Photos: Solarschmiede GmbH

Thermography not only provides the opportunity to detect existing power losses, it is also able to reveal potential future weak points that can then be resolved before major losses and costs arise.

Cell-by-cell inspection of MW power plants

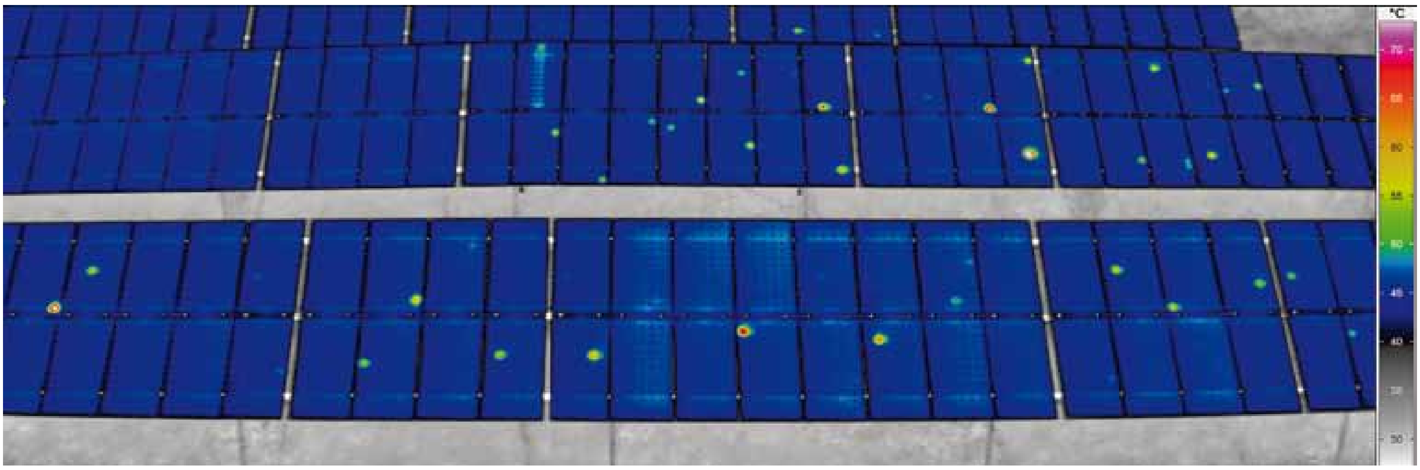
Thermography: Many power losses and failure risks in megawatt power plants continue to be undetected, despite modern monitoring systems and professional operations management. Thomas Reich and Bernhard Weinreich of Solarschmiede GmbH explain how adjusted thermography is able to prevent these losses and residual risks at reasonable costs.

As a rule, multi-megawatt PV systems are thoroughly planned, sustained investments. Environmental analyses are carried out beforehand, including yield simulations aimed at providing clarity about the profitability of the systems. Similarly, investors pay precise attention to the procurement of high-quality, durable components to ensure fault-free operation. In addition, professional plant management solutions are applied with the aim of minimizing the consequences of possible faults.

A systematic field study of PV generators carried out by Solarschmiede GmbH, of Munich, Germany, showed that there are undetected power losses of 1.5% on average even in up-to-date large systems. On average, 6% of the system power is definitely at risk of failure as a result of gradual module errors. Thermography not only provides the opportunity to detect existing power losses, it is also able to reveal potential future weak points that can then be resolved before major losses and costs arise. This way, the forecast yield can be sustainably ensured.

Electrical thermography

Electrical thermography is an analytical process that includes PV thermography. It has been in use for decades, initially to check contacts in transformer stations.



