

Module 1.6 — Motors, Controls & Motor Control Centers

The six-part motor circuit sized start to finish, then step by step: 9-lead connection, starter wiring and heater selection, MCC bucket install, and checkout.

Why this module. Motors are the biggest and most demanding loads in a commercial building. Every rooftop unit, pump, and compressor is a motor with a control circuit. The motor circuit has its own article (430) and its own sizing rules because of the starting surge. This module sizes a motor circuit start to finish with worked examples, then walks step by step through connecting a 9-lead motor, wiring a starter and picking its overload, installing an MCC bucket, and checking it all out before the motor runs.

Part A — The Motor Circuit Has Six Parts (NEC 430)

Part	Job	Rule	NEC 2026
Disconnect	Isolates the motor	"In sight from the motor controller location." Rated at least 115% of FLC	430.102, 430.110
Branch short-circuit and ground-fault protection	Clears faults; rides through starting	Sized HIGH. Must be "capable of carrying the starting current of the motor"	430.52
Conductors	Feed the motor	125% of FLC	430.22
Controller (starter)	Starts and stops	"Horsepower ratings at the application voltage not lower than the horsepower rating of the motor"	430.83(A) (1)
Overload	Protects against running overcurrent	Close to the nameplate amps	430.32
Motor	The load	Per nameplate	—

FLC vs. nameplate FLA (430.6). To size conductors, switches, and short-circuit protection, the table values (Tables 430.247 through 430.250) "shall be used instead of the actual current rating marked on the motor nameplate." Use the **nameplate FLA** only for the overload. Sizing from the nameplate instead of the table is one of the most common motor-circuit mistakes: a replacement motor with higher amps leaves the wire undersized.

- **Code letter** on the nameplate = locked-rotor kVA per horsepower (Table 430.7(B), A = lowest through V = highest). It tells you how hard the motor hits the line on starting.
- **Locked-rotor amps** (Table 430.251(B), 460 V): 10 hp 81 A, 25 hp 183 A, 30 hp 218 A. Use these to check that a horsepower-rated switch or controller can handle the start.

Worked example 1: a 10 hp, 460 V, Design B motor, service factor 1.15, nameplate 12.8 A

Step	Rule	Math	Result
FLC	Table 430.250	—	14 A
Conductor	430.22, 125%	$14 \times 1.25 = 17.5 \text{ A}$	14 AWG Cu is 20 A at 75°C; many shops use 12 AWG minimum
Inverse-time breaker	430.52, 250%	$14 \times 2.5 = 35 \text{ A}$	35 A
Dual-element fuse	430.52, 175%	$14 \times 1.75 = 24.5 \text{ A}$	25 A (next standard size)
Overload (max trip)	430.32, 125% of nameplate	$12.8 \times 1.25 = 16.0 \text{ A}$	Trip no higher than 16.0 A
Disconnect	430.110, 115% of FLC	$14 \times 1.15 = 16.1 \text{ A}$	30 A horsepower-rated switch, 10 hp or more at 480 V
Controller	430.83	at least 10 hp	NEMA Size 1 (0.125–10 hp at 480 V)

Worked example 2: a 25 hp, 460 V motor, SF 1.15, nameplate 31 A, plus a feeder for both motors

Step	Math	Result
FLC (Table 430.250)	—	34 A
Conductor, 125%	$34 \times 1.25 = 42.5 \text{ A}$	8 AWG Cu (50 A at 75°C)
Inverse-time breaker, 250%	$34 \times 2.5 = 85 \text{ A}$, not a standard size	90 A (next size up allowed, 430.52(C)(1)(a))
Dual-element fuse, 175%	$34 \times 1.75 = 59.5 \text{ A}$	60 A
Overload max trip, 125% of nameplate	31×1.25	38.75 A
Disconnect, 115%	$34 \times 1.15 = 39.1 \text{ A}$	60 A HP-rated switch, 25 hp or more
Controller	at least 25 hp	NEMA Size 2 (15–25 hp at 480 V)
Feeder for both motors (430.24)	$1.25 \times 34 + 14 = 56.5 \text{ A}$	6 AWG Cu (65 A at 75°C)
Feeder breaker (430.62(A))	largest branch breaker + other FLCs = $90 + 14 = 104 \text{ A}$	100 A maximum. Rounding up does not apply to motor feeders

