

Module 2.7 — Verifying Grounding & Bonding Integrity

The fault path is invisible until needed. Step-by-step continuity, loop-impedance, and earth-resistance tests, a bond inspection checklist, a fault-finding table, and the test report.

Why this module. Module 1.7 taught you to build grounding and bonding. This module teaches you to prove that an existing installation still works. The bonded fault path cannot be seen, and nobody notices it is broken until a fault needs it. A broken equipment grounding conductor leaves metal energized with no breaker trip. This module covers the safety rules for testing, the continuity and loop-impedance tests on the fault path, the earth-resistance tests on the electrode, a bond-by-bond inspection checklist tied to NEC 2026 sections, a table of field faults and the test that finds each one, and the report you hand in when you are done.

Part A — What You're Verifying (and Why)

There are two different paths, and each needs its own test.

Path	Its job	NEC 2026	How you test it
Bonding / equipment grounding conductor (EGC): the metal path from equipment back to the source	Carries fault current so the breaker trips. The path must be "a low-impedance circuit" that will "facilitate the operation of the overcurrent protective device"	250.4(A)(5)	Low-ohm continuity (Part B), live loop impedance (Part B)
Grounding electrode system (GES): rods, water pipe, building steel, concrete-encased electrode, ring	Holds the system near earth voltage and drains lightning and surges	250.4(A)(1)	Fall-of-potential, selective, or clamp-on test (Part C)

The earth is not part of the fault-clearing path. The NEC says the earth shall not be considered an effective ground-fault current path. OSHA says the same thing in plain words: "The path to ground from circuits, equipment, and enclosures shall be permanent, continuous, and effective" (29 CFR 1910.304(g)(5)), and the EGC must be "contained within the same raceway, cable, or cord, or runs with or encloses the circuit conductors" (1910.304(g)(8)).

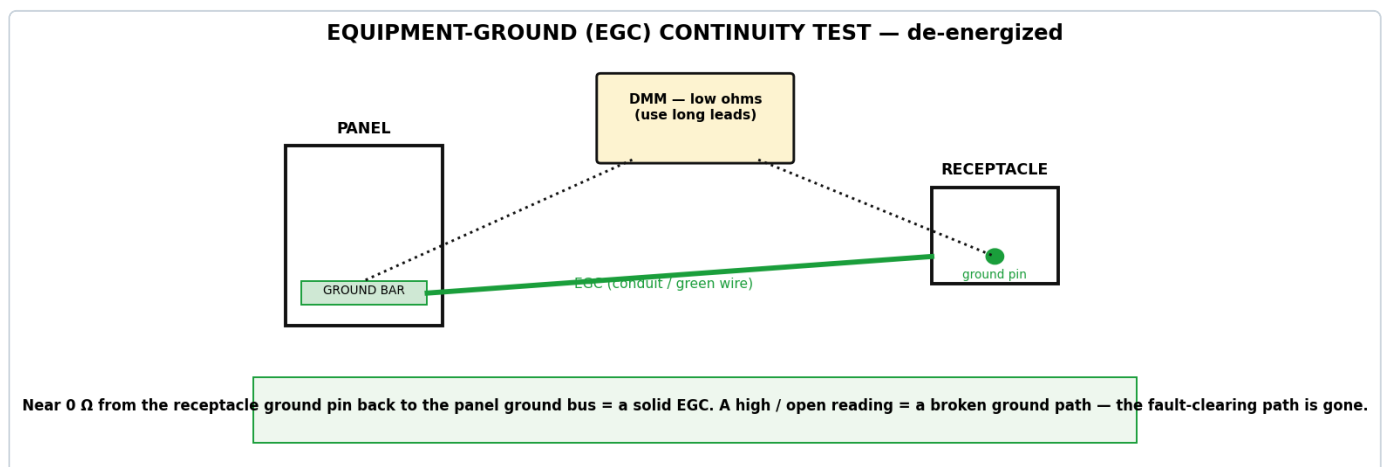
Worked example 1: why a good rod does not trip a breaker. A 120 V hot conductor faults to a metal pole that is connected only to a ground rod measuring 25 Ω . Ohm's law gives $120 \div 25 = 4.8$ A. A 20 A breaker does not trip on 4.8 A. The pole stays at nearly 120 V for as long as the fault lasts. A passing earth test therefore tells you nothing about the fault path. You must run both tests.

