

Technical Guide · U.S. Market Edition

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Grounding Grid Resistance Measurement by Fall-of-Potential

Method per IEEE Std 81 · PV, BESS and Substation Commissioning

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Abstract

This guide shows engineers and technicians how to measure the equivalent grounding resistance of the ground grid of a photovoltaic (PV) power plant, a battery energy storage system (BESS) or a primary utility service-entrance substation, using the fall-of-potential method as described in IEEE Std 81 [1].

The test uses three points of contact with the soil: the grid under test (E), the potential probe (P) and the current probe (C). Probe C is placed at a distance D of more than five times the largest dimension of the grid, and probe P is driven at 62% of D. Two further readings are taken with P moved 10% of D to each side (52% and 72% of D). If the difference between the two side readings, divided by the center reading, does not exceed 10%, the grid resistance is the arithmetic mean of the three readings. Otherwise, D is increased and the test is repeated.

The procedure can also be used in primary service-entrance substations. On very large grids, however, the method can become difficult to apply because of the length over which the current probe must be installed. The guide includes a field case study (a PV plant in Brazil), the most common errors, and the minimum content of the test report. Normative references are from the U.S. market (IEEE, NETA, NFPA, ASTM).

Keywords: ground resistance, grounding grid, fall-of-potential, 62% rule, IEEE 81, PV plant, BESS, commissioning.

1 Introduction and Scope

The ground resistance of a grounding grid is one of the most important acceptance tests in the commissioning of a PV plant, a substation or an energy storage system. It confirms that the grid installed in the field behaves as the design predicted, and it provides the baseline for future maintenance tests.

This guide covers the measurement of the **equivalent ground resistance** of a grid by the fall-of-potential method, also called the three-point or three-pole method. It does not cover soil resistivity measurement, step and touch potentials, or the continuity test between equipment and the grid, which are separate tests.

Audience: commissioning engineers, design engineers and field technicians. The text is written for those who will perform and record the test.

Normative basis: all references are from the U.S. market (IEEE, NETA, NFPA, ASTM). Section 3 lists each document and what it says about the test. Acceptance limits for each project come from the design documents and the contract, not from this guide.

2 Fundamentals of the Method

2.1 The three points of contact

The test uses three points of contact with the soil:

- **E:** the grid under test (or an access point to it), connected to terminal E of the instrument.
- **C:** the current probe, driven far from the grid. Test current is injected into the soil by C and returns to the instrument through the grid E.
- **P:** the potential probe, driven between E and C. The instrument measures the voltage between E and P.

On the HTTR-02 instrument used in the case study, the terminals are labeled H (current), S (potential), ES and E. Always check the terminal correspondence in your instrument manual before connecting the leads.

2.2 Current and voltage

The current is injected into the soil by electrode C, flows through the soil and returns to the instrument through the grid E (direction C → E). Probe P carries no current: it only senses the soil potential at its location. Resistance is calculated by Ohm's law:

$$R = V / I$$

where V is the voltage measured between E and P and I is the current injected at C, which returns through the grid E (Figure 1).

