APLUXOR MARINE ELECTRICAL LIBRARY · PART III. ENERGY: HOW MUCH YOU HAVE AND WHERE IT COMES FROM

Chapter 10. Solar and Wind

Work out what a panel will really give on your boat, and connect it safely

A solar panel and a wind generator charge your batteries with no fuel and no shore power, and neither stops when you turn a battery switch. This chapter shows you how a panel and a wind generator charge a bank, what the numbers on their labels mean, what a panel will really put into your bank in your waters and season, how each is protected and taken off for work, and how to find out why a bank does not charge from them.

AFTER THIS CHAPTER YOU CAN

- read a panel's label and tell what changes when panels are joined in series or in parallel, and when a shadow falls on one;
- check that a charge controller's input takes your string on the coldest morning, and set the controller for your battery;
- work out, month by month, how many amp-hours your panels put into your bank where your boat is, and carry that figure into your energy budget;
- find each fuse of a solar installation, and take a string off before anyone works on its wiring;
- say when a wind generator makes sense on your boat, how its own maker stops it, and why its battery is never taken away while it turns;
- follow the routes when the bank does not charge from the panels or from the wind generator.

Read first: → 1.7, → 4.2, → 5.4, → 6.1, → 7.5, → 9.4

10.1 The panel
10.2 The controller
10.3 What the panel will really give
10.4 Cables, protection, disconnect, mounting
10.5 The wind generator
10.6 On board

10.1. The panel

What does a solar panel put into your batteries, and what do the numbers on its label tell you? A panel turns light into direct current: light falling on its cells pushes current out of its positive lead and back into its negative lead whenever a circuit joins them. On a boat that circuit runs from the panel to a charge controller, and from the controller to a battery bank (→ Fig. 10.3 · p. 25); the controller decides how much of the panel's current the battery takes (→ 10.2 · p. 7). Two panel makers write that their panels make DC electricity, or pass it through their connectors, whenever sunlight or other light falls on them. The light of a dock lamp counts too. Solar panels make energy whenever light falls on them, and a battery switch stands nowhere in the panel's own wiring: where they reach your boat and how they are taken off is part of the source map in → 1.7. MFR

The label: what it promises, and under which light

A panel's label and data sheet give its ratings at standard test conditions (STC): light of 1,000 W per square meter on its face, its cells at 25 °C (77 °F), and air mass 1.5, a measure of how much air the light has crossed. One maker's data sheet for a 100 W panel prints these conditions under its table, and every number in that table holds only under them (→ Table 10.1 · p. 3). The face of a panel on a boat sees light that strong, if at all, only near noon on a clear day, and its cells then run warmer than 77 °F. So the label is a rating for comparing panels, not a day's output; the day's output is worked out in → 10.3 · p. 19. MFR

Five numbers on the label matter to you. The maximum power, Pmax, is the watts the panel gives at its best voltage. The voltage at maximum power, Vmp, and the current at maximum power, Imp, are the voltage

and current at which it gives them. The open-circuit voltage, Voc, is the voltage across its leads in light with nothing connected — the highest voltage it makes. The short-circuit current, Isc, is the current it gives with its leads joined to each other — the most current it makes. A panel cannot push much more current than its Isc into anything, which is why a short across a panel's own leads does not heat like a short across a battery; its voltage and its current both follow the light.

Table 10.1. One maker's 100 W panel in two generations, as printed on their data sheets MFR

On the data sheet	Generation A	Generation B
Maximum power at STC, Pmax	100 W	100 W
Voltage at maximum power, Vmp	20.4 V	18.6 V
Current at maximum power, Imp	4.91 A	5.38 A
Open-circuit voltage, Voc	24.3 V	22.3 V
Short-circuit current, Isc (the sheet of Generation A labels it "Short Circuit Voltage")	5.21 A	5.86 A
Cells	36	33
Bypass diodes	2	2
Maximum series fuse rating	15 A	15 A
Temperature coefficient of Voc, as printed (per °F)	−0.28 %/°C (−0.156 %/°F)	−0.28 %/°C (−0.156 %/°F)
Temperature coefficient of Pmax, as printed (per °F)	−0.37 %/°C (−0.206 %/°F)	−0.37 %/°C (−0.206 %/°F)
Nominal operating cell temperature (NOCT), as printed (°F)	47 ± 2 °C (117 ± 4 °F)	47 ± 2 °C (117 ± 4 °F)

The two generations carry the same model name and the same 100 W, yet their Voc differs by 2.0 V and their Isc by 0.65 A. The numbers you calculate with are the ones on the label of the panel on your boat, not a catalog's for its model name; they go into field 8 of the Boat Passport (→ 2.3). Where a sheet prints a metric figure, it is read as printed with its US meaning beside it: a coefficient of −0.28 % per °C is −0.156 % per °F (0.28 ÷ 1.8).

Cold raises the voltage

A panel's voltage rises as its cells get colder. One controller maker writes that at ambient temperatures below 25 °C (77 °F) the Voc will be higher; a second writes that solar panel voltage rises in cold weather and asks that the Voc stay below its controller's maximum input at the coldest temperature you can expect; a maker of land modules has a correction applied to the Voc for the lowest expected temperature at the site. The coldest moment for the panel is a frosty morning when light first reaches it: its cells are still at the temperature of the air, and its voltage is the highest of the day while its current is still small. The data sheet's Voc coefficient tells you how much higher (→ 10.2 · p. 7, worked example). MFR

Series and parallel

Panels joined in series — the positive of one to the negative of the next — add their voltages and carry one panel's current; joined in parallel — positive to positive, negative to negative — they add their currents at one panel's voltage (→ Fig. 10.1 · p. 5). One panel maker writes it for its own panels: two panels in series produce double the voltage of one, in parallel their currents are additive, and the total current of panels in parallel is the sum of their short-circuit currents. Panels in series that feed one input of a controller are a string. A panel of another model in a string carries no more current than the weakest panel lets through, so the string gives less than its labels add up to. MFR

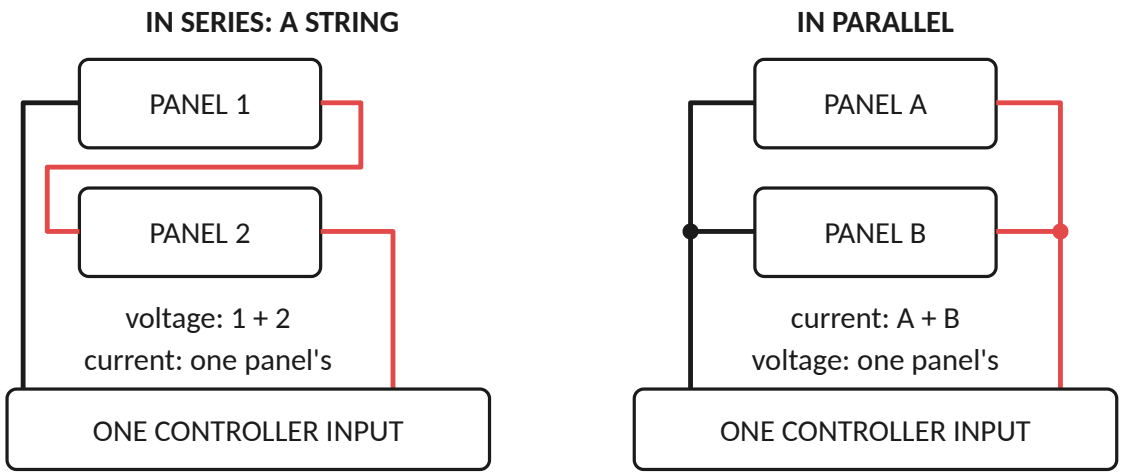


Fig. 10.1. Two panels in series make a string: their voltages add and the current is one panel's. Two panels in parallel: their currents add and the voltage is one panel's. Either way the pair feeds one input of a charge controller.

A string can reach voltages far above the 12 V or 24 V of the boat's DC system. One panel maker warns that three or more of its panels in series can produce more than 60 V DC, which it calls high voltage and an increased safety hazard. Three panels of Generation A in series MFR already give 72.9 V at 77 °F (3 × 24.3 V), and more on a cold morning. The string's voltage is the sum of the printed Voc of the panels in series on one controller input; where you cannot see how the panels on that input are joined, count all of them as in series until you have traced the wires. How such a string is taken off for work on its wiring is in → 10.4 · p. 25.

Shade on a boat

The cells of a panel are joined in series inside it, so the current of the whole panel has to pass through every cell. A shaded cell makes little current, and without help it would hold back the current of every cell in series with it. That is what bypass diodes are for: one maker's 36-cell panel has two in its junction box, each across a group of cells, and a maker of land modules writes that the number of bypass diodes in a module's junction box varies by model series (→ Table 10.1 · p. 3). MFR When cells of one group are shaded, that group's diode carries the

current of the other cells around it (→ Fig. 10.2 · p. 6): the panel loses that group's share of its voltage, not all of its current.

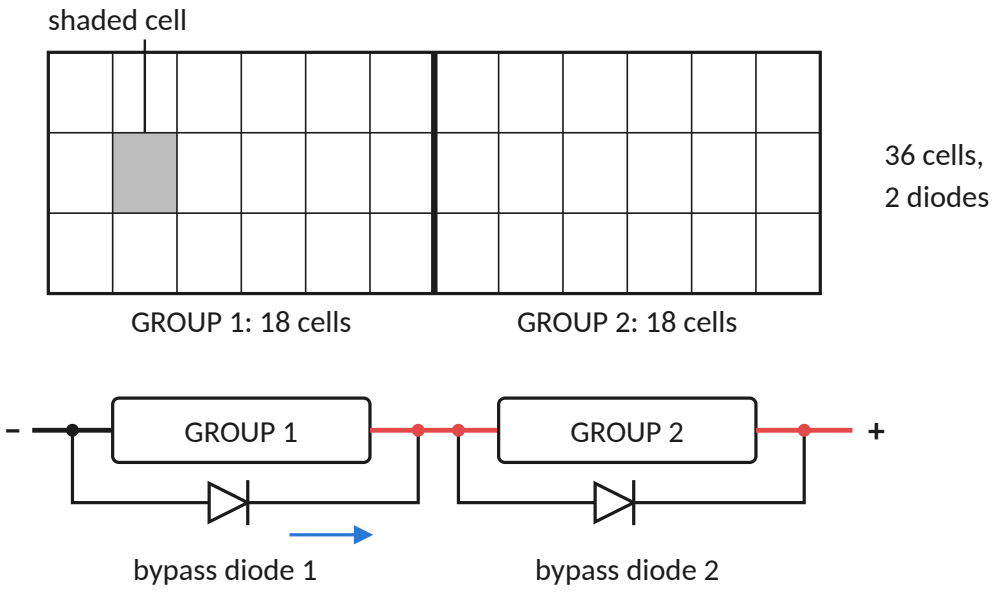


Fig. 10.2. A 36-cell panel with two bypass diodes, its cells drawn as two equal groups. A shadow on one cell of group 1 holds that group back; its diode carries the current of group 2 around it, and the panel gives about half its voltage with the current of its unshaded group. How a maker groups the cells behind each diode is on that maker's sheet or not at all.

WHY IT WORKS

Behind a single diode the cells of a group share one current, so one shaded cell is enough to take the whole group out. PRACTICE On a sailboat the boom, the mast and the rigging cast moving shadows; on any boat an antenna, a radar dome or a bimini can. With two diodes, a shadow across one narrow band of cells can take half a panel, and a shadow that crosses both groups can take nearly all of it. A controller that searches for the panel's best voltage meets a harder problem in partial shade: one controller maker writes that two or more maximum power points can then be present, and that conventional controllers tend to lock to a local one, which may not be the best. MFR

Low current from a panel in sun has other causes besides shade: salt, dirt and bird droppings on its face; a bank that is already near full, which the controller charges with less current (→ 10.2 · p. 7); another source that holds the bank's voltage high (→ 9.4); heat (→ 10.3 · p. 19); a

cracked cell or a failed diode. Comparing the panel's current at noon with a neighbor panel's, and with the controller's own reading of its stage, tells most of them apart; the route at the end of → 10.2 · p. 7 takes them in order.