Safety for every test in this module

- **Qualified persons only.** OSHA 1910.334(c)(1): "Only qualified persons may perform testing work on electric circuits or equipment." Helpers set stakes and pull tape; a qualified person makes the connections.
- **Inspect your meter and leads first.** 1910.334(c)(2) requires you to inspect instruments, leads, and probes before use and remove damaged ones from service. 1910.334(c)(3): instruments must be "rated for the circuits and equipment to which they will be connected." Use a CAT III or CAT IV meter in a service or panel.
- **Testing is energized work.** NFPA 70E-2024 counts diagnostic testing with test equipment as "working on" equipment "regardless of the personal protective equipment (PPE) a person is wearing." Loop-impedance, neutral-to-ground voltage, and clamp-on tests on a live service are energized work. 70E 130.2(C)(1) says no energized work permit is needed for "testing, troubleshooting, or voltage measuring" by a qualified person using safe work practices and PPE, but the shock and arc-flash risk assessment and the PPE on the label still apply.
- **Prove dead before every de-energized test.** NFPA 70E-2024 120.6(7): test for absence of voltage at each point of work, phase to phase and phase to ground, and check your tester on a known live source before and after.
- **Ground testers put current in the earth.** Fluke warns that "It is not safe to assume that a ground electrode has zero voltage or zero amps." Wear insulated gloves and eye protection when connecting. A ground tester can put out up to 250 mA, so keep people away from the stakes. Megger's DET guide says do not touch stakes, leads, or terminations while the instrument is on.
- **Lightning.** Never disconnect a grounding electrode conductor (GEC) when lightning is possible.

How often to retest. Fluke's application note on ground electrode testing states that NETA specifies ground electrode testing every three years for a system in good condition with average up-time requirements. A job spec or the owner may set a shorter interval.

Part B — STEP-BY-STEP: EGC Continuity Test (the fault path)



Low ohms from the receptacle ground pin back to the panel ground bus = a solid EGC.

B1. De-energized low-ohm continuity (long-lead method)

Tools: a CAT III or CAT IV digital multimeter (DMM) with a relative or zero function (REL), or a four-wire low-resistance ohmmeter (often called a DLRO or "ductor") for large bonds; a 50 to 100 ft test lead on a reel; a voltage tester; your lockout kit.

1. **Job brief.** Identify the circuit and the panel. Lock out the branch circuit per NFPA 70E 120.6.
2. **Test for absence of voltage** at the receptacle or equipment where you will put the probe.
3. **Null the leads.** Plug the long lead into the DMM COM jack. Touch the two probe tips together and press REL so the lead resistance reads 0.00 Ω . Write down the lead value before you nulled it.
4. **Clip the long lead to the EGC bar** in the panel. Use bare, clean bar metal, not a painted screw.
5. **Probe the device ground pin**, then the metal box, then the equipment frame or raceway at the device. Record each reading.
6. **Wiggle test.** Flex the cord, raceway joint, or flexible whip while you watch the meter. A reading that jumps means a loose locknut, set screw, or coupling.
7. **Compare to the expected value** (worked example 2). A reading several times the calculated value, or one that changes when you wiggle, fails.
8. **Check against the published limit.** NETA ATS 7.13 says to "Investigate point-to-point resistance values that exceed 0.5 ohm" between the main grounding system and major equipment frames, the system neutral, and derived neutral points. For bolted connections, investigate any value that deviates more than 50 percent from similar connections.
9. **Remove your lock** only after your leads are off and every cover is back on.

Worked example 2: what a good EGC should read. NEC Chapter 9 Table 8 lists the dc resistance of uncoated copper at 75°C: 12 AWG is about 1.93 Ω per 1,000 ft solid and 1.98 Ω per 1,000 ft stranded; 10 AWG is 1.21 Ω solid and 1.24 Ω stranded. A 100 ft run of 12 AWG stranded EGC should read about $1.98 \times 100 \div 1,000 = \mathbf{0.20 \Omega}$, plus a little for connections. If your meter shows 1.5 Ω , a joint is bad. If it shows 0.20 Ω but jumps to 0.9 Ω when you flex the whip, the whip fitting is loose.

A DMM only pushes milliamps. A single surviving strand or a corroded lug can read 0.1 Ω on a DMM and still burn open when hundreds of amps of fault current hit it. That is why the live loop-impedance test (B2) and the infrared check (Part D) follow the continuity test.

B2. Live loop and ground-impedance test (circuit analyzer)

A circuit analyzer such as the Ideal SureTest 61-164/61-165 plugs into a live receptacle and pulses current through the hot, neutral, and ground paths to measure their impedance. Ideal's

ranges: impedance 0.00 to 3.00 Ω (± 2.5 percent ± 0.02 Ω), neutral-to-ground voltage 0 to 10 V, rated CAT III 300 V. It is a 120 V receptacle tool and is not for 480 V circuits.

1. Put on the PPE called for by the panel's arc-flash label or the 70E table for receptacle testing.
2. Plug in. Read the wiring condition, line-to-neutral voltage, and neutral-to-ground voltage.
3. Run the impedance test. Record the hot, neutral, and ground ohms.
4. **Ground above 1 Ω :** Ideal's manual says ground impedance "should be less than 1 ohm as a rule of thumb to ensure that fault current has a sufficient path back to the panel." Move upstream receptacle by receptacle. The reading drops sharply once you pass the bad joint.
5. Ideal's troubleshooting guide for hot and neutral impedance: less than 0.048 Ω per foot of 14 AWG, less than 0.03 Ω per foot of 12 AWG, less than 0.01 Ω per foot of 10 AWG. High ground impedance means the wire is too small for the run length or a connection is bad.

