

Module 2.6 — Motors, Controls & MCCs

(Troubleshooting)

Divide the problem (control, power, or motor), then trace it step by step: overload settings, single-phasing, drive and soft-starter faults, and winding tests.

Why this module. Motors bring in the most service calls: pumps, compressors, fans, and rooftop units. The key skill is **dividing the problem**. Is it the control circuit (the logic that tells the starter to close), the power circuit (the contactor, overload, fuses, and wiring), or the motor and its load? This module walks step by step through dividing the problem, tracing a control circuit with a meter, working each motor symptom, catching single-phasing, setting overloads correctly, reading drive and soft-starter faults, and testing motor windings.

Part A — STEP-BY-STEP: Divide the Problem

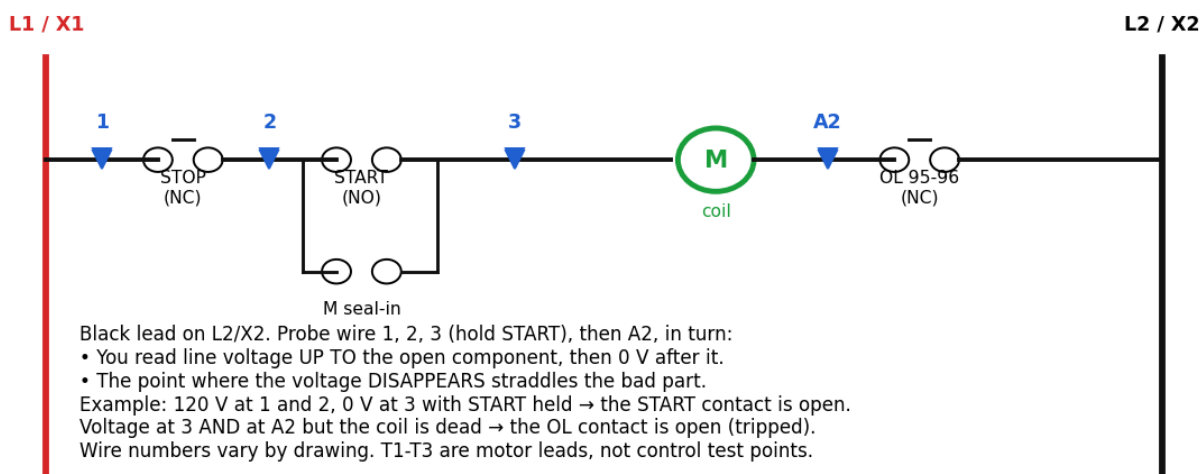
1. **Ask the operator what happened**, then read the evidence before anyone resets anything: the overload trip flag (orange flag on an Eaton C440, yellow window on an Allen-Bradley E1 Plus) and any drive or soft-starter fault code. Write it down.
2. **Read the motor nameplate and the starter or drive label** (sidebar, Part C).
3. **Check line voltage at the starter** "between L1 and L2, L2 and L3, and then between L3 and L1. If full voltage is found ... visually check the power circuit for loose connections" (NAVEDTRA 14027). It should be within 10 percent of the nameplate voltage.
4. **Press START**. Contactor pulls in: go to the power side and motor (Parts C, D). Silent: go to the control circuit (Part B). Hums but does not seat: low coil voltage, a broken shading coil, or dirt on the magnet faces (NAVEDTRA 14027 "Noisy magnet").
5. **With the contactor closed, read T1-T2-T3 at the motor**. "If there is no voltage, the trouble probably lies in the controller" (NAVEDTRA 14027).
6. **Voltage at the motor but it will not run**: lock out, uncouple the load, and try again. Fluke: "If the motor runs, the problem is with the load. If the motor does not run, the problem is with the motor."
7. Fix the cause, reset, run it, and record the amps on all three legs.

