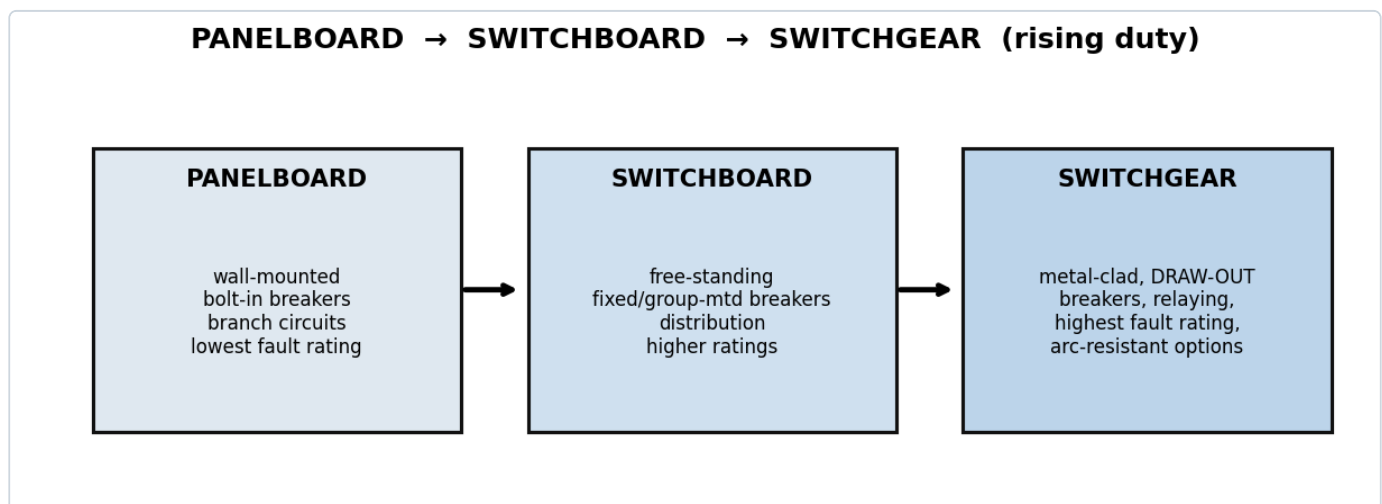


Module 1.5B — Switchgear Masterclass

The top of the system: draw-out breakers and racking step by step, the interrupting/withstand/SCCR ratings, selective coordination, arc-energy reduction and PPE, assembly, and commissioning.

Why a masterclass on this. Switchgear sits at the top of the building's electrical system. It carries the most current and the most fault energy of anything you will touch, which makes it the highest-stakes gear to install, select, and especially to work on while energized. This module covers what switchgear is and how it differs from a switchboard, how to rack a draw-out breaker step by step, the ratings that drive selection, selective coordination, arc-flash control, and the receiving, assembly, and commissioning steps from the manufacturers' instructions.

Part A — The Gear Ladder: Panelboard → Switchboard → Switchgear



Rising duty: panelboards branch power, switchboards distribute it, switchgear does it with draw-out breakers, relaying, and the highest fault ratings.

