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 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 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 than is required to charge a 12v battery, and these will require either a special boost controller, or for a number of them to be connected in series to produce a higher voltage.

Panel output 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 20v 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 light. A typical 5” (125mm) squared monocrystalline cell produces about 5.5 amps in good sunlight.

Using the example above, a 36 cell panel will theoretically produce (36 x 0.65) x 5.5 = 129 Watts in perfect conditions.

Types of Solar Panels: All types of silicon crystal solar panels will give similar performance in full sun at solar noon, but panels with monocrystalline cells generally perform better in shade and low light situations than polycrystalline. There are no standards that simulate a typical daily yield, so there is no data available to compare one type of panel with another except when under instantaneous ideal conditions. For the maximum output over the course of a day, choose panels and controllers that will give the best shade and low-light performance. Panels utilizing SunPower cells have the highest efficiency as well as higher heat tolerance and exceptional low-light performance.

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 total daily power requirements. A single, small panel is all that is typically required to keep a battery topped-up and take care of an occasional bilge pump operation, but solar installations intended to provide power for everyday needs will require a larger panel, or more likely, an array of several large panels. An estimate of the daily amp/hr demand must be calculated before being able to assess what size of array is suitable or practical, and battery size is not important at this stage. You will first need to know how much power your vessel is using before being able to estimate how much you can hope to replenish with solar power.

10 considerations regarding performance characteristics of a marine solar 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 affecting 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 so 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 shaded over a large portion of their surface area, and this will seriously reduce or cut panel output.

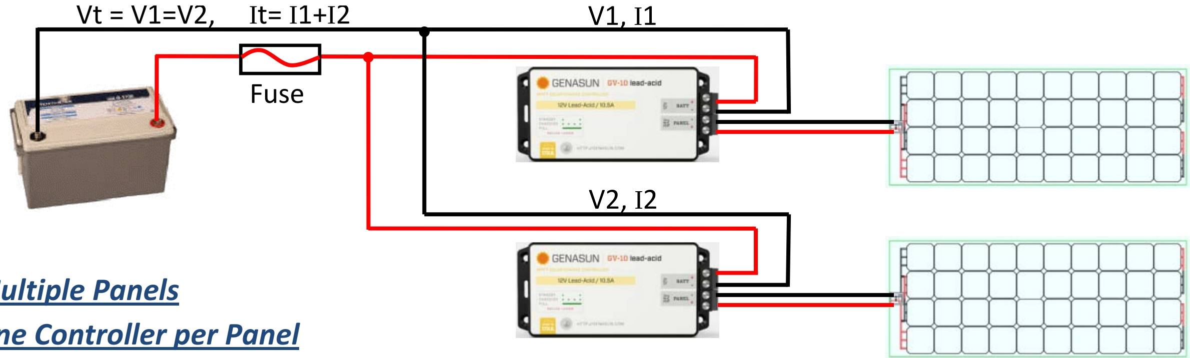
4. **Hard Shading** – If a cell is completely covered by something opaque, i.e. a portion of canvas, a towel, plastic bag, etc, there is a danger of cell damage from overheating. Silicon cells consume energy as well as produce it, and if a cell is covered, the other cells in the panel will feed power 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 if hard-shaded, 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 in normal use, 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 successfully 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 shadows, 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 on land 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 for boats, 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 the 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 efficient and effective 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

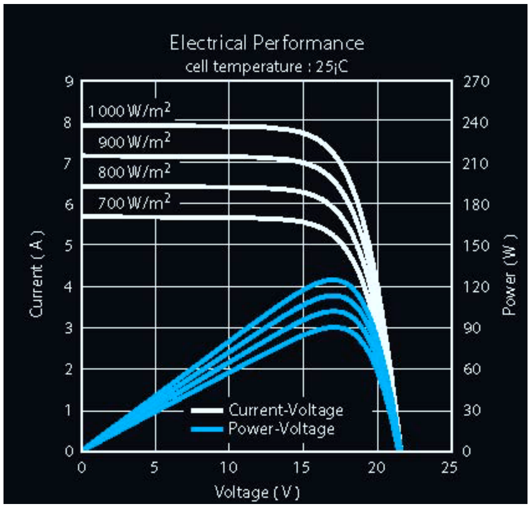
Panels Wired in Parallel to One Controller

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

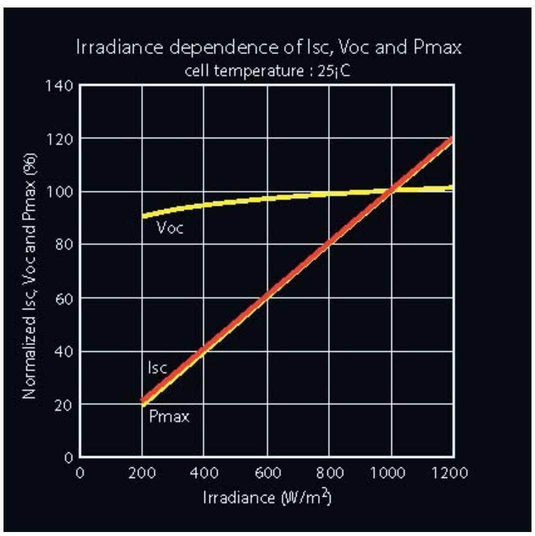
Solar panels are rated in Watts under specific test conditions known as Standard Test Conditions (STC). These are: 1,000 watts per square meter (W/m^2) of irradiance (solar energy); a cell temperature of 25C (77F); and an air quality of AM 1.5. This combination of ideal conditions will only occur rarely and momentarily, 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)



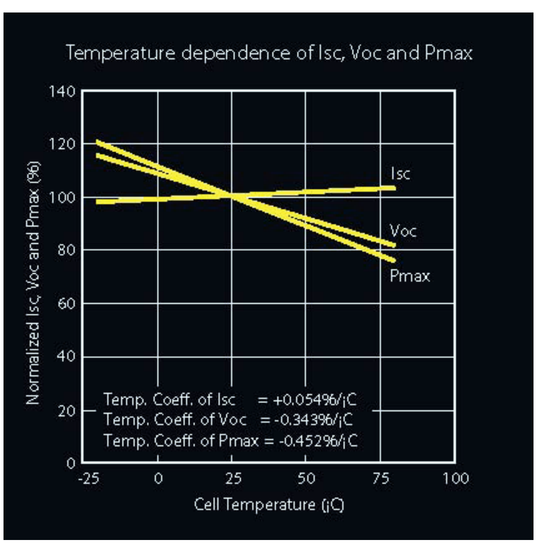
I/V (Current/Voltage), and P/V (Power/Voltage) Curves

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), and so power and voltage output may be reduced to around 70% of the panels' rating at STC.
Panels for 12v systems must have a high enough working voltage to be capable of charging batteries even when panel voltage output is reduced by high cell temperatures. Most 12v batteries require in excess of 14 volts to charge properly.

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