WHITEPAPER

SHADEFIX

A superior model for power optimization

Executive Summary
This report provides a review of the results of a study conducted by the University of Southern Denmark that compares SMA's advanced PV optimization technology relative to other forms of optimization under a variety of unshaded and shaded conditions. Its key findings provide conclusions regarding power output, lifetime energy harvest, reliability and maintenance, and fire and installer safety. The paper also notes key differences between how safety and shutdown are being prioritized and addressed in North America and Europe, and examines the variants of SMA solutions in both regions.

The State of Power Optimization

For most PV system owners, solar power represents a significant investment with expectations of predictable financial returns. Those returns are dependent on key factors, including power output (performance) and output over time (lifetime energy harvest). For more than 30 years, solar professionals have been focused on those two criteria in order to provide customers with superior PV solutions.

While most PV systems are naturally designed to receive unobstructed and unshaded light, shading occurs in some situations. Considerable time, effort, and innovation have gone into mitigating the undesirable effects of shading on PV systems. Although no solution can change shade into light, **there are methods for maximizing the power of unshaded PV modules and reducing the negative effects of shade on an array.**

Shade mitigation strategies vary across the globe and can depend on various factors. The most commonly used approach in the U.S. residential PV market involves trying to optimize power production at each PV module using a complex assemblage of components. While this model showed advantages versus antiquated string technology, a modern type of optimization has now been shown to improve energy harvest while drastically reducing the number of components and the complexity in a system. Subsequent statistical failure rates thereby increase system reliability and lifetime energy harvest.

Current Assumptions

One perception is that placing small electronic devices under each PV module in a system optimizes power production. These components are commonly known as DC optimizers. They may also be referred to as module-level power electronics (MLPEs). They work by converting or manipulating power – increasing and decreasing voltage and current – for each PV module. This may improve energy harvest, particularly under certain conditions like when PV modules are heavily shaded; however, **it comes at a cost.** This solution requires complex componentry and constant operation, and it is conducted in an inhospitable environment for installation, operation and servicing of electronics.

MORE ENERGY WITH FEWER COMPONENTS

SMA has developed an optimization model that has improved upon current industry methodology by mitigating the effects of shading and increasing power production but doing so with far fewer system components. **Why do the number of components matter?**

It's well understood that a strong correlation exists between system complexity and system failure rates. **Reducing complexity and the number of components in a system will reduce the overall failure rate.** With this in mind, SMA developed a power optimization method that produces more power under most conditions than traditional optimizers while increasing lifetime energy harvest of a PV plant.

LUSSER'S LAW

Lusser's Law is a concept in systems engineering. It is a predictor of reliability and states that the reliability of a series of components is equal to the product of the individual reliabilities of the components. Lusser's law is often described as the idea that a series system is weaker than its weakest link, as the product reliability of a series of components can be less than the lowest value component.

This can be represented by the following equation:

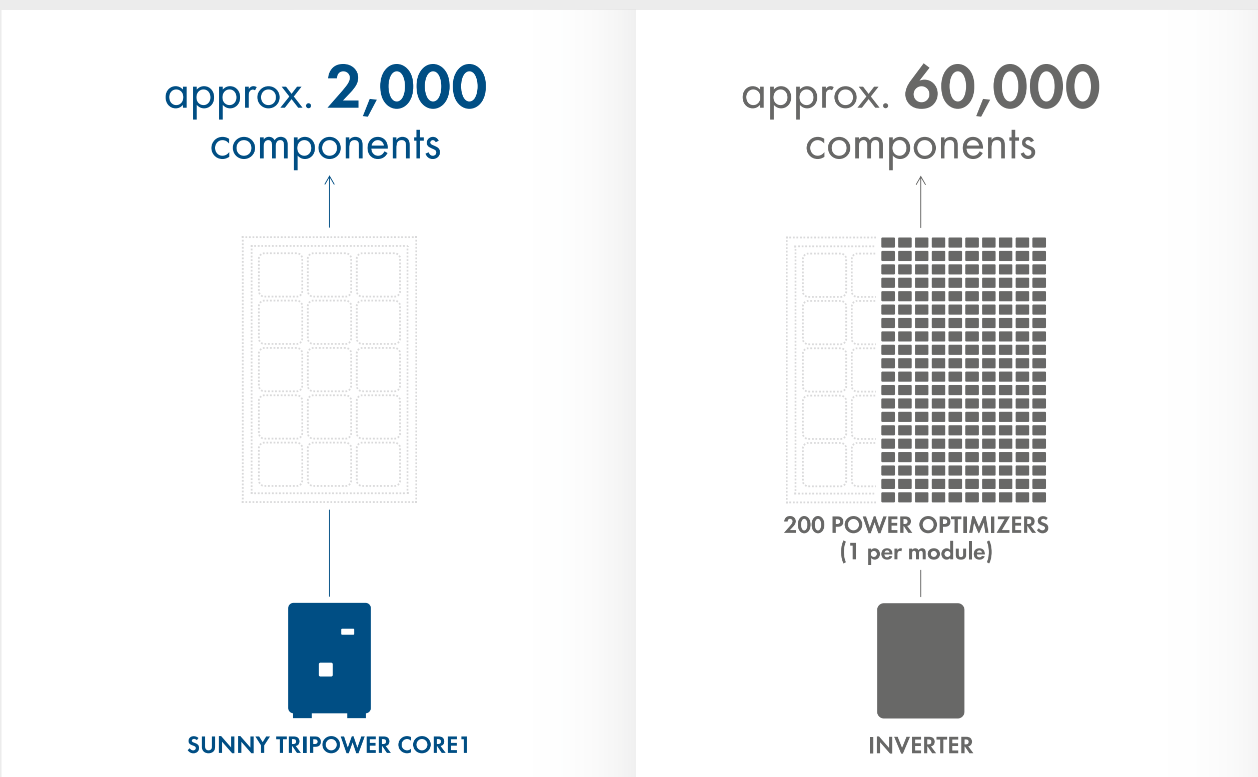
(System Reliability = Reliability of Component 1 x Reliability of Component 2...)

Example 1 – System with two components
$Rs = 0.90 \times 0.80 = 0.72$

Example 2 – System with 1, 2, 10, 100 components
Or, if all components are assumed to be of the same reliability (0.99), resulting in a system reliability of

1 component: $Rs = 0.99$
2 components: $Rs = 0.99 \times 0.99 = 0.98$
10 components: $Rs = 0.99^{10} = 0.90$
100 components: $Rs = 0.99^{100} = 0.37$