Tool	Use
CAT III true-RMS multimeter with a low-pass filter (for example Fluke 87V or 289)	Line, control, and drive output voltage
Clamp meter	Current on each leg
Insulation tester (for example Fluke 1587 FC, 50–1000 V; it will not test if more than 30 V is present)	Winding and cable insulation (Part F)
Phase-rotation tester and IR thermometer	Rotation; hot lugs and contacts

Voltage testing is arc-flash work. NFPA 70E (2024) Table 130.5(C) lists "work on energized electrical conductors and circuit parts, including voltage testing," "Working on control circuits with exposed energized electrical conductors and circuit parts, greater than 120 volts," and "Insertion or removal of individual starter buckets from motor control center (MCC)" as likely to cause an arc flash under any equipment condition. At 151 to 750 V the limited approach boundary is 3 ft 6 in and the restricted boundary is 1 ft 0 in. Troubleshooting and voltage testing need no energized-work permit (UFC 3-560-01), but PPE and boundaries still apply. NAVEDTRA 14027: "Controls with voltage over 240 volts should never be energized when you are troubleshooting." On 480 V line-voltage control, de-energize and use ohmmeter tests.

Part B — STEP-BY-STEP: Trace the Control Circuit

TRACING A MOTOR CONTROL CIRCUIT (find the open component)



Probe each point with the other lead on L2. Voltage disappears across the open device.

The probe points are named by **wire numbers**. In the standard 3-wire circuit (NAVEDTRA 14027) the STOP button sits between wires 1 and 2, the START button between 2 and 3, the M auxiliary (seal-in) contact across 2 and 3, the coil at 3, and the overload contact between the coil and L2. The coil and overload contact are "always located between line 1 and line 2." T1, T2, and T3 are the motor-lead terminals on the overload, so do not use those names for control test points. Wire numbers on real drawings vary; read the schematic in the door.

Step by step: voltage hopscotch

1. Wear the PPE on the label. Prove the meter on a known live source.
2. Put the black lead on L2 (or X2 on a control transformer). Leave it there.
3. Walk the red lead from L1 (or the load side of the control fuse, X1) to wire 1, then wire 2 (after STOP), then wire 3 (hold START), then the coil terminal A1.
4. You read line voltage up to the open device, then 0 V after it. The device where the voltage disappears is open. Example: 120 V at 1 and 2 but 0 V at 3 with START held means the START contact is open.
5. Voltage at A1 but the coil is dead: move the red lead to the coil's other terminal (A2). Voltage on both coil terminals means the overload contact (95-96) is open, usually tripped. "If there is voltage when the START button is pressed but the coil does not become energized, the coil is defective" (NAVEDTRA 14027).
6. Runs only while START is held: the seal-in contact (M across 2-3) or its wiring is bad.
7. Control fuse blows when you press START: grounded control wiring or a shorted coil.
8. Reversing starters and multiple stations: check every station and both directions.

Jumpers. NAVEDTRA 14027 shows jumping L1 to terminal 3 to bypass the buttons, and warns "a jumper should never be placed across a power-consuming device, such as a contactor coil." Live jumpering is energized work done only by the lead tech. "If an ohm-meter is used to test a coil for continuity, the power must be OFF."

Coils, auxiliary contacts, and timers

- **Coil ohms** (power off): an open coil reads infinite; shorted turns read low. Compare to a new coil with the same catalog number.
- **Coil volts** at A1-A2 while energized. Schneider: "Chatter in a starter can be caused by poor contacts in the control circuit, a chattering input device and low voltage."
- **Why coils fail** (NAVEDTRA 14027 Table 7-2): "Moisture; overvoltage; high ambient temperature; failure of magnet to seal in on pickup; too rapid duty cycle ... wrong coil." Order a replacement by "part number, voltage, and frequency" (Square D).
- **Auxiliary contacts and interlocks:** read across each contact live. Line voltage across it means open; about 0 V means closed.
- **Timer "Failure to time out":** "Mechanical binding; worn parts; motor damaged; no voltage to motor; dirt" (NAVEDTRA 14027).