The ground-impedance test will trip a GFCI. It pulses current through the EGC. Test on the line side of the GFCI or temporarily remove it, and tell the occupants first.

Worked example 3: does the breaker trip fast? A SureTest reads hot 0.20 Ω and ground 0.30 Ω at a receptacle on a 20 A circuit. The loop is $0.20 + 0.30 = 0.50$ Ω (ignoring the source). Fault current $\approx 120 \div 0.50 = \mathbf{240\text{ A}}$, which is 12 times the breaker rating. Look up the breaker's instantaneous pickup on the manufacturer's time-current curve. If 240 A is above it, the breaker trips almost at once. If it is below, the breaker trips only on its thermal curve, which takes seconds to minutes, and the equipment case stays live that whole time. This arithmetic is the 250.4(A)(5) "facilitate the operation" test in numbers.

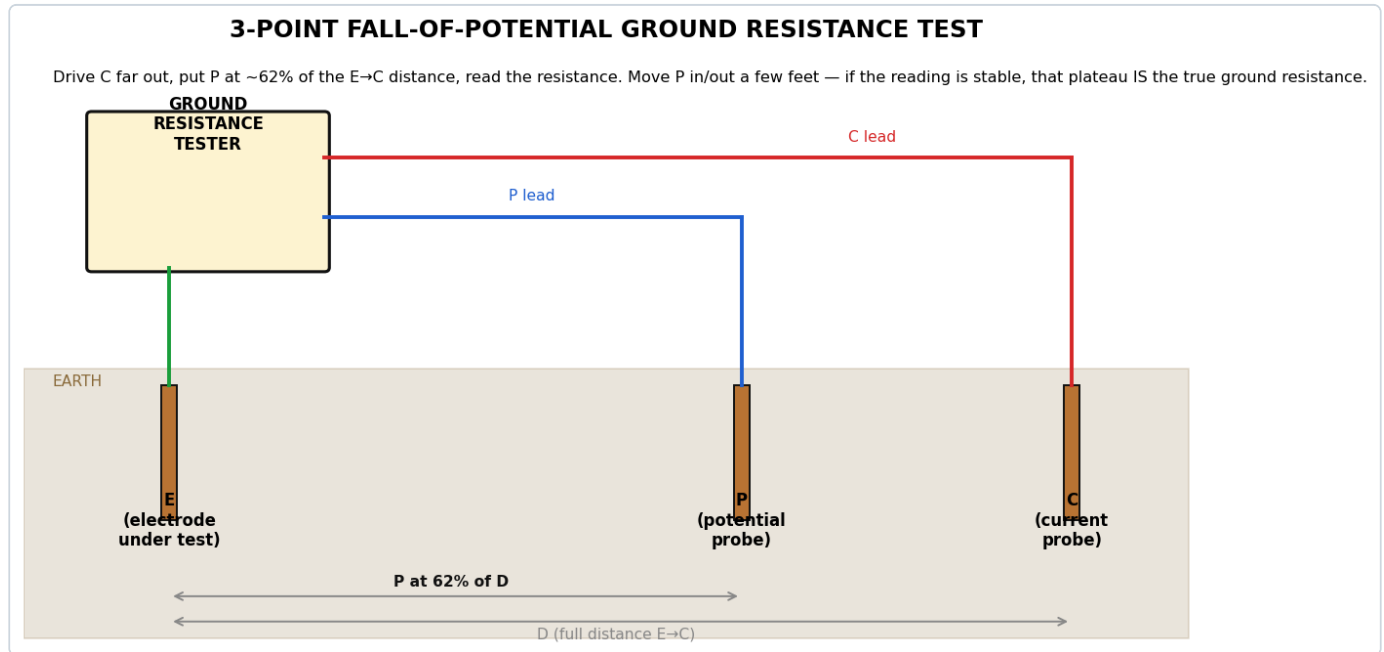
Two published tests back this up. UL 4 limits AC cable armor plus its bonding strip to 0.64 Ω per 100 ft for 12 AWG, and a UL/IAEI test calculated that 725 ft of 12 AWG AC cable would limit a ground fault to 20 A (IAEI Magazine, 2001). The GEMI study (Georgia Tech for NEMA, reported in IAEI Magazine 2004) gives maximum run lengths for steel raceway used as the EGC. Long runs can be continuous and still have too much impedance to trip the breaker quickly.

B3. Bonding bushing and raceway continuity at a service

1. Lock out the gear. Service raceways connect ahead of the main, and you cannot lock out the utility side yourself. Coordinate a utility outage, or treat the work as energized.
2. Measure low ohms from the bonding-bushing lug to the enclosure ground bar. Then measure from the bushing body to the conduit beyond the first coupling.
3. Accept per the NETA 0.5 Ω point-to-point limit. A sound jumper reads in milliohms.
4. Look for a bonding jumper at every concentric or eccentric knockout and every reducing washer. NEC 250.92(B): "Standard locknuts or bushings shall not be the only means" of bonding at a service. For circuits over 250 V to ground, 250.97 requires the same 250.92(B) methods except 250.92(B)(1), with an exception where there are no concentric or eccentric knockouts or the box is listed for bonding.

