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Extract from the report in this issue about "advances in Solar"


On the author's boat, four Kyocera 85-watt rigid solar panels are mounted on top of a hard bimini specifically installed to make this possible. Other practical mounting options include semi-flexible panels installed over canvas cockpit covers.

For a decade or so, in the technically, financially, and politically turbulent world of solar power, multiple companies and hundreds of millions of dollars in investments have come and gone. Through it all, efficiencies have crept up, costs have come down, and the technology has become ever more attractive onshore and afloat. When I recently looked at the latest optimized installations for marine applications, I was surprised at how many variables now come into play.

## Basic Building Blocks

All solar panels offered in the marine world currently use silicon-based cells, most commonly created using one of three core technologies: monocrystalline, polycrystalline, and thin-film. This hasn't fundamentally changed in decades.

Cells in monocrystalline panels are formed by placing a silicon crystal "seed" in a vat of molten silicon and then slowly withdrawing it. The molten silicon forms a solid single crystal cylinder around the seed, and the cylinder is more or less squared off and then sliced into thin wafers—the basic building blocks of cells. In the process, a fair amount of the silicon cylinder becomes waste, driving up the wafers' cost.

Polycrystalline, or multicrystalline, also starts as a seed in a vat of molten silicon, but this liquid brew consists of, among other things, scraps from monocrystalline manufacturing, cells that failed their QC test, and other sources. The silicon is simply allowed to cool and harden, with the resultant square-sided multicrystal solid once again sliced up into cells. The square-sided ingots substantially reduce waste as compared to the cylindrical monocrystalline ingots. Manufactured this way, cells are cheaper than monocrystalline cells.

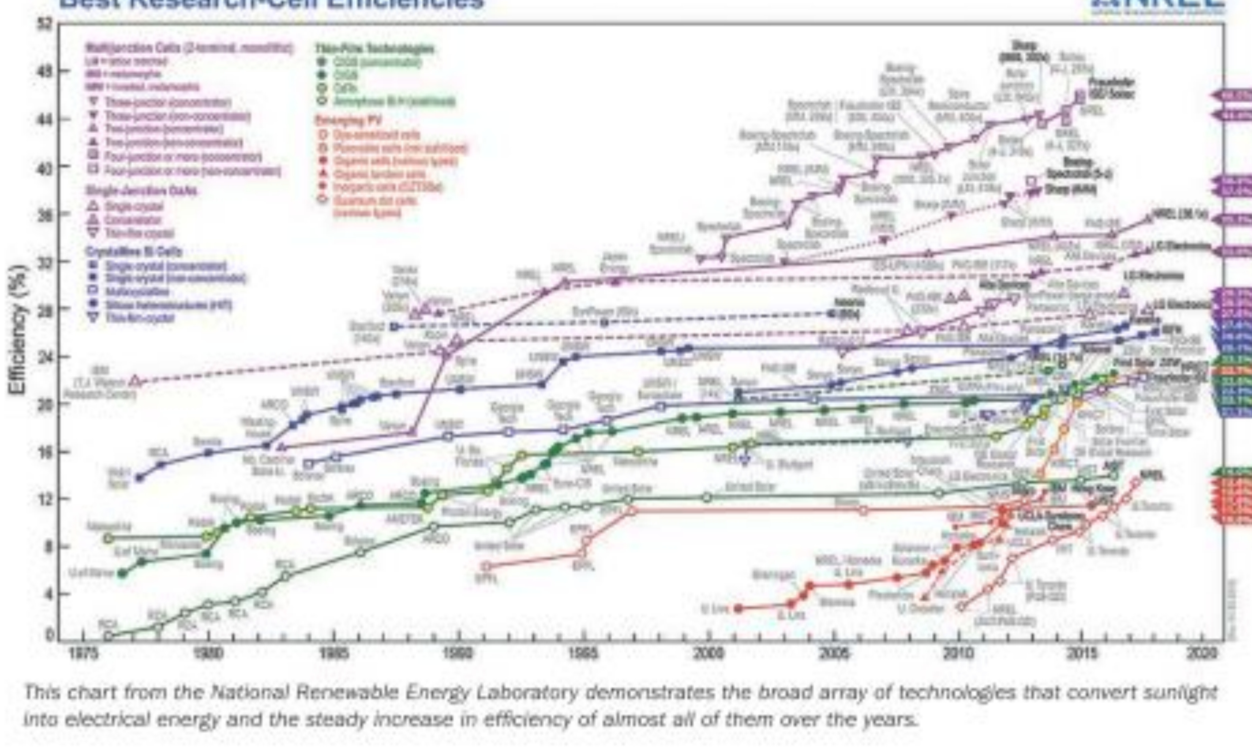
Each monocrystalline cell is cut from a single silicon crystal, so its orientation is aligned with the surface of

