APLUXOR MARINE ELECTRICAL LIBRARY · PART II. WIRE, CONNECTIONS, PROTECTION — WHAT BURNS

Chapter 4. Overcurrent Protection: The Fuse Protects the Wire, Not the Device

Where the fuse goes, which rating it gets, and what it cannot do

A positive wire that leaves the battery bank with no fuse at its start can burn along its whole length, and no switch on the boat can stop it. This chapter shows you how to find such a wire on your boat and get it protected before it catches fire.

AFTER THIS CHAPTER YOU CAN

- find every positive wire that leaves your battery and check where its first fuse or breaker sits;
- tell the starter cable — of the wires that leave the bank, the only one that may run without protection — from every wire that needs it;
- choose the rating of a fuse or breaker from three numbers: the load current, the device maker's rating and the wire's ampacity (the current the wire can carry);
- recognize fuse and breaker types and ask for main protection that can interrupt a short at your battery;
- reset a tripped breaker once, safely, and find out why it tripped;
- tell a part that belongs in a gasoline compartment from one that must stay out of it.

Read first: → 1.7, → 1.8, → 3.4, → 3.7

4.1 What a fuse does and what it doesn’t
4.2 Protection at the battery: the distance rule and the starter cable
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4.4 Protection types and interrupting rating: a fuse that won’t explode
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4.1. What a fuse does and what it doesn’t

The positive wires on your boat pass through fuses and breakers. Of the wires that leave the bank, only the starter cable may run without one; the cables that join its batteries to each other are part of the bank (→ 4.2 · p. 8). What does that fuse or breaker protect, how fast does it act, and what can it not see? The answers decide where protection must sit (→ 4.2 · p. 8) and which rating it gets (→ 4.3 · p. 16).

Follow one circuit on → Fig. 4.1 · p. 3. Current leaves the battery’s positive terminal (A) and passes the main fuse at that terminal (B is the fuse’s output). It goes through the battery switch (C is the switch’s panel-side terminal) and along the feeder to the panel. There the main panel breaker feeds a bar called the positive bus (D), and one branch breaker sends current down one branch wire (E is the breaker’s output) to the pump’s positive terminal (F). The current comes back on the pump’s own negative wire to the negative bus (G), and on one cable to the battery’s negative terminal (H). Each fuse and breaker on this path guards the wire that starts at it. The letters A to H mean these points everywhere in this chapter.

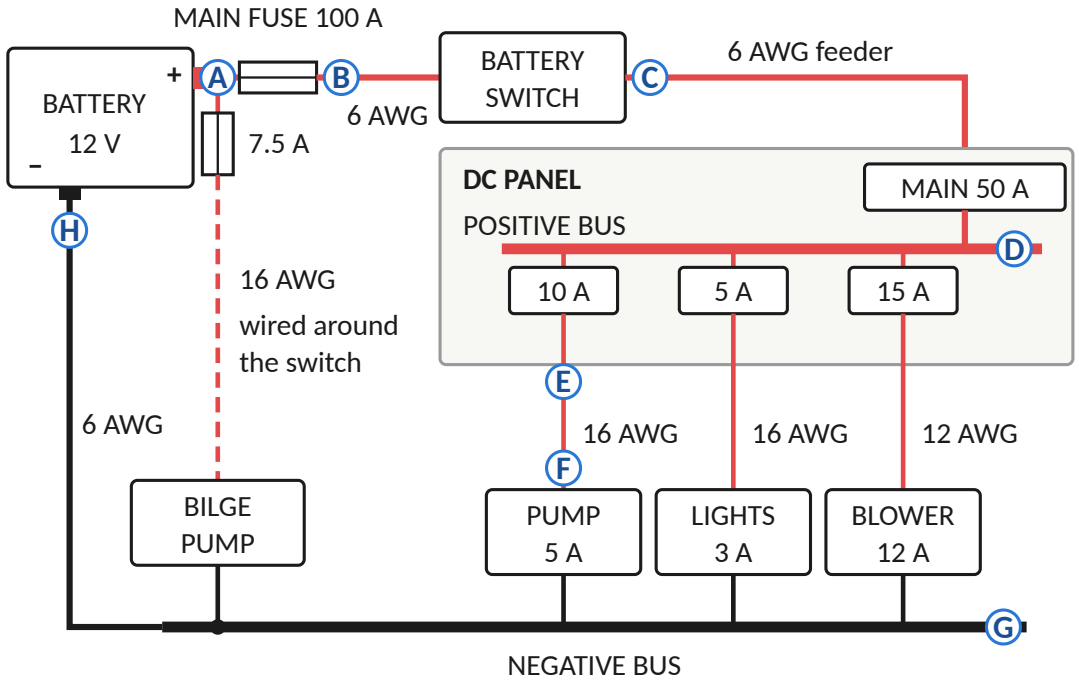


Fig. 4.1. Anatomy: from the battery to the device. One example boat: a main fuse at the battery terminal, the battery switch, the feeder, the panel with its main panel breaker and three branches, and a bilge pump wired around the switch with its own fuse at the battery. The positive runs and the negative cable carry their gauge, all wire has 105 °C (221 °F) insulation, and every protection carries its rating; the numbers are an example, not those of your boat. Points A to H mean the same points everywhere in this chapter.

In a house, the breaker in the service panel protects the wire inside the wall; nobody expects it to save the toaster. In a car, the fuse box sits near the battery, and the wiring runs through a dry, open body. On a boat the principle is the same as in the house, and three things make a fault more dangerous. A short next to the battery draws a current limited only by the battery and a few feet of wire. The wires run through closed compartments shared with fuel and bilge water. And a wire can smolder behind a panel long before anyone smells it.

A wire heats because current flows through its resistance, and the heat grows with the square of the current (I^2R): twice the current makes four times the heat. The insulation of every wire is rated for a temperature, and the current a wire can carry continuously without its insulation getting hotter than that rating is its ampacity (→ 4.3 · p. 16). Above that current the insulation softens, then chars, and bare copper meets

whatever lies next to it. At one and a half times its ampacity a wire makes more than twice the heat.

NUMBERS · HEAT IN ONE FOOT OF 16 AWG WIRE

By the ABYC circular-mil formula, one foot of 16 AWG copper (2,580 circular mils) has a resistance of 10.75 / 2,580 = 0.0042 Ω. ABYC

The regulation rates 16 AWG with insulation rated 105 °C (221 °F), outside an engine space, at 25 A. CFR At 25 A one foot of this wire turns 25 × 25 × 0.0042 ≈ 2.6 W into heat. At 37.5 A, one and a half times the current, it turns about 5.9 W into heat in every foot: 2.25 times as much.

That is why the fuse protects the wire, not the device. A fuse or breaker opens when the current through the wire rises high enough, or lasts long enough, to heat that wire past what its insulation can withstand. A device that fails inside — a pump motor that shorts, a radio that burns a circuit board — is damaged before the current rises. The fuse keeps that failure from turning the wire into a fire. Makers of marine fuses and breakers describe it the same way: protection is installed first of all to protect the wire. The rule with the numbers that set a rating stands in → 4.3 · p. 16.

Protection has two jobs, and they differ in time. An overload is a current somewhat above the wire's ampacity that lasts for a long time. Examples are a pump pushing against a clogged strainer, one more appliance on a circuit, a motor under too heavy a load. The wire heats slowly, over minutes. One breaker maker names the dangerous case: a sustained overload of about 110% to 150% of the wire's rating. It names three places for it: motor circuits, receptacle circuits, and panel feeders where more loads than intended can run at the same time. A MFR short circuit is a current many times the rating through a fault of almost no resistance: bare copper touching the engine, a metal fitting or the negative. There the wire heats in seconds, and protection must open fast.

A fuse opens by melting. Its link is a calibrated piece of metal that melts at a known current in a known time, and after that the fuse is spent. A

breaker opens a contact and can be reset. In a thermal breaker the current heats a bimetal blade until it bends and releases the contact; in a magnetic or hydraulic-magnetic breaker the current in a coil pulls the latch open. Both kinds share the property that matters on a boat: the larger the overcurrent, the sooner they open.

How soon is a property of each product, and makers publish it as a table of time against current (→ Table 4.1 · p. 5). Two things follow from such a table. First, a small overload is carried for a long time. At 135% of its rating, one maker's blade fuse is allowed up to 120 s, and one maker's MEGA fuse up to 1,800 s — half an hour. No general maximum exists; the number belongs to the fuse. Second, a short opens a fuse in hundredths of a second only when the current is many times the rating. A short at the far end of a long, thin wire draws much less current than one at the battery, because the wire itself limits it. The same fuse then takes seconds, or does not open at all.

Table 4.1. Time to open, minimum to maximum, for three products at comparable multiples of their rating, from each maker's data sheet MFR

Current	Blade fuse ATC, 4–40 A	MEGA fuse, 40–250 A	Hydraulic-magnetic breaker, delay 52
At or near the rating	110%: 100 h or more	100%: 4 h or more	100%: does not trip
A quarter to a third over	135%: 0.75–120 s	135%: 120–1,800 s	125%: 2–60 s
Twice the rating	200%: 0.15–5 s	200%: 1–15 s	200%: 1–10 s
Three and a half to four times	350%: 0.04–0.5 s	350%: 0.3–5 s	400%: 0.15–2 s
Six times	600%: 0.02–0.1 s	600%: 0.1–1 s	600%: 0.04–1 s

> The blade fuse maker gives its times at 73 °F and allows up to 240 s at 135% for ratings below 4 A. It prints the change of rating with temperature as −0.15% per 1 °C of ambient temperature (about −0.08% per °F). The breaker maker gives its times at 77 °F with the breaker mounted upright.

WORKED EXAMPLE: A SHORT AT THE FAR END OF A LONG WIRE

Suppose a cabin light at the bow is fed by 16 AWG wire with 105 °C (221 °F) insulation that runs 20 ft from the panel. The wire shorts to the negative right at the light. What decides how fast the fuse opens is the current, and the current is set by the resistance of the loop: 20 ft out and 20 ft back, 40 ft of 16 AWG.

By the ABYC formula, 40 ft of 16 AWG has 10.75 × 40 ⁄ 2,580 = 0.167 Ω. At 12.6 V the short draws 12.6 ⁄ 0.167 ≈ 76 A. With a 10 A fuse, 76 A is more than seven times the rating, past the 600% row of the blade fuse in → Table 4.1 · p. 5: it opens in 0.1 s at most. With a 25 A fuse, the same 76 A is three times the rating, between the 200% and 350% rows: the fuse takes up to several seconds. With no branch fuse and only a 100 A fuse at the battery, 76 A is below the rating, and nothing opens. The wire carries 76 A for as long as the battery lasts and turns about 24 W into heat in every foot.

What the numbers mean: a fuse sized close to the load, like the 10 A fuse, opens a far-end short right away. A fuse at the wire's full ampacity — 25 A on this 16 AWG wire — lets the same short run for seconds. A fuse above the ampacity, like the 100 A fuse at the battery, turns it into a long overload. The battery's own resistance and the feeder add to the loop and lower the current further, so the real fuse is slower still, never faster.

Where the fuse sits decides which part of the wire it protects (→ Fig. 4.2 · p. 7). A fuse at the battery end sees every fault along the wire after it. A fuse at the device end sees only the faults beyond it: a short between the battery and that fuse draws its current straight from the battery and never passes through the fuse.