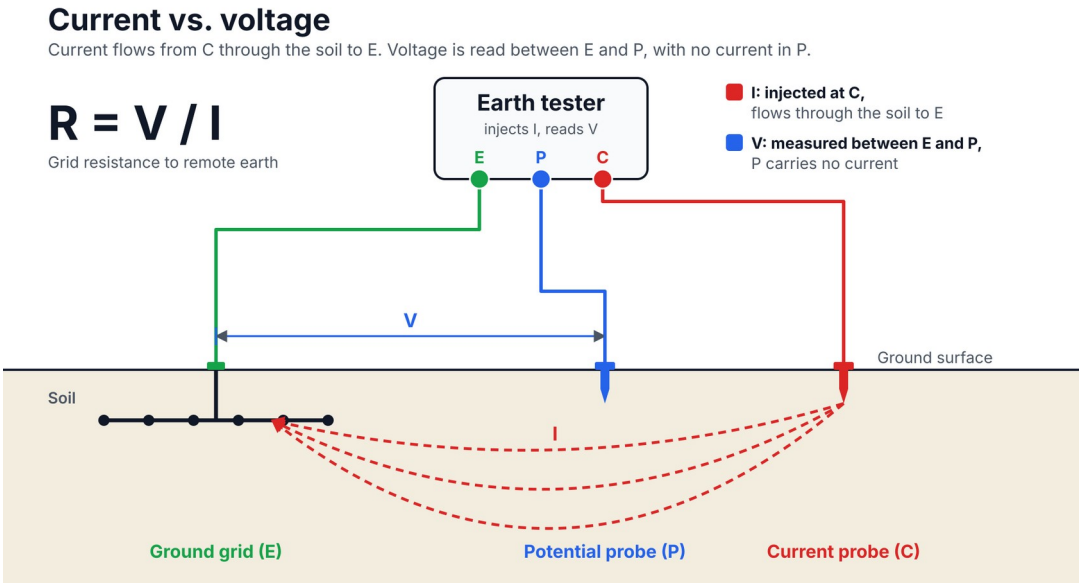


Figure 1. Current injected at C returns to the instrument through the grid E; voltage is measured between E and P (R = V / I).

2.3 The resistance-versus-distance curve

If P is moved from E toward C and the resistance is read at each position, the result is an “S”-shaped curve (Figure 2): the resistance rises near the grid, reaches a nearly flat region (the plateau zone) and rises again near C. The correct value of the grid resistance lies in the plateau zone. Measuring outside it gives a number that does not represent the grid.

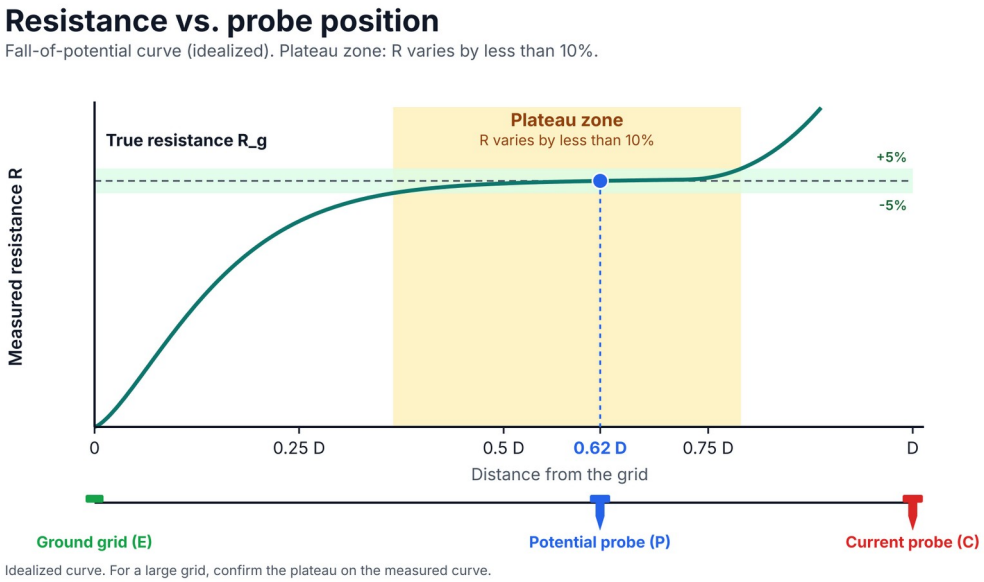


Figure 2. S-shaped resistance-versus-distance curve, with the plateau zone (10% variation) and P at 62% of D.

2.4 The 62% rule

For hemispherical electrodes in uniform soil, the plateau zone lies near 62% of the distance D between E and C (0.618 D). This is the 62% rule, described in the annex of IEEE Std 81 [1]. It is a starting rule, not a guarantee: in multilayer soil or with large grids, the plateau can be located elsewhere. For that reason, the procedure in Section 6 confirms the plateau with neighboring readings.

