How efficient is your PV system?

Words: Stefan Veit, Head of Product and Quality Management Electrical Engineering, Team Lead Electrical/Building Technology, at TÜV SÜD Industrie Service GmbH

'Home-grown' solar energy from a roof-mounted system provides greater independence, saves energy costs, and contributes to climate protection. However, dirt, technical defects, or shading from vegetation and roof structures can impair the efficiency of PV systems. Regular servicing, maintenance, and inspection ensure sustainable safety and reliability of the electrical installations, help to optimise their energy yield, and protect the investment in the long run. Modern testing and inspection methods that use infrared (IR) technology, characteristic curve measurement and the trained eye of an expert make for smooth tests and inspections that keep downtime to a minimum.

Despite rising purchase costs, photovoltaic (PV) systems still generate good returns and are particularly worthwhile investments for organisations with high electricity consumption that operate larger systems with a minimum power output of 30 kWp. Possible examples include businesses, trades, and industrial enterprises, but also public buildings or facilities run by municipalities and public utilities. As a general principle, the bigger the purchase, the more important it is to secure the investment, and investments in PV systems are no exception.

According to estimates by the German Insurance Association (GDV), roughly 400,000 of the approximately two million PV systems[1] in place in Germany have been installed incorrectly. While this is first and foremost a potential safety risk, it also means that many of these systems will not deliver the originally calculated return on investment. Thorough and expert planning is key to achieving maximum system efficiency, but it is not enough on its own. The modules to be installed must also be tested and inspected for defects at the start of operation and regularly thereafter.

Defective cells in a single PV module can reduce the output of an entire string by 4 to 6 percent, thus causing considerable energy yield losses. The reason is that any imperfection in solar cells causes higher electrical resistance, which in turn leads to a rise in temperature and thereby reduces the system's efficiency. A 'string' is the term used for all modules connected in a series, which in turn are connected to the inverter.

There are numerous causes of relevant defects. Sometimes production faults such as defective flyback diodes go undetected, or equipment is inexpertly handled during transport. Errors that limit energy yield can also occur during installation. And last but not least, external influences including aging and weathering can also leave their marks. Even minor defects in PV modules or the cable system can reduce the energy output, diminish the service life of the modules, or cause electrical safety risks.

Measuring, testing, optimising

Mandatory periodic electrical safety tests offer a good opportunity for checking the efficiency of a PV system at the same time. After initial testing in accordance with the DIN VDE 0100-600 standard before the system is taken into service, operators must have their systems periodically tested and inspected in accordance with the requirements of the German accident prevention regulation DGUV V 3 and the normative requirements of the VDE 0126-23 and DIN VDE 0105-100/A1 standards.

An important factor for the determination of the test cycles is to identify defects before they can cause damage and loss. Depending on the age of the system and its operating environment, experts recommend intervals of between 12 and 48 months for periodic testing. A target/performance comparison delivers information about the system's actual state of repair and documents any lifecycle changes in the system.

In cases where electrical safety testing is combined with analysis of the economic aspects, experts measure the actual power output on-site and record the voltage-current characteristics of the PV modules. The results are then analysed and the measured values are compared with the expected output of the modules as specified by the manufacturer.

Any deviations serve as early indicators of imperfections or defects. External output-reducing influences, such as shading caused by vegetation or dirt, can easily be identified and avoided. Proven experts also use simple visual testing to uncover initial surface defects in the equipment.

Measurements to the smallest detail

Thermal imaging cameras can be used for more detailed inspection. They visualise hotspots, build-ups of heat on the module surface, which are indicative of defective cells. However, simple thermography surveys depend on the weather and only identify defects at an advanced stage, such as inactive modules, disconnected substrings, hotspots, or potential-induced performance degradation (PID).

Where details are important and defects must be detected as early as possible, inverse thermography, or reverse-current thermography, deliver more in-depth results, particularly for thin-film modules. In these methods, the external current is fed into the PV modules; in other words, the PV modules are operated 'in reverse'. Supported by drones, for example, these types of thermography surveys can even flag minor defects. In addition to the above defects that are visualised by 'regular' thermography, this 'inverse' operation also identifies inactive cell sections and high-resistance connections.

An inverse thermography method offering even greater precision is electroluminescence measurement (EL measurement). This measurement method uses special cameras to visualise the infrared radiation emitted by the externally powered PV modules, which have a wavelength of a mere 1,150 nm.

The high resolution provided by the cameras ensures that even smaller defects can be spotted. In addition, this method even enables the identification of problems at contacts, defective bypass diodes, failed individual cells, micro-cracks, and cell fractures as well as light and elevated temperature-induced degradation (LETID).

It is particularly recommended for incoming inspection of module quality, but also for checking performance during operation. In cases involving missing or inadequate system documentation, EL measurement helps to precisely determine the routing of the module strings.

No downtime, no loss of revenue

A major advantage of thermography surveys is that they can be performed without interrupting operation and do not require modules to be dismantled. As EL measurement is carried out at night unlike simple thermography surveys, it does not even incur yield loss. The use of ultramodern testing technology can significantly reduce

Fire risk myth

PV systems are no more dangerous than any other electrical installations. Only 0.006 percent of these systems cause major fires, according to a study performed by the Fraunhofer Institute for Solar Energy Systems (Fraunhofer ISE). In the 20-year period under analysis, PV systems in Germany caused 120 fires.