Rigid, semi-flexible, portable

A rigid panel has a glass face in an aluminum frame and is bolted to a frame, an arch or a rail. A semi-flexible panel bends to a curved deck and is light. One maker of flexible panels writes that its panels are not recommended to bend beyond 30°, that they do not stay flexible once fixed, that adhesive on the back makes the mounting permanent, and that they are not walked on; for its later series it writes that the panels can get hot in normal operation and excessively hot in some failure conditions, such as cracked cells or failed protection diodes, and that they are not installed on a surface that is not fire resistant or that can be damaged by high temperatures. A portable panel travels on its own cable and plugs in where its manual shows; its limits are in that manual. Whatever the type, each maker's limits are those of its own panel, and your panel's manual is the one that decides. MFR

One land-module maker adds that under certain conditions a module may produce more current or voltage than its rated power at STC, and multiplies the short-circuit current by 1.25 when it sizes wires and protection. That margin returns in → 10.4 · p. 25. PRACTICE

10.2. The controller

Why does a panel need a charge controller between it and your battery, and which controller suits your panels and your battery? A panel pushes current whenever light falls on it and has no idea whether the battery is full. The solar charge controller — the device between the solar panels and the battery — limits that current as the battery fills. One controller maker writes that its controller prevents overcharging by limiting the current flowing into the batteries from the array; a second writes that once the battery is full its controller stops charging or greatly reduces the charge current, and that it has protection against

reverse polarity and reverse current on the panel side. That is why every panel reaches the battery through a controller, unless the battery's own maker allows otherwise (→ "When even a small panel needs a controller" · p. 8). MFR

When even a small panel needs a controller

Whether a small panel may go straight on a battery is the battery maker's decision, because it is the battery that has to take whatever the panel gives. One lithium battery maker writes that a panel of less than 60 W can be connected directly to its battery, because the battery's own management system (BMS) stops the charge when the battery is full; it calls a controller strongly recommended from 100 W and required above 200 W. That permission is for that maker's battery, and it says nothing about the sizes between 60 W and 100 W. Where your battery's maker does not give such a permission in writing, the panel goes on the battery through a controller, whatever its size. Your battery's manual and label are where you look; they go into field 12 of the Boat Passport (→ 2.3). MFR

PWM and MPPT

The solar charge controllers in this chapter are of two kinds. A PWM controller switches the panels' current to the battery in pulses (pulse width modulation), and the panels then work at about the battery's voltage. An MPPT controller keeps the panels at their maximum power point — the voltage at which they give the most power — and charges the battery from that power. The model name can say which: one maker's PWM controller carries "PWM" in its model name, another maker's MPPT controllers carry "MPPT" with two numbers, the highest panel voltage and the most current it gives the battery. The kind decides what your panels can give and how you may join them. MFR

The controller's current is matched to the panels by its own manual. One MPPT maker gives, for each of its small controllers, the most current it gives the battery and a nominal panel power for each battery voltage — 220 W on a 12 V battery for its 15 A models — and writes that its controller limits its input power if more panel power is connected;

one PWM maker writes that the total rated Imp of the panels on its 30 A controller should not exceed 30 A. So the panels are counted MFR the way your controller's manual counts them — by their power at your battery's voltage, or by the sum of their Imp — and compared with its figure.

WHY IT WORKS

A PWM controller joins the panel to the battery and opens the joint more and more often as the battery fills. While it is joined, the battery holds the panel's voltage down to its own, about 13 V on a charging 12 V battery, and the panel gives the current its cells make at that voltage — a little more than its Imp. The rest of its voltage, the difference between its Vmp and the battery's voltage, does no work. An MPPT controller lets the panel sit at its Vmp, takes its power there, and gives the battery that power at the battery's own voltage, as a larger current, less its own conversion loss. So the gain of an MPPT controller grows with how far the panels' Vmp stands above the battery's voltage — strings of several panels gain most — and shrinks as a hot deck lowers the panels' Vmp. PRACTICE One MPPT maker writes that its controller starts charging when the panel voltage is 5 V higher than the battery's and keeps charging while it stays 1 V higher. A PWM controller takes the panels its own manual allows: one PWM maker limits the array's open-circuit voltage on its controller to 28 V; a second, whose controller serves 12 V and 24 V batteries, gives 28 V on a 12 V battery and 55 V on a 24 V battery, and names panels of 36 cells for 12 V and panels of 72 cells, or two of 36 cells in series, for 24 V. MFR

WORKED EXAMPLE: ONE PANEL ON A PWM AND ON AN MPPT CONTROLLER

Suppose the 100 W panel of Generation A in → Table 10.1 · p. 3, in light of 1,000 W per square meter with its cells at 77 °F, charging a 12 V battery that stands at 13.0 V. On a PWM controller the panel works at 13.0 V; suppose it gives 5.0 A there, a little more than its Imp of 4.91 A. The battery gets 13.0 × 5.0 = 65 W. On an MPPT controller the panel works at its Vmp: 20.4 × 4.91 = 100 W. Suppose the controller loses 5 % of it: 95 W reach the battery, which at 13.0 V is 95 ÷ 13.0 = 7.3 A. What the number means: here the MPPT controller puts 95 ÷ 65 = 1.46 times as much into the battery, because the panel's Vmp, 20.4 V, stands above the battery's 13.0 V, in the rating's light with the cells at 77 °F. Warmer cells lower the panel's Vmp and a fuller battery raises its own voltage, and both shrink that gain: the Vmp on your panel's label against your battery's voltage while it charges shows how much room an MPPT controller has on your boat.

The input limit and the coldest morning

Every controller has a highest panel voltage it accepts, printed on its label or in its manual (→ Table 10.2 · p. 11), and that limit is checked against the string's Voc on the coldest morning, not at 77 °F (→ 10.1 · p. 2). One maker's controller stops charging when the panel voltage exceeds its maximum, shows overvoltage error #33, and starts again only when the voltage has fallen 5 V below its maximum; the same manual says that an overvoltage event can damage the controller, depending on how far the maximum was exceeded. A second maker accepts at most MFR 34 V on its 12 V controller and recommends panels with no more than 27 V of Voc at STC, which leaves room for the cold.

Table 10.2. Five charge controllers: panel input and battery types, as their makers print them MFR

Controller	Kind	Highest panel voltage	Battery types
Controller 1	PWM	Array Voc not to exceed 28 V	Sealed/gel, AGM or flooded; set to AGM when new; lithium not named
Controller 2	MPPT, 12 V panels	34 V maximum input; 27 V of Voc at STC recommended	A separate model for each chemistry: lead-acid models, and a model for 12 V lithium iron phosphate
Controller 3	MPPT	120 V of Voc	Lead-acid, with custom settings; “not compatible with Lithium-ion batteries”
Controller 4	MPPT	75 V or 100 V of Voc, by model	In its manual
Controller 5	MPPT	150 V or 250 V of Voc, by model	Set in the controller, lithium iron phosphate among them; charging can be disabled in a setting or by a remote on/off input

NUMBERS · COLD VOC OF A STRING

The Voc coefficient of the panel of Generation A is −0.28 % per °C, which is 0.156 % per °F: each °F below 77 °F adds 0.156 % to its Voc. Correction = 1 + 0.00156 × (77 − t), with t the panel temperature in °F. At 32 °F: 1 + 0.00156 × 45 = 1.070. At 14 °F: 1.098. At −4 °F: 1.126.

One panel: 24.3 V at 77 °F; 26.0 V at 32 °F; 26.7 V at 14 °F. Three in series: 72.9 V at 77 °F; 72.9 × 1.070 = 78.0 V at 32 °F; 80.0 V at 14 °F; 82.1 V at −4 °F. Generation B (Voc 22.3 V, with the same printed coefficient of −0.28 % per °C), three in series: 66.9 V at 77 °F, 71.6 V at 32 °F, 75.3 V at −4 °F. MFR

On land, the 2014 National Electrical Code, as one textbook on its Article 690 quotes it, corrects the Voc of series-connected modules for the lowest expected ambient temperature, uses the module maker’s coefficients where they are given, and otherwise applies its Table 690.7 — 1.12 for crystalline silicon at 31 to 23 °F. The NEC is not the rule on a boat; it shows that land installers make the same check.

WORKED EXAMPLE: THREE PANELS ON A 75 V CONTROLLER

Suppose three panels of Generation A in series on an MPPT controller whose label gives 75 V as its highest panel voltage. At 77 °F the string's Voc is 3 × 24.3 = 72.9 V, under 75 V, and the string looks right on a summer afternoon. On a 32 °F morning it is 72.9 × 1.070 = 78.0 V, 3.0 V over the limit: the controller stops at first light and shows its overvoltage error. Suppose it starts again, as one maker's does, only when the voltage has fallen 5 V below its limit, to 70 V: that is below even this string's 72.9 V at 77 °F, so its cells have to warm well above 77 °F first, and on a cold day the controller can stay stopped all day. What the number means: this string needs a controller whose input takes at least the voltage of the coldest morning on your boat, or two panels in series instead of three; Generation B's 75.3 V at −4 °F passes 75 V only in a far colder place.

The setting for your battery

A controller charges a battery fully, without overcharging it, only on a setting made for that battery's chemistry, and the numbers behind the setting are the battery maker's (→ 6.1); the stages it runs are those of → 9.3 — bulk, absorption and float, in the words a display prints. One PWM maker's controller offers sealed/gel, AGM and flooded and comes set for AGM, and the sheet of that maker's square model asks that the battery type be set before the controller is used; one MPPT maker writes that its controller's settings are not compatible with lithium-ion batteries and sends you to the battery maker for the charge settings; another builds a separate model of its controller for each chemistry. A controller with no setting for your battery is not that battery's MFR controller: on a lithium bank it is replaced, not reset. One lithium battery maker gives its charge voltages for a controller and asks that equalization and temperature compensation be disabled. How a MFR lithium bank is charged is in → 11.3.

Temperature matters to a lead-acid setting. One controller maker writes that by default its controller uses its own internal temperature for battery temperature compensation; a second uses a remote

temperature sensor on the battery; a third prints on its lead-acid controller that its temperature compensation is internal, with a warning of fire risk, and that it is used within 1 ft of the batteries. MFR A controller that reads its own temperature compensates for the air around itself: mounted far from the bank, or in sun or engine heat, it compensates for the wrong temperature. Where a sensor goes on a battery terminal, fitting it is work at a battery terminal (→ 1.8). The setting and the sensor go into field 12 of the Boat Passport.

Its own switch, and what it does not do

Not every controller can be switched off. One maker prints that its unit is not provided with disconnect devices; one PWM controller's manual describes no on/off switch for charging; a third maker's controller has a setting that disables charging and an input for a remote on/off, which a lithium battery's management system can command — and that maker writes that its controller is always active when its panel or battery terminals are powered. MFR A controller's own switch or setting stops the charge; it does not make its wires dead. Its panel terminals still carry the panels' voltage in light, and its battery terminals still carry the bank's voltage. To stop a charge for a reading, the routes of this book use the controller's own switch where there is one, or the panels covered, or the solar disconnect switch OFF (→ 10.4 · p. 25).

A lithium bank on solar



Each lithium battery's maker gives a range of temperatures for charging it, and the panels keep pushing current on a cold morning unless something stops them. Battery makers stop it three ways. In one, the BMS inside the battery stops a cold charge by itself: one maker's BMS will not allow a charging current under 32 °F and keeps discharging down to −4 °F. In a second, the battery's management system has to switch every charging source off by a signal: one maker gives its battery a charging range of 5 °C to 50 °C (41 °F to 122 °F) and asks that every charger be switched off when the lowest charging temperature is reached, and names as its ideal a charger with a remote on/off port

that the BMS controls. In a third, the battery cannot block a charge, and the source has to: one controller maker offers a low-temperature cut-off, disabled by default, that works only when its controller is part of that maker's network and receives a battery temperature from a battery sensor or a battery monitor with a temperature sensor. Which way your battery works is in its manual; on a battery that cannot block a charge itself, a controller that its management system cannot reach by a signal, and that reads no battery temperature, keeps charging. One controller maker recommends a lithium battery whose BMS can disconnect the controller when any cell is outside its rated temperature. MFR

When a lithium battery's own BMS disconnects the bank, everything on that bank goes dark: the bilge pump, the high-water alarm and the CO alarm with it, and the panels then charge nothing. What that disconnect leaves without power, and how the bank comes back, is in → 11.4; the cold and where on a boat it is cold enough is in → 11.5. Whatever the scheme, the controller's setting for a lithium bank, its low-temperature cut-off where it has one, and the BMS's means of stopping the controller go into field 12 of the Boat Passport.

