names one governing document and one table. Mixing a voltage from one document with a duration from another is a common source of disputes.

4 Example: Circuits to Be Tested

The example is the medium-voltage system of a 2.5 MWac PV plant in Brazil, operating at 13.8 kV. It runs from the step-up transformer to the point of interconnection in four sections.

Medium-voltage sections of the example plant (anonymized)

Section	Cable	Length	Conductors	Tests
Transformer to riser pole	Aluminum 95 mm², 15 kV class, shielded, 90 °C	20 m (66 ft)	3	Full sequence
Overhead span	Bare aluminum conductor, steel reinforced	515 m (1,690 ft)	3	Visual inspection and insulation resistance only
Riser pole to service entrance	Aluminum 95 mm², 15 kV class, shielded, 90 °C	45 m (148 ft)	3	Full sequence
Service entrance to point of interconnection	Copper 70 mm², 20 kV class, shielded, 105 °C	40 m (131 ft)	3 + 1 spare	Full sequence

Three points follow from the table.

- **Ten conductors** receive the full sequence, including the spare. A spare conductor that was never tested is not a spare.
- **Two cable classes** are present on the same 13.8 kV system. The acceptance voltage follows the rating of each cable: 21 kV rms for the 15 kV class sections and 26 kV rms for the 20 kV class section, in both cases limited by the rating of the terminations.
- **The overhead span is not a cable test.** A bare conductor has no insulation or shield to test. The span is inspected visually (poles, insulators, hardware, guys, sag, clearances and grounds), and an insulation resistance reading to ground is taken to detect damaged or contaminated insulators. The reading depends on weather and has no fixed minimum.

The circuits are short, so their capacitance is small and any portable VLF set covers them at 0.1 Hz. In plants with long collector circuits, the capacitance of the circuit must be checked against the rating of the test set, and the test frequency lowered if necessary.

5 Preparation and Safety

5.1 Prerequisites

- Cable installed, terminations and splices complete, and the installation released by the installer;
- Cable disconnected at both ends from transformers, switchgear, surge arresters and instrument transformers, with enough clearance at the open ends for the test voltage;
- Terminations clean and dry;
- Cable schedule, termination and splice data, and the manufacturer’s field test limits on site;
- Test procedure approved, stating method, waveform, voltage, duration and acceptance criteria;
- Repair materials and a crew available, since a breakdown during the test must be located, repaired and re-tested before energization;
- No rain, drizzle, fog or lightning. Ambient temperature and relative humidity recorded.

5.2 Safety

- **Absence of voltage, lockout/tagout and temporary grounds** before any connection is made. The temporary ground is removed only from the conductor under test, and only after the test set is connected.
- **Both ends are test areas.** The far end is energized to the full test voltage. It is barricaded and signed, and a watchman with communication to the test operator stays there for the whole test.
- **Other conductors and all shields grounded** during each test, with the test set and all exposed metal bonded to a single ground at the test location.

- **Isolation points.** An open switch or air gap that separates the cable under test from energized equipment must withstand the test voltage on one side with line voltage on the other. If that cannot be confirmed with the manufacturer, the adjacent equipment is de-energized.
- **Discharge and ground after every test.** A cable stores charge. After a DC insulation resistance test, the conductor is grounded for at least as long as the voltage was applied. After a VLF test, the set discharges the cable, and a ground is still applied before anyone touches it.
- **One person in charge of the test**, who gives the instruction to apply voltage after confirming that both ends are clear.

5.3 Instruments

Instrument	Minimum specification
Insulation resistance tester	Test voltages up to 10 kV DC, reading into the teraohm range, with timed test and discharge function
VLF AC test set	Sinusoidal output at 0.1 Hz, rated for the acceptance voltage of the highest cable class and for the capacitance of the longest circuit; leakage current and time record
Tan delta accessory (optional)	Matched to the VLF set, for measurement at 0.5, 1.0 and 1.5 times rated phase-to-ground voltage
Low-resistance ohmmeter or multimeter	For shield continuity
Grounding sticks and temporary grounds	Rated for the system
Thermo-hygrometer	Ambient temperature and relative humidity

All instruments carry a valid calibration certificate. Certificates are attached to the report.

