Detectable faults on recently installed solar modules in Western Australia

Sinisa Djordjevic*, David Parlevliet, Philip Jennings

School of Engineering and Information Technology

Murdoch University, Murdoch WA 6150, Australia.

Telephone: (+61) 8 9360 7217; Email: s.djordjevic@murdoch.edu.au

*Corresponding Author

Abstract

With lower consumer prices and the boom in solar PV module sales there has been a rapid increase in the number of PV modules installed on roof tops. In some instances, noticeable changes in the visual appearance of these modules have been observed, such as the occurrence of 'snail trails' or microcracks or discolouration. These changes raise concerns that the modules may be defective or not performing as warranted. We have examined a number of these problematic modules and identified several common defects that have appeared on installations around Australia and the effect that these defects have on the output of the individual solar modules. Results from a series of studies of modules showing these defects have been systematised and presented in this paper.

Keywords: Inspection of solar modules, Faults of solar modules, Defects of solar modules, PV quality assurance, Silicon solar cells, Microcracks in solar cells

1. Introduction

Solar PV modules that were produced before the year 2000 were largely able to withstand environmental conditions without significant degradation [1-3]. However, there are other aspects, such as solar cell spectral response, which are very sensitive to the spectral content of the incident light at locations with specific weather, season and time of the day [4].

After the opening of the feed-in-tariff scheme to applicants in WA, between 1 July 2010 to 1 August 2011, with 40 c/kWh before 1 July 2011 and 20 c/kWh from 1 July 2011 [5], there was a "flood" of newly imported PV modules from many countries, by different manufacturers, with a range of sizes and output powers. According to labelled module specifications, the quality was expected to be within existing standards and the quality was guaranteed by the warranty agreement. This was, however, not always the case. In a relatively short period of time after the installation, some customers noticed irregularities in the visual appearance of their solar modules. This often raised suspicions that the electric output may also not be as specified. These suspicions triggered requests for independent module testing.

Different methods are used for testing solar modules.

Traditionally, one of the first tests is visual inspection. Visual inspection can detect the following defects: encapsulant browning, delamination and bubble formation in the encapsulant, back sheet polymer cracks, front surface soiling, blackening at the bottom edge of the module, junction box connections corrosion, busbar oxidation and discolouration, junction cables insulation degradation, glass breakage etc. [6, 7]. It was also noticed that modules in countries with higher ambient temperatures show pronounced "yellowing" of the encapsulant [8]. One of the last observed effects is the "snail trails" [9].

Performance testing includes accelerated tests (accelerated performance degradation, accelerated UV, accelerated temperature and thermal cycling, accelerated structural degradation, and accelerated reliability testing), mechanical, vibration and shock cycling [10]. A number of key parameters that are typically tested are: open-circuit voltage (Voc), short-circuit current (Isc), maximum power output of the cell (Pmax), voltage at Pmax (Vmax), current at Pmax (Imax), conversion efficiency of the device (η), fill factor (FF), cell diode properties, cell series resistance, and cell shunt resistance [11].

A very practical method is measurement of the I–V and peak power curves in the field, with portable analysers, which are later adjusted for standard conditions. The standard test conditions can be obtained in a solar simulator.

Infrared imagery is used to diagnose faults within solar modules. A typical module at 50°C emits in wavelengths from 3 to 20 µm [12]. The problems that can be detected by an IR camera include the following:
(a) localised shunting path within a solar cell (as a result of wafer impurities, ineffective edge insolation, non-uniformity of thin films and field ageing),
(b) imaging through glass superstrates,
(c) resistive soldering in modules (current flow through a reduced number of solder bonds due to the field ageing),
(d) reverse-bias heating in modules (when modules with series-connected cells are short circuited, individual cells can heat up significantly),
(e) bypass diode functionality (due to the reverse-bias heating),
(f) temperature variations on the module (due to wind or roof temperature distribution) [12].