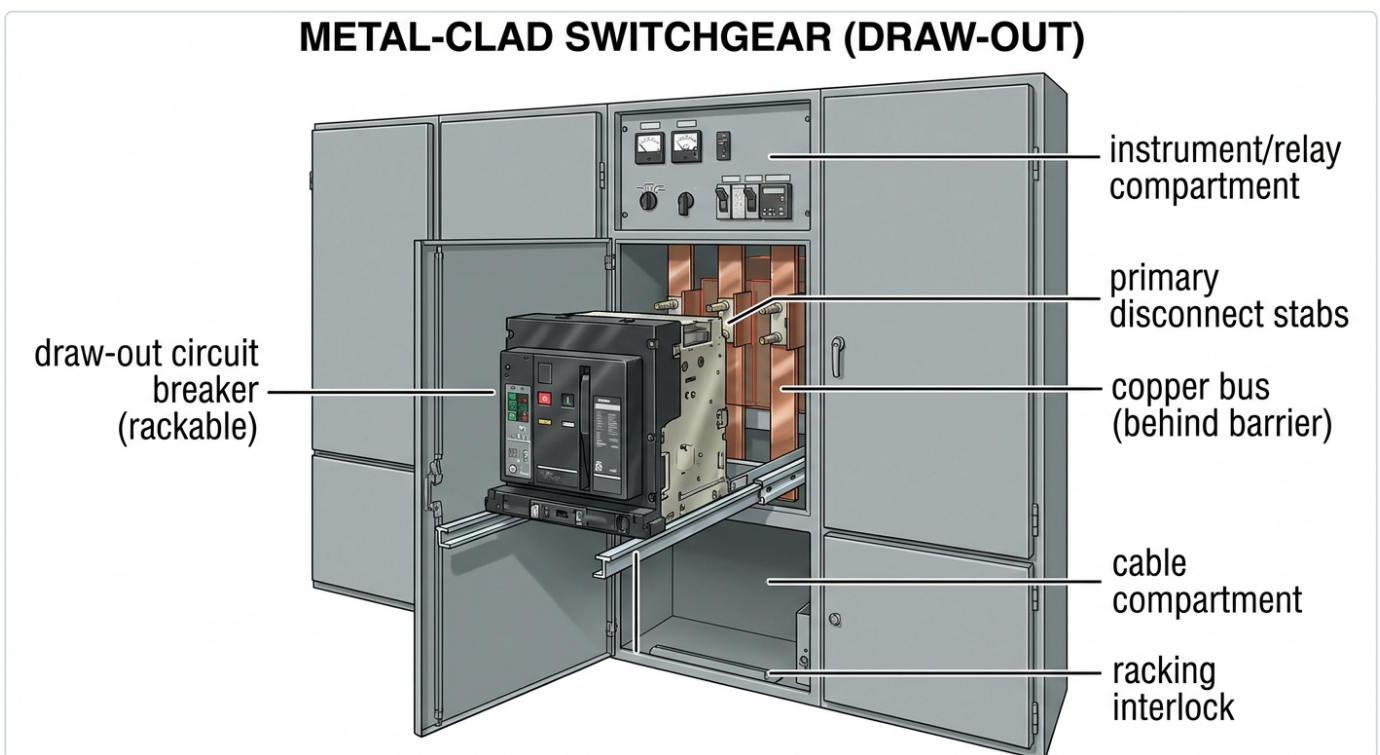
- **Panelboard:** wall-mounted, bolt-in or plug-in branch breakers, the lowest fault rating.
- **Switchboard** (built to UL 891): free-standing, fixed or group-mounted breakers, distribution duty. Art. 100: "A large single panel, frame, or assembly of panels on which are mounted on the face, back, or both, switches, overcurrent protective devices (OCPDs)... buses, and usually instruments."
- **Switchgear:** Art. 100: "An assembly completely enclosed on all sides and top with sheet metal (except for ventilating openings and inspection windows) and containing primary power circuit switching, interrupting devices, or both, with buses and connections." Low-voltage drawout switchgear is built to IEEE C37.20.1 and UL 1558, with power circuit breakers to UL 1066. Medium-voltage metal-clad gear is IEEE C37.20.2. Arc-resistant construction is tested to IEEE C37.20.7.

- **Metal-clad** is the premium build. It "shall have insulated primary conductors," "shall have barriers between sections of each circuit," and draw-out breakers are interlocked so they cannot come fully out until the closing mechanism is discharged. **Metal-enclosed** is a lighter classification.

Example gear	Ratings
Eaton Magnum DS LV switchgear	Up to 600 Vac, 10,000 A bus, 200 kA short-circuit, 100 kA standard bracing
Schneider QED-6 switchboard	200 kA at 240 V, 150 kA at 480 V, 100 kA at 600 V
LV power circuit breakers (general)	800 to 6000 A, interrupting 42 to 200 kA, short-time delay up to 30 cycles with no instantaneous override

Molded-case breakers all have a built-in instantaneous override. Power circuit breakers can hold off for up to 30 cycles, which is why they coordinate so well (Part D) and why they need arc-energy reduction (Part E).