## Refinements in solar power technology offer significant opportunities for marine applications, and some risks as well.

the cell. In a polycrystalline cell the crystals are multidirectional. How do you tell the difference? Monocrystalline cells tend to appear uniformly black, whereas polycrystallines have a bluish tint and are less uniform. In theory, a monocrystalline is more efficient than a polycrystalline cell at converting sunlight into electrical energy, especially in low-light conditions, with shading, and at low sun angles. In practice, a range of other factors also come into play to such an extent that a high-grade polycrystalline cell in a well-built panel will be more efficient, and sustain that efficiency for longer, than a low-grade monocrystalline cell in a poorly constructed panel.

Thin-film panels are made by depositing a film of material onto a substrate. Silicon applied in a thin-film format is commonly referred to as "amorphous" silicon. Although nonsilicon thin-film technologies are typically more efficient than amorphous silicon, they are less efficient than conventional crystalline and polycrystalline silicon options—with one exception: gallium arsenide, which is used on satellites but is far too expensive for marine applications.

Today, all thin-film panels sold in the marine world use amorphous silicon. The efficiency of these panels has remained relatively static over the past decade, while that of monocrystalline and polycrystalline cells has increased by up to 50%. As a result, frequently double or triple the surface area is now




*This chart from the National Renewable Energy Laboratory demonstrates the broad array of technologies that convert sunlight into electrical energy and the steady increase in efficiency of almost all of them over the years.*

required for a thin-film panel to achieve the equivalent energy output of a poly or monocrystalline panel. Thin-film panels are also susceptible to moisture intrusion. The tiniest pinhole in the surface of a flexible panel, or minor edge delamination, will rapidly degrade panel output.

For these reasons, and the lack of available space on most boats, I will focus on monocrystalline and polycrystalline panels.

## Cell Construction

Silicon solar cells contain a thin wafer of silicon treated to create electricity when the sun shines on it. One pole of the electrical circuit typically consists of three to five silver busbars embedded on the surface of the wafer (and clearly visible), with a mass of barely visible "fingers" feeding into the busbars. To manufacture the cells, the busbars and fingers are screen-printed onto a cell in the form of a silver paste and then fired in a furnace to drive the silver down into the silicon and make the necessary electrical connections. The fingers collect the current generated by the cell, feeding it to the busbars. The other pole of the electrical circuit is on the back of a cell, typically consisting of a conductive surface, often a thin layer of aluminum.

*This array of semi-flexible solar panels on a motoryacht employs SunPower cells (note the absence of fingers or busbars on the top of the cells). All the panels have 32 cells of the same size, but due to space limitations the cells have been cut in half on some panels. For a given level of sunlight, all the panels will reach a similar voltage, but the ones with half-sized cells will deliver half the amperage.*

Each cell produces around 0.6V to 0.7V in sunlight. Cells are connected in series to boost the voltage (for a nominal 12V panel, there will be anywhere from 32 to 40 cells in series). The series connections are made through a thin strip of copper soldered to the busbars on top of one cell and connected to another strip of copper soldered to the back surface of the adjacent cell. Cells and wiring are laminated between sheets of plastic or metal (flexible or semi-flexible) or between glass and plastic (rigid) to form panels. Each panel connects to an electrical system through a wire pigtail or a junction box.

The ampere output of a panel is a function of cell size (surface area), cell quality, and the level of irradiance (effective sunlight) it is exposed to. A panel with 32 cells will produce the same ampere output as one with 100 similarly sized cells, but the latter will have a much higher voltage output.