Part B — Two Protections, Sized Differently

Protection	Sizing (% of FLC for branch, % of nameplate FLA for overload)
Branch short-circuit/ground-fault (Table 430.52(C)(1), squirrel-cage)	Inverse-time breaker 250% · dual-element (time-delay) fuse 175% · non-time-delay fuse 300% · instantaneous-trip breaker 800% (1100% for Design B energy-efficient)
If the motor still won't start (430.52(C)(1)(b))	Inverse-time breaker up to 400% (FLC 100 A or less) or 300% (over 100 A); dual-element fuse 225%; non-time-delay fuse 400%
Overload (430.32(A)(1)), maximum trip	125% of nameplate for service factor 1.15 or more, or temperature rise 40°C or less; 115% for all others

The breaker or fuse handles the fault and lets the motor start. The overload handles running protection. The overload relay must be backed up by the 430.52 device (430.40). And if the starter's cover label lists a maximum fuse or breaker, that maximum "shall not be exceeded even if higher values are allowed" (430.52(C)(2)).

Setting the overload: dial at nameplate FLA, not 125 percent of it. The 125 and 115 percent in 430.32 are the most the overload may trip at. Overload relays already build that margin in: Eaton's C440 trips at about 1.15 times its dial setting and Allen-Bradley's E1 Plus at about 1.2 times. Set the dial at 125 percent of FLA and the real trip lands around 144 to 150 percent, which breaks 430.32. For heater-type starters, the Square D selection method uses **100 percent of nameplate FLA for 1.15 to 1.25 service factor motors and 90 percent for 1.0 service factor motors.**

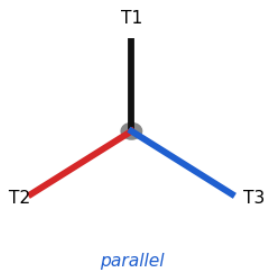
- **Trip class:** Class 10, 20, or 30 means the relay trips within 10, 20, or 30 seconds at 600 percent of its rating. Class 20 is the NEMA standard. At 6 times FLA, Square D lists Class 10 tripping in about 2 seconds, Class 20 in 9, Class 30 in 13.
- **Coordination:** "NEMA standards require that contactors be able to interrupt currents up to 10 times full load current. Therefore, it is acceptable for the overload relay to respond before the short-circuit protector up to this level."
- **Auto-reset overloads with 2-wire control** make the motor cycle on and off until "eventually the motor will burn out," and it can restart on someone working on it. Use manual reset where restart is a hazard.
- **Control circuit protection (430.72):** a tapped control circuit is not a branch circuit and is protected per Table 430.72(B). Inside the enclosure protected by the branch device (Column B): 18 AWG 25 A, 16 AWG 40 A, 14 AWG 100 A. A ground fault in the control circuit must "not start the motor" and "not bypass manually operated shutdown" (430.74).

Part C — STEP-BY-STEP: Connecting a Dual-Voltage 9-Lead Motor

DUAL-VOLTAGE 9-LEAD MOTOR (Wye) — read the nameplate

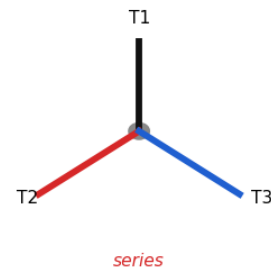
LOW VOLTAGE (e.g. 208/240V) — PARALLEL

L1→T1+T7 L2→T2+T8 L3→T3+T9
tie together: T4-T5-T6



HIGH VOLTAGE (e.g. 480V) — SERIES

L1→T1 L2→T2 L3→T3
tie: T4-T7, T5-T8, T6-T9 (internal T7-T8-T9 = star)



