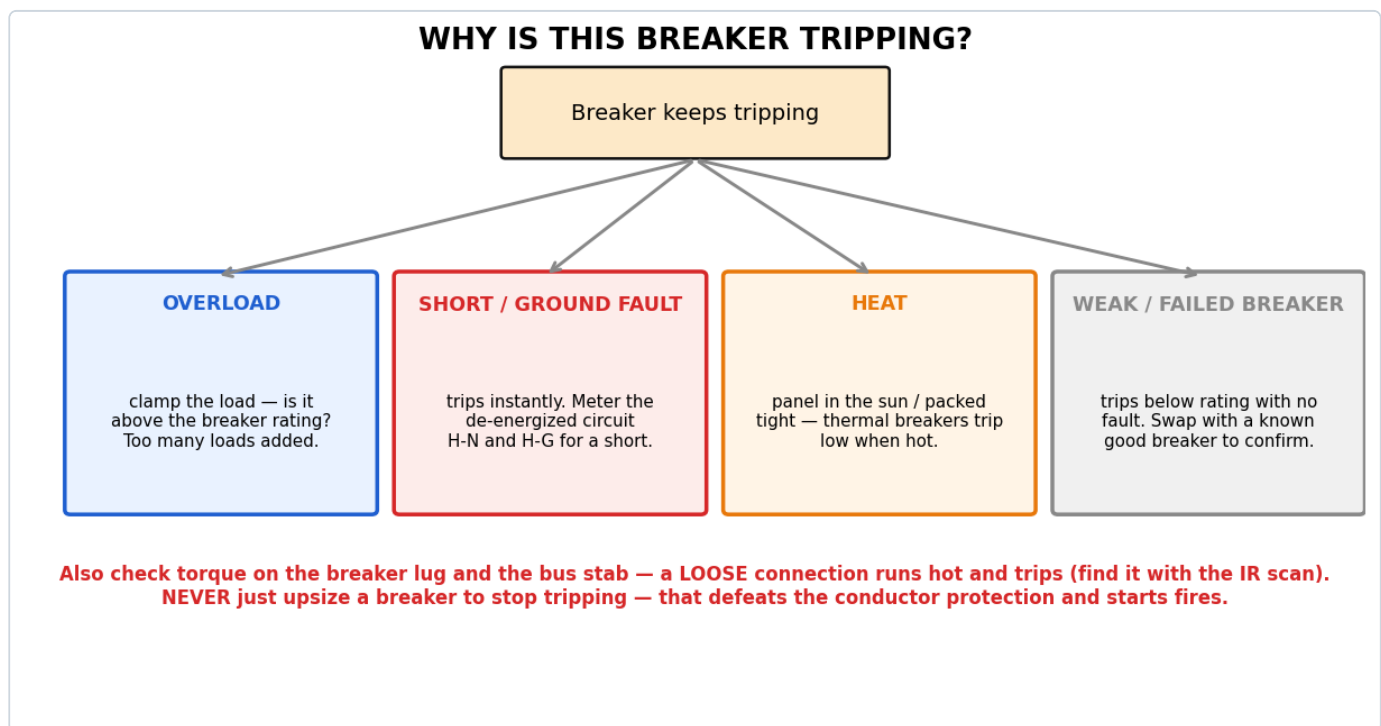


Module 2.4 — Panelboards, Feeders & Overcurrent Protection

Why it trips, finding and fixing the hot connection, coordination, panel and feeder testing, arc-flash PPE, and 480 V ground-fault protection, step by step.

Why this module. The panelboard is where problems show up first: a breaker that will not stay on, a panel running hot, or one fault that blacks out more of the building than it should. This module walks step by step through finding out why a breaker trips, finding and repairing a hot connection, explaining why the wrong breaker tripped, inspecting and testing a panel and its feeder, and troubleshooting ground-fault protection on 480 V services. All of it happens on equipment that can hurt you, so the Module 2.1 safety routine (lockout, test before touch, PPE) applies to every step.

Part A — STEP-BY-STEP: Why Is It Tripping?



Overload, short/ground fault, heat, or weak breaker. Diagnose which before you touch it.

A thermal-magnetic breaker has two ways to trip. The **thermal** part is a bimetal that heats up with current and trips on a slow overload. The **magnetic** part is a coil that trips instantly on a very high current such as a short circuit. Schneider puts it simply: "If it trips on startup, it is tripping magnetically; if it trips after a while, it is tripping thermally." Knowing which one tripped cuts the problem in half.

