Performance of Partial Shaded PV Generators Operated by Optimized Power Electronics

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Executive Summary

Inhomogeneous shading on the PV generator leads to disproportionately high losses. As the potential of PV generation on roofs or façades is to be increasingly utilised in the coming decades, these cases will occur more frequently. The aim here is to provide an overview of the challenges and state-of-the-art technical solutions for partial shading. Current developments in PV engineering show that maximum performance lies in the combination between optimised module placement, the use of modules that are tolerant of shading and optimised power electronics.

Shortly after the discovery of the solar cell, blocking or bypass diodes were used to solve the inhomogeneous currents of groups of solar cells arranged in series or parallel wiring. Even today, they are still the most efficient and robust solution for the majority of common shading PV applications.

Due to the very high rated outputs of the solar modules and the presence of only three bypass diodes, high temperatures can occur on a locally shaded solar cell. This forces heat outputs of up to 200W or 100W in the butterfly module connection through the associated activated bypass diode, which must be dissipated by the most shaded cell. If additional small-area defects occur in this affected solar cell, hotspot peak temperatures can occur, which can lead to permanent damage to the module or the risk of fire.

However, in order to prevent a third of the module output being lost in this case, four or more bypass diodes are now used in so-called shadow-tolerant PV modules. With a higher number of bypass diodes per module area, it is also possible to selectively bypass smaller, less efficient areas of the module, which leads to an increase in the module yield. The hotspot effects can also be comprehensively and robustly prevented by the small number of solar cells per bypass diode, provided the bypass diode is properly designed. The first manufacturers are beginning to place these shade-tolerant PV modules on the markets.

Today, planners can also select different power electronics systems for the next step in system integration towards grid feed-in, i.e. the connection of the individual modules in the string. This is the classic series connection of all modules in the string to the input of the DC/AC string inverter (SINV), which leads to the highest yields for weak and medium shading. This applies, for example, to light shading with a chimney or a ventilation pipe, where no more than one tenth of the modules in the string are reached by the shade at the same time during the six hours around midday, even when using standard modules with only three bypass diodes. (see Table 1)

With medium to heavy shading, the widely used DC/DC converters directly on the PV module (MLPE), often also called power optimisers, can be used profitably. However, the combination of shade-tolerant PV modules with conventional SINVs can often deliver comparable annual yields. However, if the optimisers are also used behind each module even with weak shading (allMLPE), they deliver less yield in total than the simple SINV, as their own DC/DC losses then have a negative impact compared to simple connectors. This only becomes apparent if the MLPE manufacturers' data sheet claims of 99% efficiency are not viable. The published measurements carried out in independent laboratories over the last four years are listed in this report, which suggest that losses are around 2% higher.

As the differences in yield between the power electronics variants SINV and MLPE are usually less than four per cent in annual yield for light to medium shading, the above-mentioned real MLPE efficiency at the specific operating points plays the decisive role in planning the most efficient system. However, as the commercial PV software planning tools currently use these MLPE manufacturer specifications which are over estimated, no meaningful system comparison can be expected for these shading categories. In this report the results of annual simulations performed by some sophisticated simulation tools that take these real MLPE losses into account are discussed.

Table 1: Comparison of annual electrical performance of PV system variants are given in terms of different degrees of shading and PV module types, standard modules with three bypass diodes or more and the choice of power electronics like SINV or indMLPE or allMLPE while + indicates better – less performance with 0 for no gains in performance expected.

Shading Scenarios			**PV Module**	**Power Electronic Systems**		
Shading degree	Objects	Modules affected	Type	SINV	indMLPE	allMLPE
Weak		<10%	Standard	+	+	-
			4+ Bypass diode	+	+	-
Medium		>10% and <40%	Standard	0	+	+
			4+ Bypass diode	+	+	+
Strong	Buildings, trees	>40%	Standard	-	0	+
			4+ Bypass diode	0	+	+

If there is very heavy shading in the system, so that more than 40% of the PV modules are shaded at the same time, e.g. by nearby neighbouring buildings or large trees, or if there are solar modules that have different orientations, and the strings are too short to use multi-string SINV, the allMLPE remains the most efficient system variant. It is also worth keeping an eye on future developments in power electronics, which may offer string inverters with more multi-string inputs. It could be helpful if shadow-tolerant PV modules that offer a higher DC voltage than today's standard modules come onto the market, so that the DC/DC boost converter internal to the SINV can be dispensed with and efficiency increased.

The long-term stability of the power electronics itself is also a highly relevant parameter to avoid expensive labour costs in the event of servicing, e.g. directly on the roof, when replacing the MLPE, which could possibly be more frequent due to the higher operating temperatures. PV designers can increase the annual yield by increasing the distance from the PV module to the shading object when using a SINV, without having to use an MLPE, which is one of the recommendations in the report.

Key Takeaways

- Detailed performance analyses have shown that with partially shaded PV generators, conventional string inverters sometimes even achieve better performance in these applications than the market-dominating optimisers.
- Such meaningful recommendations for high-performance systems can only be made if the realistic losses of the optimisers themselves are taken into account, which are typically overestimated at 2 %. However, as these annual performance differences between optimisers and string inverters are usually less than 3 % in a market dominated by lightly to moderately shaded PV systems, optimiser manufacturers are obliged to provide realistic efficiency data.
- To enable PV planners worldwide to offer their customers the optimal PV design under partial shading conditions, commercial PV software tools need to improve their products both in terms of component efficiency data and in terms of calculating the actual operating points of each optimiser based on each solar cell of the PV module, rather than using simple average unrealistic weighted optimiser efficiency data.
- MLPEs should have the parameter option to switch off the avoidance of hot-spot operating points in order to be able to generate the maximum PV power throughout the year without the risk of a harmful hot-spot effect, as is the case with half-cell modules.
- A wide range of additional research work is being carried out to reduce PV shading effects. They range from new variants of sophisticated power electronics for each solar cell, including the control system, to optimising the mechanical tracking of single-axis large-scale PV power plants on uneven terrain.
- The cost-effectiveness for the end customer of PV partial shading can be characterised not only by the higher investment costs for components and installation, but also by the high costs for tradesmen when replacing defective optimisers. When it comes to comparing the probability of failure rates of optimisers due to the higher ambient temperature on the roof compared to string inverters in the building, the experts still must wait for independent studies of service cases during replacement in the field.