Solar Cell Optimization: Cutting Costs and Driving Performance

Executive Summary

Over the past several years, DC optimizers have become an important technological ingredient in many residential, commercial and utility-scale solar designs. By utilizing modules integrated with this technology, system designers can reduce the power loss from shade obstructions, thus safeguarding systems against long-term module mismatch caused by uneven soiling or debris. Many PV module OEMs are now incorporating the next generation of DC performance optimization: *a highly-integrated power regulator included on each cell-string within the solar module*. This new solution brings more production upside while also addressing the limitations of first-generation solutions. In this white paper, we'll discuss the benefits of Maxim solar cell optimizer solutions and how modules with this technology enable increased energy harvest, expanded system size, extended reliability, and a simple, low-cost installation.

Solar Cell Optimization: Cutting Costs and Driving Performance

Over the past several years, DC optimizers have become an important technological ingredient in many residential and commercial solar system designs. By adding these devices to each module, system designers can reduce the power loss from shade obstructions, thus safeguarding systems against long-term module mismatch from uneven soiling or debris.

A growing number of module manufacturers have begun to include first-generation DC optimizers from various system integration manufacturers. But even while Greentech Media (GTM) forecasts that global shipments of modules with DC optimizers will grow from 1.3GW in 2015 to 3GW by 2017, broader adoption of these devices will continue to be limited by cost and installation complexity.

Forward-thinking PV module OEMs are now incorporating the next generation of DC performance optimization: a highly-integrated power regulator included on each cell-string within the solar module. This new solution brings more production upside while also addressing the limitations of first-generation solutions. Widespread adoption of this technology is expected in geographies and solar market segments that have never before considered DC optimizers. By designing it into a solar project, developers can:

- Enjoy additional performance gains by building MPPT into the cells, rather than outside the module.
- Address obstruction scenarios that module-level products can't improve, such as cross-bank shading or even soiling patterns.
- Eliminate hot-spot conditions associated with diode operation, improving long-term module reliability.
- Continue to deploy conventional installation processes, but without the increased labor needed to install optimizer boxes, additional wiring, communication devices, Internet connections, or proprietary inverters.
- Benefit from performance optimization, but with a substantially lower incremental cost than first-generation solutions.

About the Maxim Solar Cell Optimizer

Conventional solar systems are limited in performance by the series connectivity of modules: forcing the string current to equal that of the least illuminated or weakest cells. Maxim solar cell optimizer works by boosting the current of the weak cells to match those of the stronger, eliminating the corresponding performance penalty of the conventional system. The solar cell optimizer's MPPT function works alongside the inverter MPPT, to ensure that the system output is optimal under any environmental conditions. The module includes three Maxim solar cell optimizers, which replace the three diodes found in a conventional module junction box.

Benefits and Competitiveness

Over the past 20 years, many researchers, engineers and scientists have developed a variety of electronic solutions to improve the efficiency of solar module energy output. Many existing products, such as microinverters, DC optimizers, smart modules, and string-level performance monitoring systems, are available for those bankers, investors or home users who are looking for a better return on their investments.

Up until now, however, there are no electronic solutions that effectively improves solar modules from within. A module-level optimizer prevents underperforming modules from harming overall system performance, but does little to minimize energy loss caused by shading, soiling, or hot spots within the module.

To address this issue, major PV module OEMs are now integrating Maxim solar cell optimizers into their solar modules, bringing MPPT to every cell string within each module.

Modules with solar cell optimizers provide the following benefits not available from other types of PV modules:

- Increased energy harvest
- Reduced power degradation
- Expanded system size
- Flexibility in design
- Minimize soiling losses
- High-reliability solution
- Simple, low cost installation, with conventional system architecture