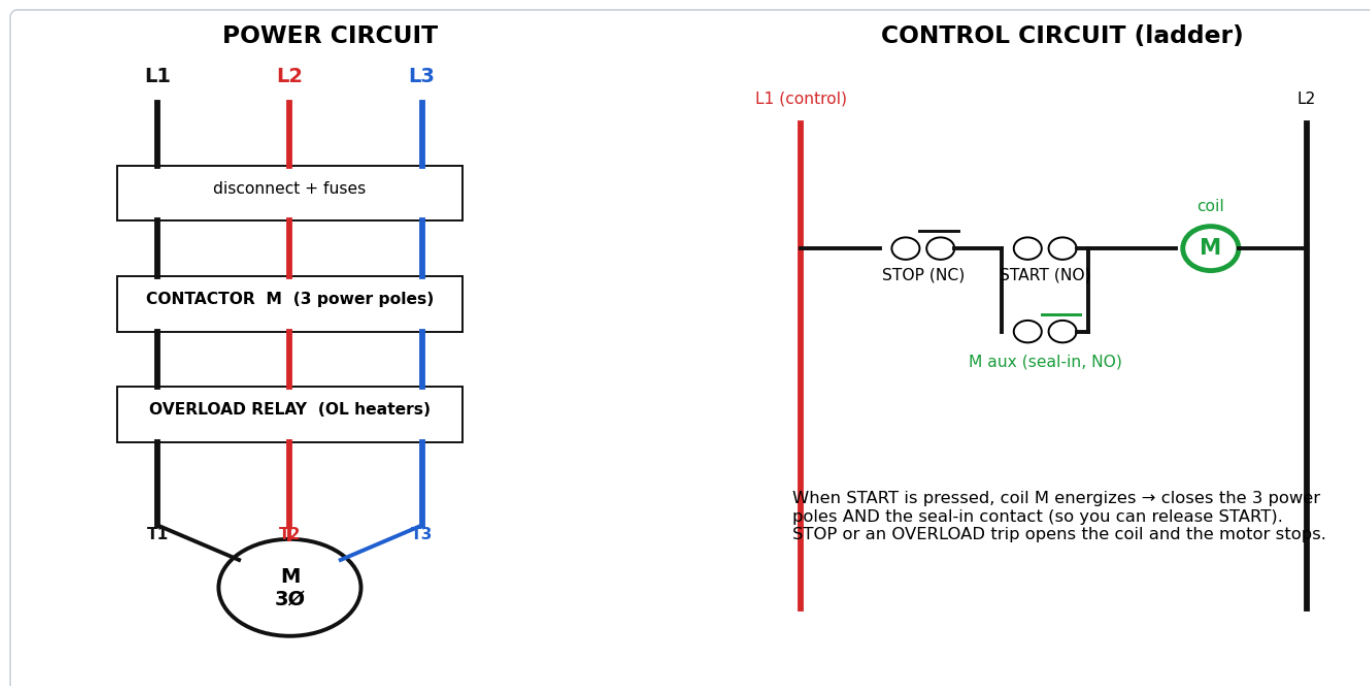
Same 9 leads, two ways to connect — the nameplate diagram is the authority. Wrong connection = burned motor.

PARALLEL for low voltage, SERIES for high voltage. The nameplate diagram is the authority.