6 Test Sequence

The tests are made in the order below, conductor by conductor.



Figure 1. Connection for one phase. The same arrangement is used for the insulation resistance test and for the VLF withstand test.

6.1 Visual and mechanical inspection

- Cable type, size, rating and manufacturer against the drawings and the cable schedule;
- Jacket and exposed insulation free of cuts, crushing or abrasion;
- Bending radius not smaller than the manufacturer's minimum;
- Terminations and splices of the specified type, assembled to the manufacturer's instructions, with correct creepage and clearance;
- Shield grounding as shown on the drawings: at one end or at both, and through window-type current transformers where required;
- Phase identification and cable tags;
- Supports, fire stopping and duct sealing in place.

6.2 Shield continuity

The resistance of the metallic shield is measured from end to end with an ohmmeter, for each cable. The shield must be continuous. A value much higher than expected for the shield construction and length, or a clear difference between phases of the same circuit, is investigated before any high-voltage test: a broken shield changes the stress distribution in the insulation and makes the following tests unreliable. Earlier editions of ANSI/NETA ATS call for investigation above 10 ohms per 1,000 ft of cable.

6.3 Insulation resistance, before

1. Connect as in Figure 1: conductor under test to the instrument, all other conductors and all shields grounded.

2. Apply the test voltage for 1 minute and record the reading. ANSI/NETA ATS takes the test voltage from the manufacturer's data or from its Table 100.1; a voltage of at least 2,500 V DC is used on medium-voltage cable. The example plan applies 5 kV DC to the 15 kV class cable and 10 kV DC to the 20 kV class cable.
3. If the procedure asks for it, continue to 10 minutes and record the readings at 30 seconds, 1 minute and 10 minutes.
4. Discharge and ground the conductor for at least the time the voltage was applied.
5. Repeat for each conductor, including spares.

The reading is compared with the minimum given by the manufacturer for that cable and length, and with the other phases of the same circuit. Insulation resistance falls as length and temperature rise, so a fixed number in megohms cannot be applied to every circuit. The minimum for a given cable is calculated from the insulation resistance constant of its standard, the ratio of the diameters over and under the insulation, and the length.

The polarization index, the ratio of the 10-minute to the 1-minute reading, is of limited use on new extruded cable. When the resistance is very high, the index can be close to 1 without indicating a defect. It is recorded for reference and is not, by itself, a reason for rejection.

6.4 VLF withstand

1. Connect the VLF set to the conductor under test, with all other conductors and all shields grounded. Confirm that both ends are clear.
2. Raise the voltage to the acceptance level for the cable class (Section 2.4) and start timing.
3. Hold for the duration stated in the procedure. Record the voltage and the leakage current at the start and at regular intervals.
4. At the end, reduce the voltage gradually, let the set discharge the cable, and apply a ground.
5. Repeat for each conductor.

Where the procedure and the capacity of the test set allow, the three phases of a circuit can be tested together, which shortens the campaign. Testing one conductor at a time identifies a failed phase directly and is the arrangement used in the example plan.

If a conductor fails, the fault is located and repaired and the test is repeated in full on that conductor, for the complete duration. The time already elapsed does not count.

6.5 Insulation resistance, after

The insulation resistance test of Section 6.3 is repeated at the same voltage and time. The second reading is compared with the first. A clear drop indicates that the withstand test changed the insulation and is investigated, even if the cable held the voltage.

6.6 Restoring the circuit

After the last test, the conductors are grounded and remain grounded until they are reconnected. Reconnection, torque of the bolted connections and removal of the temporary grounds are recorded. These steps are part of the test record because they are where a tested circuit is most often left in an unsafe condition.

