

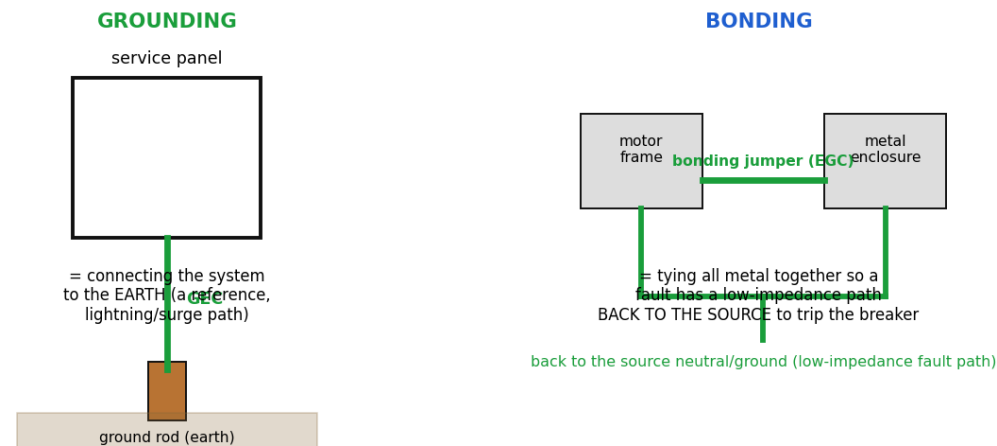
Module 1.7 — Grounding & Bonding

Grounding vs. bonding, the fault path, the electrode system, sizing the GEC, EGC and bonding jumpers with worked examples — plus step-by-step rods, CADWELD, ground testing, and service bonding.

Why this module. Grounding and bonding is the most misunderstood subject in the trade, and the one that keeps people alive. Most electricians blur "grounding" and "bonding" into one word. They are two different jobs. Article 250 is dense, but the core ideas are simple once you separate them. This module covers the ideas, then walks step by step through building a grounding electrode system, driving and testing a rod, making a CADWELD, bonding a service, sizing every bonding conductor with worked examples, and the checklist an inspector uses.

Part A — Grounding vs. Bonding

GROUNDING vs BONDING — two different jobs



The earth does NOT clear faults — bonding does. Grounding gives a reference and a surge path; bonding + the EGC are what trip the breaker on a fault.

Grounding connects the system to earth (reference/surge). Bonding ties metal together and back to the source so a fault can clear.

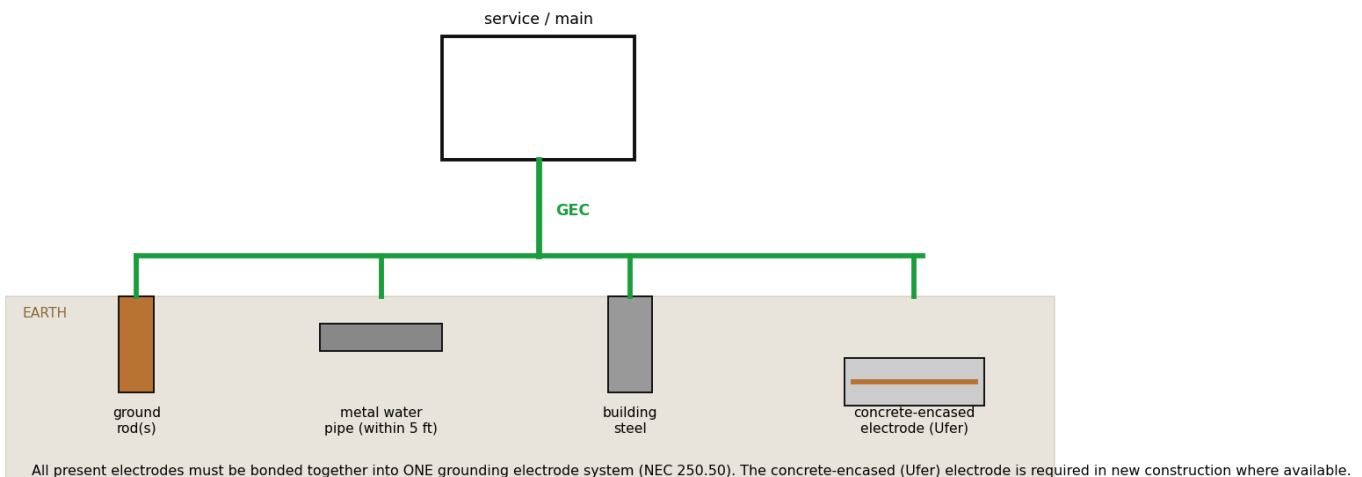
- **Grounding** (NEC 2026 250.4(A)(1)–(2)) connects the system to **earth** through the grounding electrode conductor (GEC) and electrodes. It limits voltage from "lightning, line surges, or unintentional contact with higher-voltage lines," and it keeps the "voltage to earth" stable.
- **Bonding** (250.4(A)(3)–(5)) ties all the **metal** together and back to the source with the equipment grounding conductor (EGC), "such [that] an effective ground-fault current path is established."