1. **Lock out and verify.** Lock out per OSHA 1910.147 and test for absence of voltage at the point of work, live-dead-live (NFPA 70E 120.6).
2. **Open the conduit box** and read the lead tags T1 through T9. If the tags are gone, ring them out with an ohmmeter. On a wye motor you find three pairs (T1-T4, T2-T5, T3-T6) and one group of three (T7-T8-T9). On a delta motor you find three groups of three.
3. **Measure the supply voltage** and find the matching diagram on the nameplate.
4. **Make the connection** (NAVEDTRA 14026, wye-connected motor):
 - **Wye HIGH (series, e.g. 480 V):** "Connect T6 and T9 ... Connect leads T4 and T7. Connect T5 and T8. Connect leads T1, T2, and T3 to the three-phase line."
 - **Wye LOW (parallel, e.g. 208/240 V):** "Connect lead T7 to T1 and to line lead L1. Connect lead T8 to T2 and to line lead L2. Connect lead T3 to T9 and line lead L3. Connect T4, T5, and T6 together."
 - **Delta HIGH:** T4-T7, T5-T8, T6-T9; T1, T2, T3 to L1, L2, L3. **Delta LOW:** L1 = T1+T7+T6, L2 = T2+T4+T8, L3 = T3+T5+T9.
5. **Make up and insulate** with lugs and bolts or listed connectors. Baldor: "Flying leads must be insulated with two full wraps of electrical grade insulating tape or heat shrink."
6. **Land the equipment ground** on the frame screw. Close the box.
7. **Megger the windings** if the motor was stored or got wet (Part F).
8. **Bump it uncoupled** and check rotation (Part D). To reverse, swap any two line leads.

Read the nameplate, then read it again. A motor connected for low voltage and run on 480 V draws about double the current and burns its windings in seconds. Other common mistakes: landing T4-T5-T6 on the lines instead of tying them together, not re-tagging the leads after a rewind, and swapping only one lead when reversing.

Part D — STEP-BY-STEP: Wiring an Across-the-Line Starter



Power: disconnect → contactor → overload → motor. Control: 3-wire START/STOP with the M seal-in.

The standard terminal numbers (NAVEDTRA 14027)

- Lines are L1, L2, L3. The overload elements are in the motor leads T1, T2, T3.
- Control power comes from L1 and L2, with the switching (buttons) in L1 and the coil and overload contact on the L2 side. If one line is grounded, it is L2.
- 3-wire control: STOP (normally closed) between 1 and 2, START (normally open) between 2 and 3, the M auxiliary contact across 2 and 3, the coil at 3, and the overload contact between the coil and L2.
- Reversing starters swap L1 and L3.

"When the START button is pressed, coil M is energized across L1 and L2. This action closes contact M to place a shunt circuit around terminals 2 and 3, the START button." That shunt is the **seal-in**. Three-wire control drops out on a power loss and stays off. Two-wire control (a thermostat or float switch) restarts by itself when power returns. Square D: "Three wire control is recommended when automatic restarting of a motor could be hazardous to personnel."

Step by step

1. Confirm the starter's horsepower and voltage rating is at least the motor's (430.83), and check its short-circuit rating (430.8).
2. Land L1, L2, L3 on the contactor line side. Torque to the label on the starter.
3. From the overload load side, run T1, T2, T3 to the motor in A-B-C order.
4. Install the thermal units (heaters) or set the overload dial (below).
5. Wire the control: L1 (or the fused control transformer X1) → STOP 1-2 → START 2-3 → coil → overload contact → L2 (or X2), with the M auxiliary across 2-3. With a control transformer, remove the L2 jumper, but "the overload relay control contact must be included in the separate control wiring."
6. Wire pilot lights off an M auxiliary contact if used.
7. With the motor leads lifted: START pulls in and seals. STOP drops it out. The overload test button drops it out.
8. Reconnect the motor and bump it.

Step by step: picking heaters (Square D method)

1. Get the motor's nameplate full-load current and service factor.
2. For 1.15 to 1.25 service factor motors use 100 percent of nameplate FLA. For 1.0 service factor motors use 90 percent.
3. If the motor and starter are in different temperatures, multiply by the table factor (0.9 if the motor is 10°C hotter than the controller, 1.05 if it's cooler).
4. Find the range in the starter's heater table that contains that current. "The proper thermal unit number will be found adjacent, to the right of the range." Heaters are "selected on the basis of motor full load current, not horsepower." Every manufacturer has its own table.
5. Install each heater with its catalog number visible. On melting-alloy units, the ratchet wheel must engage the pawl.