Route: the bank does not charge from the panels

WHAT CHANGED BEFORE THE PROBLEM?

- after you installed or changed a device → a new panel or a longer string: step 2; a new battery or a new chemistry: step 6
- after charging → a bank the charger or the engine has just filled takes little from the panels (→ 9.4): step 1
- after rain or washing the boat → the plug-in connectors and the deck pass-through, by eye (→ 10.4 · p. 25), then step 5
- after the boat sat unused → a cover left on the panels, shade, dirt or salt on them: step 7; the bank's own condition (→ 6.6)
- after switching sources (shore power, generator, inverter) → which source holds the bank now (→ 9.4): step 1
- nothing you noticed → step 1

ROUTE: THE BANK DOES NOT CHARGE FROM THE PANELS — POINTS Q AND R ON → FIG. 10.3 · P. 25

METER LEADS **SHORT CIRCUIT** **BLOWN FUSE** **PROVE IT DEAD**
HOT BATTERY **GASOLINE VAPOR** **BILGE PUMP** **CARBON MONOXIDE**

1 In daylight, with nothing on the panels, read what the charge controller shows — its display, its lights as its manual explains them, or its maker's app — and the bank's voltage and current on the battery monitor. Take the readings while no other source charges that bank: the charger off at its own switch — a charger with none: read where the boat has no shore power and no generator running — the engine stopped, a DC-DC charger off at its own control or stopped by its maker's run conditions, and a wind generator stopped at the control its manual names.

You will see: A charge stage and a current on the controller, and the monitor shows a charge going in: the panels charge, and how much they give is worked out in → 10.3 · p. 19. The controller shows a current and the monitor shows less, none or a discharge: the loads on that bank take the difference, or the controller's current does not pass the monitor's shunt (→ 9.4) — read again with the loads off; a source you could not stop shows on the monitor too. A small current, or a stage named float: compare the battery voltage the controller shows with the bank's voltage on the monitor. The two together: the controller is tapering as the battery fills, or another source held the bank's voltage high (→ 9.4) — read again later in the day, with the other sources off. The bank's voltage below the controller's: the controller's battery lead drops the difference (→ "Wire size" · p. 15) — the readings to a pro (What to tell the pro, → 10.6 · p. 44). An error code: its meaning is in the controller's manual; an overvoltage error on a cold morning: step 2. No charge on a cold morning and no overvoltage error shown: on a lithium bank, a message on the controller, or the battery's own indication as its manual describes it, that charging is stopped for low temperature is the battery or its BMS stopping a cold charge — read again when the battery has warmed (→ 11.5); with no such message, or on a controller with no display, step 2. Dusk, dawn or a dark overcast: one maker's MPPT controller starts only when the panel voltage is 5 V above the battery's — read again in full light. The controller dark in sun, or with no display: step 3. Panel volts shown with no current in full sun: step 6.

2. Add up the printed Voc of the panels in series on that controller input — all the panels on that input, where you cannot see how they are joined — and correct the sum for your coldest mornings with the panels' Voc coefficient, as the worked example of this section does. Compare it with the highest panel voltage on the controller's label or in its manual.
   You will see: Above that limit: the string is too long for this controller in the cold, and one maker writes that an overvoltage event can damage its controller. Until it is changed — fewer panels in series, joined by the panels' own leads, or a controller whose input takes the cold voltage (→ "Do it yourself or hire a pro" · p. 16) — keep every panel of that input off the controller on cold mornings: covered, or the solar disconnect switch OFF; on a boat left alone, that means no solar charge until then. Below the limit, after an overvoltage error: a panel of another model in the string, an extra panel on that input, or a fault in the controller — compare the labels with field 8 of the Boat Passport and take the readings to a pro. Below the limit, with no error: step 3.

3. Read the voltage at the controller's battery terminals — R against its battery negative — and at the bank, across its positive and negative terminals, the meter set as the entry of the METER LEADS sign says.
   You will see: The same at both, and the controller lit: step 5. The same at both, and the controller dark: the controller itself, or a joint that passes no current — the readings to a pro. Near 0 V at R and the bank's voltage at the bank: the controller's battery lead brings it nothing — its fuse, step 4; or, on a lead that lands after the battery switch (→ 8.2), that switch at OFF — look at where the lead lands, in field 10 of the Boat Passport, and at the switch's position first; the card "The panel went dark" (→ emergency card) turns the switch back, and the panels of that controller are covered or its solar disconnect switch is OFF before it turns and uncovered after (→ "The order of connecting and disconnecting" · p. 16); or an open negative lead, which reads the same — where the meter's leads reach, read R against the bank's negative terminal, K: the bank's voltage there points to the controller's negative lead, and the readings go to a pro. R between 0 V and the bank's voltage: a joint on the lead or its fuse holder — step 4. Everything on the bank dark: look first at the bank's main protection and the battery switch, as the card "The panel went dark" does (→ emergency card); one of them tripped, blown or at OFF: that card's steps, with the panels of the controller covered or its solar disconnect switch OFF before the bank comes back. Both intact, on a lithium bank: its BMS has disconnected the bank, and the bilge pump, the high-water

alarm and the CO alarm on it have lost their power too — the panels of the controller covered or its solar disconnect switch OFF, and the bank reconnected as its maker's manual says (→ 11.4) before they are uncovered. Terminal R out of reach: the bank's reading and the battery voltage on the controller's own display.

4. Find the controller's fuse at the battery — on a lead that lands at a distribution block, its fuse where it lands there (→ 4.2). In a holder that opens by hand: cover the panels of that controller or turn its solar disconnect switch OFF — on a controller that also takes a wind generator, stop the wind generator at the control its manual names too — then take that fuse out by hand and look at its element. A breaker there: look at its handle.

   You will see: Element whole, or the breaker on: the fuse back in its holder by hand, then the panels uncovered or the solar disconnect switch back ON, and a wind generator you stopped released as its manual says — step 5. Element broken, or the breaker tripped: it found a fault in the lead or the controller; whether and how it is replaced or reset is in the entry of the BLOWN FUSE sign — replaced, the panels uncovered or the solar disconnect switch back ON, and step 5; not replaced, the panels stay off the controller and the readings go to a pro. No fuse or breaker at the start of that lead — at the battery, or where it lands at a distribution block: an unprotected positive — write it on the first line of the Boat Passport, keep the controller from charging on it (the panels covered, or the solar disconnect switch OFF), and hire a pro to protect it at its start (→ 4.2); until then the bank takes no charge from these panels. A fuse under a nut on a stud, or one you cannot reach: the readings of step 3 go to a pro. On a controller that also takes a wind generator, the wind generator stays stopped at its control until that fuse is in and whole: the maker of one such controller writes that its battery wires are never disconnected while the turbine is charging, which destroys the controller immediately (→ 10.5 · p. 34).

5. Read the panel voltage on the controller's display, with the panels in full light and the solar disconnect switch ON. On a controller with no display, read it at Q against the controller's

panel negative, where the string's printed Voc adds up to 60 V or less; on a string over 60 V, a controller with no display leaves this reading to a pro.

You will see: A voltage near the battery's with current flowing (PWM), or near the string's Vmp with current flowing (MPPT): the panel side works — step 6. A voltage near the string's full Voc with no current: the panels are there and the controller is not charging — step 6. 0 V in daylight with nothing covering the panels: the panel side — PV, for photovoltaic, on labels and terminals — is open or shorted: the solar disconnect switch OFF, a PV breaker tripped, a PV fuse open, a connector apart or a cable broken; water in a connector or the deck pass-through; or the string joined to the controller the wrong way round. The switch and the breaker you can see and set. Anything else: look at the connectors, the cables and the deck pass-through by eye, without opening them — the open or the short stands between the panels and the controller, so no reading at the controller shows the panels beyond it dead — and take what you saw and these readings to a pro (What to tell the pro, → 10.6 · p. 44). A voltage well below the string's Voc in full sun with no load on it: a panel shaded, covered or failed — step 7.

6. Compare the controller's battery-type setting with the label and the maker's charge numbers of the bank (→ 6.1). A wrong setting that the controller lets you change: change it as its manual says, to the battery maker's numbers, and write the new setting into field 12 of the Boat Passport.

   You will see: The setting right: step 7. Changed: the bank takes a charge on the new setting the next time the panels see full light — step 1 again then. A controller with no setting for this battery's chemistry: it is not this battery's controller, and it is replaced (→ "Do it yourself or hire a pro" · p. 16); until then it charges that bank only on a setting the battery's maker allows by its numbers, and with none, every panel of it stays covered or its solar disconnect switch OFF — the bank meanwhile takes its charge another way (→ 9.2, → 9.3), and how long it lasts on its own charge is worked out by → 7.4. On a lithium bank, a low-temperature cut-off you find set for another battery, or a BMS signal lead that is not connected: the battery's manual and → 11.3 say how it is meant to work; a setting you cannot read or change: a pro.

7. At midday in full sun, look at the panels from the deck: shade from the boom, the rigging, an antenna, a bimini or a dome, and salt, dirt or droppings on their faces; compare each

panel's current with its neighbor's where the controller shows them apart.

You will see: A shadow across a panel: its output falls by the groups its shadow covers (→ 10.1 · p. 2) — a panel moved, or the shade moved, gives it back. A dirty face: cleaned as its maker's manual says. One panel far below its neighbor in the same light: a failed diode or a cracked cell — a pro, with the two readings. Nothing seen, and the bank still does not charge: take the readings of steps 1, 3 and 5 to a pro (What to tell the pro, → 10.6 · p. 44).

PUT THE BOAT BACK IN SERVICE

- A fuse you took out at the battery in step 4: back in its holder, by hand — or its breaker back on — before the panels are uncovered, the solar disconnect switch is turned back ON or a wind generator on the same controller is released.
- A lithium bank its BMS disconnected: reconnected as its maker's manual says (→ 11.4) before the panels are uncovered or the solar disconnect switch is turned back ON; the entries of the BILGE PUMP and CARBON MONOXIDE signs say what to check then.
- The panels uncovered, and the solar disconnect switch back where you found it — except where step 2, 4 or 6 keeps them off the controller until a change or a pro.
- The charger, a DC-DC charger and a wind generator you turned off in step 1: back as you found them, the wind generator released as its manual says — on a controller that also takes the panels, only with that controller's fuse at the battery in and whole (step 4).
- A setting you changed: written into field 12 of the Boat Passport.
- The meter's dial at OFF.

10.3. What the panel will really give

How many amp-hours a day will your panels put into your bank, in the waters and the months where you use the boat? The label's watts hold only in light of 1,000 W per square meter with the cells at 77 °F (→ 10.1 · p. 2). A day gives less light than that for most of its hours, and none at night; winter gives fewer hours with the sun lower; and what the

panel makes, the controller, the wires and the bank then take their share of. There is no single number of watt-hours a day for a panel in the United States: the figure belongs to a latitude, a month, the weather of that place, the way the panel faces and what shades it.

Sun hours

A day's light on a panel is counted in kilowatt-hours per square meter per day. Because the panel's rating is set at 1,000 W per square meter, each kilowatt-hour per square meter is one hour of light at the rating's strength: a day of 3.0 kWh per square meter gives the panel the light of three hours at its rated light, spread over the whole day (→ Fig. 10.4 · p. 20). These hours are sun hours. A panel's day at STC strength is its Pmax times the sun hours: 100 W in a day of 3.0 sun hours makes, at most, 300 Wh.