The earth does NOT clear faults. NEC 2026 250.4(A)(5): conductive material likely to become energized "shall be installed such that a **low-impedance circuit** is created that will facilitate the operation of the OCPD." 250.4(B)(4): "The earth shall not be considered as an effective fault-current path." Dirt is too high a resistance to trip a breaker. The bonded metal path back to the source does.

- **One neutral-to-ground bond per system.** Bond the neutral to ground in more than one place and normal neutral current flows on the conduit and grounds, which the code calls objectionable current (250.6). The fix is to remove the extra bond, never all of them.
- **OSHA** requires the path to ground to be "permanent, continuous, and effective" (1910.304(g)(5)).

Part B — The Grounding Electrode System (GES)

THE GROUNDING ELECTRODE SYSTEM (GES) — bond all electrodes together



Bond every present electrode — rods, water pipe, building steel, Ufer — into one system.

NEC 2026 250.50: "All grounding electrodes ... that are present at each building or structure served shall be **bonded together** to form the grounding electrode system." If none are present, you install one from the list. In an existing building, a concrete-encased electrode is exempt if the rebar can't be reached.

Electrode (250.52(A))	Minimum to count
Metal underground water pipe	10 ft in contact with earth, continuous to the GEC connection. Always supplemented by another electrode (250.53(D)(2))
Metal in-ground support structure (building steel)	10 ft vertical in earth
Concrete-encased ("Ufer")	20 ft of ½-inch (#4) rebar tied or welded continuous, or 20 ft of bare 4 AWG copper, with 2 inches of concrete cover, in a footing that touches earth
Ground ring	20 ft of bare copper, 2 AWG or larger, at least 30 inches deep
Rod or pipe	8 ft long. Rod ⅝ inch stainless or copper/zinc-coated steel unless listed. Pipe ¾ trade size galvanized
Plate	2 ft² of surface. At least 30 inches deep
Not allowed	Gas piping, aluminum (250.52(B))

Installation rules (250.53)

- **One rod alone is not enough.** A single rod, pipe, or plate "shall be supplemented by an additional electrode." The exception: if it tests at "25 ohms or less, the supplemental electrode shall not be required." (This 25-ohm rule is 250.53(A)(2) Exception. There is no 250.56 in the 2026 code.) In practice most crews drive two rods and skip the test. Many project specs demand 5 ohms.
- **Spacing:** multiple rods "not less than 1.8 m (6 ft) apart." Twice the rod length (16 feet for 8-foot rods) works better.
- **Depth:** 8 feet in soil, driven vertically. If you hit rock, drive it at up to 45 degrees, or lay it in a trench at least 30 inches deep. The top ends flush with or below grade unless it is protected.
- **Separation:** at least 6 feet from electrodes of another system, including lightning protection (250.53(B)).
- **Jumpers:** "Rebar shall not be used as a conductor to interconnect the electrodes" (250.53(C)). A jumper that runs only to a supplemental rod need not be larger than 6 AWG copper (250.53(E)).
- **Water pipe:** continuity "shall not rely on water meters or filtering devices," so jumper around the meter (250.53(D)(1)). Interior water pipe can be used only within 5 feet of where it enters the building (250.68(C)(1)).

