



A rooftop array in Germany. If several module strings fail completely, the result is usually high yield loss. At that point, it is worth finding out exactly where the faults are, and how to correct them.

Finding fault

O&M case studies: Two hypothetical scenarios and one actual case study of solar faults in the field serve as a reminder of both the importance of sophisticated O&M, and the need for a professional and proactive approach to PV maintenance.

Case I: 10% of installed modules have defective bypass diodes

Bypass diodes fail regularly, either because they do not have a high enough power rating or because they are overloaded due to nearby lightning strikes. This hypothetical case is realistic and shows how O&M service provider Enovos would respond.

The plant: a 5 MW ground-mounted plant, commissioned in 2011. The modules are oriented toward the south at a 30 degree angle.

The system uses a central inverter and has string-level monitoring. The performance ratio of the system is recorded via a solar radiation sensor.

The monitoring system reports: In many of the strings there are negative deviations to current compared with other strings that have a similar num-

ber of connected modules, angle of inclination, and alignment. The performance ratio of the plant is lower than in the same month of the previous year on days with comparable solar radiation. The monitoring software reports a fault. A closer look at the yield curves on days with high levels of solar irradiance reveals occasional kinks in the curves; that is, sudden drops of string current that do not rise again.

The hypothesis: The spontaneous drops in the string current indicate the failure of one or more bypass diodes in different modules. The failure of a bypass diode in a module usually results in the switching-off of one of three cell strings. The result is a sudden drop in output by one third. A decline in yield of this magnitude and in several modules can be detected in the yield curve of a string with good solar radiation conditions. In

low sunlight, this effect can be considerably less visible. After all, the failure of a single bypass diode in a measuring channel with 48 modules results in a deviation of less than 1% of the string current.

Since these effects occur in the I-V curves of several strings, it is probable that this is not a single local problem, but that the problems are scattered throughout the system. Nevertheless, it is not possible to be 100% sure that problem is down to failed bypass diodes. The problem could be dirty panels, for example, but this would not occur suddenly. In the case of a lightning strike, on the other hand, the problems generally only occur in a certain part of the system, and not in the entire plant.

Identifying the fault and the affected modules: The total yield of the plant has already fallen by more than 4%. The 2011

system receives a FIT of €0.2111/kWh. If the plant were functioning smoothly, it would generate around five million kilowatt hours per year, which it would feed into the public grid for a price of €1,055,500 per year. A 4% reduction in yield equates to an annual revenue shortfall of more than €42,000. At this price, looking into the problem is definitely worthwhile, as the cost of troubleshooting is likely to be lower than the potential benefit.

Since the fault appears to be distributed over the entire system, the first step is to conduct spot checks (with a thermographic camera and other equipment) in order to obtain a picture of the defects. Measurements of I-V curves or similar tests on each string or module are too costly at this stage. After the discovery of failed diodes on a considerable number of modules, it is time to determine the exact extent of the problem and the location of the failed diodes. For this reason, the operations manager decides to conduct a thermographic examination of the entire plant using a drone. A rough estimate of the price per megawatt is roughly €1,000. A drone pilot can take the photos in less than one day, provided that it is a day with consistently high solar radiation.

Other defects can be seen in the thermographic image, such as inactive or overheated cells. If the problem is not with the bypass diodes, the images will still help. Since a high level of solar radiation is a prerequisite for usable images in which even minor abnormalities are visible, it is necessary to plan accordingly. In Germany, it can take a few days or weeks until weather conditions are good enough. So time is of the essence.

Evaluating the survey: The thermographic image shows that around 10% of the modules have one or more failed cell strings. This confirms the assumption that the reduction in yield is caused by failed bypass diodes.

Results of the investigation: The product warranty for these modules is not valid after six years. However, since the output of a module decreases by at least 30% in the event of a permanently failed bypass diode, the operator can invoke the performance guarantee granted by the manufacturer. Such warranties generally guarantee an output of 80% of the rated capacity even after 20 years of operation. Although the costs for dismantling the

defective modules and replacing them with new ones have to be borne by the operator, the high yield losses make it worthwhile to invoke the warranty and replace the defective modules.