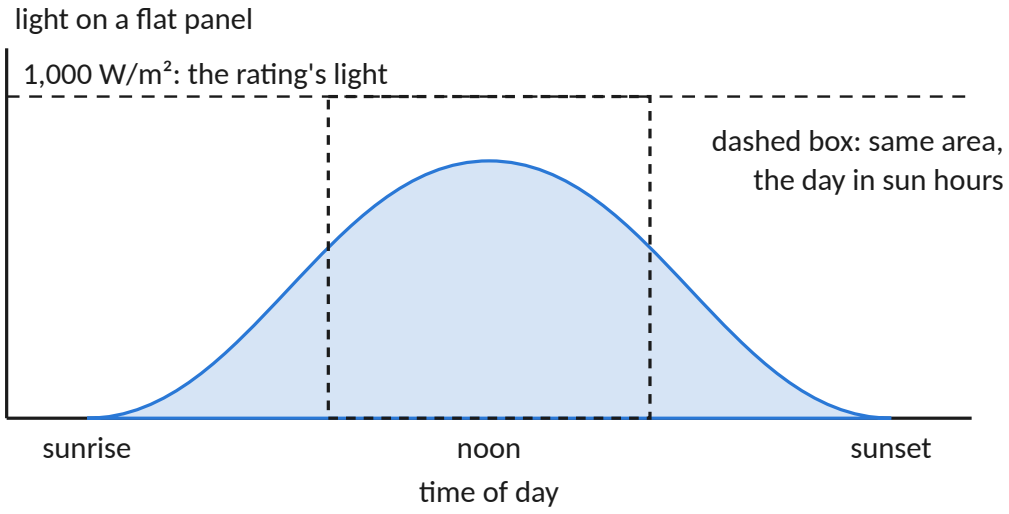


Fig. 10.4. Sun hours on an example day. The light on a flat panel rises and falls through the day and never reaches the rating's 1,000 W per square meter here; the dashed box holds the same light at full strength, and its width is the day in sun hours.

Where the figure for your waters comes from

The figure for your boat comes from public data, not from a brochure. The National Laboratory of the Rockies (NLR) — until December 1, 2025, the National Renewable Energy Laboratory (NREL) — publishes for US locations the average daily solar resource on a flat surface, month by month, in kilowatt-hours per square meter per day: the sun hours of a

panel lying flat. Its figures are averages of twelve years, 1998 to 2009, worked out from satellite data by a solar radiation model, each over a cell a tenth of a degree of latitude and longitude across, about 10 km (about 6 miles); → Table 10.3 · p. 21 gives eight US waters from it. They are the light on a flat surface, averaged over that cell; the shade on your deck, the heat of your panel and the losses of the controller and the wires are taken away in “From the label to the bank” (→ Table 10.4 · p. 23).

Table 10.3. Sun hours of a flat panel in eight US waters, in kWh per square meter per day (NLR data, averages of 1998–2009)

Waters	December	July	Year
Puget Sound, about 47.6° N	0.87	6.35	3.45
Lake Michigan, western shore, about 43.0° N	1.33	6.19	3.84
Lake Erie, southern shore, about 41.7° N	1.09	6.28	3.78
Narragansett Bay, about 41.6° N	1.59	5.90	3.86
Pacific coast, about 32.7° N	3.03	6.80	5.18
Northern Gulf coast, about 30.6° N	2.73	6.04	4.87
Eastern Gulf coast, about 27.8° N	3.28	6.02	5.19
Biscayne Bay, about 25.7° N	3.48	6.37	5.28

Latitude and season move the figures. A flat panel far north sees the sun low and for few hours in winter: on Puget Sound, December gives 0.87 sun hours against July’s 6.35, about one seventh. Nearer the tropics the months lie closer together: on Biscayne Bay, December gives 3.48 against July’s 6.37, more than half. December is the lowest month in each of the eight rows; take the month or months you use the boat — for a cruise, the worst month of it.

For waters between these rows, or far from them, the laboratory’s PVWatts calculator gives the monthly solar radiation for a latitude and longitude and a panel angle you enter, beside the energy of a grid-connected system. Its eighth release uses the laboratory’s National Solar Radiation Database, its TMY data set of 2020 — another data set, so its figures need not match Table 10.3. Three of its inputs and one of its columns decide whether its figure fits a boat. The place is your

boat's waters, given by latitude and longitude, not your home address. The tilt is the angle of your panels — 0 for a panel lying flat on a deck, a bimini or an arch. The azimuth is the direction a tilted panel faces; a boat at anchor swings, so a tilted panel faces no particular direction for long, and only the flat figure does not depend on where the bow points. And the figure you take is the monthly solar radiation column: the energy columns beside it are for a grid-connected system with an inverter and its own losses, not for a panel that charges a battery through a controller. Neither the table nor the calculator is a forecast for this month.

From the label to the bank

Between the panel's watts in sun hours and the amp-hours the bank takes, each part of the installation takes a share (→ Table 10.4 · p. 23). Heat comes first: the panel of Generation A loses 0.37 % of its power for each °C (0.206 % for each °F) its cells run above 25 °C (77 °F), and at the cell temperature its sheet gives as NOCT, 47 °C (about 117 °F), it gives 22 × 0.37 = 8.1 % less than at STC under the same light. A panel on an arch with air under it runs cooler than one glued to a deck. MFR

Table 10.4. Where the panel's watts go before the bank

What takes a share	Why	Where to read it on your boat
Heat	Power falls as the cells warm: on the panel of → Table 10.1 · p. 3, 0.37 % for each °C (0.206 % for each °F) above 25 °C (77 °F)	The Pmax coefficient on the panel's sheet
A PWM controller	The panel works at the battery's voltage, below its Vmp (→ 10.2 · p. 7)	The kind of controller, on its label; the panel's Imp, on its sheet
An MPPT controller	Its own conversion loss	Its manual's efficiency figure
Wires	The voltage drop between the panel and the controller and between the controller and the bank (→ 10.4 · p. 25)	Under charge, the battery voltage the controller shows against the bank's on the battery monitor; the panel side, worked out from its wire size (→ "Wire size" · p. 15)
Shade, salt and dirt	Each shaded group of cells drops out (→ 10.1 · p. 2)	The current at noon against a neighbor panel's
A bank near full	The controller steps the current down as the battery fills; another source on the bank holds its voltage high (→ 9.4)	The stage on the controller's display

On an MPPT controller, the amp-hours that reach the bank are the watt-hours the controller delivers divided by the bank's voltage while it charges. On a PWM controller the panel works at about the battery's voltage, so the count starts from its current instead: that current follows the light, and the amp-hours a day are about the panel's Imp, from its sheet, times the sun hours, less the share of the wires, the shade and a full bank. Those amp-hours go into the budget of PRACTICE → 7.5 as the panels' line, for the month you use the boat; the budget itself is worked there, and the battery maker's charge factor there applies to them as to every other source.

WORKED EXAMPLE: ONE 100 W PANEL IN DECEMBER AND IN JULY

Suppose the 100 W panel of Generation A (→ Table 10.1 · p. 3) lying flat on a boat on Puget Sound, charging a bank at 13.5 V; → Table 10.3 · p. 21 gives 0.87 sun hours for December there and 6.35 for July. On an MPPT controller the panel makes at most 100 × 0.87 = 87 Wh in a December day and 100 × 6.35 = 635 Wh in a July day; suppose heat, the wires and the controller take 15 % together: 74 Wh and 540 Wh reach the bank, 74 ÷ 13.5 = 5.5 Ah and 540 ÷ 13.5 = 40.0 Ah. On a PWM controller, taking its Imp of 4.91 A: 4.91 × 0.87 = 4.3 Ah in December and 4.91 × 6.35 = 31.2 Ah in July, before the wires take their share. What the numbers mean: the 18 Ah a day that the worked example of → 7.5 supposes for the panels would take one such panel in July on either controller, and four on an MPPT controller in December, since three give 3 × 5.5 = 16.5 Ah — and only while the bank is low enough to take it all. On Biscayne Bay, December's 3.48 sun hours give the same panel 100 × 3.48 × 0.85 ÷ 13.5 = 21.9 Ah on an MPPT controller: one panel alone.

LOOKS LIKE THE FIX	FIND OUT FIRST	WHAT FIXES IT
A larger panel, or a second one, because the bank never gets full on solar.	What the panels put in now, month by month, on the battery monitor; shade on them at midday; whether the controller is PWM on panels whose Vmp stands well above the battery's charging voltage; whether its setting matches the battery; whether the bank is already near full by midday, so that the controller steps down.	The shade moved off the panel, the right setting, or an MPPT controller where the panels' Vmp stands well above the battery's charging voltage — and more panel only where your budget for your month still falls short after that.

Keeping these figures for your boat as a project, comparing one layout with another and printing them as a report are the subject of → module “Calculators”; the arithmetic itself is the one in this section.

10.4. Cables, protection, disconnect, mounting

How do the panels and the controller connect to your bank, where does each fuse sit, how are the panels taken off before anyone works on their wiring, and how are the panels and their cable fixed to the boat? A solar installation has two circuits that meet at the controller (→ Fig. 10.3 · p. 25). The panel side runs from the panels through any PV fuse or breaker and any solar disconnect switch to the controller’s panel terminals; it is live whenever light falls on the panels. The battery side runs from the controller’s battery terminals to the bank; it is live from the bank whatever the light.

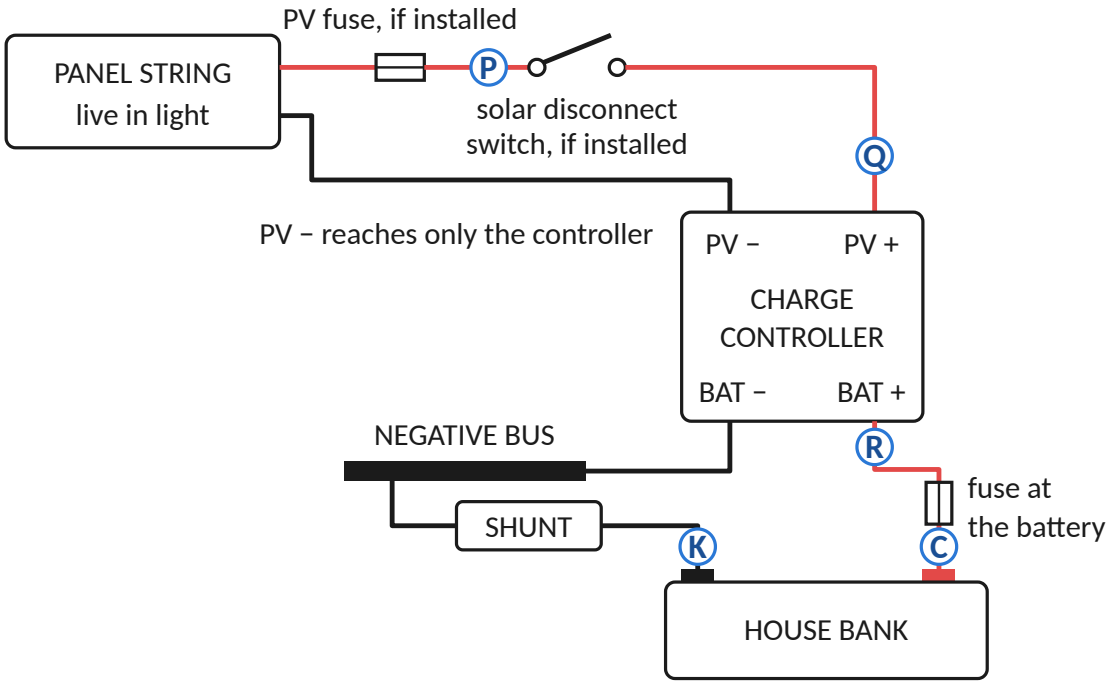


Fig. 10.3. A string, its PV fuse and solar disconnect switch where they are installed, the charge controller, and its battery lead with its own fuse at the battery. P is on the panel side of the solar disconnect switch, Q at the controller’s panel positive, R at its battery positive, C at the bank’s positive terminal, below the fuse, and K at its negative terminal. The panels’ negative joins the boat’s negatives only through the controller. One typical arrangement: your boat can be wired differently, and a controller’s battery lead can also land after the battery switch.