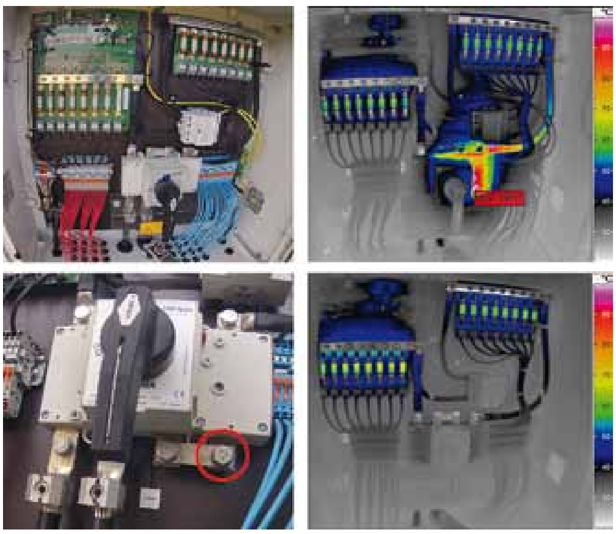
Thermal picture of a PV generator in a MW plant. Fortunately, not every generator displays so many warm cells. But not every warm cell means a defect. Long-time experience is necessary to distinguish the problematic abnormalities from the ones that do not matter.

As the cost of infrared cameras decreased, more and more connection and fuse boxes in the industrial sphere could be covered. Expensive breakdowns and even fires can be avoided through the use of this process. The cameras show components with higher temperatures, and thus heat radiation, in infrared, in a false color image. In this way, faulty contacts with increased contact resistance can be precisely located, often years before they cause problems. However, above and beyond PV thermography itself, these analyses require a high level of knowledge and experience on the part of the engineer, who should be certified according to ISO 9712. Frequently the engineer has to decide there and then whether half a MW should be shut down until a critical series fault has been repaired, for example, or whether the associated loss of yield outweighs the risks. Similar incidences occur rather often in rooftop and field PV systems.

