



Electrical Fundamentals 1: Volts, Ohms, Amps

MODULE F7

FOUNDATIONS

PREREQ F2

Field scenario. It is your third week riding along. The condenser is dead silent, the homeowner is sweating, and your lead tech hands you the meter and says "tell me what we have at the contactor." You clip one lead, touch the other, and the screen says 243.7. Is that good? Bad? Dangerous? By the end of this module you will know exactly what that number means, where it came from, and what to check next. Electricity runs every machine we touch. Roughly eight out of ten service calls end at an electrical part, so this is the most valuable module in the Foundations track.

Short Version

Voltage is electrical pressure, measured in volts. Current is electrical flow, measured in amps. Resistance is opposition to that flow, measured in ohms. Ohms law ties them together: volts equal amps times ohms ($E = I \times R$). Power is volts times amps ($P = E \times I$), measured in watts. Residential equipment runs on 240V or 120V line voltage and a 24V control circuit. Safety switches are wired in series so any one of them can stop the system. Loads are wired in parallel so each one gets full voltage. Your meter only tells the truth if you use the right mode, the right lead jacks, and the live-dead-live habit. Never measure ohms on a live circuit. Never clamp two conductors at once. Verify your meter on a known live source before you trust a zero.

Key Values

ITEM	VALUE	NOTES
Residential line voltage	240V single phase (split phase)	Two 120V legs from the utility transformer; leg to leg reads 240V, leg to neutral reads 120V
Furnace and air handler supply	120V or 240V	Check the nameplate; gas furnaces are usually 120V, electric air handlers usually 240V
Control voltage	24V AC nominal	Healthy transformers commonly read 24 to 28V; do not condemn a transformer for reading 27V
Acceptable voltage range	Nameplate plus or minus 10 percent	240V nominal: 216 to 264V acceptable. 24V control: roughly 21.6 to 26.4V at minimum load, with healthy readings often a bit higher
Ohms law	$E = I \times R$, $I = E / R$, $R = E / I$	E in volts, I in amps, R in ohms
Power formula	$P = E \times I$	Watts = volts x amps; 1,000 watts = 1 kilowatt. Motors need a power factor multiplier, covered below

ITEM	VALUE	NOTES
Typical condenser fan motor draw	Roughly 0.8 to 2.5A	Always compare to the FLA printed on the motor label, not a memorized number
Typical residential compressor draw	Roughly 10 to 20A running (RLA), about 5x that at startup (LRA)	A 3 ton R-410A compressor commonly runs near 12 to 16A; the nameplate RLA is the reference
Meter safety rating	CAT III, 600V minimum	Required for anything fed from the panel, disconnect, or condenser. CAT II meters are for plug-in appliances, not our work
Run capacitor tolerance	Within 6 percent of nameplate microfarads	Measured with the capacitance mode, power off, capacitor discharged
Frequency	60 Hz in the US	The current reverses direction 60 times per second

Field Checklist: Safe Measurement Sequence

Run this sequence every time, in this order. It takes under a minute and it is the difference between a long career and a short one.

1. **Inspect the meter.** Leads not cracked or nicked, jacks clean, battery good, CAT III 600V rating printed on the case.
2. **Confirm the mode and the jacks before touching anything.** Voltage and ohms use the V jack. If your meter has a fused amp jack, leads in that jack must never touch a voltage source. Clamp meters avoid this trap; use the clamp for amps.
3. **PPE on.** Safety glasses always. Voltage-rated gloves for live work at line voltage, per the F1 standard. No rings, no watch, no dangling lanyard.
4. **Verify the meter on a known live source.** Touch a circuit you know is hot, such as the line side of the disconnect, and confirm the meter reads it. A meter that cannot prove it works cannot prove a circuit is dead.
5. **One-hand habit.** Whenever possible keep one hand off the equipment, in your pocket or behind your back, so current cannot cross your chest. Clip one lead to common or ground and walk the other lead with your free hand.
6. **Measure.** Voltage: leads across (in parallel with) the two points. Clamp amps: jaw around one single conductor. Ohms, continuity, capacitance: power off, locked out, capacitor discharged, component isolated.
7. **Re-verify on the known live source.** If you just proved a circuit dead, prove the meter again on the live source afterward. Live, then dead, then live.