In conventional panel-construction, busbars and fingers on the front of a panel obstruct surface area, reducing output. While thinner and fewer conductors can reduce the obstruction, they increase resistance, reducing energy collection, and are more susceptible to fracturing if there is any flexing, vibration, impact, or stress from the inevitable varying rates of thermal expansion and contraction of the different materials in a panel. The silver fingers are particularly vulnerable.

*An adjustable stern rail mount holds a conventional rigid solar panel (fingers and busbars on the top of the panel). Again, these are half cells to boost the voltage to battery-charging levels in a relatively small panel.*

*The bluish color and multiple alignments of the crystals in this rigid panel clearly indicate that these are polycrystalline, or multicrystalline, cells.*

Thin, deep fingers increase strength and improve conductivity while minimizing surface obstruction, but they increase shadows cast by the grid at lower sun angles. One way or another, the construction of the top panel grid significantly affects the efficiency and reliability of a cell.

On the other side of the silicon wafer, the thin aluminum layer on many solar cells is delicate and prone to corrosion; the copper strips that connect cells in series are susceptible to work-hardening and fracture, and multiple soldered joints produce potentially damaging heat stresses during manufacture. Common failure modes are metal fatigue from flexing, detachment of the copper ribbons from the cells, and cell cracking.

## The Maxeon Cell

Enter the Maxeon monocrystalline cell from SunPower, considered by many to be the cell to beat right now. SunPower owns the rights to this cell design, first developed at Stanford University, and sometimes referred to as Interdigitated Back Contact (IBC) technology. SunPower supplies cells to premium marine solar panel manufacturers such as Solbian (in Italy) and Solara (in Germany). Until recently, it also manufactured its own semi-flexible panels but has cancelled this program to focus on its core home-power market.

The Maxeon silicon wafer's positive and negative electrode fingers are on the backside of the cell, eliminating the wire grid on the top, along with associated shading and potential failure points. On the back of the cell, the typical thin aluminum layer is replaced with a more robust copper layer, improving electrical performance and eliminating the corrosion associated with aluminum.

Silicon-based solar panels are dark in color and heat up in sunlight, but as the temperature goes up, electrical output decreases. This loss is quantified as a panel's "temperature coefficient." For example, a loss of 0.3% of output per 1°C (1.8°F) rise in temperature equals a temperature coefficient of (–0.3/°C). The copper backing on the Maxeon cells helps dissipate heat, improving performance in high-temperature environments and lowering the temperature coefficient.

The higher the number of soldered connections in a panel, the higher the series resistance and the higher the likelihood of poor connections vulnerable to corrosion and vibration damage common in marine applications. Because the positive and negative electrodes are on the back of a Maxeon cell, the thin and vulnerable top-of-one-cell-to-the-bottom-of-the-next-cell connection on conventional series-wired cells is replaced by a more rugged edge-to-edge connection. In addition, the relatively high-resistance

*The uniform black indicates that these are monocrystalline cells, while the lack of any fingers or busbars tells us they are SunPower's Maxeon cells, in this case, mounted in a semi-flexible panel.*

thin silver fingers printed on the front side of all other cells are eliminated, along with numerous soldered connections found in other panels.

According to SunPower, the various patented modifications in its cells and panels eliminate 85% of the failures in conventional designs, which, it claims, are due primarily to corrosion and electrical breaks. SunPower also claims slower degradation over time, which enables it to guarantee 92% of rated output after 25 years for its *home power panels* (this does not apply to panels in marine use; for more on warranties, see below). The cells perform well in low-light conditions and have a broad-spectrum response, which enables them to generate electricity from sunlight in the mornings and evenings. In the laboratory, SunPower cells have achieved efficiency levels above 25%. In the real world, I expect to see efficiency anywhere between 19% and 25%.

## Competing Technologies

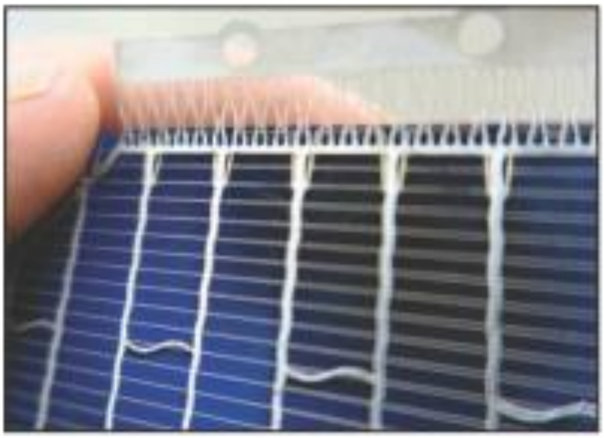
SunPower's IBC technology is not the only way to improve the performance of a solar cell. Other approaches currently being used are described by the acronyms PERC, HIT, MTAT, and MTW.