5. Check that paint was removed where metal parts bond. 250.12 and 250.96(A) require nonconductive coatings to be removed at threads, contact points, and contact surfaces, or fittings that make removal unnecessary.

Part C — STEP-BY-STEP: Ground Resistance Test (electrode to earth)



3-point fall-of-potential: drive C far out, set P at ~62%, read; move P to find the plateau.

C1. Pick the method first

Situation	Method
New rod not yet connected, or the service is de-energized	3-pole fall-of-potential (FoP)
Electrode connected to a live service, soil available for stakes	Selective: one clamp plus two stakes (for example Fluke 1625-2)
Multi-grounded system with no soil (slab, parking lot)	Stakeless: two-clamp (1625-2) or single-clamp (Fluke 1630-2, Megger DET14C/24C)
Single rod with no parallel path	Stakeless will not work. Use FoP

C2. When you may lift the GEC, and when you may not

1. FoP needs the electrode disconnected from the building. Fluke says to disconnect only during a maintenance shutdown with the service de-energized. Otherwise connect a temporary backup electrode first, or use the selective method.

2. Before you touch the clamp, put a clamp-on ammeter around the GEC. If it reads more than **1 A**, stop and find the source. Current on a GEC means neutral current is returning through the earth or the water pipe, and opening the GEC can put that voltage across your hands.
3. Do not lift a GEC with lightning in the area.
4. Lifting the GEC on a live service removes the earth reference for the whole building. That is energized work under 70E.

C3. Fall-of-potential, step by step

Tools: a 3- or 4-pole earth tester with lead reels (Fluke 1625-2 or AEMC 6470 class), two auxiliary stakes, a 300 ft tape, a hammer, a jug of water, gloves, and flagging.

1. Call for a utility locate. Pick a straight line away from buried pipes, fences, and other electrodes.
2. Connect E (C1/P1) to the electrode under test on a cleaned bare spot below the clamp.
3. Drive the current stake (H/C2) at the distance in the table below. Drive the potential stake (S/P2) at 62 percent of that distance, in the same straight line.
4. Keep the current and potential leads apart so they do not couple. If the tester flags high stake resistance, pour water around the auxiliary stakes. That does not change the answer, because you are not measuring the stakes.
5. **62 percent check** (valid only for a simple electrode in uniform soil with C2 at least 100 ft): read at 62 percent, then move P2 3 ft closer and 3 ft farther. If the three readings are about the same, record the 62 percent value. (AEMC uses 52, 62, and 72 percent.)
6. **Full curve** (required for rings, grids, or when the check fails): take at least 5 readings, better 7 or 9, moving P2 in 10 percent steps. Plot resistance against distance. The flat part of the curve is the earth resistance.
7. **No flat part?** Use the Tagg slope method (worked example 4).
8. For very low readings use the four-wire hookup. A separate P1 lead removes the C1 lead resistance from the reading.
9. Reconnect the GEC and torque the clamp to its marked value (110.14(D)). Re-check continuity across the reconnected joint: less than 1 Ω .
10. Record the soil condition and date. Resistance falls as new backfill settles, so retest a new site later. Megger's "Getting Down to Earth" covers seasonal change and "lazy spikes" (auxiliary stakes with too much resistance).

Stake distances for a single rod (Fluke, 62 percent rule, feet)		
Electrode depth	E to P2	E to C2
6	50	82
8	62	100
20	81	131
30	100	161

Stake distances for rings, grids, and arrays (Fluke, feet)		
Widest dimension of array	E to P2	E to C2
65	100	165
80	165	265
100	230	330
165	330	560
230	430	655

Worked example 4: Tagg slope method (Fluke application note, C2 = 300 ft). Take readings with P2 at 20, 40, and 60 percent of the C2 distance: R20 = 4.4 Ω (60 ft), R40 = 5.8 Ω (120 ft), R60 = 6.8 Ω (180 ft). Slope $\mu = (R60 - R40) \div (R40 - R20) = (6.8 - 5.8) \div (5.8 - 4.4) = 1.0 \div 1.4 = \mathbf{0.71}$. The slope table in the Fluke note gives P2/C2 = 59.6 percent for $\mu = 0.71$. $0.596 \times 300 \text{ ft} = \mathbf{178 \text{ ft}}$. Read the curve at 178 ft: about **7 Ω** .