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

The documents below form the normative basis of the test. Always check each standard against its most recent edition before citing an edition, item or clause in a report.

Normative documents

Document	What it provides for this test
IEEE Std 81	Guide for measuring earth resistivity, ground impedance and earth surface potentials. Reference for the fall-of-potential method and the 62% rule.
IEEE Std 80	Guide for safety in AC substation grounding. Defines the design criteria (step and touch potentials) that the measured resistance must support.
IEEE Std 142 (Green Book)	Recommended practice for grounding of industrial and commercial power systems.
IEEE Std 2778	Guide for the grounding of solar power plants for personnel protection, for plants of 5 MW and above.
ANSI/NETA ATS and MTS, Section 7.13	Acceptance (ATS) and maintenance (MTS) testing specifications for grounding systems. They call for the fall-of-potential test per IEEE 81.
NFPA 70 (NEC), Article 250	Grounding installation requirements. Includes the 25 Ω rule for a single rod, pipe or plate electrode in 250.53; numbering may vary between editions.
NFPA 70B	Recommended practice for electrical equipment maintenance, including the grounding systems chapter.
ASTM G57	Soil resistivity test method (Wenner four-electrode). Complements the grid resistance test.

3.1 How to use these documents together

- The **design** (IEEE 80, IEEE 2778) defines the resistance value the grid must reach.
- **IEEE 81** defines how to measure and how to interpret the curve.
- **NETA ATS** requires the test at acceptance; **NETA MTS** and **NFPA 70B** require it to be repeated during maintenance, with the result compared with the commissioning baseline.
- The **NEC** does not replace the design: the 25 Ω limit is a minimum for a single electrode, and a plant grid usually requires a much lower value.

3.2 Reference values

None of these standards imposes a single acceptance number for the grid of a power plant. The target value comes from the grounding study of the project, which depends on soil resistivity, fault current and clearing time. Always record that design value next to the measurement.

4 Test Planning

4.1 Before going to the field

- Obtain the **design value** of the grid resistance and the grounding plan with the grid dimensions.
- Confirm that the grid is **complete and connected** as it will be in operation, and define the access point (ground bar or inspection box) where lead E will be connected.
- Check the **instrument**: calibration certificate within its validity, charged battery, leads without splices or damage.
- Define the **direction of the E–P–C layout**: a straight line over open ground, away from metallic fences, buried pipes, transmission lines and buried cables.

4.2 Distance D between E and C

Probe C must be far enough that its zone of influence does not overlap that of the grid. For large grids, such as those of PV plants, the recommendation of IEEE Std 81 is to use a D greater than **5 times the largest dimension L of the grid**, measured along the diagonal (Figure 3). Check the value in the current edition of IEEE 81.

Example: for a grid whose largest dimension is 10 m (33 ft), D must be at least 50 m (164 ft). For a 100 m (328 ft) grid, D must be at least 500 m (1,640 ft), which makes the method difficult on large grids because of the length over which the current probe must be installed. In that case, use the large-grid procedure (more distance, confirmation of the plateau and, if necessary, methods such as the slope or multiple-potential methods described in IEEE 81) and record the limitation in the report.



Figure 3. Large grid in plan view: D > 5 × L, with L measured along the diagonal.

4.3 Soil and weather conditions

- Record the **temperature and relative humidity** at the time of the test, and whether it rained in the previous days. Resistance depends on soil moisture.
- Avoid testing right after heavy rain if the goal is to compare with the baseline; use the same conditions in maintenance measurements whenever possible.
- In very dry or stony soil, lightly wet the driving point of the probes to improve contact.

4.4 Safety

The grid may be subject to voltages during faults or lightning. Do not run the test with a storm nearby. Keep the test leads away from people and animals, use insulating gloves and footwear, and follow the site work procedures (NFPA 70E for electrical work, where applicable). If the grid is still connected to energized equipment, confirm with operations what can be disconnected.