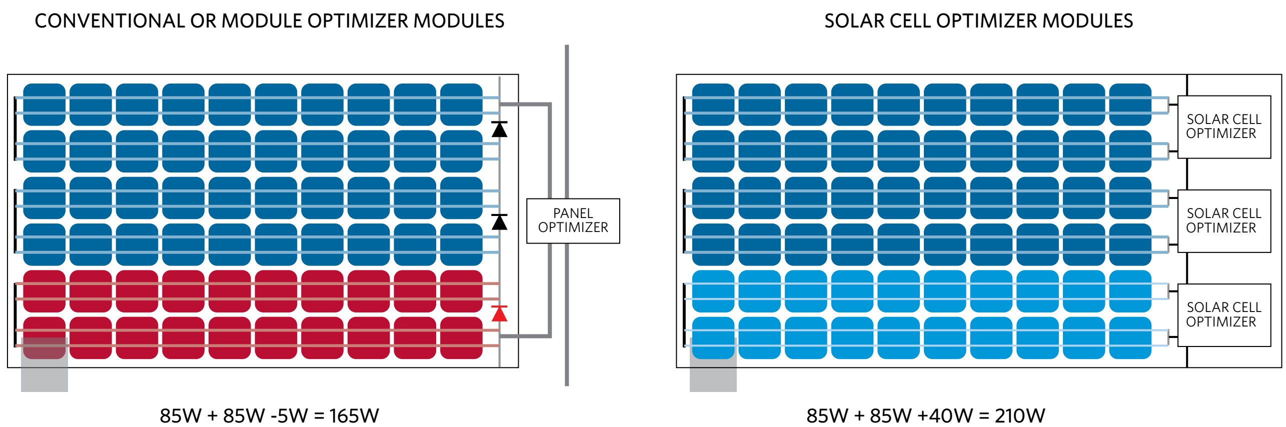

Figure 1: Performance of conventional module vs. solar cell optimizer module, when a single cell is shaded.

Increased Energy Harvest

In a conventional solar module, three bypass diodes combine to serve as a protection mechanism, allowing the module to produce power even when one of its cell strings is shaded or damaged. When the bypass diode is active, the energy production of the entire cell string is lost, even when only a small portion is shaded. The active diode now carries current, which creates heat and stress that can lead to premature failure. Such a failure results in a permanent loss of cell-string output, and potentially presents a safety issue, as the underperforming cell-string is now forced to operate in a dangerous, reverse bias condition. In the new Maxim design, however, bypass diodes are replaced with smart integrated circuits (ICs). When one cell is shaded, the smart IC chip will increase the current output from the cell-string to match that of neighboring, unshaded cell-strings. The shaded cell-string will continue to contribute all available energy, without affecting the production of unshaded strings. (In the case of a conventional solar module or module-level optimizer, one shaded cell would likely cause the entire cell-string to go offline.)

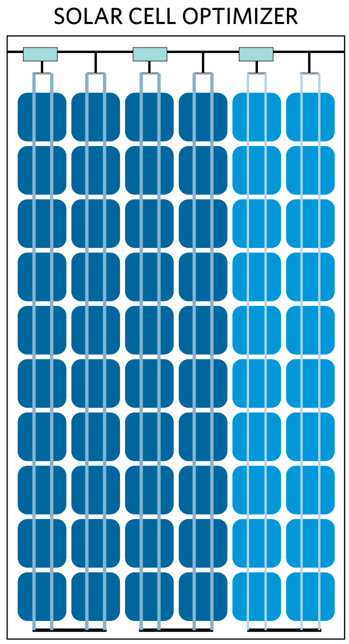

Figure 2. The worst-performing cell no longer determines module output.

Reduced Power Degradation

In a conventional PV system, since solar modules are connected in series to form strings, the same current must flow through all the modules. But due to shading caused by moving clouds, leaves from trees, soiling, or module power tolerance, each module needs to work at a different current to achieve its maximum power point (MPP). Due to the series connection, the worst-performing modules wind up determining the string current, which in turn means that the other modules will deliver less power than they are capable of producing. In a Maxim system, on the other hand, solar cell optimizers find the best working point for each of the cell-strings and modules, increasing the current of weaker cell-strings to match that of the strongest one. MPP tracking (MPPT) is performed for each individual cell-string, minimizing any energy loss due to cell mismatch.

During the long-term operation of a PV power plant, the solar modules suffer aging, cell microcracks, potential induced degradation (PID) and so on, which will cause power loss. A module-level optimizer can prevent an underperforming module from harming overall system performance, but cannot reduce loss caused by degradation within one panel. Integrating solar cell optimizers into a module, by contrast, permits a redesign that brings MPPT to every cell string within the module. As a result, we can optimize output at the cell-string level—a far more finely-tuned solution.

In a conventional or first-generation optimized module, the weakest cell in the module will determine its performance. With the Maxim module, however, mismatch within cell-strings is eliminated, so that a weak cell affects module performance much less. This module outperforms both conventional and externally optimized modules, by producing a higher energy output over the life of the system.