C4. Acceptance values

Value	What it means	Source
25 Ω or less, one rod, pipe, or plate	Supplemental electrode not required: "If a single rod, pipe, or plate grounding electrode has a resistance to earth of 25 ohms or less, the supplemental electrode shall not be required"	NEC 2026 250.53(A)(2) Exception
Over 25 Ω or not tested	Add a supplemental electrode, at least 6 ft away (250.53(A)(3)). The pair has no ohm requirement	250.53(A)(2), (A)(3)
1 to 5 Ω	IEEE 142 (Green Book) suggestion for large commercial and industrial systems	Quoted in Fluke application note
5 Ω or less	NETA ATS 7.13 for large commercial and industrial, "unless otherwise specified by the owner"	NETA ATS
1 Ω or less	NETA ATS for generating and transmission station grounds	NETA ATS
Spec value	Job specs often call for 5 Ω or lower	ERICO grounding guide

The job spec and the inspector (the authority having jurisdiction, or AHJ) set the number you must meet. The NEC only sets the "test it at 25 Ω or add a second electrode" rule. Older lessons and books cite "250.56" for this rule; that section does not exist in NEC 2026.

C5. Clamp-on (stakeless) method and its limits

One core of the clamp induces a known test voltage and the other core measures the current that flows. The result is the resistance of the whole loop, not just the rod. On a building service that loop runs through the rod, the GEC, the main bonding jumper, the service neutral, the utility

neutral-to-ground bond, the utility neutral, and the utility pole grounds. The method therefore works only after the service is energized and connected.

1. Self-check the tester on its calibration loop.
2. Clamp around the GEC or the rod below every other connection, so the only path back is through the earth.
3. Read ohms and leakage current. The Fluke 1630-2 reads both; its resistance range is 0.025 to 1500 Ω .

Megger states two rules: "There must be a loop resistance to measure" and "The earth path must be in the circuit to measure earth resistance." Clamping above a water-pipe bond measures a metal loop, not earth. A single rod with no parallel path reads open or gives a meaningless number. A very low reading usually means you clamped a metal loop, such as a rod tied to building steel at two points.

Worked example 5: parallel paths make the reading high. Megger's example: a 10 Ω rod reads **12.5 Ω** when the system has 4 parallel paths and **10.83 Ω** with 12. A bad 50 Ω rod reads 52.5 Ω or 50.83 Ω and stands out from the others. The clamp-on is best for fast trending over the years and for checking that the whole bonding-jumper, neutral, and GEC chain is connected. An open reading points to a broken connection in that chain.

C6. Selective method

The stakes go out in the same layout as fall-of-potential, but a clamp around the electrode measures only the current in that electrode. You do not have to disconnect it. Fluke says 20 m (65 ft) stake spacing is normally enough. Use it on live commercial services.

C7. Ground ring and multi-electrode systems

1. Measure low ohms between each accessible ring tap or test well and the main ground bar. All readings should be similar and under 0.5 Ω (NETA point-to-point).
2. Run a stakeless test on each down-lead or tap. One high reading among many similar ones flags the bad connection.
3. A fall-of-potential test of a whole ring needs the array distances in C3. A 230 ft array needs C2 at 655 ft. If that is impossible, use the slope or selective method.
4. Code checks: a ring is at least 20 ft of bare copper no smaller than 2 AWG at least 30 in. deep (250.52(A)(4), 250.53(F)). Buried connections must be exothermic, irreversible compression, or listed for direct burial (250.70(A)(2)).

Part D — Inspect the Bonds

D1. Service inspection checklist (de-energized or dead-front only)

#	Check	Pass	NEC 2026
1	Main bonding jumper	Present and unspliced, at the service disconnect only	250.24(C), 250.28
2	One neutral-to-ground bond per system	No neutral-to-ground connection "on the load side of the service disconnecting means"	250.24(B)
3	GEC size	Table 250.66, copper: service conductors 2 AWG or smaller → 8 AWG GEC; 1 or 1/0 → 6 AWG; 2/0 or 3/0 → 4 AWG. Larger services: read the printed table	250.66
4	GEC continuity	One length; splices only by irreversible compression listed for grounding, or exothermic	250.64(C)
5	GEC connection point	Any accessible point from the load end of the service drop or lateral to the grounded-conductor terminal at the disconnect	250.24(A)(1)
6	Electrode clamps	Listed for both the electrode and GEC material; one conductor per clamp unless listed for more; buried clamps listed for direct burial	250.70
7	Clamp access	Mechanical connections accessible (buried or encased ones exempt)	250.68(A)
8	All electrodes present are bonded	Water pipe with 10 ft in earth, structural steel, concrete-encased, ring, rods	250.50
9	Rod count	Two rods at least 6 ft apart, or one rod with a recorded test of 25 Ω or less	250.53(A)(2), (A)(3)
10	Intersystem bonding termination (IBT)	Accessible, at least 3 terminals, does not block opening the enclosure. New in 2026: also required at the disconnect of a building supplied by a feeder or branch circuit	250.94(A)
11	Metal water pipe	Bonded to the service enclosure, grounded conductor, GEC, or electrode; jumper accessible; sized per Table 250.102(C)(1)	250.104(A) (1)
12	Structural steel	Exposed, interconnected frame that may become energized is bonded	250.104(C)
13	Service raceways and knockouts	Bonding jumpers at reducing washers and concentric or eccentric knockouts	250.92(B)
14	Paint removed	Clean metal at contact surfaces	250.12
15	Torque	Marked values, applied with an approved tool	110.14(D)
16	Ground-fault protection of equipment (1000 A and larger, 480Y/277 V)	Written record of a primary-injection performance test when first installed	230.95(E)