Part B — Inside Metal-Clad Switchgear & the Draw-Out Breaker



Metal-clad switchgear: a draw-out breaker on its rails, primary disconnect stabs, copper bus behind a barrier, separate compartments, and the racking interlock.

The defining feature is the **draw-out (rackable) breaker**. Racking it is moving it between positions with a crank.

Position	Primary stabs	Control (secondary) contacts	What it's for
CONNECTED	Engaged	Engaged	Carrying load
TEST	Disengaged	Engaged	"The circuit breaker can be operated electrically without energizing the power circuit"
DISCONNECTED	Disengaged	Disengaged	Isolated, "not held captive in the cell"
WITHDRAWN	—	—	Out on the rails or the lift truck for maintenance

Eaton Magnum DS instructions IB01901001E. The door can be closed with the breaker in connect, test, or disconnect.

The interlocks (learn to point at each one)

1. **Open before racking:** "levering cannot be accomplished unless the breaker is in the opened position."
2. **Springs discharge** automatically when the breaker is removed from its compartment.
3. **No close** "until the closing springs are fully charged."
4. **Rejection interlock** so "an incorrect breaker cannot be inserted," for example a 1600 A breaker into an 800 A cell, or a 65 kA breaker into an 85 kA cell.
5. **Padlock provisions** in connected, test, or disconnected.
6. **Shutters and insulating boots** over live stabs (optional on some gear).
7. **Key interlocks** (Kirk or Superior). The "LO" mark means the key comes out only with the device Locked Open. On a main-tie-main lineup, three locks keyed alike with two keys means only two of the three breakers can be closed at once.

From the manufacturer, in capitals: "FAILURE TO HAVE THE BREAKER COMPLETELY IN THE DISCONNECT POSITION BEFORE LEVERING CAN CAUSE SERIOUS EQUIPMENT DAMAGE. ENSURE THAT THE BREAKER REACHES A POSITIVE STOP WHEN INSERTING INTO THE CELL PRIOR TO LEVERING."

Step by step: racking a breaker OUT from an energized bus

From UFC 3-560-01, Appendix E. Only a qualified worker racks breakers. As an apprentice you learn the steps, stand outside the boundary, and assist.

1. Hold a pre-job briefing. Confirm which breaker, and confirm communications.
2. Check the risk assessment and the arc-flash label. Above 40 cal/cm² at the working distance, stop and de-energize instead.
3. Put on the PPE (below). Manual racking is **Category 4** whether the door is open or closed.
4. Open the breaker, "using a remote-control device if available."

5. Rack it out with the racking crank (a $\frac{3}{8}$ -inch drive on Magnum DS). "Count the number of revolutions required to fully rack out the circuit breaker." You will use that count on the way back in.
6. If this is part of a lockout, complete the lockout. Pull the control power fuses if the procedure says to.

Step by step: racking IN

1. Same briefing and PPE. Remove the lockout and replace the control fuses.
2. "Confirm that the circuit breaker is squarely aligned in the cell and is seated into the starting position. Visually confirm that the circuit breaker is open."
3. Rack in, counting turns. "Visually confirm the circuit breaker is racked in."
4. Close it remotely if required. Then confirm it is closed.

Remote racking

A remote racker (for example Eaton's MRR1000 on a 120 V cord) clamps to the racking shaft and does the cranking while you stand back. UFC: "Ensure all personnel in the area are a minimum of 20 feet away." The operator can stand up to 25 feet away, and the PPE drops to Category 2 clothing. Use remote racking whenever the gear has it.

Ground-and-test device

On medium-voltage gear, a ground-and-test device racks into a cell in place of a breaker so the crew can ground or test the cables. UFC rules: "Do not install the device with ground cables already connected." Padlock doors where studs stay live. "After installing the device, verify by using a voltage detector that exposed studs are deenergized."

