Infrared Thermography in Maintenance of Building Applied Photovoltaics

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SUMMARY

Photovoltaic Systems (PV) are the most widely used renewable energy source in the Republic of Croatia but with a modest share in the total energy balance. EU energy policy encourages PV installation in building elements such as facades, roofs or separate constructions with the aim of achieving zero-energy buildings. Whether an integrated or stand-alone system during their lifetime requires periodic maintenance. In a normal operation, it is necessary to carry out a visual inspection twice a year before and after the winter period to determine the condition of the equipment, connecting lines and supporting structures. In the case of a significant deviation from the normal production, the inspection must be done as soon as possible. Most commonly, the problems of the unmaintained system cannot be perceived as long as the PV system is in an operational state. Dropping of dust, bird droppings or shading over a longer period may lead to system components being damaged and to necessary repair costs that can be prevented by regular maintenance procedures, including regular surface cleaning of photovoltaic panels. Infrared thermography is a fast method of detecting heat sources due to shading or defective photovoltaic module elements. The paper provides visual examples of thermal spots that can be observed during the infrared thermographic inspection of photovoltaic systems, as well as a review of their impact on the system.

KEYWORDS

Infrared thermography, Photovoltaic systems, Maintenance

INTRODUCTION

INTRODUCTION

Photovoltaic systems are the most commonly used form of renewable energy source (RES) integrated into existing buildings. Its application is encouraged by the Energy Performance of Buildings Directive (EPBD II). Directive 2010/31/EU on the energy performance of buildings requires that from 31 December 2018, all new public-use buildings to be zero energy buildings, and from 31 December 2020, all new buildings should be nearly zero energy buildings. Zero-energy Building (ZEB) is a building that meets energy needs from renewable sources to meet its own annual energy needs, thereby reducing the use of non-renewable energy in the residential sector, [1]. The most commonly used renewable energy source in the Republic of Croatia is the photovoltaic system, [2].

Table I. RES Power Plants with which HROTE has concluded an Electricity Purchase Contract under the Tariff System and whose plants are in the incentive system; - Grid-connected Power Plants - Status as at 31 December 2016, Source [2]

Nr	RES power plants	Number of power-plants	Total power (kW)	Average power (kW)	Share in total number	Share in total RES power
1.	Solar power plants	1,219	49,479	41	94.2 %	7.7 %
2.	Hydro power plants	11	3,885	353	0.9 %	0.6 %
3.	Biomass power plants	12	25,955	2,163	0.9 %	4.1 %
4.	Biogas power plants	26	30,435	1,171	2.0 %	4.8 %
5.	Landfill gas power plants	2	5,500	2,750	0.2 %	0.9 %
6.	Wind power plants	18	412,000	22,889	1.4 %	64.3 %
7.	Cogeneration plants	6	113,293	18,882	0.5 %	17.7 %
8.	Total of RES power plants	1,294	640,547	495	100.0 %	100.0 %

Table I shows that photovoltaic systems represent the most common renewable energy source in the Republic of Croatia with over 94 % of the total number of RES installations. In total power, PV participates with only 7.7 %. The advantage of photovoltaics is that their production (if we neglect maintenance) depends solely on insolation, which in spite of stochastic nature is predictable and independent of energy prices.

Designations			
AM	Air Mass	IR	Infra Red
ε	emissivity	LID	Light Induced Degradation
EVA	Ethylene Vinyl Acetate	RES	Renewable energy source
PV	Photovoltaic	PID	Potential induced degradation
STC	Standard Test Condition		

INTEGRATION OF PHOTOVOLTAIC SYSTEMS ON BUILDINGS

Photovoltaic systems on existing buildings are usually laid using an aluminum pre-fabricated structure that, in the case of a sloping roof, is fixed to the roof-mounted supports underneath the roof cover to ensure unobstructed precipitation of rainwater. In the case of flat roofs, the construction is fixed to the concrete slabs (Figure 1) or plastic trays filled with stone aggregates in the case of a flat roof where the fixture with the screws is not possible (the first example in the Republic of Croatia, Konzum maxi Sopot 2011). When constructing new buildings, it is increasingly common to integrate panels to a wooden roof structure, (Figure 2), or to use a cover with integrated photovoltaic cells (Figure 3).

Figure 1. PV panels on the flat roof, picture source Končar d.d.

