The photovoltaic test site at Danish Technical University

Electrical issues in PV systems

The landscape of solar energy operations is changing as we enter exponential market growth. Anders Rand, Founder at emazys, discusses the outlook for technical field work in solar power plants.

The solar energy market is growing exponentially, causing an escalating disparity between the number of photovoltaic (PV) power plants and the available resources for operations and maintenance (O&M)[1].

The current landscape of O&M resources, notably PV technicians, is displaying signs of stagnation. Consequently, a competitive dynamic has emerged between PV installation companies and O&M firms in their pursuit of highly skilled personnel. While this scenario presents opportunities for PV technicians seeking employment, its long-term implications for the industry may be less favourable[2].

In addition, recent investigations signal a high level of technical diversity in the electro-technical challenges observed in the field. PV technicians face more and more complicated tasks at work, to keep up with a skyrocketing amount of new and aging PV installations, see Figure 1.

This article will look at the challenges and what we can expect for the future of solar PV O&M, in terms of field work.

The total cost of PV system ownership

The expected demand for skilled labour combined with exponential growth in capacity leads to two main challenges. The quality of work in installations will over time decrease, leading to more faulty installations and thereby reduced production and higher risk of accidents and fires. This happens because the resources will have to be spread thinner and thinner. Secondly, we can expect higher prices on maintenance work, as the demand increases dramatically over a short time span.

The overall effect of this dynamic is a significant change in the structure of the total cost of ownership (TCO). Since prices for components are decreasing rapidly, O&M thus takes a relatively higher share of the TCO for PV systems[3]. If we look at a 100 kWp PV system, the O&M share will go up from 23% to 33% towards 2030. So even these simple TCO numbers outline how O&M becomes essential, and the industry must solve this challenge for the sake of both human resources and technology[4].

Focus: electro-technical challenges

According to Wood Mackenzie, solar installations nearing inverter end of life reached 21 GW by the end of 2019, representing 3.4% of the global market, increasing to more than 14% of the total cumulative capacity over the following five years. Today, a portion of solar PV projects have a monitoring system implemented. However, few are synchronised in real-time with diagnostics tools in place and even fewer have basic periodical performance assessments carried out.

In a market with so little automation in place, there is an increasing demand for in-field inspections that can lead to actionable insights that can improve the state of a PV power plant. The process of identifying and solving electro-technical issues in solar PV power plants can, however, be quite demanding, often leading to a significant drain on team resources and truck rolls in vain.

Using standard electrical and optical tools for troubleshooting complex and invisible issues can lead to ambiguous test results and interventions that do not solve the problems. This means that experts with specialized PV knowledge, the most expensive staff, must always be involved, to ensure correct reporting and data analysis.

Conventional test methods, such as curve tracing, are essential for documenting the 'light to electricity' conversion in new PV systems. A useful measurement, however,

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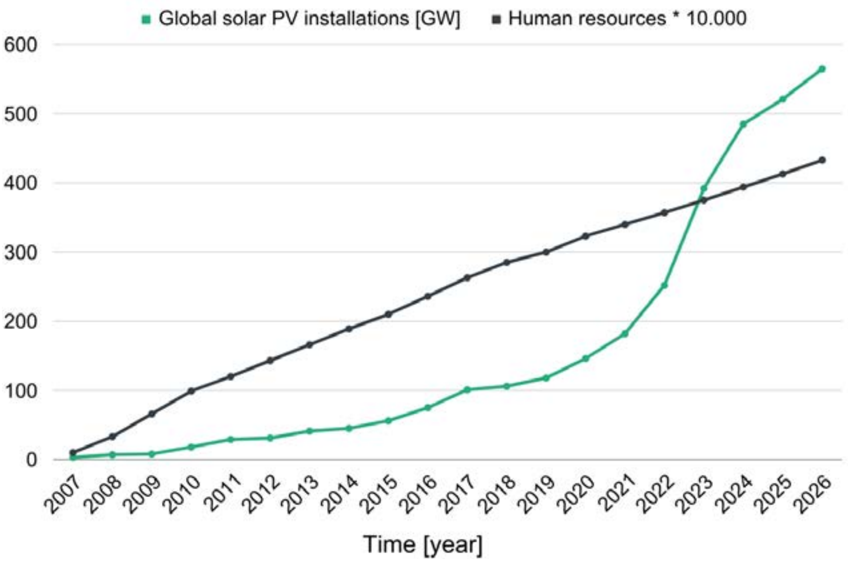

