Underperforming Assets – How much are you willing to accept?

Project team

Solarplaza Summit Asset Management Europe

SOLARPLAZA

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Introduction - Solarplaza

Over the thirteen years that we've been organizing solar asset management-focused events around the globe, we've seen a large number of pressing topics rise to the surface and dominate the discussions on stage and in the crowd. With the increasingly intelligent arsenal of monitoring and prediction tools, it's become more and more apparent how widespread the issue of asset underperformance actually is.

As we're preparing for the 12th edition of the Solarplaza Summit Asset Management Europe, we're zooming in on some of the key topics on our agenda. We're glad to be able to count on the expertise of our partner, Solarlytics, to already shed light on this topic ahead of the event.

This comprehensive paper, fully authored by Solarlytics, provides quick and clear insights into some of the main causes underlying underperformance and gives actionable pointers on how to act on them.

If you're looking for more in-depth know-how on this topic and would like to engage in further discussions, we'd encourage you to join us for the event in Prague on the 15th and 16th of October, where Solarlytics' president Rhone Rensch will also participate in a panel on 'Over & Underperforming Assets - Optimized Maintenance Strategies'. Learn more about the event on our website.

Introduction - Solarlytics

Imagine being a landlord and discovering your tenant is paying you 8%, 12%, or even 20% less than agreed for the next 20 years. Would you take action? This scenario is all too common in the solar PV industry, where underperformance is rampant, costing billions in lost revenue annually.

Underperformance can go undetected for years or be tolerated due to perceived cost-benefit reasons. However, a significant portion of the global solar fleet fails to meet expected production targets. According to the 2023 Solar Risk Assessment report by kWh Analytics, U.S. solar assets are trailing their P-50 levels by an average of 8%, with half performing even worse. This is unacceptable in any energy sector.

As the solar industry expands, it's crucial to analyze performance dynamics, identify design and equipment pitfalls, and implement cost-effective solutions to ensure solar assets meet and exceed investor and off-taker expectations.

Solarlytics

Solarlytics, a California-based tech firm, specializes in addressing these challenges. We ensure better returns for asset owners and investors by optimizing solar field performance and maximizing energy production. Our fully integrated IoT hardware and machine learning software solution: the BOOST Platform provides immediate performance improvement, data collection and analysis, voltage control, easier repowering, and aging equipment replacement all in one package.

Most common causes for underperformance

Since 2020, collaborations with large-scale solar asset owners throughout the US to analyze underperformance issues and develop hardware and AI solutions have led to this analysis. While myriad factors contribute to underperformance, we have found 5 primary categories stand out:

1. Voltage collapse,
2. String imbalance,
3. Failing inverters,
4. Lack of data-driven operations and maintenance, and
5. Equipment in need of repowering.

Voltage Collapse

Voltage collapse occurs when the solar array's peak power voltage drops below the inverter's operating range. Misaligned power voltage is typically due to wide temperature fluctuations, particularly during warm weather periods at the highest PPA tariffs.

Solution. With a smart DC-DC string optimizer platform, this issue is eliminated by increasing and maintaining the array's voltage within the inverter's range, mitigating energy loss during warm weather months.

String Imbalance

String imbalance disrupts overall solar field performance due to uneven energy distribution. This is typically caused by equipment failure, topography, shading, mismatched modules or strings, and other issues that create string misalignment.

Solution. Employing a dedicated maximum power point tracker "MPPT" for each string maximizes power output and adjusts string voltage to ensure efficiency and recover lost energy.

Failing 600V Inverters

Industry-standard 600V inverters from a decade ago are often underproduced or failing, with very little to no OEM service support. No manufacturer produces 600V replacement inverters.

Solution. A platform that acts as an intelligent adapter, seamlessly integrates higher voltage, higher-performing inverters without the need for costly restringing.

Maintenance Challenges

Missed maintenance and undetected/undiagnosed issues lead to a significant reduction in energy output. The impact of unperformed maintenance, unplanned downtime during maintenance, and problem source identification reduce energy production and decrease maintenance efficiency.

Solution. High-resolution data enables the operator to execute precise problem identification and machine learning diagnostics support his decision-making through proactive issue resolution, significantly improving maintenance efficiency.

Repowering / Mix and Match

Replacing or upgrading modules in aging solar arrays presents logistical challenges. Newer modules have higher efficiencies, different form factors, and electrical values. String imbalance is created if strings with failing modules are replaced with new modules or the entire string is replaced with new modules, resulting in energy production loss.

Solution. A string optimizer enables mixed-field operations by decoupling old and new modules electrically, maximizing production and minimizing downtime. This is realized as each string (or pair of strings) is run on its own maximum power point tracker.

Additional challenges in operation

As an operator, you may also be faced with additional challenges like power quality penalties and/or system availability due to humidity or tracker alignment.

