APLUXOR MARINE ELECTRICAL LIBRARY · PART I. YOUR BOAT AND YOUR METER

Chapter 1. Your Boat as an Electrical System: What Can Hurt You, What Can’t, and How to Use This Book

What on board can kill you, what cannot, and where to begin

Start here. The first pages show what on a boat can kill you and what cannot. Then you pick your route through the book and see, in numbers, what a mistake costs.

AFTER THIS CHAPTER YOU CAN

- Name the six things on a boat that can kill you or burn it, the sign that marks each one in this book, and where its first move is; know why the 12 V wiring does not shock you.
- Pick your route through the book: an older boat, a boat far from help, or someone else’s boat.
- Explain why a boat is not wired like a house or a car, and what your hull material and the water around it change.
- List every source of energy on your boat and remove each one, in the right order, for a fire, for flooding and for service.
- Decide which jobs are yours and which belong to a qualified marine electrician — in this book, a pro — and accept that work by things you can check.
- Read the marks next to the numbers in this book and know what each one promises.

Read first: → If It’s Happening Now, and the Safety Signs page that follows it

1.1 What is dangerous, what is not, and the first move
1.2 Three routes through the book
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1.1. What is dangerous, what is not, and the first move

Before you open a panel or lift a hatch, you need one answer: what on this boat can hurt you, what cannot, and what do you do first? The list is short. Six things on a boat can kill you or burn the boat. They are current in the water around a boat or a dock with shore power, an arc at the battery, gasoline vapor, a failing battery, 120 V AC on board, and carbon monoxide (CO) from a generator or engine exhaust. For each of them this section explains what happens physically and names what is not dangerous in the same situation. Each one also has its sign in this book — an amber triangle with a short label — and the sign leads to the first move: its entry on the Safety Signs page, in front of this chapter, and, when the danger is already happening, an emergency card (→ If It's Happening Now).

The 12 V and 24 V wiring of your boat does not shock you. To hurt you, a voltage has to push current through your skin and your body. 12 V or 24 V is too small a push to drive a dangerous current through a hand on a wire. Workplace safety rules draw the same line: 29 CFR 1910.303 requires live parts to be guarded against accidental contact only from 50 V up. So tracing a 12 V wire, reading the label on a 12 V device or touching a 12 V wire with your hand does not shock you. What 12 V can do is deliver a huge current into a short circuit. That is the arc at the battery, and it burns rather than shocks.

There is one exception on the engine. The ignition coil and the spark plug wires of a gasoline engine are a separate high-voltage circuit, not part of the 12 V system. The federal boat regulation, 33 CFR, treats them

as a circuit of their own (→ 1.9 · p. 45). Do not touch them while the engine runs. CFR

Everything else you do on board starts from this map. Table 1.1 gives the whole map; the paragraphs that follow the table explain the physics of each row.

Table 1.1. What can hurt you, what cannot, and where the first move is

Danger · not dangerous in the same situation	Its sign, and where the first move is	What shows that this one danger is under control
Current in the water. AC leaking from a boat or a dock with shore power runs through a swimmer's body. *Not dangerous:* a life ring, or anything that floats, thrown from the dock: it reaches the swimmer without putting a second person in the current.	**SHOCK IN WATER** The card "Someone got shocked — at the dock, in the water, or touching the boat" (→ emergency card)	The plug is out of the pedestal: shore power no longer reaches your boat. Your inverter and generator are other sources (→ 1.7 · p. 24). Power to the dock is off when marina staff say it is: dock lights can be on a separate circuit, so their going out proves nothing.
An arc at the battery. Metal between the battery positive and the negative or the engine block, where no fuse stands yet. *Not dangerous:* your bare hand on a battery terminal: 12 V and 24 V do not shock you.	**SHORT CIRCUIT** Its entry on the Safety Signs page; who does the work at the battery: → 1.8 · p. 38	Each positive terminal is covered — by a boot (a positive terminal cover), a covered battery box or a compartment built for the battery only — and the battery top is clear of tools and loose metal.
Gasoline vapor. It collects low in a closed compartment; a switch click ignites it. *Not dangerous:* diesel fuel below its flash point: it gives off too little vapor to ignite.	**GASOLINE VAPOR** Its entry on the Safety Signs page	The smell is gone with the hatches open and the blower running.

Danger · not dangerous in the same situation	Its sign, and where the first move is	What shows that this one danger is under control
A lithium battery fails. It hisses, vents or swells fast; its gases burn and are toxic. *Not dangerous:* a lithium bank that went dark with no hiss, no heat and no swelling: that is a power problem, not a fire (→ 11.4).	**HOT BATTERY** The card "Battery smells, is swollen, or is hot" (→ emergency card)	Everyone is off the boat, or as far from the battery as the boat allows, and help has been called.
A lead-acid battery smells of gas, is hot or is swollen. Charging drives out hydrogen; a spark ignites it. *Not dangerous:* the bank's switch outside the battery compartment and any cabin it opens into, turned with the engine stopped: its spark is away from the gas.	**HOT BATTERY** The same card (→ emergency card)	The plug is out of the pedestal and out of the boat's inlet: shore power no longer feeds the charger. The other charge sources are off by the source map (→ 1.7 · p. 24).
120 V AC on board. Shore power, a generator or an inverter can drive a dangerous current through the body. *Not dangerous:* the 12 V DC side of the same boat.	**AC — PRO** Its entry on the Safety Signs page; when someone has been shocked, the card "Someone got shocked — at the dock, in the water, or touching the boat" (→ emergency card)	The plug is out of the pedestal and out of the boat's inlet: shore power is off. The generator and the inverter are other sources (→ 1.7 · p. 24).
Carbon monoxide. Engine or generator exhaust collects in the cabin, at the stern and at the swim platform. *Not dangerous:* fresh air — the open deck, upwind, away from the stern, the swim platform and exhaust outlets.	**CARBON MONOXIDE** The card "CO alarm is sounding, or headache, nausea or drowsiness aboard" (→ emergency card)	The generator and the engines are stopped: this boat's exhaust has stopped. A neighbor's exhaust and a fuel-burning stove or heater are other sources, and a silent alarm does not prove that the air is clear.

Current in the water

A boat plugged into shore power can leak AC into the water. A chafed wire touches metal that is in contact with the water, or an appliance

fails. If the equipment grounding conductor that is meant to carry that current back to shore is broken or missing, the current goes into the water. The leaking current spreads out through the water on its way back to shore, and the water around the leak carries a voltage that falls off with distance. A swimmer in that water has one arm or leg at a higher voltage than the other, so current runs through the body. The swimmer's muscles stop answering, and the swimmer drowns. This is called electric shock drowning (ESD). It takes little current. According to IEC 60479-1, about 40 mA of AC flowing through the body for longer than 2 s can make the heart lose its rhythm (ventricular fibrillation). Much smaller currents already take away control of the muscles. In fresh water the body carries more of the current than the water around it, so a lake or a river is the more dangerous place (→ 1.5 · p. 19).

Whoever jumps in after a swimmer in trouble goes into the same current. A life ring, or anything that floats, thrown from the dock reaches the swimmer without waiting for the power to go off and without putting a second person in the water. Pulling the plug at the pedestal stops shore power to your boat and nothing else: your own inverter and generator can keep the water live after the plug is out (→ 1.7 · p. 24), and another boat or the dock can be the source. The first move, in its order, is on the card "Someone got shocked — at the dock, in the water, or touching the boat" (→ emergency card).

If you are the one in the water and you feel a tingle, the dock, the boat and a metal ladder all lie toward the source of the current; what to do then is the entry of the SHOCK IN WATER sign. When shore power may go back on after a trip or a shock is in → 17.3 and → 17.5.

An arc at the battery

A battery pushes the largest current it can into a short circuit. That current is limited only by the battery itself and by the metal that closes the circuit.

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 do not publish this number. A lithium battery maker warns that the terminals of its batteries are always live. A wrench that falls across the terminals becomes a heating element: the steel glows, the contact points melt, and molten metal flies. The danger at 12 V is this current, not a shock. MFR

Past the first fuse, a dead short on the 12 V side blows that fuse when the fuse is rated for the wire it protects (→ 4.3). A poor contact or a partial short that draws less than the rating heats without blowing it (→ 3.1). Before the first fuse, nothing stops the current: at the battery terminals, on the cable to the battery switch when no fuse stands at the battery, and at the starter stud. There, metal between the positive and the negative or the engine block makes an arc and burns you. (The battery switch is the switch some people call the main switch.) That is why every procedure in this book that puts a probe, a clip or a tool at a battery terminal starts with its sign, and why a wrench there is a question of its own (→ 1.8 · p. 38).

Taking one negative cable off is not the fix it looks like. A wrench on the positive can short as long as any battery can still push current into that positive. Two batteries in parallel share the positive through their jumper, the short cable between them: with one negative off, the other battery still holds the positive live. A second bank can feed it too, through anything that links the two banks. That can be the BOTH position of the battery switch, an automatic charging relay (ACR), a DC-DC charger, or a charger — except one with one output for each bank whose manual says its outputs are isolated from one another (→ 1.7 · p. 24). So only with the negative of the whole bank off does the positive lose every way back to a battery; what counts as the whole bank is defined in → 1.8 · p. 38. Taking a lug off a battery terminal is never the first move in an emergency.

Gasoline vapor

Gasoline gives off vapor that burns at any temperature you meet on a boat. According to the NIOSH Pocket Guide, its flash point is −45 °F. The flash point is the lowest temperature at which a fuel gives off enough vapor to ignite. Gasoline vapor burns in air from 1.4% to 7.6%.

The vapor is heavier than air, so it collects low — in the bilge and at the bottom of a closed compartment. A switch sparks every time its contacts open or close — switching a light off sparks as surely as switching it on — and a spark in that layer of vapor is an explosion. MFR

The bilge blower is the one device the boat is built to run in that vapor: its job is to pull the vapor out of the compartment. The federal regulation requires each compartment with a permanently installed gasoline engine with a starter to be open to the air or ventilated by a blower, and a boat with such a blower carries a label near the key switch that says how long to run it and what to check before starting. CFR

What is not dangerous in the same situation: diesel fuel below its flash point — above 100 °F on refiners' data sheets — gives off too little vapor to ignite. The condition is the temperature of the fuel, not of the air: diesel sprayed onto a hot engine burns. MFR

An outboard motor mounted outside the boat, or in a well open to the air, is free of the rule for protected electrical parts; a closed compartment is not. ABYC, the American Boat & Yacht Council, writes the voluntary standards that the boat industry builds to. ABYC requires every electrical device that can be a source of ignition to be ignition protected when it sits in a space with gasoline machinery, a gasoline tank or fuel-system fittings. A device isolated from the fuel is the exception. Ignition protected means built so that, in its design operating conditions, it does not ignite the gasoline vapor around it. On an outboard boat, a closed compartment that holds a gasoline tank — built in or portable — or fuel-system joints or fittings is a gasoline space. ABYC

The regulation reaches such boats too. Any gasoline boat, outboards included, must ventilate a compartment that holds a permanently installed fuel tank and an electrical part that is not ignition protected (→ 4.6). CFR

A failing battery: lithium and lead-acid

A lithium battery can fail inside, or overheat at a loose, badly crimped lug. Then it heats its own cells, and the cells vent gases that burn and

are toxic. That is not a fire you fight from inside a cabin. The first move for a lithium battery in that state is on the card “Battery smells, is swollen, or is hot” (→ emergency card). What is not dangerous: a lithium bank that went dark with no hiss, no heat and no swelling is a power problem, not a fire (→ 11.4).