Worked example 3. A motor with 14 A FLA and 1.15 service factor on a Square D 8536 SCG3 starter: use 100 percent = 14 A, which falls in the range for heater **B22**.

Step by step: the first start (Baldor manual)

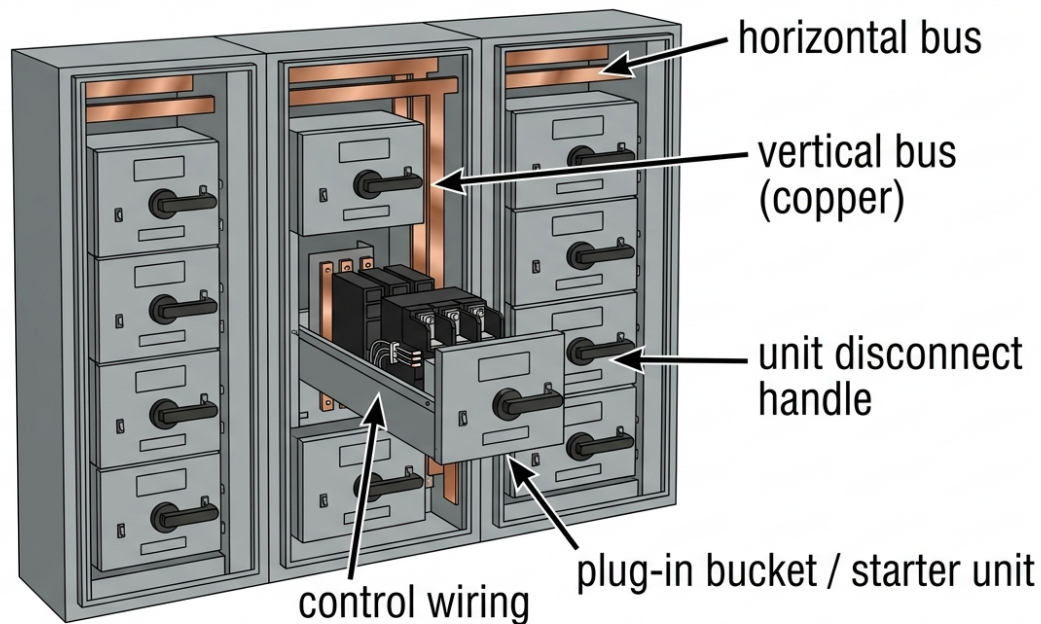
1. "Be sure the motor shaft is disconnected from the load."
2. "Manually rotate the motor shaft to ensure that it rotates freely." Replace all panels and covers.
3. "Momentarily apply power and check the direction of rotation of the motor shaft."
4. "If motor rotation is wrong, be sure power is off and change the motor lead connections."
5. "Start the motor and ensure operation is smooth without excessive vibration or noise." Run it an hour uncoupled if the manual calls for it, then couple it. Coupled: "Do not exceed the name plate ratings for amperes."

When the starter misbehaves (NAVEDTRA 14027 Table 7-2)

Symptom	Likely cause
Fails to trip on overload	Heater too large, mechanical binding, relay damaged by a past short, dirt, corrosion, motor and relay in different temperatures
Trips too low	Wrong heater, relay in a hot location
Noisy magnet	Broken shading coil, magnet faces not true, dirt on the faces, low voltage
Coil pulls in but motor is dead	Check T1, T2, T3 and the motor
Coil won't pull in	Check the control circuit

Part E — STEP-BY-STEP: Installing an MCC Bucket

MOTOR CONTROL CENTER (MCC)



Copper bus, plug-in buckets, unit disconnect handles, control wiring.