Electroluminescence imaging is a non-invasive technique developed to detect the radiative recombinations of charge carriers excited under forward bias. This technique can be used for characterisation of silicon solar cell properties like minority carrier diffusion length and series resistance, but mostly for localisation of cracks, broken fingers, dark dots and inactive cells [13].

Ultrasonic inspection of solar modules is used to examine the mechanical properties of the assembled cells. The most common defects that can be detected are air inclusions hidden between the back contact cells and the conductive back sheet foil, and delamination [14].

Among the efforts to improve solar module testing, some new techniques are developed like computer simulation of module problems [15] and aerial IR thermography [16]. Computer simulations would help to differentiate module designs (geometry, processes, and materials) and critical locations of possible defects. Areal IR thermography could be used to locate defects of solar modules on a large scale.

This paper is based on independent testing performed on a number of solar modules which have been provided by different suppliers from Western Australia and from the outdoor test site located at Murdoch University. From these tests a number of common defects were identified that these modules are susceptible to. Results from a series of modules showing these defects have been analysed and presented in this paper.

2. Methodology

The first step in testing solar modules was always visual observation as a starting point from the customer's viewpoint. Many solar panels are reported as faulty to the installers and suppliers on the basis of their visual appearance. Once the fault has been initially observed, detailed visual inspection allows the identification of gross defects, soiling and snail trails. The detailed inspection may typically involve macro and wide angle photographic surveys of the modules and areas of interest within these. Wide angle photographic surveys allow an identification of larger defects such as soiling and snail trails, while the macrophotographic survey produces a higher resolution and magnification image for more detailed diagnosis of the visible fault.

In this study, electrical measurements were performed to test the module output. The IV characteristics were measured with a PROVA 210 Solar Module Analyser and from these the temperature and irradiance adjusted efficiency, fill factor and maximum power under approximately AM1.5 conditions were calculated. These were then compared with the manufacturer's specification. This allows us to determine if the defects identified under visual inspection were detrimentally affecting the module output. The shape of the IV curve can also provide some insight into whether there are any problems within the module.

Infrared photographs of the solar module were then taken using a FLUKE Ti25 IR camera. These were taken while the panel was outside, under load and exposed to ambient lighting on a clear day. The infrared images allow the identification of possible hot spots and cracks within the module. This inspection allows the detection of defects which are not visible with a naked eye. These include cracked or broken cells, hotspots in the cells or their connections and soldering, non active cells or regions which do not contribute to photogeneration and failures in bypass diodes [17].

The source of modules for this report is the former RISE compound at Murdoch University in Perth and samples provided by different PV module suppliers from Western Australia.

3. Results and Discussion

There are many types of defects that appear on PV modules that were analysed in this work. A series of different defects that were identified via the analyses of the solar modules are shown in Table 1. These visually identify the different types of defects that were found in the measured modules. Examples of some defects are shown using infrared photography (Table 1, examples 1.15 and 1.16). The main characteristics of the defects can be described as follows:

3.1. Discolouration

Visual discolouration is the most common defect in modules that have been weathered in the field for many years. This is evident in crystalline, multicrystalline and amorphous silicon modules as can be seen in Table 1 (1.1–1.4). Discolouration reduces the sunlight that penetrates to the solar cell.

The discolouration is likely caused by internal factors (poor encapsulant quality) or external ones (high temperature, humidity).

3.2. Cracking

Cracks can be visually identified, if they are large enough. Micro-cracks can be formed during manufacturing, in manual soldering, for example, when mechanical and thermal stress is applied. Under further stress, after years in the field, those cracks can become larger and more obvious for visual detection. Electroluminescence imaging detects micro-cracks very well. Cracks of solar cells can reduce the module output. Examples are given in Table 1 (1.5, 1.6).

