PHOTON TEST RESULTS

Independent testing demonstrates technology and performance leadership of Tigo Energy

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Independent testing demonstrates technology and performance leadership of Tigo Energy

> *"In facilities which are constantly subject to the shadow of a mast, the performance optimizers provide significant yield gains ... in long strings nearly 21 percent (winner: Tigo Energy Module Maximizer)."*
>
> *PHOTON*

INTRODUCTION

"The ideal solar roof looks like this: It is high; it is wide; it has no superstructures such as chimneys, dormers, and antennas; and is neither angled nor bent. Other houses and trees are so far away that they cast no shadow on the solar modules. However, the ideal solar roof is more a theory than a reality. Because in practice, system operators need to cope with what they have – reduced profits from objects which cast shadows, and modules positioned at different angles to the sun. All of these reduce performance.

"Most modern solar modules are designed so that a relatively small shadow leads to relatively large loss. At PHOTON Laboratories, when a solar simulator test created the shadow of an antenna mast, the actual performance of the string in the solar simulator went from 1700 watts to less than 1400 watts - a revenue loss of more than twenty percent. This resulted from a shadow of less than five percent of the PV surface. The reason for this discrepancy is simple: not only does the shaded module deliver less power. The other, unshaded modules are throttled by it. For in the series connection of a string, the current of the lowest power module limits the current of all other modules. The same problem occurs when solar panels are illuminated to different degrees by the sun - for example, if in the morning and evening hours the bottom row of the solar power system is in the shade, while sunlight still falls on the upper rows." [1]

- Translated from PHOTON

[1] Source: Podewils, Christoph. PHOTON, November 2010

As photovoltaic solar power generation rapidly grows in worldwide adoption, innovative advances are being made in key areas driving efficiency up and costs down. Perhaps most visible are the recent break-throughs in BOS electronics which bring DC power maximization, safety features and advanced system management to the PV project. In the recently completed lab tests by PHOTON, the journal examined the benefits of five commercially available solutions. The results found Tigo Energy demonstrating clear advantages in energy production and highlighted the unmatched over-all value of the complete Maximizer solution. Tigo Energy departed from the conventional approach of DC/DC voltage conversion to develop a patented Impedance Matching technology. This superior energy harvest can be attributed to the 99.6% statistical efficiency and unmatched distributed MPP control accuracy of the Impedance Matching ap-proach. Tigo Energy generated 3.5 times more power production from unshaded arrays than other tested solutions. These test results solidify Tigo Energy's position as the clear market leader in DC maximizers and help to explain the rapid worldwide market adoption of the platform.

TIGO ENERGY DELIVERS HIGHEST ENERGY HARVEST IN UNSHADED TEST

The unshaded harvest test is the most important test scenario for evaluating the performance of distrib-uted MPP solutions. In a new, well architected system during peak generation hours, the array conditions will most closely resemble these test conditions. This test is an important measurement of both MPP accuracy and the efficiency of the electronics at the module. Only when a solution is not introducing ad-ditional conversion losses to the BOS can the results net a significant performance improvement in the absence of major system impairment (i.e. shade). All systems can show large harvest gains in scenarios with shade induced from a pole, tree or dormer. But in well-designed residential systems, or large com-mercial systems, these shade scenarios rarely occur. Far more important is how the system performs in balanced, full sun.

For this test at the PHOTON labs, the independent test engineers used a fully lab-grade test setup. These conditions were similar to a new, well-architected, unshaded system:

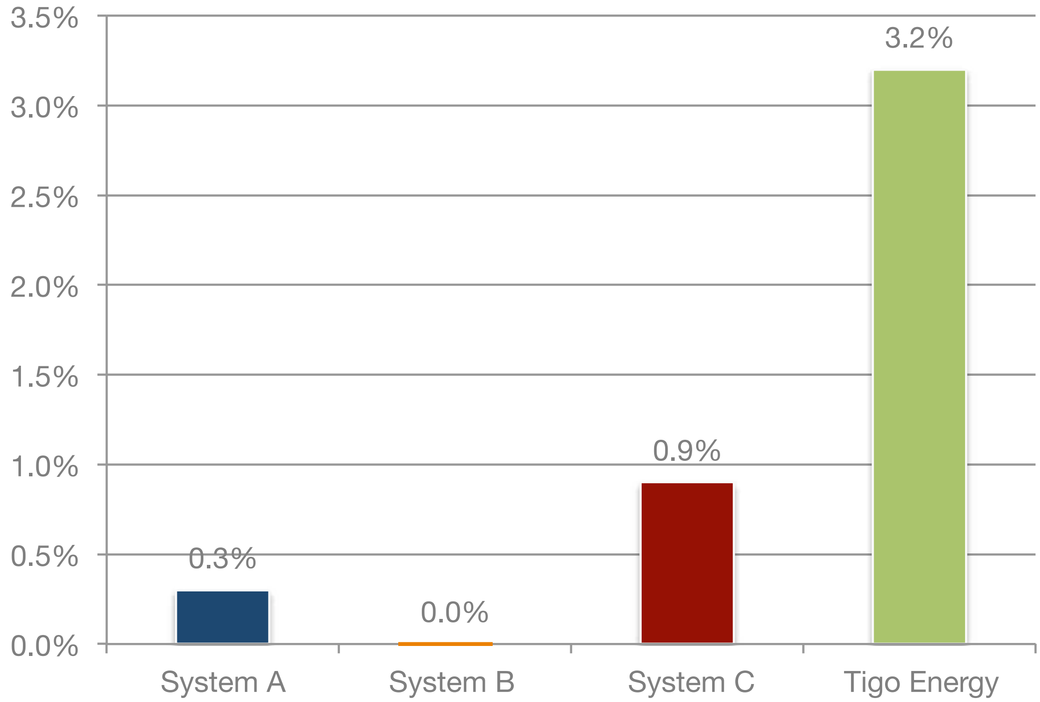
- No hard shade
- Modules of same make and model
- Front glass was cleaned
- Right angle irradiance (lamp)

The results of the test show improvement over the base case - the same string modules controlled by the identical central inverter (today's traditional architecture). Tigo Energy significantly outperformed all competition, generating 3.2% more power, compared to negligible or no gains for the others. Tigo Energy generated 3.5 times more incremental power than the closest competitor.

Since even perfect arrays under real-world environmental conditions are subject to dust, thermal gradi-ents, clouds, and silicon aging, the numbers here represent a conservative starting point for the incremental energy a system owner might expect from the Tigo Energy Maximizer system. As mismatch expands over time as system components soil and degrade, these initial harvest upsides will grow year after year.

The lower results from the other tested DC/DC solutions are predictable and easily explained. Standard approaches to distributed MPPT employ DC/DC voltage conversion circuits (boost or buck-boost). These architectures use transformers, which reduce efficiency and increase the system cost. Because of this lower efficiency, these systems consume 2-3% of the system's energy, which is a significant proportion of the mismatch-related harvest. Thus, these approaches add economic value only in shaded applications. In contrast, the Tigo Energy Maximizer was engineered only after the research team fully analyzed practical operating conditions, resulting in an Impedance Matching architecture that yields significant performance upside in both shaded and unshaded systems. The PHOTON lab results demonstrate why Tigo Energy systems today can be found in hundreds of residential, commercial and utility-scale projects.

