Practical guide
Thermography for photovoltaic plants.
Photovoltaic systems are an important contribution to the energy transition, and to a sustainable handling of resources – in recent years, driven by state subsidies, numerous smaller and larger photovoltaic systems have been installed in many countries in the world.

After the boom phase, the maintenance of existing plants in particular is gaining in significance.

This practical guide explains how thermography can support you during commissioning, documentation and maintenance, and provides helpful tips for using a thermal imager.
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Motivation and reasons for using thermography.

Detecting poor quality on the markets. In the boom years of photovoltaics, the order books were full and solar engineers were hardly able to keep up. This meant that it was not just highly trained trade experts that were filling orders. Large numbers of cross-trade and inadequately qualified contractors helped to meet the huge demand. The consequences are still being felt today: Construction errors, inadequate solar electricity yields from the plants, up to security and fire risks. It is primarily the plant operator who suffers. However, a qualitatively inferior implementation also reflects on the company doing the work, potentially allowing damage claims to be allowed based on a thermographic analysis.

Quality assurance and warranty. Using thermography, it is possible to check whether the quality of the module cells fulfils the requirements. The right combination of individual modules avoids so-called mismatches, where high-performance modules are impeded by “inferior” modules. With an inspection before the end of the warranty period, any warranty claims towards suppliers can be asserted in good time.

Avoiding customer yield losses. A new PV system is based on an extensive and detailed yield and investment analysis. Yield calculations are drawn up for up to 20 years. However, these calculations do not take into account any performance losses due to poorly installed systems. With the use of thermography, it is possible, as early on as the commissioning stage, to produce acceptance documentation.

Thermal irregularities point to a possible loss of electricity yield.
and provide proof of proper installation. This means there are no surprises for the end consumer and quality is assured. To guarantee the yield on a long-term basis, further regular checks are important, as the efficiency of a solar thermal system depends on the temperature. If modules become heated due to shade, faulty cells or substrings, i.e. consume power without generating, the efficiency drops by 0.5% per Kelvin. An average temperature rise of 10 °C compared with the mean standard temperature means a 5% lower electricity yield.

Recommendations are an important marketing instrument, especially in view of the current situation in the sector, for gaining further custom after an order has been carried out. Because only a satisfied customer will recommend a professional and trustworthy company.

**Efficient additional and follow-up business.** After the boom years’ emphasis on installing a PV system as quickly as possible, the focus today is on testing and maintaining PV systems regularly. Service contracts can form a further source of revenue in classical after-sales business. The use of thermography allows a customer to offer valuable after-sales-services which secure the value of a photovoltaic plant in the long term.

**Fire protection.** Fire protection is of increasing importance. Modern inverters and electrical components are becoming more and more powerful (high efficiency), and so the resulting high level of heat emitted must also be taken into consideration. Incorrectly fitted or inadequately cooled electrical components can quickly pose a fire risk, particularly if the mounting base is made of combustible material. Electrical components installed outdoors age especially quickly as a result of weathering and UV radiation. Corroded or loose electrical cables indicate thermal irregularities, which would show up on a thermal imager.

**Benefit: time saving.** Thermography is a non-contact, visual measurement method. Large-surface solar modules can be scanned in a very short time. Thermal irregularities or temperature differences affecting modules are immediately evident and are an initial indication of possible faults. Whereas previously all module strings were measured individually, using thermog-
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One can now concentrate on the thermally conspicuous modules and cells for all further measurements (e.g. with a characteristic curve measuring instrument).

**Benefit: insurance cover.**

Up to now, faulty bypass diodes were extremely difficult to localise after storms. Thermography is an easy and quick tool for identifying this type of damage. The costs for rectifying the fault are generally borne by the insurance company.

**Security in inspections.**

PV systems are live during daylight hours. In the case of modern module strings, voltages are often up to 1000 V. This poses a considerable risk of electric shock to personnel. For this reason, thermography is a very safe inspection method, as recording thermal images is always done with the necessary distance to the measurement object. This means that safe distance requirements are easily met.
Fault images and causes.