The battery side: a positive from a bank

The controller's battery lead is a positive wire from a bank, so it has its own fuse at the battery, within the distance and on the conditions of → 4.2; the only positive that leaves a bank without one is the starter cable, found by tracing it to the starter. The rating is the controller maker's, within the ampacity of the wire (→ 4.3), and its interrupting rating is the one → 4.4 calls for — for a lithium bank, with → 11.2. One maker gives a minimum and a maximum for each of its small controllers — 20 to 25 A for its 15 A models; a second asks for a fast-acting fuse or breaker of 20 A or less, connected close to the battery terminal or the power distribution block. Two makers' manuals allow the fuse in either the positive or the negative cable: on a boat, a fuse in the negative leaves the positive from the bank unprotected, so it goes in the positive. "Or the power distribution block" allows a landing at a distribution block, which can stand after the battery switch (→ 8.2); a lead that lands there takes its protection there, where 4.2 counts the block as its source. Where yours lands is traced and written into field 10 of the Boat Passport. MFR

The panels' negative and the battery's negative meet inside the controller. One controller maker writes that its panel input is not isolated from its battery circuit; a PWM maker asks that the array's negative and the battery's negative be connected directly to the controller. On a boat that means the panels' negative goes to the controller and nowhere else — not to the negative bus, not to a frame, not to the hull. MFR

The panel side: PV fuses and the solar disconnect switch

A single panel or two panels in parallel cannot push much more than their combined Isc into a fault, so whether the panel side needs a fuse is set by how many panels are in parallel and by each panel's maximum series fuse rating (→ Table 10.1 · p. 3). One PWM maker strongly recommends an inline fuse in the positive of both the solar and the battery circuits; one maker's 100 W panels give 15 A as their maximum series fuse rating. With three or more panels in parallel, a short inside one panel draws the current of all the others back through it. MFR

NUMBERS · CURRENT INTO A FAULTED PANEL IN PARALLEL

Panels of Generation B (Isc 5.86 A) in parallel; a short in one panel draws the Isc of every other panel. Two panels: 5.86 A. Three: 2 × 5.86 = 11.72 A, and with a land-module maker's margin of 1.25, 14.65 A — under the sheet's 15 A. Four: 3 × 5.86 = 17.58 A, and 21.98 A with the margin — over 15 A. Generation A (Isc 5.21 A), four in parallel: 15.63 A, and 19.54 A with the margin. PRACTICE

A fuse on each panel or string, where the current the others can push into it passes its maximum series fuse rating, is land practice; no boat standard that this chapter cites sets it.

A solar disconnect switch is a switch between the solar panels and the charge controller that disconnects the panels from the controller. One controller maker asks for a means to disconnect all current-carrying conductors of a photovoltaic source, writing for buildings; a second shows a solar disconnect on its wiring diagram; a third prints that its unit is not provided with disconnect devices. Not every boat PRACTICE has one: the source map of → 1.7 draws a boat without one. With one, OFF takes the panels off the controller and leaves the panels and their wires up to the switch live in light; P on → Fig. 10.3 · p. 25 stays live. Without one, the panels are taken off by covering them completely, with an opaque cover. On land, PV systems come under the National Electrical Code's Article 690; on a boat it is a comparison, not the rule.

The plug-in connector

A plug-in connector (MC4-type) is the locking plug and socket on a solar panel's leads. Two connector makers write that a tool is required to open their locking connectors once mated; one of them writes that its connector halves are never mated with those of other manufacturers, that unmated connectors are protected from moisture and dirt with sealing caps, and that a connector is not left in standing water. A land-module maker writes that connectors are only used MFR to connect the circuit, never to turn it on and off. The reason is MFR the DC arc: a direct current does not pass through zero as a 60 Hz alternating current does 120 times a second, so a joint pulled apart

while current flows draws an arc that the contacts' gap alone may not break, and it burns the contacts it jumps between. How a string is taken off before its connectors are opened is the procedure → "Taking a solar string off for work on its wiring" · p. 31.

Assembling a new connector on a cable is another job. One connector maker writes that only an electrician or an electrically instructed person may assemble, install and commission the system; the second, that the product may be assembled and installed only by suitably qualified and trained specialists. A crimp that looks right and is not fails later, out of sight, with heat at the contact (→ 10.6 · p. 44). MFR

Wire size

Solar wire is sized by the one basis of this book, ABYC's formula CM = 10.75 × I × L ÷ E, with L the round trip in feet (→ 5.4), and its ampacity is checked apart (→ 4.3). One controller maker asks for flexible multi-stranded copper cable for the battery and panel connections; one wind-generator maker asks for tinned copper wiring in marine and saltwater installations. On the panel side the drop takes voltage from the panel; on the battery side it lowers the voltage the bank sees from the controller, and the charge ends short of full. MFR

> **WORKED EXAMPLE: THE TWO LEGS OF ONE PANEL'S CIRCUIT**
>
> Suppose the panel of Generation A, 20 ft from its controller, and the controller 8 ft from the bank, on a 12 V boat. The basis: ABYC's formula with 10.75.
>
> Panel side: suppose you hold the drop to 3 % of the panel's Vmp: E = 0.03 × 20.4 = 0.612 V; I = Imp = 4.91 A; L = 20 + 20 = 40 ft. CM = 10.75 × 4.91 × 40 ÷ 0.612 = 3,450: 14 AWG, with 4,110 circular mils, is enough. Held instead to 3 % of 12 V (0.36 V), the same run needs 10.75 × 4.91 × 40 ÷ 0.36 = 5,865 CM: 12 AWG, with 6,530.
>
> Battery side: suppose the controller's rated charge current is 15 A and the drop is held to 3 % of 12 V: E = 0.36 V; L = 8 + 8 = 16 ft. CM = 10.75 × 15 × 16 ÷ 0.36 = 7,167: 12 AWG, with 6,530, is too small;

> 10 AWG, with 10,380, is enough. What the numbers mean: the battery side, short as it is, decides the larger wire, because it carries the controller's whole current at the battery's low voltage.

Where the controller goes

One controller maker asks that its controller be mounted within 3 m (about 10 ft) of the battery but never directly above it, to prevent damage from the battery's gassing, and never used where gas or dust explosions could occur; a second writes that its controller is never installed in an enclosure with vented or flooded batteries, because battery fumes are flammable and will corrode and destroy its circuits. None of the controller manuals in Sources states that its controller is ignition protected. MFR

On a boat with a gasoline engine other than an outboard, the regulation requires each electrical component not to ignite a propane and air test mixture around it, unless it is isolated from gasoline fuel sources (33 CFR 183.410, → 4.6). CFR

ABYC E-11, as ABYC quotes it, requires ignition protection in spaces with gasoline-powered machinery, gasoline fuel tanks, or fittings and other connections of a gasoline fuel system, unless the part is isolated from the gasoline fuel source (→ 4.6, Table 4.6). So a controller or a solar disconnect switch placed in a space with a gasoline engine, a gasoline tank or fuel-system joints must be ignition protected, unless it is isolated from the gasoline source in a way → 4.6 teaches; its data and marking tell you whether it is, and → 9.6 says what such a marking looks like. A controller near the bank, above none of it, in a dry space with no gasoline, keeps its battery lead short and its temperature reading close to the battery's. ABYC

Mounting the panels and passing the cable through the deck

A panel on a boat meets wind, spray and a boat that rolls. One flexible-panel maker writes that in marine applications the structure must remain rigid in heavy storm conditions, that every penetration into the surface is made watertight with sealant under, around and on top of

each screw, and that the panel's power cable is not strapped to the boat's existing wiring; it strongly recommends flame-retardant, chemically resistant cables, especially in marine environments. A panel lies where nothing shades it at midday when the boat lies as you use it, and where you can reach it to cover it. MFR

Where the cable passes through the deck, the hole is a path for water into the boat, and the water follows the cable. Water running along a cable toward a fitting finds every gap in its seal; a cable that enters the fitting from below a loop sheds that water before it reaches the hole. A deck pass-through, a fitting made to carry a cable through a deck, seals the hole when it is sized for that cable and installed as its maker's sheet says. Below the deck the cable is supported and protected from chafe as → 5.7 asks of every wire. PRACTICE

MARINE-GRADE OR NOT? · A SOLAR KIT SOLD FOR AN RV OR A HOUSE

A kit of panels, controller, cables and connectors made for an RV roof or a house. Its panels and connectors are the same kind a boat uses; what changes is what it meets. The kit's mounting is written for a roof that does not roll; its controller's manual may forbid wet places, places with gas, and enclosures with flooded batteries; its cable may not be tinned; and no controller manual in Sources states ignition protection. Read the manual of each part against where it will sit on your boat — the place, the fuse at the battery, the deck pass-through — before it goes aboard.

Verdict: read each manual

The order of connecting and disconnecting

> ⚠ COSTLY DAMAGE · A CONTROLLER CONNECTED IN THE WRONG ORDER
>
> Five makers have their controllers connected battery first and panels last: one maker's controller recognizes the system voltage from the battery, waits 10 seconds for it, and allows the panels first only where that voltage has been set by hand, and that maker writes that not following the correct procedures can disable or damage the controller or the installation; another warns that connecting panels before the battery may result in irreversible damage. Two makers have the panels disconnected first and the battery last. One maker allows any order and recommends the panel first. MFR Your controller's manual comes first; where it says nothing, the order battery first, panels last — and to take it apart, panels first, battery last — goes against none of these manuals. A controller whose battery lead lands after the battery switch gets its battery back, or loses it, each time that switch turns; with the panels lit, that is the panels-first order, so the panels are covered or their solar disconnect switch is OFF before that switch turns.

Procedure: Taking a solar string off for work on its wiring

For work on a plug-in connector, a PV fuse or breaker, the terminals of a solar disconnect switch, the controller's panel terminals or a panel's lead — and, where the job reaches it, the controller's battery side. You need an opaque cover for each panel, with ties; the connector maker's unlocking tool, where its connectors take one; and the meter.

 PROVE IT DEAD  METER LEADS  SHORT CIRCUIT  HOT BATTERY
 GASOLINE VAPOR

1. Write down the position of the solar disconnect switch and of any PV breaker, and which panels you find covered; read the panel voltage and current on the controller's display. Add up the printed Voc of the panels in series on this input — all the panels on it, where you cannot see how they are joined.

2. The sum decides the road. More than 60 V: cover every panel of this input completely, with an opaque cover, tied so that the wind cannot lift it, and leave the solar disconnect switch and any PV breaker ON for step 3. 60 V or less: cover every panel of this input the same way, in step 4 — or, for work only on the controller's side of the solar disconnect switch, leave them uncovered: the switch at OFF in step 4 takes them off that side, and the panels and their wires up to the switch stay live. A panel you cannot reach to cover, on an arch, a bimini or a hardtop: on 60 V or less, only work on the controller's side of the switch, by the switch; any other work on this string, and any work on a string over 60 V, goes to a pro.
3. On a string over 60 V, where step 1 read a panel voltage on the display: with the meter on DC volts and proven on a known live source — the bank, at C and K on → Fig. 10.3 · p. 25 — read the voltage at Q against the controller's panel negative, the solar disconnect switch ON and the PV fuse in. 0 V: turn the solar disconnect switch, or the PV breaker, OFF, and step 5. Any voltage: a panel not covered completely, a cover that lets light through, or a second string on this input — cover it and read again; a voltage that stays with every panel you know of covered: a panel or a string on this input that you have not traced — the job goes to a pro. No panel voltage on the display in step 1, or no display: panels found covered, a switch or breaker at OFF or an open between the panels and Q, or a short on the string, and a 0 V at Q would prove nothing — the job goes to a pro.
4. On a string of 60 V or less: with the meter on DC volts and proven on a known live source — the bank, at C and K — and the PV fuse in, read the voltage between the positive and the negative of the wires you will work on, on the side you will work on: where their metal is exposed, at the place you will work; at a mated connector or a sealed fuse holder, at the nearest exposed terminals of the same wires on that side — on the panel side, the panel-side terminal of the solar disconnect switch, P, or of the PV breaker, against the controller's panel negative, or against the switch's or breaker's own panel-side negative terminal where it has one; with neither, Q against the controller's panel negative; on the controller's side, Q

against the controller's panel negative. Read that point first in daylight, before the source comes off — at Q, the panel voltage step 1 read on the display is that first reading. No panel voltage there: panels found covered, a switch or breaker at OFF or an open between the panels and that point, or a short on the string, and its 0 V would prove nothing — the job goes to a pro. Then change only the source — for work on the panel side, cover every panel; for work on the controller's side, turn the switch or the breaker OFF, with the covers too where you chose them in step 2; the controller's display shows no panel power — and read the same point again. 0 V: the switch or the breaker OFF, where the boat has one, and step 5. Any voltage: on the panel side, a panel not covered completely or a cover that lets light through; on the controller's side, a switch that did not open; on either, a second string on this input — cover it or switch it off and read again; a voltage that stays: a panel or a string on this input that you have not traced — the job goes to a pro.