EXAMPLE PLANT



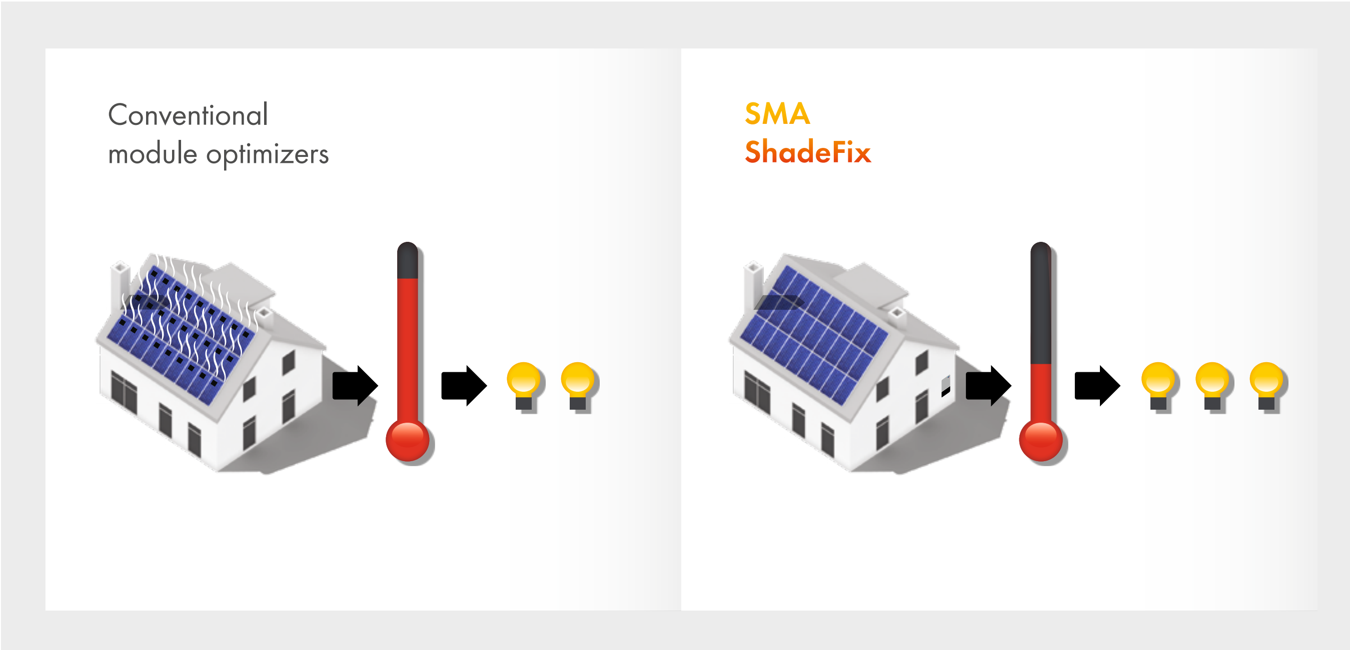
UNIVERSITY COMPARISON STUDY

This model for producing power was recently put to test by the University of Southern Denmark. University engineers tested three different systems. Two consisted of leading module-level DC optimizer solutions, and the third relied on SMA's patented, proprietary, string-level optimization – ShadeFix. The findings concluded the following:

- **ShadeFix optimization outperformed traditional module-level optimization in unshaded scenarios.**
- **ShadeFix optimization outperformed traditional module-level optimization in light to moderately shaded conditions.** Shaded conditions included situations like those that would be created by passing clouds or roof obstructions such as tree limbs, chimneys, vents, and dormer windows. In these instances, the traditional DC optimizers consumed more power than they could recoup.
- **ShadeFix optimization outperformed traditional module-level optimization on obstruction-free but overcast days,** due to the module-level devices consuming more energy than they incrementally produced.
- Traditional module-level optimizers only produced more power when PV modules within the same string experienced drastically different irradiance throughout the entire day. These included fully and permanently shaded scenarios, different orientations on the same string, and major mismatch – **scenarios that are often a result of poor system design.**
- **The daytime operating power losses when using traditional module-level optimizers resulted in lower overall energy yield** than when compared to SMA's ShadeFix optimization solution.
- **Traditional MLPEs exhibit a relatively high risk of failing** for any system applying MLPEs due to the very high component count. While the study did not extrapolate power loss due to expected failures, it indicated lifetime energy harvest would be impacted.

The study concluded that, in most PV systems, SMA ShadeFix optimization would outperform traditional module-level DC optimization – producing more energy annually and over the expected lifetime of a system.

LIFETIME PRODUCTION, RELIABILITY, AND SERVICE COSTS



As the study noted, in addition to producing more energy than traditional module-level technologies, **ShadeFix optimization has another advantage: a drastic reduction in componentry.** In a typical 50 kW commercial installation, an SMA system can total ~2,000 electronic components. All of them are housed in a weather-protected enclosure and are easily serviceable and replaceable.

By comparison, a 50 kW system using conventional module-level optimizers can have 60,000+ electronic components. Most of these electronics are housed in tight enclosures underneath the PV modules, exposed to moisture and thermal cycling, Additional measures must be taken to harden them for greater weather extremes and pests.

When one component fails, in most cases it requires a truck roll and secured roof access for service personnel and the removal of permanent and semi-permanent connections, PV modules, and fixtures, with a subsequent proper reinstallation and many hours spent on the roof. The additional components and connections also result in an amplified failure risk and increased fire risk from faulty assemblies, which will be examined in more detail later. The service requirement also introduces an unpredictable frequency and randomness into an installer's business model, which impacts scheduling, logistics, and labor costs.

