Renewable Energy 118 (2018) 138–145

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Outdoor detection and visualization of hailstorm damages of photovoltaic plants

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ARTICLE INFO

Article history:
Received 31 July 2017
Received in revised form
30 October 2017
Accepted 4 November 2017
Available online 8 November 2017

Keywords:
Crystalline silicon
PV modules
Hail damage
Characterisation

ABSTRACT

Photovoltaic modules can experience damages of varying severity in the case of heavy hail storms. In the worst case, complete glass and solar cell breakage results in efficiency and security losses of the affected modules which therefore have to be replaced. However, there is a strong need to inspect the remaining modules directly in the field in order to assure no hidden damage. Three hail-affected photovoltaic plants in the south of Austria were investigated first with common standard methods like analysis of the plant monitoring data and thermography. Then, these plants were additionally investigated by novel non-destructive methods. With the aid of two innovative characterisation tools, outdoor electroluminescence and UV-fluorescence imaging, hail-induced damaging of solar cells can be detected even when the solar glass of the modules withstood the mechanical impact of the hailstorm and no damages are visible to the naked eye or well recognizable by thermography. The non-destructive, easy to handle and fast characterization technique UV-fluorescence imaging allows the detection and visualisation of hail induced cell damage. Modules showing partial cell breakage and/or micro cracks – as proven by outdoor electroluminescence measurements – and lead to a reduced electrical performance can be unequivocally identified.

1. Introduction

Reliability and long term performance of Photovoltaic (PV) modules for warranted lifetimes of 20+ years with a total yield loss not exceeding 20% are a crucial request of the market to allow for increasing implementation of photovoltaic technology as strong part in the renewable energy mix.

Several test procedures like IEC61215 or IEC61730 exist to ensure high product quality of PV modules at the manufacturing site. One of the most frequently used methods in the laboratory and for quality insurance in the module production line is electroluminescence imaging. Electroluminescence provides information on the uniformity of the current flow in individual solar cells and whole modules and allows for detecting cell-cracks and disruptions in the electric connection system comprising of busbars, cell connectors and junction box.

However, once the modules are installed at the PV plant, besides monitoring the generated electrical power over time only limited characterisation methods are available to verify the faultless performance of individual PV-modules directly in the field. The most frequently used inspection method in the field is Infrared (IR)-thermography with a portable camera which can detect thermal (e.g. hot spots or hot cells due to temporary shadowing or impurities) and some electrical failures like unconnected modules or strings or defective bypass diodes [1–4].

As several faults and defects can't be detected in the field by the well-established thermographic method, recently strong efforts

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https://doi.org/10.1016/j.renene.2017.11.010
0960-1481/

were undertaken to develop innovative techniques like e.g. outdoor electroluminescence (EL) [5] and UV-fluorescence imaging [6–9] to provide PV-plant operators with a tool for improved non-destructive maintenance. Regular check-ups of the installed PV-modules appear necessary especially after extreme stress imposed by storm events, heavy snow loads or hail storms [10,11].

Although fluorescence effects of the aged and degraded polymeric PV-encapsulation materials were already detected by the group of Pern and Czanderna 20 years ago [12] only in the last years intensified interest to use this effect for a characterisation tool of weathered and aged PV-modules appeared. The characteristic fluorescence pattern of PV-modules obtained from the polymeric encapsulant upon irradiation with an ultraviolet (UV)-lamp contains manifold information connected with the (i) barrier properties of the backsheet used, (ii) degradation of the encapsulant, (iii) time and type of stress impact at the installation site and (iv) the integrity of the solar cells [13–15]. These effects and the fact that this method is fast, cheap and flexible allow UV-fluorescence imaging to be one of the most promising innovative inspection methods for installed PV-modules.

For the work presented, several PV-plants which experienced heavy hail storms were investigated. A decreased power-output after the stress event and numerous modules showing glass breakage were identified. After exchanging these obviously damaged modules, the question came up whether the hail storm also affected the performance of all other modules in the plant. Thus, innovative outdoor characterisation methods such as outdoor electroluminescence and UV-fluorescence imaging were chosen to non-destructively detect hidden hail storm induced damages of all modules in affected PV-plants. In order to prove the conclusions made upon the experimental data, the effect of hail impact on the degradation behaviour of modules was also simulated in the laboratory in accelerated ageing tests of test modules.