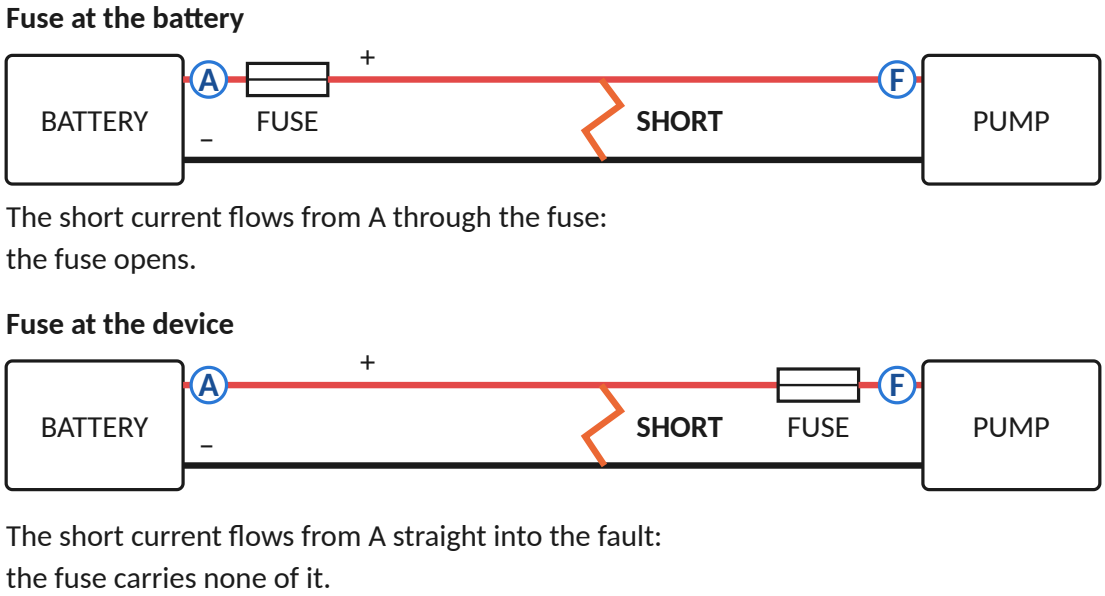


Fig. 4.2. One circuit, one short, two places for the fuse. Top: the fuse at the battery carries the short current and opens. Bottom: the fuse at the pump never sees a short between the battery and itself.

Suppose the 16 AWG wire of a bilge pump chafes through 3 ft from the battery and touches the negative there, and the only fuse of that wire sits at the pump. Suppose the battery is a premium one whose maker rates its short-circuit current at 5,000 A (→ 4.4 · p. 21), which puts its own resistance at about 12.6 / 5,000 = 0.0025 Ω. By the ABYC formula, the 3 ft of 16 AWG add 10.75 × 3 / 2,580 = 0.0125 Ω; do not count the return path of the short. The short draws about 12.6 / 0.015 ≈ 840 A, and those 3 ft of wire turn about 8,800 W into heat — close to 3,000 W in every foot. The fuse at the pump carries none of it.

Three things stay invisible to overcurrent protection, and each needs its own check. A leak of current into the water or into a person is far too small for a breaker rated in amps to notice. Only a protective device recognized by its TEST button detects leakage (→ 17.3). A bad connection heats at normal current: the current stays below the rating, and all the heat is made at the connection itself — you find it by voltage drop under load (→ 3.4). And the wire between the source and the fuse: a fault there never passes through the fuse (→ 4.2 · p. 8).

WHY IT WORKS · A DEVICE NEEDS PROTECTION OF ITS OWN

The fuse of a circuit is sized for its wire, and the wire can withstand more current than a small motor that has jammed. The industry standard lets a device carry its own built-in protection without a manual reset, provided the rest of the circuit is protected by a trip-free breaker or a fuse. ABYC

For motors, the same standard asks that the protection prevent a fire even if the motor stays energized for seven hours under any overload, a jammed rotor included. That is why a pump or blower maker names a fuse rating, and that rating can be below the wire's ampacity. It opens on the jammed motor's current, which a fuse sized for the wire alone can carry for a long time (→ 4.3 · p. 16). ABYC

4.2. Protection at the battery: the distance rule and the starter cable

Every positive wire that leaves your battery begins with a stretch that no switch on the boat can turn off. Where must its first fuse or breaker sit, and which one wire may run without one? This section gives the rule, its reason, and a procedure for checking every wire at your battery.

Follow a positive wire from the battery terminal. Until it reaches its first fuse or breaker, nothing protects it. If its insulation fails on that stretch and the copper touches the engine, a metal fitting or the negative, only the battery and the wire in between limit the current. The chafed pump wire of → 4.1 · p. 2 shows how large that current gets. The battery switch does not help: the stretch between the terminal and the switch lies before it, and a circuit wired around the switch never passes through it. The rule therefore limits length: the shorter the unprotected stretch, the less wire there is that can fail with nothing to stop the current.

Put the fuse or breaker as close to the source as you can — never farther than 7 in along the wire. Farther only if closer is impossible and the whole run is in a continuous sheath: up to 72 in for a wire straight from a battery terminal, up to 40 in from any other source. ABYC

Every positive wire that leaves a battery bank is protected, except the starter cable: only the cable that carries the starting current from the battery to the starter, directly or through the battery switch — found by tracing it, never by its size; a wire taken off the starter's battery terminal to feed anything else is not. The cables that join the batteries of one bank to each other are part of the bank.



BLOWN FUSE

When you find an unprotected positive — any other wire that leaves the bank with no fuse or breaker at its start — write it on the first line of the Boat Passport; until a pro protects it, it carries only what the sign above allows (→ 12.8 for a bilge pump on such a wire).

The bilge pump is the one load such a wire may keep, because a boat that cannot pump water is in more danger than a pump wire without a fuse. What is not dangerous here: an unloaded wire stays cool; what burns is a wire that carries current through a fault. The sign that a wire is protected is a fuse or breaker with a readable rating at its start, within the distance of the rule.

A source is any point where a wire takes its power: a battery terminal, a terminal of the battery switch, a bus bar, the output of a charger. A wire that takes its power from a switch terminal or a bus is also protected by the fuse or breaker ahead of that point, back toward the battery. That holds when the rating is not above the wire's ampacity (→ 4.3 · p. 16). Measure the distance along the wire, not in a straight line: a wire that loops around a bracket before it reaches its fuse is longer than it looks (→ Fig. 4.3 · p. 10). Read the distances as limits, not targets: a fuse that has room on the terminal and sits 6 in away meets the number and misses the rule.

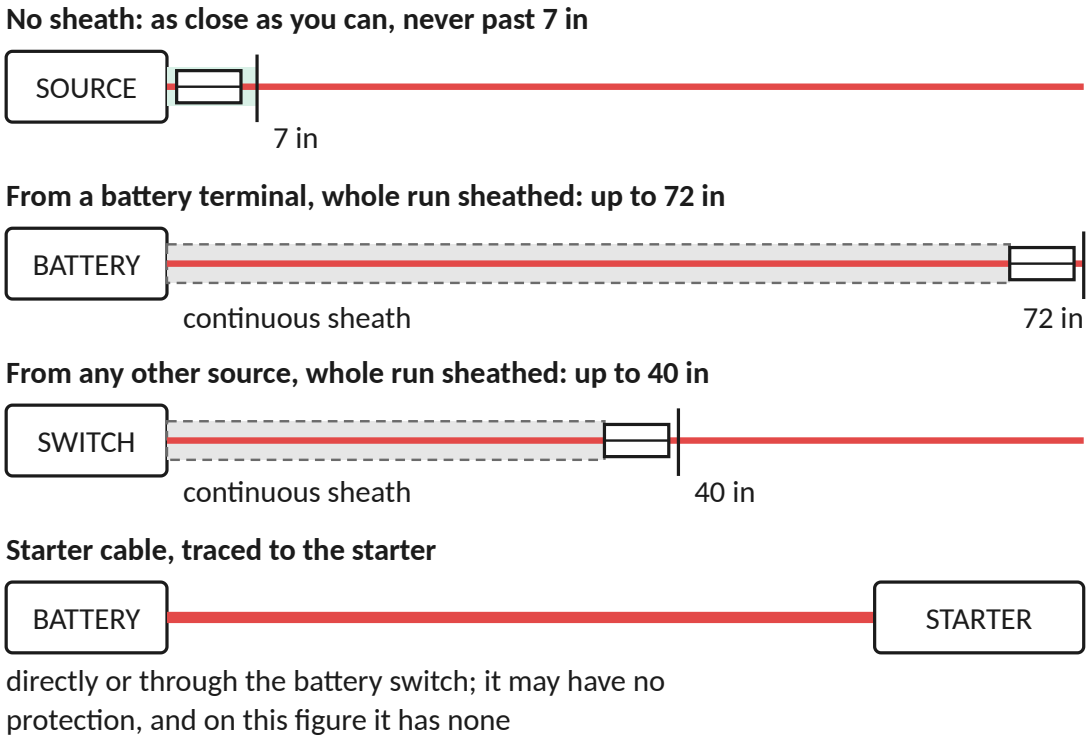


Fig. 4.3. The distance rule, drawn to one scale and measured along the wire. In the sheathed rows the fuse is drawn at the limit, the farthest it may sit; as close to the source as you can stays the rule. The starter cable is the one wire that leaves a bank and may run without protection.

A sheath is a continuous protective covering over the whole length of the run: loom, conduit, a closed raceway or a closed panel. The regulation lists electrical tape among the sheath materials, together with molded rubber, molded plastic and flexible tubing. CFR

Loom, conduit and a closed raceway are better than tape: tape slips and unwinds with time. PRACTICE

The starter cable is identified by where it goes, not by how thick it is. The cable of an inverter, a windlass or a bow thruster can be as thick as the starter cable, and each of them needs its own protection at the battery: no exception names them. Trace the thick cable from the battery terminal, directly or through the battery switch, to the solenoid on the starter; only the cable that ends there and carries the starting current is the starter cable. A wire taken off the starter's battery terminal to feed anything else is not: it needs its own protection where it starts. Where the starter is fed behind a bank's main protection, the

starter cable has protection too. Where nothing protects the starter cable, its insulation and its route are all that stand between the battery and a short. Check them first on a walk-through: no chafe where the cable passes a bulkhead or an edge, and no bare copper at its lugs.

WHAT THE STANDARD REQUIRES

Two documents set these distances. The federal regulation, 33 CFR 183 Subpart I, binds the builder of a boat with a gasoline engine other than an outboard (→ 1.9). ABYC E-11 is a voluntary industry standard that builders and pros apply on every kind of boat. The two agree on 7 in and on the starter cable, and differ on the sheath and on which conductors the 40 in and 72 in limits cover (→ Table 4.2 · p. 11). The rule of this section keeps the stricter side of each line. It keeps as close to the source as you can, 7 in as the limit, and farther only if closer is impossible. It also keeps a continuous sheath as the condition for both 40 in and 72 in.

Table 4.2. Where the first protection may sit, by document

Case	33 CFR 183 CFR	ABYC E-11 ABYC
The general rule	At the source of power; within 7 in, measured along the conductor, if placing it at the source is physically impractical	Within 7 in of the point where the conductor connects to the source, measured along the conductor
Up to 40 in	The whole run in a sheath or enclosure, from any source, if 7 in is physically impractical	The whole run in a sheath or enclosure, from a source other than a battery terminal, as close as practicable
Up to 72 in	Any output conductor from a battery, with no sheath condition; boats built before August 1, 1985 whose circuit has a switch that disconnects the battery have no distance limit	A conductor connected directly to a battery terminal, the whole run in a sheath or enclosure, as close as practicable
The starter cable	Exempt: power supply conductors in cranking motor circuits	Exempt: cranking motor conductors

WHY IT WORKS · EVERY EXCEPTION, AND WHY ONLY THE STARTER CABLE STARTS AT THE BATTERY

The regulation's general overcurrent section, 183.455, does not apply to four kinds of conductor: "resistance conductors that control circuit amperage; conductors in secondary circuits of ignition systems; pigtails of less than seven inches of exposed length; and power supply conductors in cranking motor circuits." A pigtail is a lead that comes out of a device as part of it, such as the wires of a pump or a switch. CFR

ABYC E-11 exempts cranking motor conductors and pigtails shorter than 7 in. It exempts one more conductor: the one from a self-limiting alternator with an integral regulator. The exemption holds if the conductor is shorter than 40 in, is connected to a source other than the battery, and is in a sheath or enclosure along its whole length. ABYC

The regulation also leaves out any electrical component that is part of an outboard engine. CFR

ABYC leaves out the conductors of an outboard that do not extend beyond the engine maker's cowling. The cables that run from the outboard to your battery leave the cowling, and the rule covers them. ABYC

Of all these, only the starter cable begins at a battery terminal: a pigtail begins at its device, an ignition wire at the coil, an alternator's output wire at the alternator. That is why, of the wires that leave a bank, the starter cable is the only exception. The leads of the pump in → 4.3 · p. 16 are 12 in long, and the circuit's fuse protects them.

The regulation's exemption from the 72 in limit reaches only boats built before August 1, 1985 that are in its scope and have a switch that disconnects the battery. It does not cover a boat built on or after August 1, 1985. CFR

Checking every positive wire at your battery

WHAT CHANGED BEFORE THE PROBLEM?