Sizing the GEC (Table 250.66, copper)

Largest service conductor (copper)	GEC (copper)
2 AWG or smaller	8 AWG
1 or 1/0	6 AWG
2/0 or 3/0	4 AWG
Larger services	Read the printed Table 250.66

- A GEC that goes **only to rods** need not be larger than **6 AWG copper** (250.66(A)). Only to a **concrete-encased electrode**: no larger than **4 AWG copper** (250.66(B)). Only to a ground ring: no larger than the ring.
- Parallel service sets: add up the circular mils of one phase to find the row.

Installing the GEC (250.64)

- "One continuous length without splices or joints," except irreversible compression connectors listed for grounding, or exothermic welds (250.64(C)). No split bolts.
- 6 AWG and larger may run exposed on the surface if not subject to damage. Where it could be damaged, put it in RMC, IMC, Schedule 80 PVC, EMT, or armor. Smaller than 6 AWG is always protected (250.64(B)).
- Aluminum GEC is never in concrete and never within 18 inches of earth (250.64(A)).
- A GEC in a **steel** sleeve or raceway must be bonded to that raceway at **both ends**, with a jumper at least the GEC size (250.64(E)). Otherwise the steel chokes the fault current.
- Never through vent or drain openings (250.64(G)).
- Land it on the neutral bus at the service disconnect (250.24(A)(1)), and run it to any convenient electrode with the others jumpered, or to an accessible copper busbar at least $\frac{1}{4} \times 2$ inches (250.64(F)).

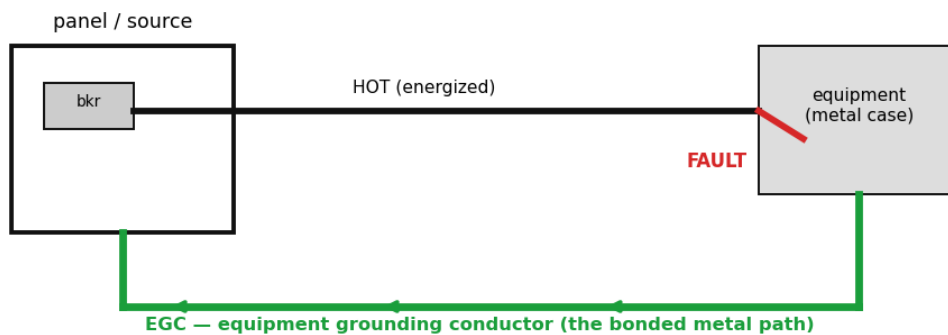
Step by step: building a commercial GES

1. **Before the footing pour:** CADWELD a 4 AWG copper pigtail to 20 feet of footing rebar (or bring a rebar stub up to an accessible point, 250.68(C)(3)). Check the 2-inch cover. Photograph it before the pour.
2. **Water pipe:** confirm 10 feet in earth. Clamp within 5 feet of entry. Jumper around the meter.
3. **Building steel:** grind off paint and lug or weld to a column.
4. **Rods where required:** two $\frac{5}{8} \times 8$ foot copper-bonded rods at least 6 feet apart (16 feet is better), flush or below grade, with direct-burial clamps (Part D).
5. **GEC:** size from Table 250.66, unspliced, protected, sleeve bonded at both ends, landed on the service neutral bus.
6. **Jumper** all the electrodes together, or land them all on an accessible busbar.
7. **Intersystem bonding termination** for phone, cable, and data (Part D).
8. **Test** a single rod by fall-of-potential if you are relying on the 25-ohm exception (Part D).
9. **Photograph** every buried joint before backfill.