Part C — The Ratings That Drive Selection

Three ratings people confuse — get them straight

- **Interrupting rating (AIC):** the most fault current a **breaker or fuse** can safely interrupt. NEC 2026 110.9: "an interrupting rating at nominal circuit voltage at least equal to the available fault current at the line terminals of the equipment."
- **Withstand rating (bracing):** how much fault current the **bus and structure** can survive while a downstream device clears. Bus is braced at 100, 150, or 200 kA.
- **SCCR (short-circuit current rating):** the rating of a whole **assembly**. 408.6: switchgear "shall have a short-circuit current rating not less than the available fault current," and the fault current and date are field-marked on the enclosure. 110.10: ratings "shall be selected and coordinated with the available fault current to permit the circuit protective devices used to clear a fault to do so without extensive damage."

Install gear with too low a rating and a fault can make it **explode** instead of clear.

Step by step: checking the ratings on a lineup

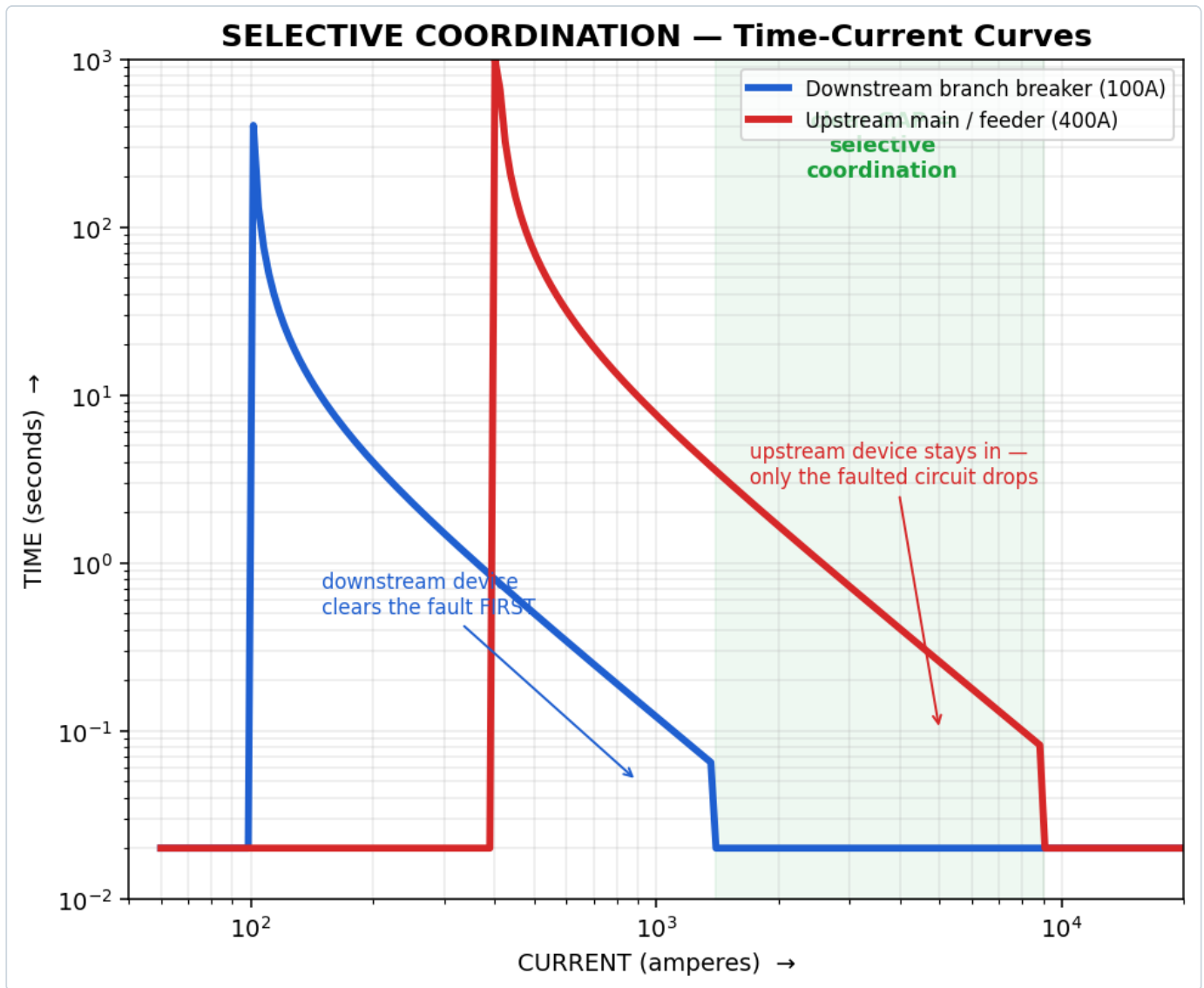
1. Get the available fault current from the one-line or the engineer's study, at the gear's line terminals.
2. Read the gear nameplate: voltage class, bus amps, bus bracing in kA.
3. Read each breaker's nameplate: interrupting rating at the system voltage.
4. Both the bus bracing and every breaker must be at least the available fault current.
5. Check the field marking: fault current and date (110.24(A), 408.6). After changes, it gets re-marked (110.24(B)).