Expanded System Size

Well-known environmental sources of mismatch that affect PV system performance include shade, soiling, temperature gradients, and cell aging. But another common source of energy loss comes from edge-of-day, row-to-row shading, in a tilted flat roof or ground-mount design. This energy loss increases in locations further from the equator and during the winter months.

A typical conventional PV system will be limited in size, to avoid object and row-to-row shading. The ground coverage ratio (GCR) is the ratio of module area to total area, and is set to minimize losses due to row-to-row shading within the system array—typically to limit annual energy loss to below three percent. By independently optimizing cell strings, rather than bypassing affected cell strings, the Maxim module continues to generate the maximum possible energy from shaded cell strings, enabling increased density and expanded system size.

Now a designer can reconfigure a system design to allow for more inter-row shading, a unique capability that delivers 10 to 20 percent more energy density than a conventional system design. Effectively, the system can maintain the same kWh/kWp as a conventional system, but with higher ground coverage ratios. Using Maxim on a commercial rooftop project, designers can achieve mono-silicon power densities with poly-silicon costs.

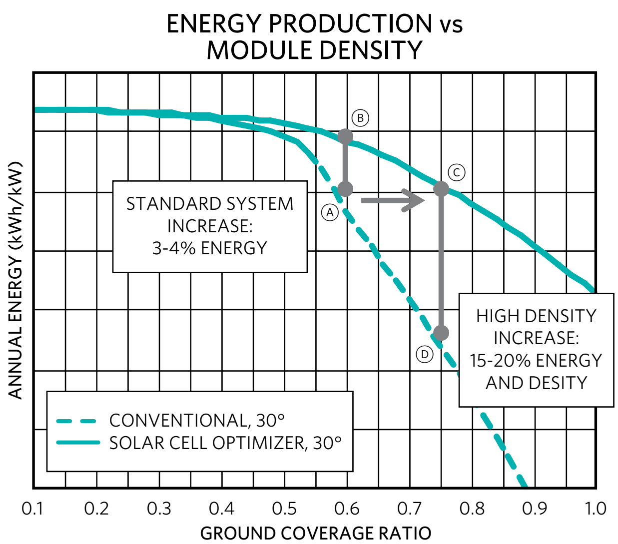

Figure 3. Energy output vs. module spacing shows a standard system increase of 3% to 4% energy, and a high-density increase of 10% to 20% energy and density.

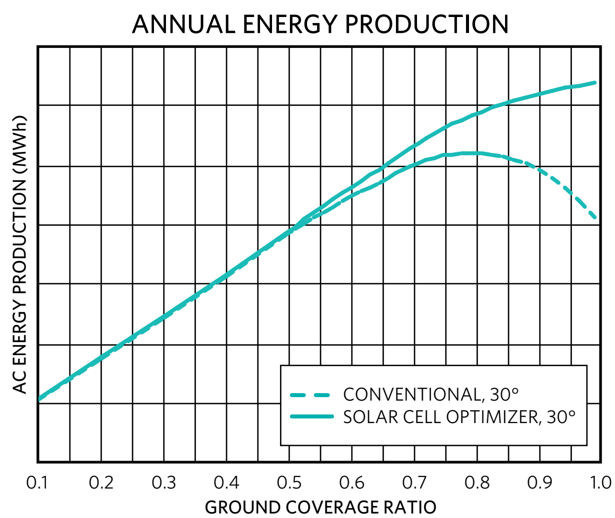

Figure 4. AC energy production continues to increase for the Maxim system with tighter row spacing; the conventional system drops off with inter-row shading.

Several observations can be made from **Figure 3**. First, Point A represents a GCR that a typical system designer chooses for a conventional system. The annual kWh/kW generation is an optimal compromise to a completely unshaded GCR, to better utilize the limited roof area. The system designer has chosen a point where a three percent annual energy loss is acceptable.

Second, the original system design substitutes modules with cell-level optimization at the same GCR (Point B). The project owner will benefit from three to four percent more energy, because of the modules' increased shade tolerance.

Third, the system designer uses the optimized modules to increase system density. This GCR is the point at which row spacing can be condensed, without sacrificing annual kWh/module production relative to the original design decision (Point C). In the free space created by the tighter row spacing, the designer can place 15–20 percent more modules, increasing the generating capacity of the project. This approach produces more electricity, while also driving overall project ROI in a favorable direction.

Finally, conventional technology becomes an irrelevant choice at the high-density GCR (Point D). In this case, energy losses are too great to provide a viable option.