5 Field Procedure

The procedure below follows the setup in Figure 4.

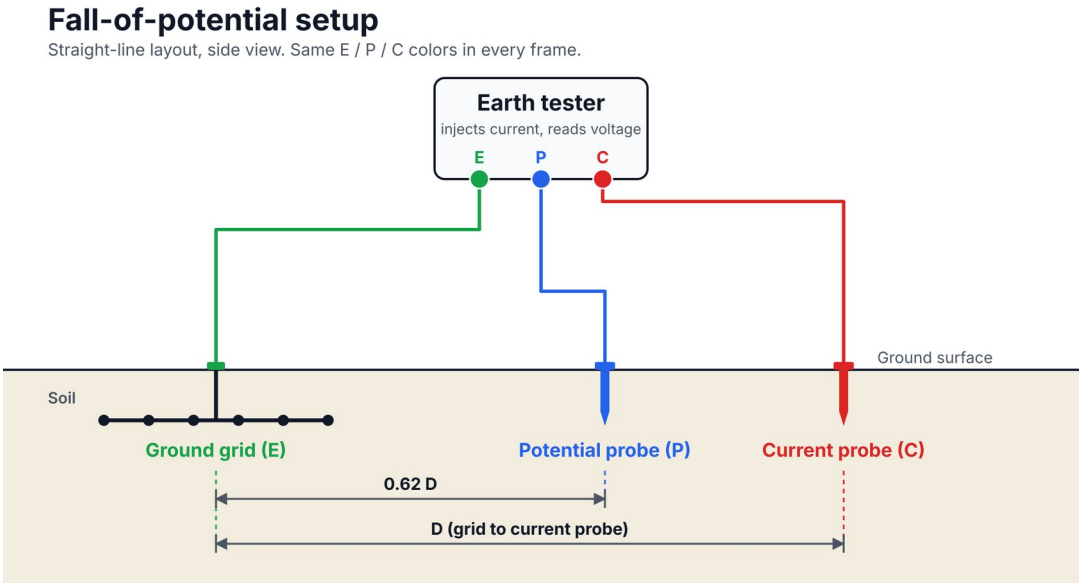


Figure 4. Test setup in side view: grid (E), probe P at 62% of D and probe C at D.

1. **Mark the layout.** From the grid access point (E), stretch a tape in a straight line out to the distance D defined in planning. Mark the position of C (at D) and the three positions of P: 52%, 62% and 72% of D.
2. **Drive probe C** at the D mark, with good penetration into the soil (12 in / 30 cm or more, per the instrument manual).

3. **Drive probe P** at the 62% mark of D.
4. **Connect the leads.** E goes to the grid access point, P to the potential probe and C to the current probe, at the matching terminals of the instrument. Keep the current and potential leads apart and do not leave them parallel and touching, to avoid coupling between them. Also avoid running the leads over metallic structures or pipes.
5. **Check contact.** Confirm that the instrument does not report a high probe resistance or noise error. If it does, wet the soil around the probe or improve the driving.
6. **Take reading R2 (62%).** Record the value, the time and the environmental conditions.
7. **Move P to 52% of D** (10% of D toward the grid) and take reading R1.
8. **Move P to 72% of D** (10% of D toward C) and take reading R3.
9. **Validate and calculate** as described in Section 6.
10. **Photograph and record** the setup, the instrument display at each reading and the instrument calibration data.

Field tip: use a visible mark (tape or stake) at each P position before starting. This prevents distance errors when moving the probe and speeds up the test.

6 The Curve, the Plateau Zone and Validation

6.1 What the plateau zone is

On the “S” curve of Figure 2, the plateau zone is the range of P positions in which the measured resistance varies little. In this guide, it is the range in which the measured resistance varies at most 10% relative to the central value. If P is inside this range, the reading represents the grid resistance. If it is outside, the reading is underestimated (near E) or overestimated (near C).

