MEASURING ON PV SLICES AND CELLS BY USING THERMOGRAPHY

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Abstract: The testing of solar cells and PV(photovoltaics) cuts by infrared thermography has been known more than 10 years and is becoming increasingly important standard. Accurate thermographic images of photovoltaic cells reveal quickly and purposefully faults (for example shunt effects, short circuits, faulty contacts etc). Infrared thermography is an NDT (non destructive) and an NTC (non contact) technique allowing the fast and safe inspection.

Keywords: Thermography, solar cell, thermogram, isnpection, NDT, NTC

1. INTRODUCTION

The basic principles are based on theory of infrared spectrum so is it possible to measure the electrical equipments under load conditions (for example under high voltage). Thermographic measurement is able to record the temperature changes much faster than the contact measurement. The uncooled thermal imaging cameras are currently being used more and more for the solar panel quality controls before installation and regular predictive maintenance checkups after the panel has been installed. Because these affordable cameras are handheld and lightweight, they allow a very flexible use in the field. But not every thermal imaging camera is suited for solar cell inspection, and there are some rules and guidelines that need to be followed in order to perform efficient inspections and to ensure that you draw correct conclusions.

2. BASIC PRINCIPLES

The thermal radiation is the emission of electromagnetic waves from all matter that has a temperature greater than absolute zero. It represents a conversion of the thermal energy into the electromagnetic energy. Thermal energy is the collective mean kinetic energy of the random movements of atoms and molecules in matter. The atoms and molecules are composed of the charged particles, i.e., protons and electrons and their oscillations result in the electrodynamic generation of coupled electric and magnetic fields, resulting in the emission of the photons, radiating energy and carrying entropy away from the body through its surface boundary. Electromagnetic radiation, or light, does not require the presence of matter to propagate and travels in the vacuum of space infinitely far if unobstructed.

The characteristics of thermal radiation depends on various properties of the surface it is emanating from, including its temperature, its spectral absorptivity and the spectral emissive power, as expressed by the Kirchhoff's law. The radiation is not monochromatic, i.e. it does not consist of just a single frequency, but comprises a continuous dispersion of the photon energies, its characteristic spectrum. If the radiating body and its surface are in thermodynamic equilibrium and the surface has perfect absorptivity at all wavelengths, it is characterized as a black body. A black body is also a perfect emitter. The radiation of such perfect emitters is called black-body radiation (Fig.1). The ratio of any body's emission relative to that of a black body is the body's emissivity, so that a black body has an emissivity of unity. The absorptivity, the reflectivity, and the emissivity of all bodies are dependent on the wavelength of the radiation. The temperature determines the wavelength distribution of the electromagnetic radiation.