Figure 2. Photovoltaic panels on the roof of a new building, [3]

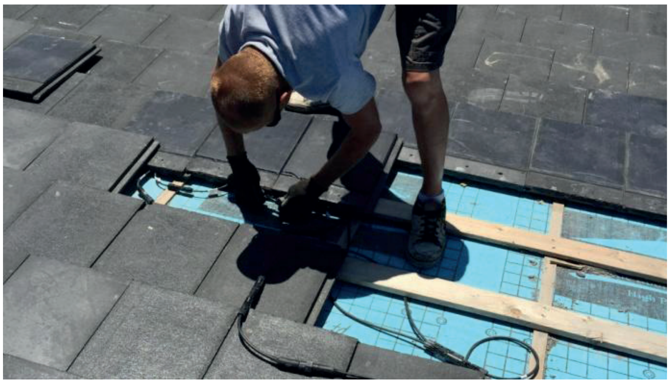

Figure 3. An integrated solar cell in roofing, [4]

The main problem of the integrated cover is reduced efficiency due to an increased panel working temperature (0.3-0.5 % and more per 1 °C increase of the temperature) due to reduced ventilation and inability to access the connection points. Reduction of the power due to the increase in working temperature is not so pronounced with panels integrated into façades of buildings, Figure 4.

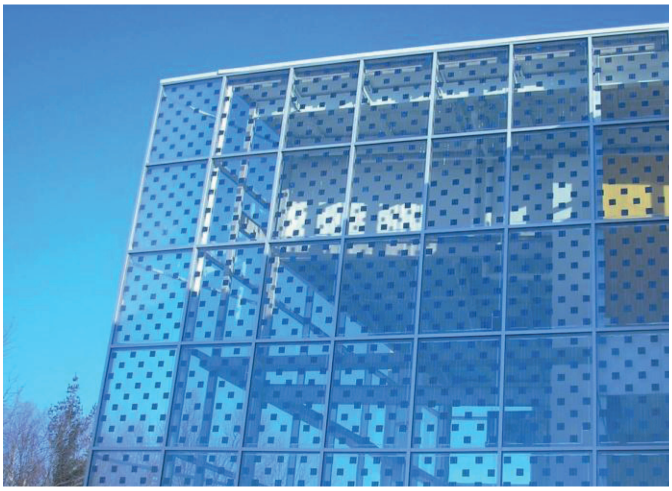

Figure 4. Photovoltaic elements integrated into the façade, [5]

For façade elements, the problem is the inability to achieve an optimal angle of sunlight because they are positioned according to architectural expression.

PV PANEL TESTING

Technical problems affecting the PV panels

Photovoltaic power plants have a life span of 25 to 30 years but photovoltaic modules are usually covered by a 20-year warranty. Cells power production typically decreases 1 % of nominal capacity per year. Numerous damages can occur during the life cycle. One of the most significant studies [6] shows the representation of all the technical problems that can affect the photovoltaic panels (Figure 5).

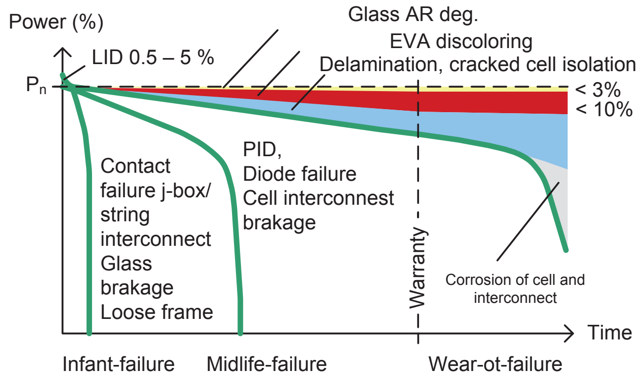

Figure 5. Causes of failure on PV panels, [6]

Figure 5 shows that the plastic used for laminating photovoltaic cells Ethylene Vinyl Acetate (EVA) significantly contributes to the reduction of the panel capacity while the glass cover as a seemingly sensitive material represents a relatively reliable component. This is especially important in façade applications because they have to choose higher quality materials that will not cause color change or delamination.