6.2 How to validate with three readings

Validation uses the three P positions of the field procedure (Figure 5):

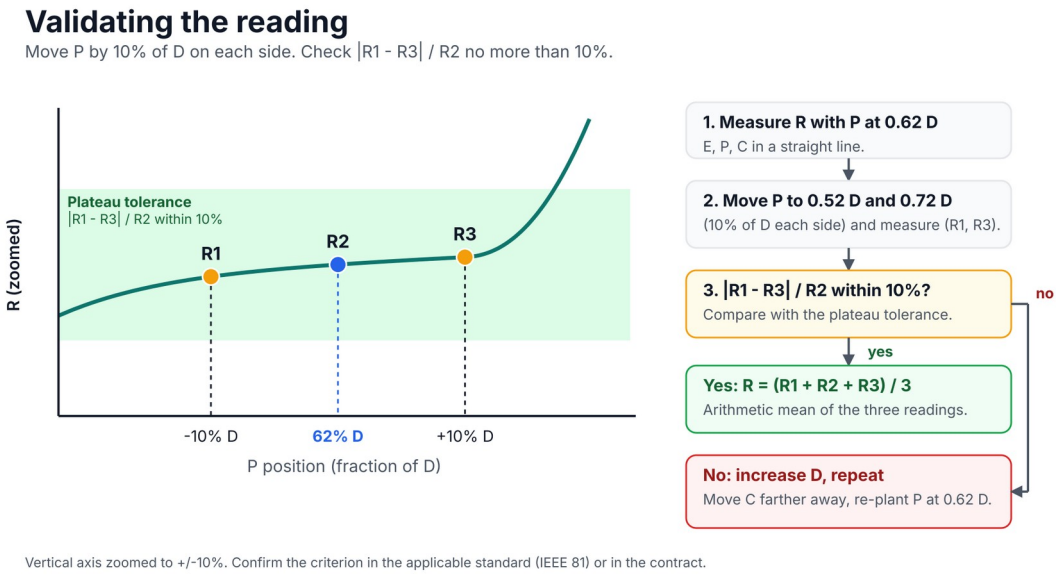


Figure 5. Validation: three readings with P at 52%, 62% and 72% of D; if |R1 − R3| / R2 ≤ 10%, R = (R1 + R2 + R3) / 3; otherwise, increase D.

P position	Reading
52% of D (62% − 10%)	R1
62% of D	R2
72% of D (62% + 10%)	R3

- P is moved **10% of D** to each side of the center point (52% and 72% of D), as in IEEE Std 81.
- The **10%** limit applies to the criterion: the difference between the side readings, divided by the center reading, |R1 − R3| / R2, must not exceed 10%.
- **If |R1 − R3| / R2 ≤ 10%**, the plateau is confirmed and the result is the **arithmetic mean**: R = (R1 + R2 + R3) / 3.
- **If it is greater than 10%**, P is not on the plateau. Increase D (for example, by 50%), redo the layout and repeat the three readings.

The final result is **not** the single reading at 62%. It is the mean of the three.

6.3 Note on the variation criterion

The criterion uses the difference between the side readings (R1 and R3), divided by the center reading (R2): |R1 − R3| / R2 ≤ 10%. It ensures that the measurements were made without overlap between the zone of influence of the grounding system and that of the current electrode. It is the same calculation as on form CL-11, |R72 − R52| / R62.

In this guide, P is moved ±10% of D (52%, 62% and 72%), as in IEEE Std 81. Instrument manufacturers such as AEMC also use 52%, 62% and 72% with the mean of the three readings. Record in the report which criterion was used.

6.4 When the 62% method is not enough

The 62% rule was derived for uniform soil. If the readings do not converge even when D is increased, the soil probably has layers of different resistivities, or there is interference from buried structures. In that case, run a full sweep (several P positions between E and C), plot the curve and identify the plateau visually, or use one of the alternative methods of IEEE Std 81.