5. Do the work: unplug the plug-in connector, with its maker's tool where it takes one, open the PV fuse holder, or loosen the terminal you came for. Cap each connector half that stays apart.
6. Where the job reaches the controller's battery side: on a controller that also takes a wind generator, stop the wind generator first at the control its manual names; then take the charge controller's own fuse at the battery — on a lead that lands at a distribution block, its fuse where it lands there — out of its holder by hand, or turn its breaker there OFF, and read 0 V at R against the controller's battery negative. Any voltage at R: the fuse you took out is not this lead's, or the lead has another feed — that fuse back in, and the battery side goes to a pro. A fuse under a nut on a stud: the battery side is a pro's.

PUT THE BOAT BACK IN SERVICE

- The controller's fuse at the battery, if you took it out, back in its holder by hand first — or its breaker back ON; the controller's display comes on.
- The connectors mated until they lock, the PV fuse back in its holder, the terminals tightened as the controller's manual gives — or, where the job leaves a joint open for a pro, its halves capped.
- The solar disconnect switch and any PV breaker back as you wrote them down in step 1.
- A wind generator you stopped in step 6: released as its manual says.
- The covers you put on in step 2 or 4 off last — none where a joint stays open for a pro, and panels you found covered stay covered; the controller shows a panel voltage and, in light, a charge.
- The meter's dial at OFF.

10.5. The wind generator

When does a wind generator make sense on your boat, how is it stopped, and how is it protected? A wind generator is an alternator turned by its blades: as long as the wind turns them, it makes current, and that current reaches the bank through its regulator — inside the turbine on one maker's design, a separate unit on others, some with a diversion load — and through a fuse or breaker at the battery (→ Fig. 10.5 · p. 36). Makers name the separate unit differently — one a "charge controller", another a "charge regulator"; this book calls it the turbine's regulator, to keep it apart from a solar charge controller. Like a lit panel, a turning wind generator is a source that a battery switch does not stop; where it reaches your boat and how it is taken off is part of the source map in → 1.7.

When it makes sense

A wind generator makes sense on a boat that spends days and nights at anchor or on a mooring in steady wind, when the panels give little — at night, in cloud, in a northern winter. At a dock in the lee of buildings it

turns slowly and gives little. One maker writes that its turbine enters overspeed protection in gusty or sustained winds above 35 mph, which stresses the turbine; another links the start of charging on its turbine to the moment its blades become a blur. The first maker's specification table gives 40 kWh a month at 12 mph for one of its models and 30 kWh a month for another — that maker's figures for its turbines at that wind, not what the wind at your mooring will give. Two makers describe their blades as lower in noise or their turbine as very low in noise emission, without a number. What a turbine gives on your boat is read on the battery monitor over days of the wind you have, and goes into your budget (→ 7.5) as the panels' figure does. MFR

How it charges, and what regulates it

One maker's turbine carries its own regulator, which monitors the battery and holds its charge, and raising its regulation set point above the factory setting does not increase its output and raises the chance of overcharging and damaging the batteries; that maker writes that no PWM, MPPT or shunt-type controller is used with it, and that any added regulator must be a diversion style regulator that diverts the excess power to a resistive load. A diversion load is a resistive load to which a wind generator's regulator sends the power the battery no longer takes. It turns that power into heat, which is why it is mounted where its heat harms nothing. A solar charge controller is not a wind generator's regulator unless the turbine's own manual names it. MFR PRACTICE

One maker's turbine sends three-phase alternating current down its wires to its regulator, which turns it into direct current for the bank, and that regulator also takes solar panels of up to 180 W and 10 A. The turbine and the bank are matched: one maker requires deep-cycle batteries and forbids automotive batteries; another names all types of lead batteries; a third writes that 24 V turbines are not connected to 12 V batteries, nor the reverse. Whether a turbine may charge a lithium bank, and on which settings, is in its own manual and in → 11.3: the maker that requires deep-cycle batteries has a technical bulletin for lithium batteries in its manual, which has the turbine's regulation set

point adjusted to the battery's manual where a lithium battery disconnects during use. MFR

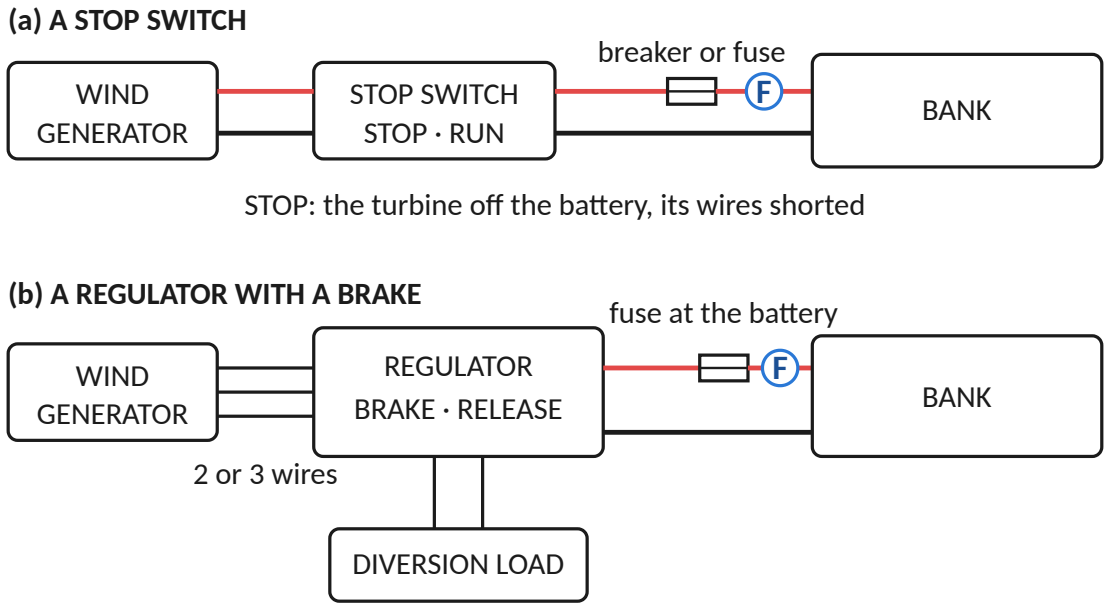


Fig. 10.5. Two ways a wind generator reaches a bank. (a) One maker's stop switch sits in the turbine's wires; its breaker or fuse sits between the switch and the battery, with F on the bank's side of it. (b) A regulator with a brake and a diversion load; F on the bank's side of its fuse at the battery. One typical arrangement of each: your boat can be wired differently.

Braking and stopping: each maker's own way

Every wind generator is stopped the way its own maker names, and the ways differ (→ Table 10.5 · p. 37). One maker's stop switch first disconnects the turbine from the battery and then shorts its positive and negative wires; on that maker's control panel the center position, which only disconnects the turbine, is not recommended. A second maker's brake is a switch on its regulator, and that maker writes that an extra stop switch in the turbine's cable, actuated while the turbine runs, will destroy the turbine or the regulator immediately. A third maker stops its turbine at the stall or shutdown switch of its regulator, and has a blade tied to the pole. A way that suits one turbine can wreck another, so the control your turbine's manual names is the one you use. MFR

Table 10.5. Three makers' ways to stop a wind generator MFR

Maker	The control it names	What the maker writes about the rotor once stopped	What that maker forbids
Maker 1	A stop switch, or its control panel at STOP	In very strong winds the blades may rotate slowly with the switch at STOP	The center OFF position of its control panel is not recommended
Maker 2	The brake switch of its regulator; a brake light shows it	The brake does not stop the blades completely; they still turn slowly	An additional stop switch in the cable or on the regulator's output
Maker 3	The stall or shutdown switch of its regulator; a blade tied to the pole	A blade tied to the pole keeps it from rotating	Turning without a connection to a regulator or batteries

WHY IT WORKS

A turbine braked by shorting its own wires stops by its own current. The short lets the alternator inside it drive a large current through its own windings, and that current pulls against the turning. At low speed the pull is small, so in a strong wind the rotor creeps around, as two makers write. The same short explains a reading that misleads: a voltmeter across two shorted wires reads 0 V while current flows around the short, so 0 V on such a turbine's wires says nothing about whether its rotor stands still. Only the blades, seen standing still and secured, say that. The control's position and its brake light show what the control was set to, not that the brake holds: a wire broken at the pole, or a failed switch, leaves the rotor free with the control at STOP. A braked rotor creeps; one that turns at STOP as fast as at RUN is not braked. Standing blades on a calm day show only that there is no wind.

Storms, and the battery while it turns

One maker recommends considering brake mode when a high wind event is forecast, with gusts above 50 mph; a second writes that its turbine can be restrained when storm winds are forecast, to reduce wear; a third asks for its brake switch to be used in a storm and for maintenance, and for a damaged blade. Lowering the turbine or MFR

tying its blades for a long lay-up follows its manual, by the procedure → “Stopping a wind generator for work” · p. 39.

> ⚠ COSTLY DAMAGE · A WIND GENERATOR LEFT WITHOUT ITS BATTERY
>
> A turning wind generator needs a load. One maker writes that its turbine must never be allowed to rotate unless it is connected to a regulator or batteries, and that connecting an open-circuit running turbine to the electrical system can cause serious damage; a second, that the battery wires are never disconnected while its turbine is charging, which destroys its regulator immediately; a third, that its turbine spins freely when disconnected from the battery, with rapid speed-ups and rapid braking that wear it and give nothing. MFR So the turbine is stopped at its control before the battery side of its circuit is opened or switched, and is connected again battery first, its brake released last. A turbine whose lead lands after a battery switch loses its battery whenever that switch is OFF, so it is stopped at its control before that switch turns OFF and released only after the switch is back ON. A lithium battery whose BMS disconnects the bank leaves the turbine without a load in the same way; for a turbine left unattended with no load for a long time, with any battery, one maker has the stop switch set to STOP.

Protection

The wind generator’s positive from the bank has its own fuse or breaker at the battery, within the distance and on the conditions of → 4.2, rated as its maker says within the ampacity of its wire (→ 4.3), with the interrupting rating → 4.4 calls for — for a lithium bank, with → 11.2. A lead that lands at a distribution block takes its protection there, where 4.2 counts the block as its source. One maker supplies a 50 A fuse to fit close to the battery in the positive wire; another places the fuse or breaker between its stop switch and the batteries; its control panel for a 160 W turbine on 12 V carries a 25 A breaker. Thin wires cost charge: one maker writes that smaller wires lower the voltage at which its turbine enters regulation and stops charging. Size them by → 5.4. MFR

Procedure: Stopping a wind generator for work

Before work on its wiring, its regulator or stop switch, its fuse at the battery, or at the turbine itself. You need its manual, a line to tie a blade, and the meter.



1. Read the maker and model on the turbine's plate, and open its manual at its pages on stopping and braking. Find the control it names: a stop switch or control panel, a brake switch on its regulator, or a stall or shutdown switch on its regulator. Without its manual, leave its circuit closed and its control as you found it until you have the manual, from its maker or through a pro.
2. Set that control to the position the manual names — STOP, BRAKE, stall or shutdown — and, where it has a brake light, see the light on. On one maker's control panel, use STOP, not the center position.
3. Watch the blades from where you stand. Standing still: step 4. Creeping slowly: stop the work here, the control left where it is, and come back in a lighter wind — until then the turbine stays braked and the bank takes no charge from it. Turning at STOP as fast as they turned at RUN: the brake does not hold — a wire broken at the pole or a failed switch; nothing on its circuit is opened, the control stays where it is, and a pro finds the fault (What to tell the pro, → 10.6 · p. 44). Blades you cannot see from where you stand: the work waits until you can.
4. Tie a blade to the pole or the mast with a line, or lower the turbine, the way its manual shows; one maker has its turbine turned out of the wind by its tail before a blade is tied. A blade you cannot reach and a turbine you cannot lower: the work waits, the control as set in step 2, and a pro does the work.
5. Where the job reaches the battery side — its fuse at the battery, or the wire from the regulator or the stop switch to the bank: on a regulator that also takes solar panels, cover them or turn their solar disconnect switch OFF first; then take the wind generator's own fuse at the battery — on a lead that lands at a distribution

block, its fuse where it lands there — out of its holder by hand, or turn its breaker there OFF. With the meter on DC volts and proven on a known live source, the bank, read the voltage at the battery terminals of the regulator or the stop switch, positive against negative. 0 V: step 7. Any voltage: the fuse you took out is not this lead's, or the lead has another feed — that fuse back in, and the battery side goes to a pro. A fuse under a nut on a stud makes the battery side a pro's.