Chart A : Energy Harvest in Unshaded Scenario



Source: PHOTON, November 2010

ALGORITHM ADAPTATION ENABLES HIGHEST RESULTS IN SHADE TESTING

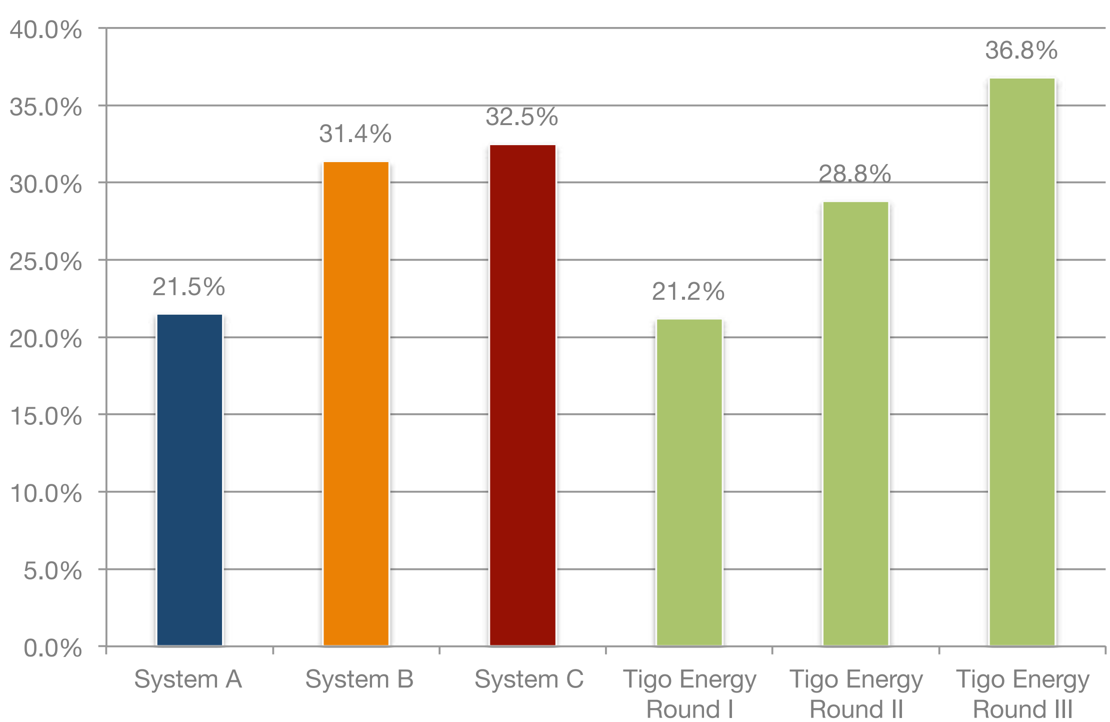
The second stage of the PHOTON performance testing was to examine the incremental performance of each DC maximization solution during controlled shade conditions. Shade patterns included those from a pole, horizontal and dormer impediments. When tests were run with Tigo Energy's full optimized adaptive tracking algorithm, Tigo Energy's results were superior to all alternative products.

Tigo Energy's sophisticated control algorithm, residing in the Tigo Energy Maximizer Management Unit, models the I/V characteristics, and calculates the distributed MPP of each module in real-time. In contrast, other PV BOS electronics solutions utilize the standard approach of a trial-and-error MPPT algorithm. These perturb and observe (P&O) implementations often sacrifice performance by oscillating around the MPP of each module, resulting in additional power loss. Tigo Energy's software algorithm and back-end analytics are constantly learning from "edge conditions" (unique, uncommon events) and optimizing the control calculations for expanded performance. This was evident during the horizontal shade testing as performed at the PHOTON labs.

The horizontal shade test involves placing the shade element across the modules, and turning on the lamps to full sun. Due to the artificial consistency of both the irradiance and the hard shade (not found in outdoor conditions), the Tigo Energy Module Maximizer was not fully calibrated during the first test. As a result, the system generated 21% incremental power – a financially beneficial result but not optimal. Because the Tigo Energy solution is based on an iterative self-learning algorithm, the second and third tests built upon the available data and employed software based enhancements. Each resulted in significant improvements. In the second test the output was 29% above the base case, and the third test showed a 36% improvement. This powerfully demonstrates the value of the Tigo Energy's adaptive algorithm, which adjusts itself for the conditions affecting any specific array in any environmental condition within the first few days of operation. Algorithm improvements are occasionally pushed to the installed base of Tigo Energy systems to deliver incremental improvement.

At greater than 36% harvest on the horizontal shade test, Tigo Energy is once again generating 3% more energy than alternative solutions. This demonstrates the fundamentally more effective and efficient approach to power optimization.

Chart B : Energy Harvest in Horizontal Shaded Scenario



Source: PHOTON, November 2010
Note: Round III not published but verified by PHOTON.

TIGO ENERGY DELIVERING THE TOTAL SOLUTION

While the majority of the PHOTON study and corresponding article focused on the benefit of incremental power production from the distributed solutions, the author points out that this is but one piece of value from a holistic implementation. The Tigo Energy Maximizer solution not only increases power production from a PV array, but also contains an advanced communications function. With this capability, the solution can disable the voltage output of each module, greatly enhancing system safety. Furthermore the Tigo Energy solution delivers module level monitoring granularity and complex system analysis tools to maximize system uptime while reducing commissioning, O&M and system debug costs. The Tigo Energy monitoring system is unique in delivering synchronous data samples from each module - information which enables accurate system debug and automated analysis.

PHOTON recognized that most alternative solutions do not provide the breadth of value found in the Tigo Energy solution and thus do not provide the economic benefits to warrant the market adoption established by Tigo Energy.