7 Case Study: PV Plant in Brazil

This section presents a real measurement recorded on form CL-11 (Equivalent grounding resistance). The site, the owner and the contract are not identified.

7.1 Test conditions

Item	Value
Date and time	Oct 26, 2026, 11:48 AM
Tester	Commissioning team
Instrument	HTTR-02 (HI-TECH), calibration valid through May 19, 2027
Ambient conditions	25.2 °C (77.4 °F) and 63.3% relative humidity
Distance E–C (D)	50 m (164 ft)
Design reference	1.011 Ω (grounding design document)

7.2 Readings

Reading	P position	Resistance
R57	28.50 m (93.5 ft)	7.91 Ω
R62	31.00 m (101.7 ft)	9.81 Ω
R67	33.50 m (109.9 ft)	8.82 Ω

Check of the criterion: |R67 − R57| / R62 = |8.82 − 7.91| / 9.81 = 9.28%, below the 10% limit. In this case study, P was moved ±5% of D (57%, 62% and 67%), a narrower spacing than the ±10% of D described in this guide.

Adopted result, the arithmetic mean of the three readings: (7.91 + 9.81 + 8.82) / 3 = **8.85 Ω**.

7.3 Field setup

The field photos show the setup with probe C, probe P and the leads stretched along the layout, the HTTR-02 instrument with the hygrometer used to record environmental conditions, the grid connection point on the medium-voltage skid, and the instrument display as a measurement reference.



Photo 1. Field layout with leads and tape (Oct 26, 2026).



Photo 2. HTTR-02 instrument open, with the hygrometer for ambient conditions.



Photo 3. Grid connection point at the medium-voltage skid, with clamp (Oct 27, 2026).



Photo 4. Instrument display: a measurement reference, not the final measurement record (Oct 26, 2026).

7.4 Notes on the results

Points of attention when reading the case-study data:

1. The adopted result is the arithmetic mean of the three readings: 8.85 Ω.
2. The P positions follow a variation of ±5% of D (±2.5 m): 28.5 m, 31.0 m and 33.5 m. This is narrower than the ±10% of D described in this guide.
3. The variation criterion |R67 − R57| / R62 = 9.28% meets the 10% limit. Just double-check the R57 value, which is about 19% below R62.
4. The distribution utility requires a grounding resistance below 10 Ω; with 8.85 Ω, the result is COMPLIANT.
5. The display photos are references of measurements taken during the test, not the record of the final measurements, which are on form CL-11.
6. With D = 50 m (164 ft), the rule D > 5 × L is met only if the largest grid dimension L is 10 m (33 ft) or less.

8 Common Errors and Best Practices

Common error	Effect on the measurement	Best practice
Probe C too close to the grid	Zones of influence overlap and there is no plateau	D greater than 5 × L; increase D if readings do not converge
P outside the plateau	Resistance underestimated or overestimated	Confirm with three readings and use the mean
Leads H and S parallel and touching	Coupling between leads, distorted reading	Keep the leads apart and avoid long parallel runs
Layout over a buried pipe or cable	Current follows the metal, not the soil	Choose another direction, over clear soil
Poorly driven probe or dry soil	High probe resistance, noise or error	Drive deeper and wet the contact point
Instrument without valid calibration	Result without traceability	Record the certificate and its validity in the report
Reporting only the 62% reading	Plateau confirmation is lost	Report the three readings and the mean
Not recording ambient conditions	Impossible to compare with future measurements	Record temperature, humidity and recent rain

8.1 Quick checklist

- Instrument calibrated and battery charged.

- D defined and marked; positions at 52%, 62% and 72% marked.
- Leads apart from each other and away from metallic structures.
- Three readings taken, moving P 10% of D.
- |R1 − R3| / R2 up to 10%; otherwise, increase D and repeat.
- Result = arithmetic mean of the three readings.
- Photos, time and ambient conditions recorded.