The usual PV panel testing methods

The first photovoltaic panel testing is carried out by the manufacturer after certain stages of the production process, lamination, and housing in the frame. The finished product is tested on a known lightsource and is released for sale. Basic test in standard circumstances, so-called STS is conducted under 1000 W/m² radiation at 25 °C and air mass AM 1.5 corresponding to Europe; (for Equator AM is 1). The work conditions after the installation change considerably in relation to laboratory conditions and the tests are usually carried out in three ways:

- measuring current-voltage conditions,
- infrared thermography and
- photoluminescence observed in infrared (IR) and near IR spectrum.

Equipment for electrical testing of photovoltaic systems requires several thousand euro investments, and the measurement and the measurement results depend on the momentary amount of radiation that changes significantly over time. Based on the results, conclusions about the malfunctions of individual cells or diodes can be made. Localization of the fault is much faster performed by IR thermography due to thermal inertia causing measurement result do not depend on rapid changes in radiation. The main condition for the IR analysis is insolation of at least 500 W/m2, [7]. Photoluminescence is a process when the inversion voltage of a few hundred volts is applied to the panel system when the panels begin to emit the light we detect in the near IR part of the spectrum with the camera and in the IR part of the spectrum by IR thermal camera. There are two international standards for testing PV, IEC 62446 and IEC 60904:

IEC 62446-1:2016 Photovoltaic (PV) systems Requirements for testing, documentation and maintenance - Part 1: Grid connected systems - Documentation, commissioning tests and inspection,

IEC 62446-3 Photovoltaic (PV) systems – Requirements for testing, documentation and maintenance – Part 3: Photovoltaic modules and plants – Outdoor infrared thermography,

IEC 60904-12 Ed1.0 Photovoltaic devices - Part 12: Infrared thermography of photovoltaic modules International and

IEC 60904-14 Photovoltaic devices – Part 14. Outdoor infrared thermography of photovoltaic modules and plants.

IR THERMOGRAPHY PV PANELS

Thermal patterns on PV panels

The PV panel analysis with an infrared thermal camera leads to the detection of different thermal patterns. The apparent temperature varies depending on the recording parameters. The most accurate values are obtained by analyzing the plastic back of the panel, which in the case of PV systems on buildings can often not be carried out.

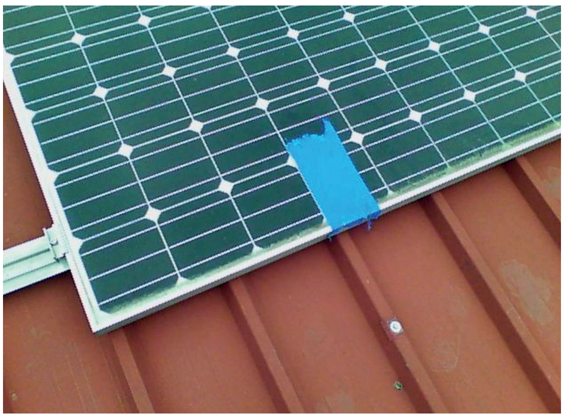

Figure 6. Shading of the panel cell

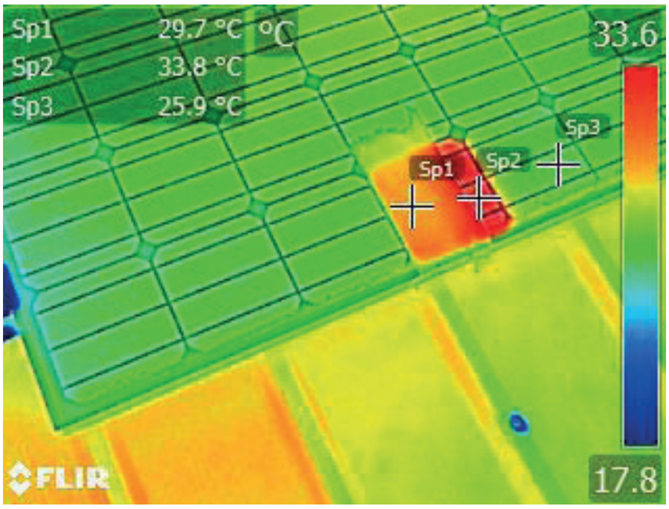

Figure 7. The thermographic pattern of the panel cell

The example of shade cell in Figure 6, does not generate electromotive force and represents resistance to the flow of current from the other cells of the series, resulting with heat dissipation shown in Figure 7. The analysis was made with the FLIR E6 infrared thermal camera resolution of 160 x 120 pixels, 45 ° × 34 ° field of view, operating temperature range from -20 °C to 250 °C, noise equivalent temperature difference or NETD <0.06 °C, refresh rate of 9 Hz and accuracy of ± 2 % or 2 °C of reading, with a set emissivity of ε = 0.85 characteristics for glass. Despite the high emissivity of glass, the problem of reflection of IR radiation is not negligible, as indicated in the paper [7].