The field sequence

1. **Ask questions first.** When does it trip: the moment it is switched on, after minutes or hours, only on hot afternoons? What was added to the circuit lately? Write the answers down.
2. **Read the breaker label.** Note the amps, number of poles, interrupting rating in kA, whether it is 100 percent or 80 percent rated, and the trip type. On an electronic trip unit, read the trip-cause light or event log **before** you reset it. Resetting can clear it.
3. **Instant trip (magnetic):** do not keep resetting it. Each reset into a fault puts arc energy into the breaker, the wire, and you. Lock out, lift the load conductors, and test the circuit dead: continuity and insulation resistance phase to phase, phase to neutral, and phase to ground (Part D, feeder megger steps).
4. **Delayed trip (thermal):** clamp every phase under normal load. Compare the reading to the breaker rating and to the 125 percent continuous-load rule below. Schneider lists the usual causes: an undersized breaker, single-phasing, worn equipment, and long motor runs.
5. **Check the connections for heat** (Part B). On plug-on breakers (QO, HOM, I-Line) look at the bus for pitting and confirm joint compound is present where the manufacturer uses it.
6. **Check the ambient temperature** around the panel (below).
7. **Only then suspect the breaker.** Schneider: "If all other causes are ruled out, replace the breaker." For larger feeder and main breakers, test it first (Part A, testing a suspect breaker).

Never just upsize a breaker to stop tripping. The breaker protects the conductor (NEC 240.4). A bigger breaker removes that protection and turns the next overload into a burning conductor. Small conductors have hard limits under 240.4(D): 12 AWG copper gets no more than a 20 A breaker. Find the cause.

The 125 percent continuous-load check

A **continuous load** is one that runs 3 hours or more, such as lighting in an office. The NEC sizes the breaker for 125 percent of continuous load because a standard breaker carrying its full rating for hours runs hot. For branch circuits, 210.20(A) says the breaker rating "shall not be less than the noncontinuous load plus 125 percent of the continuous load." Feeders use the same math: conductor ampacity under 215.4(A)(1) (215.2(A)(1) in 2023) and the feeder breaker under 215.5 (215.3 in 2023). The exception is an assembly "listed for operation at 100 percent of its rating," which is rare in panelboards and marked on the breaker.

Worked example 1 (branch circuit). A lighting circuit on 12 AWG copper and a 20 A breaker carries 13 A continuous plus 2 A noncontinuous. $13 \times 1.25 + 2 = 18.25$ A, so the 20 A breaker is fine. The owner adds 4 A more of continuous lighting. Now $17 \times 1.25 + 2 = 23.25$ A. The clamp reads only 19 A and the breaker may trip only on a hot day, but the circuit is overloaded under 210.20(A). The fix is a new circuit. A 25 A breaker on 12 AWG is never the fix (240.4(D)).

Worked example 2 (feeder). A panel feeder carries 160 A continuous plus 40 A noncontinuous. $160 \times 1.25 + 40 = 240$ A. The feeder breaker and the conductor ampacity must both be at least 240 A (215.4(A)(1), 215.5). The existing 225 A main breaker is undersized for this load, which explains the afternoon trips.

Reading a time-current curve (TCC)

A **time-current curve** is the breaker's trip chart, published by the manufacturer for each breaker family. Always use the curve for the exact breaker you are looking at.

1. The axes are logarithmic. Current runs across the bottom, time in seconds runs up the side.
2. Find the fault or overload current on the bottom axis, go straight up to the band, and read the time on the left.
3. The upper, sloped part of the band is the **thermal (overload) region**. The band is wide: the left edge is the fastest the breaker can trip, the right edge the slowest.
4. The lower, flat part is the **instantaneous (magnetic) region**. On an adjustable breaker it moves with the setting.
5. The vertical line at the far right end of the curve is the **interrupting rating**, the most current the breaker can safely open.

Worked example 3. In the Eaton/Bussmann guide, a 400 A breaker has an instantaneous adjustment of 5 to 10 times its rating, which is 2,000 to 4,000 A. The band is ± 25 percent at the 5 $\times$ setting, so a breaker set at 5 $\times$ may trip anywhere from 1,500 to 2,500 A, and ± 10 percent at the 10 $\times$ setting (3,600 to 4,400 A). Breakers ship at the lowest setting. The wide gap between the fastest and slowest trip is why molded-case breakers are hard to coordinate (Part C).

Electronic trip units have separate adjustments labeled **L** (long time, overload), **S** (short time), **I** (instantaneous) and **G** (ground fault). Many have **thermal memory**: if you reset quickly after an overload trip, the next trip comes sooner because the unit remembers the heat.