Part C — Motor Symptoms

MOTOR SYMPTOM → CAUSE

HUMS but won't start

→ Single-phasing (lost a phase — meter all 3 at the motor) · jammed load · bad start cap (1Ø)

Overload keeps tripping

→ Genuine overload (high running amps vs FLA) · single-phasing · OL set too low · high ambient

Runs but hot / noisy

→ Overload · bad bearings · voltage unbalance · over/under voltage · misalignment

Won't start, no hum

→ No control voltage (trace the circuit) · open contactor coil · blown control fuse · disconnect open

Trips instantly / grounds

→ Winding-to-frame fault (MEGGER it) · shorted turns · wrong connection

Match the symptom to its short list of causes, and always meter all three phases at the motor.

Symptom	Causes
Hums, won't start	Single-phasing (lost a phase) · jammed load · bad start capacitor (single-phase motor) · bad bearings · low voltage
Overload keeps tripping	Genuine overload · single-phasing · unbalance · OL set wrong · wrong heater · high ambient · miswired leads
Runs hot/noisy	Overload · bad bearings · voltage unbalance · over/under voltage · blocked cooling · drive at low speed
Won't start, no hum	No control voltage (Part B) · open coil · blown control fuse · disconnect open · worn contacts
Trips instantly/ grounds	Winding-to-frame fault (megger, Part F) · shorted turns · wrong connection

Step by step: won't start

1. **Check fuses under load:** with the circuit energized, read across each fuse (line side to load side, same pole). About 0 V is good; line voltage means the fuse is open. An ohmmeter alone can pass a damaged fuse. UFC 3-560-01: "Fuses can be subject to partial melting or damage by currents that might not have been of sufficient magnitude to blow the fuse."
2. Check control power: the control transformer fuse and the voltage X1 to X2.
3. Check STOP, E-stop, interlocks, and the overload reset (Part B).
4. Check the coil volts and ohms.

5. With the contactor closed, read across each pole: L1 to T1, L2 to T2, L3 to T3. "It is not unusual for one or more contacts to wear to the degree that they will not make when closed" (NAVEDTRA 14027).
6. Read T1-T2, T2-T3, T1-T3 at the motor box.
7. Check for single-phasing (Part D).
8. Lock out, uncouple, and turn the shaft by hand. If it will not turn, suspect the bearings or the load.

Step by step: trips on overload

1. Do not reset again and again. Let the relay and the motor cool (the E1 Plus auto-reset takes about 120 seconds).
2. Clamp all three legs under normal load. Compare each to the nameplate FLA and to $FLA \times$ service factor.
3. Calculate current unbalance: $100 \times (\text{largest difference from the average}) \div \text{average}$. Fluke: it "should not exceed 10 percent."
4. Check the overload setting against the **nameplate**. NEC 430.6(A)(2): "motor nameplate current ratings shall be used to determine ... (1) Separate motor overload protection." Not the breaker size and not Table 430.250.
5. Check the trip class. Hard-starting, high-inertia loads may need Class 20 or 30. NEC 430.32(C) Informational Note: "A Class 20 overload relay will provide a longer motor acceleration time than a Class 10."
6. Check the ambient. NAVEDTRA 14027: "Trips too low — Wrong heater; relay in high ambient temperature." Heater ambient factors are in Module 1.6 Part D.
7. Check the heater number against the table "inside the control enclosure cover."
8. After a motor swap, check the 9-lead ties against the nameplate. Low-voltage (parallel) ties on 480 V roughly double the current (Module 1.6 Part C).
9. Compare coupled and uncoupled amps. Fluke: "If the current is excessive under load but not when unloaded, check the load."

Setting the overload: dial at nameplate FLA

NEC 430.32(A)(1) sets the most an overload may trip at: 125 percent of nameplate for motors with a service factor of 1.15 or more or a temperature rise of 40°C or less, and 115 percent for all others. If that will not start the motor or carry the load, 430.32(C) allows up to 140 and 130 percent. Hermetic refrigerant compressors are covered by 440.52(A)(1), no more than 140 percent of rated-load current. A 3-phase motor needs three overload units, "one in each phase" (Table 430.37).