In markets where MLPE devices are required by code to perform shutdown functions, **SMA employs the use of SunSpec certified rapid shutdown devices. They omit power-conversion features, which reduces MLPE componentry to less than 50% compared to traditional module-level optimizers.** Relying instead on SMA ShadeFix optimization, these systems experience increased power production, greater lifetime energy harvest, and lower maintenance costs.

Lifetime energy harvest is further amplified in the ShadeFix model by the service standard adopted to support it. When relying on traditional module-level optimization for power production, an integrator is likely to experience increased device failures. Each failure results in energy loss for the system owner, but sending a service technician to replace units as they fail is inefficient and costly. Installers are typically restricted to replacing traditional optimizers in batches, which means those incremental energy losses add up over time, impacting an installer's entire portfolio of systems. This service strategy also places a system owner at risk for finding backwards compatible replacements, as manufacturers frequently update their proprietary technology, which has often created installation and operation issues with older models.

The ShadeFix optimization strategy relies on less complicated devices performing less electronic work, so lifetime harvest is maximized. To further streamline service operations, ShadeFix leverages the automated functions of SMA Smart Connected to greatly reduce service needs. Smart Connected proactively monitors inverter health, alerts installers to issues, and sends remediation guidance or even replacement devices automatically. This saves an installer from making a diagnostic truck roll, reducing service trips by half.

Safety with SunSpec

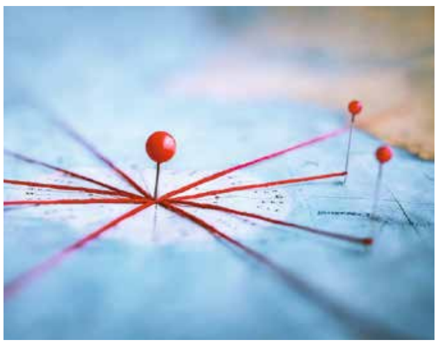
The SunSpec Alliance is a trade organization comprising more than 100 solar and storage industry participants from North America, Europe, and Asia. Its goal is to establish standards to enable "plug & play" system interoperability.

Rapid Shutdown
CERTIFIED

SMA Smart Connected reduces truck rolls by half

GLOBAL DIFFERENCES WITH CODE COMPLIANCE

In addition to power production, a case is usually made for the inclusion of traditional module-level devices to perform a shutdown or safety function. **However, the application of this function is differs in North America, Europe, and other regions across the globe, and there is continued debate about how it impacts safety and fire risk, as well as system performance and reliability.** With this function, it is important to evaluate both the intended result and its impact on individuals who encounter the system.



In considering whether to apply module-based shutdown devices, first responder safety is usually cited. Reducing system voltage in the event a first responder encounters exposed wiring and an energized system is important. U.S. code has settled on an 80V limit, which can still be hazardous but does provide a safer environment than no requirement. Firefighting best practices also still advise extreme caution and avoidance measures when dealing with fires where a PV system is present.

In this environment, it is critical to comply with code via a method that maximizes safety and fully meets shutdown requirements, but also does not sacrifice lifetime production. By utilizing the SunSpec communications standard and a SunSpec certified rapid shutdown device, **SMA has identified a solution for these markets that reduces the amount of rooftop electronics and minimizes both first responder and installer risk on multiple fronts.**

The SunSpec rapid shutdown signal is a simple ripple broadcast over the DC powerlines. Its receiver, located at the PV module, is a minimalist device that improves first responder safety but addresses other common problems as well. Unlike traditional optimizers that are constantly and actively converting power, consuming energy, creating heat, and experiencing wear, the SunSpec device operates passively. This allows the SunSpec device to minimize wear and tear and energy consumption is negligible. It can be pre-installed on the ground, reducing installation time on the roof. Finally, a device that operates on the SunSpec signal is designed to be interoperable, which means should a supplier exit the market, an integrator is not hindered by servicing or replacing a propriety solution.

It is also important to examine the reasons global markets have not adopted similar statutes.