PERC stands for either passivated emitter and rear cell, or passivated emitter and rear contact. These cells have an additional layer on the back, or small grooves that reflect light back through the cell, providing a second opportunity to generate electricity, improving the movement of electrons, and reducing heat absorption by reflecting light of certain wavelengths out of the cell. Because the addition of a PERC layer does not add substantially to the cost of cell manufacture, these cells with up to 21.5% to 22% efficiency are becoming common in commercial applications.

HIT stands for heterojunction with intrinsic thin-layer. The technology was first developed in 1990 by Sanyo, whose patents have expired. By far the most dominant player is Panasonic. HIT cells combine monocrystalline technology with ultrathin amorphous silicon layers to improve overall efficiency and performance in higher ambient temperatures. In the laboratory, Panasonic has achieved efficiencies above 25%. In the real world, the HIT commercial cells range up to 24%. Along with SunPower IBC cells, Panasonic HIT cells are recognized as the highest-power commercial silicon cells available. In recent years, a few companies have been successful in adopting this technology.

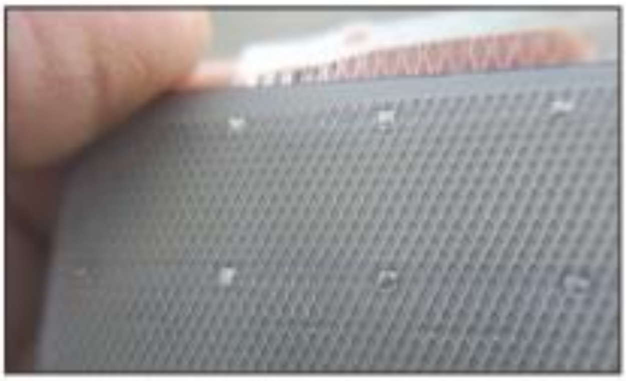
MTAT stands for Merlin advanced metallization technology, a proprietary interconnect technology developed by Merlin Solar in California, and now owned by the Filipino Ayala Corporation. MTAT creates a closely spaced, low-profile, copper-based grid structure applied to the front and back of solar cells.

*A Merlin MTAT energy-collection grid, held up against a solar cell wafer screen-printed with silver fingers, shows: (1) the multiple thin busbars on the MTAT grid with many connection points to the fingers and short energy paths to the grid, (2) the wavy grid that allows for differential expansion and contraction of the wafer and grid, and (3) the wavy connection points (top of the photo) that will make the series connection to the next cell.*



This interconnect technology can be used on all cell types with the exception of SunPower IBC cells. The conventional silver fingers are first screen-printed onto cells but not the busbars. In place of the wide busbars, the MTAT grid is added, creating more numerous and thinner current paths. The primary conductors are tapered from one end to the other, gaining in cross-sectional area from one side of a cell to the other as they collect more and more current from the cell. The conductors snake slightly back and forth, creating a "spring" effect, which absorbs differential expansion and contraction with changes in temperature. This effect is particularly pronounced at the otherwise vulnerable cell-to-cell series connections, reducing the risk of fracture. In testing, this cell-to-cell connection withstood a million flex cycles. MTAT grids have been successfully tested for satellite applications, where the temperature can alternate between -140°C and 140°C (-220°F and 284°F) as many as 15 times a day.

