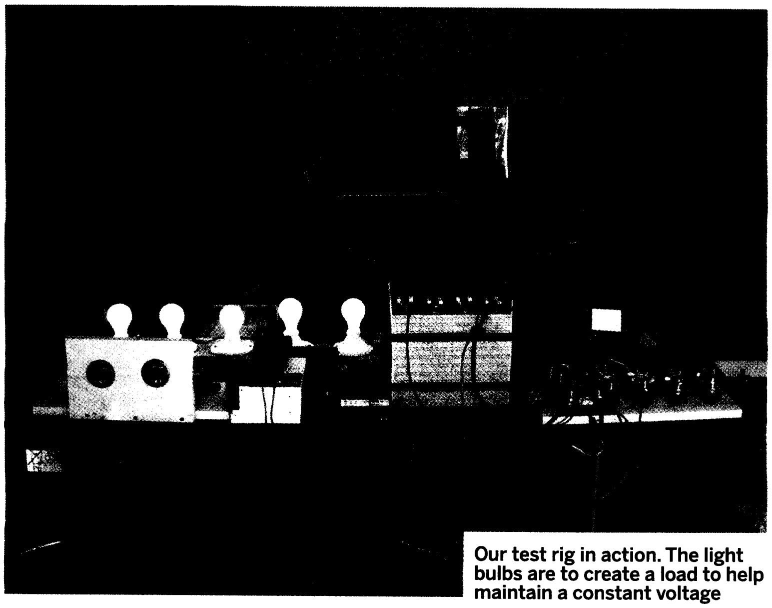


Our test rig in action. The light bulbs are to create a load to help maintain a constant voltage

Tech Notes

By Nigel Calder

Edited by
CHARLES J. DOANE

Like Night and Day

Wiring configurations have a major impact on the productivity of shaded solar panels

Last month I reported on a battery conditioning exercise in which we used a 24-volt solar panel to deliberately overcharge a 12-volt TPPL battery. We regulated the panel's output by shading it with a trash can, and I was amazed at how little shade it took to effectively render the panel useless. Given that solar panels on sailboats are often shaded by spars, sails and rigging, I decided to investigate further.

With the help of my friend Bruce Schwab, a former Vendée Globe competitor who now runs his own marine energy business, I set up four 80-watt Solbian solar panels on a rig that allowed us to move the panels together relative to the sun. We wired them via various combinations of serial and parallel connections to a number of different voltage regulators and tested the effects of different degrees of shading over four glorious days of unobstructed sunshine.

The Solbian panels have 32 cells. In bright sunlight without a regulator they have an open-circuit voltage of around 18 volts. Peak short circuit amperage (i.e., measuring across the output leads when they are not connected to a circuit) is nominally around 6.7 amps. We made no particular effort to optimize sun angles and during our tests typically saw outputs between 4.5 and 5.0 amps when the panels weren't shaded.

The output of solar panels is significantly affected by the voltage of the system to which they are wired. To keep our system voltage stable, we wired our panels and regulators to two 100Ah 12-volt lithium batteries connected in parallel for 12 volts and in series for 24 volts. Prior to testing we discharged these to a 50 percent state of charge. Lithium batteries can maintain very stable voltage over a wide range of charge and discharge conditions, and the voltage in our tests never varied by more than 0.2 volt. Typically the variation was no more than 0.1 volt. For 12-volt testing, we kept system voltage at 13.5 to 13.6 volts; for 24-volt testing it was 26.8 to 27.0 volts.

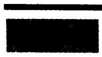
The regulators we used were a Blue Sky 3024i unit, rated at 30 amps at either 12 volts or 24 volts; a Ganz GCC-D10A unit, rated at 10 amps at either 12 volts or 24 volts; a Genasun GV-10 unit, rated at 10 amps at 12 volts; and a Genasun GVB24-8 unit, rated at 8 amps at either 12 volts or 24 volts. The GVB24-8 also has the ability to boost a 12-volt input to charge a 24-volt battery bank. Our purpose was not to compare the voltage regulators, but to ensure that our results were not skewed by differences between brands and models.

Although the regulators had very different capabilities and features, varying from an 8-amp rating (the GVB24-8) to a 30-amp rating (the 3024i), with no user-adjustable setpoints on the Genasuns and Ganz units and multiple setpoints on the Blue Sky unit, the regulated output from the solar panels in a given configuration with a given amount of shading was similar. This enabled us to draw conclusions about the effects of shading, which was our ultimate purpose.