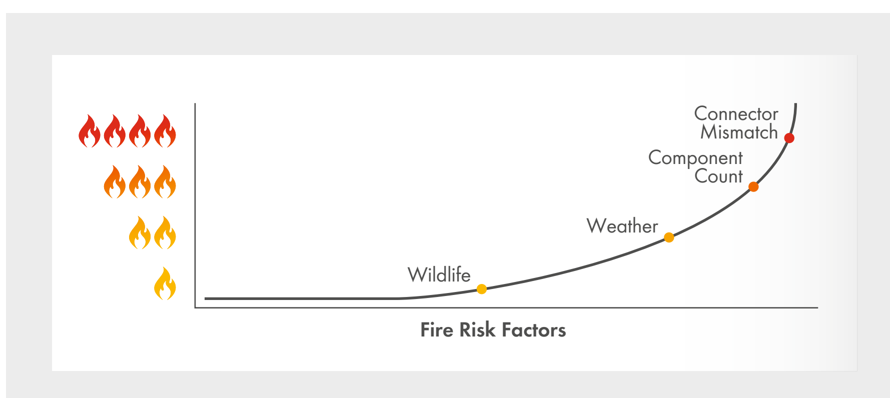
DISCUSSION IN EUROPE REGARDING FIRE RISK

In regions that have not mandated module-level shutdown, three primary reasons are cited: risk to installers, a false sense of safety, and an increased fire hazard.

When implementing module-level shutdown, conditions require installers to spend more time on a roof, which places them at risk for falls. According to 2018 OSHA figures, "The leading causes of private sector worker deaths in the construction industry were falls, followed by struck by object, electrocution, and caught-in/between." Falls accounted for 33.5% of all construction deaths.

By mandating personnel spend additional time on the roof to install and service devices intended to mitigate the potential danger encountered by first responders, code is significantly increasing fall risk to installers to decrease de-energization risk to first responders.

In addition to the amplified danger faced by solar professionals, **the application of numerous electronic devices to a rooftop environment has also been cited as a potential fire hazard,** increasing the likelihood of property damage and putting first responders at risk for the very event the industry is trying to avoid.



TÜV RHEINLAND / FRAUNHOFER ISE STUDY

In a study published by the U.S. Department of Energy conducted by safety authority TÜV Rheinland and the global scientific and engineering research firm Fraunhofer Institute for Solar Energy Systems, authorities examined the risk of fire in PV systems.

That study noted "Often safety components like fuses and switches are integrated in the DC part of PV systems. Each additional component poses the risk of additional contact points and other sources of faults. The same applies to the installation of switches in the DC wiring, concerning the risk of fire emergencies in a PV system, however, additional switches are simply yet another source of faults."

Standard PV modules are equipped with two DC connectors. Each added MLPE device introduces four additional connectors. By tripling the number of cables and contacts that can loosen over time or be compromised by mismatch between different manufacturers, water intrusion, weather, and wildlife, fault and fire risk are also increased.

HIGH-PROFILE COMMERCIAL FAILURES

This concern recently played out during a widely reported dispute between retail giant Walmart and solar integrator Tesla. It resulted in Walmart suing Tesla for the removal of PV systems installed at 240 stores following several fires. This lawsuit was widely reported in the media. Walmart alleged gross negligence. Rooftop connections became one of the focal points of the accusation.

Although the case was settled out of court and all parties denied fault, the lawsuit exemplified the importance of reducing rooftop components with connectors. With fewer connections, cables, and electronic components on the roof, integrators can reduce the risk of failure or fire.

While markets address this topic differently across the globe, one thing is constant: SMA's ShadeFix optimization addresses safety functions via a model that meets code, maximizes energy production and lifetime energy harvest, and reduces business risk.

A SUPERIOR MODEL FOR POWER OPTIMIZATION

While traditional module-level optimization corrected some of the problems found in the earliest PV systems, an advanced optimization technology has now been shown to increase both system output and lifetime energy harvest, while improving installer safety and mitigating service risk. Integrators can find out more about SMA ShadeFix and SunSpec certified shutdown devices by visiting www.SMA.de, www.SMA-America.com, or contacting their local SMA office.

Sources

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THAT
CHANGES

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