Looking for the hotspot. Shadowed or defective module cells form an internal electrical resistance which can lead to undesired warming "hotspot". The cell can heat up so much that not only is it damaged itself, but it also damages the casing material (EVA) and the backing film (TPT).

Bypass diodes are intended to prevent this effect. However, faulty or unsuitable bypass diodes (where shade is minimal) continue to lead to uncontrollable hotspots. If shade is not taken into account in the planning phase (e.g. caused by HV plants or trees), the module cells and bypass diodes are subject to permanent loading all year round.

Hotspots and their consequences. There are generally two consequences of hotspots:

- The electricity yield decreases, as individual cells or the entire module are consuming electricity instead of generating it.
- Unwanted electricity consumption heats up the cells and modules. Aside from the damage to individual cells and a further reduction in the electricity yield, this can also lead to a real fire risk.

Identifying hotspots with thermography.
In general, faults in the operation of PV systems as of solar radiation of approx. 600 W/m² can be quickly diagnosed from changes in the thermal properties showing up on a thermal imager. These kind of changes occur, for example, due to:

- Defective bypass diodes
- Contact faults and short circuits in solar cells
- Moisture penetration, dirt
- Cracks in cells or in the module’s glass
- Non-functioning or disconnected modules
- So-called mismatches, i.e. loss of performance due to different capacities of individual modules
- Faulty wiring and loose contacts
- Wear and tear
Fault images in cells and modules
The infrared image shows typical fault images for defective individual cells and substrings. The connection sockets visible in the image show visible warming. This does not necessarily indicate a fault. However, connection sockets can overheat, so testing the temperature development as required is necessary.

Modules at open circuit. It is not uncommon for modules to run at open circuit. This may be caused by incorrectly connected modules or cables that have worn through or been chewed through. This is conspicuous in the thermal image by a consistently warmer infrared image in comparison to the other modules.

Delamination. Due to external influences or poor quality, the EVA protective layer may come away. Any moisture getting in may lead to cell corrosion and to a performance loss. With a thermal imager, this can be detected before the layers become visibly “milky”.

Typical fault images in solar cells and modules.
**Cell rupture.** Micro-cracking and cell ruptures can already occur during transport and installation. External mechanical influences can also be the cause of this. While micro-cracking is not critical, cell rupture can reduce performance.

**Checking electrical and mechanical components.** 
Aside from the individual cells and modules, electrical components can also be checked using thermography. Corrosion on electrical conductors and connectors or loose cables can lead to electrical transfer resistances, indicated by a considerable rise in temperature. This means that, in addition to the generating modules, electrical components can also be checked:

- Corroded contacts or connectors
- Inverter
- Loose contacts
- Overheated connection points

![Left inverter is significantly hotter.](image1)

![DC cable without critical heating.](image2)

![Significant heating at electrical connections.](image3)
**Overview of fault images and causes.**
The following overview lists typical fault images and their possible causes.

| Infrared image 1 | Description: Constant heating of module compared with the others. Possible faults: Module is at open circuit. Possible cause: Module not connected, cable worn through or broken. |
| Infrared image 2 | Description: The module has line-like heating of a string. Possible faults: Short circuit in a cell string. Possible cause: Faulty bypass diode e.g. after a storm. |
| Infrared image 3 | Description: “Patchwork pattern” where individual cells are randomly distributed and significantly hotter. Possible faults: Complete module in short-circuit. Possible cause: Incorrectly connected or all bypass diodes faulty. |
| Infrared image 4 | Description: Only part of a cell is significantly hotter. Possible faults: Cell rupture. Possible cause: Transportation or installation damage or other external mechanical influence. |
| Infrared image 5 | Description: Heating at specific points or unevenly. Possible faults: Crack in a cell or artefact formation. Possible cause: Manufacturing fault with cell cracking. Shade due, for example, to dirt (bird droppings, etc.). |
| Infrared image 6 | Description: Heating of an individual cell. Possible faults: Not necessarily a fault. Possible cause: Shade or faulty cell. |
**Tips & tricks on measurement and avoiding errors.**

**Meteorological prerequisite.** Testing should take place on clear, dry days, with intensive solar radiation (approx. 600 W/m²). During direct solar radiation, the solar panels work at full capacity, and damaged solar cells show up warmer than the other cells on the infrared image because they are overloaded or have stopped working. Radiation of approx. 600 W/m² is a guide value. If the solar radiation changes during the measurement, for example, due to overclouding, the infrared image can no longer be used.