Electronic overload relays already trip above their dial setting. Eaton C440: "1.05 x FLA: does not trip; 1.15 x FLA: overload trip." The Allen-Bradley E1 Plus: "Trip rating is 120% of dial setting."

Set the dial to nameplate FLA. The margin is built in. Adding 125 percent on the dial puts the real trip near 144 to 150 percent, which breaks 430.32.

Worked example 1 (overload dial). A 15 hp, 460 V motor, nameplate 19.5 A, service factor 1.15. Table 430.250 FLC is 21 A, so the inverse-time breaker is $21 \times 2.5 = 52.5$ A, next size 60 A. Maximum overload trip = $19.5 \times 1.25 = 24.4$ A.

Dial setting	C440 trips at ($\times 1.15$)	E1 Plus trips at ($\times 1.2$)	Within 430.32?
19.5 A (nameplate)	22.4 A	23.4 A	Yes, both under 24.4 A
24.4 A (125% added)	28.1 A = 144%	29.3 A = 150%	No, over even the 140% ceiling
60 A ("set to the breaker")	—	—	No. A single-phased motor at 34–39 A trips nothing

Worked example 2 (current unbalance). The same motor reads 20.1, 18.4, and 21.6 A. Average = 20.03 A. Largest difference = $21.6 - 20.03 = 1.57$ A, and 18.4 is 1.63 A below, so use 1.63 A. Unbalance = $100 \times 1.63 \div 20.03 = 8.2$ percent, under the 10 percent limit. The 21.6 A leg is above FLA (19.5 A) but below FLA $\times$ SF (22.4 A): check the load and the voltage balance.

Worked example 3 (voltage unbalance). Line voltages 474, 468, and 455 V. Average = 465.7 V. Largest difference = 10.7 V. Unbalance = $100 \times 10.7 \div 465.7 = 2.3$ percent. NEMA recommends 1 percent or less at the motor terminals. The DOE rule of thumb for extra temperature rise is $2 \times (\text{percent unbalance})^2$, here $2 \times 2.3^2 = 10.6$ percent. Current unbalance runs 6 to 10 times the voltage unbalance, about 14 to 23 percent here. Fluke: "Two to three percent voltage unbalance has the potential to cause a drive problem."

Hums but won't start

Cause	Test
Single-phasing	Line-to-line volts at the motor box with the contactor closed (Part D)
Locked rotor or jammed load	Lock out, uncouple, turn the shaft by hand
Bad capacitor (single-phase motor)	Discharge it, then measure microfarads; should be within ± 20 percent of the label (Fluke)
Bearings	Rough or seized shaft, noise, heat
Low voltage	More than 10 percent low during the start attempt
Centrifugal switch (single-phase)	"a distinct click should be heard ... as the motor slows down"

Capacitor test. Discharge it with a "15 to 20 kilohms resistor rated 5W or greater ... for at least 10 sec" (EC&M). A running capacitor can be checked with a clamp and meter: microfarads = $2652 \times \text{capacitor amps} \div \text{capacitor volts at 60 Hz}$. **Worked example 4:** a 7.5 μF capacitor reads 1.0 A at 350 V: $2652 \times 1.0 \div 350 = 7.6$ μF , which is good. An unsteady microfarad reading means internal arcing; replace it.

Runs hot

- **Unbalance** (worked example 3). "Every operating temperature increase of 10 °C halves the life of motor-winding insulation" (Fluke).
- **Blocked cooling**: "Clean all ventilation openings."
- **Running in the service factor**: "An induction motor operated at any service factor greater than 1.0 will have a reduced life expectancy" (NEMA MG 1, quoted by ABB).
- **Drive at low speed**: 430.126 Informational Note, overheating "can occur when operated at reduced speed, even at current levels less than a motor's rated full-load current," because the shaft fan turns slower.
- **A hot lug or contact upstream** shows up as voltage unbalance at the motor. IR-scan the disconnect and starter.