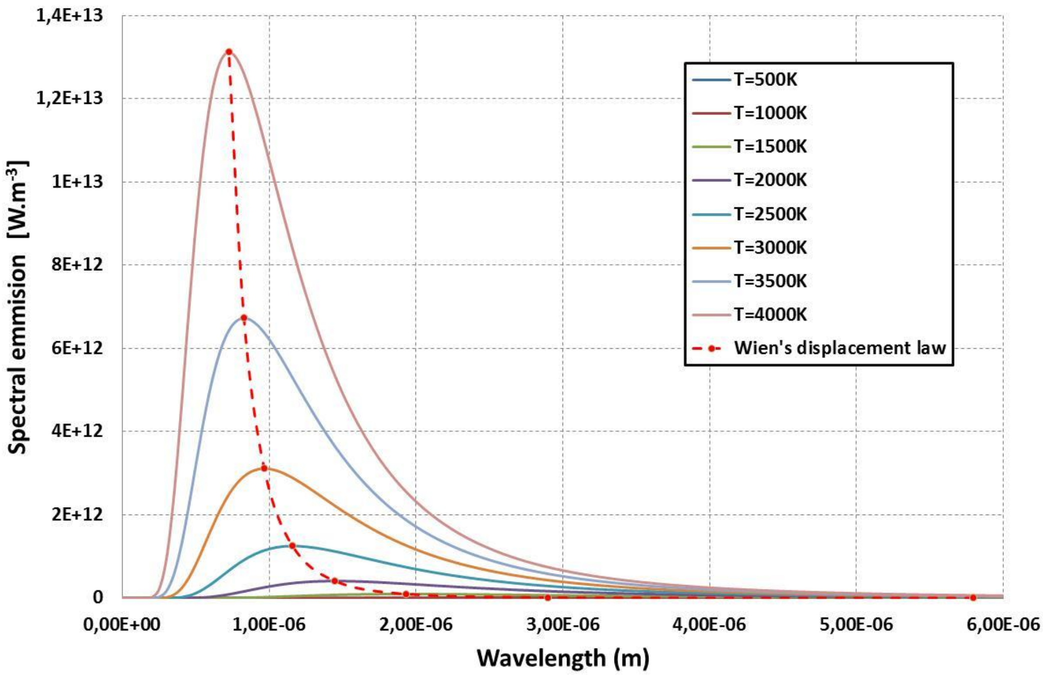

Figure 1: The Planck`s law calculation for the black body.

The Planck's law:

$$W_\lambda = \frac{2\pi h c^2}{\lambda^5} \frac{1}{e^{\frac{hc}{k\lambda T}} - 1} \tag{1}$$

, where $W_\lambda[Wcm^{-2}\mu m^{-1}]$ = spectral radiant emittance, $\lambda[\mu m]$ = wavelength, $T[K]$ = blackbody temperature, e = base of the natural logarithm, h = Planck constant, k = Boltzmann constant, c = speed of the light.

The Wien's displacement law:

$$\lambda_{max} = \frac{2898}{T}, \tag{2}$$

where $\lambda_{max}[\mu m]$ = wavelength corresponding to the maximum of $M_{0\lambda}=f(\lambda)$, $T[K]$ = temperature.

Thermogram measuring:

A microbolometer is a specific type of a bolometer used as a detector in a thermal camera. Infrared radiation with wavelengths between *7,5-14µm* strikes the detector material, heating it, and thus changing its electrical resistance. This resistance change is measured and processed into the temperatures which can be used to create an image. Unlike other types of infrared detecting equipment, microbolometers do not require cooling. A microbolometer consists of an array of pixels, each pixel being made up of several layers. The electrical contacts are deposited and then selectively etched away. A reflector, for example, a titanium mirror, is created beneath the IR absorbing material. Since some light is able to pass through the absorbing layer, the reflector redirects this light back up to ensure the greatest possible absorption, hence allowing a stronger signal to be produced. Next, a sacrificial layer is deposited so that later in the process a gap can be created to thermally isolate the IR absorbing material from the ROIC. A layer of absorbing material is then deposited and selectively etched so that the final contacts can be created. The quality of images created from microbolometers has continued to increase. The microbolometer array is commonly found in two sizes, 320×240 pixels or less expensive 160×120 pixels. Control logic is similar to the sensor, which is used in CCD image sensor or dynamic DRAM (Fig.2).