A lead-acid battery gives off hydrogen when it is charged. According to the U.S. Department of Energy, hydrogen burns in air across a very wide range, from 4% to 75%, and a small spark ignites it. Battery makers name several causes for a battery that smells of gas, is hot or is swollen: overcharging, high heat, a recharge after a deep discharge, too little electrolyte, a blocked valve, a failure inside. One maker counts PRACTICE a slight outward bulge of the end walls of its AGM battery as normal; how to tell it from swelling is in → 6.5, and a battery you cannot judge goes to the card. The first move is on the same card, and its order follows from this physics: charging drives the hydrogen out, the people must be out before anything sparks, and a switch contact is a spark. The full treatment is in → 6.5.

120 V AC on board

Three things can put 120 V on your boat: shore power through the inlet, a generator, and an inverter, which makes 120 V AC from the batteries. An inverter/charger can switch its inverter on by itself when shore power is lost, so the outlets can stay live after you unplug shore power (→ 1.7 · p. 24). At 120 V the push is large enough to drive a MFR dangerous current through your body, even through wet skin.

WORKED EXAMPLE: HOW MUCH CURRENT 120 V DRIVES THROUGH YOU

Suppose the worst case: your skin adds nothing, and the only resistance is the inside of your body, 500 Ω, the value a body model built on IEC 60479-1 uses. What decides the answer is Ohm's law, current = voltage ÷ resistance, compared with the threshold of about 40 mA. At 120 V the current is 120 ÷ 500 = 0.24 A, which is 240 mA — six times the threshold. On a 120/240 V service each hot conductor is 120 V to ground and to the water. 240 V exists only between the two hots: a hand on each drives 240 ÷ 500 = 0.48 A — twelve times the threshold. At 12 V the same worst case gives 12 ÷ 500 = 0.024 A, below the threshold. At 24 V it gives 0.048 A, slightly above the threshold for AC. For direct current, IEC 60479-1 puts the current that disturbs the heart several times higher. What the numbers mean: on the AC side the inside of your body alone passes six times the dangerous current. Wet skin lowers the current without making 120 V safe. On a 12 V or 24 V DC system even the worst case stays below the current that disturbs the heart with direct current.

The AC side has its own protection against leaks. A protective device such as a GFCI (ground-fault circuit interrupter) or an ELCI (equipment leakage circuit interrupter) watches for leaks. It compares the current that goes out on the hot conductor with the current that comes back on the neutral. When they differ, current is going somewhere else — into the water or through a person — and the device trips. An ordinary breaker trips only on too much current: it does not see a leak.

When a protective device trips on its own, it has found a leak or a fault on the circuit it watches (→ 17.3). You recognize such a device by its TEST button, on the device itself or on a module beside it. Its label — GFCI, GFPE, ELCI, RCD, RCBO or the maker's own name — only confirms it, and a RESET button alone does not identify it. Whether and how a tripped device is reset is on the card "Shore power tripped and won't come back on" (→ emergency card).

When the boat's metal — a rail, a ladder, the hull — shocks someone on board, the boat itself is live, and so is everything on it, the AC panel

included. That is why the card for a shock starts at the pedestal and not at the panel (→ emergency card). Unplugging stops only shore power: your own inverter or generator can still put current onto the boat's metal and into the water (→ 1.7 · p. 24).

A reverse polarity indicator lights when the hot and the neutral are swapped somewhere between the pedestal and your panel. Then every switch and breaker on board that opens only one wire opens the wrong wire, and a device that is switched off stays live inside. The light therefore decides whether that shore power is used at all; what follows when it lights is in → 17.3.

Taking the AC side off the boat means removing each AC source by its own action: shore power, the generator and the inverter, each by its row of the source map (→ 1.7 · p. 24). The plug out of the pedestal and out of the boat's inlet tells you that shore power is off, and nothing more. What is not dangerous: the 12 V DC side of the same boat.

Carbon monoxide

Gasoline engines on boats, onboard generators included, make carbon monoxide, a poisonous gas. According to the CDC, carbon monoxide builds up in the air space under the stern deck and on and near the swim platform. A boat that idles or runs slowly collects it in the cabin, the cockpit and the aft deck. The first signs — headache, dizziness, weakness, nausea — look like seasickness. The Coast Guard advises treating them as possible CO poisoning unless you can be sure they are not.

The first move is on the card "CO alarm is sounding, or headache, nausea or drowsiness aboard" (→ emergency card). The last row of → Table 1.1 · p. 3 shows how you know that this boat's exhaust has stopped. A silent alarm does not prove that the air is clear. If the alarm sounds and no engine or generator runs on your boat, the source can be the boat next to you or a fuel-burning stove or heater. The full treatment is in → 17.6.

ABYC requires a CO alarm on every boat with an enclosed accommodation compartment. How your alarm gets its power ABYC

matters when you turn switches off. It can be wired around the battery switch, wired after it, or run on its own battery — boats differ. Trace yours and write it in the Boat Passport (→ 8.2, → 2.3).

1.2. Three routes through the book

Where do you start? The book covers a whole boat, and you do not need all of it on the first day. Your situation sets what you need first. The book is built around three situations: a boat that is 20 to 40 years old, a boat that is far from help, and a boat that is not yours. Pick the route that fits you; the others wait until you need them.

Your boat is 20 to 40 years old

You bought a boat with somebody else's wiring on it, and on some boats that is the wiring of three previous owners laid on top of each other. Your question is not "how does this work" but "where do I start, and in what order". Start with what burns and what sinks, and leave what is convenient for last. The order is this:

1. Walk the boat once without tools, from the batteries to the panel, and write down what you find (→ 2.1). The Boat Passport keeps it on one sheet (→ 2.3).
2. Look for every positive wire that leaves a battery without a fuse or breaker near it, other than the starter cable, which you identify by tracing it to the starter, directly or through the battery switch, not by its size; a wire taken off the starter's battery terminal to feed anything else is not the starter cable (→ 1.9 · p. 45), and a jumper between the batteries of one bank is part of the bank (→ 6.4). One fuse near the battery turns a chafed wire from a fire into a blown fuse (→ 4.2). Write each one on the first line of the Boat Passport; what you do with such a wire until a pro adds the protection is in → 1.8 · p. 38.
3. Check that the bilge pump starts by itself and pumps water overboard with its switch where it stays while you are away from

the boat (→ 12.2, → 12.7): pour a bucket of water into the bilge and watch the pump start and water leave at its outlet.

4. Take the procedure "The starter circuit's drop map" (→ 3.4): its numbers give you the order of repair. The charging circuit's drop is read with the engine running, and that reading is a pro's (→ 3.8). A repair at a battery terminal is work at the battery (→ 1.8 · p. 38).
5. Only then plan upgrades, in the order of → 18.2.

Your boat is far from help

Away from a dock there is no pro, no parts store and no shore power, and a failure that is a nuisance in the marina can end the trip. Your questions are how long your energy lasts, what fails first, and what you can fix yourself at sea.

Count your daily energy use and how much of it your charging really returns to the batteries (→ 7.1, → 7.5). Learn how the engine, the charger and the solar panels share the job (→ 9.4, → 10.3). If you plan to change to lithium batteries, read the checklist before you buy (→ 11.8). Carry the spares and tools of the list in → 19.4. Know the three kinds of repair at sea — permanent, temporary, and what waits for shore (→ 19.5). The sequences for smoke and for a boat that has lost all power are in → 19.6.

It is someone else's boat

On a charter boat or a friend's boat you have a week, a set of keys and no drawing of the wiring. Electricity is the least visible part of a boat you do not know. You need to understand it in minutes, find what is dangerous, and know what not to touch.

Read the emergency pages in front of this chapter first: they work on any boat (→ If It's Happening Now). Then go through the 20-minute check of → 2.6 before you leave the dock, and keep → 2.7 for the moment the panel goes dark.

Shore power is plugged in and unplugged in a set order, the same on any boat (→ 17.2).

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). Whatever you change with a tool, the next crew inherits.

How the text works

Every chapter has one main text that says what is happening, whether it is dangerous and what to do; it reads straight through. Two kinds of boxes sit beside it. "Why it works" gives the physics and names where a rule stops working. "Numbers" gives the calculations, tables and limits. You can skip both and still act: no step lives only in a box. Worked examples open with a stated condition, and their numbers belong to the example; they are not settings for your boat.

Safety rules are not repeated through the chapters. Each rule is stated once, on the Safety Signs page in front of this chapter, under its sign: an amber triangle with a short label, such as GASOLINE VAPOR or SHORT CIRCUIT. In a chapter the sign stands once, at the start of the procedure whose work carries that hazard, and it leads to its entry; read the entry before step 1. Two warning boxes mark a passage whose subject is a danger itself: ⚠ Danger to life, and ⚠ Costly damage. An arrow such as "→ 4.2" sends you to section 4.2 of this book. A letter in a circle on a drawing, such as A or B, marks a measuring point. The same letter means the same point in the drawing, in the steps and in the answers of that chapter. The small marks next to numbers — CFR, ABYC, MFR, PRACTICE, VERIFY — say where each number comes from (→ 1.9 · p. 45). Each chapter ends with "On board". It holds the chapter's rule, a table of what you notice and what it means, the line between your work and a pro's, and questions with answers.

When something is wrong and you do not know which chapter holds it, go to the emergency pages at the front of the book for anything urgent. For everything else, use the Symptom Index at the back: it sorts similar complaints by what tells them apart. If you need the basics — current, voltage, resistance, what each setting of a multimeter does — they are in → App. F.

This book does not teach you how to design or install an AC system, how to repair a generator or how to use an engine maker's dealer software. It does not teach the trade of repairing other people's boats either. Full diagnostic scenarios with alternative causes and real cases with numbers form a separate title → module "Scenarios".

1.3. How a boat differs from a house and a car

Why can't you wire a boat the way you wire a house or a car? You already know two electrical systems: the 120 V wiring of a house and the 12 V wiring of a car. Each habit you learned there is correct in a house or in a car. On a boat, several of those habits start fires, eat metal or put current into the water. The reason is physical: a boat floats in a conductor, shakes all the time, keeps fuel in closed spaces and has several sources of energy at the same time.

Where the current returns

In a house, the utility brings 120 V on the hot conductor, and the current returns on the neutral conductor. A third wire, bare or green — the equipment grounding conductor — connects every metal case back to the service panel. It carries no current until a hot wire touches a metal case. Then the fault current rushes back on that wire, the breaker trips, and the case does not stay live. It is the grounding conductor that trips the breaker, not the ground under the house.

In a car, the steel body is the negative. Every lamp and motor takes its positive through a fuse and a wire, and returns its current through the body to the battery negative. That works because the body is one piece of steel, it stays dry, and it is not in water.

A boat has neither a dry steel body nor a ground of its own. A fiberglass hull does not conduct at all. A metal hull sits in water: any current that uses the hull runs partly through the water and dissolves the metal where it leaves (→ 1.4 · p. 16). So on a boat every DC load has two wires: a positive, and its own negative back to the negative bus. The negative bus is the bar where the negative wires meet and connect to the

battery negative. The hull, the bonding wires that tie the underwater metal together, and the water are never the return path. The one exception is equipment mounted on the engine, which returns through the engine block. ABYC

On the AC side, the cord set — the shore power cable from the pedestal to your boat's inlet — brings the hot, the neutral and the grounding conductor. That grounding conductor is the only metal path that carries fault current from your boat back to shore, where it trips a breaker or a protective device. When it is broken, fault current has no metal path home, and it takes the water — and anyone in it (→ 1.5 · p. 19, → 17.5).

