Marine Solar Systems – Planning and Installation Guide

Typical marine solar panels are comprised of a number of silicon cells (normally 32+) connected together in a series string. Individual silicon cells produce only around 0.6v, 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 must be connected between the panel and the battery to reduce the panel output to a safe charging voltage. Some smaller panels have only half the normal number of cells and produce less voltage than is required to charge a 12v battery, and these will need either a special boost controller, or for two of them to be connected in series to produce a higher voltage.

Panel power is given in Watts. Watts = Volts x Amps or, W = V x I (Amps is always represented by "I")

- Panel ***voltage*** is dependent on the number of cells, and the temperature of the cells. A typical 36 cell panel will produce about 22v (36 x 0.6) at room temperature, but less as the cells get hotter in bright sunlight.
- Panel ***current*** is dependent on the size, type, and quality of the cells, and the strength and quality of the available sunlight. A typical 5" (125mm) square monocrystalline cell produces about 5.5 amps in good sunlight.

Using the example above, a 36 cell panel will produce (36 x 0.6) x 5.5 = 119 Watts in perfect conditions.

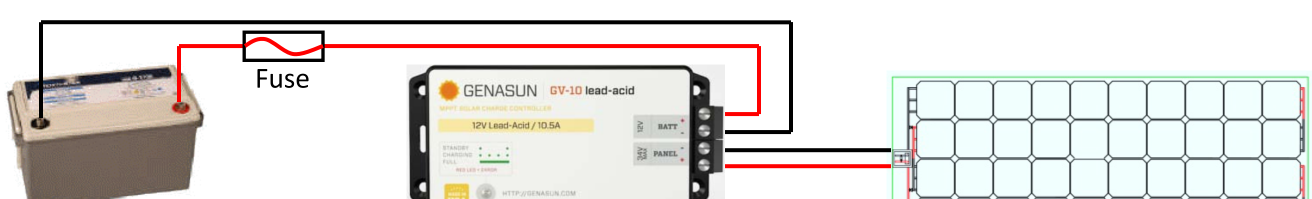
10 things that effect solar panel output in a marine installation:

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 (which is given at room temperature, 25C/77F), once the cells heat up in bright sunlight. Current output actually goes up very slightly at higher cell temperatures.
2. **Quality and Quantity of sunlight** – 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** – Shade from rigging, etc., will reduce the current output of a silicon cell. As the cells are connected in a series string, what shading affects any portion of any one cell, will affect the whole panel proportionally. So if a shadow on one cell reduces the current output of that cell by 1/4, then the total panel current will be reduced by 1/4, and the panel power output will also be reduced by 1/4. Voltage is not degraded to any significant degree by soft shading. Some panel manufacturers use large numbers of smaller cells in an effort to make their panels "shade tolerant". But the smaller the cell size, the higher the probability that one or more cells will become completely shaded and seriously reduce or cut panel output.
4. **Hard Shading** – If a cell is completely covered by something opaque, i.e. a portion of canvas, a towel, plastic bag, etc, there is a danger of cell damage from overheating. Silicon cells consume energy as well as produce it, and if a cell is covered, the other cells in the panel will feed power in to it. If this power is great enough, it can cause a "hot spot" and literally burn through the cell and the substrate. To prevent this, panel manufacturers install by-pass diodes that will shunt dangerous currents around a section of the panel where a cell is hard shaded. It is generally considered that anything less than 50w will not cause a cell to burn, and so by-pass diodes are typically installed across sections of panels 50w and above. If light to a cell is completely blocked and a by-pass diode "switches on", the panel voltage will be reduced in proportion to the number of cells that have been by-passed, and this could reduce the voltage to a point lower than can be used to charge a battery. By-Pass Diodes do not consume any energy and are an important safety feature.
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 possible to engineer into large land arrays, it is mostly impractical to implement it on a small boat that is moving around. 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** – The only way to ensure the maximum power output from multiple panels is to use one controller per panel. A configuration of several panels connected in a series string to one controller should only be considered where there is absolutely no chance of any shading, as any shading of just one cell will reduce the total output of all the panels combined. A single controller used for multiple panels connected in a parallel configuration will be working on a compromised mix of all the panels' outputs when shading occurs. Blocking diodes, required with a parallel configuration, reduce panel output 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 in a location where shade will not be an issue, any form of shade on any one cell anywhere on the panel will cause a proportional decrease in total output. Multiple, smaller panels are recommended where shade is expected and/or unavoidable.
9. **Wiring size** – Wiring from 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 charging parameters according to the ambient temperature. Locating the controller near the battery also minimizes any volt drop between them, and so ensures good charging regulation. Most solar cable is AWG 10 and is good for a 50' run with 3% volt-drop at nominal 12v.
10. **Controller type** - The main job of a solar controller is to ensure that the voltage at the battery is kept at a safe level, although most also incorporate multi-stage charging regimes. The simpler, voltage-regulating models will allow full power from the panel to the battery until the battery voltage reaches a pre-determined upper limit, and will then pulse the battery with the panel output at varying rates to prevent it from rising any higher. This form of regulation is known as Pulse Width Modulation (PWM).
    The more sophisticated Maximum Power Point Tracking (MPPT) models employ sophisticated circuitry and algorithms that enable them to compute and track the best mix of voltage and current that will 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 controller without MPPT.

