Identification of Solar Cell Defects using Thermal Imaging Techniques

It stands to reason that for maximum power generation, system life and the best return on investment, every solar cell on a solar panel must be working. To provide this assurance, both post production and once the panel is operating in the field, the industry is increasing employing thermal imaging as its preferred method for locating defects. Thermal imaging allows anomalies to be seen clearly and, unlike other methods, can be used to scan installed solar panels during normal operation. It is also a highly time efficient process as a large area can be scanned in minutes.

Cooled thermal imaging cameras have been used in the research and development of solar panel technology for many years but it is the commercial uncooled cameras that are typically fulfilling the post-production, quality control and maintenance applications.

Ambient and Measurement Conditions

A few guidelines need to be observed when using thermal imaging to determine the working efficiency of photovoltaic modules with crystalline solar cells or thin-film modules in the field. Fundamentally it is necessary to ensure there is sufficient energy from the sun to achieve a good thermal contrast for accurate thermographic measurement; a solar irradiance of 500W/m2 or higher is needed and optimally, 700W/m2.

Ideally the sky should be clear as clouds reduce solar irradiance and also produce interference through reflections. However, informative images can still be obtained with an overcast sky provided the chosen camera has sufficient thermal sensitivity. Calm conditions are also desirable as airflow on the surface of the module will cause convective cooling, reducing the thermal gradient. The cooler the air temperature the higher the potential thermal contrast, so early morning inspection is certainly the best option.

Choosing the Right Camera

Handheld thermal imaging cameras typically have an uncooled microbolometer detector that is sensitive in the 8-14µm waveband. However, glass is not transparent in this region. So when solar cells are inspected from the front, a thermal imaging camera sees the heat distribution on the glass surface but only indirectly the thermal performance of the underlying cells.

As a result, the temperature differences that can be measured and seen on the solar panel’s glass surface are small. In order for these differences to be visible, the camera needs a thermal sensitivity of <80mK. It should also allow manual adjustment of the level and span function to optimise visual contrast.

Photovoltaic modules are generally mounted on highly reflective aluminium framework which shows up as a cold area on a thermal image. This is because it reflects the thermal radiation emitted by the sky. In practice this will mean a thermal imaging camera will record the framework temperature as being well below 0°C.

As the camera’s histogram equalisation automatically adapts to the maximum and minimum measured temperatures, many small thermal anomalies will not be immediately visual. With manual correction of level and span however, clear contrast can be achieved. In this regard, Digital Detail Enhancement (DDE) is a useful function as it automatically optimises image contrast in high dynamic range scenes. A camera with this feature is therefore particularly well suited to solar panel inspection.

Some thermal imaging cameras now have in-built GPS and this is particularly useful for tagging faulty modules in large areas, a solar farm for example. An in-built digital camera is also beneficial as it allows a visual image to be saved with its thermal counterpart. Fusion is another relevant feature as it allows the thermal and visual images to be superimposed to give even greater clarity to resultant reports. Voice and text comments can also be added in the field.

Another feature that should be considered is Multi Spectral Dynamic Imaging – MSX technology. This technology takes detail from the visual image to improve the thermal image. It makes it easier for the operator to see the problem in even greater detail, making solar panel inspection with MSX quicker and more effective, reducing time and cost.

On Site Considerations

The emissivity of a material is the relative ability of its surface to emit energy by radiation. It is therefore vital that this value is factored in to any thermal measurement and professional thermal imaging cameras will allow this to be pre-programmed.

As with all highly reflective material, the glass on a solar panel requires particular attention as any thermal image of its surface will also pick up the radiated temperature of surrounding objects including the camera and its operator! In the worst case, this results in false...

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hotspots and measurement errors. By adjusting the viewing angle these problems can be minimised or avoided and for this purpose a tripod will prove a useful accessory.

For some applications longer distance measurement can be advantageous as larger areas can be inspected in a single camera pass. To safeguard the clarity of the thermal image over a distance a thermal imaging camera with a minimal image resolution of 320 x 240 pixels is needed and better still one with 640 x 480 pixels. The high resolution camera should also have an interchangeable lens so the operator can switch to a telephoto lens for long distance observations.

**IMAGE ANALYSIS**

The shape and location of hotspots on the thermal image will indicate a variety of faults. If an entire module is warmer than usual interconnection problems should be suspected. When individual cells or strings of cells are abnormally hot or shown as a warmer patchwork pattern, the cause can usually be found either in defective bypass diodes (see Figure 3), internal short circuits or a cell mismatch.

Shadowing and cracks in cells are evidenced by hotspots or polygonal patches in the thermal image. And the temperature rise of a cell or part of a cell may indicate a defective cell or shadowing.

Thermal images obtained under load, no-load and short circuit condition should be compared. And if the front and rear faces of the module have been both inspected, these should be associated too, although temperatures obtained from the back may be higher as the cell is not covered by a glass surface.

It should also be emphasised that classification and assessment of the thermal anomalies require a sound understanding of solar technology, the system under inspection and additional electrical measurements.

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**Other Applications for IR Devices**

As well as monitoring solar panels for any defects that might cause loss of power generating performance, thermal imaging cameras and infrared thermometers have many other applications in manufacturing. With the help of Optris GmbH and IRISS we take a look at applications within plastic processing, electronic circuit board assembly and airport maintenance.