Figure 1: The graph shows the development in human resources in the PV industry, and the development in PV capacity over time. The number of people grows in a straight line, whereas the number of installed solar panels is accelerating. The curves are fitted to the same Y-axis, to illustrate how the exponential growth sets in these years

requires that results are captured close to Standard Test Conditions (STC). In short, it means that comparative performance-based field studies are limited to the sunny season.

More importantly, the performance-based methods were never developed to troubleshoot and locate discrete 'point like' issues in PV module strings. This is important, because the main share of electro-technical issues found in the field seems to have a root cause that is not necessarily related to the absorber efficiency and its degradation over time.

Novel studies point at the importance of understanding the interplay between all components in the solar panel circuit, and to avoid entirely focusing on the semiconductors. The latter is the traditional approach, which was transferred from academia to the field, but it is time to revise the strategies.

DC distribution: faults in cables and connectors

In 2016 there was clear evidence that failure modes in PV power plants were not only linked to material degradation in the light absorbers. The report 'technical risks in PV projects from TÜV' concluded that unmated PV module connectors were a leading cause of PV module failure[5].

This is an excellent example of the above mentioned electro-technical testing and analysis challenges. Imagine that a string of PV modules presents itself with a reduced open circuit voltage. In a case with unmated connectors, the lower voltage is thus not caused by cell efficiency degradation, but from an increase in series resistance in one or more connector sets. See Figure 2.

When the connectors are unmated, there can be a mechanical tolerance that leads to separation of the current carrying tips inside the connector set. The PV system voltages set up an electrical arc to transport the electrical current, creating a plasma of several thousand degrees. Such extreme temperatures lead to chemical transformations in the metal parts of the connector resulting in a 'welded' connector. The connector is now made of a different material and left in a state of high resistance, which is why a significant voltage drop can be measured across the module string. See Figure 3.

Diodes

A PV module normally features so-called bypass diodes in a junction box on the back of the module. The diodes serve as an effective point for disabling DC power in the event of an arc fault or other unsafe operating conditions.

But when the bypass diodes blow up and disconnect after an arc fault or a lightning strike, you end up with an unprotected PV module. Now, if a single cell is shaded while the bypass diode is open circuit, the module can no longer shift the voltage polarity, and the string current must pass through a shaded non-conducting cell.

The local dissipation of electrical power becomes a hot spot, that has the capacity to melt the lamination and cause an ingress of water. This can escalate and open the module to the external atmosphere, while creating a severe isolation resistance issue. This is another example of a complex fault scenario, that has nothing to do with the solar cell material degradation.

Recently, even more sources have pointed out that DC distribution and wire management is a prominent root cause of issues in PV power plants[6]. By counting fault events using workflow software, a database of knowledge was created, and the statistical analysis confirms that 59% of all issues are related to field-made connectors and wire management in DC distribution.

The great thing about workflow software reporting is that the findings tend to be free of confirmation bias and guesswork. The data is simply a description of the issues found by technicians during their daily work.