- after you installed or changed a device → start with that device's positive wire at the battery
- after charging → start with the charger's output wires at the battery
- after rain or washing the boat → start with the holders the water reaches: a crust or a darkened body
- after the boat sat unused → start with the circuits wired around the battery switch: they stay live while the boat sits
- after switching sources (shore power, generator, inverter) → start with the inverter's cable at the battery
- nothing you noticed → start at the positive terminal of the first battery and go battery by battery

PROCEDURE: EVERY POSITIVE WIRE AT THE BATTERY — POINT A ON → FIG. 4.1 · P. 3

GASOLINE VAPOR SHORT CIRCUIT AC — PRO SHOCK IN WATER

1. Use a cloth tape measure or a piece of string, not a metal tape. Open the battery compartment and count the wires on the positive terminal (A) of every battery in every bank.
   You will see: A list of wires, with the gauge printed on the insulation of each.
2. Follow each wire from the terminal, by eye and by hand and without pulling on it, to the first fuse or breaker it meets.
   You will see: A holder with a rating you can read — or a wire that reaches a switch, a bus or a device with no holder on the way.
3. Measure along each wire, with the cloth tape or the string, from the terminal to its first fuse or breaker.
   You will see: 7 in or less: within the limit; if there is room for the fuse or breaker closer to the terminal, write that down too, because the rule is as close as you can. Farther: it meets the rule only where closer is impossible and a continuous sheath covers the whole run, up to 72 in for a wire straight from a battery terminal. The sheath is loom, conduit, a closed raceway or a closed panel. Farther than that, or no sheath: the place fails the rule, and the stretch up to the fuse is an unprotected positive (step 5).

4. Trace every wire that has no protection to its far end.
   You will see: A cable that carries the starting current to the solenoid on the starter, directly or through the battery switch, is the starter cable — the one exception. A cable that runs straight to a terminal of another battery of the same bank joins the batteries of the bank and is part of it, not a wire that leaves it; whether your bank needs protection between its batteries is a question for its battery maker and a pro, and the answer goes into the Boat Passport. A wire taken off the starter's battery terminal to feed anything else, and any other wire without protection, is an unprotected positive.

5. Write each unprotected positive — a wire with no protection (step 4), or the stretch up to a fuse that sits too far (step 3) — on the first line of the Boat Passport. Until a pro protects it, it carries only what the sign over the rule for an unprotected positive allows (→ 4.2 · p. 8).
   You will see: The first line of the Boat Passport names the wire, where it starts and what it feeds; a pro adds protection at its start, or moves it there (→ 4.8 · p. 35).

6. Repeat steps 2 and 3 at the terminals of the battery switch and at every bus bar — for a bus bar behind the panel, with the panel open: each wire that leaves them is measured from that terminal.
   You will see: 7 in or less, or — only where closer is impossible — up to 40 in with the whole run in a continuous sheath: the place meets the rule. No fuse near that terminal: the fuse or breaker ahead of it, back toward the battery, protects the wire when its rating is not above the wire's ampacity (→ 4.3 · p. 16). Write that rating next to the wire. Neither: an unprotected positive (step 5).

7. Write every wire into the Boat Passport: what it feeds, and the type and rating of its protection. Add the interrupting rating printed on it or given in its maker's data, and the distance measured along the wire.
   You will see: A table you can hand to a pro.

PUT THE BOAT BACK IN SERVICE

- Put back every cover and cap you lifted over the battery terminals and the switch terminals.
- Close the battery compartment.
- Put the panel cover back if you opened it. If you turned the AC sources off to open it: the inverter and the generator back as you found them, and shore power back last, in the order of → 17.2.

IF YOUR BOAT IS 20 TO 40 YEARS OLD

1. **Check first:** the fuse holders near the battery. An in-line holder has a printed maximum fuse rating, and one holder maker also gives a lower continuous current — 16 A for a holder that takes up to a 20 A fuse. MFR A fuse rated above the holder's maximum lets the holder run hot; a darkened or melted body shows that it already has.
2. **Replace first if you find it:** a breaker that resets by itself. Two makers of automotive breakers describe this type: it keeps cycling on and off until the fault is corrected. MFR A boat needs a breaker that you reset by hand and that opens even when its handle is held in ON (→ 4.7 · p. 33). On a panel with AC breakers on it, replacing a breaker is a pro's work; behind a DC-only panel it is yours when the new breaker has the same rating and passes the five properties of → 4.7 · p. 33, with the panel dead as step 4 of the route "A connection, a holder or a wire runs hot" makes it (→ 4.8 · p. 35). A different rating is a pro's (→ 4.3 · p. 16).
3. **What may be missing, and how you can tell:** protection at the start of the feeder, the wire that brings current to the panel. Trace the feeder from the battery terminal, through the battery switch, to where it enters the panel, as steps 2 and 6 of the procedure above do. If there is no fuse or breaker on that path — none at the battery and none at the switch — the first protection of the feeder is the main panel breaker at its far end, and the whole feeder is an unprotected positive (→ 4.2 · p. 8).

4.3. The triad: load current, protection rating, wire ampacity

Which rating does the fuse or breaker of one circuit get? Three numbers decide it, and one rule puts them in order.

The first number belongs to the wire. Its ampacity is the current a wire can carry continuously without its insulation getting hotter than its temperature rating. Three things set it: the wire's gauge, the temperature rating printed on its insulation, and where the wire runs — a hot engine space lowers it. The second number is the load current, from the device's label or measured with a clamp meter (→ 3.3). The third is the fuse rating the device maker asks for, from the label or the manual of the device.

The fuse protects the wire, not the device. Load current ≤ protection rating ≤ ampacity of the thinnest wire in the circuit.

If the device maker requires a rating smaller than the wire's ampacity, the smaller rating is used: one fuse covers both requirements, and the rule does not call for a second fuse on the same circuit.

The left half of the chain keeps the device working: a fuse rated below the load current opens in normal use of the device. The right half keeps the wire from burning: a fuse larger than the ampacity lets the wire carry, for minutes or hours, a current that overheats it (→ 4.1 · p. 2). The thinnest wire counts because it heats first. The device maker's rating sits inside the chain: it is chosen to open on that device's own failure, such as a jammed motor, and it also protects the device's own leads.

A maker of marine fuses and holders gives the same advice for the opposite case: when the device maker's fuse value is too high to protect the wire, use a bigger wire. A bigger fuse is never the answer to a wire that is too thin. MFR

Read two things printed on the wire: its gauge, and the temperature rating of its insulation. Then find its ampacity in → Table 4.3 · p. 17. In an engine space the regulation lowers the ampacity by a factor for each insulation rating: 0.85 for 105 °C (221 °F) insulation, 0.75 for 75 °C (167 °F)

insulation. A wire bundled with other current-carrying wires carries less as well. The regulation corrects bundles only at 50 V and up; for 12 V and 24 V bundles the correction comes from ABYC (→ 5.3). CFR

Table 4.3. Ampacity of one wire run alone, by gauge and by the insulation rating printed on the wire, outside and inside an engine space CFR

Gauge	75 °C (167 °F) insulation	105 °C (221 °F) insulation	105 °C (221 °F) insulation, engine space
16 AWG	15 A	25 A	21.25 A
14 AWG	20 A	35 A	29.75 A
12 AWG	25 A	45 A	38.25 A
10 AWG	40 A	60 A	51 A
8 AWG	65 A	80 A	68 A
6 AWG	95 A	120 A	102 A
4 AWG	125 A	160 A	136 A

The data sheet of one freshwater pump lists a maximum current draw of 5 A at 25 psi and a 10 A fuse that does not come with the pump. Its leads are 16 AWG, 12 in long. These numbers belong to this pump; the rating for yours is on its own label or in its own manual. MFR

WORKED EXAMPLE: THE TRIAD ON A FRESHWATER PUMP CIRCUIT

Suppose you install that pump on your boat and run its circuit in 16 AWG wire with 105 °C (221 °F) insulation outside the engine space. Your panel came with a 15 A breaker in every position. What decides the rating is the chain of three numbers.

Load current: 5 A. Maker's rating: 10 A. Ampacity of 16 AWG with 105 °C insulation outside the engine space: 25 A. The chain 5 A ≤ 10 A ≤ 25 A is met, so the circuit gets a 10 A breaker or fuse (→ Fig. 4.4 · p. 18). The panel's 15 A breaker passes the wire test (15 A ≤ 25 A) and fails the maker's test (15 A is more than 10 A). A pro replaces it with a 10 A breaker: a breaker of a new rating is a pro's work, also behind a DC-only panel. One 10 A breaker then protects the 16 AWG run, the pump's own 12 in leads and the pump's motor; the circuit needs no second fuse.

What the numbers mean: a factory breaker that is big enough for the wire can still be too big for the device. Suppose instead the wire's insulation were rated only 75 °C (167 °F): its ampacity would be 15 A, and 10 A would still pass.

Your turn. Suppose a device's label says 3 A, its manual asks for a 5 A fuse, and its 16 AWG wire with 75 °C (167 °F) insulation runs through the engine space. What is the ampacity there, which rating does the circuit get, and does a 15 A panel breaker protect this wire? Answer: 15 A × 0.75 = 11.25 A; 3 A ≤ 5 A ≤ 11.25 A, so the circuit gets 5 A. A 15 A breaker is above the wire's ampacity in the engine space and protects neither the wire nor the device: that wire is an unprotected positive (→ 4.2 · p. 8).

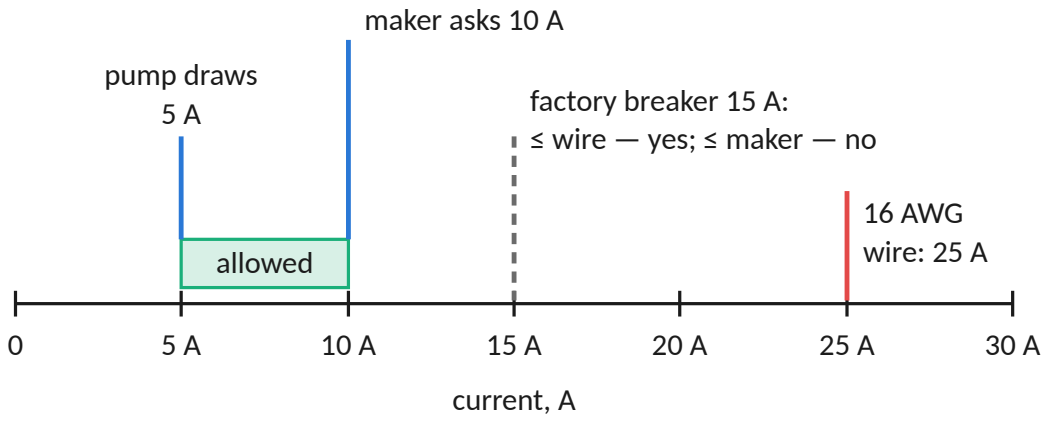


Fig. 4.4. The triad of the pump circuit in the worked example: the rating lies between the pump's current and the smaller of the maker's rating and the wire's ampacity. The factory 15 A breaker passes the wire and fails the maker's rating.

A thinner wire that leaves a bus or a splice without its own holder is a tap. The fuse or breaker ahead of it protects it only if that rating is not above the tap's ampacity. The Coast Guard's electrical handbook for boat builders names three places where protection may sit: where a conductor receives its power; where a smaller conductor joins a larger one; and where the circuit first receives its power, if the protection is sized for the smallest conductor in the circuit.

Suppose a 5 A fuse feeds a 14 AWG run with a 16 AWG tap: 5 A is below the ampacity of both wires, and the tap is protected. Suppose a 30 A

breaker feeds a 16 AWG tap with 75 °C (167 °F) insulation: the protection rating is above the wire's ampacity (30 A against 15 A), and the tap is unprotected.

WHY IT WORKS · WHERE A RULE ALLOWS A LARGER RATING

In circuits under 50 V the regulation allows a rating up to 150% of its table value for the conductor it protects. For 16 AWG with 105 °C (221 °F) insulation, whose table value is 25 A, that is 37.5 A. CFR

A breaker maker explains why it accepts such an allowance: it counts on an overcurrent lasting only a short time. The same maker warns that a sustained overload of 110% to 150% of the wire's rating does heat the wire and the protection. MFR

ABYC E-11 allows, in a branch circuit, the next larger standard rating above the wire's ampacity up to 150% of it, and limits the main protection of a panel to 100%. VERIFY

The triad never asks for more than the ampacity, so it never needs either allowance. Both allowances are for the wire only, never above the device maker's rating. A pro who uses one names the clause and writes it in the Boat Passport.