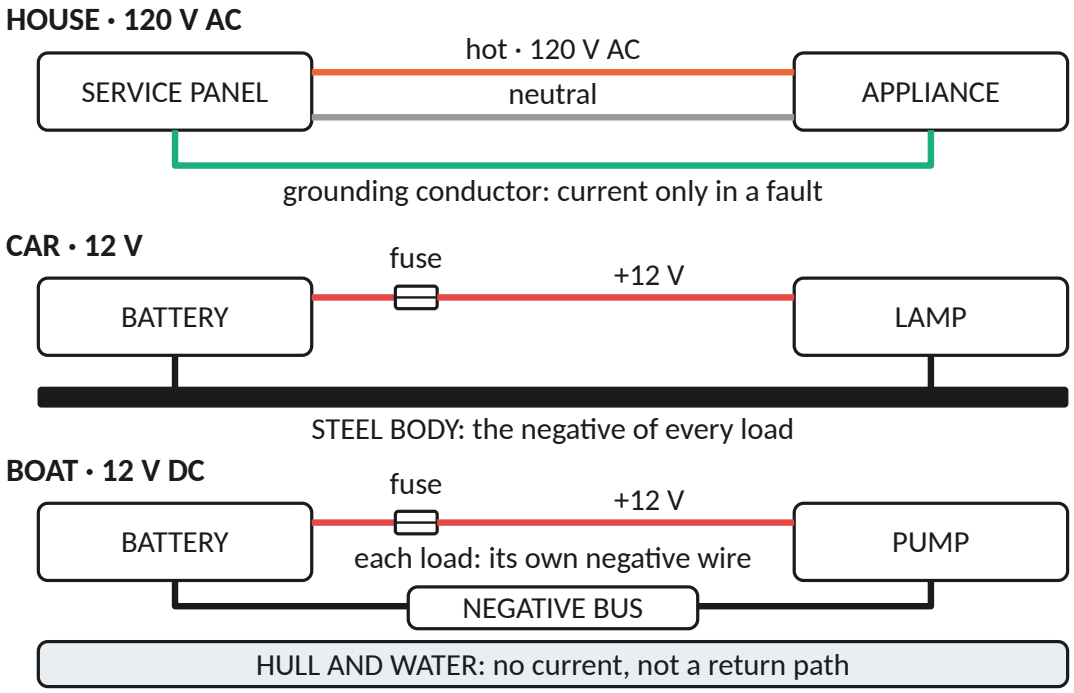


Fig. 1.1. Where the current returns. In a house, the neutral carries the current back, and a separate grounding conductor carries current only when a hot wire touches a metal case. In a car, the steel body is the negative of every load. On a boat, each load has its own negative wire to the negative bus; the hull and the water carry no current.

Water, salt, vibration, vapor, several sources

Water conducts, and salt water conducts far better than fresh (→ 1.5 · p. 19). Spray and damp air leave salt on terminals and in panels. When the salt gets wet again, it conducts between parts that must stay

apart and corrodes the metal it sits on. That is why connections on board are crimped, sealed with adhesive-lined heat shrink and covered (→ 5.6).

A boat also shakes and flexes all the time — the engine, the waves, the trailer on the road. The federal boat regulation, 33 CFR, requires insulated, stranded copper for the conductors of a boat within its scope (→ 1.9 · p. 45), with a few named exceptions; solid copper wire, the kind inside house walls, is not stranded. What ABYC adds about solid wire and about wire that flexes is in → 5.1. CFR

A car lets fuel vapor escape through its open underbody. A boat keeps the engine and the tank in closed compartments below deck. Gasoline vapor is heavier than air, and it stays there until a blower or open hatches remove it (→ 1.1 · p. 2).

A house has one source, the utility, and one breaker at the service panel removes it. A car has one battery and one alternator. A boat can have shore power through one or two inlets, a generator, an inverter, one or more battery banks, solar panels and a running engine, all at the same time. Turning off one of them leaves the others on. Where each one reaches, and how to remove it, is in → 1.7 · p. 24.

What this means on your own boat: no load takes its negative from a nearby piece of metal, and the wire is stranded. Before you work on anything, you ask which sources can reach it. These three habits replace the ones you learned in a house and in a car.

1.4. Hull material comes first

What does your hull material change in the wiring? More than any other single fact about your boat. A hull either conducts or it does not, and if it conducts, it sits in the water as part of your electrical system. Fiberglass and wood do not conduct. The metal parts that reach the water through them do: the propeller, shaft, rudder, through-hulls, a sterndrive or an outboard's lower unit. On many boats bonding wires join these parts (→ 15.2). Aluminum and steel conduct everywhere: the whole hull is metal in water.

When direct current leaves a metal part into the water, it takes metal with it: the metal dissolves where the current leaves. This is stray current corrosion, and it is fast. A marine systems specialist writing in a boatbuilding trade magazine describes it destroying a propeller, a shaft or a sterndrive in a matter of days. On a fiberglass boat it eats the running gear; on an aluminum boat, the hull itself. PRACTICE

Metal in water can also be harmed by too much protection. Anodes protect underwater metal by corroding in its place (→ 1.5 · p. 19); this is called cathodic protection. ABYC warns that on a wooden boat too much cathodic protection damages the wood around the underwater fittings, and too much protection harms aluminum as well. ABYC

An aluminum hull is a conductor, but no load returns current through it: every negative runs by wire to the negative bus. The negative is tied to the hull at one point, through the engine block or the outboard bracket, and that one tie is not a fault. A second point is a fault, and so is a load's current through the hull. ABYC

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.

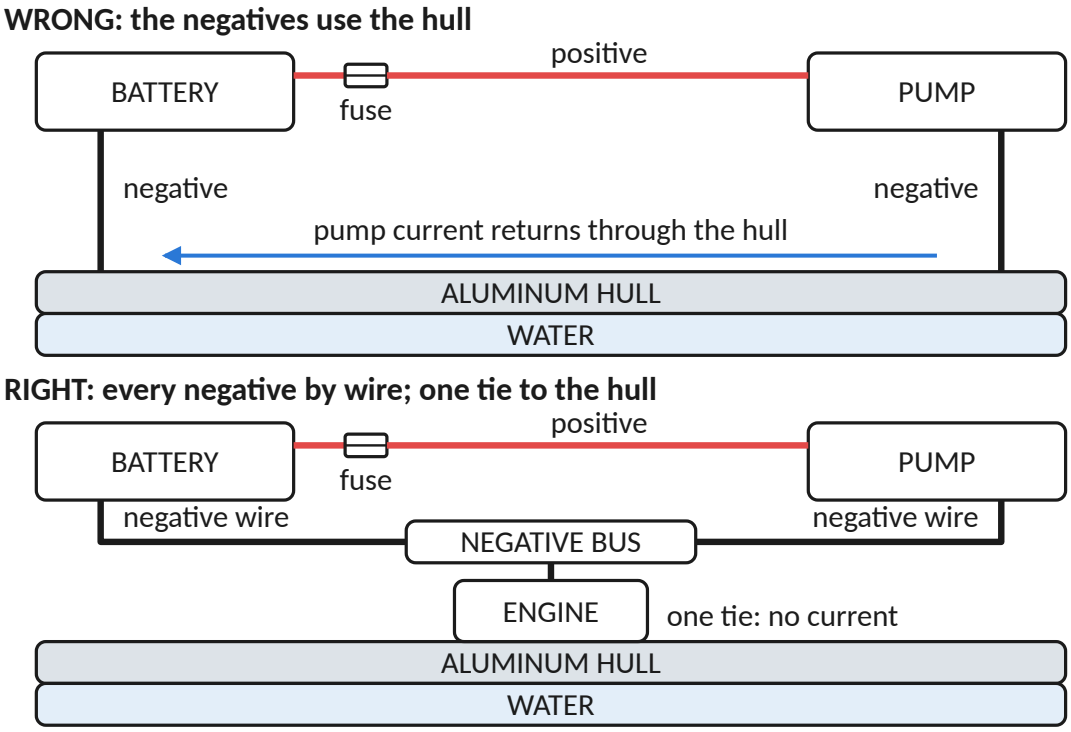


Fig. 1.2. The same pump on an aluminum boat, wired two ways. Top: both negatives are bolted to the hull, and the pump current returns through the aluminum. Bottom: each negative runs by its own wire to the negative bus. The bus is tied to the hull at one point, through the engine, and no current flows in the hull. In both drawings the fuse sits at the battery positive.

WHY IT WORKS · ONE TIE POINT, AND WHY A SECOND ONE EATS THE HULL

A single connection between the negative and the hull makes no loop. Current needs a way out and a way back. With one point it has only one way, so the hull sits at the voltage of the negative and nothing flows. Now add a second point: for example, a pump negative screwed to the hull at the bow while the engine ties the negative at the stern. The hull becomes a second conductor beside the negative wire. Part of the pump current now runs through the aluminum. The water around the hull is in parallel with that stretch of metal. So some of the current leaves the hull into the water at one place and comes back at another. Where it leaves, the aluminum dissolves.

Where the rule changes: some metal boats are built with no tie at all between the negative and the hull — a fully insulated two-wire system. On such a boat the one tie point does not exist, and the check is different (→ 16.2).

The rule holds for any metal hull, and the full treatment — the physics and the practice — is in → 16.1. What you check on your own boat: write the hull material in the Boat Passport. On a metal hull, follow the negative wire of every load you can reach. Each one must end at the negative bus or at the battery negative, never at a screw in the hull. A new fishfinder, light or pump with its negative on the nearest bolt is the mistake this rule exists for. The measurement that proves no current flows through the hull is in → 16.3.

1.5. Salt, fresh, brackish: what changes

Does the water you keep your boat in change its electrical system? Some things change with the water, some do not, and one thing becomes more dangerous in fresh water, not less. Knowing which is which saves you from buying the wrong anodes and from the belief that a lake boat can be wired with less care.

What changes with the water is the anode material and the speed of corrosion. Anode makers give this choice: salt water — zinc or aluminum; brackish water — aluminum; fresh water — magnesium. Zinc does not work in fresh water. For an aluminum anode in fresh water, follow your anode maker's data: makers disagree. Magnesium goes on an aluminum hull or an aluminum drive only after the hull potential has been measured (→ 15.6). The hull potential is the voltage between the hull and a reference electrode in the water. Too much protection destroys aluminum. MFR

What does not change with the water: the wire, the overcurrent protection, the ignition protection and the shore power are the same in salt, brackish and fresh water.

What becomes more dangerous in fresh water is current in the water. In fresh water the body conducts better than the water and becomes the path of the current; in salt water it is the other way around. "A lake-only boat" does not mean "simpler is fine": it means current in the water kills here.

An anode is a piece of a more active metal fastened to the underwater metal; in the water it corrodes in place of the bronze, steel or aluminum it protects. It protects only while it can push enough current through the water. Fresh water conducts poorly, and a zinc anode builds an oxide skin there and stops working. Some anode makers say the same of aluminum, and others say aluminum stays active; that is why the rule leaves aluminum in fresh water to your anode maker. Magnesium, with its higher driving voltage, keeps working. In salt water, magnesium works too hard and is used up fast. Salt water also wears the anode faster: an outboard maker's manual asks for periodic anode inspection, especially in salt water, because salt water speeds up the anode's erosion. MFR

Table 1.2. Water type: what changes, what does not, what becomes more dangerous

	Salt water	Brackish water	Fresh water
Anode (anode makers' data)	Zinc or aluminum	Aluminum	Magnesium; zinc stops working; aluminum — follow your anode maker
Speed of corrosion	Fastest	Between salt and fresh	Slowest
Wire, overcurrent protection, ignition protection, shore power	The same	The same	The same
Current in the water	Most of it passes around the body	Where the water is close to fresh, through the body	Runs through the body: the most dangerous

Current in the water follows the easiest path from the leaking boat back to shore. In fresh water your body conducts better than the water around it, so the current crowds into you. It enters on the side facing the leak, crosses your body, and leaves on the side facing shore. In salt water the water conducts better than your body, and most of the current passes around you. That is why the same leak is more dangerous in a lake or a river than in the sea (→ Fig. 1.3 · p. 21).