Worked example 1. A 2500 kVA, 480 V transformer at 5.75 percent impedance. Full-load current = $2,500,000 \div (1.732 \times 480) = 3,007$ A. Fault current with an unlimited utility = $3,007 \div 0.0575 = \mathbf{52,300\text{ A}}$. Gear braced at 85 kA with 65 kA breakers passes. 42 kA breakers fail. A common quoting mistake is "85 kA rated switchgear with 65 kA rated breakers" written as if the whole lineup were 85 kA. Show both ratings on the one-line.

Reconditioned gear: reconditioned switchgear sections are allowed, but they must be marked with the reconditioner's name, the date, and "reconditioned," and "the original listing mark shall be removed" (110.21(A)(2)).

Part D — Selective Coordination

When a fault happens, you want **only the breaker nearest the fault** to open, not the main that blacks out the whole building. NEC 2026 Art. 100 defines selective coordination as "localization of an overcurrent condition to restrict outage to the circuit or equipment affected, accomplished by the choice and installation of protective devices and their ratings or settings for the full range of overcurrent conditions." You prove it by overlaying the devices' time-current curves (TCCs).



Time-current curves. The downstream (blue) device clears faster than the upstream (red) at every fault current, so only the faulted circuit drops.

Reading a time-current curve

- It is a log-log graph: current (RMS symmetrical amps) across the bottom, time in seconds up the side.
- A fuse is a band from minimum-melt to total-clear.
- A breaker curve has an overload region, an instantaneous region where it unlatches in under 0.01 second, and a vertical line at its interrupting rating.
- The rule for breakers: "no overlap of time-current curves (including the unlatching time) is permitted up to the available short-circuit current."
- **Worked example 2, fuses.** A 400 A LPJ fuse over a 100 A LPJ fuse is a 4:1 ratio. The maker's selectivity ratio guide needs only 2:1, so they coordinate "for any overcurrent condition up to 200,000A," with no curves needed. A 1200 A KRP-C over a 400 A LPS-RK is 3:1 against 2:1 required, and passes.

- **Worked example 3, two breakers.** A 400 A breaker with its instantaneous set at $5 \times (2000 \text{ A})$, with a ± 25 percent band, may unlatch as low as 1500 A. For a 4000 A fault below a 90 A breaker, the 90 A unlatches, the 400 A unlatches too, the 90 A clears, and the 400 A opens anyway. They are not coordinated above 1500 A.
- **Worked example 4, short-time delay.** A 30 A breaker under a 200 A power breaker with 6 cycles of short-time delay, under an 800 A power breaker with 20 cycles: each one waits for the one below it. That coordinates, but "this intentional delay will increase incident energy," so it gets paired with arc-energy reduction (Part E).
- **Electronic trip units (LSIG)** have adjustable **L**ong-time (overload), **S**hort-time (through-fault delay), **I**ntermediate, and **G**round-fault settings. Zone-selective interlocking (ZSI) "allows the breaker closest to the fault to trip without any preset time delay."
- **Settings come from the study.** Breaker coordination "cannot be, based upon an amp ratio of their handle ratings." Set trips "in accordance with coordination study provided by end user." Eaton: "Factory settings ... do not reflect specific site requirements." Trips ship at their minimum, and leaving them there is a common mistake.
- **Series rating is not coordination.** A series rating means a lower-rated downstream breaker is protected by an upstream one, but both may trip. That does **not** meet a selective-coordination requirement.