NUMBERS · ONE MAKER'S SELECTION AIDS

A breaker maker advises that a fuse or breaker carry no more than 80% of its rating continuously, so that the fuse or breaker itself does not overheat. The same maker shows the inrush current — the short surge a device draws when it is switched on — on its test system. A 17 A motor load drew 80 A (4.7 times its running current), and a 44 A resistive load drew 126 A (2.9 times). The maker advises sizing protection for such an inrush lasting about half a second. MFR Both numbers help to choose a part; neither is a diagnosis. A clamp meter read after start-up does not see the inrush current.

Do it yourself or hire a pro: the rating

DO IT YOURSELF OR HIRE A PRO · CHOOSING A RATING

HIRE A PRO · A rating above the triad, a new run fed from a battery, from the battery side of a battery switch or from the panel's feeder, protection added where a wire has none, or a breaker of a new rating. Order protection for the circuit by the triad, with the ampacity of the wire on its route. Accept the work by three signs: the rating is readable on the holder and passes the triad — or the pro names the clause of 33 CFR 183.455(c) or ABYC E-11 that allows a higher rating, never above the device maker's rating, and it is written in the Boat Passport; the fuse or breaker sits where → 4.2 · p. 8 puts it; its type, rating, interrupting rating and distance are in the Boat Passport the same day.

If no pro is available:  **BLOWN FUSE** Keep the rating the triad gives. Until a pro replaces a breaker that is above the ampacity of its wire, that wire has no working protection: it is an unprotected positive (→ 4.2 · p. 8), and it carries only what this sign allows.

When a pro may do it differently: A pro may fit a rating above the wire's ampacity where the regulation allows it: in circuits under 50 V, up to 150% of the regulation's table value for that wire, 33 CFR 183.455(c). The allowance is for the wire only, never above the device maker's rating, and it is never a reason to fit a larger fuse or breaker to stop trips. You see it by the pro naming that clause and writing it in the Boat Passport; a rating above the triad with no clause named, or above the device maker's rating, is not accepted.

DO IT YOURSELF, IF…

- A fuse you reach without opening the panel, after the battery switch, changed to the rating the triad gives — with the circuit dead, as step 4 of the route "A branch breaker trips or a fuse blows" makes it (→ 4.8 · p. 35).
- On a DC-only panel, a breaker swapped for one of the same rating that passes the five properties of → 4.7 · p. 33, with the panel dead as step 4 of the route "A connection, a holder or a wire runs hot" makes it (→ 4.8 · p. 35).

DO IT YOURSELF · Read the load current on the device's label, the maker's fuse rating in its manual, and the gauge and the temperature rating on

> the wire; check each circuit against the triad and write the three numbers in the Boat Passport.

4.4. Protection types and interrupting rating: a fuse that won't explode

A fuse must do more than melt: it must stop the current. What does the protection at your battery have to withstand, and how do you tell the types apart?

When a fuse link melts, the current does not stop right away. The gap it leaves fills with an arc — a column of hot, conducting metal vapor — and the fuse has to stretch and cool that arc until it goes out. With AC the current passes through zero 120 times a second, and each zero gives the arc a chance to go out. With DC it never passes through zero, so the fuse or breaker must force it down, and the larger the current, the harder that is. Above a certain current the arc keeps burning inside the body until the body ruptures, and the circuit is not broken at all.

That limit is the interrupting rating (AIC): the largest current a fuse or breaker can interrupt at its rated voltage and stay intact. Makers print it under several names, and on small fuses it is not always on the body at all — only in the maker's data sheet. It falls as the voltage rises: one terminal fuse interrupts 10,000 A at 14 V and 5,000 A at 32 V. Read the number for your system voltage; on a 24 V system, the number at 28 V to 32 V or above. MFR

The protection at the battery needs an interrupting rating at least equal to the current the battery can push into a short at that point. That current is the battery's short-circuit current, and only the battery's maker can give it to you.

One maker lists a short-circuit current of 5,000 A for its 100 Ah battery of the TPPL AGM type (thin plates of pure lead) — a premium lead-acid type at the top of the range for this number. MFR

Makers of ordinary flooded and AGM batteries publish no short-circuit current. One lithium maker gives the internal resistance of its battery,

another the response time of its battery management system (BMS), and neither gives a short-circuit current. If the data sheet of your battery gives no short-circuit current, ask its maker for the number. Without it, the protection at the battery is a question for a pro.

Suppose the maker of your lithium battery lists its internal resistance as 1 mΩ at 12.8 V. A dead short at its terminals would draw about 12.8 / 0.001 = 12,800 A. That is more than the 10,000 A a terminal fuse interrupts at 14 V, and less than the 20,000 A of a Class T fuse (→ Table 4.4 · p. 22). The internal resistance gives only the order of the current; the maker's short-circuit number, where it exists, decides.

The main protection of a lithium bank has an interrupting rating, at the bank's voltage, at least equal to the bank's short-circuit current — the battery maker's figure for one battery, times the batteries joined in parallel — and is the type the battery's maker names, where it names one; in practice, a Class T fuse. The BMS is not overcurrent protection. Where the maker gives no short-circuit figure, or the protection on the bank is not the type the maker names, or its interrupting rating cannot be read, a pro sizes it. It is replaced only with the same rating, and with a type and an interrupting rating that meet this — never with a lower interrupting rating. Until a pro has done it, the bank stays in use while the cable it protects has its insulation whole, nothing chafing it and nothing wet on it, and the finding is the first line of the Boat Passport (→ 11.2). Fitting or replacing the main protection is work at the battery terminal, a pro's (→ 1.8).

The BMS disconnects the cells to save them. One lithium maker's manual says it plainly: the short-circuit protection of its BMS protects the battery's cells, and a short can still produce a spark and damage the cable or the bolt. Battery makers also differ on the fuse they require. One names only its Class T fuse and forbids an ANL, a MIDI or any other type in its place. Another names "a T-fuse or an MRBF fuse" with an interrupting rating of 15,000 A — a number no terminal fuse in → Table 4.4 · p. 22 reaches at 12 V. The manual of your battery decides the type.

MFR

Table 4.4. Fuse and breaker types, and the interrupting rating one or two makers print for

their part MFR

Type, by the name printed on the part	Where you find it	Interrupting rating, DC, as printed
Blade fuse ATO / ATC: flat plastic body with two blades, 1–40 A	Branch circuits, fuse blocks	1,000 A at 32 V (two makers)
MAXI: a larger blade fuse	Heavier branch circuits	1,000 A at 32 V (two makers)
MIDI: bolt-down, 30–200 A	Feeders, chargers	2,000 A at 32 V (one maker)
MEGA / AMG: bolt-down, larger than MIDI	Feeders, inverters	2,000 A at 32 V (a 32 V series); 2,500 A at 70 V (70 V series of three makers)
ANL: bolt-down	Main protection, windlass, inverter	6,000 A at 80 V (one maker); 2,700 A, voltage not stated (another maker)
MRBF: a fuse that mounts on the battery's positive terminal in an isolated holder, 30–300 A	Main protection at the terminal	10,000 A at 14 V; 5,000 A at 32 V; 2,000 A at 58 V (one maker)
Class T: bolt-down	Main protection of large banks, and of a lithium bank (→ 11.2)	20,000 A (three makers, at 125 V or 160 V)
Glass tube AGC / 3AG	Branches of older panels	No DC rating in two makers' data: 1,000 A and 300 A at 32 V AC
Thermal breaker, surface mount, with a reset lever	Feeders, windlass	5,000 A at 14 V; 3,000 A at 28 V; 1,500 A at 48 V (one maker)
Hydraulic-magnetic panel breaker, toggle or rocker	Panel branches and main panel breakers	7,500 A at 65 V (one maker); 7,500–10,000 A at 80 V, by product and rating (two makers)

The type of a fuse does not set its interrupting rating: two makers' ANL fuses differ by more than two times. The number that counts is the one for your part, from its maker's data, at your system voltage.

LOOKS LIKE THE FIX	FIND OUT FIRST	WHAT FIXES IT
A Class T fuse at the battery, because its interrupting rating is the highest in → Table 4.4 · p. 22.	The short-circuit current of your battery, from its maker, and the fuse type the manual of your battery names.	Main protection of the type your battery's manual names, with an interrupting rating at least equal to that current, at the distance of → 4.2 · p. 8. Fitting it is work at the battery terminal, a pro's (→ 1.8).

The terminal fuse and its holder

A terminal fuse (MRBF) sits on the battery's positive terminal in an isolated holder. The holder keeps the battery's stud apart from the fuse's output stud, so the current goes from the terminal (A), through the fuse link, to the output (B) where the cable lug sits. Mounted without its holder, straight on the battery stud, the fuse is bypassed. The stud and the nut carry the current around the link, and even if the link opens, the circuit does not (→ Fig. 4.5 · p. 25). The fuse maker and one battery maker say the same: never mount this fuse without its isolated holder. Fitting it is work at the battery terminal, a pro's (→ 1.8). MFR

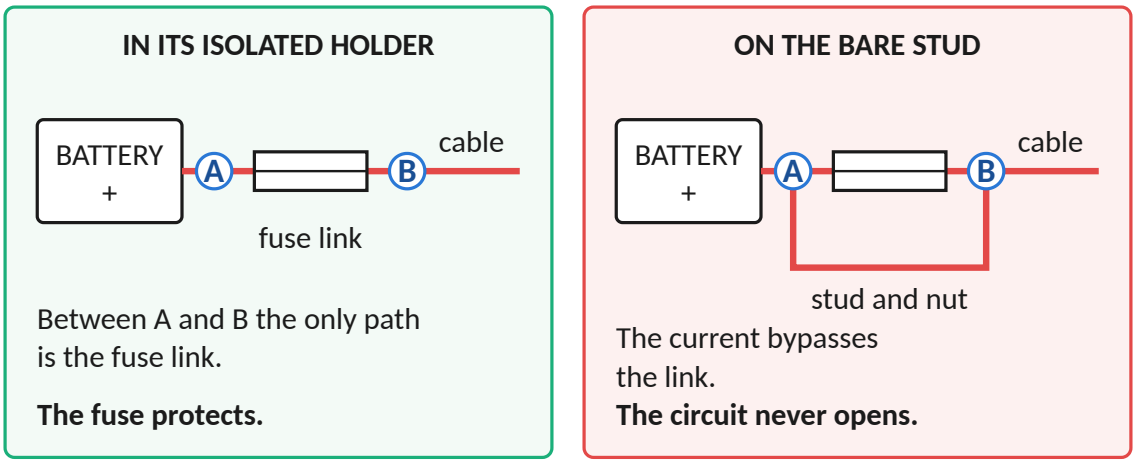


Fig. 4.5. A terminal fuse (MRBF) as a circuit. In its isolated holder the only path from A to B is the fuse link. On the bare battery stud, the stud and the nut join A and B around the link, and the circuit never opens.

A branch fuse next to a big battery

The interrupting rating matters at every fuse, not only at the battery. A fuse block close to a large bank can see a short-circuit current above the interrupting rating of the fuses on it, because only a few feet of wire lie between them. The main protection ahead of that block does not lower this current: only resistance lowers it. A Class T fuse limits the current it lets through while it opens. That does not allow a smaller interrupting rating after it, unless the maker of the part after it documents that combination.

> **WORKED EXAMPLE: IS A BLADE FUSE ENOUGH NEXT TO A BIG BATTERY?**
>
> Suppose a fuse block with blade fuses is fed by 6 AWG wire, 10 ft from one premium battery whose maker rates its short-circuit current at 5,000 A. What decides: the current a short right at the block would draw, against the blade fuse's interrupting rating of 1,000 A.
>
> The battery's own resistance is about 12.6 / 5,000 = 0.0025 Ω. By the ABYC formula, the wire — 20 ft of 6 AWG (26,240 circular mils) out and back — is 10.75 × 20 / 26,240 = 0.0082 Ω. Together 0.0107 Ω, so a short at the block draws about 12.6 / 0.0107 ≈ 1,180 A — more than 1,000 A. With 4 AWG over the same run the short draws about 1,640 A.