The same shade tolerance achieved by cell-string isolation also applies to near-object shading that can render a project or specific location financially unviable. Obstacles such as trees, rooftop obstructions, parapet walls, or adjacent buildings can severely degrade the energy harvest. But by independently optimizing cell strings, designers can expand system size, or address otherwise unviable rooftops, simply by placing modules closer to shade obstructions—all without experiencing array-wide performance loss.

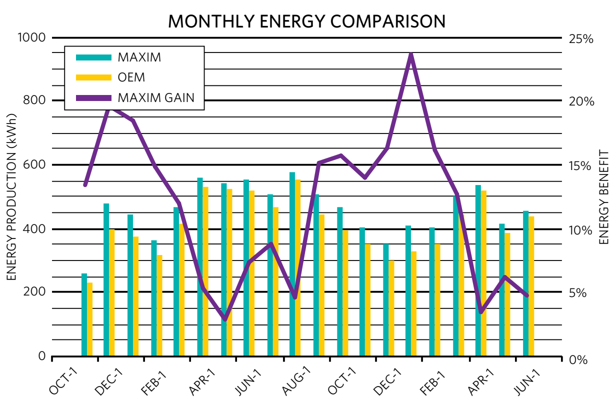

Figure 5. Performance chart of a side-by-side comparison, with and without solar cell optimizers.

Flexibility in Design

By incorporating modules with solar cell optimizers, system designers can accomodate differing string lengths, multiple orientations, and different module power levels. The technology expands the string's peak power output over a wider voltage range. This greater power output allows two uneven strings to be connected in parallel, so the inverter can find an operating voltage at which both produce their peak power. This flexibility, which accommodates the site location, is not possible in a conventional system, where an inverter finds a single operating point that does not achieve peak power from either string.

Minimize Soiling Losses

Soiling losses are always factored into modeling exercises. In fact, in most sites with extensive solar resources, they cannot be avoided. Further, these soiling patterns are frequently common to all modules (see Figure 7), and so cannot be addressed by panel-level optimizers.

A module with solar cell optimizers, however, can act as an insurance policy to mitigate performance loss from dust and debris. A common example is bottom corner soiling or snow buildup. In these cases, there is no panel mismatch, so a conventional module and a module-level optimizer effectively respond in the same way. If 15 percent of the bottom row is affected, the bypass diode turns on, thereby reducing panel output by one third. Absent module-to-module mismatch, module-level optimizers provide no benefit. Only by removing the bypass diode, isolating the cell strings, and continuing to generate energy from the shaded cell string can the impact of this effect be reduced. In a rooftop study, the array with solar cell optimizers lost only 2.4 percent power, compared to an unshaded reference module. The panel-level optimized module lost 16.4 percent.

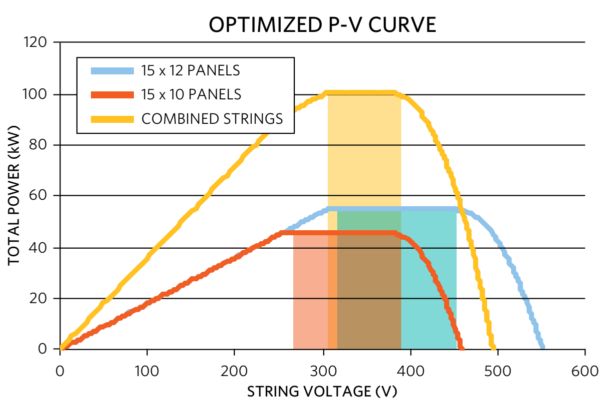

Figure 6. Performance gained when uneven strings are connected in parallel.

Figure 7. Uniform soiling pattern commonly found on large systems.

A High-Reliability Solution

The inclusion of the Maxim solar cell optimizer in modules from leading PV OEMs brings an unprecedented level of reliability to the system designer and project owner:

1. Proven Component Reliability of Solar Cell Optimizer

In the PV industry, the PV module must meet the IEC/UL solar standards and tests, which will prove its reliability. Junction boxes/modules have passed IEC61215, IEC61730 and UL1703 test requirements. The Maxim solar cell optimizer has also passed rigorous semiconductor reliability tests, such as high-temperature operation, salt atmosphere exposure, thermal cycling, and damp heat exposure.

2. Low Component Count

Maxim modules use the single-chip Maxim solar cell optimizer (**see figure 9**), resulting in higher reliability than solutions with hundreds of discrete components.