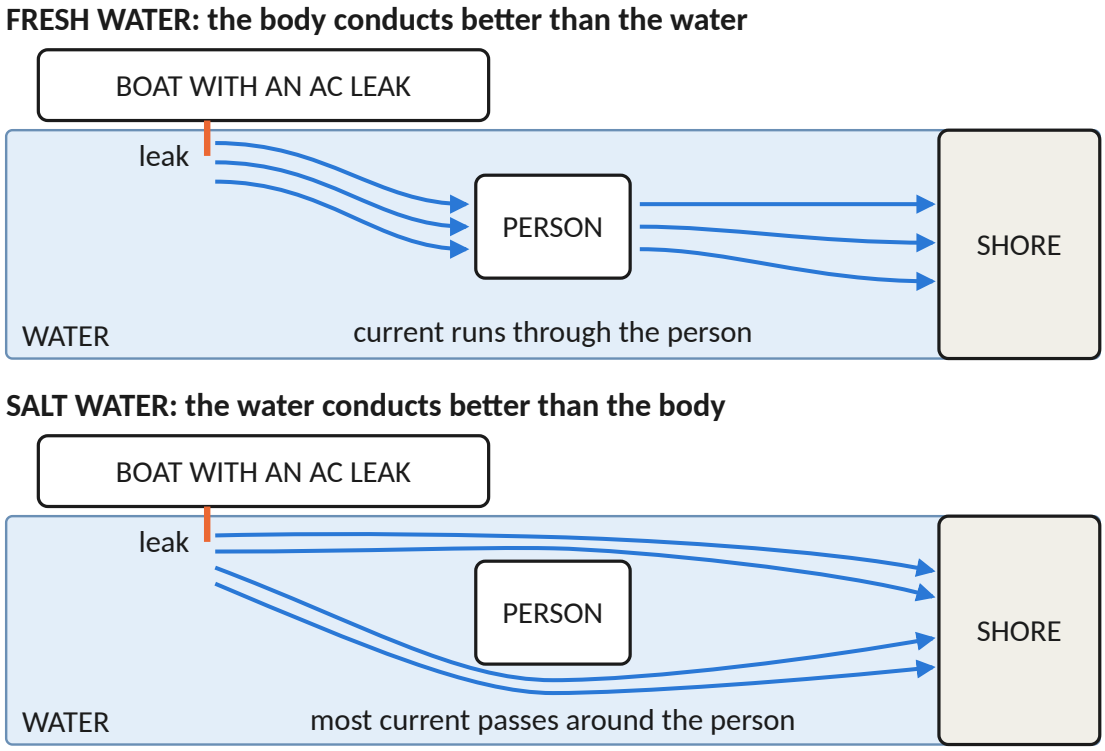


Fig. 1.3. The same AC leak in two kinds of water — a model of how the current spreads, not a place to measure. In fresh water the current lines crowd into the person, cross the body and leave on the shore side. In salt water most of them pass above and below the person.

> **NUMBERS · HOW WELL WATER AND THE BODY CONDUCT**
>
> According to EPA data, the conductivity of US rivers ranges across a factor of 30. According to NOAA data, sea water conducts about 30 to 860 times better than that river water. An electrical engineer writing in a trade magazine for electrical contractors gives a conductivity for human muscle. Set against the EPA and NOAA figures, muscle conducts 2.4 to 70 times better than river water and about one twelfth as well as sea water. Brackish water spans the gap, and where it is close to fresh, the body again conducts better than the water around it. PRACTICE

SHOCK IN WATER

Diving on your own boat to work on underwater fittings, or to get back something you dropped, puts you in that water. Salt water does not make it safe: it carries most of a leak's current around a swimmer, not all of it. Unplugging your own boat takes its shore power out of the water, and nothing more: your generator and inverter are sources of

their own (→ 1.7 · p. 24), and the leaks of the boats around you and of the dock reach the same water. In fresh water the body of a swimmer is the easiest path for any of them. What to do when someone in the water is in trouble is on the card "Someone got shocked — at the dock, in the water, or touching the boat" (→ emergency card), and the full treatment is in → 17.5. Which anodes your boat needs and how fast a working anode wears is in → 15.3.

1.6. The cost of a mistake: what burns and what sinks

How often does a mistake with a boat's electrical system end in a fire or a sinking, and what do you do about each? In this section, each number stands next to the action it asks of you.

The national numbers come from the Coast Guard's yearly report, Recreational Boating Statistics. For 2024 it verified 3,887 incidents with 556 deaths and 2,170 injuries. The report also says what it does not count. It leaves out people who swim or dive from a boat that is anchored, docked or moored. It also leaves out damage to a boat that is properly docked or moored and is lost for lack of maintenance. So a swimmer killed by current near a dock, and a boat that sinks in its slip because nobody maintained its pump, are not in these numbers. A small number there is not a small risk. Current in the water (→ 1.1 · p. 2, → 1.5 · p. 19) and the pump setting when you leave the boat (→ 12.2) matter more than the national report can show.

Table 1.3. What the numbers say, and what you do

What the number says	What you do
Fires and explosions were 208 of the 3,887 incidents of 2024, with 2 deaths and 100 injuries. Their property damage was almost twice that of flooding (USCG Recreational Boating Statistics 2024).	Know every source on your boat and how to remove it (→ 1.7 · p. 24), and protect every positive wire at the battery (→ 4.2).
Electrical system failure was the primary contributing factor in 39 incidents, with 1 death and 10 injuries (USCG Recreational Boating Statistics 2024).	Find bad connections by measuring under load, not by looking (→ 3.4).

What the number says	What you do
Carbon monoxide exposure caused 5 incidents, with 2 deaths and 26 injuries (USCG Recreational Boating Statistics 2024).	Keep a working CO alarm, and keep people away from the stern and the swim platform while a generator or an engine runs (→ 1.1 · p. 2, → 17.6).
According to one large insurer's claims, about three quarters of the fires that start on the boat itself are electrical. More of them start on the DC side than on the AC side. Most AC fires start between the pedestal and the boat's inlet. PRACTICE	Before you plug in, look at the plug, the cord ends and the inlet: darkened or melted contacts mean the connection heats (→ 17.2).
In a boating safety foundation's fire tests, the crew had three or four minutes. In that time they had to make a VHF radio call, find and use the extinguishers, put on life jackets and get ready to leave the boat. PRACTICE	Know the fire order of → 1.7 · p. 24 before you need it: in it, the VHF call comes before the battery switches, because the fixed radio goes off with them.
According to the same insurer's claims, as a boating safety foundation's course reports them, four boats sink in their slips for every one that sinks underway. In half of the dockside sinkings, water came in at underwater fittings, and rain or snow accounts for 32% of sinking claims. PRACTICE	**BILGE PUMP** Check the underwater fittings, and set the pump switch for leaving the boat (→ 12.2).

What burns starts small. Suppose a battery cable lug has a resistance of 0.01 Ω and the starter draws 200 A through it. The lug drops 0.01 × 200 = 2 V and turns 2 × 200 = 400 W into heat — a soldering iron at one connection (→ 3.1).

You can now prevent six things: an arc at the battery, a gasoline explosion, a fire that spreads before you can act, a sinking in the slip, carbon monoxide in the cabin and a death in the water. Each danger has its sign and its first move (→ 1.1 · p. 2), the source map shows how each source comes off (→ 1.7 · p. 24), and the pump setting for leaving the boat is in → 12.2.

1.7. Where the energy is on board, and how to shut it all off

Where can energy reach a given spot on your boat from, and how do you remove all of it? A house has one source and one breaker at the service panel. A boat has several sources that work independently of each other, and the battery switch removes only one of them. Main switch OFF does not mean no voltage anywhere.

Energy comes onto the boat from outside through each shore power inlet; some boats have two, and each is a source of its own. It is made on board by a generator and by the engine's alternator while the engine runs. Solar panels make it whenever light falls on them, and a wind generator whenever it turns. It is stored in each battery bank. And it is converted. An inverter makes 120 V AC from a bank, and a charger makes DC from AC. Automatic charging relays (ACR) and DC-DC chargers move energy between banks. On your boat you need the full list, and the drawings show where each one connects on one typical boat.

The battery switch sits in the positive cable between a bank and the boat's loads. With the engine stopped, the switch at OFF removes current from everything after it — point B and the DC panel on → Fig. 1.4 · p. 25 — and from nothing else. Why the engine must be stopped first is the subject of "The running engine" below. ABYC

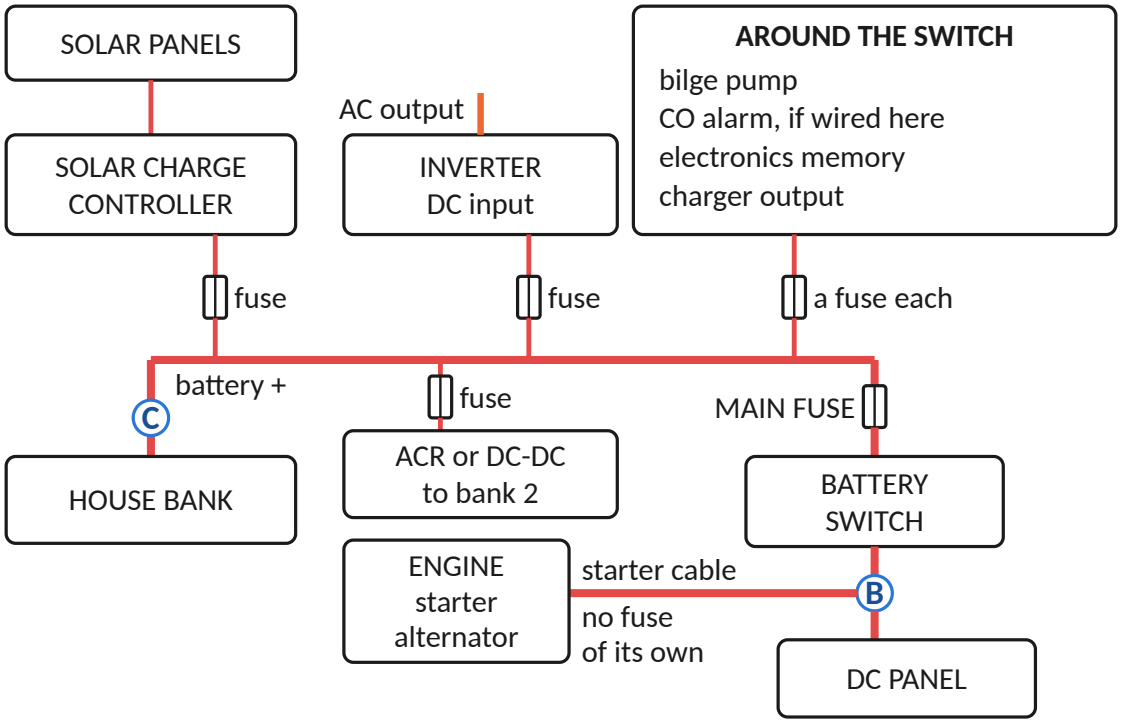


Fig. 1.4. Source map, DC side, on one typical boat; your boat can be wired differently. Every line except the inverter's AC output is a positive DC conductor; negatives are not drawn. Point C is the bank's positive terminal; point B is the panel-side terminal of the battery switch. Everything on the battery positive has its own fuse at the battery and stays live when the switch is OFF. On this boat the engine — starter and alternator — is connected to point B by the starter cable, so the alternator charges the bank through the switch. The starter cable has no fuse of its own. On this boat the main fuse at the battery, between the battery and the switch, carries the starting current too (→ 4.2). With the switch OFF and the engine running, the alternator keeps point B and the DC panel live and has lost its battery.