If the module manufacturer is no longer a going concern and its original module warranty has become worthless, it pays to take a closer look at the junction box and the diodes. Plug-in diodes that can be replaced in a few easy steps were often used during this time, and with material costs in the range of just a few cents, a fully functional module can be obtained. If the diodes are soldered in, the effort increases. But if the junction boxes are sealed, the diodes can no longer be replaced.

Key troubleshooting data: estimate of the cost of troubleshooting upon detection of decreased performance in monitoring: around €5,000 for the thermographic survey + one workday.

Estimated waiting time until the faulty modules were located: a few weeks.

Case II: Insulation faults in individual connectors of 20 module strings

Individual insulation failures are often difficult to detect in monitoring. And when insulation problems are suspected in the system, it is an additional challenge to pinpoint them precisely. In the following hypothetical case, Enovos would send a technician to the plant to examine strings and modules individually.

The plant: a 1 MW commercial flat-roof system from 2010, in Germany. The crystalline modules are oriented with a 20 degree inclination to the south. The system is equipped with 40 multi-string inverters. In monitoring, five strings are combined for each inverter.

The monitoring system reports: the ease with which insulation faults can be detected in monitoring depends, among other things, on the type of inverter used. Some inverters provide direct insulation values, others simply switch off when the value falls below a certain limit. The system described here uses inverters that do not measure insulation values. The result is that the monitoring first indicates reduced performance in the affected inverter when compared with the other inverters.

A closer look at the monitoring data shows: In the yield curves of the affected strings, isolated failures of entire invert-



Bypass diodes in the junction box can be a regular source of module failure.,

ers and all of the connected strings can be seen. This is especially the case in the early morning hours, but sometimes occurs at other times of day as well. This effect occurred relatively infrequently in summer but now that fall has arrived it is happening more often.

The hypothesis: The time at which the inverters fail may indicate one or more insulation faults. This is indicated on the one hand by the delayed start of the system in the morning hours when dew and moisture cover the modules, cables, and connectors, and on the other hand when rain reaches the affected area with the insulation problem. In order to determine the latter, the yield curves of the individual strings and inverters have to be compared with corresponding weather data.

Identifying the fault and the affected modules: Because insulation faults cause a reduction in yield and pose a potential safety risk (in extreme cases due to arcing), the operator decides to address the problem. A technician has to go to the plant. If the faults cannot be detected with the naked eye, it becomes complicated. After all, the insulation faults only occur at certain times, such as in wet and humid weather, and they can only be measured then. This means that the technician has to measure the individual strings and modules at the times when problems were detected during monitoring; in the early morning hours, for instance. Because the technician is in the

plant at the right time, the detective work can begin. First, they can set to work on all of the strings of the affected inverters individually and measure the insulation of the string at the inverter. Each time, they have to unplug the connector and insert the insulation measuring device. A single reading takes about two minutes to record. Added to this is the time spent on the roof walking between the various inverters.

Results of the investigation: Once the affected connectors have been identified, they are quickly replaced. This eliminates the occasional yield losses due to insulation faults. The plant owner no longer has to worry about plant safety and thus fulfils their obligation as operator.