3. Proven Integrated Circuit Fabrication Technology

Maxim Integrated has shipped more than one billion DC power regulators over the past 15 years. This solar cell optimizer product is built on a long-standing reputation for quality and durability.

4. Enhanced Long-term Module Reliability

Because the Maxim module does not utilize diodes to manage power production, a cell-string will not be bypassed even if fully shaded. (The diffuse light will still generate some energy.) And, because all available energy is being harvested, a shaded cell is not in reverse bias, thus eliminating the cause of hot spots and removing a common cause of long-term cell stress. Should environmental conditions still result in a cracked or otherwise degraded cell, this cell will only affect the performance of its local cell-string, without further affecting the module or array.

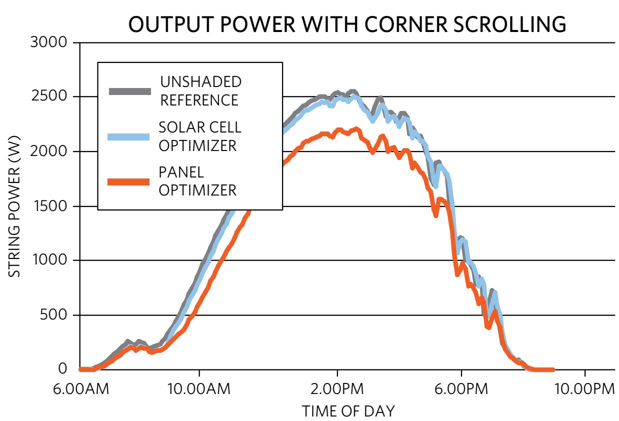

Figure 8. Performance of cell optimizer vs. module optimizer with uniform soiling pattern (as in Figure 7).

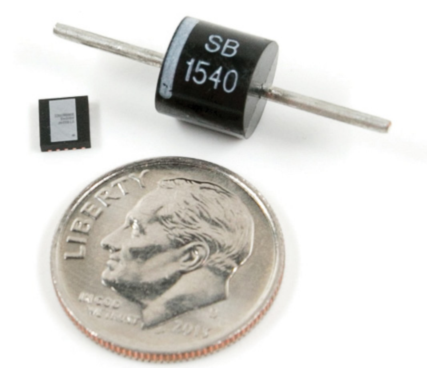

Figure 9. Solar cell optimizer IC from Maxim Integrated.

Simple, Low-Cost Installation, With Conventional System Architecture

An important element of initial PV plant cost is related to installation time. Traditional optimizer systems increase hardware, installation steps and system configuration requirements, thus raising costs—substantially so in larger systems. By incorporating modules enabled with solar cell optimizers, a system designer can maximize harvest without raising installation costs. Maxim-enabled modules require no additional hardware or installation steps, and are compatible with all inverters, monitoring systems, and mounting and tracking hardware. Installation is identical to that of a conventional system, and far simpler than that of a module-level optimizer system.

The module-level optimizer system must be installed on racking rails, increasing labor and materials costs with additional optimizer devices that must be installed in arrays: bolts, specific frames, DC cables, and so on. In contrast, Maxim-enabled modules do not have any more installation requirements than conventional systems. In addition, certain panel optimizers must be used with proprietary inverters, due to a lack of interbrand compatibility; others require an extensive communications system to be installed at the site before the product is functional; and both require an on-site Internet connection to complete installation and operate the systems. Fortunately, modules with Maxim solar cell optimizers can be incorporated as direct substitutions for conventional modules, and deliver outstanding system performance. And, because of the advantage of cell-string level MPPT, they improve energy production by 10-20% in high-density solar plants, compared to both conventional modules and those with module-level optimizers.

Including Maxim Enabled Modules in Your Next System Design

Lifetime system performance gains, enhanced module reliability, and higher ground coverage (module density) can be attained with the simple and low-cost addition of a PV module that incorporates Maxim solar cell optimizers. One of Silicon Valley's largest analog and mixed-signal semiconductor companies, Maxim Integrated has applied over 15 years of power integration expertise to deliver this innovation. Before you start your next system design, simply ask your OEM module supplier for more information on their Maxim-enabled modules, or look for the innovative OEMs who provide these modules on the *Maxim Solar Partner Page*. Put the next generation of PV module innovation to work in your next PV project.

Learn more

For more information, visit:
www.maximintegrated.com/solar