Other causes of thermal trips

Cause	Clue	What to do
High ambient temperature	Trips on hot afternoons; panel in the sun or packed full	Square D breakers are "calibrated in 40 deg. C ambient." Above that they trip lower. Measure the air temperature at the panel and get the manufacturer's derating data.
Inrush	Magnetic trip the moment a motor or transformer is switched on, but the megger readings are good	The closing current is hitting the instantaneous setting, which ships at its lowest. Raising it is an engineering decision (Part C), not a field adjustment.
Aging or weak breaker	Trips below rating with no fault and normal load	Low contact pressure or worn contacts. Confirm with a hold-in test (below), not by swapping breakers until the trips stop.
Loose or hot connection	One breaker or lug much hotter than its neighbors	Heat from the joint flows into the thermal element. See Part B.

Touch is not a test. Breakers run warm by design. UL 489 allows a terminal temperature rise of 50°C (90°C total) on standard breakers and 60°C (100°C total) on 100 percent rated breakers, and 85°C on a nonmetallic handle. Use an IR camera or thermometer, and let a newly installed breaker carry load for 3 hours before judging it.

Testing a suspect breaker

1. **Mechanical check** (de-energized): cycle the handle ON and OFF several times, press the push-to-trip button if it has one, then reset. Schneider: "If the circuit breaker does not trip, or if it does not reset after tripping, it must be replaced."
2. **Pole-to-pole comparison under load.** A millivolt reading across each pole under the same load shows one pole with higher contact resistance. There is no published field pass/fail number for this reading, so use it only to compare poles. It requires the cover off, which is energized work (Part E).
3. **Bench tests** with the breaker removed. NEMA AB 4 describes a millivolt-drop test at rated DC current (no more than 24 V DC, under 1 minute, three readings per pole). The 1996 edition says to consult the manufacturer when the average exceeds 200 mV. Motor circuit protectors and 15 A breakers read high by design. Schneider prefers a low-resistance ohmmeter (DLRO) at 10 A DC for breakers under 100 A and 100 A DC at 100 A and up, taking the median of three readings.
4. **Hold-in test** for a breaker suspected of nuisance tripping (Schneider): all poles in series, 25°C ambient, 100 percent of rated current. It must not trip within 1 hour (under 100 A) or 2 hours (over 100 A).
5. **Primary injection** (done by a test company or the manufacturer's service group, breaker removed or isolated): current is pushed through the breaker at 300 percent of its rating and the trip time is compared to the NEMA AB 4 limits below. Wait 20 minutes between tests on a thermal pole so it cools.

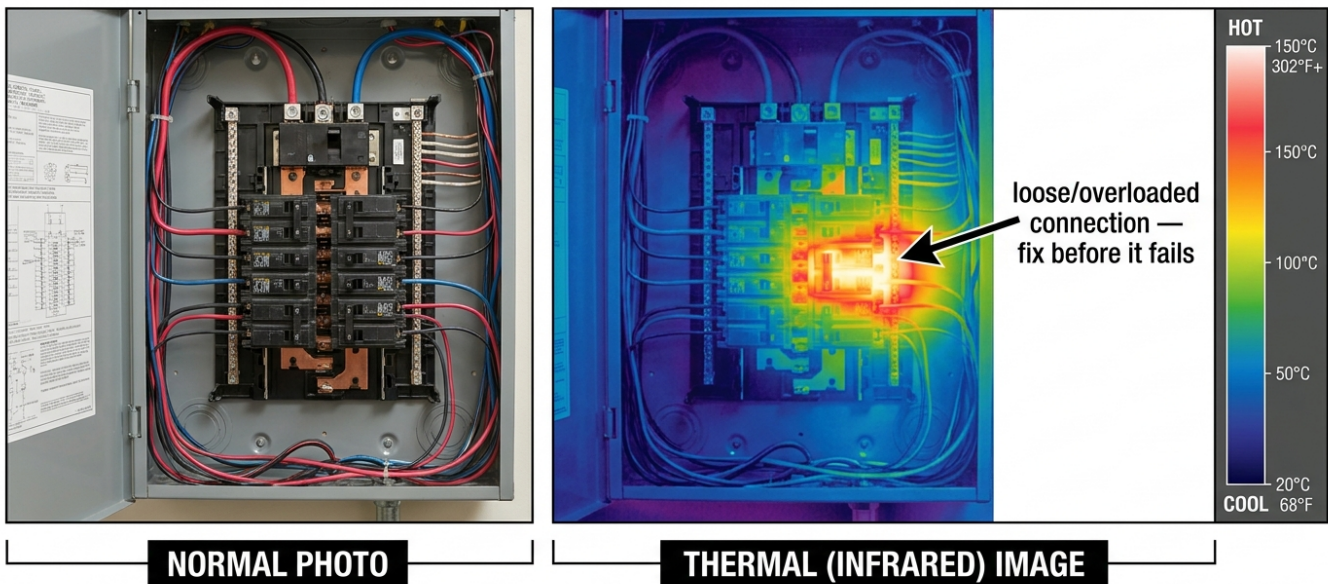
Breaker rating	Max trip time at 300%, 250 V or less	Max trip time at 300%, 251-600 V
0-30 A	50 s	70 s
31-50 A	80 s	100 s
51-100 A	140 s	160 s
101-150 A	200 s	250 s
151-225 A	230 s	275 s
226-400 A	300 s	350 s