> What it means: the blade fuses on that block are asked to interrupt more than their rating. The resistance of connections, the battery switch and the main protection lowers the real current, and a pro calculates it. The fix is protection rated for the current at that point, or a combination its maker documents.

Breakers

A breaker on a boat must reset only by hand and be trip-free: it opens on an overcurrent even when its handle is held in ON. One maker of panel breakers states that its breakers trip on overload even when the handle is forcibly held in ON. CFR

A breaker whose interrupting rating is below the short-circuit current where it sits can be protected by a fuse ahead of it — only when the breaker maker's document names that fuse. ABYC

A thermal breaker senses heat, so it responds to the temperature around it as well as to the current. A maker of hydraulic-magnetic breakers reports that a 10 A thermal breaker can trip as early as 7 A in a hot place and as late as 13 A in a cold one. A hydraulic-magnetic breaker senses the current in its coil and stays close to its rating across temperatures. In a hot space, check the circuit against the triad with the engine-space ampacity of → Table 4.3 · p. 17; a temperature correction for the breaker itself comes only from its maker. MFR

When the main protection at the battery trips or blows, the cause lies somewhere after it. What you do until a pro has found it is in → 1.8; the route "The whole panel went dark" (→ 4.8 · p. 35) shows how you tell that the main protection opened.

4.5. The panel: from the battery to the device

Current reaches each device along one path and comes back along another. How does that path run through your panel, and what behind the panel tells you whether the wiring is sound?

Follow the path on → Fig. 4.1 · p. 3. The main fuse at the battery protects the cable to the battery switch and the feeder beyond it. At the panel the feeder meets the main panel breaker, which feeds the positive bus (D). Each branch breaker takes its current from that bus and sends it down one branch wire (E) to one device (F). The current returns on the device's own negative wire to the negative bus (G), and from there on one cable to the battery's negative terminal (H).

Two things in this path differ from house wiring. First, the main panel breaker does not protect the feeder that brings current to it: it sits at the far end of that wire. The feeder is protected by the fuse at its start — the rule of → 4.2 · p. 8, and the triad of → 4.3 · p. 16 applied to the feeder. Second, each device must return its current on a wire of its own to the negative bus. The engine block returns current only for equipment mounted on the engine, and it is tied to the negative by its own cable; the hull, the mast, the outboard bracket and the bonding wires never carry a load's return current (→ 1.4). The panel frame carries no load's return current either. ABYC

The negative bus is not the grounding bus, where the green wires end, and a panel maker warns not to confuse the two. MFR

A panel has a current limit of its own, and its label and its maker's document can print different numbers: one panel's product page gives 50 A where its installation instruction says 100 A. Take the smaller number. Check that the main panel breaker is rated no higher than that number: a larger one lets the panel's own bus carry more current than its maker built it for. MFR

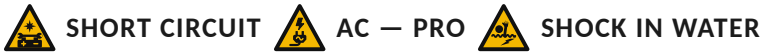
One panel maker ships its panels with 15 A breakers in every position, and its instruction says to replace any breaker that is too small for its circuit. The instruction does not name the opposite case: a breaker too large for the wire or for the device. Check every position against the triad (→ 4.3 · p. 16). MFR

The standard asks that every switch and every breaker be marked with what it controls; it excuses only a control whose purpose is obvious and whose wrong use causes no hazard. A position with no label, or a ABYC

label that no longer matches what the breaker feeds, goes into the Boat Passport as an unknown connection until you have traced it.

You can use a branch breaker to switch its circuit on and off: breaker makers allow it, and one rates its breakers for 10,000 on-off operations at rated current and voltage. The exception is a push-button breaker that only resets: it cannot be switched off at all. MFR

What you find behind the panel



Open the panel and look: what you find behind it tells you whether the wiring is sound (→ Table 4.5 · p. 28). Where the panel carries the AC side behind the same cover, 120 V AC sits next to the 12 V wiring, and 120 V AC can drive a current through your body. On the positive bus the danger is a tool that bridges the bus and a negative: the current of a short, and its heat. The repairs of the last column are a pro's behind a panel with AC breakers on it; behind a DC-only panel they are yours, with the panel dead as step 4 of the route "A connection, a holder or a wire runs hot" makes it (→ 4.8 · p. 35), and with the terminals and crimps of → 5.6 — on any negative connection, only after the readings of step 3 of its procedure "Replacing a terminal on a wire after the battery switch". When you are done, the cover goes back on, a DC breaker, an isolation switch or a fuse that those readings turned off or took out comes back as you found it, and the AC sources you turned off come back as you found them — shore power last, in the order of → 17.2.

Table 4.5. Behind the panel: what you see, why it matters, what to do ABYC

What you see	Why it matters	What to do
Wires joined with a twist-on wire nut	The standard does not allow twist-on connectors: vibration loosens them, and a loose joint heats	Write it in the Boat Passport; the joint is remade with a crimped connector (→ 5.6)
A bare wire under a screw, with no ring or captive spade terminal	The standard asks for ring or captive spade terminals; a bare wire under a screw works loose	Write it down; a ring or captive spade terminal is crimped on (→ 5.6)

What you see	Why it matters	What to do
Five or more lugs on one stud	The standard allows no more than four conductors on one terminal stud; more are joined by a jumper or a copper strap to another stud	Write it down; a jumper or a copper strap moves the extra lugs to another stud (→ 5.6)
A ring terminal larger than its stud	The standard asks that the ring be the same nominal size as the stud	Write it down; a ring of the stud's size is crimped on (→ 5.6)
A device's negative wire on the panel frame	Every negative goes to the negative bus; the frame is not a return path	Write it down; the negative wire goes to the negative bus (→ 5.6)
An added wire under another circuit's breaker terminal	That breaker now protects two circuits, and its rating must pass the triad for the thinnest wire of both	Compare the rating with both wires (→ 4.3 · p. 16); hire a pro
Heat marks, melted insulation, a darkened terminal	A connection that has been heating at normal current	The route "A connection, a holder or a wire runs hot" (→ 4.8 · p. 35) finds it by its drop under load and says who repairs it

4.6. Ignition protection in gasoline compartments

Gasoline vapor in a closed compartment needs only a spark to explode. Which spaces on your boat need electrical parts that cannot make that spark, how do you recognize such a part, and what must never go into those spaces?

Gasoline vapor is heavier than air and collects low in a compartment. The regulation puts the intake of a bilge blower in the lower third of the compartment, and a blower maker names the reason: that is where the vapors collect. Every electrical part that switches, arcs or heats CFR can light them. Examples are the contacts of a switch or a relay as they open, a breaker as it trips, the brushes of a motor, and a fuse link as it melts.

The regulation requires that blower only in a compartment with a permanently installed gasoline engine that has a cranking motor, and

only where that compartment is not open to the atmosphere; it also requires the warning placard next to the key switch (→ 1.1). CFR

An ignition-protected part is built so that, in its design operating conditions, it does not ignite a flammable mixture around it. An explosion inside it does not reach the mixture outside, or it cannot release enough energy to light it, or its source of ignition is sealed. Ignition protected is not the same as explosion-proof; the marine test is a test of its own. ABYC

The regulation requires it on the boats in its scope: boats with a gasoline engine other than an outboard, for propulsion, mechanical power or electrical generation. On such a boat, each electrical component must not ignite a propane and air test mixture around it, unless it is isolated from gasoline fuel sources. The sources are the engine, and the valves, connections and fittings of fuel lines and tanks. The regulation counts a part as isolated in three cases. A tight bulkhead separates it from the fuel source. Or it sits lower than the fuel source, with a means that keeps leaking fuel and vapor from reaching it, or higher, with a deck or another enclosure between them. Or at least 2 ft of space open to the atmosphere lie between them. CFR

ABYC E-11 ties the requirement to the space, not to the engine: spaces that contain gasoline-powered machinery, gasoline fuel tanks, or joints and other connections of a gasoline fuel system. On an outboard boat, which the regulation's electrical rules do not cover, that reaches a space that holds a gasoline tank — built in or portable — or fuel-system joints or fittings, whether it is a closed compartment or open to the atmosphere. The standard's exceptions are a boat whose only fuel is diesel, and an outboard mounted outside the boat or in a compartment open to the atmosphere. The second frees the outboard itself, not a space with the tank or those joints (→ Table 4.6 · p. 31). ABYC

Table 4.6. Where electrical parts must be ignition protected, by document

Space on your boat	33 CFR 183.410 CFR	ABYC E-11 ABYC
A space, closed or open to the atmosphere, with a gasoline inboard, sterndrive or generator engine, or with a gasoline tank or fuel fittings, on such a boat	Required, unless the part is isolated	Required, unless the part is isolated
A space, closed or open to the atmosphere, that holds a gasoline tank — built in or portable — or fuel-system joints or fittings, on a boat whose only gasoline engine is an outboard	Not in scope	Required, unless the part is isolated
Any space on a boat whose only fuel is diesel	Not in scope	Not required
An outboard mounted outside the boat or in a compartment open to the atmosphere	Not in scope	Not required for the engine

You recognize a protected part by its marking or its maker's document, never by its brand or by its job. The markings include "Ignition Protected", "SAE J1171 MARINE" and "UL 1500 Marine-Ignition Protected". ABYC

One maker lists its Class T fuse holder for 110–200 A as ignition protected, and its holder for 225–400 A as not. The same job, the same maker, two answers: read the label of the part in your hand, or its maker's data. MFR

Some parts never go into these spaces unmarked. Two panel makers warn that the breakers of their panels are not ignition protected, and one of them says the panels must not be installed in gasoline engine rooms. MFR

A cabin fan, a relay, a switch or a fuse block with no marking and no maker's document that names it ignition protected stays out as well: you treat such a part as not protected. PRACTICE

Procedure: replacing an electrical part in a gasoline compartment

A switch, a fan, a relay, a fuse block or any other electrical part in one of these spaces is replaced with its circuit dead, by a part that carries an ignition-protection marking: a space with a gasoline engine — not an

outboard mounted outside the boat or in a compartment open to the atmosphere — or with a gasoline tank, built in or portable, or fuel-system joints or fittings, whether it is a closed compartment or open to the atmosphere; a space open to such a compartment. The exception is a part isolated from the fuel source in one of the three cases above; an isolation you cannot confirm counts as none. How you make the circuit dead depends on how the part is fed: after the battery switch, or on a circuit wired around it, which stays live with the switch OFF; the Boat Passport shows which (field 10; → 2.3).



1. Before you buy the new part, read its marking or its maker's document: "Ignition Protected", "SAE J1171 MARINE" or "UL 1500 Marine-Ignition Protected". With no such marking and no such document, it is not the part for this compartment.
2. A part fed after the battery switch: with the engine stopped, prove the part's wires dead, as the entry of the PROVE IT DEAD sign says, turning the battery switch OFF after its first reading.
3. A part on a circuit wired around the battery switch: take out its own fuse at the battery, in the state the entry of the SHORT CIRCUIT sign gives for that fuse. In a holder that opens by hand, the fuse comes out by hand or with its puller. A fuse under a nut on a stud is work at the battery terminal, a pro's (→ 1.8), and the part stays live until then. No fuse of its own at the battery: the circuit is an unprotected positive (→ 4.2 · p. 8), the part stays live, and its replacement waits for a pro. If that circuit feeds the bilge pump, the boat has no working pump while the fuse is out: stay on board until it is back.
4. Before you touch the part's wires, read the voltage between its positive terminal and the battery's negative terminal (H), then on the battery's positive terminal (A): 0 V at the part, battery voltage at A. Any voltage at the part: it has a second feed, and the entry of the PROVE IT DEAD sign says what follows.

5. Replace the part, and connect each wire of the new part where the same wire of the old one was.

PUT THE BOAT BACK IN SERVICE

- A fuse you took out at the battery back in the way it came out, in the state the entry of the SHORT CIRCUIT sign gives for that fuse; then the loads and the charging sources you turned off for it back as you found them.
- After step 2: turn the battery switch back to its working position, with the engine still stopped (→ 1.7).
- A CO alarm on the circuit of step 3 lost its power while its fuse was out, and one wired after the battery switch while the switch was OFF in step 2; the entry of the CARBON MONOXIDE sign says how you see that it is working again.
- After step 2: check that the bilge pump's automatic switch has power (→ 12.2).

