



Marine Solar Systems

Planning and Installation

Courtesy of:  Coastal Climate Control, Inc.

Introduction: Typical marine solar panels are comprised of a number of silicon cells (normally 32+) connected together electrically in a series string. Individual silicon cells produce only around 0.6v to 0.7v, and so enough of them have to be connected together in series to produce a voltage high enough to be able to charge a 12v battery. A Charge Controller, also known as a regulator, must be connected between the panel and the battery to reduce the panel output to a safe charging voltage. Some panels have less than the normal number of cells and produce less voltage. These will require either a special boost type controller, or for a number of them to be connected in series to produce a higher voltage.

- Panel **power** (W_p) is given in Watts at Standard Test Conditions (STC). Watts = Volts x Amps or, $W = V \times I$
- Panel **voltage** (V_{mp}) is dependent on the number of cells, and the temperature of the cells. A typical monocrystalline cell will produce about 0.6v to 0.7v at room temperature, but less as the cells get hotter.
- Panel **current** (I_{mp}) is dependent on the size, type, and quality of the cells, and the strength and quality of the available light. A typical 5" (125mm) squared monocrystalline cell produces about 5.5 amps in good sunlight.

Types of Cells: All types of solar panels with silicon cells will give similar performance in full sun at solar noon, but monocrystalline cells generally perform better in shade, low light, and at low sun angles than polycrystalline cells. In marine installations we are more interested in the potential daily amp/hour output over the course of a complete day rather than an instantaneous power figure. Panels utilizing genuine, high grade SunPower® cells have the highest efficiency as well as higher heat tolerance and exceptional low-light performance.

Ratings of Solar Panels: Solar panels are rated in Watts under specific test conditions known as Standard Test Conditions (STC). These are: 1,000 watts per square meter (W/m^2) irradiance (solar energy); a cell temperature of 25C (77F); and an air quality of AM 1.5. This combination of ideal conditions will rarely (if ever) occur in real life, and then only momentarily, but the STC rating is used so that cabling, fusing etc. can be sized to handle it safely.

Types of Solar Panels: Most solar panels on the market are designed and manufactured to be installed on a solid, stable surface like a house or cabin roof. While these panels are relatively inexpensive, they tend not to fare well in a salt water environment and when subjected to the torsional and kinetic loads, vibration, and other stresses common in marine installations. Marine solar panel manufacturers like Solbian (flexible panels for canvas installations), and Solara (rigid glass panels and semi-flexible walk-on panels) offer solar products specifically designed and fabricated for marine applications, backed up with worthwhile marine-specific warranties.

Sizing Solar Panels: Solar panels on boats can either provide a small trickle charge to prevent the battery from discharging while the vessel is unattended, or they can provide all or a portion of the vessel's daily power requirements. A single, small panel will keep a battery topped-up and take care of an occasional bilge pump operation. Larger installations that are intended to provide power for everyday needs will require a bigger panel, or an array of several panels. An estimate of the vessel's daily amp/hr demand must be calculated in order to assess what size array is suitable or practical. The following is an estimate of the potential output of various panel types on a good solar day with a full-time load:

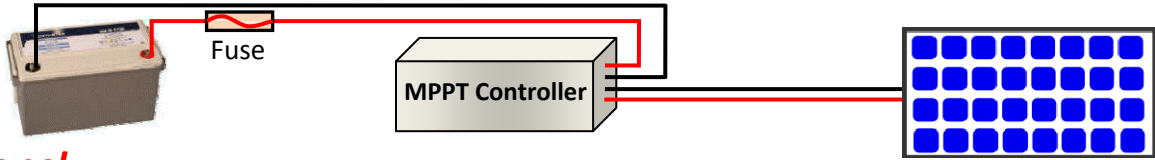
- Panels with genuine, high grade SunPower® cells Divide panel wattage by 3, for amp/hours per day.
- Panels with regular monocrystalline cells Divide panel wattage by 4, for amp/hours per day.
- Panels with polycrystalline cells Divide panel wattage by 5, for amp/hours per day

10 things that affect the performance of marine solar installations:

1. **Temperature** – The hotter the cells get, the lower the voltage, and hence the lower the panel output. Panel voltage can easily drop 3v from the rated voltage once the cells heat up in bright sunlight.
2. **Quality and Quantity of sunlight (Irradiance)**– Solar panels perform better in bright sunlight than in cloudy conditions, and better at solar noon than in the morning or the afternoon.
3. **Soft Shading** – Soft shade will reduce the current output of a silicon cell to varying degrees, but not completely. As the cells are connected electrically in a series string, shading any portion of any one cell will affect the whole panel proportionally. The smaller the size of the cell, the smaller the shadow required for it to be 100% shaded. Shading from a mast or rigging, typically extends across the whole panel, and so panels made up of several “sub panels” with large numbers of small cells tend to handle shading poorly compared to panels with a single string of full-size cells.
4. **Hard Shading** – If a cell is completely covered by something opaque, i.e. canvas, towel, plastic bag, etc, there is a danger of cell damage from overheating (Hot Spots). Most panel manufacturers install By-Pass Diodes that will shunt dangerous currents around a section of the panel where a cell(s) is hard shaded. By-Pass Diodes do not consume any power, and are an important safety feature that should be installed on all groups of cells over 50 watts.
5. **Location** – In Summer, the lower the latitude, the stronger the irradiance but the shorter the solar day and the hotter the cell temperature. Higher latitudes experience lower levels of irradiance but have longer solar days and cooler cell temperatures. In fact, in Summer months, the same amount of daily irradiance is available all along the entire East coast of the USA, from southern Florida to northern Maine.
6. **Panel Angle** – To realize the maximum power output, solar panels should ideally be positioned perpendicular to the sun at all times. While this is sometimes possible to engineer into large land arrays, it is mostly impractical to implement successfully on a small boat that is constantly moving around, and so fixed, horizontal mounting is recommended. In Southern Florida, the loss from having a horizontally mounted panel versus one at the ideal angle to the sun is only about 7%, and this loss diminishes the further south toward the equator one travels.
7. **Multiple Panel Configuration** – If there is a possibility that any one panel in an array of multiple panels could be shaded, the only way to harvest maximum power is to use one controller per panel. An array of several panels connected in a series string to one controller should only be considered where there is absolutely no chance of shadows, as any shading of just one cell will reduce the total output of all the panels in the array. A single controller connected to multiple panels in a parallel configuration will be working on a compromised mix of all the panels’ outputs when shading occurs. Also, panels connected in a parallel configuration must have blocking diodes installed to prevent power back-feeding from an unshaded panel into a shaded one. Blocking diodes reduce panel voltage by 0.7v.
8. **Panel size** – The trend with land-based solar arrays is to use increasingly larger panels with a large number of cells resulting in a high voltage output. Where this is a very practical solution on land in locations where shade will not be an issue, any form of shade on any one cell anywhere on a large, high voltage panel will cause a proportional decrease in total output. Multiple, smaller panels are recommended for marine applications where shade is expected and/or unavoidable. The typical maximum size for marine solar panels is 140 watts, which produce around 24v at full power.
9. **Wiring size** – The wiring from solar panel to controller must be sized for minimum volt-drop but within practical limitations. Most solar controllers are required to be mounted in a location which is at the same temperature as the batteries, as they alter the charging parameters according to the ambient temperature. Locating a controller near the battery also minimizes volt drop and ensures proper charging. See the wire sizing guide at the end of this document.
10. **Controller type** - Solar controllers ensure that a battery is not subjected to excessive voltages, and also prevent back-feeding at night. Pulse Width Modulation (PWM) models simply reduce the panel voltage to a safe charging voltage, but a considerable amount of the available solar power is wasted in the process.
The more efficient and effective Maximum Power Point Tracking (MPPT) models track the best mix of voltage and current to yield the maximum power possible. Under reduced sunlight and soft-shading conditions, a good MPPT controller can yield at least 30% more charging power than a PWM controller, and MPPT controllers actually put more amps into the battery than a panel produces! See the solar controller guide on the last page of this document.

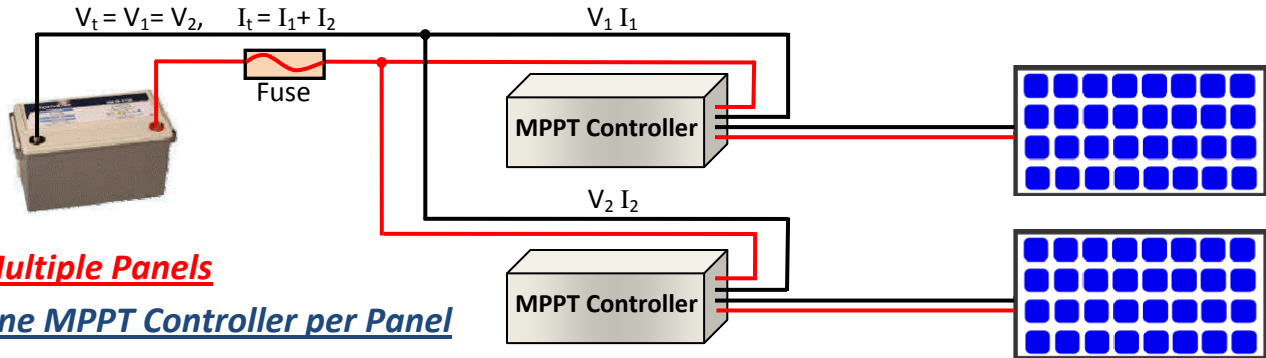
Solar Panel - Controller - Battery: Wiring Configurations