Values from NEMA AB 4-2009 Table 3 (confirm against the current edition before using them as acceptance numbers).
NEMA: "Circuit breakers that do not trip within these maximum time limits should be withheld from further service."

Part B — STEP-BY-STEP: Find the Hot Connection

A loose lug or worn bus stab has extra resistance. Resistance under load makes **heat**, and heat oxidizes and loosens the joint further until it arcs. You find these joints with an infrared (IR) camera while the panel is loaded, then you fix them with the panel dead.

INFRARED SCAN FINDS THE HOT CONNECTION



An IR scan shows the loose/overloaded connection glowing hot while everything around it is cool.

Step by step: the IR survey

1. **Get load on it.** Scan at no less than 40 percent of the panel's normal load, and as close to full load as you can. Clamp and record the load on each phase. A joint that is fine at 10 percent load can be dangerous at 80 percent.

2. **Treat cover removal as energized work.** Only a qualified person removes the dead front, with an energized-work justification and PPE per Part E.
3. **Scan all three phases side by side:** main lugs, every breaker's line and load terminals, the neutral bar, the ground bar, and any bus stabs you can see.
4. **Grade what you find** with the NETA table below. Compare like with like: the same part on the other phases, at the same load.
5. **Interpret the pattern.** A hot spot at a joint that cools off along the wire is a bad connection. A whole conductor that is warm end to end is an overload or an undersized wire; clamp it. A leg that is cooler than the other two may have a failed component or an open.
6. **Save the record:** a visible-light photo and the IR image, the load amps, and the ambient temperature. This becomes the baseline for the next scan.

ΔT vs. same part on another phase, same load	ΔT vs. ambient air	Action (ANSI/NETA Table 100.18)
1–3°C	1–10°C	Possible deficiency; warrants investigation
4–15°C	11–20°C	Probable deficiency; repair as time permits
—	21–40°C	Monitor until corrective measures can be accomplished
Over 15°C	Over 40°C	Major discrepancy; repair immediately

The two columns use different scales. A lug 12°C hotter than the same lug on the other phases is a "probable deficiency." A lug 12°C above room air may be a normal loaded lug. Never grade a phase-to-phase difference with the ambient column.