4.7. Marine-grade or not? Automotive fuses, house breakers

Fuses and breakers from a car parts store or a hardware store cost less and are easier to find. Which of them can protect a circuit on your boat, and what do you check before you buy one?

The question is not "automotive or marine". It is five properties of the part, each printed on it or given in its maker's data, and a part is right only when it passes all five. The letters DC printed alone do not make it right.

- ☐ The rating passes the triad of the circuit (→ 4.3 · p. 16).
- ☐ The voltage rating is not less than your system voltage; for a breaker, a DC rating printed on it or given in its maker's data. ABYC
- ☐ The interrupting rating at your system voltage is not less than the short-circuit current where the part goes (→ 4.4 · p. 21).

- ☐ A breaker resets only by hand and is trip-free: it opens even when its handle is held in ON. CFR
- ☐ In a gasoline space, the part carries an ignition-protection marking (→ 4.6 · p. 29).

MARINE-GRADE OR NOT? · BLADE FUSE FROM A CAR PARTS STORE

An ATO or ATC blade fuse. It is the fuse that marine blade fuse blocks take. One maker of such blocks lists ATO and ATC fuses for its 32 V DC block. It sells the fuse itself as the standard circuit protection device for cars and trucks: 32 V DC, with an interrupting rating of 1,000 A. On a 12 V or 24 V branch it does its job. Next to a large battery the short-circuit current at the block can pass 1,000 A, and then the fuse is asked to interrupt more than it can (→ 4.4 · p. 21). MFR

Verdict: Fine in branches

MARINE-GRADE OR NOT? · BREAKER FOR A HOUSE PANEL

A breaker for a house panel. It is built for 120/240 V AC, where the current passes through zero 120 times a second and the arc goes out at a zero. DC never passes through zero, and the breaker must force the arc out (→ 4.4 · p. 21). One maker states that the main breakers of its house panels have no DC rating at all. Among its branch breakers, only certain two-pole breakers with a particular suffix in their catalog number carry a DC rating, printed on their UL label. A house breaker belongs on the DC side of your boat only when a DC rating is printed on it. MFR

Verdict: DC rating required

MARINE-GRADE OR NOT? · AUTOMATIC-RESET BREAKER FOR A CAR

An automatic-reset breaker. Two makers describe this type the same way: it resets by itself and keeps cycling on and off until the fault is corrected. On a boat a breaker must reset only by hand, so that a fault stays off until someone finds it. MFR

Verdict: Not on board

MARINE-GRADE OR NOT? · GLASS TUBE FUSE

A glass tube fuse (AGC, 3AG). Two makers rate their 15–30 A glass fuses for 32 V AC only, with interrupting ratings of 1,000 A and 300 A; a third prints 32 V DC with no interrupting rating. With no DC interrupting rating from its maker, a glass fuse cannot pass the third property of this section: nothing tells you that it stops a DC short. One already in a branch of an older panel is not an emergency; when a pro works on that panel, have it replaced with a fuse that passes all five. As the main protection at a battery it never belongs. MFR

Verdict: Replace when rewiring

MARINE-GRADE OR NOT? · IN-LINE FUSE HOLDER

An in-line fuse holder. A holder has numbers of its own: the largest fuse it takes and, from one maker, a lower continuous current — 16 A for a holder that takes up to a 20 A fuse. Between those two currents the holder's own contacts heat while the fuse stays whole. A fuse rated above the holder's maximum lets that happen; a darkened or melted holder shows that it already has. MFR

Verdict: Check holder rating

Part numbers on the US market with their ratings, and US replacements for the metric parts of a European-built boat, are the subject of → module "Components".

4.8. On board

A breaker tripped, a fuse blew, a wire or a holder runs hot, or a wire burned and nothing tripped: what do you do first, and how do you find the cause? First, whatever happened, switch off the device on that circuit, and look and smell before you touch any breaker or fuse. Smoke, melted insulation or a burning smell from wiring means the fault is already a fire: stop troubleshooting and go to the card "Smoke, a burning smell, or an overheated wire" (→ emergency card). With no smoke, no burning smell and no hot case, take the route for what you see.

ON BOARD: GOLDEN RULE

Every positive wire that leaves the bank starts with its protection; the starter cable is the one exception. The stretch between the source and the first fuse is the one piece of wire that nothing on the boat can switch off.

A tripped breaker or a blown fuse has found a fault. The routes below find it: the current at switch-on, how long the breaker held, where the protection sits and what it is rated.

A tripped shore power breaker, on the AC panel or at the pedestal, and any device with a TEST button belong to the AC side: what to do is on the card “Shore power tripped and won’t come back on” (→ emergency card) and in → 17.3.

Why a breaker is reset only once: the first trip already tells you that the circuit carries more current than its protection allows. A second reset into the same fault sends the fault current through the same wire again, and the wire and its connections get hotter each time. Why the engine stops before a battery switch turns: the running alternator must not lose its battery (→ 1.7).

Each breaker shows a trip the way its maker built it. On one maker’s panel breakers the handle moves to OFF; one surface-mount breaker has a lever that shows the trip; a push-button breaker resets when you push its button. Read how yours resets on its label or in its maker’s data: a handle from OFF to ON, a lever as marked, a button pushed in. MFR

What it means

Table 4.7. What it means

What you notice	What is happening	First check	Yourself or a pro
A branch breaker trips the moment you switch the device on	A short in the wire or the device, a jammed motor, or an inrush current the breaker's delay does not pass	The current at switch-on against the breaker's rating: the route "A branch breaker trips or a fuse blows", step 3 (→ 4.8 · p. 35)	**Do it yourself, if…**
A fuse blows the moment you switch the device on	The same causes: a short, a jammed motor, or an inrush current the fuse does not pass	Where the fuse sits — after the battery switch, at the panel on a circuit wired around it, or at the battery — sets how it is replaced: the same route, steps 4 to 6	**Do it yourself, if…; a fuse on a stud at the battery: Hire a pro**
A branch breaker trips after the device has run for minutes	An overload: the current is above the rating, or the breaker sits in a hot place	The current with the device running, against the breaker's rating and the triad (→ 4.3 · p. 16): the same route, step 3	**Do it yourself, if…**
A breaker trips only when two or more devices run together	The total current of the circuit is above its rating: a sustained overload	The current with each device switched on in turn, the total against the rating: the same route, step 3	**Do it yourself, if…**
The fuse in the bilge pump's switch on the panel blew	A short or an overload on the pump circuit, which is wired around the battery switch and stays live with the switch OFF	The same route, step 5; until the fuse holds, the boat has no working pump on that circuit	**Do it yourself, if…**

What you notice	What is happening	First check	Yourself or a pro
The whole panel went dark, and the main panel breaker has tripped	An overload or a fault on the positive bus or in a branch whose own breaker did not open	The route “The whole panel went dark”, step 3 (→ 4.8 · p. 35)	**Do it yourself, if…**
The whole panel went dark, and the main panel breaker is at ON	The battery switch is off; the main protection at the battery opened; the switch, the feeder or the main panel breaker does not pass current; the negative cable to the battery is open; or the battery itself is discharged or cut off	The battery switch’s position, then A, B and C against H (→ Fig. 4.1 · p. 3): the route “The whole panel went dark”, steps 1 and 4	**Do it yourself, if…; the main protection, the switch, the feeder and the negative cable: Hire a pro**
A fuse holder, a terminal or a wire is warm or hot, and nothing trips	Heat at a bad connection, at normal current, or a wire too thin for its current	The voltage drop across the connection under real load: 5 mV or more across one connection means it is heating — the route “A connection, a holder or a wire runs hot” (→ 4.8 · p. 35)	**Do it yourself, if…; at the battery beyond the planned job on a battery (→ 6.5), or behind a panel with AC breakers: Hire a pro**
A fuse at the battery blew	A short or an overload on that circuit; for the bank’s main protection, a fault anywhere after it	The holder decides: the route “A branch breaker trips or a fuse blows”, step 6; the bank’s main protection: → 1.8	**Do it yourself, if…; a fuse on a stud or the main protection: Hire a pro**

What you notice	What is happening	First check	Yourself or a pro
A wire burned or melted, and its fuse did not open	A fault ahead of the fuse, a bad connection after it, a thin tap under a larger fuse, or a fuse too big for the wire	Where the wire's first protection sits and where the damage sits, and the rating against the ampacity of the thinnest wire (→ 4.3 · p. 16): the route "A wire burned, and nothing tripped" (→ 4.8 · p. 35)	**Hire a pro**

Route: a branch breaker trips or a fuse blows

WHAT CHANGED BEFORE THE PROBLEM?

- after you installed or changed a device → the new device and its circuit: its current against the triad (→ 4.3 · p. 16)
- after charging → the charger's own output fuses and the circuits the charger feeds
- after rain or washing the boat → water in a switch, a connector or a deck fitting on that circuit
- after the boat sat unused → the device itself: a pump or a motor that has stuck draws more current
- after switching sources (shore power, generator, inverter) → the circuits fed by the inverter or the charger
- nothing you noticed → the one test of step 3

ROUTE: A BRANCH BREAKER TRIPS OR A FUSE BLOWS — POINTS C, D, E AND F ON → FIG. 4.1 · P. 3

GASOLINE VAPOR SHORT CIRCUIT METER LEADS AC — PRO CARBON MONOXIDE SHOCK IN WATER BLOWN FUSE BILGE PUMP PROVE IT DEAD

1. Switch off the device on the tripped circuit, and write down which breaker or fuse opened and how it shows it.
   You will see: A handle at OFF, a lever that shows the trip, a button to push, or a fuse with a broken link.

2. Put a DC clamp meter, zeroed (→ 3.3), around the branch wire of that circuit between the breaker output (E) and the device (F). Where you reach the branch wire only behind the panel, open the panel for it.
   You will see: About 0 A with the device off.

3. Reset the breaker, then switch the device on and watch the clamp meter and the breaker: this one switch-on is the test.
   You will see: It trips right away: a short or a jammed motor — a breaker that opens this fast leaves the clamp meter no time to show the current. It does not trip, and the current is below the rating: write down the current. It does not trip, and the current is near or above the rating: an overload. It trips after a while: an overload, or a breaker in a hot place.

4. For a fuse after the battery switch: with the engine stopped, prove the fuse holder dead, as the entry of the PROVE IT DEAD sign says, turning the battery switch OFF after its first reading. Put in a new fuse. With the engine still stopped, turn the battery switch back to its working position, and switch the device on as in step 3.
   You will see: The same four outcomes as in step 3; if the new fuse blows: step 7.

5. For a fuse at the panel on a circuit wired around the battery switch, such as the fuse in the bilge pump's panel switch: it stays live with every battery switch OFF. Switch the circuit's own switch OFF, and take the fuse out and put the new one in by hand. Then switch the device on as in step 3; on a bilge pump circuit, the test is a few seconds in MAN if there is water in the bilge.
   You will see: A new fuse that does not blow at one switch-on of the device. If it blows: step 7.

6. For a fuse at the battery, the holder decides. In a holder that opens by hand, take the fuse out by hand or with its puller and put the new one in the same way. A fuse under a nut on a stud is work at the battery terminal, a pro's (→ 1.8). The bank's main protection: → 1.8.
   You will see: A new fuse that does not blow at one switch-on of the device. If it blows: step 7.

7. If the breaker or fuse opened again: write down the current at switch-on, the time until it opened, the rating and the wire gauge. A bilge pump on that circuit is off with it.
   You will see: The record you hand to a pro.

8. If it did not trip or blow: compare the current with the triad of the circuit (→ 4.3 · p. 16). A current below the rating does not prove the device bad. The first trip then came from one of three causes: the breaker's delay does not suit the device's inrush current, the breaker is worn, or the run has a fault that comes and goes. A pro decides which from your record.
   You will see: A current within the triad and no second trip: watch the circuit at the next use.

9. After a second trip, the circuit stays off and labeled until its cause is found and removed — the overload of step 3 by moving a load to another circuit, any other cause by a pro from the record of step 7. Only then is the breaker reset and the device switched on.
   You will see: It does not trip during a normal run of the device.