7 Acceptance Criteria

Test	Acceptance
Visual and mechanical inspection	No deviation from the drawings, the cable schedule and the manufacturers' instructions
Shield continuity	Continuous; resistance consistent with the shield construction and length, and between phases
Insulation resistance, before	Not less than the manufacturer's minimum for the cable and length; consistent between phases
VLF withstand	No breakdown or flashover during the full duration; leakage current stable, with no rising trend
Insulation resistance, after	No significant reduction from the reading before the withstand test

In the withstand test, the pass criterion is that the cable system holds the voltage for the whole time. A result of this kind says that no defect failed during the test; it does not rank the condition of the cable.

8 Diagnostic Tests as a Baseline

Two diagnostic measurements can be made with the same VLF source during the acceptance test. Neither replaces the withstand test. Their value at commissioning is the baseline they leave for the life of the plant.

- **Tan delta (dissipation factor).** Measured at steps of the rated phase-to-ground voltage, typically 0.5, 1.0 and 1.5 times. Three figures are evaluated: the stability of the readings over time, the change between voltage steps, and the mean value at rated voltage. IEEE Std 400.2 and ANSI/NETA ATS-2025 give evaluation tables by insulation type. The criteria differ by insulation type and by whether the cable is new or aged.
- **Monitored withstand.** Tan delta is recorded during the withstand test. A stable value supports the pass result; a rising value is a warning even if the cable holds.
- **Partial discharge.** Locates defects in terminations and splices. It needs a quiet electrical environment and specialized equipment, and is usually specified for long or critical circuits.

Tan delta is measured with at least six readings at each voltage step, with the same voltage ramp on every phase so that the results can be compared.

For new cable, IEEE Std 400.2-2024 treats tan delta differently from aged cable. The assessment tables in the body of the standard apply to maintenance tests on cable systems that have been in service for five years or more. Guidance for newly installed cable is given in an informative annex, and it is meant for setting a baseline and following the trend, not as a pass or fail limit for acceptance. For polyethylene-based insulation (XLPE and TR-XLPE), the guidance is as follows, in units of 10^{-3}.

Tan delta guidance for newly installed XLPE and TR-XLPE cable (IEEE Std 400.2-2024, Annex G)

Assessment	Stability at rated voltage (standard deviation)	Tip up (1.5 minus 0.5 times rated voltage)	Mean value at rated voltage
Acceptable	0.1 or less	0.8 or less	No guidance
Further study advised	Above 0.1	Above 0.8	Subject to further research
Action required	No level defined	No level defined	No level defined

The three figures are read in order of importance: stability first, then tip up, then the mean value. On new cable the mean value is the least useful of the three; its main use is to confirm that the phases of the same circuit give similar readings. A reading outside the acceptable range on a new circuit is a reason to look at the terminations and splices of that phase before energization.

For a plant with a few short circuits, as in the example, a withstand test with insulation resistance before and after is the usual scope. For plants with many long collector circuits and dozens of splices, adding tan delta at commissioning costs little and gives the owner a reference for every later maintenance test.

9 Common Errors and Best Practices

Common error	Consequence	Best practice
Insulation resistance accepted as the acceptance test	Workmanship defects in terminations and splices not detected	Specify a withstand test for every new circuit
Test voltage stated without waveform or rms/peak	Cable under-tested or over-tested by about 40%	State method, waveform, frequency and voltage basis in the procedure and the report
Maintenance voltage used on a new cable	Test too mild to find installation defects	Use the acceptance level for the cable class
Test time shortened on site	Result does not meet the specification	Agree the duration beforehand; do not change it in the field

Common error	Consequence	Best practice
Surge arresters or instrument transformers left connected	Equipment damaged or false failure	Disconnect and record; reconnect and record
Shields left floating	Wrong stress distribution; hazard at the shield	Ground all shields for every test
Far end not guarded	Exposure of people to the test voltage	Barricade and post a watchman at the far end
Spare conductor not tested	Spare unusable when needed	Test spares as service conductors
No reading after the withstand test	Change caused by the test goes unnoticed	Repeat insulation resistance at the same voltage and time

9.1 Quick checklist

- Governing document and table named in the procedure.
- Cable class, insulation type, length and accessories recorded for each circuit.
- Both ends disconnected, clear and guarded.
- Other conductors and all shields grounded.
- Shield continuity measured before high voltage is applied.
- Insulation resistance before and after, at the same voltage and time.
- Withstand voltage, waveform, frequency, duration and leakage current recorded.
- Conductors grounded after each test and until reconnection.