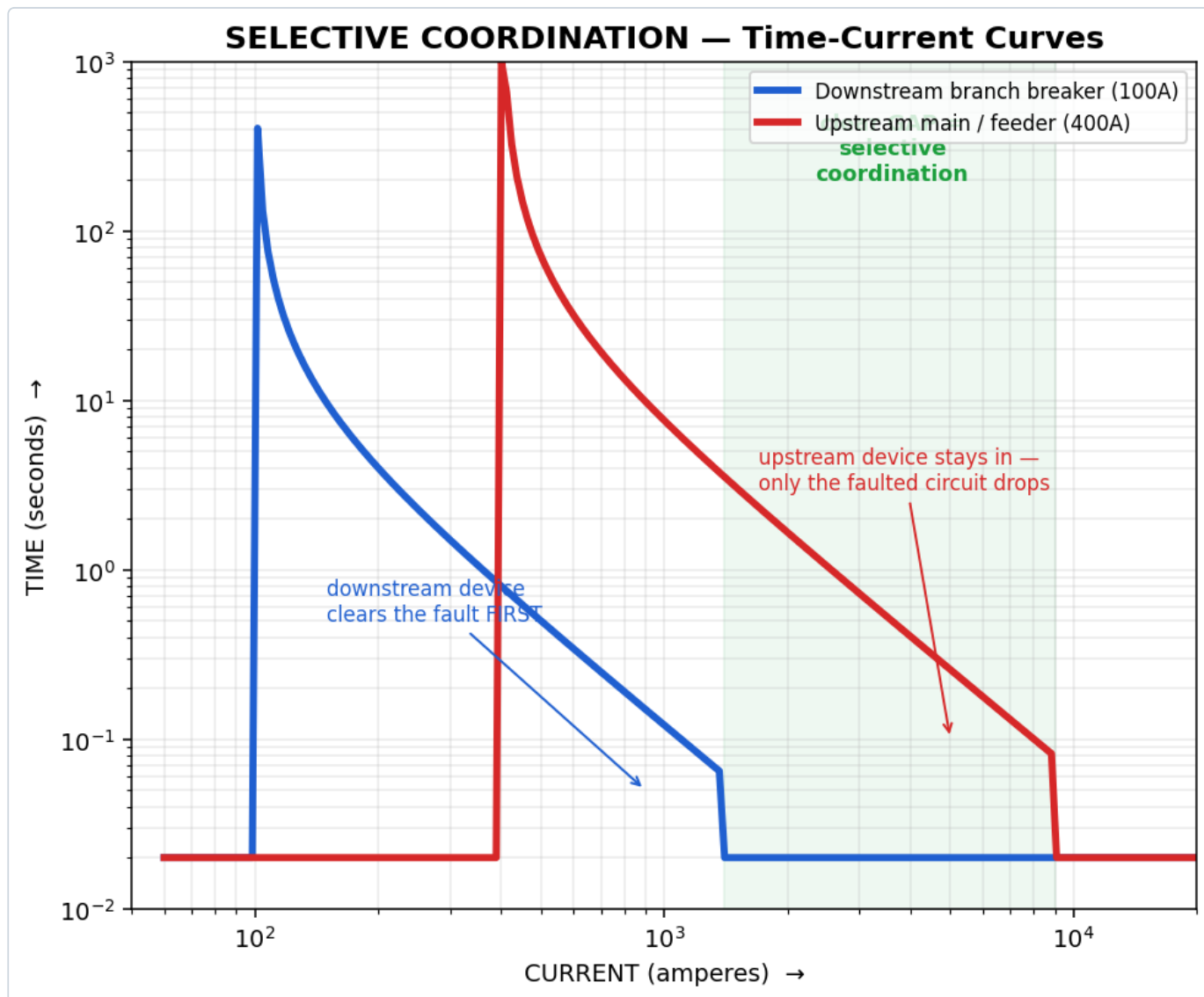
Step by step: the repair (de-energized only)

1. Schedule the outage. Lock out the panel's feeder breaker and test for absence of voltage at the point of work, live-dead-live (NFPA 70E 120.6).
2. Inspect the flagged joint: discoloration, pitting, melted or browned insulation, arc tracking.
3. **Copper:** clean and dress the contact surfaces. **Aluminum:** Schneider: "Overheated aluminum connectors must be replaced and damaged portions of the conductor removed." If the conductor is then too short, splice it.
4. **I-Line and other plug-on breakers:** if the jaws are pitted, discolored, or deformed, replace the breaker. The jaws "are not field replaceable. Do not bend or adjust them." Reapply the manufacturer's joint compound (Square D PJC-7201) if it was removed.
5. **Set-screw lugs:** arcing can damage the screw threads so the screw feels tight but the wire is still loose. Replace the lug.
6. Torque the repaired connection to the value on the equipment label, with a calibrated torque tool (NEC 110.14(D): torque "as indicated on equipment or in installation instructions," using an approved means). If no value is given, 110.14(D) Informational Note 2 points to UL 486A-486B Annex I, or call the manufacturer.

7. Re-energize and re-scan under load. The joint is fixed when its ΔT is back in line with the other phases.

Do not re-torque connections that are not hot. Schneider's field maintenance guide (0600IB1201): "If there is no evidence of overheating or loose connections, do not disturb or re-torque connections." Re-torquing a lug with the panel energized is never done. The IR scan decides which joints get worked on.

Part C — Coordination: Why the Wrong Breaker Tripped



Coordinated: the nearest device clears first. Overlapping curves = a branch fault trips the main.

When a fault on one branch circuit trips the **main** or the upstream feeder breaker instead of the branch breaker, the time-current curves of the two breakers overlap at that fault current. That is a **coordination** problem: more of the building goes dark than had to. On adjustable (LSIG) trips

the settings may be wrong. A **coordination study** by an engineer sets them so only the nearest device opens (full treatment in Module 1.5B).

Where the code requires coordination

- Emergency systems (700.32), legally required standby systems (701.32), and critical operations power systems (708.54) must be selectively coordinated. The design is selected by a licensed professional engineer or other qualified person and documented.
- Under 701.32(B), the coordination must be re-evaluated if replacement breakers are not "the same manufacturer and type of OCPDs and with the same ratings or settings."
- 240.11 requires feeder OCPDs fed directly by a service OCPD to be selectively coordinated with it where other rules require feeder coordination.
- Breakers rated 1200 A or more need an arc-energy-reduction method under 240.87, such as zone-selective interlocking, differential relaying, or an energy-reducing maintenance switch. A maintenance switch left ON makes the breaker trip fast and breaks coordination. Check that it is OFF when the work is done.