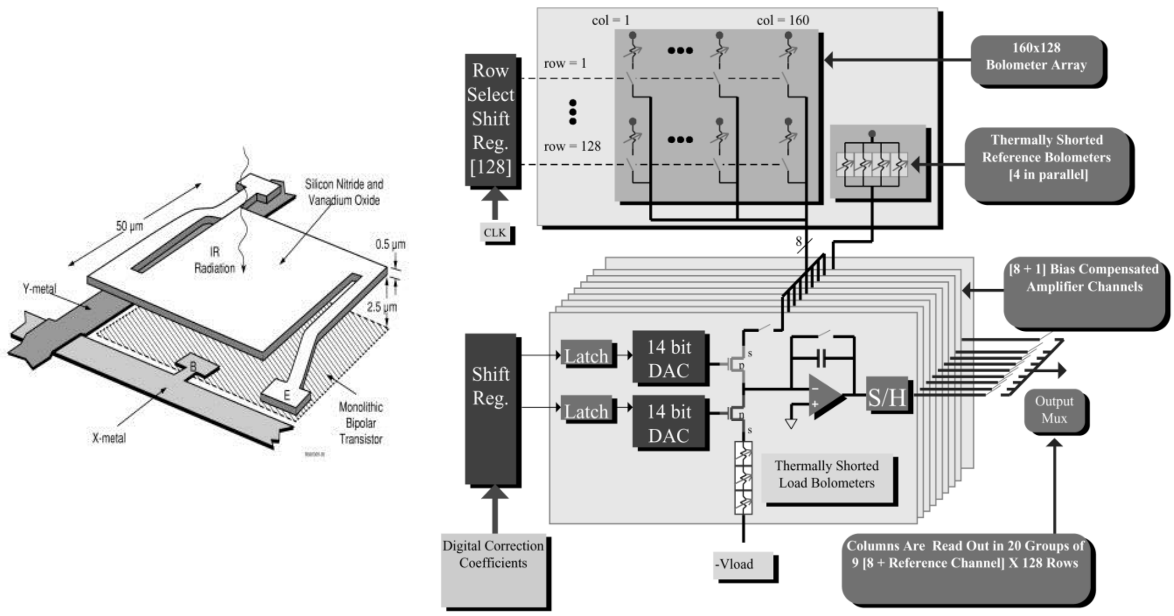

Figure 2: a) Structure of the microbolometer b) Block diagram of the control logic integrated in microbolometer with 160x128 matrix.

Procedures for inspecting

During the development and production process, solar cells are triggered either electrically or by the use of flash lamps. This ensures that there is sufficient thermal contrast for accurate thermographic measurements. This method cannot be applied when testing solar panels in the field, however, so the operator must ensure that there is a sufficient energy input by the sun. To achieve sufficient thermal contrast when inspecting solar cells in the field, a solar irradiance of $500W/m^2$ or higher is needed. For the maximum result a solar irradiance of $700W/m^2$ is advisable. The solar irradiance describes the instantaneous power incident on a surface in units of kW/m^2, which can be measured with either a pyranometer (for global solar irradiance) or a pyrheliometer (for direct solar irradiance). It strongly depends on location and local weather. Low outside temperatures may also increase the thermal contrast.

Positioning of the camera: (take intoaccount the reflections and emisivity)

Even though glass has an emissivity of *0,85–0,90* in the *8–14µm* waveband, thermal measurements on glass surfaces are not easy to do. Glass reflections are specular, which means that surrounding objects with different temperatures can be seen clearly in the thermal image. In the worst case, this results in misinterpretations (false "hotspots") and measurement errors. In order to avoid reflection of the thermal imaging camera and the operator in the glass, it should not be positioned perpendicularly to the module being inspected. However, emissivity is at its highest when the camera is perpendicular, and decreases with an increasing angle. A viewing angle of *5–60°* is a good compromise (where 0° is perpendicular) (Fig.3).

Figure 3: Recommended viewing angle („Ok“ sections).

Looking at it from a different perspective

In most cases installed photovoltaic modules can also be inspected with a thermal imaging camera from the rear of a module. This method minimizes interfering reflections from the sun and the clouds. In addition, the temperatures obtained at the back may be higher, as the cell is being measured directly and not through the glass surface.

Ambient and measurement conditions

When undertaking thermographic inspections, the sky should be clear since clouds reduce solar irradiance and also produce interference through reflections. Informative images can, however, be obtained even with an overcast sky, provided that the thermal imaging camera used is sufficiently sensitive. Calm conditions are desirable, since any airflow on the surface of the solar module will cause convective cooling and thus will reduce the thermal gradient. The cooler the air temperature, the higher the potential thermal contrast. Performing thermographic inspections in the early morning is an option. Another way to enhance thermal contrast is to disconnect the cells from a load, to prevent the flow of current, which allows heating to occur through solar irradiance alone. A load is then connected, and the cells are observed in the heating phase. Under normal circumstances, however, the system should be inspected under standard operating conditions, namely under load. Depending on the type of cell and the kind of fault or failure, measurements under no-load or short-circuit conditions can provide additional information.