PUT THE BOAT BACK IN SERVICE

- A circuit that opened twice stays off and labeled until its cause is removed.
- A charger, solar panels or any other source you turned off for the readings of step 4: back as you found them, except a feed that reaches a circuit the item above keeps off.
- A battery switch you turned OFF in step 4 and did not turn back: once the circuit that waits for a pro is off at its own breaker or switch, back to its working position, with the engine still stopped (→ 1.7).
- A CO alarm wired after the battery switch lost its power while the switch was OFF in step 4; the entry of the CARBON MONOXIDE sign says how you see that it is working again.

- If you turned the battery switch in step 4, or replaced a fuse on a bilge pump circuit in step 5 or 6: check that the bilge pump's automatic switch has power and the pump is not running by hand (→ 12.2).
- Put the panel cover back if you opened it. If you turned the AC sources off to open it: the inverter and the generator back as you found them, and shore power back last, in the order of → 17.2.

LOOKS LIKE THE FIX	FIND OUT FIRST	WHAT FIXES IT
A bigger breaker, so the circuit stops tripping.	Why it trips: the current at switch-on and while running, from the one test of this route. Compare it with the triad of the circuit: the device maker's rating and the ampacity of the thinnest wire (→ 4.3 · p. 16).	Removing the cause: the fault, the stuck motor, the extra load moved to another circuit. A device that needs more current than its wire allows gets a thicker wire and a new rating by the triad — a pro's work. A bigger breaker on the same wire moves the heat from the breaker into the wire.

Route: the whole panel went dark

The steps of this route start with the engine stopped: if it is running, get to safe water or anchor first, then stop it (→ 1.7).

WHAT CHANGED BEFORE THE PROBLEM?

- after you installed or changed a device → the new load on the panel: the total current against the main panel breaker
- after charging → the charger's connection to the bank and the main protection at the battery
- after rain or washing the boat → water at the panel or at the battery switch
- after the boat sat unused → the battery itself: its resting voltage (→ 3.5)
- after switching sources (shore power, generator, inverter) → the battery switch position and the loads the inverter added
- nothing you noticed → step 1

ROUTE: THE WHOLE PANEL WENT DARK — POINTS A, B, C, D, G AND H ON → FIG. 4.1 · P. 3

GASOLINE VAPOR · SHORT CIRCUIT · METER LEADS · AC — PRO · CARBON MONOXIDE · SHOCK IN WATER · BLOWN FUSE · BILGE PUMP

1. Look at the battery switch: is it at the working position written in your Boat Passport? If it is not, turn it there — where that is BOTH, 1+2 or ALL, to 1; where it is COMBINE, to ON. Do not move it from one bank to the other before the main protection of the bank in use and the main panel breaker are checked (steps 2 to 4), and never turn it to BOTH, 1+2, ALL or COMBINE, or turn a parallel switch or a charging relay's own combine control ON: they tie the banks together.
   You will see: It was at its working position: step 2. You turned it, and the panel comes back: the route ends here. The panel stays dark: step 2.
2. Look at the main panel breaker.
   You will see: Tripped: step 3. At ON: step 4.
3. With the extra loads off and the engine stopped, turn the battery switch OFF, reset the main panel breaker, and turn the battery switch back on.
   You will see: The panel comes back: switch the loads on one at a time, and follow the route for a tripped branch in this section for any branch that trips. Another trip: the fault is on the positive bus or in a branch whose own breaker

did not open, and a pro finds it. It does not trip, and the panel stays dark: step 4.

4. At the battery, put the meter's negative probe on the battery's negative terminal (H), and measure the battery's positive terminal (A), the output of the main protection (B) and the panel-side terminal of the battery switch (C).
   You will see: 0 V at A, or far below the resting voltage of a charged battery: the battery itself is discharged or cut off, not its protection or the switch. Its resting voltage and what it means are in → 3.5. A lithium battery can be cut off by its own BMS; its manual says how it comes back on (→ 11.4). Battery voltage at A and 0 V at B: the bank's main protection at the battery opened, or its connection at the terminal; what you do until a pro has found the cause is in → 1.8. Battery voltage at B and 0 V at C: the battery switch, or the cable from B to it, does not pass current — hire a pro. Battery voltage at C: step 5.

5. Open the panel, put the meter's negative probe on the negative bus (G), and measure the positive bus (D), then the panel-side terminal of the battery switch (C).
   You will see: Battery voltage at D: the panel has power up to its bus; for a dark branch whose breaker tripped, follow the route for a tripped branch in this section. 0 V at D and battery voltage at C: the feeder or the main panel breaker does not pass current — hire a pro. 0 V at D and 0 V at C against G, though step 4 read battery voltage at C against H: the negative cable from G to H is open — hire a pro.

PUT THE BOAT BACK IN SERVICE

- Put the panel cover back if you opened it.
- If the fault lies at the main protection, in the battery switch, in the feeder or in the negative cable: with the engine stopped, turn the battery switch OFF; it stays OFF until a pro has repaired the fault.
- A bilge pump that takes its power, or returns its current, through the faulted part has stopped with the panel; the Boat Passport shows how yours is wired (→ 2.3). If yours has stopped, the boat is without it until the fault is repaired; if the water rises, bail with a manual pump or a bucket.

- A CO alarm that went dark with the panel, or that is wired after the battery switch, was without power while the panel was dark or the switch was OFF; the entry of the CARBON MONOXIDE sign says how you see that it is working again, and what you do while it has no power.
- If you turned the battery switch in step 1 or step 3: check, with the battery switch where it now stands — at its working position, at the position step 1 gives in its place, or OFF by the second item — that the bilge pump's automatic switch has power (→ 12.2). Where the check cannot pass, the entry of the BILGE PUMP sign says what you do while its automatic switch has no power.
- If you turned the AC sources off to open the panel: the inverter and the generator back as you found them, and shore power back last, in the order of → 17.2.

Route: a connection, a holder or a wire runs hot

WHAT CHANGED BEFORE THE PROBLEM?

- after you installed or changed a device → the connections you made, and the wire of the new device: its current against the wire's ampacity
- after charging → the charger's output connections at the battery and at the bus, under charging current
- after rain or washing the boat → a green or white crust at connections the water reaches
- after the boat sat unused → corrosion at connections, and a stiff motor that draws more current
- after switching sources (shore power, generator, inverter) → the connections of the inverter's cable, under the inverter's load
- nothing you noticed → step 1

ROUTE: A CONNECTION, A HOLDER OR A WIRE RUNS HOT — PROBES ON THE TWO SIDES OF ONE CONNECTION

On a windlass or thruster circuit the machine runs only for each reading: take the readings of this route by the procedure "A windlass or a thruster as the load" (→ 3.4).

GASOLINE VAPOR SHORT CIRCUIT METER LEADS AC — PRO
CARBON MONOXIDE SHOCK IN WATER BLOWN FUSE BILGE PUMP
PROVE IT DEAD

1. With the load on that circuit running, find the warmest point along the run: touch the insulation next to each connection with the back of a finger — behind the panel too, with the panel open.
   You will see: One hot spot at a connection or a holder, or a wire warm along its length.

2. If a battery is itself hot, swollen or gassing, the route ends here: the card “Battery smells, is swollen, or is hot” says what to do (→ emergency card). Otherwise, with the same load running, put the meter’s probes on the two sides of the hot connection, at the points P and Q of → 5.8: P, the bare tongue of the lug or terminal on the wire, and Q, the stud or terminal it lands on. Read the voltage (→ 3.4).
   You will see: Under 5 mV — 0.00 V on the volts range — at the largest current the connection carries: a sound contact. 5 mV or more: the connection loses volts and heats; step 4 names who repairs it.

3. If no connection shows the drop and the wire is warm along its length: measure the current with the clamp meter and compare it with the wire’s ampacity (→ Table 4.3 · p. 17).
   You will see: A current above the ampacity, and nothing trips: the wire is too thin for this load, and its protection is rated above the wire’s ampacity. That wire has no working protection: it is an unprotected positive (→ 4.2 · p. 8). A pro fits a thicker wire and a rating by the triad.

4. Where the hot connection sits sets who repairs it, and how. If a repair below turns the battery switch OFF and the boat needs its navigation or anchor lights, or its electronics, while it is OFF — at anchor after dark, or under way — that repair waits until the boat does not, and the circuit waits as the restore below leaves it. **On the positive side after the battery switch, outside the panel:** with the engine stopped, prove the connection dead, as the entry of the PROVE IT DEAD sign says, turning the battery switch OFF after its first reading; then take the connection apart, clean it and tighten it, or

replace the lug (→ 5.6), and turn the battery switch back to its working position, the engine still stopped. **The negative lug on the engine block:** the procedure "The negative lug on the engine block" (→ 3.8). **Elsewhere on the negative side, outside the panel:** the same repair as on the positive side, on any negative connection only after the readings of step 3 of the procedure in → 5.6. **At the battery, on either terminal:** once the connection has cooled, do the planned job on a battery (→ 6.5), then take this route again from step 1. A connection there that still reads 5 mV or more after that job, a new lug or cable there, and anything else at the battery terminal beyond that job, a pro's (→ 1.8). **Behind the panel:** behind a panel with AC breakers on it, a pro's; behind a DC-only panel, the same repairs as outside it — and a connection on a circuit wired around the battery switch only after its own fuse at the battery is out, as step 3 of the procedure in → 4.6 · p. 29 takes it out.

You will see: After the repair, the same measurement under the same load reads under 5 mV.

PUT THE BOAT BACK IN SERVICE

- Covers back. Loads back as they were only on circuits whose connections now read under 5 mV under load and whose current is within the wire's ampacity.
- A circuit with a hot connection that waits for its repair, or with a current above its wire's ampacity, stays off and labeled until it has been repaired. A bilge pump on it is off with it, and the boat is watched as the entry of the BILGE PUMP sign says. A circuit that feeds a CO alarm or a high-water alarm stays on instead, with every other load on it — a bilge pump included — off at its own switch and labeled, so that the circuit carries only the alarm's own current. Where the alarm cannot stay on without another load, that circuit goes off too, and the entries of the CARBON MONOXIDE and BILGE PUMP signs say what you do while the alarm has no power. Under way, or at anchor after dark, the circuit that feeds the navigation or anchor lights or what steers the boat stays on, as the entry of the BLOWN FUSE sign says.

- A fuse you took out at the battery, a DC breaker or an isolation switch you turned OFF, and a charger, solar panels or any other source you turned off in step 4: back as you found them, a fuse in the way it came out, except a feed that reaches a circuit the item above keeps off.
- A battery switch you turned OFF in step 4 and did not turn back: once every circuit that the second item keeps off is off at its own breaker or switch, back to its working position, with the engine still stopped (→ 1.7). A hot connection that every circuit shares keeps every circuit off but those that item keeps on. Where nothing of its own switches such a circuit off, the battery switch stays OFF until a pro has repaired it. Under way, or at anchor after dark, the switch goes back for the navigation or anchor lights and what steers the boat, and that circuit runs with them, as the second item says.
- If you turned the battery switch in step 4: check, with the battery switches as they are now, that the bilge pump's automatic switch has power (→ 12.2). With the pump's circuit kept off by the second item, or a battery switch kept OFF that the pump is wired after, the check cannot pass: the entry of the BILGE PUMP sign says what you do while its automatic switch has no power.
- If you turned the AC sources off to open the panel: the inverter and the generator back as you found them, and shore power back last, in the order of → 17.2.

Route: a wire burned, and nothing tripped

WHAT CHANGED BEFORE THE PROBLEM?

- after you installed or changed a device → the new wire and the fuse or breaker that feeds it: a thin tap under a larger fuse
- after charging → the charger's output wires and their fuses
- after rain or washing the boat → the connections of the burned run that water reaches
- after the boat sat unused → a connection that corroded and heated
- after switching sources (shore power, generator, inverter) → the inverter's cable and its fuse at the battery
- nothing you noticed → step 1

ROUTE: A WIRE BURNED, AND NOTHING TRIPPED — POINTS A AND E ON → FIG. 4.1 · P. 3

GASOLINE VAPOR **SHORT CIRCUIT** **AC — PRO** **CARBON MONOXIDE** **SHOCK IN WATER** **BILGE PUMP**

1. Switch the burned circuit off at its breaker or switch and leave it off; a stretch that no breaker or switch turns off stays live. Then trace the burned wire back toward its source to the first fuse or breaker that feeds it: at a branch, open the panel and find the breaker output (E); at the battery, the terminal (A).
   You will see: Where the protection sits, and where the damage sits.