Rod facts (ERICO Practical Guide to Electrical Grounding). A 10-mil copper-bonded rod lasts 30 years or more. Depth and soil matter more than rod diameter. On sectional rods, a loose coupling disconnects every section below it. Ground-enhancing backfill (bentonite) helps; salt corrodes the rod.

Part C — Why Bonding Clears a Fault

WHY BONDING MATTERS: the ground-fault path that trips the breaker



At the source the EGC ties to the grounded conductor — completing a LOW-IMPEDANCE loop so high fault current flows and trips the breaker FAST.

No bond / broken EGC = the case stays energized and the breaker never trips. That is the shock that kills.

A ground fault travels the EGC back to the source, completing a low-impedance loop that trips the breaker.

What counts as an equipment grounding conductor (250.118)

- A wire or busbar. RMC, IMC, and EMT. AC cable armor. MI cable. Cable tray, cablebus, and listed raceways.
- **MC cable** only with an EGC inside it, or a sheath listed as an EGC.
- **Listed liquidtight flex (LFMC):** $\frac{3}{8}$ to $\frac{1}{2}$ inch only on circuits of 20 A or less; $\frac{3}{4}$ to $1\frac{1}{4}$ inch only on 60 A or less; no more than 6 feet total of flex in the fault path; and a wire EGC wherever the flex is there for movement or vibration (250.118(A)(6)).
- **Flexible metal tubing:** 20 A or less and 6 feet or less.
- Never the GEC or the building frame (250.118(B)).

Metal raceway only works as the EGC if "all connections, joints, and fittings [are] made tight" (250.120(A)), and paint is removed at contact surfaces (250.96(A)). A loose coupling or missing bonding bushing breaks the fault path, and the next fault leaves the conduit energized instead of tripping the breaker.

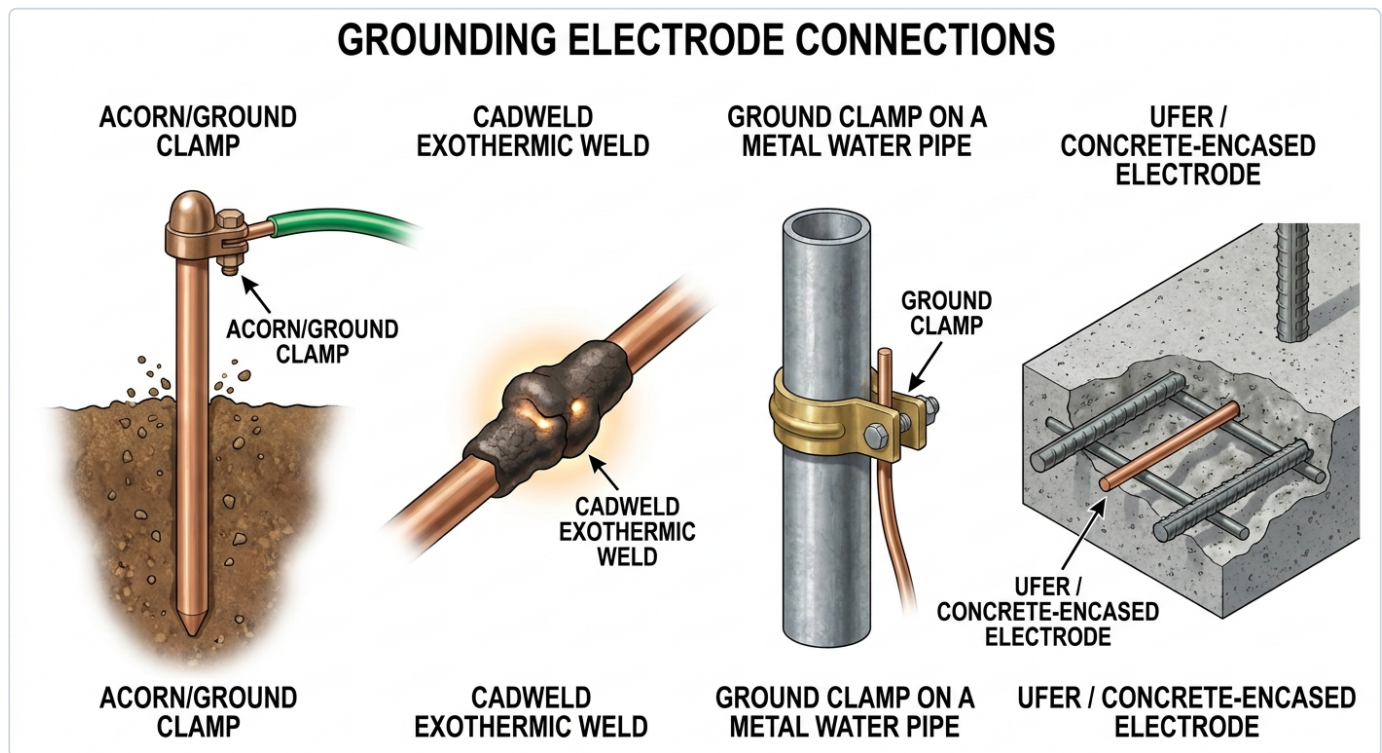
Sizing the EGC (Table 250.122, copper)