Also check at each feeder-fed **subpanel**: neutral bar isolated, EGCs on a bonded ground bar, 4-wire feed, no bonding screw (Module 1.4). At a separate building, 250.32(B)(1) says the grounded conductor "shall not be connected to the equipment grounding conductors or to the grounding electrodes." At **transformer secondaries**, confirm the X0 bond and electrode connection under 250.30 (D5 below).

D2. STEP-BY-STEP: finding a downstream neutral-to-ground bond

Symptoms: current on conduit, the water pipe, or an EGC; complaints about magnetic fields; nuisance ground-fault trips. NEC 250.6 calls this objectionable current. The fix is to discontinue one but "not all" of the bonds, or to relocate them.

1. **Look.** Lock out each subpanel and look for a green bonding screw or strap on the neutral bar, or EGCs landed on the neutral bar.
2. **Clamp it live** (energized work, 70E PPE). Clamp the feeder EGC or the conduit: correct wiring reads near 0 A. Clamp all feeder conductors together, neutral included: correct wiring reads near 0 A. A net reading means current is leaving by another path (Mike Holt's net-current method).
3. **Prove it dead.** With the subpanel locked out and its feeder neutral lifted, measure ohms from the neutral bar to the can. It should read open (megohms). A low reading means a bond, a stray EGC on the neutral bar, or a neutral touching a box downstream. Lift branch neutrals one at a time to divide and conquer.
4. **Read neutral-to-ground voltage** at the subpanel bus under load. Fluke's power-quality note: a reading at or very near 0 V points to an illegal neutral-to-ground bond at that subpanel. With an illegal bond, the case-to-earth voltage rises to the neutral voltage drop at that point (Mike Holt's example: about 1.25 V of feeder neutral drop, 3 to 4.5 V at a bonded receptacle).

D3. Neutral-to-ground voltage at a receptacle (energized)

Take three readings with a true-RMS DMM while the circuit is loaded: hot-to-neutral (H-N), neutral-to-ground (N-G), and hot-to-ground (H-G).

Reading	Meaning
H-G = H-N + N-G (example: 120.0 = 118.5 + 1.5)	Normal
N-G about 2 V or less under load	Normal. A few volts suggests overloading; Fluke treats 5 V as the upper limit
N-G = 0 V with load on	Neutral-to-ground bond in the receptacle (loose neutral strands or a "bootleg" jumper) or at the subpanel
N-G about 120 V, H-G a few volts	Hot and neutral reversed
H-N greater than H-G under load	Neutral and ground swapped. Fix it now
High N-G	Shared neutral, overloaded branch, or loose neutral

D4. Isolated-ground (IG) receptacles

An IG receptacle is identified by an **orange triangle** on its face, may be used only with an isolated EGC, and needs a nonmetallic faceplate in a nonmetallic box (NEC 2026 406.11(C), 406.3(D) in 2023). Its grounding terminal is "connected to an insulated equipment grounding conductor run with the circuit conductors" (250.146(D)(1)). That conductor may pass through panels and boxes to land at the EGC terminal of the service or derived system that feeds it (250.146(D)(2); 408.40 Exception). The raceway and box must still be bonded. 250.96(B) Informational Note: an isolated EGC "does not relieve the requirement for an effective ground-fault current path."

1. **Look:** orange triangle; a separate insulated EGC (green or green with yellow stripe) to the IG terminal; the box bonded by its own EGC or raceway.
2. **Adapter test (Ideal 61-176 IG adapter with a SureTest):** read ground impedance normally, then through the adapter with its clip on the box or yoke screw. The same reading both ways means the receptacle is not isolated. A lower reading with the adapter means it is.
3. **De-energized:** ohms from the IG pin to the box should read open. IG pin to the EGC bar at the source neutral-to-ground point: under 1 Ω .
4. **Where it lands:** on the EGC bar of the service or the transformer that feeds it. Not on the neutral bar, and not on a ground rod by itself.

D5. Transformers (separately derived systems)

NEC 250.30(A)(1): the system bonding jumper (SBJ) goes "at any single point" from the source to the first disconnect and "shall remain within the enclosure where it originates." Exception No. 2 allows an SBJ at both the source and the first disconnect only for an outdoor transformer feeding a building, and only if no parallel path is created. 250.30(A)(5): the GEC lands "at the same point on the separately derived system where the system bonding jumper is connected."