IB STANDARD

Island Breeze techs perform the live-dead-live check on every circuit they intend to touch with hands or tools. Verify the meter on a known energized source, test the target circuit dead, then verify the meter on the known source again. If the meter fails the second check, the dead reading is void and the circuit is treated as live. No exceptions, including "I just had the panel open."

Full Breakdown

What electricity is

Everything around you is made of atoms, and atoms carry tiny charged particles called electrons. Electricity is the movement of those electrons through a material. Materials that let electrons move easily, like copper, are conductors. Materials that block them, like rubber and plastic, are insulators. Every wire on a job is a copper highway wrapped in an insulator so the electrons go where we want and nowhere else.

The classic teaching tool is the water analogy, and it is genuinely useful as long as you know where it breaks:

- **Voltage is like water pressure.** It is the push that wants to move electrons. Pressure can exist with no flow, exactly like a closed faucet on a pressurized pipe. A wire can sit at 240V all day with zero current flowing.
- **Current is like flow rate.** It is how many electrons actually move past a point each second, measured in amperes, which everyone shortens to amps.
- **Resistance is like a kink in the hose.** It opposes flow. More resistance, less current for the same pressure.

Now the limits, because the analogy will eventually lie to you. Water spills out of a cut pipe; electricity does not leak into the room from a cut wire, it needs a complete loop back to its source. Water flows in one direction; the alternating current we use reverses direction 60 times per second. And water pressure cannot reach across an air gap, but high voltage can arc across one. Use the analogy to build intuition, then graduate to the real definitions below.

Voltage, current, and resistance with HVAC examples

Voltage (E, measured in volts, V) is electrical pressure, formally called electromotive force, which is why formulas use the letter E. The utility company supplies it, transformers raise or lower it, and your meter reads it as the difference in pressure between two points. That last part matters: voltage is always measured between two points. There is no such thing as "the voltage at this terminal" without saying what the second lead touches. At the condenser you will read about 240V between L1 and L2, about 120V from either leg to ground, and about 24V across the contactor coil when the thermostat calls.

Current (I, measured in amps, A) is the actual flow of electrons doing work. The letter I comes from intensity. Current is what spins motors, heats elements, and unfortunately, current is also what kills people. As little as 0.1A across the heart can be fatal, and a healthy compressor circuit carries over a hundred times that. Respect for amps is the foundation of every safety rule in this module.

Resistance (R, measured in ohms) is opposition to current. Every load has it on purpose: a heat strip might be 10 to 15 ohms, a 24V contactor coil commonly reads somewhere near 10 to 25 ohms, motor windings often

read single digits. Wire and closed switch contacts should have almost none, well under 1 ohm. Resistance is how a load converts electrical energy into work and heat. A reading of OL on the ohms scale means over limit: the resistance is too high to measure, which on a winding or coil means an open, a broken path.

Ohms law, with worked field examples

Ohms law is the relationship between the three quantities:

- $E = I \times R$ (volts equal amps times ohms)
- $I = E / R$ (amps equal volts divided by ohms)
- $R = E / I$ (ohms equal volts divided by amps)

The memory triangle: draw a triangle with E on top and I and R side by side on the bottom. Cover the one you want. Side by side means multiply, stacked means divide.

Worked example 1, the heat strip. An electric heat element measures 12 ohms cold and runs on 240V. $I = E / R = 240 / 12 = 20A$. If your clamp reads about 20A on that element, it is doing its job. If it reads 0A with 240V applied, the element is open, because voltage applied to a load should always produce current.

Worked example 2, the 24V contactor coil. You measure a contactor coil at 12 ohms with the wires off. Ohms law says $I = 24 / 12 = 2A$. But when you clamp the energized coil wire you read closer to 0.2 to 0.5A. Did Ohms law fail? No. The coil is an electromagnet, and an energized magnetic coil pushes back against alternating current. That pushback is called inductive reactance, and it adds opposition your ohmmeter cannot see because the ohmmeter tests with DC. The lesson: Ohms law with a measured DC resistance is exact for resistive loads like heat strips, and a rough floor check for coils and motors. For coils, use the resistance reading to answer one question only: is the coil open (OL), shorted (near 0 ohms), or plausible (somewhere in the expected range)?

Worked example 3, finding voltage from current. A crankcase heater is rated 40 ohms and your clamp reads 0.6A through it. $E = I \times R = 0.6 \times 40 = 24V$. Wait, it should see 240V. Either the heater is half failed or it is not getting full voltage, and now you know to measure across it next. Ohms law turns two known numbers into a third without guessing.