3.3. Snail tracks (snail trails)

This is a relatively new phenomenon, described as discolouring of the silver grid across the cell or along the edge. It has been found that snail tracks do not emerge in modules that are stored indoors; they appear after 3–5 months of outdoor exposure. Snail tracks develop to a certain width and seem not to (or maybe very slowly) grow any further. The degree of EVA cross linking does not correlate with snail tracks, and snail tracks make cell cracks “visible”. The origin of snail tracks is still a matter of speculation [18]. An example is shown in Table 1 (1.7).

3.4. Antireflection (AR) coating damage

AR coatings exhibit changes in spectral transmittance primarily in the high visible range (600–700 nm). AR coating and performance loss can result from dirt and dust retention [19]. We don’t have any examples of that damage.

3.5. Soiling

Soiling is a form of shading that can decrease the module’s performance over time and has been well documented with respect to dust concentration, wavelength and spectral transmittance [20]. Soiling consists of aggregated dust, grime, bird droppings and even moss in some situations (Table 1: 1.12). If soiling extends far enough to cover a portion of the cells, the output current is reduced, as can be seen in the I–V curve [21].

3.6. Busbar oxidation and corrosion

This is important in reliability issues and diminishing output including loss of adhesion and delamination, chemical instability under current collection conditions, and compatibility of materials [22].

3.7. Hot spots and strings

Hot spots appear when a solar cell within a module generates less current than the string current of the module. That happens when the cell is shaded, damaged or electrically mismatched [23]. Hot spots can be attributed to the properties of the solar cell like local shunts, deformations of the p–n junction, impurities, wafer resistance or other processing problems [24].

3.8. Encapsulant

Encapsulant delamination is one of the main degradation modes of PV modules. It occurs at the interface between the encapsulant and the front surface of the solar cell and between the encapsulant and the glass cover [25]. The encapsulant material is usually EVA (ethylene vinyl acetate), processed under defined temperature and time during the lamination. Cheap material or incorrect processing results in a change of colour or delamination. Encapsulants should be tested for moisture, resistivity, adhesion, UV exposure, water ingress, etc [26].

3.9. Physical impacts

Some modules measured in this study had been exposed to severe physical impacts. These had resulted in wide scale breakage of the glass on the module's surface. These fairly extreme examples are likely to have been caused by weather, mishandling upon relocation, major thermal expansion mismatches or acts of vandalism. These cases of damage can be seen in Table 1 (1.19 and 1.20).

Each of the above mentioned damage and failures affects more the output of the PV module to some extent and each has to be addressed individually in further research. Some defects can be prevented by improving manufacturing processes, some by using better materials, some by better protection or more careful handling, etc.

Relatively new methods that can be used for further research are: Stress analysis [15], aerial PV thermography [16] or modelling and simulation of solar cell and module defects, like thermal fatigue [26] or long-term thermal ageing [27,28].

Although almost all of the defects that were detected here are also found in other parts of the world, their number is relatively small compared with the number of modules in very good operating state. This suggests that failed modules can be replaced without too much concern about the predicted life expectancy of 25 years of a PV system. A typical description of life expectancy was given in Reference [29], which states that modules can be properly tested, but "it is impossible to provide a 30-year certification for any PV module submitted for test".

Typical samples of the effect of module and cell degradation and failure on the electrical characteristics and performance of the modules are presented in Figures 1 to 4. The examples shown highlight the link between the infrared measurements and the electrical measurements for determining the impact the defect has on module performance.

4. Conclusions

Defects and faults of solar modules, recently installed in Western Australia, were presented in this paper. Modules have been exposed to solar radiation and other environmental conditions for up to ten years. Defects were described and illustrated, and compared to the same defects described in the published literature. New defects, specific to Western Australia were not found. There is, however, an exception, specific to WA, about regions with extremely high solar radiation and temperature during the year, which suggests that defects, faults and the degree of degradation can be related to those extremes. Development of defects and degradation under specific WA conditions is a topic for further research. The number of defects and failures are relatively small compared to the total number of installed PV systems. Some defects do not significantly affect the output of solar modules.