Power quality

Inverters convert DC power to AC power and supply it to the grid. For this, the DC energy is chopped at a high frequency, a very fast switch-on-and-off procedure. With fast switching, harmonics are created, which are minimized to a low level to mitigate repercussions on the downstream grid-switching elements.

Harmonics are always produced to an extent, but the harmonics are more pronounced near the lower MPPT voltage window of the inverter. After several years of operation, degraded modules and hot weather further aggravate the situation and increase the level of harmonics. In this case, downstream elements may be triggered and switch off the plant or parts of the grid, a nightmare scenario for each grid operator. Therefore, grid codes have to be complied with and, in several areas, non-compliance is penalized with hefty, liquidated damages.

Solution. Increasing the DC field voltage well into the available MPPT window will reduce the level of harmonics generated and avoid such penalty payments.

Symmetrical DC field architecture

A decade ago, a select few inverter manufacturers adopted a bipolar architecture to reduce component cost. This topology exploits the voltage differences between the earth's ground and the positive and negative rails of the array. Unfortunately, early morning humidity often causes current to leak from either the positive or negative rail to the frame, producing voltage imbalance and resulting in a failed inverter start-up.

Solution. A bipolar inverter can start despite humidity with a DC-DC optimizer. This is because the optimizer isolates the shortcomings of the inverter topology from the unexpected consequences of leakage with the modules.

Tracker alignment

While single-axis tracker systems in regions with high direct irradiation are generally a good solution to increase the energy yield of a plant, sometimes a row may be out of order or misaligned from the neighbor rows. This will reduce the voltage and current of such strings and lead to a string mismatch which will impact the energy production of the central inverter.

Solution. A string optimizer that decouples the different strings electrically, thus maximizing production. This is realized as each string (or pair of strings) is run on its own maximum power point tracker.

How to improve PV energy production?

Knowing the problem in the field is challenging enough but finding a solution can be even more difficult. A string optimizer platform that uses IoT hardware, detailed data collection, and machine learning analytics can provide solutions for many issues, including:

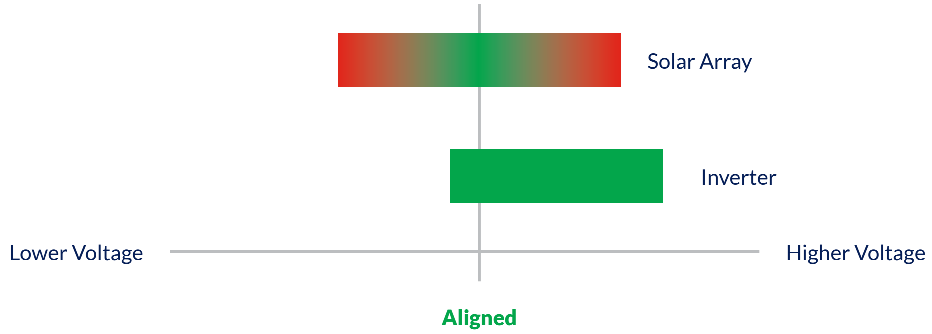
- Correcting voltage collapse issues without replacing the PV modules or inverter
- Normalize string imbalance created by mixing new and legacy PV modules on the same central inverter

- Increase DC loading without overloading the existing inverter or electrical BOS
- Recover energy lost from variable degradation and other sources of mismatch
- Replace legacy inverters with modern inverters without costly and time-consuming rewiring
- Pinpoint necessary maintenance with precise solutions with real-time knowledge monitoring and analytics

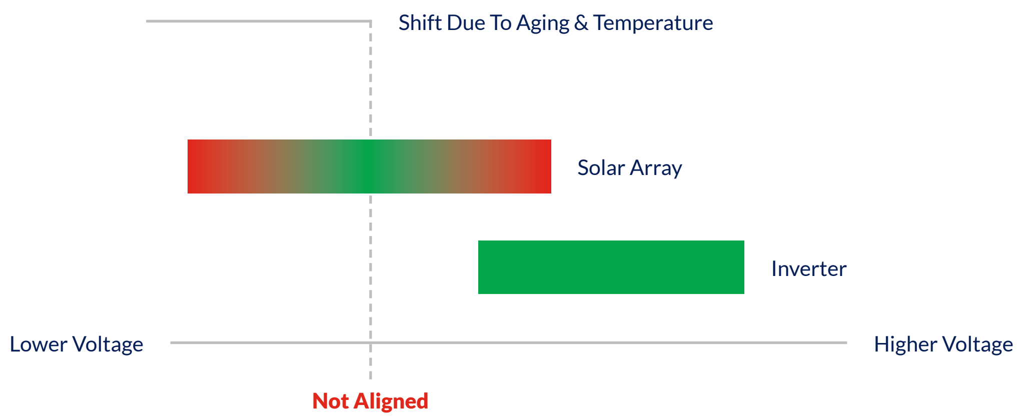
A string optimizer platform can improve the performance of existing large-scale PV systems. Expenses for equipment replacements and downtime are mitigated, resulting in lower costs, faster remediation time, and stronger financial returns.