Sidebar: reading the nameplate for troubleshooting

Nameplate item	What it tells you
FLA	The overload dial setting
Service factor (SF)	Maximum continuous amps = FLA × SF
Insulation class	Allowed rise over 40°C ambient (by resistance): B 80°C, F 105°C, H 125°C
Code letter	Locked-rotor kVA per hp (Table 430.7(B), Module 1.6)
Design letter	Torque and slip type
Voltage and connection diagram	Check the lead ties
Inverter duty / NEMA MG 1 Part 31	Suited to drives with long leads

Rotation: swap any two line leads to reverse a motor on a starter (Module 1.6). UFC 3-560-01: "After work has been performed on circuits to rotating machines, check direction of rotation."

Part D — Single-Phasing: the Silent Motor-Killer

Lose one phase and a running 3-phase motor "single-phases." It hums and won't start, or keeps running on two phases at very high current, cooking the windings. Bussmann: "When secondary single-phasing occurs, current in the remaining phases increases from 173% to 200% of the motor's rated full-load current." Breakers "do not provide single-phasing protection": a breaker sized at 250 percent will not open at 173 to 200 percent. A correctly set overload in each phase should catch it.

Causes (Bussmann): "The utility loses one phase; Overheated conductor termination; Disconnect does not 'make' one pole; Controller contact burns open." A single-phased winding shows one burned phase group when the motor is torn down. EASA: "The open is usually caused by a blown fuse, an open contactor, a broken power line or bad connections."

Step by step

1. **Running:** clamp all three legs. One leg near zero and two high means single-phased.
2. **Stopped or humming:** read line-to-line volts at the motor with the contactor closed.
3. **Walk upstream:** across each contactor pole, the overload, across each fuse, the disconnect line side, then the feeder.
4. **Find why the fuse opened:** megger the motor and leads (Part F). Confirm all three fuses are the same class and rating.
5. **Replace fuses as a matched set** and check the clips. NAVEDTRA 14027 lists "copper oxide on ferrules and clips" as a cause of premature blowing.
6. **Megger the motor before condemning it.** It may be fine; the cause was upstream.
7. **Prevent it** with an electronic overload that has phase-loss protection (the C440 trips at 50 percent phase loss; the E1 Plus typically in 3 seconds) or a phase-monitor relay.

Part E — MCC Buckets & VFDs

Step by step: an MCC bucket (de-energized)

1. Read the MCC label (bus rating, short-circuit rating, source, 430.98(A)) and the arc-flash label. UFC 3-560-01 lists a 600 V MCC at PPE Category 2 with a 5 ft boundary (65 kA or less, 2 cycles) or Category 4 with a 14 ft boundary (42 kA or less, 20 cycles). The label on the gear takes precedence.
2. Handle OFF. Withdraw the bucket only as the site program allows; it is an arc-flash task (Part A).
3. Test for absence of voltage (NFPA 70E 120.6).
4. Ohmmeter checks: the coil; each pole with the contact carrier pushed in by hand; heater continuity on each phase; 95-96 closed when reset.
5. Contacts: Square D: "Discoloration and slight pitting do not harm the contacts. Do not file the contacts ... Replace the contacts only when worn thin." NAVEDTRA 14027: "Do not file silver tips."
6. Check the control fuses against the unit drawing.

Replacing contacts, coils, and overloads

1. Square D Class 8536: "Disconnect all power. Do not remove any wiring." Loosen the captive screws and lift the actuator.
2. Contacts: "You must replace all three movable contacts and springs and all six stationary contacts."
3. Coil: disconnect the leads, remove the magnet, coil, and armature, fit the new coil, "Manually operate the contact carrier and insert the complete unit." Torque to the values in the bulletin.
4. Operate it by hand before closing up.