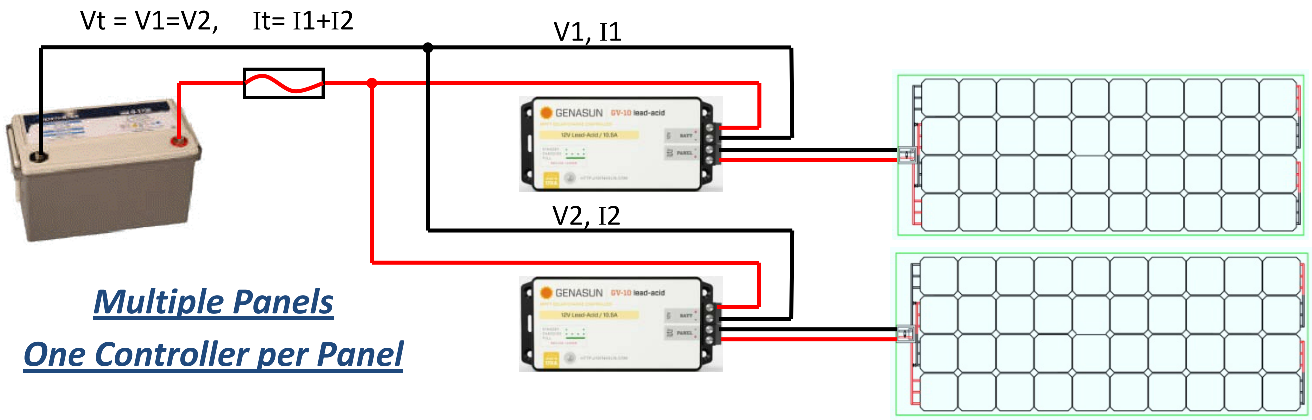
Panel - Controller - Battery wiring configurations

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 to enable isolation of the battery, and the solar charger could be connected to this switch, or to a Battery Combiner, Isolator, etc.



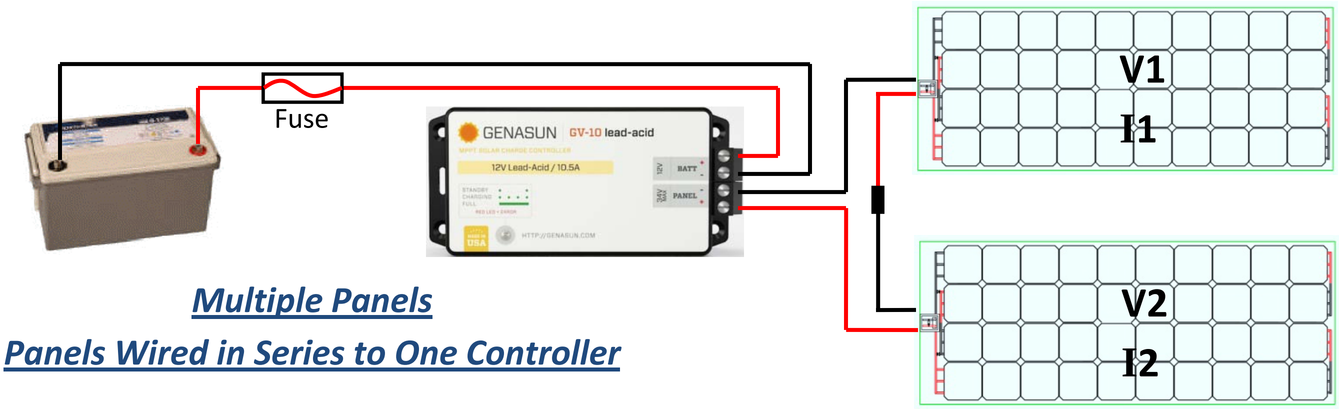
Single Panel

Controller must be able to handle full rated voltage and current output of the panel. Cables must able to safely handle maximum current, and be sized for 3% volt-drop. Fuse should be max current plus 50%