A motor control center (MCC) is a lineup of sections with a horizontal bus feeding vertical buses, and plug-in "buckets" that each hold a starter. On a Rockwell CENTERLINE 2100: 90-inch sections hold units in 6.5-inch steps, up to twelve per section. The horizontal bus is 600 to 3200 A, the vertical bus 300 or 600 A. The unit stabs are tin-plated copper, spring-backed, and "designed to tighten during heavy current surges." The MCC nameplate carries its bus rating and short-circuit rating (430.98(A)). Phases run A-B-C front to back, top to bottom, or left to right, with B as the high leg on a 4-wire delta (430.97(B)).

The bucket interlocks (Rockwell)

- Units "cannot be inserted or withdrawn when the disconnect means is in the ON/I position."
- "The disconnect means cannot be switched to the ON/I position unless the door is closed. This interlock also prevents you from opening the unit door unless the disconnect is in the OFF/O position." An externally operated defeater exists for qualified persons only.
- Shutters cover unused stab openings.

Inserting or removing a bucket is an arc-flash task. NFPA 70E (2024) Table 130.5(C) lists "Insertion or removal of individual starter buckets from motor control center (MCC)" as likely to cause an arc flash under any equipment condition. Our rule: de-energize and lock out the MCC main or the section feeder, unless the site arc-flash study and an energized-work permit say otherwise. PPE per the label.

Step by step

1. Read the MCC nameplate (bus amps, short-circuit rating, voltage) and match the bucket to it.
2. Lock out the MCC main or section feeder. Verify absence of voltage at the vertical bus.
3. Bucket handle OFF. Open the door. Remove the shutter cover from the space.
4. Set the bucket on its support pan, line up the stab housing, and push it in until the latch engages. Confirm the ground stab is engaged.
5. Land T1, T2, T3 and the control wiring on the unit's terminal blocks per the schematic.
6. Install heaters or set the overload dial at nameplate FLA, catalog number visible.
7. Close the door, engage the handle, and fit the engraved nameplate.
8. Remove the lockout, energize, and run the checkout (below).

Single-phasing: lose one phase and a running motor pulls high current on the other two and cooks. Melting-alloy relays can be slow to catch it on a lightly loaded motor; solid-state relays trip in under 3 seconds. Clamp all three phases at T1, T2, T3. More than 10 percent current unbalance means find the open or the voltage unbalance.

Part F — Motor Checkout and Megger Test

Megger the windings

1. Lock out. Lift T1, T2, T3 at the starter so you test the motor alone.
2. Test at 500 V DC for windings rated under 1 kV. Each phase to the frame for 60 seconds.
3. Discharge the winding after each test. Never start a megger test with outside voltage present in the circuit.
4. Accept: IEEE 43 / NETA minimum for random-wound motors under 1 kV is **5 megohms**. Baldor: "Minimum resistance of motor winding insulation is 5 Meg ohms or the calculated minimum, whichever is greater." In storage, a reading that drops below 50 percent of the first reading needs attention.

Checkout sequence

1. Nameplate matches the drawings: hp, volts, FLA, service factor, code letter.
2. Breaker or fuse no larger than Table 430.52 and no larger than the starter cover maximum.
3. Disconnect in sight (430.102), horsepower-rated, at least 115 percent (430.109, 430.110).
4. Overload set at nameplate FLA, or the right heater installed.
5. Motor leads lifted: control voltage right, STOP, overload test, and every safety drop it out, seal-in holds.
6. Megger if stored or wet (5 megohms or more at 500 V DC).
7. Reconnect, bump uncoupled, verify rotation.
8. Run uncoupled, then coupled. Clamp amps on all three phases and compare to the nameplate. Check voltage balance (Module 1.0B). Listen for a noisy magnet or vibration.
9. Record: breaker, wire size, overload setting or heater number, amps per phase, megger readings, rotation.

