COMBINATION OF THREE METHODS OF PHOTOVOLTAIC PANELS DAMAGE EVALUATION

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In broken photovoltaic (PV) cells the flow of electric current can be reduced in some places, which results in a lowered efficiency. In the present study, the damage of PV cells and panels was evaluated using three methods – electroluminescence, infrared camera imaging, and visual examination. The damage is detectable by all these methods which were presented and compared from the viewpoint of resolution, difficulty, and accuracy of monitoring the PV panels damage.

photovoltaics, PV panel, PV cell, electroluminescence

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INTRODUCTION

Photovoltaics (PV) is an important renewable energy source. It can be used for example in agriculture in the form of fixed or portable devices. However, PV panels can be affected by different kinds of damage, the most common of which are broken PV cells and interrupted connection contacts, degradation of encapsulant, corrosion of bus bars, etc. Broken PV cells and interrupted connection contacts are the worst case of damage. Broken cells and/or contacts represent about 40.7% of the total PV panels failures (Wohlgemuth, 2003). If the electrical contact is not interrupted above the damage spot, current can still flow through PV panels, but sooner or later it will be interrupted. At the PV panels installation site, PV panels are stressed by atmospheric changes (change of sunshine intensity, air temperature) and also mechanically (wind, hailstones, animal attacks, and other external influences). When the electrical contact is interrupted, current flows only through a part of the solar cell, and the flow of current through the whole row of serially connected PV cell sections (the so called strings) is limited. This lowers the PV panels efficiency. Moreover, current flowing through individual parts of PV panel is of different density. Thus, the individual parts of PV panel are unequally heated, which increases the PV panel degradation. Worsening of the characteristics can be seen also in the *I-V* characteristic.

Larger cracks in parts of PV panels can be detected with the naked eye, or with the help of a magnifying glass. Cracks and PV panels non-active parts can be inspected using electroluminescence (EL), when we let current flow into PV panels and observe radiation in the near infrared spectrum. The damaged part of PV panels can also be visualized using the infrared (IR) camera imaging. The PV panels parts without current flow are colder.

The PV panels damage has been studied e.g. by Wohlgemuth, 2003; Munoz et al., 2011; Rösch et al., 2012; Wen, Yin, 2012; Chaturvedi et at., 2013; Spertino et al., 2015; Sharma, Chandel, 2016 using the methods of EL and IR camera imaging. The use of EL for the damaged PV panels examination was described by Kasemann et al. (2008) and Liu et al. (2016).

The objective of the study was to compare the options (EL, IR camera imaging, and visual inspection) for a simple evaluation of the PV panels mechanical damage, and to compare usability of these non-destructive methods. Based on the results, the methods were further discussed from the viewpoint of price, complexity, and accuracy.

MATERIAL AND METHODS

The PV panel damage was examined using the three above-mentioned methods: electroluminescence, IR camera imaging, and visual examination. A single PV panel was used for testing.

For the EL inspection in the near infrared spectrum, we let direct current flow into the PV panel. We used an OPX 1200SP apparatus as a power source and pictures were taken by a cooled CCD chip CRYCAM-D camera (Crytur, Czech Republic) in a dark room. This camera is supposed to work in the visible spectrum, but it has some sensitivity in the near infrared spectrum as well. Electroluminescence could be seen thanks to long exposition (resolution 2052 × 1342 pixels (px)).

For IR camera observation of the PV panel mechanical damage a VarioCAM (InfraTec, Germany) was used and current was applied in the same way. Resolution of the camera is 640 × 480 px. As the parts of PV panel without flowing current are colder, non-functional parts of PV panel could be distinguished.

For visual observation we used a magnifying glass and an Olympus 5060 camera (Olympus, Japan) in 'supermacro' regime (resolution 2592 × 1944 px), and for obtaining the *I-V* characteristic a semiautomatic Prova 210 apparatus (Prova Instruments Inc., Taiwan) was applied.

We have tested a lot of PV panels. In this paper we demonstrate the method on a very damaged small PV panel SMP 8-180 (135 × 195 mm^2 in size) with nominal output power P_{max} = 1.8 W, open circuit voltage U_{oc} = 11.9 V, and short circuit current I_{sc} = 0.21 A. There are two rectangular rows of ten PV cell sections in this PV panel. These 20 sections are connected in series. The main contact is in the middle of each row as shown in Fig. 1. In the PV cell sections there is a collecting contact in the shape of a conductive lattice printed by screen printing.