10 Minimum Report Content

- **Identification:** plant, circuit, from and to, date, testing organization, persons who tested and who witnessed.
- **Cable data:** manufacturer, insulation type, voltage class, conductor size and material, length, number and type of terminations and splices.
- **Conditions:** ambient temperature, relative humidity, weather.
- **Instruments:** model, serial number and calibration date.
- **Method:** governing document and edition, waveform, frequency, voltage basis, test voltage and duration.
- **Results per conductor:** shield resistance; insulation resistance before and after; withstand voltage, time and leakage current; pass or fail. On a failure: the voltage at failure, the time on test and the component that failed.
- **Nonconformities:** description, corrective action and re-test.
- **Restoration:** reconnection, torque values and removal of temporary grounds.

References

Standards (U.S. market)

1. ANSI/NETA ATS-2025, *Standard for Acceptance Testing Specifications for Electrical Power Equipment and Systems*, section on medium- and high-voltage cables, Tables 100.1 and 100.6, and Appendix B.
2. IEEE Std 400-2023, *IEEE Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems Rated 5 kV and Above*.
3. IEEE Std 400.2-2024, *IEEE Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF) (less than 1 Hz)*. Supersedes IEEE Std 400.2-2013.
4. IEEE Std 400.3, *IEEE Guide for Partial Discharge Testing of Shielded Power Cable Systems in a Field Environment*.
5. ICEA S-94-649, *Standard for Concentric Neutral Cables Rated 5 Through 46 kV*.
6. ICEA S-97-682, *Standard for Utility Shielded Power Cables Rated 5 Through 46 kV*.
7. IEEE Std 48, *IEEE Standard for Test Procedures and Requirements for Alternating-Current Cable Terminations*.
8. IEEE Std 386, *IEEE Standard for Separable Insulated Connector Systems for Power Distribution Systems*.
9. NFPA 70, *National Electrical Code (NEC)*. Use the edition adopted by the authority having jurisdiction.
10. NFPA 70E, *Standard for Electrical Safety in the Workplace*.
11. OSHA 29 CFR 1910.269, *Electric power generation, transmission, and distribution*.

Confirm the current edition of each document before use. The voltages in Section 2.4 are those of IEEE Std 400.2-2013 and must be checked against the 2024 edition.

Example data

- Commissioning plan of a 2.5 MWac PV plant in Brazil, medium-voltage cable tests, October 2026 (anonymized). The example presents the planned tests; no test results are reported.

Annex A: Test Record Template

One sheet is used per circuit. The readings are entered per conductor.

Item	Record
Plant / circuit	
From / to	
Cable: manufacturer, insulation, class	
Conductor size and material / length	
Terminations and splices (type, quantity)	
Governing document and table	
Ambient temperature / humidity / weather	
Instruments (model, serial no., calibration)	

Reading	Phase A	Phase B	Phase C	Spare
Shield resistance (Ω)				
Insulation resistance before: test voltage (kV DC)				
Insulation resistance before: 1 min (GΩ)				
Insulation resistance before: 10 min (GΩ)				
VLF: voltage (kV rms) / waveform / frequency				
VLF: duration (min)				
VLF: leakage current, start / end (mA)				
VLF: result (pass / fail)				
Insulation resistance after: 1 min (GΩ)				
Grounded after test (yes / no)				

Item	Record
Nonconformities and re-test	
Reconnection, torque, temporary grounds removed	By: ____ *Date:* _
Tested by / witnessed by	