5. References

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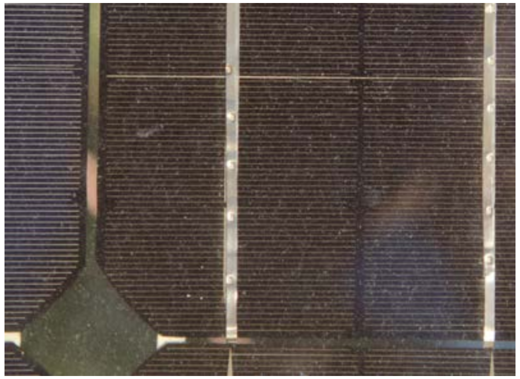
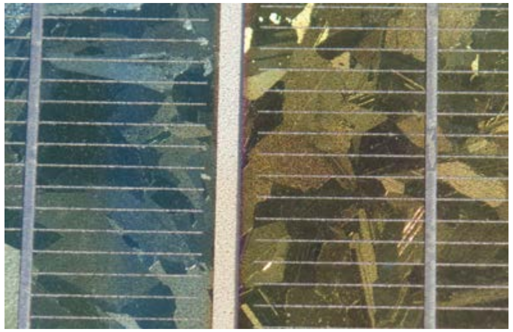
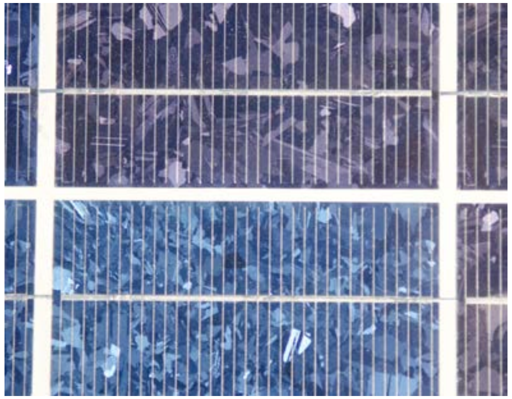
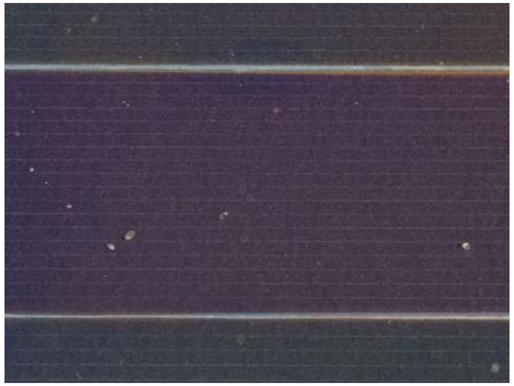
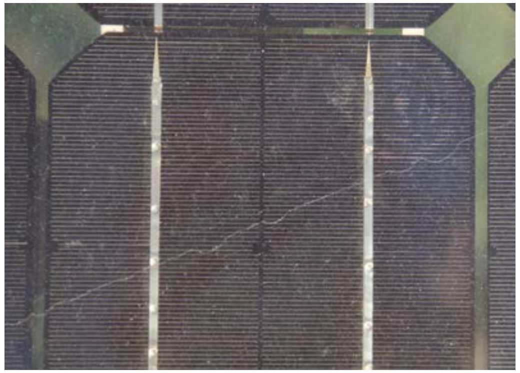