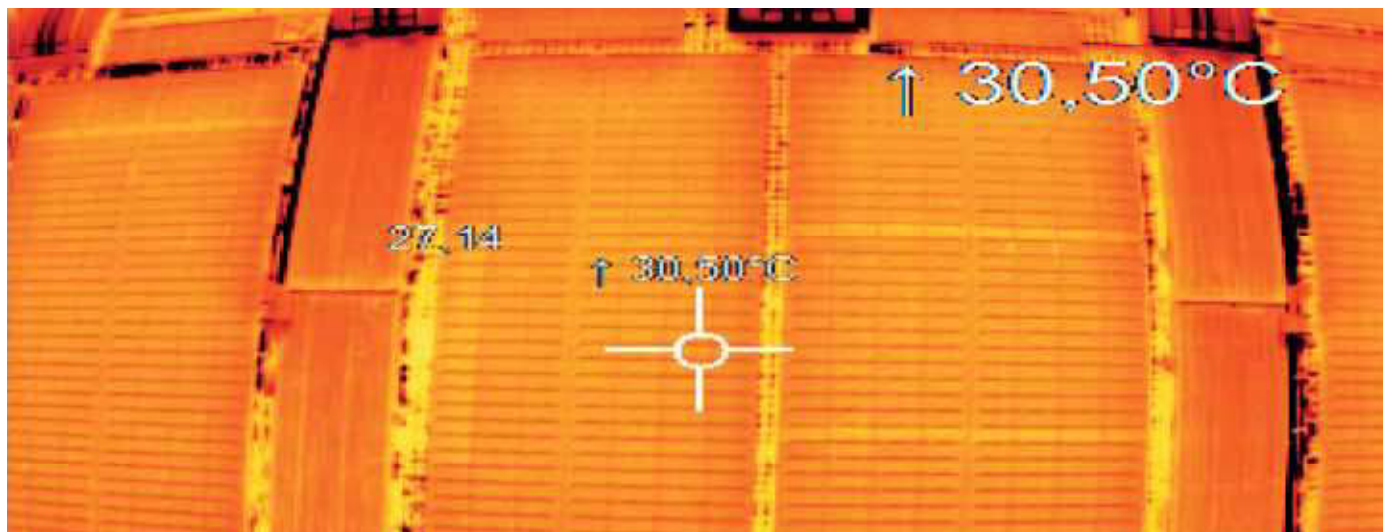
The monitoring system reports: Monitoring initially reveals that, for its size and location, the total plant produces a yield that is 6% too low in two of the three subsystems (approximately 1,700 kWp). Six module strings with eight modules each are interconnected for monitoring. The yield data of the individual measuring channels in the junction boxes (GAKs) are very different, although the conditions in the system are actually relatively uniform, with regard to the orientation and inclination of the modules, for instance.

The hypothesis: There are no visible signs of any unusual features on the front side of the modules, and the rear side of the modules cannot be visually inspected due

therefore recommends that the operator carry out a drone-based thermographic survey of the entire plant for around €2,000. An external service provider takes the images and sends them to the plant manager. The result confirms the manager's suspicion. The thermographic image shows that 20 module sub-strings have failed either completely or partially, and identifies the individual modules affected. It is likely that the problem has existed for several years.

Results of the investigation: The plant manager transfers the results of the thermographic examination onto a diagram of the modules and sends a technician to the plant. Based on the module diagram, the technician can repair the individual

Photo: Ensibo



A thermographic examination of a solar plant can pinpoint faults already identified, and spot additional areas of weakness or underperformance.

Key troubleshooting data: estimate of the cost of troubleshooting upon detection of decreased performance in monitoring: One workday.

Estimation of the cost of repair: One workday and small parts.

Case III: Several failed module strings

If several module strings fail completely, the result is usually high yield losses. At that point, it is worthwhile to find out exactly where the faults are and correct them. But even string failures can pose challenges, as evidenced by an actual case involving the O&M company Ensibo in a pitched roof system running parallel to the roof.

The plant: parallel-mounted, pitched-roof system with thin film modules and 4 MW of capacity, which Ensibo acquired as an existing system. The plant was built in 2009 in Germany.

to the roof-parallel installation method. In view of the plant's reduced output, the operator suspects that entire module strings may have failed.

Identifying the fault and the affected modules: Two factors would make it more difficult for a technician on-site to perform a string measurement: First, the backs of the modules can only be accessed with great effort due to the lack of maintenance openings and the installation method parallel to the roof. Additionally, the panels are thin film modules, which are connected in series in groups of eight modules with six sub-strings connected in parallel. The failure of a sub-string causes only a 17% lower string current at the generator junction box, which can only be detected under favorable weather conditions.

But this still does not localize which sub-string is affected. The plant manager

modules and strings in a targeted manner. He discovers a large number of module connectors are disconnected. These were probably not reconnected following a major rebuild of the plant in 2012.

The technician found no defective plugs in the system. He reconnected the disconnected plugs. The repairs increased the yield of the plant by almost 1%. With the 2009 feed-in tariff averaging €0.37 per kilowatt hour, the plant generated an additional €3,700 per year after repair.

Key troubleshooting data: estimated cost of troubleshooting following the monitoring alarm: €2,200.

Estimated waiting time until the module faults were located: three months.

Estimate of how long the diminished yield probably already existed: five years. ♦

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