5. **Eaton C440 overload:** match the FLA range and starter size, set the dial to nameplate FLA, set the DIP switches for class, unbalance, ground fault, and reset mode, press TEST and confirm 95-96 opens, then reset.
6. **A-B E1 Plus overload:** mount it to the matching 100-C contactor, set the dial to FLA, select the class. "Do not use automatic reset mode in applications where unexpected automatic restart of the motor can cause injury."

VFD fault codes (PowerFlex 520 example; codes differ by brand)

Read the code, look it up, and find the cause before resetting. Check that Auto Restart is off, or intended, before you reset.

Code	Manual text	First checks
F004 UnderVoltage	"DC bus voltage fell below the minimum value"	Input voltage, input fuses, sags
F005 OverVoltage	"Bus overvoltage can also be caused by motor regeneration. Extend the decel time or install dynamic brake option."	Decel time, high line voltage
F007 Motor Overload	"Internal electronic overload trip"	Load; [Motor OL Current] parameter set to nameplate
F012 HW OverCurrent	"output current has exceeded the hardware current limit"	Jam, boost setting, shorted leads
F013 Ground Fault	"A current path to earth ground has been detected at one or more of the drive output terminals"	Megger the motor and cable with the leads lifted (Part F)

The bus regulator prevents "nuisance overvoltage faults resulting from aggressive decelerations, overhauling loads" by stretching the decel time, and a Stall fault occurs if it is held for 1 minute; "a properly sized dynamic brake resistor will provide equal or better performance in most cases."

Measuring on a drive

- A plain true-RMS meter reads drive output "as much as 20 to 30% higher than what the drive controller is indicating." Use the meter's low-pass filter. The three output line-to-line readings should agree within 1 percent (Fluke 87V note); output unbalance over 2 percent is a problem.
- **DC bus** $\approx 1.414 \times$ input line-to-line volts. Fluke: "For a 480 volt input, the dc bus should be approximately 679 VDC." **Worked example 5:** at a high line of 504 V, $1.414 \times 504 = 713$ V DC.
- Bus ripple above 40 V points to failing capacitors or an undersized drive. Uneven ripple peaks point to a bad input diode. Voltage drop from drive to motor should be 3 percent or less.
- **Long motor leads** raise charging current and "can lead to nuisance faults from the drive, such as an earth fault" (ABB). About 50 ft is a starting point for a dV/dt filter on motors that are not inverter-duty.

- **Carrier frequency:** with 150 ft of cable, ABB shows insulation life dropping "from 100,000 hours to 25,000 hours, when carrier frequency is increased from 3 to 12 Khz." Use "the lowest setting at which the sound level is acceptable."
- **Bypass:** a bypass circuit needs its own overload (430.124(B)). Trips in drive mode only: look at the drive and its settings. Trips in both: look at the motor and load.

Step by step: locking out a VFD (NFPA 70E 120.6 order)

1. Identify all sources, including the bypass feed and any external control power.
2. Open the disconnects.
3. Verify the blades are open.
4. Release stored electrical energy: wait for the DC bus capacitors (below).
5. Block stored mechanical energy per the site procedure.
6. Apply lockout/tagout (OSHA 1910.147).
7. Test for absence of voltage, including the DC bus.

Drive	Manual instruction
Allen-Bradley PowerFlex 520	"wait three minutes ... verify ... voltage L1, L2, L3 (Line to Line and Line to Ground) ... DC voltage across DC- and DC+ bus terminals ... keep the meter on the terminals until the [voltage] discharges to zero volts." "Darkened display LEDs is not an indication that capacitors have discharged."
ABB ACH580	"always wait for 5 minutes to let the intermediate circuit capacitors discharge," then measure L1-L3 and UDC+/UDC- to PE, "close to 0 V," with a meter of "at least 1 Mohm"

Wait times differ by model. Read the drive label or manual, wait the full time, then meter the bus anyway.