The MTAT copper grid structure, best thought of as a network of springs connected to the front and back of the cell, with a series of compliant springs linking adjacent cells to each other, adds a considerable measure of stability to the otherwise brittle silicon cell wafers. It minimizes the failures associated with traditional soldered conductors. In the event of



*A Merlin MTAT energy-collection grid for the back side of a solar cell—with many connection points and short energy paths to the grid—lowers resistance, increases efficiency, and can significantly minimize the effects of any cell cracking and other damage.*

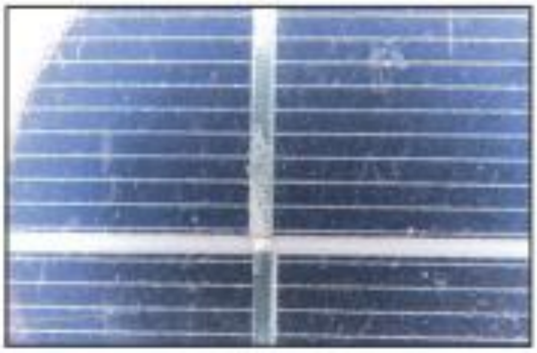
microscopic cell fractures that can severely impact cell performance, the multiple conductors and connection points (the front of each cell has around 2,000) minimize the loss of panel output. MTAT panels have been crushed in testing and still retained most of their output. The technology lends itself particularly to the semi-flexible panels commonly found in marine applications. The extremely low profile of the grid minimizes shading effects on the front side of cells, improving efficiency, especially in low-light conditions and at low sun angles. The complex grids and multiple interconnection points also improve efficiency by reducing the panel series resistance.

In metal wrap through (MWT) technology, minute holes are drilled through silicon wafers and filled with metal contacts. As with SunPower's IBC cells, this enables the positive and negative cell contacts to be made on the back side of the wafer. However, unlike IBC technology, it does not completely eliminate the grid on the front of the wafer, but it allows the busbars to be removed, although the fingers remain. This minimizes the loss of effective surface area and the shading effect. Cell efficiency is improved, and reduced failure rates are reported. MWT technology has not yet been widely adopted. Manufacturing these cells is expensive, and the efficiency benefits are not high compared to more affordable technologies. The first U.S. factory manufacturing these cells opened in 2019.

## Efficiency Ratings

For any given type of cell (e.g., Maxeon, HIT), because of the manufacturing processes for solar cells, the efficiency of individual cells varies. The cells at the top and bottom of the large crystal sliced up to make monocrystalline cells are particularly low quality and should be discarded. Following manufacture, cells are tested and sorted based on their performance. Cells that look identical may vary considerably in performance, and there may well be minute cracks and other flaws in lower-grade cells that accelerate performance degradation over time. These lower-grade cells will likely be a fraction of the cost of high-grade cells, enabling panel manufacturers to produce much cheaper panels but with reduced performance.

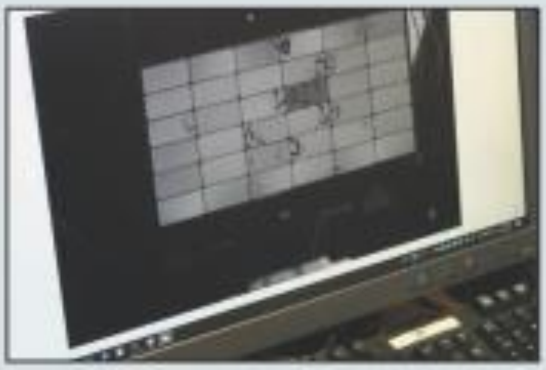
*In a conventional polycrystalline cell with fingers and busbars, you can see where the busbar on the cell in the lower half of the photo ducks under the cell in the upper part of the image to make the series connection to the backside of the upper cell. These thin intercell connections are easily damaged, especially by flexing and vibration.*



Cell efficiency is measured in defined standard test conditions (STC), which rarely correlate with real life but do provide a mechanism for an apples-to-apples comparison at the cell level—but not at the panel level. A panel comparison must also account for the spaces between cells and the width of edges when comparing outputs based on the total surface area of a panel. Its efficiency will be less than that of a cell; the reduction is a function of the added area in relation to the cell surface area plus resistance in cell connections. Another measure sometimes employed is the efficiency of all cells in a panel, excluding interconnect areas and margins. This encompasses the efficiency differences between individual cells, providing a rating for the total cell surface area.

None of these efficiency ratings account for real-world conditions such as shading, poor light, low light angles, resistive losses in connections, etc. In marine applications, we are interested in the total energy output over the course of the day in widely variable conditions. Quite logically, panels using high-grade cells will typically outperform those with lower-grade cells, often by a considerable margin.