Addressing Voltage Collapse

Voltage collapse emerges as a critical issue affecting energy production when the solar array's peak power voltage misaligns with the inverter's operating range – the DC bus voltage falls below the inverter's required level to produce its AC output voltage at full available power. When the plant is new, the solar array and inverter are aligned, as shown in Figure 1, and the maximum energy is transferred from the solar array to the inverter. Figure 1 illustrates the alignment.



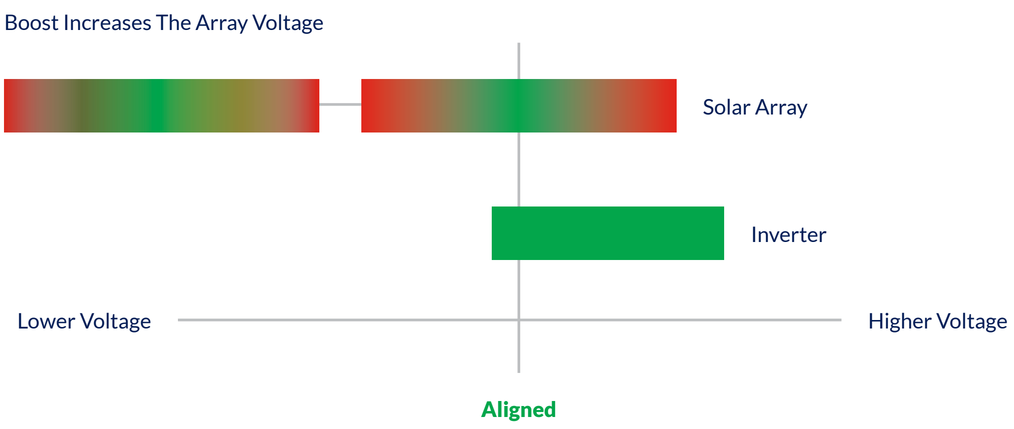
In contrast, alignment becomes a problem as the solar array ages and modules degrade, especially when warm weather reduces the module voltage. As shown in Figure 2, the solar array voltage collapses and shifts to the left.



The solar array's peak power voltage and the inverter's MPPT range are no longer aligned, resulting in a loss of energy production.

The problem is further exacerbated if the grid operator requires the site to produce higher voltages. A required AC voltage increase shifts the inverter's operating range to the right, creating even greater misalignment. Voltage collapse problems can be difficult to address because they are expensive to both ignore and fix. Ignoring the problem results in lost revenue from low energy production.

To address voltage collapse, correct alignment must be created between the solar array and the inverter - the PV field and the inverter need to work together. The optimal cooperation must be engineered for the local temperature profile and grid voltage, so the string voltage fits nicely in the inverter operating window. This can be achieved through the expensive effort of replacing large numbers of modules or swapping inverters. Or the asset owner can utilize a much more cost-effective solution by installing a string optimizer platform, which solves voltage collapse and increases energy production by aligning the solar arrays' voltage with the inverter's operating range. See Figure 3



By maintaining the correct voltage range, asset owners can maximize energy transfer from the solar array to the inverter.

Addressing String Imbalance

String imbalance leads to uneven energy distribution across the solar field and affects energy production. Central inverters maximize energy production when all the connected strings perform equally. String imbalance occurs when the performance of one or more strings differs from the other strings feeding into an inverter, resulting in a loss of energy production. There are many sources of string imbalance, including:

- **Terrain**: Arrays not mounted in a co-planar fashion will be imbalanced, resulting in energy loss. This is common when sites are implemented on uneven terrain, such as a rolling hillside.
- **Uneven Aging**: Solar modules degrade in power at a rate of 0.5 to 1.2% per year. Unfortunately, the degradation is not necessarily uniform amongst modules. The difference in degradation over a period will create a string imbalance.
- **Temperature** Gradient: Uneven temperatures across a solar field will result in string imbalance. Due to airflow, the temperatures of modules on the edges of a solar site are considerably lower than in the center of the site. Since older p-type mono- and poly silicon modules degrade at a rate of @0.4% per degree C° difference from 25 C°, a 10° difference equates to a 4% string imbalance, resulting in a loss of energy production.
- **Mixed PV Modules**: When new PV modules replace a legacy PV module due to module failure or damage, string mismatching can occur, creating a string imbalance
- **Shading and Soiling**: Solar arrays are susceptible to shading from vegetative growth, soiling, and other factors. If plants grow faster than the contracted vegetation management can control them, different strings will have different performance levels.