"However, it is likely that future performance optimizers will be purchased for a completely different reason: They permit the monitoring and control of the system at module level. So that they can, in case of fire, eliminate the output voltage of the photovoltaic system in a very short time. Moreover, it is theoretically possible to detect faulty modules very quickly. A prerequisite for these systems will be active communication such as that of Tigo ..." [2]

While other tested solutions re-partition and distribute existing balance of system elements (MPPT or the inverter's boost stage), Tigo Energy's Impedance Matching represents a new and innovative approach. The semi-distributed approach with centralized intelligence is maturing rapidly and consistently improving. Tigo Energy brings the advantages of distributed electronic intelligence while optimizing conversion efficiency and deployment cost.

As Micro Inverter or DC/DC conversion technologies fully distribute and replicate power tracking (P&O MPPT) or inversion in every module, they can be easily tested with power supplies and simulators. Yet the full distribution of these functions have a corresponding penalty in cost and efficiency. To achieve the unprecedented operational efficiencies, Tigo Energy's Impedance Matching requires the Maximizer to be present on each module in the inverter's MPPT path. When testing, the Maximizer system will not function as a partial system or with power-supply based simulators. The power control is always implemented relative to the best performing module in the system and thus can be deployed in most new or existing on-grid or off-grid (charge controller) system.

Distributed optimization technologies are reaching maturity in the market, so their value propositions (cost and performance) can be tested and verified objectively. This testing by PHOTON represents important progress in objectively assessing the available solutions. As manufacturers' marketing claims are replaced with independently verified performance data, customers will become better informed and can select the most beneficial technology for the maximization of the their PV project.

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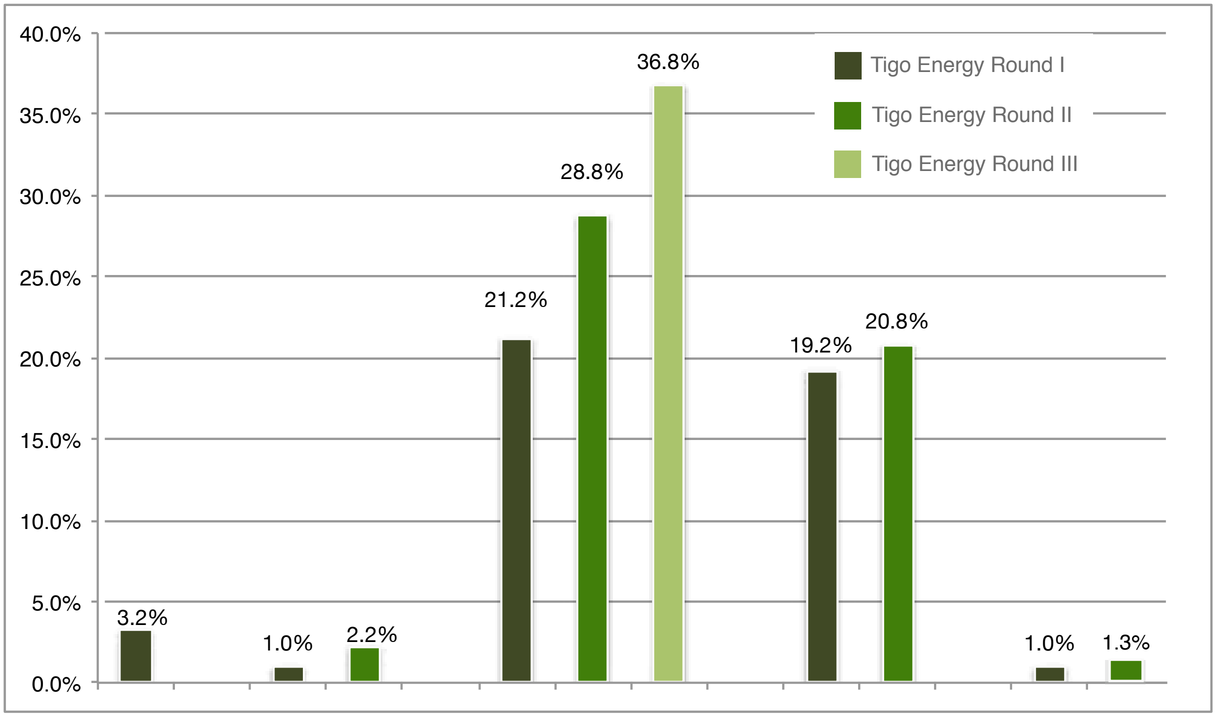
[2] Source: ibid.