The measurement errors

The measurement errors arise primarily due to poor camera positioning and suboptimal ambient and measurement conditions.

Typical measurement errors are caused by:

- too shallow viewing angle
- change in solar irradiance over time (due to changes in sky cover, for example)
- reflections (e.g., sun, clouds, surrounding buildings of greater height, measurement set-ups)
- partial shadowing (e.g., due to surrounding buildings or other structures).

What can you see in the thermal image?

If parts of the solar panel are hotter than others, the warm areas will show up clearly in the thermal image. Depending on the shape and location, these hot spots and areas can indicate several different faults. If an entire module is warmer than usual that might indicate interconnection problems. If individual cells or strings of cells are showing up as a hot spot or a warmer ‘patchwork pattern’, the cause can usually be found either in defective bypass diodes, in internal short-circuits, or in a cell mismatch (Fig.4). Shadowing and cracks in cells show up as hot spots or polygonal patches in the thermal image. The temperature rise of a cell or of part of a cell indicates a defective cell or shadowing. Thermal images obtained under load, no-load, and short circuit conditions should be compared. A comparison of thermal images of the front and rear faces of the module can also give valuable information. Of course, for correct identification of the failure, modules showing anomalies must also be tested electrically and inspected visually.

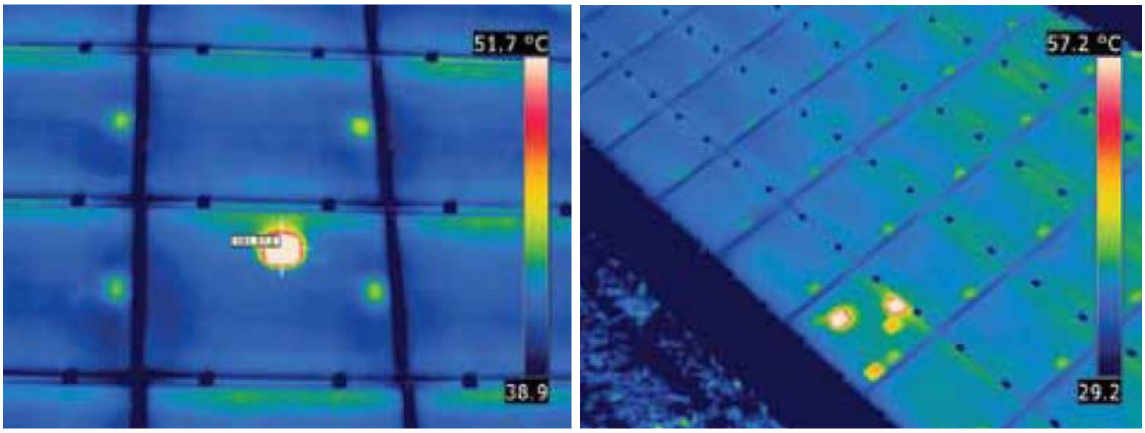

Figure 4: a) Physical damage (hot spot) b) Panel with defective bypass diode.

3. CONCLUSIONS

The thermographic inspection of photovoltaic systems allows the fast localization of potential defects at the cell and module level as well as the detection of possible electrical interconnection problems. The inspections are carried out under normal operating conditions and do not require a system shut down. THIS PAPER WAS FOCUSED ONLY FOR THERMOGRAPHY THEORY. The concrete analysis and measured results will be present after creation and design of the new laboratory task. Future steps to do can be discussed:

- Laboratory instructions will be made,
- Devices will be purchased,
- Important characteristics will be measured,
- Results will be presented etc.

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