Series and parallel circuits, and where each lives in HVAC

A **series circuit** has exactly one path. Current must pass through every device in the chain, so the same current flows everywhere, and the source voltage divides among the devices. The critical property: open any single device and everything in the chain stops.

A **parallel circuit** has multiple branches. Each branch receives full source voltage, each branch draws its own current based on its own resistance, and the branch currents add together at the source. Open one branch and the others keep running.

HVAC uses both, deliberately:

- **Safeties are wired in series.** The high pressure switch, low pressure switch, and condensate float switch sit in series in the 24V Y circuit feeding the contactor coil. Any one of them can open and kill the compressor call. That is the whole point: every safety holds veto power. When a unit will not start and you read 24V

leaving the thermostat on Y but 0V arriving at the contactor coil, one of those series safeties is open, and you walk the circuit with one meter lead on common to find which one.

- **Loads are wired in parallel.** The compressor and the condenser fan motor both sit across L1 and L2 through the same contactor. Each gets the full 240V, each draws its own amps. The blower, the transformer primary, and the inducer in a furnace are likewise parallel branches. If loads were in series, they would starve each other of voltage and one failure would take everything down.
- **Voltage division is your diagnostic superpower.** In a series 24V circuit, a closed switch carrying current reads about 0V across it, because both leads sit at the same pressure. An open switch reads full source voltage across it, because the entire 24V piles up at the break. Read 24V across a pressure switch and you have found your open. This single principle solves more no-cool calls than any other.

Power: watts, VA, and why amps matter

Power is the rate of doing work, measured in watts (W). For resistive loads:

P = E x I. Volts times amps equals watts. 1,000 watts is one kilowatt (kW). A 240V heat strip drawing 20A consumes $240 \times 20 = 4,800W$, or 4.8 kW.

Motors complicate this slightly. A motor is an electromagnetic load, and some of the current it draws sloshes back and forth building magnetic fields without doing useful work. So for motors, true watts = $E \times I \times PF$, where PF is the power factor, a number less than 1 (often around 0.7 to 0.9). Volts times amps without the power factor gives volt-amperes (VA), which is how transformers are rated. A standard 40 VA control transformer at 24V can deliver about $40 / 24 = 1.7A$ to the control circuit before it overloads. Add a big humidifier, a zone board, and a smart thermostat to one 40 VA transformer and you can exceed that, which is why control fuses blow on accessory-stuffed systems.

Why amps matter to you daily: amps are the diagnosis number. Voltage tells you what the circuit is offered; amps tell you what the load is actually doing. A motor drawing its nameplate FLA (full load amps) is working normally. A motor drawing well above nameplate is overloaded, failing, or fighting a mechanical problem. A compressor pulling its LRA (locked rotor amps, the startup inrush, roughly five times the running amps) and never dropping is locked. Amps also size everything: wire gauge, breakers, and fuses are all chosen by ampacity, the current a conductor can carry safely.

AC vs DC, 60 Hz, and split-phase 240V

Direct current (DC) flows one direction, like water in a pipe. Batteries, thermostat electronics, and the rectified internals of inverter boards use DC. **Alternating current (AC)** reverses direction in a smooth wave. In the US it completes 60 full cycles every second, which we call 60 hertz (Hz). AC won the grid because transformers, which only work on AC, let the utility step voltage up for efficient long-distance travel and back down for safe use.

Residential power in Phoenix and everywhere else in the US is **single phase, split phase 240V**. The utility transformer on the pole or pad has a single 240V winding with a center tap. That center tap is the neutral, and it is bonded to earth ground at the panel. The two ends of the winding are the two hot legs, L1 and L2. Measure leg to leg: 240V. Measure either leg to neutral: 120V, because the neutral sits exactly in the middle. The two legs are mirror images of each other, which is why this is still called single phase even though there are two hot wires. Big motors and heat strips use both legs at 240V. Lights, plugs, and gas furnaces use one leg plus neutral

at 120V. Three phase power, with three hot legs, lives in commercial buildings and is covered later in the program.