Figure 8. The surface of the panel covered with bird droppings

Shading of the PV panel does not have to be obvious in the visible part of the spectrum to be noticeable with an infrared thermal camera in the infrared part. Figure 8 shows the surface area covered with bird droppings. On the corresponding thermogram, a 1.6 °C apparent temperature increase can be observed (Figure 9).

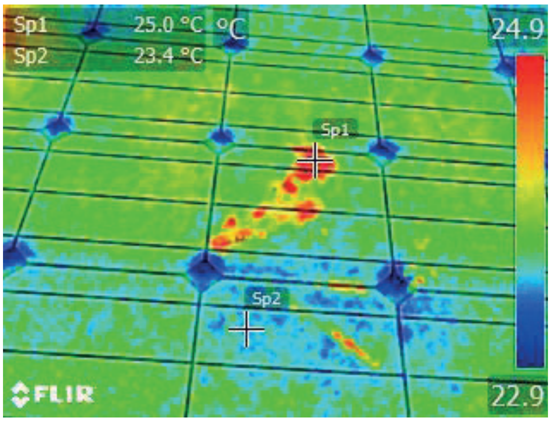

Figure 9. The thermal pattern reveals the position of the bird droppings

Bird droppings and accumulation of dust on panels lead to a decrease in production, but also to the different thermal stresses of individual cells, which cause cracking between the cells or the cells themselves. Therefore, periodic cleaning of the panel surface is important not only to maintain the production but also for the reliability of the system.

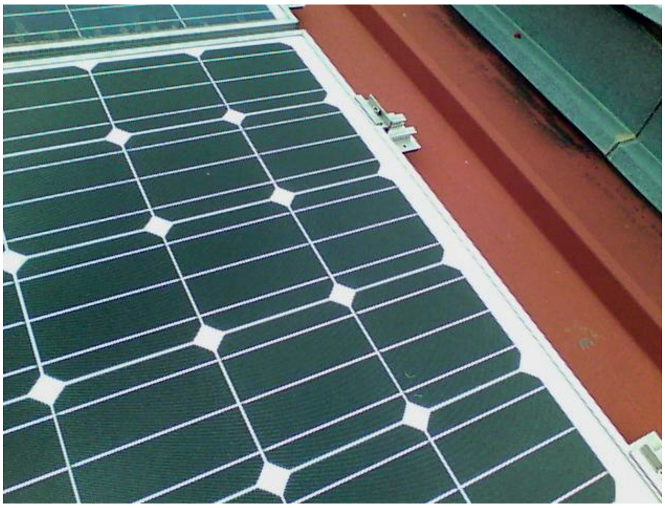

Figure 10. The side of a PV panel where the connection box is located

The PV panel cells are connected in the connection box by wires. The box is located at the bottom of the panel. Figure 11 shows the characteristic thermal pattern of the connection box. Because of the thermal resistance of the connection box, the place where the box is located is 1.7 °C warmer than the rest of the panel.