**TEMPERATURE MEASUREMENT IN THE PLASTICS INDUSTRY**

Process and production temperatures are important parameters for many processes used in the plastics industry, and non-contact temperature measurement with an infrared sensor system is a very effective method for process monitoring and control, allowing companies to achieve high levels of quality since, during production and testing, all products are subjected to thermal processes.

Infrared thermometers, or pyrometers, are used for single point process temperature measurement, provided the critical point of the process is known. Infrared cameras, for example the compact and fast optris PI thermal imager, can reveal weak points by helping to visualise thermal events, optimising and monitoring production processes.

Plastic materials processors produce a great number of products with differing dimensions, thicknesses, textures, colours and embossed patterns, either in roll or tabular format. Depending on the conditions, infrared measuring devices can be used in different ways to improve these processes.

**Process control during thermoforming**

An important application for infrared temperature sensors is the fitting of pyrometers in thermoforming and packing machines. During the thermoforming process, plastic materials are heated to 190°C and thermally homogenised. A high homogeneity over the surface, coupled with a specific set-up of the converting temperature, leads to higher quality being achieved during forming: a defined cool down period closes the process.

To achieve constant product quality for the material and to avoid local combustion and crack formation, an infrared camera is used to regulate the temperature of the material as it is fed into the thermoforming and packing machines. Pyrometers, positioned at selected measuring points, are used to control the process to ensure the product quality is maintained.

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*FLIR*

Permanent temperature monitoring at an embossing calender, supported by the infrared thermometer optris CT LT

Thermal image shows an example of 'patchwork pattern' indicating that this panel has a defective bypass diode.

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Infrared thermometer during temperature measurement of assembled circuit board points, present a complete temperature pattern of the thermofoming process to the machine operator, who is then able to regulate the temperature according to the specification of the particular process in hand.

**Surface finishing at an embossing calendar**

During this application, bulk plastic is being extruded, with wide slot extruders, into a strip and then calanedered to the required gauge by temperature controlled calender rollers. The material is again heated to 190°C and homogenized: it is then transported to the heated embossing calender where it receives a product-specific, surface structure: again, a defined cool down period closes the process.

A constant and consistent temperature profile, with variances below 5K over the range, is necessary during the embossing process to obtain a constant thickness, homogenous gradation and depth of the structure. To monitor the temperature profile during the embossing process, up to 16 pyrometers may be needed and the data inputted to a PLC for the effective process control.

**Injection moulding – reduction of distortion**

During the production of injection moulded parts, dimensional stability is of the utmost importance as liquid plastic is injected under pressure into the moulding tool. The outer skin of the component is already set when it is separated and stabilizes the component, as the middle is still mostly liquid, with the inherent heat slowly dissipating through the skin. If too much heat is retained in the component during separation, distortion can take place, resulting in the loss of the component’s specified dimensions.

A thermal imaging camera can contribute to the optimization of the tool temperature via the heating and cooling systems. Currently, only temperature sampling has been employed and longer separation times set-up as a precautionary measure - a huge waste of production capacity. The separation time needs to be raised if the temperature is above the process specification, and reduced if the temperature is below it.

A 120Hz online infrared camera system can automatically monitor the temperature at critical stages of the production process and make adjustments without disruption – it is able to detect the optimum component temperature before separation takes place. Productivity therefore increases as more components can be produced in the same time.

**FUNCTION TESTS OF PRINTED CIRCUIT BOARDS USING THERMAL IMAGERS**

More and more manufacturers of electronic components and printed circuit boards are turning to the use of non-contact temperature measurement to test the quality of their components, the thermal images of which can be captured and analysed through the use of modern infrared measuring devices.

A detailed, real-time analysis of the thermal behaviour of assembled circuit boards, used in the R&D field or for serial production, can be achieved through the assistance of an infrared thermal imager, using the standardized USB2.0 interface which allows video recording at 120Hz. This is extremely advantageous for transient thermal activities which can then be analyzed in slow motion following a test procedure. Individual pictures can be isolated for further analysis, which takes places via dedicated software offering multiple measurement points and user defined parameters. Alarms can be defined and displayed as well as maximum, minimum and average temperatures. Besides the recording function, the software also offers the possibility to record and store photographic images.

**It is not always necessary to use a camera**

Due to high volumes and the large number of test stations in printed circuit board (pcb) production and test facilities, the cost of installing infrared cameras can be too high. A more cost-effective alternative is to use infrared thermometers for monitoring temperature; not only for pcb production lines but for any series production control of critical components within large volume production applications.

Critical components on each circuit board will then be monitored and the temperature measurements forwarded to the test station for routine analysis. Any defective boards can then be recycled and faults rectified.

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**‘Live’ Thermal Inspection Saves Costs and Assures Reliability**

If Stansted airport fails to meet an agreed level of service, compensation becomes due to its customers, the airlines and handling agents. As the airport is open for business 24/7, engineers only have four hours per night in which to conduct predictive maintenance surveys of its low voltage equipment: by the time they make the system safe, the window of opportunity reduces even further. This means the entire inspection cycle is significantly protracted and no system can be checked under load.

With the installation of 72 infrared windows, it now takes just five hours to complete the job in daylight hours. Previously it took engineers two nights to inspect just one electrical panel. There is no need for isolations or back feed, personnel safety is completely assured and a single thermographer, without full PPE, can do everything.

**Note:** An infrared window is a data collection point for a thermal imaging camera and adoption of this technology is growing fast as increased awareness of electrical safety and risk reduction drives its acceptance. Critically, IR windows also enable systems to be inspected under load so their true ‘health status’ can be quickly ascertained.

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