How power reaches the equipment

Follow the path, because every link in it is a possible failure point and a required test point:

1. **Utility transformer** drops distribution voltage to split phase 240V.
2. **Meter and main panel.** The panel splits power into branch circuits, each protected by a **breaker** sized to the wire and the equipment. The condenser breaker is a 2-pole breaker grabbing both legs; the nameplate on the unit dictates the maximum size.
3. **Disconnect.** A box within sight of the condenser holding a pull-out block or switch, sometimes fuses. It exists so a tech can kill power at the unit without trusting someone at the panel. Line side (top, from the panel) stays hot when the pull-out is removed; load side goes dead. Know which side is which before you trust any reading.
4. **Whip.** The short flexible liquid-tight conduit carrying the conductors from the disconnect into the condenser. Sun-baked whips with cracked insulation are a routine Phoenix find.
5. **Contactor.** Inside the condenser, the line voltage lands on the contactor, the 24V-controlled switch that connects L1 and L2 through to the compressor and condenser fan when the thermostat calls. Line side is always hot when the disconnect is in. Load side is hot only when the contactor is pulled in.

The 24V control transformer

Line voltage is too dangerous and too clumsy for thermostat wiring stapled through walls, so every system has a **step-down transformer**, usually in the furnace or air handler, that converts 120V or 240V down to a nominal 24V. Two coils of wire share an iron core; the primary coil takes line voltage in, the magnetic field couples across the core, and the secondary coil delivers 24V out. There is no wire-to-wire connection between the two sides, which is also a diagnostic gift: line voltage on the primary plus 0V on the secondary equals a failed transformer, full stop.

The 24V side feeds the thermostat and the letters you will live with for the rest of your career: R is the hot 24V supply, C is common (the return path), Y calls cooling, G calls the fan, W calls heat. The thermostat is just a switch box connecting R to those letters. A real-world note: "24 volt" systems routinely measure 24 to 28V on a healthy transformer. Do not condemn a transformer for reading 27V.

Multimeter mastery, mode by mode

Your meter from module F2 has several personalities. Each mode has its own rules for lead placement and its own ways of lying to you.

VAC (AC voltage). The mode you will use most. Leads in the V jack and COM jack, placed across the two points, meaning in parallel. The circuit stays live, that is the point. Auto-ranging meters pick the scale; manual meters must be set above the expected voltage. What it lies about: **ghost voltage.** A modern meter has very high internal resistance, so a disconnected wire lying next to a hot wire picks up a few induced volts and the meter dutifully reports 40, 60, even 100V on a wire that cannot light a bulb. The tell is a reading that is not a

sane system number. The cure is the LoZ mode (low impedance) if your meter has one, which loads the circuit slightly and collapses ghost readings to zero, while real voltage stays.

VDC (DC voltage). Same lead placement, used on board diagnostics, thermostat batteries, inverter buses, and flame sensing circuits later in the program. Polarity matters: reversed leads just show a minus sign, which is harmless but tells you which lead is on the positive point.

Ohms (resistance). The meter pushes a tiny DC test current through the component and calculates resistance. Three iron rules: power off, component isolated (at least one wire disconnected so you are not reading sneak paths through the rest of the circuit), and capacitors discharged. What it lies about: **ohms on a live circuit is not a lie, it is a casualty.** Outside voltage shoved into a meter set to ohms gives garbage readings at best and a blown meter or arc at worst. Also, an in-circuit reading can show a parallel path through another component and convince you a good part is shorted. Isolate, then measure.

Continuity. The same ohms test with a beeper, and the beeper typically fires below roughly 30 to 50 ohms depending on the meter. Use it for what it is: a fast check that a wire, fuse, or closed switch is a complete low-resistance path. The vocabulary discipline from the NATE world is worth adopting: switches get checked for continuity, loads get measured for resistance. What it lies about: the beep proves a path exists, not that a component is healthy. A motor winding shorted from 4 ohms down to 1 ohm still beeps happily. A transformer primary beeps whether it is good or half-shortened. Never declare a load good from a beep; read the number.

Capacitance (microfarads, uF). Power off, capacitor discharged through a bleed resistor tool per the F1 standard, never a screwdriver blade, then at least one lead disconnected and meter leads across the capacitor terminals (HERM to C or FAN to C on a dual run cap). Compare the reading to the nameplate: within 6 percent is serviceable, below that it is failing. What it lies about: a charged capacitor can damage the meter and you, and a capacitor still wired into the circuit can read its neighbors. Looks also lie in both directions; a bulged cap is bad, but a perfect-looking cap can be stone dead. The meter decides, not your eyes.