Note: The schematics show the solar wiring going directly to a battery for simplicity. In a typical installation there will be a Battery Switch in the main positive battery cable, and the solar charger may be connected to this switch, or to a Battery Combiner, Isolator, bus bar, etc. via a fuse. There should be no On/Off switch to disconnect the panels from the battery.



Single Panel

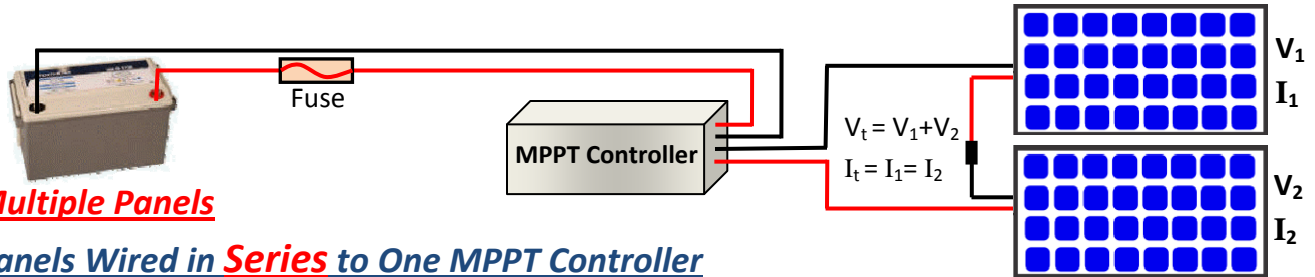
MPPT Controller must be able to handle full rated panel voltage, and max current plus at least 30%. Cables must be able to safely handle maximum current, and be sized for 3% volt-drop. Fuse size should be maximum anticipated current plus 50%.



Multiple Panels

One MPPT Controller per Panel

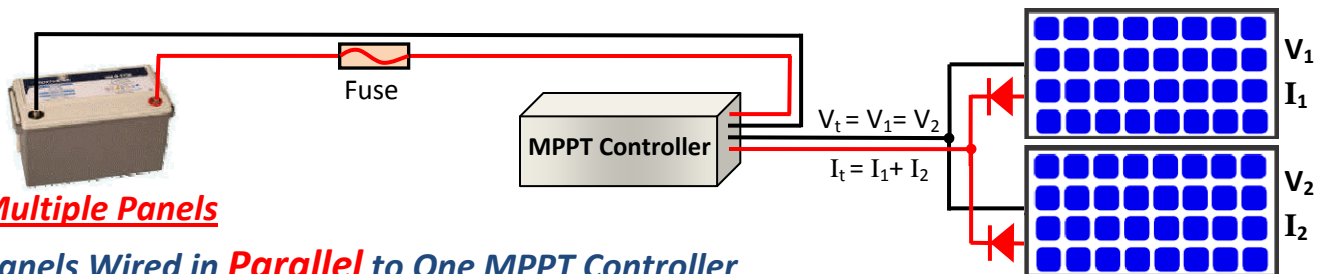
Best solution for multiple panels. MPPT Controllers must be able to handle full rated panel voltage, and maximum individual panel current output plus at least 30%. Cables must be able to safely handle maximum expected current, and be sized for 3% volt-drop. Fuse size should be maximum anticipated current plus 50%.



Multiple Panels

Panels Wired in Series to One MPPT Controller

Should only be considered where shade is not anticipated. Panels must be of same size and type. Total array voltage (V_t) will be sum of V_1 and V_2 ($V_t = V_1 + V_2$). Total array current (I_t) will be equal to I_1 and to I_2 ($I_t = I_1 = I_2$). MPPT Controller must be able to handle V_t , and also I_t plus at least 30%. Cables must be able to safely handle maximum expected current (I_t), and be sized for 3% volt-drop. Fuse size should be maximum anticipated current plus 50%.