To achieve the highest possible and therefore easily detectable temperature gradients, we recommend carrying out the measurement when outdoor temperatures are low (e.g. morning or evening). The cooling effect on panels caused by wind may also have to be taken into account.

**Correct alignment.** During thermographic measurement, the alignment of the imager in relation to the PV module is key. The energy radiated is dependent on direction, i.e. during the IR temperature measurement, the alignment of the imager in relation to the module surface should be 60 – 90 °C. The PV module should be aligned so that it is as vertical as possible to the direction of solar radiation.

Angle-related measurement errors lead, for example, to possible temperature differences and false reflections. It should be ensured that the measurement image is not affected by reflections, for example of the imager itself, the measuring technology technician, the sun or nearby buildings. Reflected radiation is also detected by the imager. Reflections can be detected through changes in the angle of view, as they also move.

*Cloud reflections are visible.*
Interpretation and evaluation. If temperature deviations occur during the evaluation of the thermograms, this does not necessarily mean that the affected modules must be faulty. For example, questionable thermal images can indicate partial shade caused by dirt. At the same time, an individual damaged cell does not necessarily lead to a loss of performance of the entire panel. Only the failure of entire sub-sections of the panel will result in major performance losses. Additional checks such as a visual inspection, a characteristic curve measurement or an electroluminescence measurement are therefore necessary in order to localise suspected causes of faults.

Care should be taken when interpreting the absolute temperatures shown on the thermograms. Reflections of the cold sky radiation can, for example, lead to misinterpretations – clear blue summer sky radiates at up to -25 °C. We recommend working here with ΔT values and paying particular attention to extreme temperature differences within a panel or compared with the adjacent panel.
Hotspots do not necessarily indicate a defective cell. Not every hotspot automatically indicates a fault in a solar cell. For example, mounting systems and connection points may be visible as a result of the heat transfer to the module surface.

Modules with significant deviations are not necessarily faulty, they may just be dirty and should be cleaned.

Level and span. Adjustment of the so-called level and span is extremely important for the identification of faults. In automatic mode, thermal imagers detect the hottest and coldest point and adjust colour grading across the entire range. The wide spread therefore eliminates any relevant temperature differences.
What does the ideal \textbf{thermal imager} look like?

Checking photovoltaic plants using thermography places very high requirements on the use of a thermal imager. Several criteria must be taken into account when choosing a thermal imager suitable for this purpose:

- Infrared resolution of the detector
- Thermal resolution (NETD).
- Exchangeable lenses.
- Camera functions
- Software

\textbf{IR resolution or geometric resolution.} The geometric resolution (given in mrad) describes a thermal imager's capability of recognizing objects (e.g. individual faulty modules) from a certain distance. As the geometric resolution is dependent, among other things, on the IR resolution of the detector, IR resolutions of at least 320 × 240 pixels (76,800 measurement points) are recommended in the case of large PV systems and for measurements from a long distance. When checking small systems and carrying out measurements from a short distance, IR resolutions from 160 × 120 pixels (19,200 measurement values) may also be sufficient.

\textbf{Thermal resolution (NETD).} The thermal resolution describes the capability of a thermal imager to detect temperature differences on an object surface. A thermal resolution of 0.05 °C (or 50 mK), for example, means that the thermal imager can detect this difference and can carry out different colour grading on the display. The lower the thermal resolution, the better the IR image generated.