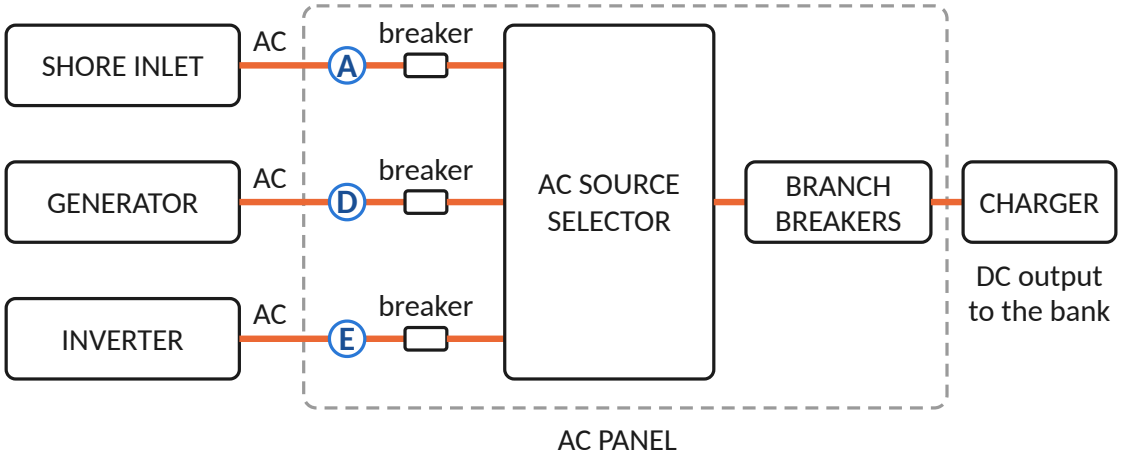


Fig. 1.5. Source map, AC side, on one typical boat; your boat can be wired differently. Shore power, the generator and the inverter each feed their own breaker on the AC panel; the AC source selector then connects one of them to the branch breakers. Points A, D and E are on the supply side of each source's breaker: there a zero proves that the source is off. A boat with two shore inlets has two shore sources.

What stays live when the battery switch is OFF

With every battery switch OFF and the engine stopped, point B and what it feeds — the DC panel and the starter cable — have no voltage. Everything else keeps its voltage:

- the battery terminals and the cable up to the switch — point C — always;
- every circuit wired around the switch, each on its own fuse at the battery: the bilge pump, the memory of electronics such as a stereo, the charger output, the solar charge controller, and the CO alarm if it is wired there;
- the inverter and everything its AC output feeds: an inverter/charger can switch its inverter on by itself when shore power is lost;
- automatic charging relays and DC-DC chargers between banks, and the second bank they connect. Count them as wired around the switches, through their own fuses at the batteries, until you have traced them on your boat. A relay or a DC-DC charger is fed from both banks it connects;
- a DC-DC charger whose forced charging is turned on: one maker's charger then draws from the start battery with the engine off;

- the solar panels and their wires up to the charge controller whenever light falls on the panels, and a wind generator whenever it turns;
- the whole AC side while shore power or a generator is connected (→ Fig. 1.5 · p. 26);
- a lithium bank with its own protection: its terminals stay live. When its battery management system (BMS) switches the bank off, everything on that bank goes dark at the same time — including a pump or a CO alarm fed from it (→ 11.4).

The CO alarm needs a word of its own. ABYC permits it to take its power from the battery side of the switch, where it stays on with the switch OFF. ABYC

Alarm makers differ. One allows its alarm after the battery switch, where it goes off with the switch, and that maker then says the boat must not be occupied. Another sells models with a built-in battery. So on your boat the alarm can be wired around the switch, wired after it, or run on its own battery. Trace yours and write it in the Boat Passport (→ 8.2). MFR

The same holds for the bilge pump. Pump makers' instructions run its power from the battery through its own fuse. On an older boat the pump can be connected after the switch and stop when you turn the switch OFF: trace yours (→ 12.2). MFR

The running engine

A running engine is a source. Its alternator makes the charging current, and it needs a battery to push that current into. On the boat of → Fig. 1.4 · p. 25, the alternator output lands on point B together with the starter cable, so the alternator charges the bank through the switch. Other boats land it elsewhere. One battery-switch maker's instructions show four wirings: at the starter, on the switch terminal that feeds the engine, at the start battery, and at the house battery. Where yours lands decides which batteries stay connected to a running alternator when someone turns a switch. You find it by tracing the heavy output wire from the alternator (→ 9.2). MFR

The rule does not depend on where the alternator output lands: stop the engine before you turn any battery switch, so that a running alternator never loses its battery. That holds at the dock and at anchor as much as underway; if you are heading for shore under power, you leave the switches alone until the engine is stopped.

> ⚠ **COSTLY DAMAGE · A BATTERY SWITCH TURNED WITH THE ENGINE RUNNING**
>
> If a battery switch is turned OFF while the alternator is making current, the battery that was taking that current is gone instantly, and the voltage jumps. This spike is called load dump. A battery-switch maker warns that it quickly destroys the diodes in the alternator. Two battery-switch makers print the same instruction in their manuals: stop the engine before you turn the switch to OFF. One of these makers also allows its make-before-break switch to be turned between 1, ALL and 2 with the engine running. A make-before-break switch connects the new bank before it disconnects the old one. The rule of this book is stricter: stop the engine before you turn any battery switch, whatever its positions. A third maker builds an alternator field disconnect (AFD) into its switch, for the moment the switch is turned by mistake with the engine running. The AFD protects the alternator only when the alternator has an external regulator, and it is not a permission to turn the switch. With the switch OFF and the engine running, the alternator also keeps point B live.

Removing each source

Each source has its own way off, and each way off shows itself in its own way. What you see covers one source only: the plug out of the pedestal tells you that shore power is off, and nothing about the inverter or the batteries. Only the whole map, source by source, tells you the boat is dead.



Table 1.4. Source map: what removes each source, and what stays live

Source	What removes it	What shows that this one source is off	Still live after that
Shore power, at each inlet	Its breakers OFF — the shore power breaker on the AC panel and the pedestal breaker — and every shore cord unplugged, in the order of → 17.2.	The plug is out of the pedestal and out of the boat's inlet.	The inverter, if it switched itself on; the generator; every battery bank.
Generator	Stop it, and keep it from starting again: its automatic start OFF, the way its manual shows.	The generator is silent, and its automatic start is OFF.	AC from shore power or the inverter; the generator's own start battery.
Inverter	Inverter OFF at its own switch, then its DC supply cut: the DC breaker or isolation switch that feeds it OFF. Until its DC supply is cut, its terminals and DC cable stay live, and a remote panel can turn it back on. MFR	The DC breaker or isolation switch that feeds it is OFF.	The cable from the battery to that breaker or switch. PRACTICE With no such breaker or switch — on the boat of → Fig. 1.4 · p. 25 its feed has only its fuse at the battery — the inverter, its DC cable and the AC side it feeds stay live.
Battery charger	No action of its own: it charges only while AC reaches it. With shore power off, a charger fed by the generator, or plugged into an outlet the inverter feeds, keeps charging until that source is off by its own row.	Every AC source that can reach it is off by its row of this table.	Its output wires, fed by the bank through their own fuses at the battery.
Running engine	Stop the engine.	The engine is stopped and the key is off.	Point B, from the bank, while the battery switch is ON.

Source	What removes it	What shows that this one source is off	Still live after that
Each battery bank	Its battery switch OFF — with the engine stopped.	0 V at point B, the panel-side terminal of the switch.	Point C and every circuit wired around the switch. A lithium bank's terminals stay live even after its BMS has switched the bank off.
Circuits wired around the switch	Each by its own fuse at the battery: a fuse in a holder that opens by hand comes out of its holder; a fuse under a nut on a stud is work at the battery (→ 1.8 · p. 38). The bilge pump's fuse stays in unless your work is on the pump circuit: without it, the pump's automatic switch has no power.	The fuse is out of its holder.	The battery side of each fuse holder. A circuit with no fuse at the battery stays live along its whole length: it is an unprotected positive (→ 1.8 · p. 38).
Relays and DC-DC chargers between banks	By the fuse at each bank it connects, the same way.	The fuses at both banks are out of their holders.	Until both are out: the relay or charger and its cables, from the other bank. After that, the battery side of each fuse holder.
Solar panels; a wind generator	Cover the panels completely, with an opaque cover, or open the solar disconnect switch between the panels and the charge controller; stop a wind generator as its manual says.	The panels are covered or the solar disconnect is open; the wind generator's stop or brake control is at STOP (its brake light on, where it has one).	The panels and their wires up to the solar disconnect; the wires from a wind generator to its stop control, while it turns; the charge controller's battery side, from the bank.

Three scenarios: fire, water in the boat, service

How you remove the sources is set by why you remove them. In a fire you have minutes and must not go into smoke. With water coming in,

the pump must keep running. For service you have time, and you prove each source off before you touch anything. The three sequences differ for these reasons.

PROCEDURE: FIRE OR SMOKE

BILGE PUMP **CARBON MONOXIDE**

Smoke with a gasoline smell — switch nothing on or off. At the dock, get everyone off the boat; on the water, life jackets on and everyone as far from the smoke as you can, ready to leave the boat. Call for help from a phone or a handheld VHF: at the dock — 911; on the water — VHF channel 16; say the boat's name and where you are. These steps are for smoke without a gasoline smell.

1. Tell everyone on board.
   You will see: Everyone on board knows, and the way off the boat is clear.
2. Stop the engine. Generator stopped and its automatic start OFF.
   You will see: Both are silent; the generator cannot start by itself.
3. Turning off all battery switches also shuts off the fixed VHF radio: make the VHF call before you turn them off, or use a handheld. All switches OFF removes current only from circuits after the switches. Call for help: at the dock — 911; on the water — VHF channel 16; say the boat's name and where you are.
   You will see: Help has been called.
4. Engine stopped first: turn every battery switch OFF that you can reach without going through smoke. A switch you cannot reach stays as it is; go on with the next step.
   You will see: The DC panel goes dark. The battery terminals, the cables up to the switches and every circuit wired around them keep their voltage.

5. Do this step only if you can reach the inverter and the breaker or switch that feeds it without going through smoke. Inverter OFF at its own switch, then its DC supply cut: the DC breaker or isolation switch that feeds it OFF.
   You will see: The inverter is OFF, and so is the breaker or switch that feeds it; until that breaker or switch is OFF, the inverter's terminals and DC cable stay live.
6. Pedestal breaker OFF, unplug at the pedestal — every shore cord. Do not go into smoke to reach the AC panel.
   You will see: The plug is out of the pedestal: shore power no longer reaches the boat.
7. If you can reach them without going through smoke, cover the solar panels or open the solar disconnect switch.
   You will see: The panels are covered or the solar disconnect is open.
8. If you can reach the propane cylinder without going through smoke, close its valve.
   You will see: The cylinder valve is closed.
9. Keep the engine hatch closed: opening it to look lets in a rush of air that feeds the fire.
   You will see: The hatch stays shut.