Coordination is mandatory for critical systems. NEC 2026 requires selective coordination for emergency (700.32), legally required standby (701.32), and critical operations (708.54) systems. 701.32(A): the devices "shall be selectively coordinated with all supply-side and load-side OCPDs," selected by "a licensed professional engineer or other qualified persons," and "documented and made available." Replace a breaker with anything other than the same manufacturer, type, ratings, and settings and the coordination must be re-evaluated (701.32(B)). Feeders fed directly by the service breaker must also coordinate with it (240.11).

Part E — Working on Switchgear Safely

NEC 2026 240.87 — arc energy reduction

Where a breaker's highest continuous trip setting "is rated or can be adjusted [to] 1200 amperes or higher," one of these is required: zone-selective interlocking, differential relaying, an energy-reducing maintenance switch with a local status indicator, an active arc-flash mitigation system, an instantaneous trip setting, an instantaneous override, or an approved equivalent. "Temporary adjustment of the instantaneous trip setting to achieve arc energy reduction shall not be permitted." The system must be "performance tested by primary current injection testing or another approved method when first installed on site," with "a written record" for the inspector. Fuses 1200 A and up have a similar rule (240.67).

Equipment (NFPA 70E-2024 Table 130.7(C)(15)(a))	Parameters	PPE category	Arc-flash boundary
600 V class switchgear and switchboards	≤ 35 kA, ≤ 0.5 s (30 cycles), 18 in.	4	20 ft
600 V class MCC	≤ 65 kA, ≤ 0.03 s, 18 in.	2	5 ft
600 V class MCC	≤ 42 kA, ≤ 0.33 s, 18 in.	4	14 ft
Metal-clad switchgear 1–15 kV	≤ 35 kA, ≤ 0.24 s (15 cycles), 36 in.	4	40 ft
Arc-resistant gear, doors closed and secured, within its rating	—	N/A	N/A

Category minimum arc ratings: 1 = 4 cal/cm², 2 = 8, 3 = 25, 4 = 40. Categories 3 and 4 need an arc-rated flash-suit jacket, pants, and hood. The arc-flash boundary is the distance where incident energy falls to 1.2 cal/cm². If the gear has an arc-flash label from a study, the label governs.

- **Manual racking PPE (UFC 3-560-01):** Category 4: arc-rated suit pants, jacket, and hood, leather boots, hearing protection, voltage-rated gloves with leather protectors (Class 0, red label, 1,000 V max use).
- **Arc-resistant gear** (IEEE C37.20.7, for example Type 2B at 100 kA/480 V for 500 ms) "does nothing to prevent internal arcs." It "contains and redirects the arc gases" out roof flaps or a plenum. Its rating is void unless the doors are "CLOSED and SECURED" and the fault is within its nameplate rating.
- **De-energize first.** OSHA 1910.333(a)(1): live parts "shall be deenergized before the employee works on or near them, unless the employer can demonstrate that deenergizing introduces additional or increased hazards or is infeasible." Then the NFPA 70E 120.6 steps: test each phase, phase to phase and phase to ground, with a rated meter proved on a known source before and after.
- **Before drawing out a breaker (UFC):** remote rack where available, open the breaker, "Discharge the stored-energy mechanism," "Check that protective interlocks are functioning," and tell everyone nearby.
- **Never defeat an interlock.** NETA's acceptance test does the opposite: "Attempt closure on locked-open devices. Attempt to open locked-closed devices." The interlocks should win.

Working space

- **Up to 1000 V:** Table 110.26(A)(1) depth (3, 3½, or 4 feet at 151–600 V), width of the gear or 30 inches, height 6½ feet, and the dedicated space from the floor to 6 feet above the gear with "no piping, ducts, leak protection apparatus, or other equipment foreign to the electrical installation" (110.26(E)(1)(a)). Gear 1200 A or more and over 6 feet wide needs an entrance at each end (110.26(C)(2)).
- **Over 1000 V:** working space at least 6½ feet high and 3 feet wide, not used for storage (110.32). "On switchgear and control panels exceeding 1.8 m (6 ft) in width, there shall be one entrance at each end" (110.33(A)). Depth for 1001–2500 V is 3, 4, or 5 feet by condition (Table

110.34(A)). Rooms with exposed live parts "shall be kept locked" with a "DANGER—HIGH VOLTAGE—KEEP OUT" sign (110.34(C)).