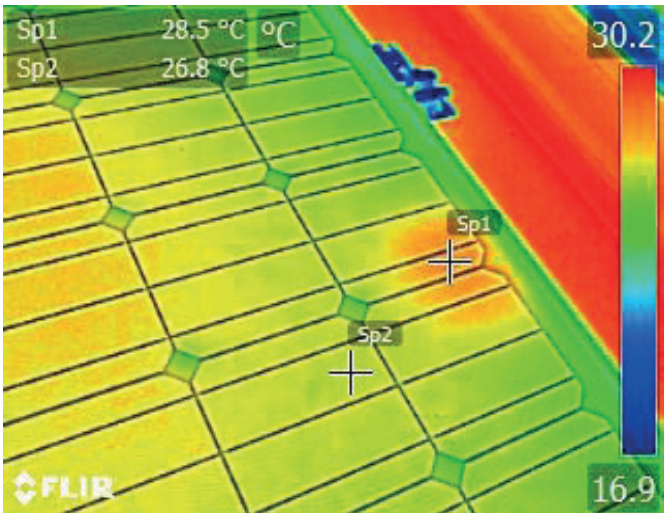

Figure 11. The thermal pattern of a PV panel connection terminal

A temperature difference of the individual parts of the panel, so-called hot spots, seen on previous examples does not necessarily mean malfunction. Often at the location of the connection box increased temperature can be seen and therefore, for the correct conclusion based on infrared thermal inspection, it is necessary to have knowledge about the panels operation as well as basic training in the field of IR thermography. In the field of electrical engineering, there is no single technical standard for assessing the correctness of electrical installations based on infrared thermography. The methodology mainly focuses on the analysis of the temperature difference between similar components often neglecting loads of individual components. That is why there are more organizations that have developed their own maintenance methodology over the years. One such organization is the International Electrical Testing Association (NETA) whose criteria are set out in Table II. [8]

Table II. Recommended maintenance procedures based on the temperature difference, [8]

Priority	The temperature difference (Delta-T) based on comparisons between	Recommended action	
	Similar components under similar loading	Components and ambient air temperatures	
1	> 15 °C	> 40 °C	Major discrepancy; repair immediately
2	-	21 – 40 °C	Monitor continuously until corrective measures can be accomplished
3	4 – 15 °C	11 – 20 °C	Indicate probable deficiency; repair as time permits
4	1 – 3 °C	1 – 10 °C	Possible deficiency; warrants investigation

The above examples (illustrated in Figures 9 and 11, with temperature differences of 2 and more °C) according to Table II require observation. In the case of a connection box, the pattern will not change, but in the case of the bird droppings pattern disappears with the appearance of the first rain or PV panel cleaning. In Fig. 12, the panel temperature can be read at 24.6 °C and at the point of hotspot 41.2 °C. This is a temperature difference of almost 20 °C, which leads to the conclusion that the panel will most likely be replaced (Figure is an example from the FLIR Tools software).

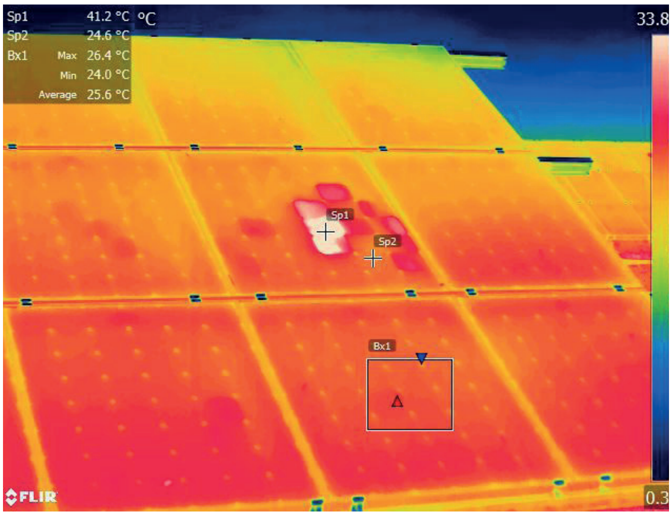

Figure 12. Thermal hot spot pattern, Source: FLIR Tools

Consequences of lack of PV panel maintainence

Monitoring the condition of the equipment is indispensable because defective equipment can lead to significant negative consequences. Figures 13 and 14 show the consequences of the defective PV system.

Figure 13. The consequence of fire on photovoltaic system, example [9]

Figure 14. The consequence of fire on photovoltaic system, example, [10]

CONCLUSION

Photovoltaic systems on buildings represent the simplest way to meet the EU energy policy in terms of archiving zero energy buildings goals. Ensuring a nominal lifetime of the photovoltaic system of 20 years and more requires continuous supervision and maintenance in other to PV system perform its function of electricity production. Infrared thermography is a fast, non-contact method of photovoltaic system inspection. Usage of IR thermography in maintenance can lead to problem prevention while still in development and do not pose a severe threat to the system. The problem is localized quickly, and the greatest advantage is that the procedure can be carried out in the operational state without turning off of the power plant.

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