The battery terminals, the cables up to the switches and every circuit wired around them keep their voltage. If the smoke comes from one of these, the switches do not stop it. Use the extinguisher at the base of the fire if the fire is small and your way out is clear. Otherwise leave the boat and call for help. Do not pour water on equipment until its power is off: water shorts circuits, and AC through water shocks.

PUT THE BOAT BACK IN SERVICE

- Switch nothing back on. After a fire, the boat goes back into service only after a pro has found the cause.
- If that leaves the bilge pump without power, the boat has no automatic pump: what to do before you leave it is the last line of the BILGE PUMP entry.

PROCEDURE: WATER IN THE BOAT

GASOLINE VAPOR AC — PRO HOT BATTERY CARBON MONOXIDE SHOCK IN WATER BILGE PUMP

1. If the boat smells of gasoline: a pump that is already running keeps running; if it is silent, bail with a bucket or a manual pump. Call for help: at the dock — 911; on the water — VHF channel 16; say the boat's name and where you are.
   You will see: If the boat does not smell of gasoline, go on with the next step; if it does, step 2 waits until the smell is gone.
2. Leave the bilge pump running; put its switch in MAN (on some panels, ON). If it is a spring-return switch, hold it in MAN by hand; if no one can hold it, leave it in AUTO. Shore power off: its breakers OFF and every shore cord unplugged. The inverter OFF at its own switch; the generator stopped and its automatic start OFF. Battery switches stay as they are; turn one only with the engine stopped: if you are heading for shore under power, leave them until the engine is stopped.
   You will see: The pump runs, and water leaves at its outlet. The plug is out of the pedestal and out of the boat's inlet; the inverter is OFF; the generator is silent.
3. Watch the water. If it gains on the pump, reaches the batteries, or the pump stays silent, you need help. Call for help: at the dock — 911; on the water — VHF channel 16; say the boat's name and where you are. Bail with a bucket or a manual pump as well.
   You will see: The water level falls, or help has been called.
4. A pump that stays silent, or a float that sticks: what to do is in → 12.1.
   You will see: The pump runs and the water level falls, or help has been called.

PUT THE BOAT BACK IN SERVICE

- A bank whose batteries the water reached: nothing charges it until a pro has checked it — a DC-DC charger off, the solar panels covered or their solar disconnect switch OFF, a wind generator stopped at the control its manual names, and the engine not run unless you need it to reach safety; after that check, the DC-DC charger, the panels and the wind generator back as you found them.
- When the water is out and the leak is found: the pump switch where its automatic switch has power and the pump is not running by hand.
- Water reached the shore inlet, the cord or any AC equipment: shore power, the inverter and the generator stay off until a pro has checked them. Otherwise, and only after a pro has checked any bank whose batteries the water reached: the inverter ON at its own switch if you use it; the generator's automatic start as you found it; shore power back last, in the order of → 17.2.
- Then pour a bucket of water into the bilge and watch the pump's automatic switch start it. If it stays silent, the boat has no automatic pump: what to do before you leave it is the last line of the BILGE PUMP entry.

For service, the question "What changed before the problem?" points to the source you are most likely to miss. The steps then remove every source and prove the result at points A to E.

WHAT CHANGED BEFORE THE PROBLEM?

- after you installed or changed a device → the new device can be wired around the switch: find its fuse at the battery before you trust the switch
- after charging → the charger output and any relay or DC-DC charger between banks are wired around the switches: they stay live
- after rain or washing the boat → look for water at the pedestal, the cord, the inlet and the AC panel before you touch them. A wet AC panel or inlet is not touched: shore power comes off at the pedestal, and the panel and the inlet wait for a pro (→ 17.2)
- after the boat sat unused → a lithium bank can be switched off by its BMS; its terminals are still live
- after switching sources (shore power, generator, inverter) → the inverter can have switched itself on: look at its display or status lights
- nothing you noticed → go through the source map in order, row by row

PROCEDURE: SERVICE — POINTS B AND C ON → FIG. 1.4 · P. 25, POINTS A, D AND E ON → FIG. 1.5 · P. 26

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

1. Stop the engine. Stop the generator, and turn its automatic start OFF the way its manual shows.
   You will see: Both are silent; the engine key is off; the generator cannot start by itself.

2. Shore power off: its breakers OFF — the shore power breaker on the AC panel and the pedestal breaker — and every shore cord unplugged, in the order of → 17.2.
   You will see: The plug is out of the pedestal and out of the boat's inlet: shore power is off — and only shore power.

3. Inverter OFF at its own switch, then its DC supply cut: the DC breaker or isolation switch that feeds it OFF.
   You will see: That breaker or switch is OFF. With no such breaker or switch, the inverter stays a live source — its terminals, its DC cable and the AC side it feeds — and work that they reach waits for a pro.

4. Cover the solar panels completely, with an opaque cover, or open the solar disconnect switch; stop a wind generator as its manual says.
   You will see: The panels are covered or the solar disconnect is open; the wind generator's stop or brake control is at STOP (its brake light on, where it has one).

5. If you will work on a wire after the battery switch, take the first reading of the entry of the PROVE IT DEAD sign now, at the spot where you will work. Then turn every battery switch OFF.
   You will see: The DC panel goes dark, except the circuits wired around the switch.

6. For each circuit wired around the switch that reaches the spot where you will work, take its fuse at the battery out of its holder. Leave the bilge pump's fuse in unless your work is on the pump circuit. A relay or DC-DC charger between banks that reaches the spot comes off by its fuse at each bank, the same way. A fuse under a nut on a stud stays in, because

taking it out is work at the battery (→ 1.8 · p. 38), and so does what it feeds: do not work on that circuit, nor on a circuit around the switch that has no fuse at the battery.

You will see: The device on that circuit stops; the battery side of its fuse holder stays live.

7. Take the procedure "Proving the AC side off at the AC panel" (→ 3.7) at points A, D and E, on the supply side of each source's breaker.

   You will see: Every pair reads under 1 V at points A, D and E, between two good readings on the proving unit: the AC side is off.

8. Prove the DC panel side off at point B. Meter on DC volts; black probe on the battery negative terminal; red probe on point C, then on point B, then on point C again.

   You will see: Bank voltage at point C before and after, and 0 V at point B: the meter works, and the panel side of the switch is off. Point C keeps its voltage too. Battery terminals always have voltage on them — that is normal.

PUT THE BOAT BACK IN SERVICE

- Each fuse you took out goes back into its holder at the battery, the bilge pump's first.
- Battery switches back to their working positions from the Boat Passport (field 6).
- The pump switch at its working position. Then prove that the pump's automatic switch works: pour a bucket of water into the bilge, and watch the pump start and water go overboard.
- Solar panels uncovered or the solar disconnect switch closed; the wind generator running again as its manual says.
- The DC breaker or isolation switch that feeds the inverter back ON, then the inverter at its own switch as you use it; the generator's automatic start as you found it.
- Shore power back last, in the order of → 17.2.

1.8. Do it yourself or hire a pro

Which work on your boat is yours, and which belongs to a qualified marine electrician — in this book, a pro? The line is not drawn by how good you are with tools. It is drawn by four things you can see in the job itself, and it sorts every job in this book into one of four levels.

Four things tell you that a job is not yours. The energy cannot be switched off and proven absent. The result cannot be confirmed by a measurement. The damage from a mistake appears late and out of sight: as corrosion, as a connection that smolders, or as insulation that ages. The work changes the boat's status with its insurer or under the standards. If any one of the four is present, the job belongs to a pro.

Every job in this book carries one of four levels. STOP: you never touch it while it is live. Hire a pro: a pro does it, and you order the work and accept it. Do it yourself, if…: you do it when the named condition is met; where the work carries a hazard, its sign stands before the work, and the condition is the entry of that sign. Do it yourself: you do it.

Table 1.5. The four levels, and what always stands next to each

Level	What it means	What always stands next to it
STOP	You do not touch it while it is live — never.	"What to do this minute": one action that takes you away from the danger or takes the source away.
Hire a pro	A pro does the work; you order it in words and accept it by things you can check.	"If no pro is available", and "When a pro may do it differently".
Do it yourself, if…	You do it when the named condition is met.	The condition, before the action; where the work carries a hazard, its sign, which leads to its entry on the Safety Signs page.
Do it yourself	You do it.	Nothing more.

Work at the battery

A battery terminal is live all the time, and nothing between it and a wrench limits the current except the battery itself (→ 1.1 · p. 2). A wrench

that touches the positive and the engine block or the negative at the same moment closes a short circuit with the full current of the bank. Past the battery switch and past a fuse rated for its wire, the same slip blows that fuse. That is why work at the battery has its own levels, and why the kind of fuse holder decides the level.

A fuse at the battery sits either in a holder that opens by hand or under a nut on a stud. In a holder that opens by hand, the cover comes off by hand and the fuse itself comes out by hand or with a puller. A fuse clamped by a nut on a stud — ANL, MEGA, MIDI, Class T and others — puts a wrench on a live stud. So does an MRBF fuse, which sits in a holder bolted onto the battery terminal itself. This holds even when a cover over the fuse lifts off by hand.

A fuse in a holder that opens by hand is a job you can do yourself: no wrench comes near a live stud. A fuse under a nut on a stud, an MRBF on its terminal and a lug on the battery terminal itself all put a wrench on a live stud, and the block at the end of this section gives that work to a pro. One job at a battery terminal is yours all the same: the planned job on a battery (→ 6.5), listed with its signs in the block at the end of this section.

One term recurs in this book: the negative of the whole bank. It means every negative lead that leaves the bank, on the negative terminal of every battery in it — the main cable to the negative bus and the small negatives of the charger and of circuits wired around the battery switch; the jumpers between the batteries stay. It also means the same leads of every bank tied to it on the positive side — by a battery switch at BOTH, ALL, 1+2 or COMBINE, a parallel switch ON, a charging relay (ACR) whether or not it seems closed, a DC-DC charger, or a charger — except a charger with one output for each bank whose manual says its outputs are isolated from one another.

Why the whole bank: a wrench on the positive can short to something only if the positive is still connected to a battery whose negative is still in place. Take off one battery's negative in a bank of two parallel batteries, and the second battery feeds the positive through the jumper. A second bank tied through a battery switch at BOTH, ALL, 1+2

or COMBINE, a parallel switch ON, a charging relay (ACR) whether or not it seems closed, a DC-DC charger, or a charger — except one with one output for each bank whose manual says its outputs are isolated from one another — does the same. With every negative lead of the whole bank off, the positive has no way back to a battery; a charging source — a charger, solar, wind or a running engine — still can close a circuit through the wrench, until it is off.

 **BLOWN FUSE**  **CARBON MONOXIDE** The bank's main protection is a different case. It is the fuse or breaker nearest the bank's positive terminal, which protects the cable that leaves the bank. When it has tripped or blown, it has stopped the full current of a short somewhere on that cable or after it, and a new fuse on the same short feeds the same current again: that is why it waits for a pro, who finds the short first.

With the main protection open, everything after it is dark. A bilge pump wired around the switch, ahead of the main protection, keeps running; a pump fed after the main protection has stopped with the panel, and so has a CO alarm fed there. The high-water alarm can be dead too (→ 12.5).