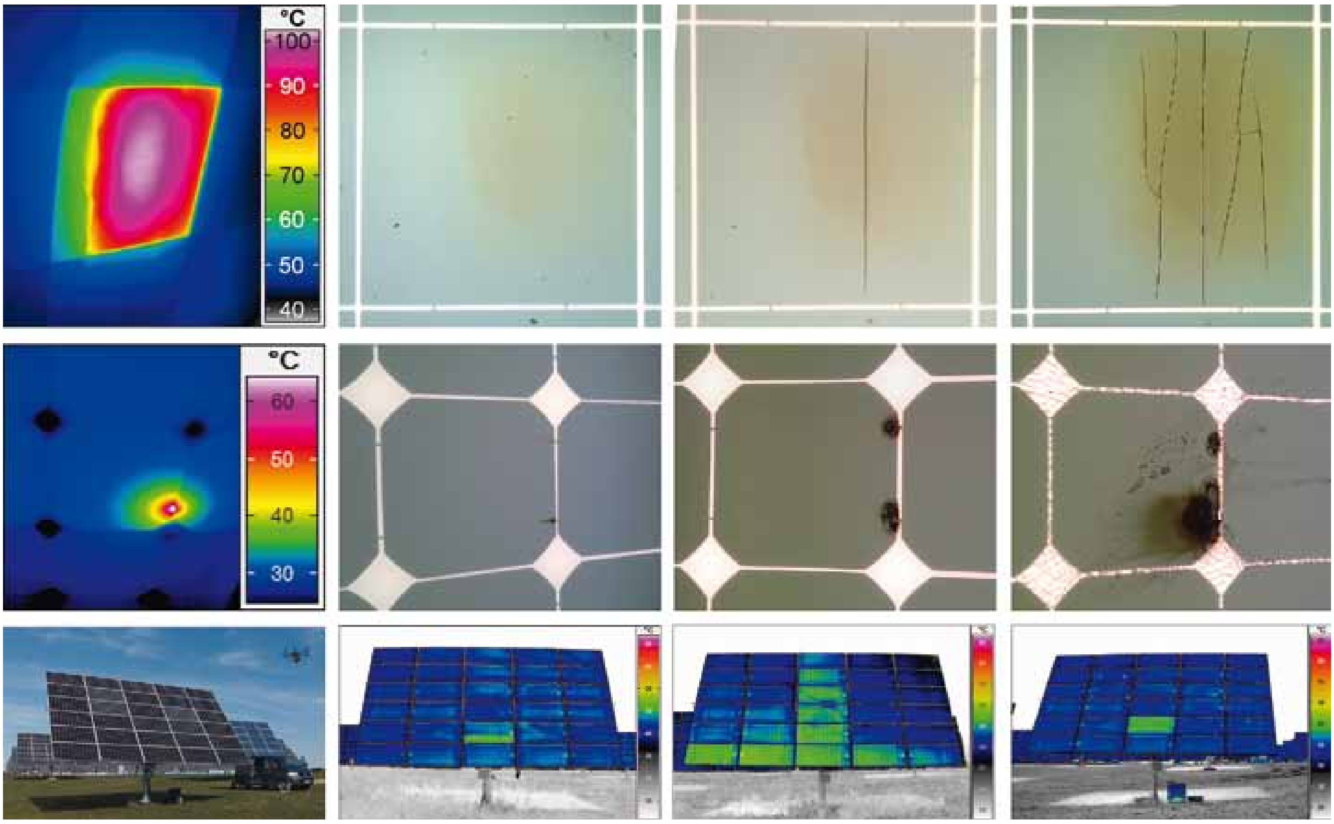
Thermography of PV modules

PV thermography not only examines string connection boxes. Mostly PV generators, i.e. the modules, are the objects of the investigation. Like electrical thermography, it can reveal contact faults, such as soldering faults between solar cells. In addition, PV thermography makes use of the thermal operating behavior of cells. A PV module that works perfectly converts part of the solar irradiation into electrical power and transmits it for use. The remaining irradiation fraction is absorbed by the module and then partly emitted as heat radiation. Because PV thermography measures this proportion on a quantified basis, it can draw a conclusion about the emitted electrical power. A module that cannot transmit any electrical energy is shown in the thermal image as being up to 6 K warmer than an active module. The possibility of finding a trivial fault such as an unplugged module is just one aspect of thermography. With sufficient experience, practically every possible faulty operating state can be clarified in the thermogram, such as:

- reverse voltages via broken cells;
- short circuits due to switching and bypass diode faults;



A string connection box (SCB) with a loose screw connection. Even if the position of the defect is known, it cannot be detected visually.
Thermogram on the top right: a loose screw is causing a temperature rise of 150 K. This means acute danger of fire. The box needs to be taken out of operation and repaired immediately.
Image bottom right: temperature distribution of a fault-free SCB.



Various detectable module faults. Similar cases are documented, so fault development and relevance can be forecast.

First row: Broken cell working in the fourth quadrant of its I-V-curve as a load reaching temperature increases of about 50 K and absolute temperatures of over 100°C. Eventually this may lead to a rapid degradation of an EVA and Tedlar backside foil in the course of one year. The degradation speed depends on the average absolute temperatures and the quality of the foils.
Second row: Transfer resistance on cell connectors. If the temperature rises over a critical value that is defined for electrical thermography at about 10 K in the first step (always extrapolated to full load), the contact resistance may start to develop further, which leads to an even higher temperature, faster rising resistance and so on. According to experience, a connector that shows temperatures of over 35 K will degrade until an electrical arc destroys the module glass, in the best case.
Third row: Solar tracker inspected by a thermography drone. The first thermogram shows the most common module failure, a disconnected substring, in this case within the connection socket of the module. This means the bypass diode will be under load until it breaks some day, as it is typically not designed for permanent load. If this happens, all of the power of the module string is lost until the problem is solved. If the failure wasn't located before by thermography this job can be very difficult because the disconnection can be in the connection socket of every module of a string. On a roof, that would mean dismounting about one third of the modules until the defect can be found. The last picture shows provisional bypassing of the module.