Chart C : Tigo Energy Harvest in Each Shade Scenario



Source: PHOTON, November 2010
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APPENDIX

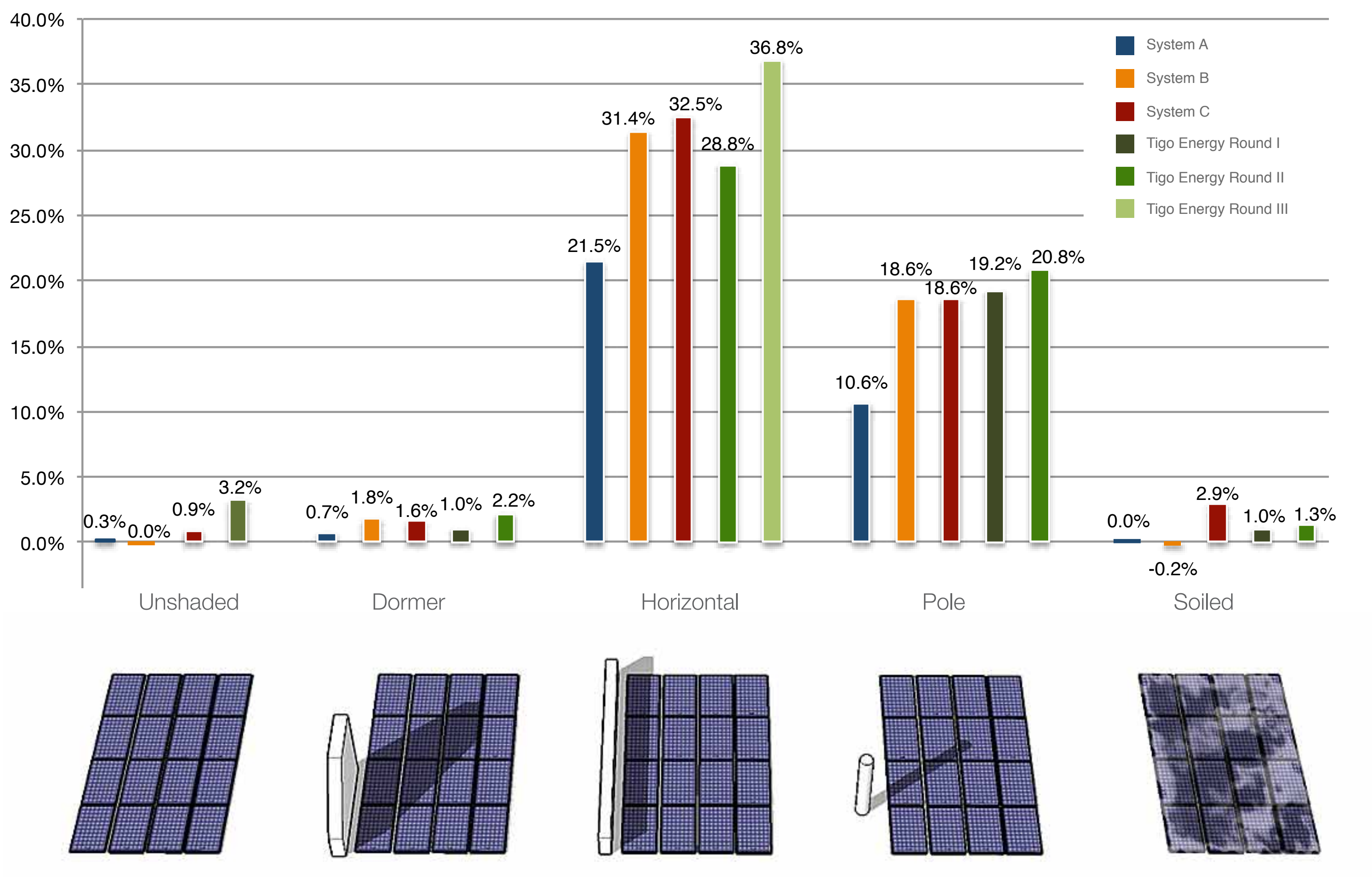
Test setup:

System size: 2.5kW

Modules: 180W Modules from Tier I manufacturer

Inverter: Off-the shelf Sunways AT2700 inverter. This was the same inverter used in the base case. No other changes were made to the inverter settings or system wiring.

Chart D : Full Test Results from Shade Scenarios



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