VFDs and soft starters (sidebar)

- **Drive input conductors:** "not less than 125 percent of the rated input current to the power conversion equipment" (430.122(A)). Drive-to-motor conductors: at least 125 percent of motor FLC (430.122(B)(1)). The disconnect may be in the incoming line, rated at least 115 percent of the drive's input current (430.128).
- **Overload:** no separate overload if the drive is marked as providing it, but a bypass circuit needs its own overload (430.124).
- **Motor heating:** 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 (430.126 Informational Note).
- **Cable** (Rockwell drive wiring guide): copper only, sized at 75°C. XLPE (XHHW-2) instead of THHN, because the drive's voltage spikes can break down PVC insulation. Shielded cable for sensitive areas, many drives, or long runs. Up to 200 hp, one full-size ground; above 200 hp, three symmetrical grounds. "Shields of motor and input cables must be bonded at both ends," control shields at one end only. No splices in motor cable. Consider a reflected-wave reducer on runs over 50 feet.
- **Soft starters** ramp the voltage with SCRs to cut the 6 to 10 times FLA starting current, then a bypass contactor closes at full speed. They give no speed control.
- The Army electrical safety manual: VFDs "should generally be maintained by manufacturer's personnel." Module 2.6 covers drive troubleshooting.

Common mistakes

Mistake	Why it matters
Sizing wire and breaker from the nameplate instead of Table 430.250	Undersized when the motor is replaced
Overload dial set at 125% of FLA	Real trip lands near 150%, over 430.32
100% heater on a 1.0 service factor motor	Oversized heater, reduced protection
Auto-reset overload with 2-wire control	Cycling burnout and restart hazard
No disconnect in sight	430.102
Fuse or breaker larger than the starter cover allows	430.52(C)(2)
Wrong lead pairing or wrong voltage on 9 leads	Windings burn
Bucket stabbed live without a permit and PPE	Arc-flash task under any condition
THHN or loose single conductors on a long VFD run	Insulation breakdown, bearing currents, trips
Bumping the motor coupled	Reverse rotation damages the load

NEC 2026 Checkpoints (Article 430 numbering unchanged from 2023)

- **430.6** FLC tables • **430.7(B)** code letters • **430.8**, **430.83** controllers • **430.22**, **430.24** conductors • **430.32**, **430.40** overloads.
- **430.52** branch protection • **430.62** feeder protection • **430.72**, **430.74** control circuits • **430.97**, **430.98** MCCs.
- **430.102-430.110** disconnects • **430.122-430.130** drives • Tables **430.250**, **430.251(B)** • **440** A/C equipment.

Hands-On Field Exercise

- Size a 10 hp and a 25 hp motor circuit start to finish (FLC, conductor, breaker, fuse, overload, disconnect, controller), then the feeder for both.
- Ring out an untagged 9-lead motor, then connect it for high and low voltage from the nameplate.
- Wire a NEMA starter with 3-wire start/stop. Test seal-in, STOP, and the overload test with the motor leads lifted.
- Pick heaters from a manufacturer's table for a 1.15 and a 1.0 service factor motor.
- Install an MCC bucket de-energized: insert, land power and control, set the overload, close up.
- Megger a motor at 500 V DC and run the full checkout, recording amps on all three phases.

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 430.

- NAVEDTRA 14026 Construction Electrician Basic, Chapter 7, and NAVEDTRA 14027 Construction Electrician Intermediate, Chapter 7: maritime.org/doc/pdf/
- Square D / Schneider Electric, Overload Relays and Thermal Unit Selection, Class 9065 catalog 9065CT9701: se.com
- Rockwell Automation, CENTERLINE 2100 MCC Selection Guide 2100-SG003; Wiring and Grounding Guidelines for PWM AC Drives DRIVES-IN001: literature.rockwellautomation.com
- AutomationDirect, Practical Guide to AC Motors and Control Options.
- Baldor-Reliance (ABB) MN408, Integral HP AC Induction Motors manual.
- IEEE 43 / NETA ATS insulation-resistance minimums. NFPA 70E, 2024 edition. OSHA 29 CFR 1910.147 and 1910.333: osha.gov
- Army TM 5-682, Electrical Facilities Safety.

Next: Module 1.7 — Grounding & Bonding.