Breaker or fuse ahead of the circuit	15 A	20 A	60 A	100 A	200 A
Copper EGC	14 AWG	12 AWG	10 AWG	8 AWG	6 AWG

- Never larger than the circuit conductors (250.122(A)).
- **Upsized wire means an upsized ground** (250.122(D), 250.122(B) in 2023): if you upsize the hots for voltage drop, the EGC goes up "proportionately to the increase in circular mil area."
- One EGC in a raceway with several circuits is sized for the largest breaker (250.122(E)).
- Re-identify a black 4 AWG or larger EGC with green tape, paint, or by stripping, at every accessible point (250.119).

Worked example 1, upsizing. A 20 A circuit with #12 hots upsized to #8 for voltage drop. #12 is 6,530 circular mils and #8 is 16,510 (Chapter 9, Table 8). The ratio is $16,510 \div 6,530 = 2.53$. The EGC goes up the same: $6,530 \times 2.53 = 16,510$, so the ground becomes **#8 copper**.

Part D — STEP-BY-STEP: Making the Connections



Listed, permanent connections: acorn clamps, CADWELD, water-pipe clamps, Ufer.

Drive a ground rod

Tools: $\frac{5}{8}$ × 8 foot copper-bonded rod, an SDS-Max rotary hammer in hammer-only mode with a ground-rod driver (for example Milwaukee 48-62-4091) or a sledge or slide hammer with a driving cap, a spade, a listed direct-burial acorn clamp, and a torque wrench.

1. **Call 811** for a utility locate and check the drawings for buried lines.
2. Pick undisturbed earth near the service, ideally under the roof drip line where the soil stays damp, and at least 6 feet from any other electrode.
3. Dig a small pocket so the top of the rod will end up flush with or below grade.
4. Drive it vertically. Hands clear of the driver. Eye and hearing protection on.
5. If you hit rock, pull it and re-drive at up to 45 degrees, or trench 30 inches deep and lay it in.
6. Wire-brush the top of the rod. Set a clamp **listed for direct burial** (250.70), one conductor per clamp unless it is listed for more. Torque to the clamp's marked value (110.14(D)).
7. Drive the second rod at least 6 feet away and jumper it with at least 6 AWG copper.
8. Test if required (below), backfill, and photograph.

CADWELD (exothermic weld): permanent and corrosion-proof

Kit: the graphite mold whose tag matches the connection type and conductor size, a handle clamp, the weld-metal cartridge named on the mold tag, a steel disk, starting material, a flint igniter, a propane torch, a soft mold brush, a wire brush, and mold packing.

CADWELD safety (nVent ERICO guide). Safety glasses and gloves. The reaction exceeds 2500°F (1400°C). "Contact between hot molten metal and moisture or contaminants may result in spewing of hot material." No smoking near the starting material. Don't look at the flash. Clear flammables and warn the crew. Never weld on a container that held anything flammable.