Over the years, I have steadily amended my calculation for the anticipated daily output of a solar panel. Today, given quality monocrystalline



A brand-new 36-cell panel is subjected to electroluminescence testing. The camera reveals an underperforming cell and some microscopic cracking.

## Electroluminescence Imaging

If an external current is applied to a solar panel, it causes light emission at various wavelengths. A special electroluminescence camera, which detects specific wavelengths, can reveal many weaknesses such as hidden cracks, broken contacts, dead spots, weak areas, and weak cells, which appear darker compared to higher-performing cells. Because weak and damaged cells dissipate some of the power from higher-performing cells, it is critical for panel manufacturers to properly match cells when assembling a panel, and for the panel not to be subsequently damaged during handling, shipping, and installation. Some panel manufacturers employ electroluminescence imaging to check every cell before installation and every panel after manufacturing is complete; others do not. —*Nigel Calder*

cells in a quality panel, I assume I will see the equivalent of three hours' worth of output at the panel's full rated capacity, i.e., a 100-watt panel will deliver 3 x 100 watt-hours = 300 Wh a day (which, at 12V, translates to 25 amp-hours). This crude calculation seems to work reasonably well in the summertime regardless of latitude, and in the tropics year round. It does not work at all in high latitudes in the wintertime because of the limited daylight hours, and does not take account of significant differences in panel efficiencies.

### Shading and Hot Spots

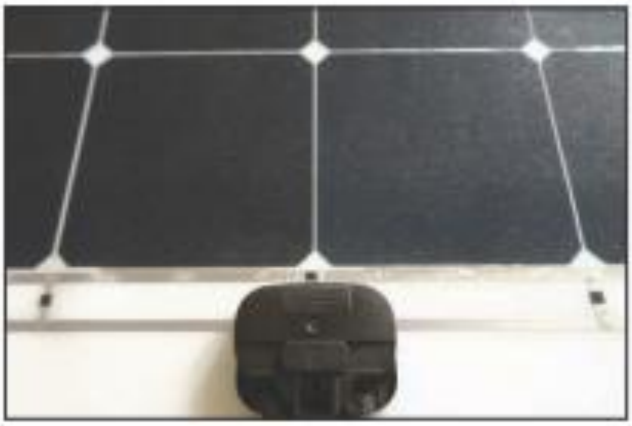
Bruce Schwab of OceanPlanet Energy and I have conducted shading tests on Solbian panels built with high-grade cells. We demonstrated that a hard shadow (in our case, a piece of wood clamped to the surface of a cell) has the effect of knocking out a percentage of the panel's output equal to the percentage shading of a single cell. For example, shading one-quarter of a single cell knocks out one quarter of the panel's output. When panels are connected in series to boost voltage—for example, two 12V panels connected in series to produce 24V—shading on one panel has an equal effect on the output of all others. In contrast, if panels are installed in parallel, shading on one can have little or no effect on the others.

We can draw a couple of somewhat contradictory conclusions from these facts:

- Given a shadow of a particular size, the smaller the cells in a panel, the greater the shading of any cell and the higher the percentage loss of output, so it pays to use larger cells.
- For a given level of output, having a larger number of small panels (i.e., containing small cells) in parallel as opposed to a smaller number of larger panels in parallel will reduce shading effects by limiting the loss of output to only the shaded panel.

*The author's four nominally 12V panels are wired in series and parallel for 24V. The output of the two panels overshadowed by the boom is knocked down by 50%, and the total array by 25%.*

Soft shadows (for example, from rigging at some distance from the panel) have nowhere near the same effect.



*These SunPower monocrystalline (black) Maxeon cells are wired with bypass diodes (the three small, square, black devices in the main busbars) between each 50-watt to 60-watt series string in the panel.*

When cells are totally shaded, they consume power from nonshaded cells in a series string. In the case of hard shadows, it is possible for shaded cells to become hot enough to melt plastic cases and even to start fires. This is currently the subject of a lawsuit between Walmart and Tesla, the owners of Solar City, which has installed solar arrays on 240 Walmart stores. To date, eight of these arrays have started fires, causing millions of dollars in damage. To prevent hot spots, bypass circuits and diodes are often installed at strategic points in series strings. If a cell becomes completely shaded, the bypass diodes limit the back-feeding of the shaded cell to that part of the string between the nearest bypass diodes, isolating a string of cells that cannot absorb energy from other cell strings or from other panels connected in series with this panel.