Multiple Panels

Panels Wired in Parallel to One MPPT Controller

Use where shade is anticipated, but where installing individual dedicated MPPT controllers is not possible or is impractical. Blocking Diodes must be installed to prevent back-feeding and cell damage, but will reduce panel voltages by 0.7v. Panels must be same size and type. System current (I_t) will be sum of I_1 and I_2 ($I_t = I_1 + I_2$). Total voltage (V_t) will be equal to V_1 and to V_2 ($V_t = V_1 = V_2$). MPPT Controller must be able to handle V_t , and also I_t plus at least 30%. Cables must be able to safely handle maximum current (I_t), and be sized for 3% volt-drop. Fuse size should be maximum anticipated current plus 50%.

Selecting a Solar Controller (Regulator), and Choosing Wire Size

SOLAR CONTROLLER (REGULATOR)

NOTE: In multiple panel installations, the employment of small, individual solar controllers, preferably one controller per panel, will result in maximum possible performance if shading is ever likely to occur on one or more panels. Don't be tempted to use a single, large controller for multiple panels simply because it has a display and monitoring capabilities. Monitoring of output and performance can be better achieved with remote monitoring devices such as the Watt Wizard from Coastal Climate Control, Inc.

A controller is required in order to safely connect one or more solar panels to a vessel's battery system. There are different types of controllers available, but we will be discussing only MPPT (Maximum Power Point Tracking) models in this guide.

The voltage output of even small solar panels is far in excess of the highest permissible voltage that a regular boat battery can safely be charged at. The solar controller regulates the panel voltage down to the correct charge voltage for different battery types. In the process of reducing the panel voltage to a safe charging level, MPPT controllers subsequently boost the output current, so that very little power is lost in the conversion. (Remember: Watts = Amps x Volts). It may be difficult to comprehend, but there will actually be more current coming out of an MPPT controller than goes in from the panel(s)! Most MPPT controllers that are suitable for small marine solar systems are typically rated for: 1) Maximum Current; 2) Maximum Voltage; and 3) Maximum Wattage.

1) **Maximum Current** - MPPT controllers are rated for their maximum current *output*, not the maximum current input from the panel as one might expect. The current output of MPPT controllers is self-regulated, so there is little danger of damaging the controller, but using a controller with an under-sized current output capability will result in some of the available solar power not being utilized for charging. A good MPPT controller will deliver somewhere in the region of 30% to 65% more current at its output terminals than is present at the input terminals from the panel(s), so this must be factored into the selection process for MPPT controllers. As a guide, divide the total wattage of the solar panels in the array by the controllers' bulk or absorbance/acceptance charging voltage (typically 14.4/28.8 or so). This will give an approximation of the expected maximum output current from the controller under ideal conditions.

2) **Maximum Voltage** - The controller specifications will show the maximum allowable input voltage. See over for calculating total maximum array voltage (V_t) in multiple panel configurations.

3) **Maximum Wattage** - The controller specifications will show the maximum permitted total wattage for 12v and 24v operation. In multiple panel configurations, this will be simply the sum of the individual panel wattages in the array.

WIRING

The wires or cable connecting solar panels to a controller should be dedicated solar products that are sunlight, UV, and ozone proof, rated for wet locations, and must have at least 19 copper conductors to be ABYC compliant. For maximum performance, the wire size should be in accordance with the chart below to facilitate a maximum 3% volt drop. Using wires or cables smaller than those recommended below will result in higher volt drop and reduced performance. Coastal Climate Control Inc. offers ABYC compliant multi-strand solar wire and cables with tinned conductors, in AWG 10 and AWG 12 sizes, with or without MC 4 connectors. The wiring run from the controller(s) to the vessel's battery system should be made with boat cable using standard practices.

One-way distance between panel and controller	15'	25'	35'	50'			
Low Current Output Panels - Up to 5 amps					Wire Size - AWG		
Single panel	14	12	12	10	22	5	110
Two panels wired in series	16	14	12	12	44	5	220
Two panels wired in parallel	12	10	8	6	22	10	220
Three panels wired in series	16	16	16	16	66	5	330
Three panels wired in parallel	10	8	6	6	22	15	330
High Current Output Panels - Over 5 amps							
Single panel	12	10	10	8	22	7	154
Two panels wired in series	14	14	12	10	44	7	308
Two panels wired in parallel	10	8	6	6	22	14	308
Three panels wired in series	16	14	14	14	66	7	462
Three panels wired in parallel	10	6	6	4	22	21	462



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