Step by step: after an upstream trip

1. Find the downstream fault first (Part A, instant-trip steps). The upstream breaker did its job.
2. Photograph the as-found settings on every adjustable breaker involved, including the maintenance switch position.
3. Compare the settings to the coordination study. If they match the study and coordination still failed, report it to the engineer.
4. Do not change any setting without the engineer's sign-off. Record any change on the study and the equipment.

Part D — Inspecting the Panel

Visual checklist (de-energized or with PPE per Part E)

- **Discolored or pitted bus or stabs** show arcing damage. On plug-on bus, replace the breaker, and the panel if the bus is damaged.
- **Melted or browned insulation** shows chronic overheating. Find out whether it is the joint or the load.
- **Double-tapped breakers** (two wires under one terminal not rated for two) are a violation and a heat source.
- **Two neutrals under one screw** on the neutral bar violate 408.41, which requires each grounded conductor to be "in an individual terminal that is not also used for another conductor."
- **Missing filler plates or open knockouts** open the enclosure to fingers and tools.
- **Panel overcurrent protection** no larger than the panel's rating (408.36). For a panel fed from a transformer, the protection is on the secondary side (408.36(B)).
- **Circuit directory** (408.4(A)): every circuit "and circuit modification" described in a way that is "clear, evident, and specific." Update it whenever you change a circuit.

- **Tracking, debris, water, and rodent damage**, and any missing barriers.

Step by step: feeder insulation-resistance (megger) test

1. Lock out the feeder at the source and verify it is dead at both ends.
2. Lift the feeder conductors at both ends. Disconnect surge protective devices, meters, and electronic trip units, which the test voltage can damage.
3. Test at 1,000 V DC for 600 V-rated cable, for 1 minute: each phase to the other phases, and each phase to ground.
4. Accept per ANSI/NETA Table 100.1: for 600 V equipment tested at 1,000 V DC, the recommended minimum is **100 megohms**. Correct for temperature and compare to past readings; a falling trend matters even above the minimum.
5. Discharge each conductor after testing. Record readings, temperature, and humidity.

Step by step: feeder voltage drop under load

1. With normal load running, measure phase-to-phase and phase-to-neutral voltage at the load terminals of the feeder breaker and at the panel's main lugs at the same time (two meters, or one meter quickly while the load is steady). Clamp the current at the same moment.
2. Voltage drop percent = (source volts – panel volts) ÷ source volts × 100.
3. Compare it to the 215.4(A) Informational Note No. 2 guideline of 3 percent for the feeder and 5 percent for feeder plus branch. This is a design recommendation, not an enforceable limit.
4. Compare phases. One phase dropping more than the others at the same current points to a bad joint on that phase.

Worked example 4. The switchboard reads 480 V and the panel reads 467 V with 180 A flowing. $480 - 467 = 13$ V, and $13 \div 480 \times 100 = 2.7$ percent. That is within the 3 percent guideline. If phase B alone read 458 V at the same current, phase B has a hot joint somewhere between the two points; IR-scan it.

Neutral problems

- **Symptoms of a loose neutral:** lights brighten and dim as other loads switch, 120 V equipment sees 90 V or 150 V, and the neutral bar or lug runs hot. Line-to-neutral voltages swing with the load imbalance. IR-scan the neutral lug.
- **Overloaded neutral:** on 208Y/120 V panels feeding computers and electronic ballasts, harmonic currents (the "triplen" harmonics) add up on the neutral instead of canceling. Clamp the neutral with a true-RMS meter; it can carry more than the phases.
- **Neutral-to-ground (N-G) voltage** under load tells you where the neutral-to-ground bond is. At the service it reads 0 V because neutral and ground are bonded there. At a subpanel it equals the voltage drop on the feeder neutral (Mike Holt's example: 3 V). At a receptacle it is the feeder plus branch neutral drop (his example: 4.5 V). Fluke: N-G voltage "higher than 3 % should trigger further investigation."

- **Zero N-G volts at a loaded subpanel is a red flag.** It means the neutral is bonded to ground there, which the code forbids (Part F).

Part E — Arc-Flash Safety for Cover Removal

Removing a panel dead front exposes energized parts. NFPA 70E (2024) Table 130.7(C)(15)(a) gives PPE categories for panelboards, but only when the available fault current is 25 kA or less, the breaker clears in 0.03 seconds or less, and you work at 18 inches.