Amps via clamp. The clamp jaw senses the magnetic field around a conductor, so nothing is interrupted and the leads stay out of it. The rule that everyone breaks once: **clamp exactly one conductor.** Clamp the whole whip or a two-wire pair and the opposing fields cancel, reading at or near zero on a running unit. Clamp the common wire at the compressor for compressor amps, the fan wire for fan amps. For small 24V currents, wrap the wire around the jaw multiple times and divide the reading by the number of wraps, or use a low-amps clamp. In-line amp measurement through the meter's amp jacks puts the meter in series with the load and is reserved for tiny DC circuits later in your career; at line voltage, the clamp is the only tool.

Safe measurement habits

Everything from F1 still applies: lock out and tag the disconnect for any work with hands inside, discharge capacitors with a bleed resistor before touching terminals, and treat every circuit as live until the live-dead-live sequence proves otherwise. Add the habits from the Field Checklist above until they are automatic: meter inspection, mode and jack check, glasses and gloves, known-source verification, one hand, correct placement per mode, re-verification. A useful bench habit when tracing 24V circuits: clip the meter common lead to the transformer common, which is usually bonded to the equipment chassis, and walk the other probe point to point with one hand. Where the expected 24V disappears, the fault lives between the last good point and the dead one.

PHOENIX FIELD NOTE

On a 112 degree June afternoon around 5pm, every condenser in the neighborhood is running and the grid is at full strain. Utility voltage sags, and a condenser that read 243V at 9am can read 225V or lower at peak. Two consequences for your readings. First, low voltage raises motor amps: a motor must pull more current to do the same work at lower voltage, so a compressor clamping a few amps over its morning number at 5pm is reacting to the grid, not necessarily failing. Second, do not condemn a transformer or call "low control voltage" without checking the primary side first; a sagging 208V primary on a 240V tap produces a sagging secondary. Measure supply voltage at the disconnect before judging anything downstream, and note the time of day on your readings. Voltage below 216V, which is minus 10 percent of 240, is a utility or building supply problem worth documenting with a photo of the meter.

Common Mistakes

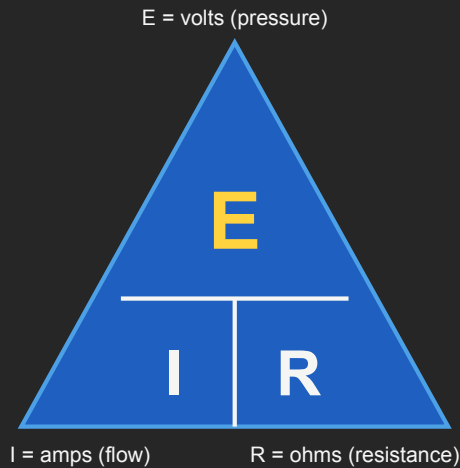
1. **Measuring ohms or continuity on a live circuit.** The meter injects its own test current and expects no outside voltage. Outside voltage means false readings, a blown meter fuse, a destroyed meter, or an arc. Power off, verify dead, isolate the component, then measure.
2. **Reading amps the wrong way.** Two flavors of this mistake. Clamping more than one conductor cancels the magnetic fields and reads near zero, so techs condemn running motors as drawing nothing. Worse, putting test leads in the amp jacks and touching them across a voltage source connects a near-dead-short through the meter; that is how meters explode. Clamp one conductor, and keep leads out of the amp jacks at line voltage.
3. **Trusting a continuity beep across a coil or winding.** The beep means a low-resistance path exists, nothing more. Shorted windings beep. Half-failed transformer primaries beep. Use continuity for switches, wires, and fuses; use the actual resistance number, compared to an expected value, for loads.
4. **Ignoring the meter category rating.** A bargain CAT II meter on a 240V condenser circuit can fail violently during a voltage spike, and Phoenix monsoon season delivers spikes. CAT III 600V minimum for everything fed from the panel, disconnect, or unit. Check the rating printed next to the jacks, and check that the leads carry the same rating, because the system is only as safe as its weakest piece.
5. **Floating neutral confusion.** In a split-phase service, the neutral carries only the imbalance between the two 120V legs. If the neutral connection corrodes or breaks, the two legs stop dividing evenly: one side of the house swings high, maybe 140V, while the other sags to 100V, and readings wander as loads switch on and off. Techs chase these wandering numbers into thermostats and boards for hours. When 120V measurements are unstable or the two legs to neutral are unequal but sum to 240V, suspect the neutral, stop, and document it; a floating neutral is an electrician and utility problem that cooks electronics house-wide.
6. **Condemning a transformer for reading above 24V.** Nominal is not actual. Healthy control circuits read 24 to 28V. The transformer is judged against its primary: correct primary voltage in and no secondary voltage out is a failure; 27V out is a Tuesday.