Soft-starter faults (Allen-Bradley SMC Flex example)

Code	Fault	Manual action
1-3	Line Loss	"Check for line and load loose connections. Check for open line (e.g., blown fuse)."
4-6	Shorted SCR	Resistance check per the manual's power module check, or replace the power module
7-9	Open Gate	Resistance check; gate leads seated (the starter retries three times first)
21	Overload	"Check programmed values for overload class and motor FLC; verify current draw"
23	Jam	"Correct source of jam or excessive loading"
24	Stall	Motor "did not reach full speed by the end of the programmed ramp time"

Part F — STEP-BY-STEP: Winding Insulation and Resistance Tests

1. Lock out and test for absence of voltage.
2. **Isolate the electronics.** Rockwell: "Do not perform any Megger test on a motor or motor leads without disconnecting the motor leads at the motor lead terminals on the drive. Failure to do so will result in damage to the drive." Schneider: a megger test "may not be done on a drive." Also disconnect soft starters, surge devices, power-factor capacitors, and control transformers.
3. **Megger the leads and motor together** at 500 V DC for 60 seconds (windings rated under 1000 V, IEEE 43). If the reading is low, split at the motor box and test the motor and the cable separately.
4. **Record the winding temperature.** Insulation resistance drops as the winding warms, so readings are corrected to 40°C before comparing. Use the tester's temperature compensation or the IEEE 43 correction curve.
5. **Compare to the minimum.** IEEE 43 minimum at 40°C: 5 megohms for random-wound and form-wound motors under 1 kV. Also compare to the last reading; a falling trend matters.
6. **Polarization index (PI)** for large, form-wound, or borderline windings: the 10-minute reading divided by the 1-minute reading. Minimum 2.0 for Class 130 (B) insulation and above, 1.5 for Class 105 (A). PI "may not apply to small random winding machines" and is not recommended when the 1-minute reading is over 5000 megohms.
7. **Discharge:** let the tester discharge the winding, then ground it. IEEE 43: ground the winding at least 4 times as long as it was charged.
8. **Winding resistance** with a low-ohm meter on the three pairs T1-T2, T2-T3, T1-T3. Random windings should be within 2 percent of the average (1 percent for form coils; EASA AR100 notes "Some concentric windings may exceed the 2% limit").

Worked example 6 (megger). A 480 V motor reads 40 megohms at 1 minute at a winding temperature of 20°C. Corrected to 40°C, the reading will be lower, roughly 10 megohms if resistance halves for each 10°C (a rough rule; use the tester's compensation for the real number). That is above the 5 megohm minimum, so it passes.

Worked example 7 (PI). 1-minute reading 120 megohms, 10-minute reading 300 megohms: $PI = 300 \div 120 = 2.5$, above the 2.0 minimum.

Worked example 8 (winding resistance). 0.842, 0.851, and 0.868 ohms. Average = 0.854 ohms. Largest difference = 0.014 ohms. $0.014 \div 0.854 \times 100 = 1.7$ percent, inside the 2 percent limit for a random winding.

Never start a megger test with outside voltage in the circuit. Army TM 5-682: "Never start a megohm test if there is any external voltage in the test circuit." The Fluke 1587 FC will not test if more than 30 V is present.

Common Mistakes

Mistake	Why it matters
Replacing a motor that was single-phased by a fuse	The motor may be fine; the cause is upstream. Megger first.
OL dial set to the breaker rating	The breaker is 175–250% of FLC; the OL must trip at 115–125% of nameplate
Adding 125% on the dial	The relay already trips at 115–120% of the dial
Meggering through a VFD or soft starter	Destroys the power electronics; the reading means nothing
Unfiltered meter on drive output	Reads 20–30% high
Dark display taken as a dead drive	The bus stays charged for minutes
Checking fuses only with an ohmmeter	Partially damaged fuses pass
Filing silver contacts	Removes contact material
Auto-reset overload on 2-wire control	Unexpected restart
Resetting a drive fault without reading it	It repeats; F013 means a ground fault exists
Calling control test points T1–T4	T1–T3 are motor leads; use wire numbers

NEC 2026 Checkpoints (Article 430 and 440 numbering unchanged from 2023)