Bypass diodes should be installed with any series string of 50–60 watts or greater. This will limit the maximum available back-feeding energy to levels that will not cause excessive heating or cell burning. Bypass diodes can be built into a panel or added on and mounted externally.

Bypass diodes will not protect against hot spots generated by damaged cells, those with manufacturing impurities, or low-grade cells with nonvisible flaws. *There are no protection mechanisms against this kind of cell burning.*

## Blocking Diodes

Although diodes in operation create a voltage drop of around 0.7V, in normal panel operation they are not part of the conducting circuit and do not consume energy or diminish panel output. But, if a cell is shaded and the diodes become part of the circuit, the combined effect of the shading and diode will dramatically reduce output.

If panels wired in parallel and to a common voltage regulator are exposed to significantly different light conditions when one is partially shaded, the higher-performing panel will back-feed the lower-performing panel. To prevent this, blocking diodes are required at panel outputs. These permanently wired components *will* create a permanent voltage drop and also absorb a very small amount of energy. To avoid this permanent inefficiency, you can add individual solar regulators, which contain their own blocking diodes, to each panel. Depending on the regulator type, this will optimize the output of each panel.

## Regulators

To charge a battery, it is necessary to raise voltage above the battery's at-rest voltage. This is why a 12V solar panel has between 32 to 40 cells in series, with each producing between 0.6V and 0.7V. In sunlight and disconnected from a battery, a voltmeter across the output terminals of a 12V solar panel will typically read from 16V to more than 20V. The higher the voltage, the greater the ability to maintain charging voltages in the face of voltage drop from connections and wiring, losses through diodes and regulators, and declining output from elevated temperatures. If a solar panel is unregulated, and in the absence of external loads, the output of even a moderately sized panel is sufficient to destroy a battery over time through overcharging. *A regulator is needed on all but the smallest panels.* These regulators also invariably incorporate a diode that prevents the battery from back-feeding a solar panel overnight or when the panel is seriously shaded. Two types of regulators are commonly used: pulse width modulated (PWM) and maximum power point tracking (MPPT).

A PWM regulator feeds panel output directly through to a battery whose voltage determines the solar panel's output voltage. A significantly discharged battery will accept everything the solar panel can throw at it at relatively low voltage—the "bulk charge" phase. In that mode, the regulator will do nothing, but as a battery becomes more fully charged, voltage creeps up. At a predetermined acceptance voltage, the regulator kicks in to hold it at that level. It does this by disconnecting and reconnecting the solar panel at a high frequency, pulsing the battery with charging current. As the battery state of charge climbs, and its ability to absorb charging current continues to decline, the regulator's "on" periods get shorter compared to the "off" periods; this is the pulse width modulation. When the battery is fully charged, the regulator trips to a lower-voltage "float" setting.

In different light conditions, the output voltage at which the maximum energy can be extracted from a solar panel varies. Because the output voltage of a panel connected to a PWM regulator is controlled by the battery voltage, the regulator cannot modify the voltage to optimize panel output. An MPPT regulator effectively disconnects the solar panel from the battery, determines the optimum panel voltage in the given light conditions, and loads the panel in a manner that holds it at this voltage. The panel's output is inverted to high-frequency AC and then back to DC to feed the battery. The DC output is managed with a multi-step charging program similar to a PWM regulator.

A variant of a conventional MPPT regulator is a "boost" regulator. In the event a panel is shaded and the bypass diodes engage—shutting down one or more strings on the panel and dropping its output voltage—the boost function will continue to raise the output voltage above battery voltage, enabling charging to continue. A boost regulator is more expensive but in situations where shading is likely, notably on sailboats, is a good investment.

In less-than-ideal light conditions, an MPPT regulator can push the output of a panel up by as much as 30% compared to a PWM regulator. However, the complex electronics in the MPPT regulator will absorb energy and negate some of this gain. The best are now more than 95% efficient, with some claiming in excess of 99% peak efficiency.