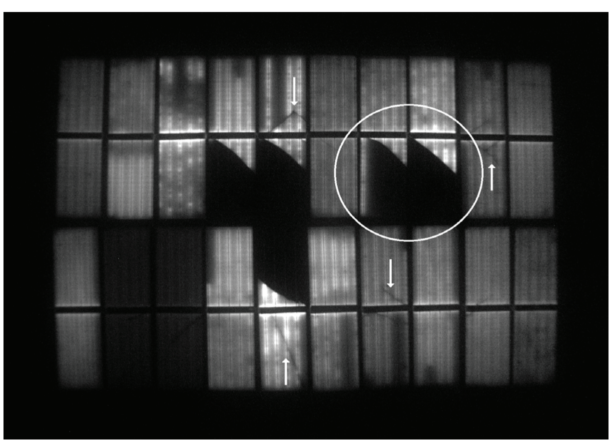

Fig. 1. Image of electroluminescence of a small damaged photovoltaic panel

RESULTS

The PV panel EL image is given in Fig. 1. A severe damage is evident. White arrows indicate broken PV cell sections with uninterrupted contact. PV cell sections with interrupted contacts are also well visible. Parts of PV cell sections with no flow of current are black because there is no EL. Even in some undamaged sections we can see that the density of current is not homogeneous. Lighter regions match higher density of current. A detail of the place in the visible spectrum with a little circle is given in Fig. 2. There we can see cracks and interruption of contacts even with the unaided eye and with a magnifying glass. Little cracks without interruption of contacts are usually not visible by this method. For comparison, a larger PV panel without any damage is presented in Fig. 3. There are no apparent cracks, only small defects due

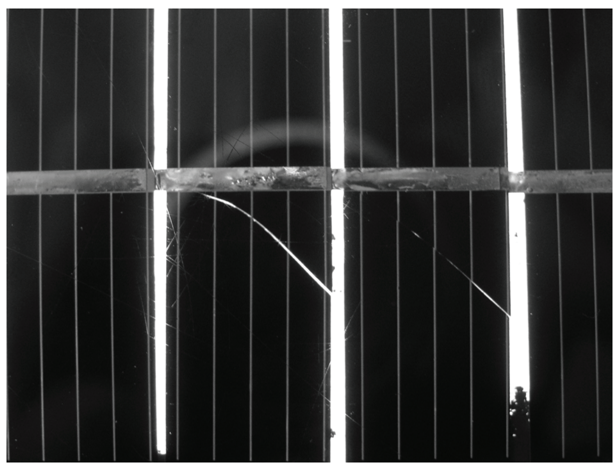

Fig. 2. Detail of the damaged place in the visible spectrum

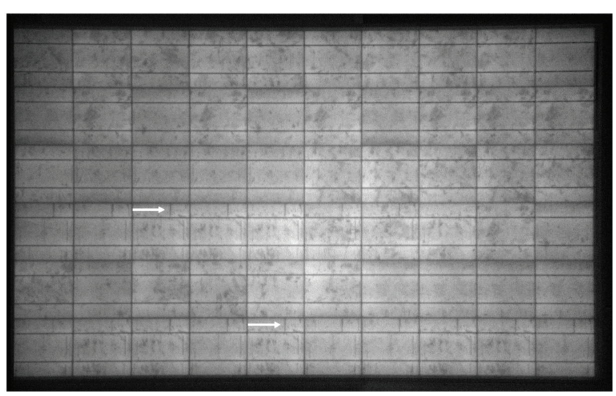

Fig. 3. Image of electroluminescence of a larger undamaged photovoltaic panel

to interruption of the connection lattice caused by screen printing. Two of these places are indicated by arrows. Electrical current is flowing evenly through the whole surface of PV panel.

In Fig. 4 there is a PV panel image taken by the IR camera. Resolution of the image is not as good as in the case of EL imaging, but some parts of PV panel without current flow are observable because of lower temperature. On the other hand, damaged parts with current flow are lighter, because they are warmer than the undamaged parts of PV panel and the same current flowing through the smaller surface has a higher density.