9 Recording Data and Minimum Report Content

The test report must allow another person to repeat the test under the same conditions. Recommended minimum content:

- **Identification:** plant, contract, grid tested, access point, date, time and tester.
- **Instrument:** model, serial number and calibration validity.
- **Geometry:** grid dimensions (largest dimension L), distance D, P and C positions in meters (feet) and a sketch of the layout with its direction.
- **Environmental conditions:** temperature, relative humidity and recent rain.
- **Readings:** R1, R2 and R3 with the P positions, the calculated variation and the criterion used.
- **Result:** arithmetic mean of the three readings, with the design value next to it and the conclusion (meets or does not meet), stating the limit used.
- **Evidence:** photos of the setup, the connection point and the instrument display at each reading.
- **Normative references:** editions of the standards used (IEEE 81, NETA ATS/MTS and others).
- **Limitations:** any deviation from the procedure (for example, D less than 5 × L) and its justification.

Keep the result as the commissioning **baseline**. In periodic maintenance (NETA MTS, NFPA 70B), compare the new measurement with it and investigate any relevant increase.

References

Always check each standard against its most recent edition before citing it in a formal document.

Standards (U.S. market)

1. IEEE Std 81, *IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Grounding System*. Confirm the current edition (the 2012 edition is the most cited).
2. IEEE Std 80-2013, *IEEE Guide for Safety in AC Substation Grounding*.
3. IEEE Std 142, *IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems* (Green Book).
4. IEEE Std 2778-2020, *IEEE Guide for the Grounding of Solar Power Plants for Personnel Protection*.

5. ANSI/NETA ATS, *Standard for Acceptance Testing Specifications for Electrical Power Equipment and Systems*, Section 7.13 (Grounding Systems).
6. ANSI/NETA MTS, *Standard for Maintenance Testing Specifications for Electrical Power Equipment and Systems*, Section 7.13 (Grounding Systems).
7. NFPA 70, *National Electrical Code (NEC)*, Article 250 (Grounding and Bonding), especially 250.53.
8. NFPA 70B, *Standard for Electrical Equipment Maintenance*.
9. NFPA 70E, *Standard for Electrical Safety in the Workplace*.
10. ASTM G57, *Standard Test Method for Measurement of Soil Resistivity Using the Wenner Four-Electrode Method*.

Technical material consulted

- Megger, *Getting Down to Earth: A Practical Guide to Earth Resistance Testing*.
- AEMC Instruments, application note on ground resistance measurement by the fall-of-potential method (readings at 52%, 62% and 72% with the mean).
- IEEE PES, *IEEE Std 81-2012 Tutorial* (current probe distance greater than 5 times the largest grid dimension).

Field data

- Form CL-11, *Equivalent grounding resistance*, case-study PV plant (anonymized), measurement of Oct 26, 2026.

Annex A: Blank Form CL-11 Template

The form below, with no data filled in, serves as a report template for the equivalent grounding resistance test by the three-point method. Fill in the location, the instrument, the distance D, the three readings (R62, R52 and R72), the check |R72 − R52| / R62 ≤ 10%, the adopted resistance (arithmetic mean of the three readings) and the result, and attach the photographic records.

CL-11 – Equivalent grounding resistance – three-point method (Test 11)

Plant / site:		Date:		Tester:	
Instrument / serial no.:		Calibration valid until:		Ambient temp. / RH:	

Measuring point:	Interconnections connected:	☐ Yes ☐ No	Date / time:	

Total length E–C (D) (m)	P position	E–P distance (m)	Measured resistance (Ω)
	62% of D		R62 =
	52% of D (− 10%)		R52 =
	72% of D (+ 10%)		R72 =

Adopted resistance – mean (Ω)	Check |R72 − R52| / R62 ≤ 10%	Design reference (Ω)	Result (C/NC)	Remarks

Record (photos):	

General remarks of the tests:

Executed by (CONTRACTOR):		Witnessed by (CLIENT):	