With PWM regulation, when panels are wired in parallel, it is common practice to run multiple panels to a single regulator, with blocking diodes to prevent panels back-feeding one another. Although this can also be done with MPPT regulators (assuming the regulator is rated to carry the combined output of the panels), it will undermine the benefits of the MPPT technology, especially if the panels are in different light conditions. To fully optimize panel output, a separate regulator should be used on each panel.

Because charging parameters vary with battery temperature, many regulators are located close to the batteries to be in a similar ambient temperature, or they connect to a temperature sensor attached to the batteries. Either way, there may be a relatively long cable run between the solar panels and the regulators and batteries. Those cables should be sized to minimize voltage drop; also, the section of cabling that attaches directly to the panels and is outside needs to be resistant to sunlight, UV, and ozone.

## Buyer Beware

Solar panels in home applications and tied to the electricity grid must meet various standards, such as IEC 61215, IEC 61730 and UL 1703. There are no such standards for off-grid solar, including marine, and no required third-party testing to verify claims. Panel manufacturers have been known to quote the cell efficiency of high-grade cells from a manufacturer such as SunPower, when in fact they are using significantly less-efficient lower-grade cells from the same manufacturer. It should also be noted that many panel manufacturers are supplied with SunPower cells through the "gray" market rather than through SunPower directly. Purchasing marine solar panels is very much a case of buyer beware.

*Delamination of a semi-flexible solar panel is a common failure. Once again, these are SunPower Maxeon cells.*

No matter how efficient the cells, if a panel is assembled from unsuitable materials, is poorly constructed, is damaged in shipping, handling, or installation, has inadequately sealed wiring connections, or is connected to the boat with undersized wiring, it will perform poorly and likely fail prematurely. Encapsulating materials and cable exits vary widely in their resistance to damage and water penetration. Note that with flexible and semi-flexible panels, the resistance of edge margins to water penetration is at least in part a function of width, which also varies widely.

It is not unusual to see cheap solar panels fail in as little as two years. A good indication of quality is the warranty—how many years it is valid, and what it covers in those years (e.g., full replacement for failures and loss of output, or pro-rated replacement). Most household panels carry no warranty when used in marine and mobile installations.

In marine applications, where the environment is particularly tough and the installation cost is often a significant part of the overall expense, it doesn't pay to buy cheap, poorly constructed panels with limited warranties and life expectancy. The higher cost of high-quality semi-flexible panels may be more cost-effective overall if they can be installed on existing surfaces as opposed to building a support structure for less-costly rigid panels. Either way, the total installation cost is currently eligible for a 30% United States federal tax credit that will start to phase out at the end of 2019.

## Conclusions

The key to an effective solar installation on a boat is to buy quality panels with an excellent *marine* warranty from a recognized marine vendor, and check them carefully for shipping damage *before* installation. Ideally, the panels will have been electroluminescence tested (see the **sidebar,** page 46) before shipping to ensure that there are no hidden flaws. Install them with care and adequate support in a location that minimizes shading. Make sure that the wiring is sized to minimize voltage drop and that the connections are watertight; and add an MPPT regulator to each panel. The result should be an installation that gives at least a decade of service with minimal degradation in output. Panels incorporating the MTAT technology are likely to be inherently more capable of doing this than other cell interconnect approaches. PBB

*[Editor's Note: Since writing this article, Nigel Calder became a minority partner with Bruce Schwab and OceanPlanet Energy, a company that has rights to the MTAT technology in the marine market and has exclusive rights to the combined HIT+MTAT panels for marine applications. While we remain confident of the accuracy of the information presented here, in full disclosure, Calder feels it is important that our readers are aware of his interest. We agree.]*

***About the Author:*** *A contributing editor of* Professional BoatBuilder, *Nigel Calder is the author of* Boatowner's Mechanical and Electrical Manual *and other marine titles (including, earlier in his career,* Marine Diesel Engines), *and is a member of the American Boat & Yacht Council's Electrical Project Committee. He thanks Bob Brainard of Merlin Solar, Bruce Schwab of OceanPlanet Energy, and Rob Warren of Coastal Climate Control for their considerable help with this article.*

### PBB Resources

- Merlin Solar Technologies: merlinsolar.com
- OceanPlanet Energy: oceanplanetenergy.com
- Panasonic HIT panels: na.panasonic.com
- Solara Solar Systems: solara.eu
- Solbian: solbian.eu
- SunPower: us.sunpower.com