Part F — Receiving, Setting, and Assembling the Lineup

From the Eaton Magnum DS instructions IB01901001E. Your gear's bulletin governs (NEC 110.3(B)).

1. **Receive** against the shipping list. "Do not discard any packing material until it is certain that every item has been received." File carrier claims at once.
2. **Store** "dry and clean... heated." Outdoors only under a loose cover with about 250 W of heat per vertical section. "CARE MUST BE TAKEN THAT INTEGRAL CONTROL POWER TRANSFORMERS ARE NOT BACK-FED. DISCONNECT PRIMARY AND SECONDARY FUSES." Never store indoor gear outdoors, "even for a brief period."
3. **Rig** by the lifting angle over the bus compartment. Front lift plates are for stability only. Outdoor sections need spreader bars. "READ INSTRUCTIONS FOR LIFTING SWITCHGEAR PRIOR TO ATTACHING CABLES, CHAINS OR SPREADER BARS."
4. **Roll** on at least four rollers, about one per 1½ to 2 feet of length.
5. **Set level.** Remove the skids; the skid bolt holes are the anchor holes. Conduits may rise no more than 3 inches above the enclosure bottom (408.5).
6. **Bolt the shipping splits.** Ground bus splice first ("It must be connected to the station ground before energizing"), then the main bus and neutral splice plates.
7. **Prepare every joint.** Plated surfaces, lint-free cloth, water then mineral spirits or isopropyl alcohol. No abrasives. NEC 2026 110.12(B): busbars "shall not be damaged or contaminated by foreign materials such as paint, plaster, cleaners, abrasives, or corrosive residues."
8. **Torque** with a calibrated wrench. Grade 5 hardware: $\frac{3}{8}$ -16 = **20 ft-lb**, $\frac{1}{2}$ -13 = **50 ft-lb**. Belleville washers are standard. NEC 2026 110.14(D): torque "as indicated on equipment or in installation instructions provided by the manufacturer," by "an approved means."
9. **Land and lash the cables** per the bracing drawing, fit lug boots, and connect the split control wiring. "Verify that all shipping split wiring has been correctly connected."
10. **Label:** circuit description at each breaker (408.4(A)), source of supply "not handwritten" (408.4(B)), fault current and date (408.6, 110.24), and arc-flash labels front and rear (110.16), applied before energizing.

Part G — Commissioning and the Pre-Energization Checklist

Commissioning tests on switchgear are usually done by a NETA-certified testing firm. Know what they check so the gear is ready when they arrive. Values below are from the public ANSI/NETA ATS-2009 and 2013 copies; confirm against the edition named in your project spec.

Test	How	Accept
Bolted-joint resistance	Low-resistance ohmmeter across every splice	Investigate any joint more than 50 percent above the lowest similar joint
Bus insulation resistance	1 minute, phase to phase and phase to ground, each section	600 V gear: 1000 V DC, 100 megohms or more
Control wiring insulation	500 V DC (300 V wire) or 1000 V DC (600 V wire), 1 minute	2 megohms or more
Breaker pole resistance	Across each pole	Manufacturer's range; investigate any pole more than 50 percent above the others
Trip unit	Primary injection of long-time, short-time, ground-fault, instantaneous	Per the coordination study and tolerance band
Ground-fault protection (services 1000 A+, over 150 V to ground)	Performance test per NEC 230.95	Written record
Arc energy reduction	Primary injection per 240.87(C)	Written record
Phasing	Double-ended or dual-source gear	Correct from each source

Final check before energizing (Eaton's 12 items)

1. All breakers exercised by hand.
2. Insulation tested and recorded. Keep the baseline readings "for future reference in determining when trends occur."
3. Relay and meter connections checked. Electric operators checked.
4. Ground-fault system tested. Trips set to the study.
5. Field wiring secured away from live bus. All grounds made.
6. Debris and tools out, vents clear. Shipping bracing and loose parts removed from the cubicles.
7. Barriers and covers on, doors latched.
8. "Turn all circuit breakers to the OFF position before energizing the bus."
9. Leave electrically operated breakers disconnected, and rack them in "one at a time after the assembly is energized" so their charging motors don't all start at once and blow the control fuses.