6. Where the job reaches the turbine's own wires, between the turbine and the regulator or the stop switch: the blade stays tied, or the turbine lowered, through the work — on a turbine whose control brakes it by shorting its wires, opening those wires takes that brake away. With the meter proven on a known live source, read the voltage between the wires you will work on, on DC volts and then on AC volts. 0 V on both: step 7 — on a turbine braked by a short, that 0 V comes from the short itself, and only the tied blade holds the rotor. Any voltage: the rotor turns or the wires have another feed — stop here, and the job goes to a pro.
7. Do the work: disconnect the turbine's wires at the regulator's input or at the stop switch, or do the job you came for on the battery side.

PUT THE BOAT BACK IN SERVICE

- Its fuse at the battery, if you took it out, back in its holder by hand first — or its breaker back ON; the regulator's display or light comes on.
- The wires back on the regulator's input or the stop switch, tightened as its manual gives.
- Solar panels you covered or switched off in step 5: back as you found them.
- The blades untied, or the turbine raised, as its manual says, once its wires are back on the regulator or the stop switch; wires left off for a pro keep the blade tied.

- Its stop or brake control released last — RUN or RELEASE, as its manual names it — unless the work left a fault for a pro. Released: the brake light out, the blades turning, and the regulator or the battery monitor showing a charge in wind. Left for a pro: the turbine stays stopped at its control, and the bank takes no charge from it until then.
- The meter's dial at OFF.

Route: the wind generator turns, and the bank does not charge

WHAT CHANGED BEFORE THE PROBLEM?

- after you installed or changed a device → a new regulator or a new bank: the turbine's voltage against the bank's, step 3
- after charging → a bank the charger, the engine or the panels have filled: the regulator holds it, step 2
- after rain or washing the boat → the regulator's terminals and the wires at the base of the pole, by eye: step 5
- after the boat sat unused → the stop or brake control left at STOP after a storm or a lay-up: step 1
- after switching sources (shore power, generator, inverter) → another source holds the bank's voltage high (→ 9.4): step 2
- nothing you noticed → step 1

ROUTE: THE WIND GENERATOR TURNS, AND THE BANK DOES NOT CHARGE — POINT F ON → FIG. 10.5 · P. 36

METER LEADS SHORT CIRCUIT BLOWN FUSE HOT BATTERY
GASOLINE VAPOR BILGE PUMP CARBON MONOXIDE

1 Look at its stop or brake control and, where it has one, its brake light.

You will see: At RUN, the light out: step 2. At STOP, BRAKE, stall or shutdown: find out first why it was set. A damaged or loose blade, a blade still tied, or someone at the turbine: it stays as it is, and the blade or the work comes first, by its manual and the procedure → "Stopping a wind generator for work" · p. 39. A storm forecast: it stays as it is until the storm has passed, as its manual says. A lithium bank in the cold: the battery's manual says whether it may take a charge now (→ 11.5); not yet, it stays as it is. A battery switch at OFF where the

turbine's lead lands after it: it stays as it is — step 3. None of these, by what you see from the deck, the forecast and the bank: release it as its manual says — RUN or RELEASE, the brake light out — and step 2. One maker's regulator can brake by itself and light its brake light: its manual says why and how it releases.

2. **Read the charge current on the regulator's display or on the battery monitor, and the bank's voltage on the battery monitor, with the turbine turning in wind.**
You will see: A small current, the regulator showing that it regulates, and the bank's voltage at the regulator's setting: the bank is full and the regulator holds it there, sending the rest to its diversion load or holding the turbine back — no fault. The regulator regulating while the bank's voltage stays below its setting: the wires between them drop the difference — one maker writes that smaller wires lower the voltage at which its turbine enters regulation (→ "Protection" · p. 38, → 5.4) — the readings to a pro. Another source holding the bank's voltage high: read again with it off (→ 9.4). Gusts above 35 mph: one maker's turbine enters overspeed protection and its output falls. Blades turning slowly: little or no charge in that wind. No current with the blades turning fast, the bank low or not: step 3.

3. **Read the bank's voltage across its terminals, the meter set as the entry of the METER LEADS sign says, and compare the voltage on the turbine's plate with the bank's.**
You will see: A 24 V turbine on a 12 V bank, or the reverse: one maker forbids it — the turbine stopped at its control, and a pro. A battery switch at OFF where the turbine's lead lands after it: the turbine has no load — set its stop or brake control to the position its manual names right away; the card "The panel went dark" (→ emergency card) turns the switch back, and the turbine is released only after that. Everything on the bank dark: the bank's main protection and the battery switch first, as that card does. Both intact, on a lithium bank: its BMS has disconnected the bank — the turbine has no load, so set its stop or brake control to the position its manual names right away; the bilge pump, the high-water alarm and the CO alarm on that bank have lost their power too; the bank comes back as its maker's manual says (→ 11.4), and the turbine is released only after that. A bank whose voltage is far down (→ 3.5): one maker writes that its turbine can fail to charge a battery below a voltage its manual gives — compare with your turbine's manual, and charge the bank another way first (→ 6.6), then step 2 again. A bank at a normal voltage: step 4.

4. **Set its stop or brake control to the position its manual names, as steps 1 to 3 of the procedure "Stopping a wind generator for work" say; on a regulator that also takes solar panels,**

cover them or turn their solar disconnect switch OFF too. Then find its fuse or breaker at the battery, next to F — on a lead that lands at a distribution block, its fuse where it lands there. In a holder that opens by hand, take that fuse at the battery out by hand and look at its element; a breaker, look at its handle.

You will see: Element whole, or the breaker on: the fuse back in its holder by hand, panels you covered back as you found them, the control released as its manual says, and step 5. Element broken, or the breaker tripped: it found a fault; whether and how it is replaced or reset is in the entry of the BLOWN FUSE sign — and the turbine stays stopped at its control until then. No fuse or breaker at the start of its lead — at the battery, or where it lands at a distribution block: an unprotected positive — the first line of the Boat Passport; the turbine stays stopped at its control, and a pro protects the lead at its start (→ 4.2). A fuse under a nut on a stud: a pro.

5 Look at the regulator's terminals and at the turbine's wires where you can see them from the deck, by eye: a loose or green terminal, a scorched spot, a wire chafed at the base of the pole.

You will see: Something found: work on it only by the procedure → "Stopping a wind generator for work" · p. 39. Nothing found: take the readings of steps 2 and 3 to a pro (What to tell the pro, → 10.6 · p. 44).

PUT THE BOAT BACK IN SERVICE

- A fuse you took out in step 4: back in its holder, by hand, before its stop or brake control is released; panels you covered in step 4 back as you found them after it, and only with the regulator's fuse at the battery in and whole.
- A lithium bank its BMS disconnected: reconnected as its maker's manual says (→ 11.4) before the turbine is released; the entries of the BILGE PUMP and CARBON MONOXIDE signs say what to check then.
- Its stop or brake control at RUN or RELEASE, as its manual names it — unless a step above leaves it stopped: for a blade, a storm, a cold lithium bank, a battery switch at OFF, or a pro; while it stays stopped, the bank takes no charge from it.

- A source you switched off in step 2: back as you found it.
- The meter's dial at OFF.

10.6. On board

What charges your bank from the sun and the wind, by which path and through which fuses, is something you can find, read and write down. This section turns what you notice into a first check, says which of this work is yours, gives you the words for a pro, and says what to plan for far from help.

ON BOARD: GOLDEN RULE

Put a charge controller, set by the battery maker's numbers, between every panel and the bank, unless the battery's own maker allows otherwise in writing, and protect its battery lead at its start. Check the controller's input against the string's voltage on the coldest morning, judge a panel by the sun hours of your waters and month, not by its label, and stop a wind generator only by the control its own maker names.

What it means

Each first check below names the procedure or route that carries it out; the signs at the start of that procedure go with it.

Table 10.6. What it means

What you notice	What is happening	First check	Yourself or a pro
The panels are in full sun and the monitor shows no charge	Among the causes: loads on the bank larger than the panels' current, the controller without its battery, the panel side open, a wrong setting, a full bank, another source holding the bank's voltage high	The route "The bank does not charge from the panels" (→ 10.2 · p. 7)	**Do it yourself, if... you can do that route, with its signs**
At midday the controller shows float, or a small current	The bank is near full, another source holds it at or above the controller's setting, or the controller's battery lead drops the voltage the bank sees	Step 1 of that route; "What the monitor shows" (→ 9.4)	**Do it yourself; a battery lead to replace: Hire a pro**
An overvoltage error on cold mornings	The string's Voc in the cold passes the controller's input limit	Step 2 of that route; the worked example of → 10.2 · p. 7	**Do it yourself, if... you rejoin the string with the panels' own leads, or fit a controller for the colder voltage, as "Do it yourself or hire a pro" says (→ 10.6 · p. 44)**
A lithium bank takes no solar charge on cold mornings	The battery or its BMS stopping a cold charge, or the string's voltage in the cold above the controller's limit	Step 1 of that route, then step 2; the battery's manual (→ 11.5)	**Do it yourself**
The controller is dark in full sun	Its battery lead brings it nothing: its fuse, a battery switch where the lead lands after it, an open negative lead, the bank's main protection, or a lithium bank disconnected by its BMS	Steps 3 and 4 of that route	**Do it yourself, if... you can do that route, with its signs**

What you notice	What is happening	First check	Yourself or a pro
The charge falls when a shadow crosses a panel	A shaded group of cells drops out behind its bypass diode	"Shade on a boat" (→ 10.1 · p. 2); step 7 of that route	**Do it yourself**
A 100 W panel does not come near 100 W	The label's light and cell temperature are not the deck's; a PWM controller works the panel at the battery's voltage	"From the label to the bank" (→ 10.3 · p. 19); the kind of controller (→ 10.2 · p. 7)	**Do it yourself**
A connector or the deck pass-through is wet, green or loose	Water has found the joint or the hole	"The plug-in connector" and "Mounting the panels and passing the cable through the deck" (→ 10.4 · p. 25)	**Do it yourself, if... the string is taken off by the procedure of → 10.4 · p. 25; a new connector on a cable: Hire a pro**
The controller's battery lead has no fuse or breaker at its start — at the battery, or where it lands at a distribution block	An unprotected positive from a bank	Step 4 of the route in → 10.2 · p. 7; → 4.2	**Hire a pro**
The controller or the solar disconnect switch sits in a space with a gasoline engine or tank, with no ignition-protection data	A part with nothing to show that it does not ignite gasoline vapor	Its maker's data and marking (→ 4.6, → 9.6)	**Hire a pro**
The wind generator turns and the bank does not charge	Among the causes: its brake left on, a full bank, thin wires, a fuse at the battery, a voltage mismatch, a lithium bank disconnected, too little wind	The route "The wind generator turns, and the bank does not charge" (→ 10.5 · p. 34)	**Do it yourself, if... you can do that route, with its signs**

What you notice	What is happening	First check	Yourself or a pro
The wind generator is braked and still turns	On two makers' turbines a braked rotor creeps in wind; one that turns as fast as at RUN is not braked	Its manual; "Braking and stopping" (→ 10.5 · p. 34)	**Do it yourself; turning as at RUN: Hire a pro**

AWAY FROM HELP

1. **What fails most often:** what salt, sun and motion work on — a plug-in connector left apart without its cap, the deck pass-through, a flexible panel bent beyond its maker's limit, a fuse holder at the battery, and on a wind generator its brake left on after a storm.
2. **What you lose:** the panels' and the turbine's line in your budget (→ 7.5); the bank then lasts only as long as → 7.4 works out on its own charge and the engine's. PRACTICE
3. **How to get to shore without it:** the engine's charge (→ 9.2) and the loads cut to what the passage needs (→ 7.7).
4. **Spares to carry (with ratings):** a fuse of the rating and type on each solar and wind fuse holder at the battery and in the PV leads, as each maker's manual gives it; sealing caps for the plug-in connectors; a panel lead with connectors assembled by their maker, of the same maker as yours; an opaque cover with ties for each panel; the controller's and the turbine's manuals.
5. **What not to do at sea:** do not raise a controller's or a turbine's regulation voltage to win back a short day — one turbine maker writes that it gives no more output and can overcharge the batteries; do not open a turning wind generator's circuit to quiet it — stop it at its control.