Panelboard	PPE category	Arc-flash boundary
240 V and below (for example 208Y/120 V)	1	485 mm (19 in.)
Over 240 V up to 600 V (for example 480Y/277 V)	2	900 mm (3 ft)

1. Look for an arc-flash label from an engineering study. If one exists, its PPE and boundary take precedence over the table.
2. If you use the table, confirm the fault current and clearing time are within its limits. Non-dwelling service equipment must be field-marked with the available fault current and the date it was calculated (110.24(A)).
3. If you cannot confirm either, stop and ask before removing the cover.
4. Install or remove molded-case breakers de-energized. The Department of Defense criteria (UFC 3-560-01) say to install them de-energized or stop work.

Part F — STEP-BY-STEP: 480 V Ground-Fault Protection (GFPE)

Ground-fault protection of equipment (GFPE) watches for current leaking to ground on large 480Y/277 V services and opens the main before an arcing ground fault burns up the switchgear. It is a different device from the GFCI that protects people.

Rule	NEC 2026	What it says
Where required	230.95(A)	Solidly grounded wye services over 150 V to ground and up to 1000 V phase to phase, for each service disconnect rated 1000 A or more. Feeders (215.10) and branch disconnects (210.13) follow the same 1000 A threshold.
Setting	230.95(C) (230.95(A) in 2023)	"The maximum setting of the ground-fault protection shall be 1200 amperes, and the maximum time delay shall be one second for ground-fault currents equal to or greater than 3000 amperes."
Testing	230.95(E) (230.95(C) in 2023)	Performance tested when first installed, by qualified persons, "using a test process of primary current injection," with a written record available to the AHJ.

Why a GFPE trips when there is no fault, or fails to trip

- **Neutral bonded to ground downstream of the sensor.** Part of the normal neutral current returns on the ground path, bypasses the sensor, and looks like a ground fault. 250.24(B) forbids reconnecting the neutral to ground "on the load side of the service disconnecting means," and 250.142(B) and 250.6(B) cover the same problem.
- **Neutral sensor wired backwards** (reversed polarity).
- **Wrong conductors through a zero-sequence sensor:** one phase or the neutral left out of the window, or the equipment ground run through it.
- **Multiple sources.** ABB/GE: "Don't bond the neutral of downstream switchboards fed by low voltage service entrance equipment." A 3-pole transfer switch with a separately derived generator causes nuisance trips; 4-pole switching fixes it (Eaton).

Step by step: finding a downstream neutral-to-ground bond

1. **Energized screen.** Clamp each feeder's equipment grounding conductor and bonding jumper. A steady current that tracks the neutral current means neutral current has a parallel path on the ground. Measure N-G voltage at each subpanel under load. A subpanel reading 0 V is the suspect (Part D).
2. **De-energized test.** Lock out the service. Remove the neutral disconnect link or main bonding jumper. Megger the neutral bus to ground. It "should be a minimum of 1 megohm" (EC&M, Beisert).
3. If the reading is low, open the feeder neutrals one at a time until it comes up. That feeder leads to the bond.
4. At the suspect subpanel look for a green bonding screw or strap, neutral and ground bars tied together, and equipment or receptacles with neutral-to-ground jumpers. Remove the bond.
5. **Reinstall the main bonding jumper** before re-energizing. Re-test, and document what you found.

Sidebar — Replacing a Breaker Like for Like

1. Match make, type, amps, poles, and interrupting rating, and confirm the breaker type is listed on the panel's label. NEC 110.3(B) requires equipment to be installed per its listing and labeling.
2. Check the interrupting rating against the available fault current on the 110.24 label. 110.9 requires the interrupting rating to be "at least equal to the available fault current at the line terminals." Breakers rated other than 5000 A must show the rating (240.83(C)).
3. **Series ratings** (240.86): a breaker with a lower interrupting rating may sit downstream of a higher-rated device only as a tested combination marked on the equipment, or as an engineered system on an existing installation. Equipment applied this way must be field-marked (110.22(C)). Changing either device voids the combination.
4. In a selectively coordinated system, a different type of replacement breaker triggers re-evaluation (701.32(B), 708.54).

5. Reconditioned panelboards and breakers fall under the new 408.3 (Reconditioned Equipment). Use new or listed reconditioned parts only.

Diagnostic Path and Records

Follow this order on any panel complaint: interview and trip log, then instant or delayed trip. For an instant trip: lock out and megger. For a delayed trip: clamp the phases and neutral and apply the 125 percent rule. Then IR-scan at 40 percent load or more and grade with NETA 100.18, check ambient, and measure voltage drop and N-G volts under load. Then de-energize, inspect, repair only what was hot, and megger. Test the breaker if it is still suspect, replace like for like, re-scan, and document.