- **430.6(A)(1)** table FLC for conductors, switches, and short-circuit protection • **430.6(A)(2)** nameplate current for overloads • **430.7** nameplate marking.
- **430.32(A)(1)** overload maximum 125% / 115% of nameplate • **430.32(C)** up to 140% / 130% if needed • **430.36, Table 430.37** one overload in each phase.
- **430.52** branch short-circuit protection, "capable of carrying the starting current of the motor" • **430.98(A)** MCC marking.
- **430.102(A)** disconnect in sight • **430.103** opens all ungrounded conductors • **430.107** readily accessible.
- **430.122(A)** drive input conductors 125% • **430.124** drive overload and bypass • **430.126** low-speed heating • **430.128** drive disconnect 115%.
- **440.52(A)(1)** compressor overload 140% of rated-load current • Table **430.250** (460 V: 10 hp 14 A, 15 hp 21 A, 20 hp 27 A).

Hands-On Field Exercise

- Voltage-trace a control circuit that won't energize using wire numbers, and find the open device.
- Diagnose a motor that hums but won't start by metering all three phases at the motor and walking upstream.

- Compute current unbalance from three clamp readings and voltage unbalance from three voltage readings.
- Set an electronic overload dial from the nameplate and calculate where it will actually trip.
- Test an MCC bucket's contactor coil, poles, heaters, and overload contact de-energized.
- Megger a motor at 500 V DC with the leads lifted from the drive, record the temperature, and check winding resistance on three pairs.
- On a running drive, read the DC bus and the filtered output voltage and compare them to the keypad. Read a fault code and find its cause.

Sources used in this module (public documents)

- NFPA 70, National Electrical Code 2026 (free read-only access at [nfpa.org](https://www.nfpa.org)): Articles 430 and 440. NFPA 70E, 2024 edition, 120.6 and Table 130.5(C).
- NAVEDTRA 14027 Construction Electrician Intermediate, Chapter 7, pp. 7-16 to 7-27 (controller troubleshooting): maritime.org/doc/pdf/
- UFC 3-560-01 Electrical Safety, O&M (Change 3, 2023): [wbdg.org](https://www.wbdg.org). Army TM 5-682 Facilities Engineering, Electrical Facilities Safety. OSHA 29 CFR 1910.147: [osha.gov](https://www.osha.gov)
- Eaton Bussmann series, Selecting Protective Devices; Motor Protection: single-phasing and voltage unbalance; Eaton C440 overload relay instructions IL04210001E and manual MN04210004: [eaton.com](https://www.eaton.com)
- Rockwell Automation: PowerFlex 520-series manual 520-UM001; SMC Flex manual 150-UM008; E1 Plus 193-IN039 and 193-TD011; Knowledgebase 42078 (meggering a motor): [rockwellautomation.com](https://www.rockwellautomation.com)
- ABB: ACH580 hardware manual 3AXD50000289554; Technical Notes on voltage stress, drive sound, and motor cable distance; NEMA nameplate guide 9AKK108388: library.e.abb.com
- Schneider Electric / Square D: Class 8536 Series C instruction bulletin; FAQs FA120094 and FA230269: [se.com](https://www.se.com)
- Fluke application notes on motors, drives, voltage unbalance, and single-phase motors; Fluke 87V, 289, and 1587 FC documents: [fluke.com](https://www.fluke.com)
- U.S. DOE Motor Systems Tip Sheet 7, Eliminate Voltage Unbalance: [energy.gov](https://www.energy.gov)
- IEEE 43-2013, Recommended Practice for Testing Insulation Resistance of Electric Machinery: [ieee.org](https://www.ieee.org). ANSI/EASA AR100-2020 and EASA technical articles: [easa.com](https://www.easa.com)
- EC&M, Capacitor Testing for Electric Motors: [ecmweb.com](https://www.ecmweb.com)

Next: Module 2.7 — Verifying Grounding & Bonding Integrity.