Do it yourself or hire a pro

DO IT YOURSELF OR HIRE A PRO · SOLAR AND WIND

STOP · HOT BATTERY A battery that turns hot, swells, hisses or smells while the panels or the wind generator charge it; smoke or a burning smell at a controller, a connector or a diversion load.

What to do this minute: The card "Battery smells, is swollen, or is hot" (→ emergency card); at smoke, the card "Smoke, a burning smell, or an overheated wire" (→ emergency card).

HIRE A PRO · A new plug-in connector assembled on a cable — the connector makers give its assembly to an electrician or an electrically instructed person, or to qualified and trained specialists; a new lead or fuse at a battery terminal, or any fuse under a nut on a stud (→ 1.8); a controller's or a turbine's battery lead with no fuse or breaker at its start; a controller or a solar disconnect switch in a space with a gasoline engine or tank and no ignition-protection data (→ 4.6); work on a string whose panels you cannot all cover, other than on the controller's side of its solar disconnect switch; a wind generator whose stop control you cannot find in its manual, whose turbine voltage does not match the bank, whose braked rotor turns as at RUN, or whose blades you cannot reach to secure. Order the work in the words of "What to tell the pro" in this section, and accept it by the checks there.

If no pro is available: Until the pro comes, the panels stay covered or their solar disconnect switch OFF, and a wind generator stays stopped at its control, where the fault calls for it. The bank then takes no charge from them: on a boat left alone, the bank — and the bilge pump and alarms it feeds — runs on its own charge for as long as → 7.4 works out, unless another source charges it (→ 9.2, → 9.3).

When a pro may do it differently: A pro may place the solar disconnect switch, the PV fuses or the controller differently from → Fig. 10.3 · p. 25, or land the controller's lead after the battery switch, where the controller's or the panels' manual asks for it; the panels are then covered or their solar disconnect switch OFF before that battery switch turns (→ "The order of connecting and disconnecting" · p. 16). You see it in the labels, in the readings written down with the light they were taken in, and in the Boat Passport the pro updates.

DO IT YOURSELF, IF…

- The routes and the procedures of this chapter, each with the signs at its start: "The bank does not charge from the panels" (→ 10.2 · p. 7), "Taking a solar string off for work on its wiring" (→ 10.4 · p. 25), "Stopping a wind generator for work" and "The wind generator turns, and the bank does not charge" (→ 10.5 · p. 34).

- **HOT BATTERY** A controller's battery-type setting that you can read and change, set to your battery maker's numbers as the controller's manual says — then you change it by step 6 of the route in → 10.2 · p. 7.
- **PROVE IT DEAD** A panel lead or connector pair made up by its maker, of the same maker as the halves it mates with, or a string rejoined with fewer panels in series by the panels' own leads, each connector half left apart capped — then you change it with the string taken off by the procedure in → 10.4 · p. 25.
- **PROVE IT DEAD** A controller replaced by one whose input takes the string's voltage on the coldest morning and that has a setting for your battery, on the leads and the fuse at the battery already there, where its manual gives that fuse's rating and wire size — then you change it with the string taken off and its fuse at the battery out by the procedure in → 10.4 · p. 25, set it to your battery maker's numbers, and connect it again battery first, panels last (→ "The order of connecting and disconnecting" · p. 16).

DO IT YOURSELF · Reading the controller's display and the battery monitor; looking at the panels, their shade and their faces from the deck; covering the panels; finding the plates, the labels and the manuals; working out your sun hours and your amp-hours; writing the Boat Passport.

On someone else's boat there are three levels, not four: switches and buttons — yes; tools — no; the gray zone — only with the permission of the charter base or the owner, by phone (→ 2.6). A cover over the panels and a wind generator's stop control are switches and buttons; a fuse holder, a connector and a terminal are tools.

What to tell the pro

WHAT TO TELL THE PRO

For a bank that does not charge from the panels, ask for this: "In full sun the controller showed this — its stage, its panel voltage and its current — and the monitor showed no charge going in; at the controller's battery terminals I read this, and at the bank this; the fuse at the battery was

whole; the setting is this, for a battery of this chemistry. Find why, and give me the panel voltage and current at the controller in full sun, the drop on the battery lead at full charge current, and each panel's current against its neighbor's." For a string that passes the controller's input limit on cold mornings: "The panels' printed Voc adds up to this on one input, and the controller's limit is this; lay out the string, or choose the controller, so that the coldest morning here stays under the limit, and show me the arithmetic with the panels' own coefficient (→ 10.2 · p. 7)." For a lead with no fuse: "Protect the controller's battery lead at its start, at the rating its manual gives within the wire's ampacity and the interrupting rating 4.4 calls for (→ 4.2, → 4.3, → 4.4)." For a wind generator: "It turns in wind at RUN with its brake light out, and the monitor shows no charge; the bank reads this, and its fuse at the battery is whole. Find why, by its maker's manual." For a brake that does not hold: "At STOP it turns as fast as at RUN. Find the fault, by its maker's manual." Accept the work by these checks. In full sun, the controller shows a panel voltage and a charge stage, and the monitor shows a charge going in (→ 10.2 · p. 7); after a string change, the arithmetic of the coldest morning is written down. Every new lead from a battery has its own fuse at the battery, except the starter cable, identified by tracing it to the starter, not by its size (→ 4.2); a new controller or switch in a space with a gasoline engine, a gasoline tank or fuel-system joints shows its maker's ignition-protection statement or marking, or sits isolated as → 4.6 teaches; new connectors are of one maker, mated halves to halves. The work is written into field 16 of the Boat Passport the same day.

REMEMBER

- A panel's label holds at 1,000 W per square meter with its cells at 77 °F; the deck rarely sees both (→ 10.1 · p. 2).
- In series voltages add, in parallel currents add; a shadow on one cell takes out its diode's group of cells.
- A panel's voltage is highest on the coldest morning, and that is the voltage the controller's input has to take (→ 10.2 · p. 7).
- A controller between every panel and the bank, unless the battery's own maker allows otherwise in writing; its setting follows the battery maker's numbers.

- A PWM controller works the panel at the battery's voltage; an MPPT controller works it at its best voltage.
- A panel's day is its watts times the sun hours of your waters and month on an MPPT controller, or about its Imp times the sun hours on a PWM one, less what the controller, the wires, heat and a full bank take (→ 10.3 · p. 19).
- The controller's battery lead is a positive from a bank, with its own fuse at its start (→ 10.4 · p. 25).
- Each wind generator has its own maker's way to stop, and a braked rotor can still turn slowly; a turning wind generator stays connected to its battery, and is stopped at its control before anything between them is opened (→ 10.5 · p. 34).

Self-check

1. **Before you measure.** Suppose three panels of Generation A of → Table 10.1 · p. 3 in series on a controller whose highest panel voltage is 75 V. What does the string's Voc reach at 77 °F and at 32 °F, and what does the controller do at first light on the cold morning?
   Answer: 72.9 V at 77 °F; 72.9 × 1.070 = 78.0 V at 32 °F, above 75 V. The controller stops and shows its overvoltage error until the panels warm and the voltage falls below its restart point (→ 10.2 · p. 7).
2. **Sun hours.** Suppose two 100 W panels lying flat, 2.0 sun hours in your month, 15 % taken by heat, wires and an MPPT controller together, and the bank charging at 13.5 V. How many amp-hours a day reach the bank while it is low enough to take them?
   Answer: 2 × 100 × 2.0 = 400 Wh; 400 × 0.85 = 340 Wh; 340 ÷ 13.5 = 25.2 Ah (→ 10.3 · p. 19).
3. **The brake.** Suppose a wind generator whose stop switch shorts its wires, at STOP in a strong wind, and you read 0 V across its wires. Is its rotor still?
   Answer: the reading cannot tell: shorted wires read 0 V while current flows around the short. Only the blades, seen standing still and secured as its manual says, tell you that (→ 10.5 · p. 34).

4. **On your boat.** Read the label of each panel and write its Pmax, Vmp, Voc and Isc, how the panels are joined on each controller input, and the sum of the printed Voc in series, into field 8 of the Boat Passport; write the controller's highest panel voltage beside it.
   Answer: the numbers as printed, the way the panels are joined as you traced it — "?" where you could not see it, counting all the panels on that input as in series meanwhile; a sum that, corrected for your coldest mornings, passes the controller's limit calls for fewer panels in series or a controller for that voltage (→ 10.1 · p. 2, → 10.2 · p. 7, → 10.6 · p. 44).
5. **On your boat.** Find the controller's fuse at the battery and the wind generator's, and read their ratings and holders; compare each rating with its maker's manual, and write the ratings, the holder type and where each lead lands — at the battery or after the battery switch — into field 10.
   Answer: each lead with its own fuse or breaker at its start — at the battery, or where it lands at a distribution block — at a rating within its maker's range and its wire's ampacity; a lead with none goes on the first line of the Boat Passport (→ 10.4 · p. 25, → 10.5 · p. 34).
6. **On your boat.** Find your waters in → Table 10.3 · p. 21, or run the laboratory's PVWatts calculator for your boat's latitude and longitude with a tilt of 0 for flat panels, and write the sun hours for the months you use the boat; turn the lowest of them into amp-hours a day for your panels, as the worked example of → 10.3 · p. 19 does, and enter that figure in your budget (→ 7.5).
   Answer: a figure for each month, from the table or the calculator's solar radiation column, not its energy columns, worked by the line for your kind of controller. Compare your figure with what the monitor counts on a sunny day of that month; far less points to shade, the controller or a full bank (→ 10.3 · p. 19).

Terms

solar charge controller
The device between the solar panels and the battery that limits the panels' current as the battery fills, by a setting made for the battery's chemistry.

standard test conditions (STC)
The conditions of a panel's ratings: light of 1,000 W per square meter, cells at 25 °C (77 °F), air mass 1.5.

open-circuit voltage, Voc (solar panel)
The voltage across a solar panel's leads in light with nothing connected; its label prints it at standard test conditions, and it is higher when the panel is cold.

short-circuit current, Isc (solar panel)
The current a solar panel gives with its leads joined to each other; its label prints it at standard test conditions.

string (of solar panels)
Solar panels joined in series that feed one input of a charge controller; their voltages add.

bypass diode
A diode in a solar panel's junction box that carries the current around a group of its cells when they are shaded or fail.

PWM
A charge controller that switches the panels' current to the battery in pulses (pulse width modulation); the panels then work at about the battery's voltage.

MPPT
A charge controller that keeps the panels at their maximum power point — the voltage at which they give the most power — and charges the battery from that power.

sun hours
A day's light on a panel counted as hours at 1,000 W per square meter: the solar radiation in kilowatt-hours per square meter per day.

solar disconnect switch
A switch between the solar panels and the charge controller that disconnects the panels from the controller; the panels and their wires up to it stay live in light.

plug-in connector (MC4-type)
The locking plug and socket on a solar panel's leads. MC4 is one maker's name for the type.

deck pass-through
A fitting made to carry a cable through a deck and seal the hole around it.

wind generator
An alternator turned by blades in the wind, which charges a bank through its regulator.

regulator (of a wind generator)
The unit that holds the bank at its setting while a wind generator turns, by sending the surplus to a diversion load or holding the turbine back; inside the turbine on one maker's design, a separate unit on others.

diversion load
A resistive load to which a wind generator's regulator sends the power the battery no longer takes.

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