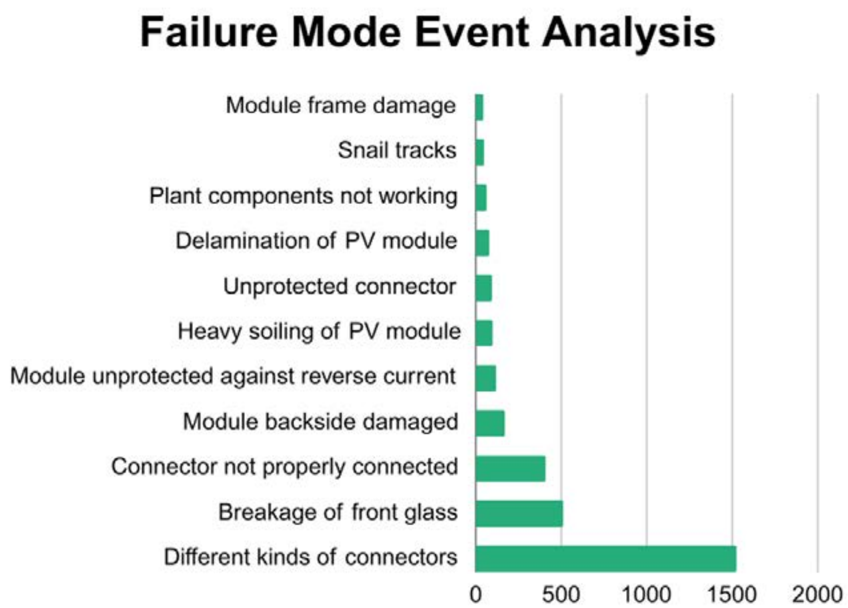

Figure 2: Example of rating of PV module failures based on classic Fault Mode Event Analysis, Report on Technical Risks in PV Project Development and PV Plant Operation, Horizon 2020 EU. Connectors and DC side issues dominate the failure modes observed

Figure 3: An example of a PV MC4 connector that has gone through stages of heating. If you don't test specifically for high resistance points in the string, you must inspect all connector sets to make sure that everything is on order. However, a visual inspection can require checking millions of connectors, so alternative testing principles are required to maintain the system ROI

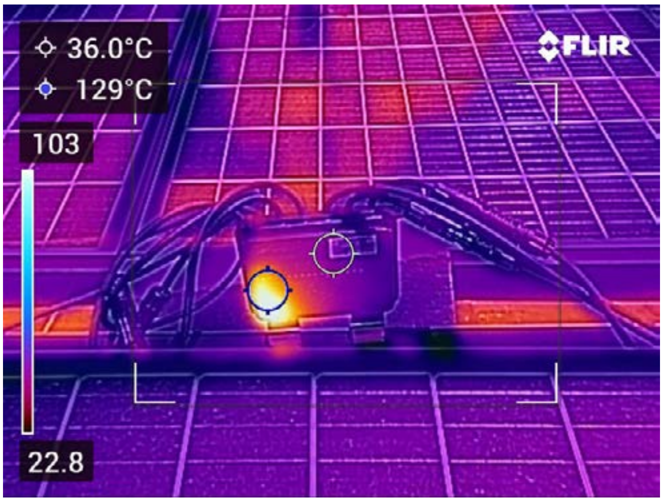

Figure 4: Infrared image of a Rapid Shutdown Device (RSD) that has a hotspot that measures 129°C. Such high temperatures bear witness of upcoming failure. Ironically, the RSD is put in place to protect the system against fire events, but here it seems to do the opposite

Newer investigations show evidence of continuing safety issues related to Rapid Shutdown Devices (RSD) and mismatched connectors. See Figure 4.

Module Level Power Electronics (MLPE) may certainly solve one task, but in some cases the MLPE introduce new technical risks as well[7].

MLPE components carry high currents, they sit in outdoor environments and endure challenging conditions, thermal cycling, exposure to moisture and mechanical movements. So, when MLPE deploy unmated connectors, a lot of things can go wrong.

The growing prevalence of 'extra' module electronics and components has contributed to a statistically significant increase in failure points within rooftop solar systems across the United States and elsewhere[8].