1. Find the one SBJ: at X0 in the transformer or in the first disconnect, not both.
2. In the panel fed by the transformer, confirm the neutral bar is isolated (bonding screw removed).
3. Lock out, lift the SBJ, and measure X0 to the case. It should read open. A low reading means a second bond downstream. Reinstall the SBJ and torque it.
4. Energized: clamp the supply-side bonding jumper or feeder EGC between the transformer and the panel. It should read near 0 A. Current on it means two bonds.

D6. Infrared check of ground connections

Grounding conductors normally carry close to 0 A, so a warm GEC, main bonding jumper, EGC, or bonding jumper means objectionable current (go to D2). Opening covers for an infrared scan is energized work; 70E 130.2(C)(2) exempts thermography from the permit only when the restricted approach boundary is not crossed. NETA's temperature-rise table, as reproduced by Fluke:

Rise over similar parts	Rise over ambient	Action
1-3 °C	1-10 °C	Possible deficiency; investigate
4-15 °C	11-20 °C	Probable deficiency; repair as time permits
—	21-40 °C	Monitor until corrected
Over 15 °C	Over 40 °C	Major discrepancy; repair immediately

Part E — Field Faults, Symptoms, and the Test That Finds Each One

Fault	What you see	Test that finds it	NEC 2026 / source
Corroded water-pipe or rod clamp	Stakeless reads high or open; FoP high; clamp warm	Low-ohm across the clamp (over 1 Ω fails); stakeless	Fluke
Cut or stolen GEC	Stakeless open; earth reference lost; surge damage	Visual; stakeless	Fluke
Rod clamp missing or rod not connected	Rod passes FoP but the electrode system is open	Low-ohm from GEC to rod	250.70
Painted steel never bonded	Tingle from steel; point-to-point over 0.5 Ω	Low-ohm from steel to ground bar	250.12, 250.104(C), NETA
EGC not landed or loose locknut	No trip on a ground fault, case live; analyzer ground over 1 Ω or open	B1 continuity, B2 loop impedance	250.4(A)(5)
Neutral-to-ground bond in a subpanel	Current on conduit or water pipe; N-G near 0 V at the subpanel; ground-fault nuisance trips	D2	250.24(B), 250.6
Bootleg neutral-to-ground jumper at a receptacle	N-G = 0 V under load; analyzer reports a false ground	D3; circuit analyzer	Ideal, Fluke
IG landed on the wrong bar or bonded to the box	IG adapter readings equal; noise complaints	D4	250.146(D), 406.11(C)
Second system bonding jumper at a transformer panel	Current on the supply-side bonding jumper	D5	250.30(A)(1)
Breaker does not trip on a fault	High-impedance fault path; fault current below the instantaneous pickup	B2 loop math (worked example 3)	250.4(A)(5)
"Tingle" at a sink or shower	Water pipe not bonded, or neutral current on the pipe	Clamp the water-pipe bond; checklist row 11	250.104(A)(1)

STEP-BY-STEP: working a "breaker won't trip" or "tingle" call

1. Get the symptom in the customer's words: where, when, and what loads were running.
2. Live readings first, with PPE: three-reading receptacle test (D3) and a circuit-analyzer ground impedance (B2) at the complaint point.

3. Clamp the GEC, the water-pipe bond, and the feeder EGCs. Anything well above 0 A is a path for neutral current; go to D2.
4. Lock out and run the long-lead continuity test (B1) on the suspect circuit. Wiggle every fitting.
5. Walk the service with the D1 checklist.
6. Fix, then re-run the same tests and record before and after values on the test report (Part F).

Part F — The Test Report

A test with no record did not happen as far as the owner and the inspector are concerned. 230.95(E) already requires a written record of the ground-fault protection test to be available to the AHJ. NETA ATS 7.13 follows the same order every time: inspect, low-ohm the bolted connections, run fall-of-potential, then point-to-point. Fluke recommends repeating site measurements over the years so you can see the trend. Fill in one sheet per test location.

Field	What to write
Job, location, test point	Building, panel or electrode ID, photo number
Date, weather, soil	Dry, damp, wet; last rain if known
Instrument	Model, serial number, calibration date
Lead null value	Ohms nulled out before the test
Method	FoP, selective, stakeless, two-point low-ohm, or loop impedance
Stake distances	E to P2 and E to C2 in feet
Readings	Every reading; the full curve if you plotted one
Acceptance criterion and its source	For example "25 Ω , NEC 250.53(A)(2) Exception" or "5 Ω , job spec"
Pass or fail	And the repair made, with the retest value
Photos	Every clamp, bushing, and bonding jumper inspected
Tested by	Name of the qualified person

Mistakes to avoid

Mistake	Why it matters
Calling a ground rod "tested" with a megohmmeter	An insulation tester does not measure earth resistance. Use a fall-of-potential, selective, or clamp-on ground tester
Treating a passing rod test as proof the breaker will trip	A 25 Ω rod passes only 4.8 A at 120 V
Not nulling the long lead	100 ft of test lead adds its own resistance to every reading
Lifting a GEC without clamping it first	More than 1 A on it means a shock hazard when it opens
Clamp-on test above the water-pipe bond	Measures a metal loop, not earth
Clamp-on test on a single isolated rod	No loop, no meaningful reading
Stakes too close or not in a line	No plateau; the reading is wrong
Ground-impedance test on a GFCI circuit without warning	Trips the GFCI and drops the occupant's load
Citing "250.56"	Not in NEC 2026. The 25 Ω rule is the 250.53(A)(2) Exception