In ten of these cases, the building burnt down. In other words, PV systems that are expertly planned, installed, tested, inspected, serviced, and maintained pose a very minor risk.

Nevertheless, PV systems call for special care and attention as they cannot be turned off. They generate power whenever the sun shines.

Upstream of the inverter, this power comes in the form of direct current at 120 volts, which can be lethal. If a connected battery storage unit is used, this presents an additional potential safety risk.

Here, a firefighter safety switch that disconnects the energised line in the event of damage is a useful tertiary safety measure to support emergency forces in operation.

Also, obligatory is a clearly visible sign at the building informing rescue workers of the situation in case of fire.

Finally, a layout plan that maps the generator field, the main lines, and the inverter and is accessible from the outside is recommended to facilitate firefighting operations.

the efforts and costs of test preparation. Where cranes and lifting platforms were once necessary to gain a comprehensive view of the PV system from above, drones can now be used to carry the cameras.

Model calculation

Every defect in a solar cell, from cracks to poor solder connections, results in higher electrical resistance, which, in turn, produces heat. Model calculation in Figure 1 shows the extent to which such individual hotspots influence the yield of the entire system.

Typical mid-range PV systems have around 16 individual modules in a string. If every module produces an output of 350 Wp, the string generates as much as 5.6 kWp. However, if a defective module reduces the output of the entire string by roughly 5 percent, as is often the case in practice, this would add up to as much as 0.28 kWp in our example. In Germany, 1 kWp of installed capacity generates around 1,000 to 1,300 kWh of electricity. The defective module would thus shave 280 to 336 kWh off the electricity yield. Assuming an electricity tariff of 40 to 50 ct/kWh and full own consumption, a defect in a single module would cause losses of between 100 € and 130 € per year.

Conclusion

Experience has shown that many systems have unidentified defects and thus offer opportunities for improving yields. Production faults, errors in planning and installation, weather influences, and aging can never be fully excluded.

Simple actions can remedy or mitigate many defects or other yield-reducing factors: individual defective modules can be replaced, glass surfaces cleaned and trees and bushes cut back.

Early identification prevents unplanned secondary costs, thus keeping the value of the PV modules stable over the long term. Even minor maintenance and optimisation measures may deliver significantly higher yields.

Thermographic surveys can be performed without interruption of service or major technical efforts. They visualise defects that are hidden to the human eye. EL measurement offers even deeper insight. It is of critical importance that the tests are performed by experienced and recognised experts with the necessary ultramodern equipment.

TÜV SÜD maximises synergy effects by combining electrical safety and fire safety tests with analysis of yield parameters. This type of analysis is recommended even for smaller systems, for example, shortly prior to the expiry of the manufacturer's or installation company's warranty. In cases of damage, proof of defects can be provided to the insurance company.

Operators gain certainty that their energy generation systems and battery storage units are safe. They increase the availability of their systems and obtain a clear picture of the opportunities for yield improvement. On top of all these advantages, they fulfill their responsibilities and legal obligations as owners and operators.

www.tuvsud.com/is-pv-anlagen

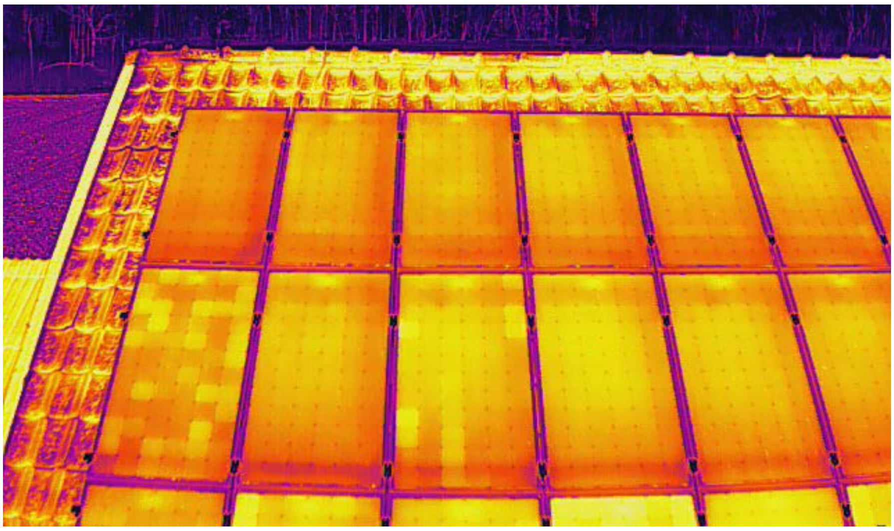

Figure 1: model calculation shows the extent to which such individual hotspots influence the yield of the system

References

[1] German Federal Statistical Office, destatis.de

Legal requirements for electrical equipment

Electrical equipment must be tested for safety before it is first taken into service and thereafter at periodic intervals.

System-specific test intervals must be defined. They result from documents such as the enforcement regulation for DGUV V3 or the DIN VDE 0100-712, IEC 62548 and EN 62446 standards. The tests cover aspects such as:

- Continuity of the earthing and equipotential bonding conductors
- Insulation resistance at the AC side
- Automatic switch-off in case of failure
- Correct wiring of the individual PV modules
- Inverter function
- Insulation resistances of the PV generator.

Operators are under obligation to define inspection intervals that ensure early identification of defects.

To do so, they must take the operating environment and any empirical experience acquired from the operation of similar systems into particular consideration.