2. Compare the two places.
   You will see: Damage between the source and the protection: the fault was ahead of the fuse, where no fuse sees it (→ 4.1 · p. 2). That burned stretch stays live from the battery, and nothing on the boat switches it off. Keep hands and tools off it, write it on the first line of the Boat Passport, and hire a pro: taking it off the battery is work at the battery terminal (→ 1.8). Damage after the protection: step 3.

3. Compare the protection's rating with the ampacity of the thinnest wire it feeds, the burned wire included (→ Table 4.3 · p. 17).
   You will see: The protection rating is above the wire's ampacity: that wire had no working protection — a thin tap under a larger fuse, or a fuse too big for the wire (step 5). Not above: step 4.

4. Look at the connections of the burned run.
   You will see: A connection with heat marks: it was heating at normal current, which no fuse sees (→ 3.4). Nothing found: the case left is a short at the far end of a long, thin wire, which draws too little current to open its fuse quickly (→ 4.1 · p. 2). A pro decides from your record.

5. A wire whose protection fails the triad, or has none — the starter cable excepted — is an unprotected positive (→ 4.2 · p. 8). Write down the wire's gauge, the protection's type and rating, and where both sit.
   You will see: The record you hand to a pro.

PUT THE BOAT BACK IN SERVICE

- The burned circuit stays off and labeled until a pro has repaired it. If it feeds a bilge pump, the boat has no automatic pump until then.
- Put back every cover you lifted; the panel cover too, if you opened it.
- If you turned the AC sources off to open the panel: the inverter and the generator back as you found them, and shore power back last, in the order of → 17.2.

Do it yourself or hire a pro

DO IT YOURSELF OR HIRE A PRO · OVERCURRENT PROTECTION

STOP · CARBON MONOXIDE Defeating protection: a fuse larger than the triad allows, a bolt, foil or a piece of wire in a fuse holder, a breaker held or taped in ON. The trip tells you that the circuit carries more than its wire can withstand; defeat it, and the heat moves into the wire, behind panels, where nothing watches it.

What to do this minute: Leave the circuit off and label it.

HIRE A PRO · Work at a battery terminal or stud (→ 1.8): any fuse clamped by a nut on a stud — ANL, MEGA, MIDI, Class T — also under a cover that lifts off by hand, an MRBF on the terminal, and a lug or a cable replaced on the terminal. A wrench that touches the positive stud and any metal connected to the negative at the same time shorts the battery, and only the battery limits that current. The bank's main protection that tripped or blew, and its replacement — for a lithium bank, by the type, rating and interrupting rating of → 11.2. Also a pro's work: protection for an unprotected positive, a new run fed from a battery, from the battery side of a battery switch or from the panel's feeder, a breaker of a new rating, a hot connection behind a panel with AC breakers on it or at the battery beyond the planned job on a battery (→ 6.5), the negative lug on the engine block when its procedure finds voltage between the block and a positive terminal next to it (→ 3.8), and any other negative connection where the readings of step 3 of the procedure in → 5.6 find voltage. The words for the order and the signs for accepting the work stand in "What to tell the pro".

If no pro is available: Until the pro comes, the circuit waits as the restore of the route that found the fault leaves it, and the Boat Passport holds that route's record. Work at a battery terminal waits for the pro; how the panel stays while the bank's main protection waits for one is in → 1.8.

When a pro may do it differently: A pro may leave without its own protection a conductor that a rule exempts. It is a device lead shorter than 7 in, the wiring within an outboard's cowling, or the output wire of a self-limiting alternator that meets every ABYC condition (→ 4.2 · p. 8). A pro may put a fuse ahead of a breaker whose interrupting rating is too

low, when the breaker maker's document names that fuse (→ 4.4 · p. 21). You see it by the pro naming the rule or the document and writing it in the Boat Passport.

DO IT YOURSELF, IF…
The procedures and routes of this chapter, each with the signs at its start: "Every positive wire at the battery" (→ 4.2 · p. 8); "Replacing an electrical part in a gasoline compartment" (→ 4.6 · p. 29); and the four routes of this section. With them: one reset of a tripped branch breaker or main panel breaker; a fuse after the battery switch, a fuse at the panel on a circuit wired around it, and a fuse at the battery in a holder that opens by hand; a hot connection after the battery switch, outside the panel or behind a DC-only panel; the planned job on a battery (→ 6.5); a new branch circuit from a spare breaker on a DC-only panel, after the battery switch (→ 5.10); a breaker swapped behind a DC-only panel for one of the same rating that passes the five properties of 4.7; and the negative lug on the engine block, by the procedure "The negative lug on the engine block" (→ 3.8).

DO IT YOURSELF · Read ratings and gauges, trace wires without tools, check each circuit against the triad and keep the Boat Passport. Switch a circuit on and off with its breaker: breaker makers allow it — except a push-button breaker that only resets.

On someone else's boat there are three levels, not four: switches and buttons — yes; tools — no; the gray zone — only with the permission of the charter base or the owner, by phone (→ 2.6). A tripped branch breaker is a switch: reset it as on your own boat (→ 4.8 · p. 35). Then tell the base or the owner what tripped and what you did. A fuse is not the gray zone: on someone else's boat you do not replace it — you tell the base or the owner which one blew (→ 2.6).

What to tell the pro

WHAT TO TELL THE PRO

"Check the overcurrent protection of every positive conductor at the battery and at the panel. Check its location under 33 CFR 183.455 and 183.460 and ABYC E-11. Check its rating against the ampacity of the

thinnest conductor and the device maker's rating, and its interrupting rating against the short-circuit current where it sits. Add protection where a conductor has none." Accept the work by three signs. The rating is readable on each holder and passes the triad — or the pro names the clause of 33 CFR 183.455(c) or ABYC E-11 that allows a higher rating, never above the device maker's rating, and it is written in the Boat Passport. Each fuse or breaker sits by the rule of → 4.2 · p. 8. Its type, rating, interrupting rating and distance are in the Boat Passport the same day. The pro shows you the millivolts across each new connection under load.

REMEMBER

- The fuse protects the wire, not the device: load current ≤ protection rating ≤ ampacity of the thinnest wire in the circuit. A device maker's smaller rating covers both with one fuse.
- Every positive wire that leaves the bank starts with its protection. Put the fuse or breaker as close to the source as you can — never farther than 7 in along the wire. Farther only if closer is impossible and the whole run is in a continuous sheath: up to 72 in for a wire straight from a battery terminal, up to 40 in from any other source. Of the wires that leave the bank, only the starter cable may run without protection: the cable that carries the starting current, directly or through the battery switch, found by tracing it to the starter, not by its size — a wire taken off the starter's battery terminal is not.
- A fuse at the device end does not protect the run before it: a short there never passes through the fuse.
- The protection at the battery must interrupt the short-circuit current the battery can deliver there; for a lithium bank that is, in practice, a Class T fuse, and the BMS is not overcurrent protection.
- A trip tells you that something on the circuit is wrong — a fault, an overload, a worn breaker or a hot place — and the routes of 4.8 find which. A bigger breaker only moves the heat into the wire.

- A hot connection is found by millivolts under load; no fuse sees it.
- In a gasoline compartment, only parts marked ignition protected.

Self-check

1. **Decide first.** A 16 AWG wire runs 20 ft from the panel to a light and shorts at the light. Will a 25 A fuse on that circuit open faster or slower than a 10 A fuse, and why?
   Answer: slower. The short draws about 76 A. That is more than seven times a 10 A rating, which opens in 0.1 s at most, but only three times a 25 A rating, which takes up to several seconds (→ 4.1 · p. 2).
2. **Before you measure.** The panel is dark, the main panel breaker is at ON, and the battery switch is at its working position. By step 4 of the route "The whole panel went dark", you will measure A, then B, then C, against the battery's negative terminal (H). Which pair of readings tells you that the bank's main protection at the battery opened?
   Answer: battery voltage at A and 0 V at B (→ Fig. 4.1 · p. 3); what you do then is in → 1.8. 0 V at A as well points to the battery itself, not to its main protection (→ 3.5).
3. **On your boat.** By the procedure "Every positive wire at the battery" (→ 4.2 · p. 8), list every positive wire on the positive terminal of each battery, find its first fuse or breaker, and measure the distance along the wire; write each one into the Boat Passport.
   Answer: a wire passes by the rule of → 4.2 · p. 8. Any wire without protection other than the starter cable — the cable that carries the starting current, found by tracing it to the starter, not by its size — is an unprotected positive, and the same rule says what it may carry until a pro protects it.
4. **On your boat.** Pick one circuit: read the device's current on its label, the maker's fuse rating in its manual, and the gauge and temperature rating printed on its wire; read the rating of its breaker or fuse.
   Answer: the rating passes when load current ≤ rating ≤ the smaller of the

maker's rating and the wire's ampacity from → Table 4.3 · p. 17 (the engine-space column if the wire passes the engine space). A rating above the wire's ampacity leaves that wire without working protection: it is an unprotected positive (→ 4.2 · p. 8). A rating above the maker's rating only: a fuse goes to the triad's rating, as "Do it yourself or hire a pro" in 4.3 allows; a breaker of a new rating is a pro's task, written in the Boat Passport.

5. **A breaker you use every day to switch the cabin lights on and off: a defect or not?**
   Answer: not a defect. Breaker makers allow switching a circuit with its breaker; the exception is a push-button breaker that only resets and cannot be switched off.
6. **Why does the BMS of a lithium battery not count as the fuse of its cable?**
   Answer: the BMS disconnects the cells to protect them; it does not protect the cable, and a short can still spark and damage the cable or the bolt. The cable needs main protection with an interrupting rating at least equal to the bank's short-circuit current (→ 4.4 · p. 21, → 11.2).
7. **A windlass cable at your battery is as thick as the starter cable and has no fuse. Is it exempt?**
   Answer: no. Of the wires that leave the bank, only the starter cable may run without protection, and you identify it by tracing it to the starter, not by its size. The windlass cable is an unprotected positive (→ 4.2 · p. 8); a pro adds its protection at the battery.

Terms

ampacity
The current a wire can carry continuously without its insulation getting hotter than its temperature rating, set by the gauge, the insulation rating and where the wire runs.

overload
A current somewhat above the rating of a wire or its protection that goes on for minutes or hours, so that the wire heats slowly.

short circuit
A path of almost no resistance from a positive conductor to the negative or to metal connected to it; the current is limited only by the source and the wiring.

interrupting rating (AIC)
The largest current a fuse or breaker can interrupt at its rated voltage and stay intact.

triad
The rating rule of this book: load current ≤ protection rating ≤ ampacity of the thinnest wire in the circuit.

sheath
A continuous protective covering over the whole length of a run: loom, conduit, a closed raceway or a closed panel.

starter cable
The cable from the battery to the starter, directly or through the battery switch: the one wire that leaves a bank and may run without protection, identified by tracing it to the starter; a wire taken off the starter's battery terminal to feed anything else is not the starter cable.

unprotected positive
A positive wire, other than the starter cable and the cables that join the batteries of one bank, whose first fuse or breaker is missing, sits beyond the distance the rule allows, or is rated above the wire's ampacity.

pigtail
A lead that comes out of a device as part of it, such as the wires of a pump or a switch.

tap
A thinner wire that leaves a bus or a splice without its own fuse holder; it is protected only if the protection ahead of it is not above its ampacity.

trip-free
Said of a breaker that opens on an overcurrent even when its handle is held in ON.

fuse holder
The part that holds a fuse; a holder that opens by hand is one where the fuse itself comes out by hand or with a puller.

main protection
The fuse or breaker nearest a bank's positive terminal, which protects the cable that leaves the bank.

main panel breaker
The breaker at the input of the DC panel that feeds its positive bus.

positive bus
The bar in the panel from which every branch breaker takes its current.

negative bus
The bar to which every device returns its current on its own negative wire; one cable joins it to the battery's negative terminal, through the shunt where there is one.

feeder
The wire that carries current from the battery switch to the panel.

branch circuit
One circuit leaving the panel through its own breaker or fuse to one device or group of devices.

inrush current
The short surge a device draws when it is switched on, several times its running current.

MRBF
A fuse that mounts on the battery's positive terminal in an isolated holder.

Class T fuse
A compact bolt-down fuse with a very high interrupting rating on DC.

ignition protected
Built so that, in its design operating conditions, it does not ignite the gasoline vapor around it.

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