NEC 2026 Checkpoints (2023 number in parentheses where it moved)

- **250.4(A)(1), (A)(5)** grounding and the effective ground-fault current path • **250.6** objectionable current • **250.12** clean surfaces.
- **250.24(A)(1), (B), (C)** service grounding, no load-side bond • **250.28** main and system bonding jumpers • **250.30(A)(1), (A)(5)** separately derived systems • **250.32(B)(1)** separate buildings.
- **250.50** electrode system • **250.53(A)(2) Exception** the 25 Ω rule (there is no 250.56 in 2026) • **250.53(A)(3)** 6 ft rod spacing • **250.64(C)** GEC splices • **250.66** GEC size • **250.68(A)** access • **250.70** connections.
- **250.92(B)** service bonding • **250.94(A)** IBT, now also at the disconnect of feeder-fed buildings • **250.96(A), (B)** bonding other enclosures and isolated grounding circuits • **250.97** over 250 V to ground.
- **250.104(A)(1), (C)** water pipe and structural steel • **250.118** EGC types • **250.122** EGC sizing • **250.146(D)** IG receptacles.
- **406.11(C)** IG receptacle orange triangle (406.3(D)) • **408.40 Exception** IG conductor through a panelboard • **110.14(D)** torque • **230.95(E)** ground-fault protection performance test record • Chapter 9 **Table 8** conductor resistance.

Hands-On Field Exercise

- Run a long-lead EGC continuity test from a receptacle ground pin to the panel bus. Null the lead, wiggle each fitting, and compare your reading to the Table 8 calculation for the run length.
- **Plot a fall-of-potential curve.** C2 is at 300 ft. Plot these nine readings (P2 distance in ft : Ω) on graph paper: 30 : 3.7, 60 : 4.4, 90 : 5.3, 120 : 5.8, 150 : 6.5, 180 : 6.8, 210 : 7.0, 240 : 7.7, 270 : 8.8. Mark where the curve flattens. Then use the 60, 120, and 180 ft readings to do the Tagg slope calculation from worked example 4 and check that you land near 7 Ω at 178 ft.
- On a training board with one hidden neutral-to-ground bond and one swapped neutral and ground, use the three-reading receptacle test (D3) to find both.
- Test an IG receptacle with a circuit analyzer and IG adapter. Explain what equal readings would mean.
- Clamp a GEC above and below the water-pipe bond with a stakeless tester. Explain why the readings differ.
- Walk a service with the D1 checklist and fill in a Part F test report for one electrode.

Sources used in this module (public documents)

- NFPA 70, National Electrical Code 2026 (free read-only access at [nfpa.org](https://www.nfpa.org)): Article 250, 110.14, 230.95, 406.11, 408.40, Chapter 9 Table 8.
- OSHA 29 CFR 1910.304(g) and 1910.334(c): [osha.gov](https://www.osha.gov)
- NFPA 70E-2024, as quoted in EC&M, "Is Troubleshooting Considered Energized Work?" ([ecmweb.com](https://www.ecmweb.com)) and the Panduit NFPA 70E white paper ([panduit.com](https://www.panduit.com)).
- Fluke application notes: Checking Ground Electrode Impedance (2550440); Earth Ground Resistance booklet; Selective Measurement; Measuring Ground Loop Resistance Without Stakes; Power Quality Troubleshooting (1266009); Power quality at the receptacle (2403225); Diagnosing Power Problems at the Receptacle; thermal imaging with the NETA temperature table (3358415): [fluke.com](https://www.fluke.com)
- Megger, Getting Down to Earth; Stake-less Earth/Ground Testing application guide; DET series user guide: [megger.com](https://www.megger.com)
- Ideal SureTest 61-164/61-165 circuit analyzer instructions: [idealind.com](https://www.idealind.com)
- ANSI/NETA ATS 7.13 grounding test values, as quoted on forums.mikeholt.com and [globalpowerinc.com](https://www.globalpowerinc.com).
- Mike Holt, Neutral-to-Ground Voltage; Electro Magnetic Fields (net-current method): [mikeholt.com](https://www.mikeholt.com)
- IAEI Magazine, Type AC Cable Ground Fault Test (2001) and the GEMI study (2004): [iaeimagazine.org](https://www.iaeimagazine.org)
- EC&M, Diagnosing Power Problems at the Receptacle: [ecmweb.com](https://www.ecmweb.com)
- ERICO, Practical Guide to Electrical Grounding (nVent ERICO).

Next: Module 2.8 — Preventive & Predictive Maintenance.