Module Visuals

1 OHMS LAW TRIANGLE POWER WHEEL

Ohms Law Triangle and the Power Wheel

Cover what you want to find. Side by side means multiply. Stacked means divide.

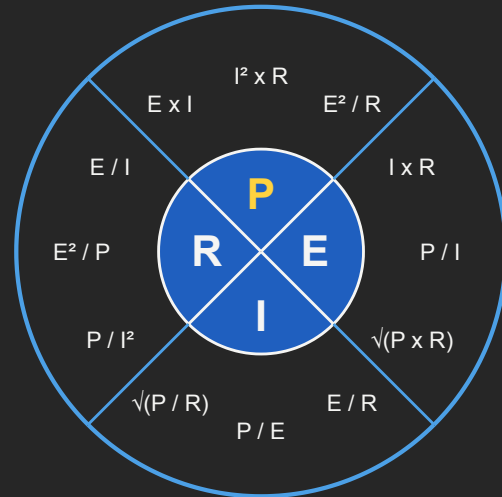


$$E = I \times R$$

$$I = E / R$$

$$R = E / I$$

Field check: 240V across 12 ohms = 20 amps



Pick the inner letter you need, then any outer formula in its slice.

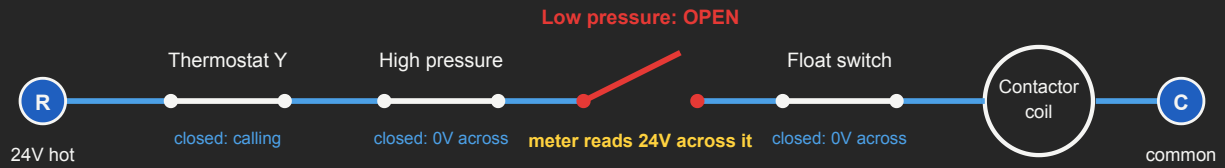
P = E x I. Watts = volts x amps. 1,000 W = 1 kW.

2 SERIES VS PARALLEL HVAC

Series Safeties vs Parallel Loads

Where each circuit shape lives in a residential AC system, and why

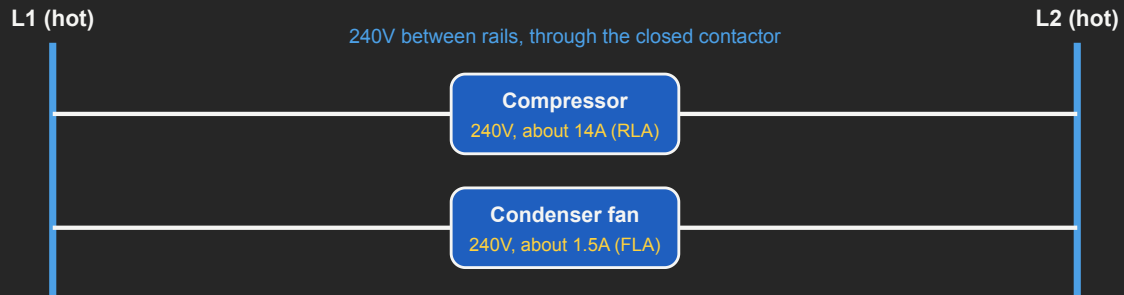
SERIES: the 24V safety chain (one path, every device holds veto power)



Same current through every device. One open device stops the whole chain.

Diagnosis rule: a closed switch reads about 0V across it. The OPEN device reads full source voltage.