1. **Clean and dry** the conductors and the rod or surface with a wire brush, then dry them with the torch. Steel must be ground bright; "Wire brushing will NOT suffice."
2. **Dry the mold** with the torch to about 250°F (120°C). "Graphite absorbs moisture," and moisture causes a porous weld.
3. **Position the conductors** in the mold, close the handle clamp, and pack any gaps after closing.
4. **Drop in the steel disk**, concave side up, seated over the tap hole.
5. **Pour the weld metal.** Put $\frac{1}{4}$ to $\frac{1}{3}$ of the starting material on top, close the lid, and put the rest on the lid's edge.
6. **Ignite** from the side with the flint igniter and pull your hand away.
7. **Wait about 30 seconds.**

8. **Open the mold** without chipping it. Clean the mold with the soft brush, never a wire brush. A mold averages about 50 connections.

What you see	Cause
Porous weld	Moisture or contaminants
Heavy slag	Disk leaked or wasn't seated
Fins	Mold not closed, or worn
No bond	Conductors not cleaned or dried
High riser	Wrong weld-metal size, or moisture
Thin slag on the surface	Normal

Test a rod: three-point fall-of-potential

A ground-resistance tester (Fluke or AEMC type) measures how well a rod connects to earth. A megohmmeter does **not**; it tests insulation.

1. **Isolate the rod** so you measure only the electrode. Lifting the GEC on a live service is a hazard: do it only with the service de-energized or under NFPA 70E controls.
2. **Connect the leads:** E (green) to the rod, H (red) to the outer current stake, S (blue) to the inner potential stake.
3. **Set the current stake** 8 to 10 times the rod depth away (80 to 100 feet for a 10-foot rod). Fluke's table: for a 9.8-foot rod, inner stake at 65 feet and outer at 98 feet.
4. **Put the potential stake at 62 percent** of the distance and read. Move it to 52 percent and 72 percent and read again. If the three readings agree, average them. If not, move the current stake farther out and repeat.
5. **Troubleshoot:** a poor current-stake contact shows as a fault light; drive it deeper or wet the soil. Noise on the potential lead means stray voltage; twist the leads.

Acceptance: 25 ohms or less lets one rod stand alone (250.53(A)(2) Exception). Two rods need no test. Project specs often call for 5 ohms. Telecom and static bonds are often under 1 ohm.

Service bonding and the main bonding jumper

1. **Install the main bonding jumper** at the service. 250.24(C): "an unspliced main bonding jumper shall be used to connect the equipment grounding conductor(s) and the service-disconnect enclosure to the grounded conductor." A screw jumper is green (250.28). On a Square D NQ panel, the strap is used "only when the panelboard is installed as service entrance equipment," with its screws at 10–12 lb-in (10-32) and 25–30 lb-in (¼-20).
2. **Bond the service raceways** (250.92). "Standard locknuts or bushings shall not be the only means." Use bonding bushings with jumpers, bonding locknuts, or wrenchtight threaded hubs, especially at reducing washers and concentric or eccentric knockouts. There is no breaker ahead of the service conductors except the utility's primary fuse, so these bonds carry the full fault current.

3. **Land the GEC** on the neutral bus.
4. **Install the intersystem bonding termination** (250.94(A)): outside and accessible, at least three terminals for phone, cable, and data, mounted to the service or meter enclosure, and connected with 6 AWG copper. In 2026 it is also required at the disconnect of a building fed by a feeder.
5. **No neutral-to-ground bond anywhere downstream** (250.24(B)). Subpanels keep the neutral isolated (Module 1.4).