- all operating states from partial load to polarity reversal; and
- potential-induced degradation (PID), even in allegedly PID-free modules.

Beyond electrical thermography

PV thermography exceeds the limits of electrical thermography. It can also be used, for example, to explain a large number of non-electrical faults, especially on the mounting system of the PV generator. In the simplest cases, module clamps and module frames are easy to separate from each other in infrared, thanks to their different emissivities. This way, missing clamps or wrong clamp positions can be detected easily. And it is possible to go even further. In a concrete case, a complete MW roof system with large glass-glass modules had to be dismantled and reassembled after installation. Thermography had revealed through heat conduction patterns that the rubber buffers specified by the module manufacturer between the modules and upper profiles were missing. Because it was difficult to inspect the frame visually, this situation would probably have remained undetected without thermography until the first modules broke in a storm, which might be too late to be able to claim compensation.

Still major differences in quality

Different kinds of infrared radiation have to be distinguished. Several analytical processes are using infrared, for example electroluminescence within the shortwave (SW) infrared spectrum. But even within the long-wave (LW) spectrum of thermography there are major differences in techniques and quality. Currently, infrared analyses using drones are becoming increasingly popular. Unfortunately, these drones often only make use of simple infrared cameras that only produce brightly colored images rather than quantitative measurement results. On the basis of these images, many of the analyses described above are excluded from the start. In order to make the quality and value of an analysis more transparent for customers, Solarschmiede initiated a pre-standard committee within the DKE (German Commission for Electrical, Electronic & Information Technologies of DIN and VDE) two years ago, which started work in mid-2013. In the long term the group aims to work with module manufacturers to define rules for analyses. That way, a complaint process following an extensive analysis of a PV power plant could progress smoothly.

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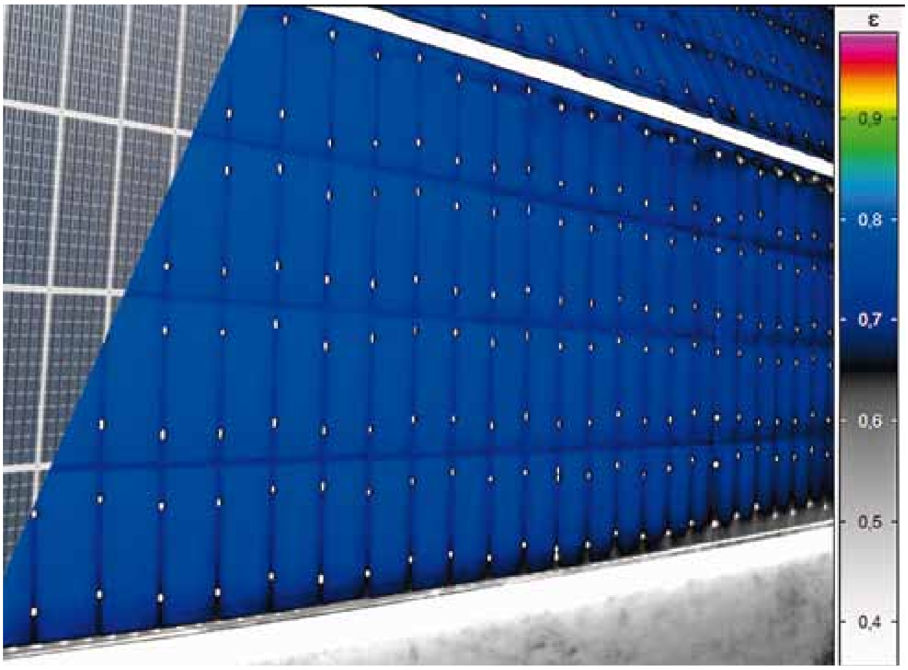

Superimposed visual image on the left and infrared image on the right: Missing or incorrectly positioned module clamps are the most frequent but not by any means the only faults that thermography can reveal in the mounting system. Deeper anomalies can also be detected and explained.