DISCUSSION

Fig. 5 shows *V-I* and *V-P* characteristic of PV panel during the autumn season with solar radiation intensity of 775 W m^{-2}. According to this characteristic, the nominal output power P_{max} should be 1.4 W. As a result of the damage, this PV panel does not reach the above mentioned parameters declared by its producer. The P_{max} and short-circuit current I_{sc} attain about 60% of the declared values (0.84 W and 1.08 A, respectively). In accord with the theory of fundamental physics, the open circuit voltage is not influenced by the damage of PV cells. The corrected ratio is 0.84/1.4 = 0.6. It means that the power was reduced to 60% of the original value. Fig. 1 shows that there are totally five PV cells with the active area reduced by about 40% connected in series. It is well known that electric current in serial strings of PV cells is limited to the value showed by the cell generating minimum current. So the power reduction of PV panel is in line with 'dark' area of the solar cells disconnected from the initial string of solar cells.

Also, from the shape of *V-I* characteristic we can see that current shows limitation probably because of the smallest active surface from all PV sections connected in the series. Characteristic of an undamaged PV panel would probably look like a plot growing to the higher value of the short-circuit current (approximately like the dotted line) (see Carrero et al., 2011; Munoz et al., 2011; Ding et al., 2014).

CONCLUSION

To detect a damage of PV panels, three nondestructive methods were applied. The visual inspection is very cheap and quick, however revealing only major cracks. The method of electroluminescence is the most accurate at the present. We have developed an equivalent of the industrial EL tester with the silicon CCD chip enabling a sufficient resolution using the CRYCAM-D camera in combination with image editing software. In high resolution images even small cracks without interruption of contacts are displayed, which cannot be detected by IR camera and can only rarely be seen during visual examination. But the EL method is more expensive and more time consuming compared to visual inspection.

Finally, IR camera does not yield as precise results as the CCD EL method. It provides low resolution images, but its use is more simple because the inspection, unlike using CCD EL, can be performed at daylight (not in a dark room). The method using IR camera is not applicable to hybrid solar panels (Matuška, 2012; Matuška et al., 2015) cast in the polysiloxane gel (Poulek et al., 2012, 2013) because the spread of temperature is affected by cooling media in the photothermal part of the hybrid solar panel.

All the three described methods are suitable for field inspection of installed PV arrays. For the field PV panels inspection more expensive InGaAs NIR cameras sensitive in near IR and not sensitive in visible spectra are recommended. A standard EL camera with silicone chip cannot be used because of high sensitivity to solar daily radiation and very low sensitivity in

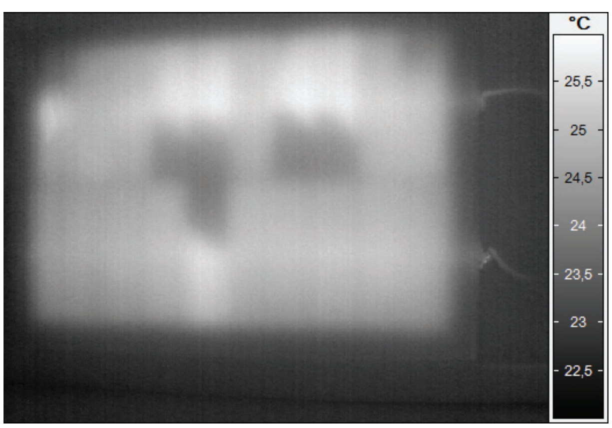

Fig. 4. Infrared camera image of a small photovoltaic panel

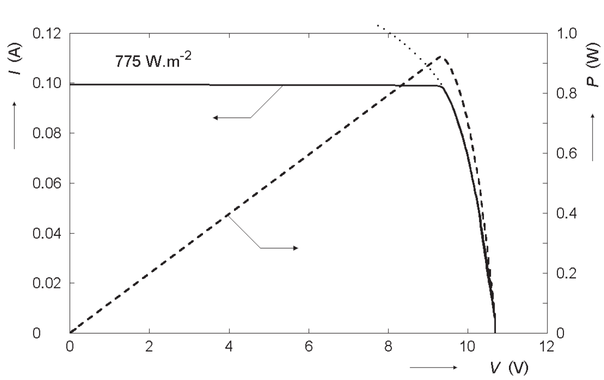

Fig. 5. *V-I* and *V-P* characteristic of a photovoltaic panel during autumn season with solar radiation intensity of 775 W m^{-2}

NIR area. Standard EL cameras with silicone chips can be used in dark rooms only where the strong daily solar radiation 'noise' is eliminated. Arrangement of the optical systems (lenses, etc.) has to be adjusted according to the real PV array layout.

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