Table 250.102(C)(1): largest copper service conductor	Main bonding jumper / supply-side jumper (copper)
2 AWG or smaller	8 AWG
1 or 1/0	6 AWG
2/0 or 3/0	4 AWG
over 3/0 through 350 kcmil	2 AWG
over 350 through 600 kcmil	1/0
over 600 through 1100 kcmil	2/0
over 1100 kcmil	12½% of the largest ungrounded conductor's area

- **Worked example 2, a 200 A service on 3/0 copper.** Main bonding jumper 4 AWG copper. GEC to a Ufer only: 4 AWG copper. GEC to rods only: 6 AWG copper.
- **Worked example 3, an 800 A service with two sets of 500 kcmil copper.** One phase totals 1000 kcmil, so the main bonding jumper is **2/0 copper**. Each raceway's supply-side bonding jumper is sized on the 500 kcmil in that raceway: **1/0 copper**.

Bonding raceways over 250 volts (480 V work)

NEC 2026 250.97: circuits over 250 V to ground use the service bonding methods (bonding bushings, bonding locknuts, threaded hubs). The exception: where there are no oversized, concentric, or eccentric knockouts, or the box is listed for bonding, you may use threadless fittings, double locknuts on rigid, or shouldered EMT connectors with one locknut inside. **Field rule:** at 480 V gear, every conduit in a concentric knockout gets a grounding bushing with a jumper sized from Table 250.122. Expansion fittings get a bonding jumper (250.98).

Bonding piping and building steel (250.104)

- **Metal water piping** bonds to the service enclosure, the neutral, the GEC, or the electrode, with a jumper from Table 250.102(C)(1) no larger than 3/0 copper, at an accessible point.
Worked example 4: a 400 A service on 500 kcmil copper needs a **1/0 copper** water-pipe bonding jumper.
- **Other metal piping** likely to become energized bonds to the EGC of the circuit that could energize it, sized from Table 250.122.

- **Structural steel** likely to become energized bonds to the service enclosure, neutral, GEC, or electrodes.
- **At a transformer** (separately derived system), the nearest water pipe and steel bond at the same point as the system bonding jumper and GEC.

Isolated-ground receptacles

An isolated-ground (IG) receptacle's ground terminal is insulated from its yoke and "connected to an insulated equipment grounding conductor run with the circuit conductors" (250.146(D)). That insulated ground may pass through panels and boxes without landing until it reaches the source's EGC terminal. The raceway must still be bonded normally (250.96(B)): "Use of an isolated equipment grounding conductor does not relieve the requirement for an effective ground-fault current path." IG receptacles are marked with an orange triangle (406.11(C), 406.3(D) in 2023).

Re-ground a transformer secondary (250.30)

1. Lock out. Mount the ground bar on bare metal, paint scraped, not over a vent.
2. Land the supply-side bonding jumper from the primary side.
3. Set **one** system bonding jumper, X0 to the bar, sized from Table 250.102(C)(1). It "shall remain within the enclosure where it originates."
4. Run the GEC from the same point, sized from Table 250.66.
5. Bond the nearest water pipe and building steel (250.104(D)).
6. Pull the bonding strap in the secondary panel and confirm its neutral bar is isolated.

Worked example 5: a 75 kVA 480–208Y/120 V transformer with 4/0 copper secondaries gets a **2 AWG copper** system bonding jumper (over 3/0 through 350 kcmil row). Full transformer steps are in Module 1.5C.

Safety. Follow the NFPA 70E (2024) 120.6 process to an electrically safe work condition before working inside gear, including the absence-of-voltage test at each point of work. Lifting a GEC or bonding jumper on an energized system can put voltage on it, so do it only de-energized. CADWELD and rod-driving PPE are listed above. On portable generators that are separately derived systems, OSHA 1926.404(f)(3)(iii) requires the neutral "bonded to the generator frame."