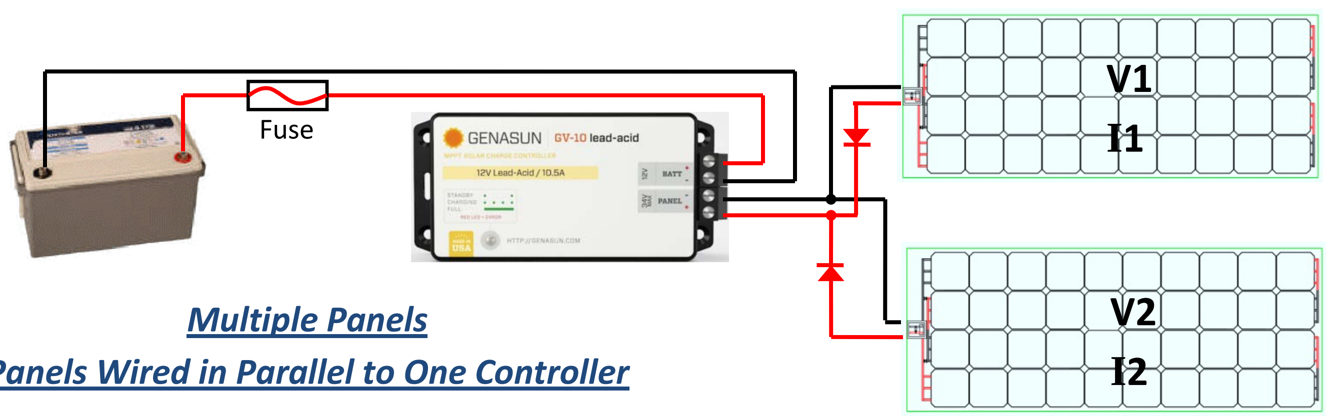
Multiple Panels
One Controller per Panel

The best solution for multiple panels. Controllers must be able to handle full rated panel voltage and current output . Cables must able to safely handle maximum current, and be sized for 3% volt-drop. Fuse should be max current plus 50%.



Multiple Panels
Panels Wired in Series to One Controller

Should only be considered where shade is not anticipated, as any shading on any part of even one cell will reduce current output of the whole array proportionally. Total system voltage (Vt) will be sum of V1 and V2 (Vt =V1+V2). Total current (It) will be equal to I1 and I2 (It=I1=I2). Controller must be able to handle Vt and It. Cables must able to safely handle maximum current (It), and be sized for 3% volt-drop. Fuse should be max current plus 50%.



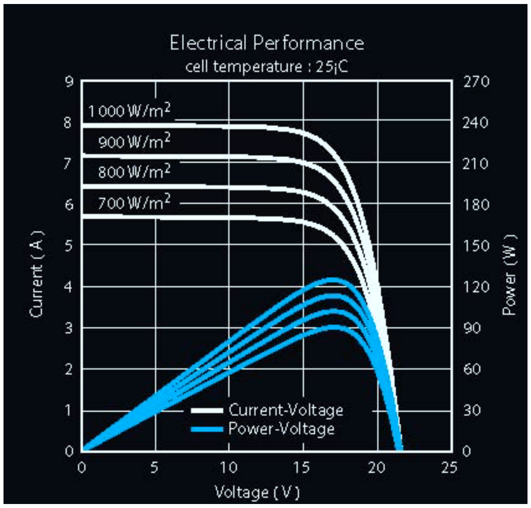
Multiple Panels
Panels Wired in Parallel to One Controller

Use where shade is anticipated, and where installing dedicated controllers, i.e. one per panel, is not possible or is impractical. Blocking Diodes should be installed as shown to prevent cell damage in the event of hard shading of cells. System current (It) will be sum of I1 and I2 (It =I1+I2). Total voltage (Vt) will be equal to V1 and V2 (Vt=V1=V2). Controller must be able to handle Vt and It. Cables must able to safely handle maximum current (It), and be sized for 3% volt-drop. Fuse should be max current plus 50%.