A string optimizer solution overcomes the impact of string imbalance in two ways:

- It maximizes the string's peak power through maximum power point tracking (MPPT) dedicated to each string instead of a single MPPT in the central inverter used for all 50-200 strings. As a result, each string operates at maximum power, increasing energy production.
- The string's output voltage is increased to a range compatible with the inverter. This allows the inverter to operate with a high, fixed-voltage bus while each string delivers full power. As a result, the system captures energy production that would otherwise be lost. By maximizing the string peak power, asset owners can maximize energy transfer from the solar array to the inverter.

Addressing End-Of-Life 600V Inverters

600V inverters were the industry standard in PV installation 10 years ago. These 600V inverters are at end-of-life; most are underproducing and many have failed. They need to be replaced, but replacement 600 V inverters are no longer available; 1000V and 1500V have become the industry standard. Since the replacements are incompatible, restringing the modules on the tables/trackers is necessary. This is costly and time-consuming, particularly if row-to-row underground cabling or completely new homeruns to the recombiners or central inverters are required. Installation labor and prolonged plant downtime make this an expensive and time-consuming solution.

The string optimizer performs as an intelligent adapter that allows legacy inverters to be replaced by higher-performing off-the-shelf inverters. It can be set to increase the voltage from the PV array to a fixed level within the new inverter's operating range, allowing new higher-capacity inverters (1000V or 1500V) to be used in place of the existing inverter and deliver full available power from the PV array. By mitigating the need to replace the strings, inverter replacement becomes considerably faster and less expensive, awarding the asset owner a stronger ROI as no cabling or new homeruns to the recombiners or central inverters are required.

Addressing Effective Maintenance Practices

Missed maintenance and undetected/undiagnosed issues can significantly reduce energy output. The impact of unperformed maintenance, unplanned downtime during maintenance, and problem source identification reduce energy production and decrease maintenance efficiency. The asset owner too often has limited visibility into the underlying causes of underperformance. A powerful IoT solution can improve maintenance by providing high-resolution data. Current, voltage, power, energy, and module temperature are collected at the string level and recorded in the cloud every 30 seconds. The data is available to the plant SCADA system for the customer and the operations and maintenance

provider. It becomes a valuable tool for the O&M (operation & maintenance) to spot problems in addition to visual inspections, drone snapshots, or other means. In addition, machine learning-based diagnostics are utilized to automatically identify potential problems in the array without the need for human manual analysis and provide the asset owner with specific recommendations for improved O&M. This information allows the O&M team to make an informed decision about whether the identified issue warrants an immediate field trip or not. Such high-fidelity data acquisition can significantly improve energy production due to enhanced maintenance as it enables insights into string performance that are impossible with traditional sampling rates common to inverters and monitoring systems. These insights include failing by-pass diodes, panel shorts, shadowing, and more. With high-resolution data, operations and maintenance are enhanced, thereby improving energy production. The cloud data can be made available to existing monitoring or asset management platforms through an application program interface API.

Addressing Repowering with mixed fields of old and new modules.

If the existing modules have defects of a mechanical or electrical nature, they must be retired. Just filling the gaps with new modules is not an option. Therefore, the broken modules are removed and replaced with salvaged modules from other areas of the site. This creates multiple empty strings that can be filled with new modules on the old racking. This “soft repowering” creates string imbalances, limiting the production of the new modules. The string optimizer platform electrically decouples the old and new strings. Each string is operated at its maximum power point and the optimizer outputs are connected to the existing combiner and DC cabling into the central inverter. So, with such string optimizers, a site can combine new and old modules and maximize production.

Machine Learning

Machine Learning enhances energy production in two ways:

- First, an enhanced MPPT algorithm automatically trained on its individual string can respond substantially faster to irradiance changes common in Eastern North America, Hawaii, or Northern Europe. Under such conditions, conventional MPPTs lose some energy due to the time required to locate peak power during changing irradiance. In contrast, such a Machine Learning algorithm harvests more energy as it adjusts to peak power in milliseconds.
- Second, Machine Learning pattern recognition algorithms automatically identify potential solar field problems such as short circuits due to moisture, shortfalls in predicted energy production compared with the original yield prediction out of the bankability study and more. Machine Learning pattern recognition algorithms are powerful tools that will take O&M as well as Asset management to the next level while improving energy production.

Conclusion

The solar industry is slowly realizing that utility and C&I assets are underperforming and, in many cases, underperforming significantly. Solarlytics is a performance expert and is committed to solving these problems and maximizing energy production at utility-scale solar plants.

Our fully integrated IoT hardware and machine learning software solution provides immediate performance improvement, data collection and analysis, voltage control, easier repowering, and aging equipment replacement all in one package.

By addressing voltage collapse, string imbalance, end-of-life equipment, and implementing effective repowering and maintenance practices, the BOOST Platform empowers asset owners and investors to achieve optimal returns.

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