2. Experimental & methods

2.1. Description of the hail-affected PV-plants

Three hail-affected PV plants in the south of Austria (Carinthia) were investigated. The distance over air of the 3 plants is approximately 10 km. All three PV-systems comprise of standard glass/backsheet modules installed on flat roofs. PV plant 3 is a research installation, PV plant 2 is a company owned plant on a shopping centre, and plant 1 is a company owned system installed on the roof on a production hall.

A heavy hail storm took place in this region in summer 2015 at the afternoon of the 8th of July. Hailstones with a diameter up to 40 mm dropped down on the PV-modules. After the hail storm, all three inspected power plants showed some modules with visible detectable damages (broken glass). The details for the plant construction and module types as well as the number of damaged modules after the hail storm are summarized in Table 1.

2.2. Yield data evaluation

For comparison, the monitoring data of all three power plants is analysed and the performance ratio (PR) for each plant calculated. The PR is the quotient of the actual measured yield (averaged per month) and the targeted yield (calculation based on irradiance measurements and the labelled module/system power) of the PV plant (IEC 61724) and is expressed within the paper in percent.

In addition, the relative yield (RY) of a hail affected and glass broken module compared to a healthy reference module is checked with a module fine monitoring system from Solar Edge at plant 3. It allows for a comparison of string performance ratio and energy yield per module. In addition, the behaviour of the glass-broken module is monitored over two years at plant 3 (Figs. 1 and 6).

As plant 1 has no own irradiation sensor, the irradiation data are taken from the nearby plant 2 (10 km distance). For all calculations whether PR or RY, a monthly average is used.

2.3. Thermography (TG)

Thermography is one of the common measurement techniques for inspecting photovoltaics plants as all sun illuminated PV modules emit infrared radiation. Thermographic cameras detect radiation in the long-infrared range of the electromagnetic spectrum and produce images of that radiation. The basic requirement for this measurement is sunlight of at least 600 W/m^2 [4] in order to generate measureable temperature differences for the evaluation of PV modules. The most important feature is the evaluation of the temperature homogeneity distribution within a module, as good working modules show equal (± 2 °C) cells temperatures for all cells. All inspections are made with a high resolution standard infrared camera with a measurement range of 7–12 μm wavelengths. The camera (Testo 890) is equipped with a micro bolometer detector with a resolution of 640 × 480 Pixels.

2.4. Twilight electroluminescence (TW-EL)

Electroluminescence (EL) is an optical and electrical phenomenon in which a material emits light in response to the passage of an electric current or a strong electric field. When investigating PV modules, current is fed into a solar cell/module and radiative recombination of carriers causes light emission. The PV module string/modules are powered in forward direction and work as large „LED array", which is emitting light in the near infrared range at 1100 nm (bandgap of Si). For EL measurements it is important to have dark environment, thus, measurements are usually performed in a dark chamber of a laboratory. Recently a corresponding outdoor method for measurements directly in the field has been developed which has to be performed after sunset [5]. For twilight electroluminescence measurements a modified consumer camera without an IR blocking filter is used to detect the emitted 1100 nm infrared light. The used camera is a Canon EOS 700D with picture shooting times of about 2 s.

2.5. UV-fluorescence-imaging (UV-F)

UV-Fluorescence measurements are performed in dark environment (night) by illumination of the PV-modules with UV-light and detection of the fluorescing light in the visible region by the eye or a photographic camera system. In our experimental setup the UV-Fluorescence is detected with a digital photographic camera (Olympus OM D, equipped with high pass filter to cut-off the UV-irradiation). Excitation with UV-light is performed with a self-made UV-lamp consisting of 3 power-tuneable LED-arrays with an emission maximum at 380 nm (exchangeable to 360 nm) and a low pass filter to cut off all visible light. Power supply is a modified DC/DC converter with a controllable and piecewise constant voltage/constant current characteristic, sourced by a 12 cell Lithium-polymer-accumulator with a capacity of 5000 mAh. This characterization method is non-destructive, non-invasive, easy to handle and fast (an exposure time of 30 s is sufficient to achieve a well contrasted UV-fluorescence image of a module).

2.6. Laboratory tests with test modules

In order to gain a better understanding of the fluorescence patterns observed in the field, test modules are manufactured,