PARALLEL: line voltage loads (every branch gets full 240V, currents add)



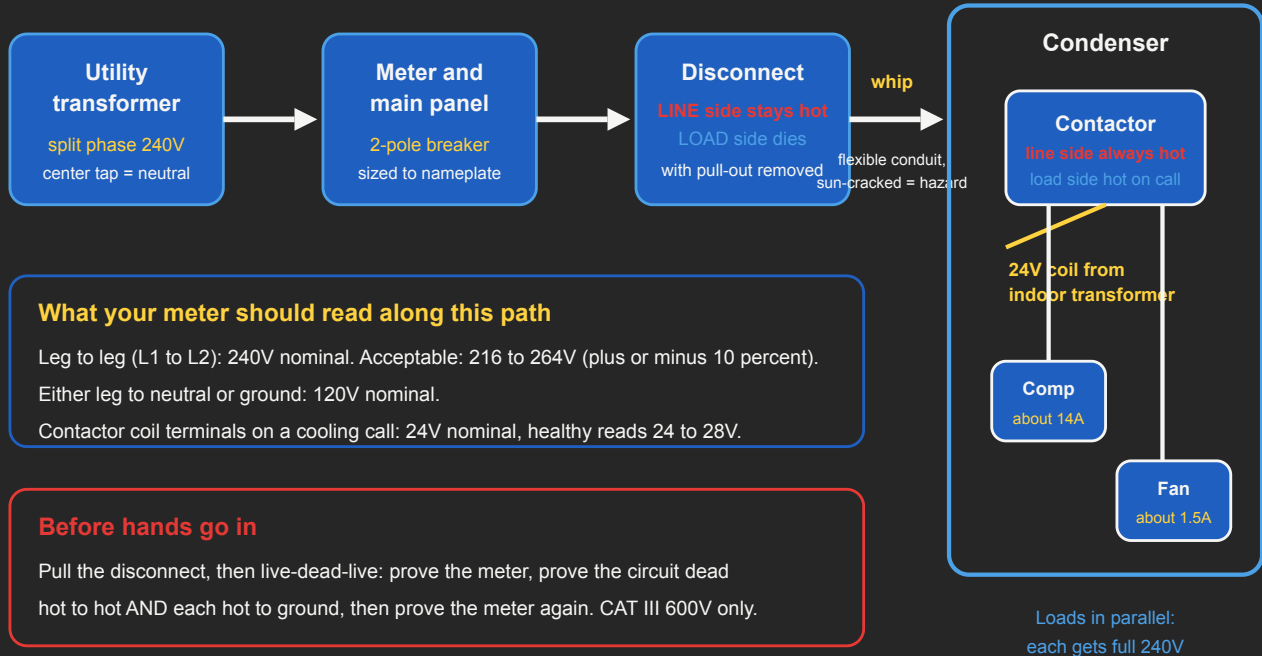
Each branch sees full voltage and draws its own amps. Total at the source: about 15.5A. One branch can fail while the other keeps running.

Safeties in series so any one can stop the system. Loads in parallel so each gets full voltage.

3 POWER PATH PANEL TO CONDENSER

The Power Path: Pole to Compressor

Every link is a test point. Know which side of each device stays hot.



4 METER MODES LEAD PLACEMENT

Meter Modes and Lead Placement

Right mode, right placement, right circuit state. And what each mode lies about.

Mode	Circuit state	Placement	It lies about
VAC AC voltage	LIVE (that is the point)	Leads ACROSS two points (parallel). V and COM jacks. One hand walks, other clipped to common.	Ghost voltage on floating wires. Odd number? Retest on LoZ.
VDC DC voltage	LIVE	Leads across two points. Boards, batteries, sensor circuits.	Minus sign just means leads are reversed. Harmless.
OHMS resistance	DEAD, verified. Component isolated, caps discharged.	Leads across the component with at least one wire pulled off. OL = open. Near 0 = shorted.	In-circuit sneak paths. Live circuit = wrecked meter. DC test misses coil reactance.
BEEP continuity	DEAD, verified. Isolated.	Across switches, fuses, wires. Continuity for SWITCHES. Resistance numbers for LOADS.	The beep proves a path, not a healthy part. Shorted windings still beep.
uF capacitance	DEAD, discharged with a bleed resistor, never a screwdriver.	Leads across cap terminals, wires off. Compare to nameplate: within 6 percent or replace.	Looks lie both ways. A perfect-looking cap can be dead. A charged cap can bite.
CLAMP amps	LIVE and running, hands out of the cabinet.	Jaw around ONE conductor only. Small 24V currents: wrap x4, divide reading by 4.	Two conductors cancel to zero. Leads in amp jacks at line voltage = short through the meter.

Before trusting any reading: prove the meter on a known live source. Live, dead, live.