\textbf{Exchangeable lenses.} Aside from the IR resolution of the detector, the opening angle of the lens also affects the geometric resolution. In order to be able save time measuring large areas, e.g. from a elevated platform, imagers with exchangeable telephoto lenses should be selected. The imagers testo 882, testo 885 and testo 890 enable fast lens changes.

A high geometric resolution facilitates the inspection of large plants.
Rotating display. A rotating display, such as featured in the testo 885 and testo 890 imagers, for example, assists you in the correct positioning of the imager (see Tips & Tricks) in order to avoid measurement errors. This makes it possible to take thermographic images overhead. Measurements on the rear of modules are also made easier. The thermal imager can be rotated into the required position without someone having to lie on the floor.

Solar mode. This recording mode is one which is especially useful for solar thermography. In solar mode, the solar radiation in W/m² can be stored with each image to document the relevant ambient conditions.

Video sequences. A full radiometric video measurement or logging function enables video sequences to be recorded. In this image mode featured in the imagers testo 885 and testo 890, a vehicle moves away from individual freestanding system arrays supported by a mounting system while the thermal imager records video sequences. The images are then evaluated using software on the PC to save time.

In large plants it is only the conspicuous modules which need to be further examined.
**Software.** The analysis software (e.g. testo IRSoft) enables the optimization and analysis of the thermal images, and ensures that the findings in the images are clearly presented and documented. The software should be intuitive to use, clearly set out and extremely user-friendly. In the testo IRSoft, meaningful, professional reports can be created in minutes using pre-defined report templates.

The image shows the temperature histogram of a solar module. Various aspects can be read off from this. While the temperature mean value is 53.4 °C, there are maximum values of up to 77.9 °C compared with the minimum temperature value of 38.7 °C. The frequency as a percentage enables a conclusion to be reached as to how many cells are in critical temperature ranges. The image used in the example shows that approx. 55% of all temperature values are higher than 63 °C and therefore already 10 °C more than the mean value of 53.4 °C.
## Technical data in comparison.

<table>
<thead>
<tr>
<th></th>
<th>testo 872</th>
<th>testo 882</th>
<th>testo 885</th>
<th>testo 890</th>
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<tr>
<td>Resolution</td>
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<td>320 x 240</td>
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<td>Image refresh rate</td>
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<td>Solar mode</td>
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<td>Sequence capturing and fully radiometric video measurement</td>
<td>No</td>
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</table>
Thermography

Thermal imagers – ideal tools for the inspection of photovoltaic plants.

Even a small technical defect is sufficient to have a considerably negative effect on the solar yield – and therefore the economic viability of a photovoltaic plant. The causes are various: Carelessness during installation, degeneration of the laminates or slow damage due to years of UV radiation and weathering. The use of a thermal imager helps to determine the causes of error quickly and reliably, and to eliminate them.

At the forefront of a thermographic analysis is the identification of hotspots, which not only cause yield losses, but also represent areas of danger. This also plays an important role when it comes to the issue of warranty claims. Imager tests are furthermore carried out on electrical distributors, in order to detect the location of bad wiring. Thermal images can also ensure that live components do not overheat and cooling systems are working properly.

Thermal imagers from Testo are specially designed for solar thermography requirements. They allow solar engineers to offer their customers a valuable after-sales service, while plant operators obtain a reliable statement on the status of their solar plants.

Solar thermography: Overview of applications and benefits

- Early identification of faults, avoidance of yield loss
- Increasing operational safety, prevention of fire danger
- Fast, safe inspections
- Identification of hotspots, modules at open circuit, short circuits, delamination, cell rupture, corroded and loose contacts, overheated connection sockets
- Creation of added value for solar engineers and plant operators
Practical application tips

- Measure in sunshine and at low outdoor temperatures
- Point the thermal imager correctly, bear reflections in mind
- If possible, measure on the rear
- Carefully analyse the causes of temperature deviations

Selecting the right thermal imager

- Observe suitable geometric and thermal resolution for the application
- Imagers with exchangeable lenses and rotating display provide more flexibility
- Useful functions such as solar mode and video sequence recording, as well as a versatile analysis software, simplify measurement and analysis