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Debunking string inverter misconceptions

Words: Mike Mahon, SMA America

There are common, and intertwined, misconceptions in the PV industry about string inverters today. The first is that they are subject to the 'Christmas light effect', meaning, if one module can't produce power, the whole string will stop working. The second is that in the presence of shade, inverters will be forced to work at the point of the 'weakest module in the string', sacrificing large amounts of power that only module level power electronics (MLPE) can regain. SMA America is here to help put the record straight.

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The above theories are incorrect for a couple reasons. Firstly, inverters are not the component of a PV array that prevents the 'Christmas light effect.' Additionally, current technologies in PV modules and inverters have solved the problem of the 'weakest module in the string' and provide optimized performance without the continuous power loss and complexity of MLPE.

The Christmas light effect

This describes the effect in a string of lights where one burnt-out bulb can stop the whole string from functioning. For a string of PV modules, the implication is that if one module is not producing power, none of the modules in the string will work.

This belief is incorrect, and the reason it is not true has nothing to do with the inverter connected to the modules. Before introducing the devices that prevent the Christmas light effect, let's explain the reason they are included in PV modules.

A common layout of crystalline silicon PV modules consists of 72 PV cells. These cells are all connected electrically in series within the PV module. PV modules have external leads that allow for the modules to be connected into a string; this is also a series electrical connection. If 10 of these modules are wired in series, that means there are 720 PV cells wired in series in this string.

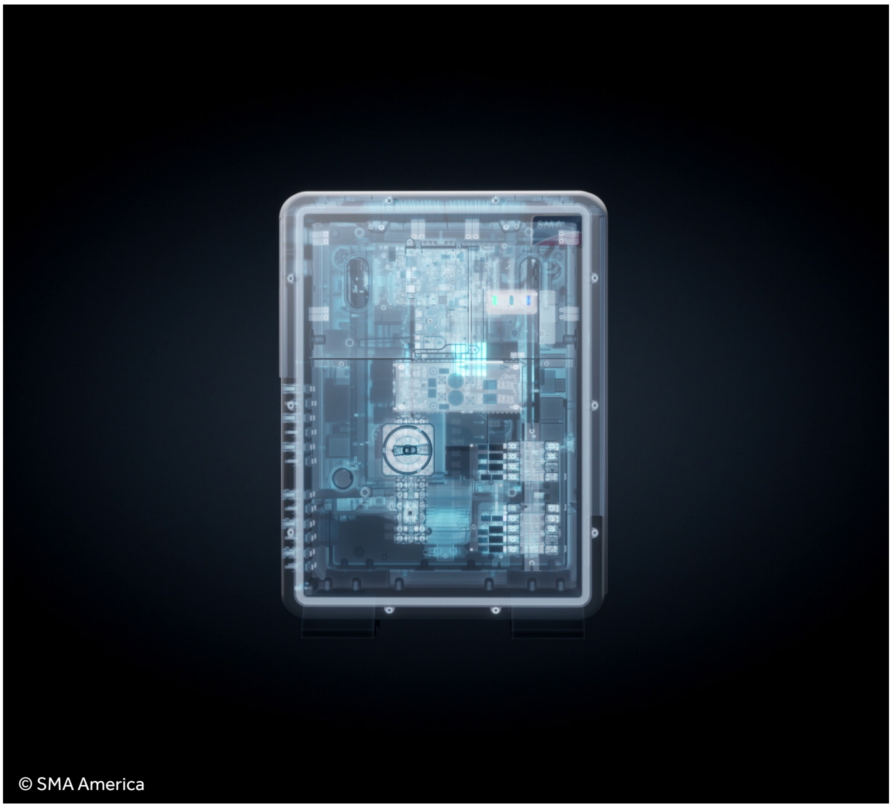
In a series circuit, each element has a single electrical connection to its neighbour in either direction. There is only one path for current to flow through a series circuit and for current to flow, it must have a continuous electrical path. That means that a failure with any device wired in series, including the wiring between the devices, has the potential to stop the whole circuit from working. Any single point of failure brings the system to a screeching halt.

Bypass diodes

To ensure there is no single point of failure in a PV string, silicon cell PV module manufacturers include devices called bypass diodes. Manufacturers typically include three bypass diodes in their products.

Bypass diodes are wired in parallel with a subset of the cells in the module. As the name suggests, parallel wiring provides two or more parallel paths for current to flow between two points in a circuit. With parallel wiring, if one current path between the two points is blocked, there is another path for current to take around this roadblock. PV module bypass diodes act as an alternate path for current to flow around any failure in the portion of the module wired in parallel with the bypass diode.