Record: the as-found trip indication and settings, load on each phase, IR images with load, ambient, ΔT and action, torque applied, megger readings with temperature, catalog number and interrupting rating of any replacement, and the updated circuit directory. UFC 3-560-01 calls for a test report plus a sticker on the equipment with the company name and date.

Common Mistakes

Mistake	Why it matters
Upsizing a breaker to stop trips	Conductor is no longer protected (240.4)
Resetting an instant trip over and over	Each reset closes into the fault
Re-torquing every lug "while we're here"	Schneider says do not disturb joints that show no heating
Any torquing with the panel energized	Never done
IR scanning at light load and calling the panel clean	Scan at 40 percent load or more
Grading a phase-to-phase ΔT with the ambient column	Underrates a real problem
Bonding neutral to ground in a subpanel	Objectionable current, GFPE nuisance trips (250.24(B))
Different-brand breaker without checking the panel label and series rating	Voids the listing and the tested combination
Changing trip settings without the coordination study	Bigger outages and missed faults
Using the PPE table without knowing fault current and clearing time	The table may underprotect you

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

- **110.3(B)** listing • **110.9, 110.10** interrupting rating • **110.14(D)** torque • **110.22(C)** series-rating marking • **110.24** fault-current label.
- **210.20(A)** branch 125% • **215.4(A)(1)** (215.2(A)(1)) feeder conductors 125% • **215.5** (215.3) feeder OCPD 125% • **215.10, 210.13** GFPE.
- **230.95(A)** GFPE required • **230.95(C)** (230.95(A)) setting • **230.95(E)** (230.95(C)) performance testing.
- **240.4, 240.4(D)** conductor protection • **240.11** feeder coordination • **240.83(C)** IR marking • **240.86** series ratings • **240.87** arc energy reduction.
- **250.6, 250.24(B), 250.142(B)** no downstream N-G bond • **408.3** reconditioned equipment • **408.4(A)** directory • **408.36** panel OCPD • **408.41** one neutral per terminal.
- **700.32, 701.32, 708.54** selective coordination.

Hands-On Field Exercise

- For a tripping breaker, interview the user, read the label, decide instant or delayed, clamp the load, and run the 125 percent check.
- Read a manufacturer's TCC: find the trip time band for 3 times and 10 times the rating, and mark the interrupting rating.
- IR-scan a panel at 40 percent load or more, record load and ambient, and grade every finding with the NETA table.
- De-energize and repair one flagged joint, torque it to the label value, and re-scan to prove the fix.
- Megger a feeder at 1,000 V DC and measure its voltage drop and N-G voltage under load.
- Inspect a panel for double-taps, shared neutral terminals, discolored bus, and an out-of-date directory.
- Read an adjustable breaker's LSIG settings, compare them to the coordination study, and explain coordination.

Sources used in this module (public documents)

- NFPA 70, National Electrical Code 2026 (free read-only access at [nfpa.org](https://www.nfpa.org)). NFPA 70E, 2024 edition, Table 130.7(C)(15)(a) (copy published by University of Notre Dame EHS, ehs.nd.edu).
- Schneider Electric / Square D: FAQs FA232232, FA173839, FA278588; data bulletin 0600DB1603 Circuit Breaker Operating Temperatures; 0600IB1201 Field Testing and Maintenance Guide: [se.com](https://www.se.com)
- Eaton/Bussmann, Time-Current Curves: How to Read; Eaton CAG 27.0 Molded-Case Circuit Breakers and Enclosures; Eaton white paper on 3-pole and 4-pole transfer switching: [eaton.com](https://www.eaton.com)
- ABB/GE Industrial Solutions white paper on ground-fault protection of multiple-source systems: library.industrialsolutions.abb.com
- Fluke application notes on thermal imaging of electrical systems and on unbalance and overloading: [fluke.com](https://www.fluke.com)
- ANSI/NETA ATS and MTS, Tables 100.1 and 100.18 (InterNational Electrical Testing Association, [netaworld.org](https://www.netaworld.org)).

- NEMA AB 4, Guidelines for Inspection and Preventive Maintenance of Molded Case Circuit Breakers: nema.org
- EC&M, Performance Testing of Ground-Fault Protective Devices (Beisert): ecmweb.com. Mike Holt, Neutral-to-Ground Voltage: mikeholt.com
- UFC 3-560-01 Electrical Safety, O&M (Change 3, 2023): wbdg.org

Next: Module 2.5 — Switchgear & Transformers (Troubleshooting).