 **PROVE IT DEAD** A fuse after the battery switch, or work on a circuit after it: do it yourself, if the condition of this sign's entry is met. The switch cuts only what is wired after it: a circuit wired around it, a charger, solar, another bank or an electronics memory wire can still feed the wire in your hands.

A zero counts only from a meter that reads the battery voltage right before and right after it. A dead meter, or a black probe on a negative that no longer reaches the battery, also reads zero. The service procedure in → 1.7 · p. 24 shows the measurement at the switch.

 **BLOWN FUSE** A positive wire that leaves a battery with no fuse or breaker is an unprotected positive, unless it is the starter cable, which you identify by tracing it to the starter, directly or through the battery switch, not by its size; a wire taken off the starter's battery terminal to feed anything else is not the starter cable. A jumper between the batteries of one bank is part of the bank (→ 6.4). An unprotected

positive can start a fire as soon as its insulation chafes through (→ 4.2), and a pro adds the protection. A bilge pump on such a wire is the hard case: a boat whose pump is off is in more danger than one whose sound pump wire has no fuse yet (→ 12.8). Each one you find goes on the first line of the Boat Passport.

Behind the panel

Behind the panel, AC and DC wiring can share one space, and many connections sit close together. You can learn a lot there — which breaker feeds what, which wires were added later, what is labeled — without changing anything. Behind a panel with AC breakers on it, the reason to disconnect nothing is physical: every terminal you loosen there has to be tightened again correctly, and one tightened badly becomes a new connection that heats under load (→ 3.1). Proving the AC side off tells you the state of the wires at that moment (→ 3.7), not that the work on them is yours.

What you never do yourself

Some work is never yours in this book, whatever your skill. Insulation testing with a megger is a pro's job, done only on a cable disconnected at both ends: a megger is an insulation tester that pushes a high test voltage into the insulation to find a leak, and every device left on the circuit sees that voltage (→ 3.7). Meter probes in the shore power inlet or inside the pedestal put your hand at a live AC connection that nothing on the boat switches off.

DO IT YOURSELF OR HIRE A PRO · THE WORK OF THIS CHAPTER

STOP · Anything that stays live and cannot be proven off: the AC side while any source is on, the shore power inlet, the inside of the pedestal, a megger on an assembled circuit.
What to do this minute: Take your hands and tools away, then remove the source by its row of the source map (→ 1.7 · p. 24).

HIRE A PRO · A wrench on a live stud at the battery: a fuse clamped by a nut on a stud, also under a cover that lifts off by hand; an MRBF in its holder on the terminal; or a lug on the battery terminal itself, outside

the planned battery job below — and, away from the battery, every other stud that stays live with every battery switch OFF, as the entry of the SHORT CIRCUIT sign names them. Also the bank's main protection after it tripped or blew; insulation testing on a cable disconnected at both ends; and any AC connection made, loosened or replaced, even with the AC side proven off. Order the job in the words of "What to tell the pro" in this section. Accept it by two or three things you can check: the rating is printed on the part and readable in place; the new connection is crimped, covered and labeled; the pro shows you the measurement that proves the fix.

If no pro is available:  **SHORT CIRCUIT**  **BLOWN FUSE** Work at a battery terminal or stud that cannot wait: the entry of the SHORT CIRCUIT sign gives the one way without a pro. The bank's main protection: the entry of the BLOWN FUSE sign says how the boat stays until a pro comes. The rest of this work waits for a pro.

When a pro may do it differently: A pro may put the fuse farther from the battery than 7 in only by the rule of → 4.2. 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. You can see it: the run is covered end to end, and the reason is written in the Boat Passport. A pro may choose a fuse rating above the one the triad gives only by naming the clause of 33 CFR 183.455(c) or ABYC E-11 that allows it, never above the device maker's rating: the allowance is for the wire only. That clause is written in the Boat Passport (→ 4.3). ABYC

DO IT YOURSELF, IF…

-  **SHORT CIRCUIT**  **GASOLINE VAPOR**  **METER LEADS**  **BLOWN FUSE** At the battery: a fuse in a holder that opens by hand; a measurement with probes on the battery terminals. Behind a panel: looking, tracing, reading labels and measuring.
-  **SHORT CIRCUIT**  **GASOLINE VAPOR**  **METER LEADS**  **HOT BATTERY**  **BILGE PUMP**  **CARBON MONOXIDE**  **BATTERY ACID** The planned job on a 12 V lead-acid battery, on its own or in a bank joined in parallel: taking it out and putting it or a new one back, cleaning or tightening its terminals (→ 6.5).

-  **BLOWN FUSE**  **PROVE IT DEAD** After the battery switch: a fuse, or work on a circuit.
-  **AC — PRO** Behind a panel with AC breakers on it: the same work. In the bilge: a hand in the bilge water, on the float, the pump or its wiring. At the dock: unplugging shore power, in the order of → 17.2.
- The zero check of the AC side, by the procedure “Proving the AC side off at the AC panel” (→ 3.7).
-  **SHOCK IN WATER** Shore power plugged back in, in the order of → 17.2, and a protective device on your boat reset after a trip (→ 17.3).
-  **BILGE PUMP** The pump switch, set when you go ashore (→ 12.2).

DO IT YOURSELF · Tracing 12 V wires with your eyes and hands; reading labels; testing a protective device with its TEST button.

A boat that is not yours: three levels

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). Whatever you change with a tool, the next crew inherits without knowing it. Resetting a tripped shore power protective device counts as using a button: you handle it as on your own boat, by the card “Shore power tripped and won’t come back on” (→ emergency card), and then you tell the base or the owner what tripped and what you did.

Working with a pro

A pro you hire is only as good as the job you describe and the way you accept it. ABYC certifies individuals, not shops. According to ABYC’s certification rules, a certified pro has passed ABYC’s exam in a field such as Marine Electrical and has two years of work experience. The certificate is valid for five years. Ask to see the certificate, or its sticker or patch, and find the name in ABYC’s online directory of certified pros. Certification tells you that the pro knows the standard. How this pro will do your job, you learn from five questions before you order the work:

1. Are you certified for marine electrical work, and do you work on boats like mine — this hull material, this engine, lithium if I have it, the AC side if the job touches it?
2. How will you find the cause before you replace any part: which measurement, at which point?
3. What will you measure after the work to show that it is fixed, and will you show me the reading?
4. Will you label what you change and mark it on my one-line diagram in the Boat Passport?
5. Which standard do you work to, and will you tell me in writing where you do something differently from it, and why?

The pro's written description of the job names four things: the problem as the pro understands it; what will be done, with the parts named by function and rating — wire gauge, fuse type and rating, the kind of connection; what will be measured before and after; and what the job does not include.

You accept the work without an instrument when four things are true. The device works in every one of its modes: a pump, for example, starts by itself and water goes overboard. Every new wire and fuse is labeled. Each fuse rating is printed on the part and readable in place. The Boat Passport is updated. You accept it with an instrument when the pro shows you the reading that proves the fix, at the same points as before the work. For a connection, that reading is the voltage drop across it under load (→ 3.4). You have the right to ask to see the measurement.

Warning signs: parts are replaced before anything is measured. A larger fuse or breaker is offered "so it stops tripping", with no word about the wire it protects (→ 4.3). On an aluminum boat, a negative is fastened to the hull (→ 1.4 · p. 16). A positive wire is left at the battery without protection. The job is called finished without a test of the device in every mode. The pro will not show you the reading.

> **WHAT TO TELL THE PRO**
>
> Describe what you found, where, and what you measured, in the words of the trade: "The positive wire from the house battery to the windlass

> has no overcurrent protection at the battery. Add a fuse or breaker at the battery end, rated for the load and for the wire, and label it." You accept the work when three things are true. 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 by the rule of → 4.2. 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. The change is written in the Boat Passport. ABYC

Doing this work on other people's boats for pay is a trade with its own rules → module "Service".

1.9. What this book is built on

Where do the rules in this book come from, and how binding is each one? Two documents carry most of them: the ABYC standards and the federal regulation 33 CFR. They differ in who they bind, and you need to know the difference when a pro, a surveyor or a seller tells you that something is "required".

ABYC is a voluntary industry standard, not a law. ABYC describes its standards as voluntary safety standards for the design, construction, maintenance and repair of recreational boats, and as the basis of marine surveys. Builders in the boat certification program of the National Marine Manufacturers Association (NMMA) build to ABYC standards, and the program's inspectors check each certified model every year. This book follows ABYC wherever ABYC gives a rule for a typical boat.

33 CFR is a federal regulation, and its electrical part has a narrow scope. Subpart I of Part 183 covers boats with a gasoline engine other than an outboard — for propulsion, mechanical power or electrical generation. So a boat with an outboard and a gasoline generator is inside it, and a boat whose only gasoline engine is an outboard is not.

Part 183 binds the builder. The rule in this area that binds you, the person who runs the boat, is 33 CFR 175.201. No one may operate a gasoline boat built after July 31, 1980 without an operable ventilation system. CFR

How your state adopts and enforces boating rules — registration, inspection, licensing of electrical work — is a separate subject → module “State Guides”.

At the dock the boat ends and the marina begins. ABYC’s standard for electrical systems on boats, E-11, covers the boat’s AC system up to the point of connection to the shore outlet. That includes the cord set: the cord is part of your boat. The pedestal and the wiring of the dock ABYC follow the National Electrical Code, Article 555, which covers the wiring and equipment of docks, marinas and boatyards. The fire standard NFPA 303 covers how marinas are built and run. This book explains where your boat ends and does not teach work on the marina’s side (→ 17.7).

A boat built to European rules follows rules other than ABYC. A CE plate, a craft identification number (CIN) in place of a US hull identification number (HIN), and wire marked in square millimeters are clues to such a boat. They are clues, not proof of how the boat is wired after years of refits. How to recognize a European-built boat and what that changes is in → 2.5; what upgrading it to ABYC changes is in → 18.5.

Rules without exceptions, on purpose

Many rules in this book are simplifications written without exceptions on purpose. Such a rule is right in about nine cases out of ten and builds no habit that starts a fire. That is enough to act on a typical boat without a list of special cases. The other cases are named where they belong: in the “Why it works” boxes, and in the line “When a pro may do it differently” of each “Do it yourself or hire a pro” block.

The marks next to numbers tell you where each number comes from.

- **CFR** — A requirement of 33 CFR, checked against the regulation text on ecfr.gov or govinfo.gov.
- **ABYC** — Wording confirmed by the standard or by a document that quotes it word for word; the document and the edition year of the standard are in "Sources".
- **ISO** — A requirement of an ISO standard, confirmed by the standard's text or its word-for-word national edition; used only to recognize a European-built boat.
- **MFR** — Data from the maker of one product, from its data sheet or manual with the date of the document; it holds for that product only.
- **PRACTICE** — Accepted practice without a primary source: a regulation, a standard or a maker's document that answers for it.
- **VERIFY** — A number or wording the book has not yet confirmed in its primary source; the book never presents it as a requirement, and no step you take depends on it.

A number without a mark is (1) a teaching number set by the condition of an example; (2) arithmetic from marked numbers; (3) a number from a document named in the text next to it (a report or a government document, a code for docks and marinas, an organization's published rules for its own programs, a materials-property handbook, a standard on the effects of current on people) that is listed in "Sources". An arrow such as "→ 4.2" points to a section of this book, or to a figure (Fig.), a table or an appendix (App.). In the PDF, a page number follows when the target is in the same file.