If there are three bypass diodes within the PV module, as is commonly seen, one-third of the module cells are each protected by one diode from the single point of failure issue of series wiring. A common physical layout for PV modules is six columns of cells, so for a 72-cell module, the layout would be six columns of 12 cells each. Two columns of 24 cells would be protected by one of the three bypass diodes.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Current will flow in an electrical circuit along the path of least resistance. Any issue that causes the normal current path through the PV cells to act as a high enough resistance will dictate that current will instead flow across the bypass diode, and thus around the issue.

The bypassed PV cells do not contribute PV power to the overall string, but they do not prevent the other sections of the PV module from operating, either. The diodes' action also allows all other modules in the string to operate. Put plainly, bypass diodes will isolate the issue to the portion of the module they belong to, preventing the Christmas light effect.

This scenario holds true even when it comes to shaded PV modules. Shade will cause the cells to act as high resistance, so bypass diodes allow shaded portions of one module to be isolated from the other portions of that module. They also allow completely shaded modules to be independent of remaining modules in the string. If a PV module manufacturer chooses to place more bypass diodes in their modules, there are more portions of that module that will act independently, improving resilience against shade.

It is important to emphasize that the reason the Christmas light effect is incorrect is actually completely independent of the inverter. Bypass diodes have been built into commercially available PV modules for years, and there is no need for the use of MLPE, such as DC optimizers, to avoid the effect when modules are built this way.

The 'weakest module in the string' myth

This misconception is a variation on the Christmas light effect. It addresses a scenario in which there is partial shade on the string, where the shaded portions can possibly produce power but not at the same level as unshaded portions.

It is important to understand the operational curve of a PV array, called the I-V curve, to discuss the impacts of partial shade and how a string inverter minimizes the impact. I stands for current and V stands for voltage.

All PV devices, individual cells, one PV module of cells wired in series, or a string of PV modules, have an I-V curve that details the allowed combinations of current and voltage for operation at any specific temperature and irradiance. This information can also be used to create a power versus voltage curve that shows the maximum power point (MPP) for the string.

The I-V curve is set by the type and number of PV cells wired in series in the string and the irradiance and temperature the PV cells are experiencing. It does not matter what inverter type is harvesting power; the inverter cannot adjust the shape of the I-V curve. But the inverter does dictate the voltage point at which the system will operate along the I-V curve.

The primary job of an inverter is to find the voltage at which maximum power is available and track it even as light and temperature levels change. A basic MPP tracking algorithm is effective if the power curve is smooth, with one maximum. With uniform light and temperature throughout the string, the curve is smooth with one maximum power point.

If the I-V curve represents multiple cells, there could be different irradiance on different cells. This situation is described as 'partial shade,' where all parts of the circuit receive light but not at a uniform level. This scenario will lead to a power curve that has multiple local MPP's where, in a narrow range of voltage around each point, power goes down with either an increase or decrease in voltage.

Using a basic MPP tracking algorithm, a string inverter would remain on a local maximum, which is the highest power point within a narrow voltage range along the curve. But only one of these local maximum points will result in the highest power. Unless the basic algorithm is working on that point, there is another operating point, the global maximum, that would yield more power. Working on a local but not the global maximum is usually what someone means when they say the inverter is working at the point of the weakest module in the string.

Optimized MPP tracking to maximize production with partial shade

String inverter manufacturers have created a direct solution to this problem: optimizing the MPP tracking algorithm with a function that will periodically test the whole I-V curve to ensure there is not a better maximum point available than the current operating point.

Testing the curve means the string inverter will periodically switch from the basic algorithm to a sweep function. The inverter pushes operating voltage down to the minimum value for inverter operation, then moves operating voltage back up, past the start point and up to the maximum voltage the string can produce, then finally back down to the voltage where the sweep started.

During the sweep, the inverter is tracking string power and if the point where the sweep started and ended has lower power than another point tested, the inverter will move the operating point to that higher power point, the global maximum.

All major PV string inverter manufacturers have optimized their products this way to ensure their inverters can find a global maximum, even if there is partial shade. These optimized algorithms prevent the weakest module in the string from trapping the inverter and seriously impacting power production, even in partial shade. Most importantly, this optimization resides in the string inverter and does not require any MLPE to deliver this benefit.

While it is still common to see misleading claims in the industry around the 'Christmas light effect' or 'weakest module in the string,' current technology in PV modules and modern string inverters laid them to rest a long time ago.

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