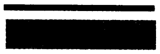
With individual 12-volt solar panels wired to the 12-volt battery bank, we found that by shading one quarter of one cell (or 0.8 percent of the panel's active surface area) we decreased total output by 10-20 percent, depending on the regulator. By shading one half of one cell (1.5 percent of the active surface area), we decreased output by 35-45 percent. Shading three quarters of one cell (2.3 percent of the active surface area) decreased output by 65-80 percent, and shading one complete cell (3.1 percent of the active surface area) pretty much wiped out the output.

When we wired the panels in series for 24 volts, the results were even worse. Effectively, with the same amount of shade on just one cell, we saw the same percentage output loss across the two panels in series. In other words, the shaded area was now half of what it was before relative to the total surface area of the two panels, but the impact on performance was the same. The bottom line is that when you connect solar cells

ALSO IN BOATWORKS:



Servicing fuel injectors Page 70



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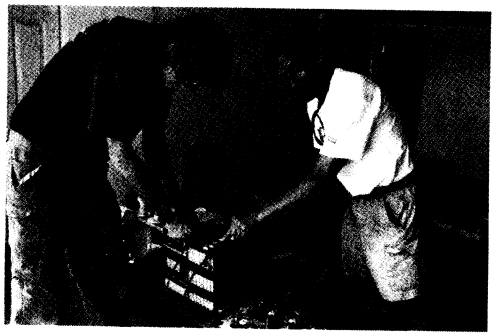
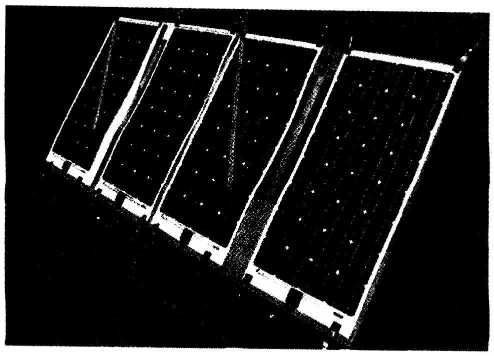
Photos by *Nigel Calder*

in a series, shading one cell has the effect of destroying the output from all of the cells in the series string.

Interestingly, you can shade one quarter of the area of all the cells in a panel and the effect is about the same as shading one quarter of just one cell. It seems the output amperage is reduced to that of the most shaded cell, and the shading of other cells has little additional effect. In other words, the negative effect of shading is not a function of the total area shaded, but is driven by the maximum amount of shade affecting any one cell. Even if a boom is shading 10 percent of a panel, if the maximum shade on any one cell is 1.5 percent of the total panel area, the loss of output will be 35-45 percent, as described above. This helps limit the effect of long, thin shadows, such as those cast by spars and rigging.





Bruce Schwab helped me conduct the tests (top). We clipped strips of wood across the panels to simulate the shading effects of masts and booms (bottom)

In principle, you can mitigate shading effects by using bypass diodes within a panel, effectively taking a shaded cell or group of cells out of the circuit and leaving the rest to function as normal. However, the contribution made by the shaded cell(s) to the total panel voltage is also lost, reducing the open-circuit voltage of the remaining cells. This is particularly significant once the black silicon in a panel heats up in the sunlight. As panel temperature rises, the open-circuit voltage falls. With or without bypass diodes, partial shading of one or two cells will now reduce a hot panel's open-circuit voltage to a point where it is no longer effective in the final stages of battery charging. At this point the panel is once again essentially useless. You can add more cells to the panel to raise its open-circuit voltage, but this is an expensive way to maintain output.

We ran experiments with two panels wired in parallel (i.e., at a nominal 12 volts) charging a 24-volt battery pack using the boost function in the Genasun GVB24-8 regulator. Shading one panel reduced that panel's output exactly as described above, but had no effect on the second panel. In other words, whereas we lost both panels when they were wired in series to get 24 volts, when they were wired in parallel to the boost regulator, we lost only the shaded panel. This was true even when the two panels were wired in parallel to a single regulator.

The message is clear. To best cope with shade, you should buy the *lowest voltage solar panels available*, wire them in parallel, and use a boost converter to get voltage up to the required charging level. In other words, make as few series connections as possible. This is pretty much the opposite of what is done in the home power market, where series connections are used to boost system voltage and minimize cable sizes. But home power installations typically do not have to deal with shade.

On my boat, which has 24-volt house systems, I have four 12-volt solar panels wired in a series/parallel configuration to create two 24-volt arrays. Now I plan to break them down to four 12-volt panels wired to a 12-to-24 volt boost regulator. Given that my panels are normally shaded by the spars and standing rigging, I should see a substantial increase in their average daily output. I just wish I had learned this sooner, because rewiring the panels will be a pain in the backside! 𝒜

My thanks to Bruce Schwab (bruceschwab.com), Genasun (genasun.com), Blue Sky Energy (blueskyenergyinc.com) and Rob Warren (coastalclimatecontrol.com) for their help with this article.