Here is how one rule reads in this book. 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 or enclosure (→ 4.2): up to 72 in for a wire straight from a battery terminal, up to 40 in from any other source. ABYC

Of the wires that leave the battery, only the starter cable may run without protection — directly or through the battery switch. You identify it by tracing it to the starter, not by its size; a wire taken off the starter's battery terminal to feed anything else is not the starter cable.

A jumper between the batteries of one bank is part of the bank, not a wire that leaves it. The regulation and ABYC name a few more exceptions, listed in → 4.2. For your boat, the rule is: no positive wire leaves a battery bank without protection, except the starter cable.

The book uses US units: wire in AWG, lengths in inches and feet, volumes in US gallons, temperatures in °F. A metric number appears only where the part itself is metric — as printed on it, with its US meaning next to it; the conversion tables are in → App. B.

1.10. On board

ON BOARD: GOLDEN RULE

Before you touch anything, ask where energy can reach this spot from, and remove each source by its own action. Main switch OFF does not mean no voltage anywhere: shore power, the generator, the inverter, the solar panels, a running engine and every circuit wired around the switch reach the spot by their own paths. And a battery switch turns only with the engine stopped: a running alternator must not lose its battery.

What it means

Table 1.6. What it means

What you notice	What is happening	First check	Yourself or a pro
Gasoline smell in the bilge or the engine compartment	Vapor from a leak collects low; the spark of any switch can ignite it	 **GASOLINE VAPOR** The first move is the entry of this sign; why: → 1.1 · p. 2.	**STOP**
A wrench sparked when it touched the battery	The wrench closed a short from the positive to the negative or the engine block	 **SHORT CIRCUIT** Take the tool away; who does the work at the battery: → 1.8 · p. 38.	**Do it yourself, if...**
Someone in the water near the dock feels a tingle, freezes or cannot swim	AC leaking into the water from a boat or the dock runs through the body and takes away control of the muscles	No measurement: the card “Someone got shocked — at the dock, in the water, or touching the boat” (→ emergency card); why: → 1.1 · p. 2.	**STOP**
The battery switch is OFF, but the stereo clock, the bilge pump or the CO alarm still works	That circuit is wired around the switch on its own fuse at the battery, or it is fed from another bank, a charger or solar	Trace its positive wire from the device back toward the battery with your eyes and hands, and write it in the Boat Passport (→ 1.7 · p. 24).	**Do it yourself**

What you notice	What is happening	First check	Yourself or a pro
Shore power is unplugged, but the outlets still work	The inverter switched itself on, the generator is running, or a second shore inlet is still plugged in	Look at every shore inlet, at the AC source selector and at the inverter's display or status lights; each source that is still on comes off by its row of → Table 1.4 · p. 29.	**Do it yourself, if...**
A lithium battery hisses, vents or swells fast	A cell is failing and venting gases that burn and are toxic	**HOT BATTERY** The card "Battery smells, is swollen, or is hot" (→ emergency card).	**STOP**
A lead-acid battery smells of gas, is hot or is swollen	Overcharging, high heat, a recharge after a deep discharge, too little electrolyte, a blocked valve or a failure inside; it gives off hydrogen	The card "Battery smells, is swollen, or is hot" (→ emergency card); why its steps come in that order: → 1.1 · p. 2, → 6.5.	**STOP**
The CO alarm sounds, or someone has a headache or nausea while the generator or an engine runs	Carbon monoxide from exhaust, or from a fuel-burning stove or heater, is building up where people are	The card "CO alarm is sounding, or headache, nausea or drowsiness aboard" (→ emergency card); why: → 1.1 · p. 2, → 17.6.	**STOP**

What you notice	What is happening	First check	Yourself or a pro
Shore power tripped at the dock	A protective device found current leaking, or a breaker found an overload	The card “Shore power tripped and won’t come back on” (→ emergency card); what tripped, and why: → 17.3.	**Do it yourself, if…**
The reverse polarity indicator is lit	The hot and the neutral are swapped between the pedestal and your panel	**SHOCK IN WATER** The first move is the entry of this sign; what the light means: → 1.1 · p. 2, → 17.3.	**Hire a pro**
On an aluminum boat, the hull or the lower unit pits fast	Current leaves the metal into the water somewhere; the metal dissolves there	Follow the negative wire of each load you can reach: each must end at the negative bus, not at the hull (→ 1.4 · p. 16, → 16.3).	**Do it yourself**

REMEMBER

- The 12 V and 24 V wiring does not shock you. What can kill you or burn the boat is current in the water, 120 V AC, an arc at the battery, gasoline vapor, a failing battery and carbon monoxide; each has its sign, and the sign leads to its first move.
- Main switch OFF does not mean no voltage anywhere: each source comes off by its own action, and a battery switch turns only with the engine stopped.
- Gasoline vapor is heavier than air and collects low in a closed compartment, and every switch contact is a spark, on or off.
- In a fire, the VHF call comes before the battery switches: the fixed radio goes off with them.
- What you see covers one source: the plug out of the pedestal and out of the boat’s inlet means that shore power is off — and only shore power.

- One battery's negative off proves nothing: only with the negative of the whole bank off does the positive lose its way back to a battery.
- An aluminum hull is a conductor, but no load returns current through it: every negative by wire to the negative bus, one tie to the hull.
- In fresh water the body carries the current: "a lake-only boat" does not mean "simpler is fine".
- A job is not yours when the energy cannot be proven off or the result cannot be measured. It is not yours either when the damage from a mistake would appear late, or when the work changes the boat's status with its insurer or under the standards. You have the right to ask to see the measurement.

Self-check

1. **Before you measure.** On the boat of → Fig. 1.4 · p. 25 the battery switch is ON and the engine is stopped. The switch goes to OFF. Which of points B and C keeps the bank voltage, and which falls to 0 V? And what would a running alternator do to point B at that moment?

   Answer: point C keeps the bank voltage — it is the bank's own terminal; point B falls to 0 V. With the engine running, the alternator would keep point B live and lose its battery — load dump — which is why the engine is stopped first. A check with a meter puts a probe on point C, a battery terminal: that is the last step of the service procedure in → 1.7 · p. 24.

2. **Your turn.** Suppose wet skin adds 1,000 Ω to the 500 Ω inside the body. What current does 120 V drive, and how does it compare with the threshold of about 40 mA?

   Answer: 120 ÷ 1,500 = 0.08 A, which is 80 mA — twice the threshold. Wet skin lowers the current of the worst case, and 120 V still drives a dangerous one.

3. **Fresh water.** A friend says the lake is safer than the sea for a swim near the docks because fresh water conducts worse. What is wrong with that?

   Answer: because fresh water conducts worse than the body, the leak current

crowds into the swimmer and runs through the body. In salt water most of it passes around the body. “A lake-only boat” does not mean “simpler is fine”: it means current in the water kills here.

4. **Aluminum.** How fast can stray current eat underwater metal, and what one habit prevents it on an aluminum boat?
   Answer: in days, not seasons — a marine systems specialist describes a propeller, shaft or sterndrive destroyed in a matter of days. The habit on an aluminum boat: every negative runs by wire to the negative bus; nothing takes its negative from the hull.
5. **Gasoline.** You open the engine hatch and smell gasoline. Your hand is on the light switch, and the light is on. Why is switching it off no safer than switching it on?
   Answer: a switch sparks whenever its contacts open or close, whichever way it turns, and gasoline vapor is heavier than air, so it sits low in that compartment, where the spark is. What to do first is the entry of the GASOLINE VAPOR sign (→ 1.1 · p. 2).
6. **On your boat.** Find every source of energy by the list of → 1.7 · p. 24. Count the shore inlets, and find the generator, the inverter, the solar charge controller, any ACR or DC-DC charger, and each circuit wired around the battery switch. Write them in the Boat Passport.
   Answer: every source you cannot find goes in as “don’t know” — that is a task for the walk-through of → 2.1, not a mistake.
7. **On your boat.**  GASOLINE VAPOR  BILGE PUMP With the engine stopped and every battery switch OFF, what still works — a stereo clock, the bilge pump, the CO alarm, a charger’s lights? Write it down, and afterwards return the switches to their working positions.
   Answer: each device that still works is wired around the switch or fed from another source. Trace its positive wire toward the battery with your eyes and hands and write down where its fuse is. A CO alarm that went dark is wired after the switch, and that goes into the Boat Passport too.
8. **On your boat.** Write your hull material in the Boat Passport. On a metal hull, follow the negative wire of three loads you can reach. Where does each one end?

Answer: at the negative bus or the battery negative. A negative that ends at a screw in the hull is a fault to fix (→ 16.1).

9. **A pro's work.** A pro has added a fuse at the battery for your windlass. Which three things do you check before you accept the job?

   Answer: 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 sits by the rule of → 4.2. 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. And the change is written in the Boat Passport. You have the right to ask to see the measurement.

Terms

a pro
A qualified marine electrician: the person you hire for any work this book marks "Hire a pro".

battery switch
The switch in the positive cable between a battery bank and the boat's loads; with the engine stopped, OFF removes current only from the circuits after it.

source map
The list of every place energy can reach your boat's wiring from, with what removes each one; going through it source by source is the only way to prove that the boat is dead.

circuit wired around the battery switch
A circuit connected on the battery side of the switch, so it stays live in every switch position; it needs its own fuse at the battery.

alternator
The engine's charging device; it must not lose its battery while the engine runs.

generator
A machine with its own engine that makes 120 V or 120/240 V AC; you stop it to remove it as a source.

inverter
A device that makes 120 V AC from a battery bank; it can be live with shore power unplugged.

load dump
The voltage spike when a running alternator suddenly loses the battery it was charging.

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

the negative of the whole bank
Every negative lead that leaves a bank, on every battery in it and in every bank tied to it on the positive side; the jumpers between the batteries stay (→ 1.8 · p. 38).

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.

bonding
Wires that tie the underwater metal parts of a boat together; they carry no current in normal operation and are never a return path.

equipment grounding conductor
The green or bare wire of an AC system that carries fault current back to its source, so that a breaker or a protective device trips.

cord set
The shore power cable between the pedestal and the boat's inlet, with a plug at one end and a connector at the other.

GFCI
A protective device that trips when current leaks out of an AC circuit; it protects outlets and, like every protective device, is recognized by its TEST button.

ELCI
A breaker on the boat's shore power that also trips on leakage current; like every protective device, it is recognized by its TEST button.

GFPE (ground-fault protection of equipment)
A protective device that trips when current leaks out of an AC circuit; it protects the pedestal's receptacles and, like every protective device, is recognized by its TEST button.

RCD / RCBO
Labels of protective devices built to European rules, found on European-built boats.

pedestal
The marina's power outlet on the dock, with its own breaker, where the cord set plugs in.

shore power inlet
The connector on the boat where the cord set plugs in.

electric shock drowning (ESD)
Drowning caused by AC in the water that takes away a swimmer's control of the muscles.

carbon monoxide (CO)
A poisonous gas in the exhaust of engines and generators.

flash point
The lowest temperature at which a fuel gives off enough vapor to ignite.

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

bilge blower
The fan that pulls vapor out of a gasoline engine compartment before the engine starts.

anode
A piece of a more active metal that corrodes in place of the underwater metal it protects; the type of water decides its material: zinc or aluminum in salt water, aluminum in brackish water, magnesium in fresh water (→ 1.5 · p. 19).

stray current corrosion
Fast corrosion where direct current leaves metal into the water.

gray zone (on someone else's boat)
Anything you are not sure is a switch or a button; on someone else's boat, only with the permission of the charter base or the owner, by phone.

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