The first proposals for quality standards were finalized in the autumn of 2013. Solarschmiede presented this publication at the Thermography Colloquium 2013 of the German Society for Non-Destructive Testing (DGZfP) under the title “Geometric resolution in PV thermography.” This work defines one of the most important parameters of a survey. The number of IR pixels with which a solar module and a solar cell should be recorded is crucial for the validity of an analysis, and also for the cost of the survey. Around 25 (= 5 x 5 or ~4 x 6) pixels for each solar cell were proposed as an optimum with regard to both thermographical quality and economical aspects. For most of the other fields of thermography a minimum resolution has been defined in the past. In electrical thermography the smallest cable diameter in a picture has to be wider than 3 ideal pixels.

Efficiency in multi MW plants

PV thermography is particularly suitable for multi-MW power plants. Under good conditions analyses of up to 10 MW per person-day are possible at a price of well below €1,000/MW. Future cost reductions are to be expected. An analysis of this type can include a comprehensible assessment of every single anomalous cell and every cell binder. No other measurement method can achieve such a favorable relationship between cost and depth of analysis. And in every form of thermography it is possible to individually adapt both procedure and scale to tests already carried out or to the maintenance concept.

THE AUTHORS

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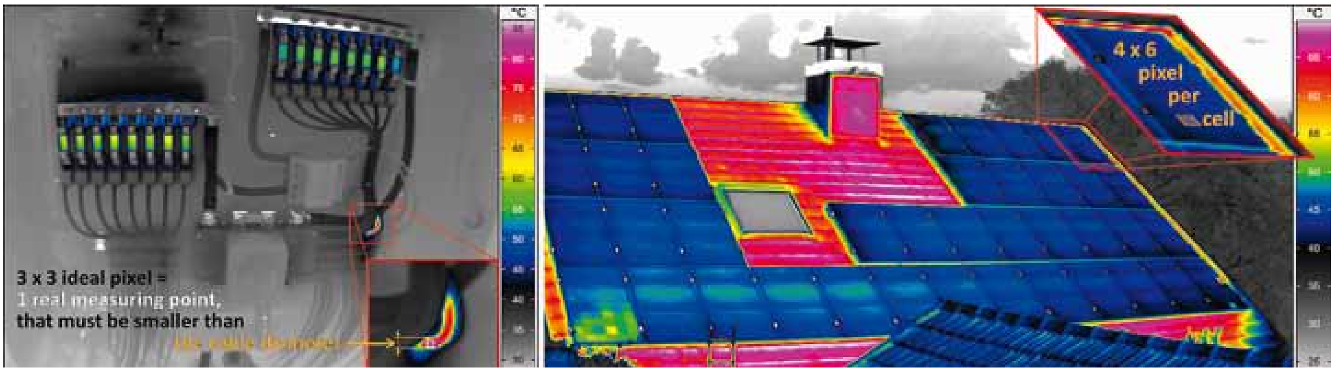
Bernhard Weinreich, physical engineer, is the initiator of the DKE pre-standardization process and responsible for the PV thermography department at Solarschmiede GmbH in Munich, Germany.

Conclusion

In contracting thermographic services, especially in PV, it is necessary to look at the quality of the service. Even if the inspection and the report are done well, and apart from all the aforementioned benefits, PV thermography still has its limits. If the exact module power has to be assessed there is no alternative to a measurement of the I-V-curve. In spite of the discussion of replacing permanently installed string monitoring systems by thermography, there is still a long way to go before a power plant can be inspected every week by a drone at an affordable price. It is not impossible to see this development in the far future in power plants of over 100 MW. However, there are still about ten years to go to develop the necessary level of automation.

It will always be in the responsibility of the plant manager to combine all of the existing measurement methods over the plant’s service life in a way that the cost for measuring, services, the losses and the risks can be minimized. A thermographic check one month after the plant was set under load, one before the module warranty expires, and a third one after ten years will help to reach this goal.



Recommendation for geometric resolution in electrical and PV thermography.