Common mistakes

Mistake	Why it matters
Levering before the breaker hits its positive stop	Damages the racking mechanism and stabs
Pulling a breaker without discharging springs or confirming open	Stored energy, and a closed breaker under load
Manual racking in Category 2 because "the door is shut"	Manual racking is Category 4 either way
Inserting a ground-and-test device with grounds attached	Grounds a live bus
Leaving factory trip settings	No coordination, wrong protection
Lowering the instantaneous "temporarily"	Not allowed (240.87)
Abrasives, paint, or plaster on bus	110.12(B)
Back-feeding the control power transformer while the gear is dead	Energizes the primary from the secondary
Pipe or duct in the dedicated space	110.26(E)
A wide lineup with only one exit	110.26(C)(2), 110.33(A)

Tools for switchgear work

Calibrated torque wrenches ($\frac{3}{8}$ and $\frac{1}{2}$ inch drive), the racking crank or remote racker, a breaker lift truck or rail lifter, a low-resistance ohmmeter, an insulation tester (1000 to 5000 V DC), a voltage detector and proving unit, Class 0 or 00 gloves with leathers, a 40 cal/cm² suit and hood, lint-free cloths and isopropyl alcohol, the splice kit with Belleville washers, and label stock.

NEC 2026 Checkpoints

- **Art. 100** switchboard, switchgear, selective coordination • **110.9, 110.10, 110.12(B), 110.14(D), 110.16, 110.21(A)(2), 110.24.**
- **110.26** (≤ 1000 V) and **110.31-110.34** (over 1000 V) working space • **408.4, 408.5, 408.6.**
- **240.11, 240.67, 240.87 • 230.95** GFPE • **700.32 / 701.32 / 708.54** selective coordination.

Hands-On Field Exercise

- With a qualified electrician, **rack a draw-out breaker** on de-energized gear through connected, test, and disconnected, counting the turns. Point out the stabs, bus barrier, shutters, and every interlock.
- Set up a remote racker and walk the 20-foot clear zone.
- Read a gear nameplate: voltage class, bus rating, bracing, and each breaker's interrupting rating. Compare to the fault-current marking.

- Work the 2500 kVA fault-current example and decide which breakers pass.
- Overlay two breakers' time-current curves and decide whether they coordinate. Identify the LSIG settings on an electronic trip unit.
- Read an arc-flash label, find the boundary and the PPE category, and lay out the PPE before opening a compartment.
- Prep and torque a bus splice to the bulletin values.

Sources used in this module (public documents)

- NFPA 70, National Electrical Code 2026 (free read-only access at [nfpa.org](https://www.nfpa.org)).
- Eaton: Magnum DS Low-Voltage Switchgear design guide and instructions IB01901001E; Power Distribution Systems Consulting Application Guide; Bussmann Selective Coordination guide and Selecting Protective Devices handbook: [eaton.com](https://www.eaton.com)
- ABB, MNS-SG Low Voltage Metal-Enclosed Drawout Switchgear Application Guide.
- Schneider Electric: Medium Voltage technical guide AMTED300014EN; Digest 178 Switchboards and Switchgear; Masterpact MTZ user guide.
- UFC 3-560-01, Operation and Maintenance: Electrical Safety: [wbdg.org](https://www.wbdg.org)
- ANSI/NETA ATS, Acceptance Testing Specifications (2009 and 2013 public copies).
- NFPA 70E, 2024 edition, Tables 130.7(C)(15)(a) and (c), Article 120. OSHA 29 CFR 1910.333: [osha.gov](https://www.osha.gov)

Companion to Module 1.5. Next masterclass: Transformers.