Common mistakes

Mistake	Rule
Neutral bonded to ground in a subpanel or a transformer's secondary panel	250.24(B), 250.142(B)
GEC spliced with a split bolt	250.64(C)
Ordinary clamp on a buried rod	250.70 (direct-burial listing)
Rod top sticking 12 inches out of the ground	250.53(A)(4)
Rods 3 feet apart	250.53(A)(3)
Plain locknuts at reducing washers or concentric knockouts at the service or on 480 V	250.92(B), 250.97
Steel GEC sleeve bonded at one end only	250.64(E)
Rebar used as the jumper between electrodes, or the Ufer skipped on new work	250.53(C), 250.50
Water clamp past the meter with no jumper	250.53(D)(1)
Several grounds under one terminal meant for one	250.8, the terminal's listing
IG conductor landed at the first panel, or IG raceway left unbonded	250.146(D), 250.96(B)
Flex over 6 feet, or flex on a 30 A circuit with no wire ground	250.118(A)
Paint under a ground bar	250.96(A)
Damp mold or oily conductor on a CADWELD	Porous weld
"Meggering" a ground rod	Use a fall-of-potential tester

Inspection checklist

Item	Accept
Electrodes	Every type present is bonded together (250.50)
Ufer	20 ft of #4 rebar, 2 in. cover, photo before the pour
Rods	8 ft in soil, 6 ft or more apart, flush; two rods, or one rod tested at 25 ohms or less
GEC	Table 250.66 size, unspliced, protected, steel sleeve bonded at both ends
Clamps	Listed for the materials, direct-burial where buried, one conductor each
Main bonding jumper	Present, unspliced, sized from Table 250.102(C)(1), torqued
Service raceways	Bonding bushings or locknuts at concentric knockouts, never plain locknuts alone
Intersystem bonding termination	3 or more terminals, accessible, 6 AWG copper
Water pipe and steel	Jumper sized from Table 250.102(C)(1), 3/0 copper max, accessible, meter jumpered
480 V raceways	Service-type bonding at concentric or eccentric knockouts
EGC continuity	De-energized ohm check from device ground to panel bus; low and consistent with the run length
Subpanels	Neutral bar isolated, ground bar bonded to the can
Transformers	One system bonding jumper, GEC at the same point, pipe and steel bonded
Torque	Marked value, with a torque tool (110.14(D))
Photos	Every buried or encased joint documented

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

- **250.4** performance • **250.6** objectionable current • **250.50, 250.52, 250.53** electrode system (the 25-ohm rule is **250.53(A)(2) Exception**; there is no 250.56).
- **250.64, 250.66, 250.68, 250.70** GEC and connections • **250.24, 250.28** service bond • **250.30** separately derived systems.
- **250.92, 250.94, 250.96, 250.97, 250.98, 250.102, 250.104** bonding • **250.118, 250.119, 250.120, 250.122** (250.122(D) was (B)) EGC.
- **250.146(D)** isolated ground • **406.11(C)** (406.3(D)) IG marking • **110.14(D)** torque.

Hands-On Field Exercise

- Walk a service and list every electrode present. Confirm they are all bonded (250.50). Size the GEC (250.66), the main bonding jumper (Table 250.102(C)(1)), and a feeder EGC (250.122).

- **Drive two rods** 6 feet or more apart with direct-burial clamps, torqued.
- Run a **fall-of-potential test** on a single isolated rod at 52, 62, and 72 percent and average it.
- Make a **CADWELD** connection under supervision and inspect it against the reject table.
- Set a **main bonding jumper** and a service bonding bushing with jumper. Ohm a device ground back to the panel bus.
- Upsize an EGC for a voltage-drop job using Chapter 9, Table 8.
- Set a transformer's X0 system bonding jumper and GEC, and confirm the secondary panel's neutral is isolated.

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; 406.11; Chapter 9 Table 8.
- ERICO, Practical Guide to Electrical Grounding.
- nVent ERICO, Cadweld Installation and Inspection Guide (E1294W): [nvent.com](https://www.nvent.com)
- Fluke, "Fall-of-Potential Measurement": [fluke.com](https://www.fluke.com). AEMC, "Fall-of-Potential Testing with the Model 3640": [aemc.com](https://www.aemc.com)
- Schneider Electric bulletins 80043-712-06 (NQ panelboards) and 43006-850-01 (dry-type transformers): [se.com](https://www.se.com)
- OSHA 29 CFR 1910.304 and 1926.404: [osha.gov](https://www.osha.gov). NFPA 70E, 2024 edition.

Next: Module 1.8 — Underground & Site Distribution.