In conclusion; unmated connectors are the root cause of most problems and even fire prevention electronics can overheat due faulty connectors. So why add them to the system knowing what we know? See Figure 5 for an example of a real and recent photovoltaic fire event.

As time goes by, I start to wonder if the solution is to keep things ultra simple and focus on quality and craftsmanship instead of adding circuits to an already complicated system.

Figure 5: Solar panels catch fire at Lidl distribution centre in Peterborough. Arguably it is possible to avoid such events by a combination of rational system design, component quality, craftsmanship and preventive troubleshooting

Solar energy has enormous and proven potential, but it is time to adopt to an exponential mindset and try new technologies while constantly striving to make things simpler

There are even well described processes and methods to provide an early warning. Although these actions are classified as recommendations, the science behind it all is for real[9].

Transitioning to bi-facial modules and 1500 V systems, will only outline the challenges.

DC distribution: electrical isolation and ground faults

Another failure mode in PV systems, which is not directly linked to cell efficiency degradation, is electrical isolation faults.

In the beginning of the PV industry era, many projects were sold as 'maintenance free', but over the years we have learned that with currents of 10-100 A DC and millions of components at play, electrical isolation plays a critical role with regards to safety and financial ROI in PV.

According to the Photovoltaic Systems textbook published by NJATC, a solar PV ground fault is 'the condition of current flowing through the grounding conductor.' This type of current flow is an unintentional electrical connection. It flows between a current-carrying conductor in the PV system, and the equipment grounding conductor.

When there is a ground fault present, the electric current that was supposed to flow to the inverter or the combiner box, is flowing directly to the ground terminal. Above a certain current threshold, the inverter shuts down for safety reasons, and the ROI is on hold until the fault is mitigated.

When a technician goes to the field to lure out ground faults, we again see that standard testing can lead to prolonged service interventions. Traditionally, one would impose a high voltage pulse of the PV system and basically test the strength of the electrical isolation resistance (Riso). While this method is of course a rational safety requirement, it can unfortunately also ionize the equipment.

Moreover, knowing the isolation resistance as a number, will not reveal where the fault is sitting in the system. To pinpoint the fault, one must therefore carry on and work it out. When Riso is less than say 100 kOhm, the fault is manifested in the system, and it can be located after some trial and error.

The problem occurs when the Riso value is higher, but still low enough to create a permanent or an intermediate power shutdown, which is more often the case.

When testing the isolation resistance, the value you get is often much higher than the highest resistance value that will register on a standard multi-meter. In this way only clear-cut faults can be found. The intermittent faults stay present in the systems and demand repeated service interventions, until they manifest strongly enough to be found; exactly what we don't want to happen.

In the future we will likely see an escalation in systems that are not properly installed, which will manifest as more ground faults and dangerous work environments.

The exponential mindset: a necessity for the future of solar PV

For many years the field-approach to testing PV module strings has been focused on light to electricity conversion. In the field however, we have learned that the external circuit is of equal importance when it comes to the long-term operations and maintenance of the power plant.

The amount of experienced PV engineers per GW of installed solar capacity is dropping by the hour and it will likely lead to disruptions in automation solutions. We are already seeing entirely new concepts for on-site inspections, in the form of autonomous robots[10] and alternatives to conventional test equipment.

Such innovations enable the use of artificial intelligence (AI), which is a somewhat proven way to deal with a workforce that is simply not growing fast enough to keep up.

Solar energy has enormous and proven potential, but it is time to adopt to an exponential mindset and try new technologies while constantly striving to make things simpler.

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About emazys

The Danish Energy Agency has funded the Danish Technical University, European Energy, emazys and Micro Technic during 2022 and 2023.

Through the Energy Development and Demonstration program: EUDP 64021-2082 DigitalPV, the consortium has successfully worked out an advanced reliability study of high power 1500 V DC bi-facial PV modules