Ratings and Performance Characteristics of Solar Panels

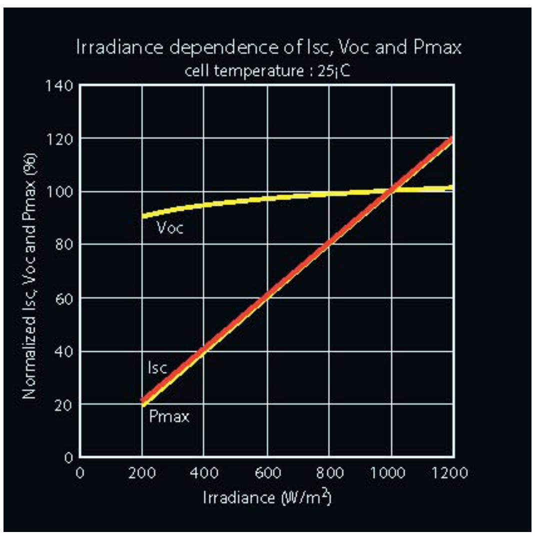
Solar panels are rated in Watts under specific test conditions known as Standard Test Conditions (STC). These are: 1,000 watts per square meter (W/m^2) of irradiance (solar energy); a cell temperature of 25C (77F); and an air quality of AM 1.5. This combination of ideal conditions will probably never occur in real life, but the resulting power output data is published so that equipment, cabling, fusing etc. can be sized to handle it safely.

Performance data (Typical only. Results are dependent on cell type, panel type, and manufacturer)



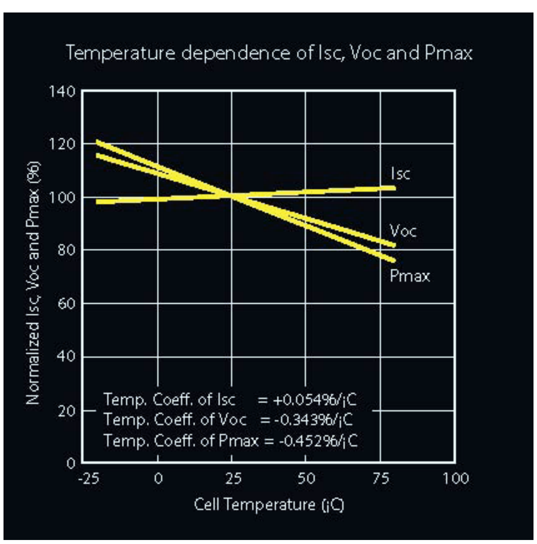
I/V (Current/Voltage), and P/V (Power/Voltage) Curves

These show how current and power output are affected by the available irradiance at levels other than that at STC (1,000 W/m^2). The maximum power point (P_{max}) is the crest of the blue curves at the different irradiance levels, and this is the moving target that MPPT controllers track as conditions and light levels change. Note that voltage at P_{max} changes very little with decreased light levels.
These curves are shown at STC cell temperature (25C/77F).



Effects of Irradiance on Power, Current, and Voltage

Current (I_{sc}) and maximum power (P_{max}) are reduced proportionally to the amount of available irradiance; i.e. from 100% at STC (1,000 W/m^2) to 20% at 200 W/m^2. Voltage (V_{oc}) is only slightly degraded with reduced irradiance down to approximately 100 W/m^2, where it then plummets down to zero (not shown).
Soft shading of cells will reduce current output, but will not affect voltage significantly until light to the cell is almost completely blocked.
Note that these curves are shown at STC cell temperature (25C/77F)



Effects of Cell Temperature on Power, Current, and Voltage

Power (P_{max}) and voltage (V_{oc}) decrease linearly as cell temperature increases, while current (I_{sc}) actually increases slightly.
Solar panels operating in lower latitudes may experience cell temperatures in the region of 100C (212F), when power and voltage output are reduced to around 70% of the panels' rating at STC. Panels for 12v systems must be selected that have a high enough working voltage to be still capable of charging batteries even when panel voltage output is reduced by high cell temperatures. Most batteries require in excess of 14 volts to charge properly.

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