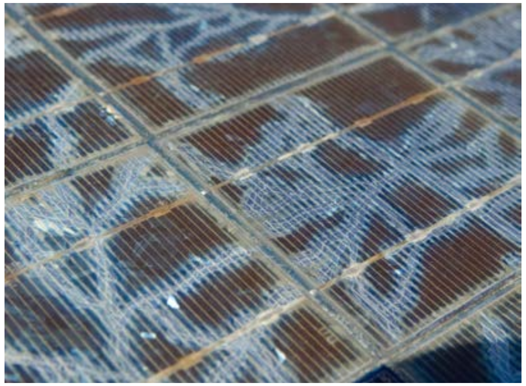
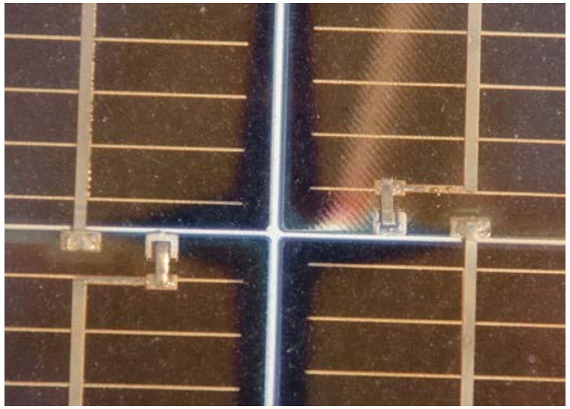
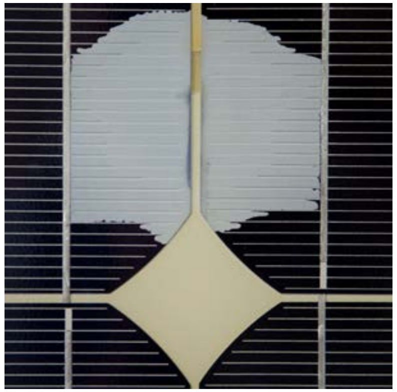
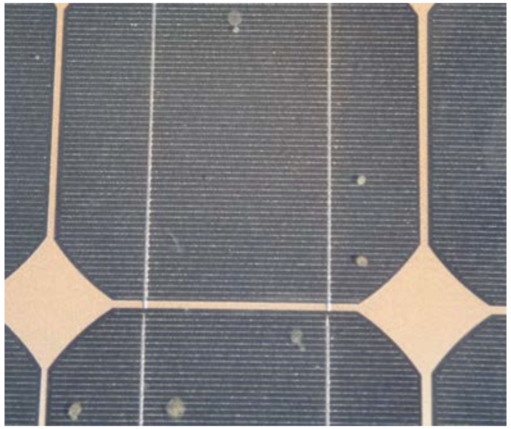
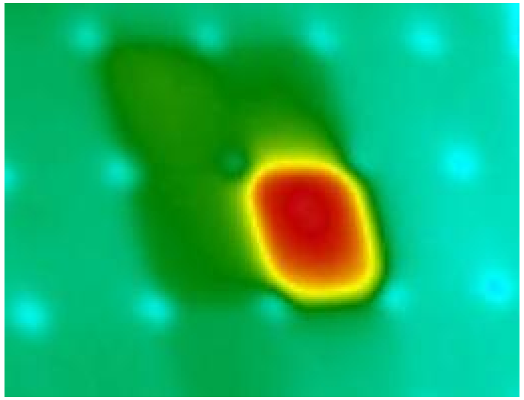
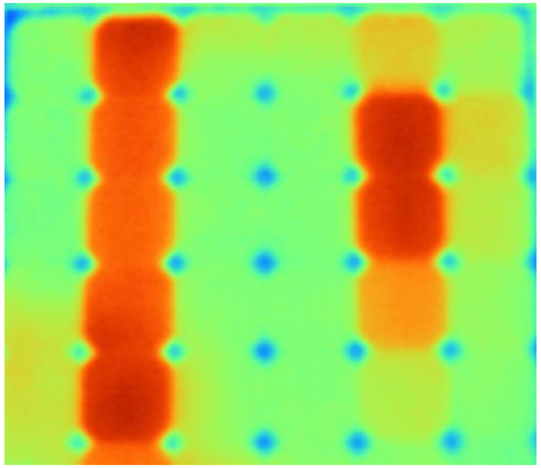
Table 1 - List of solar module and cell defects and failures

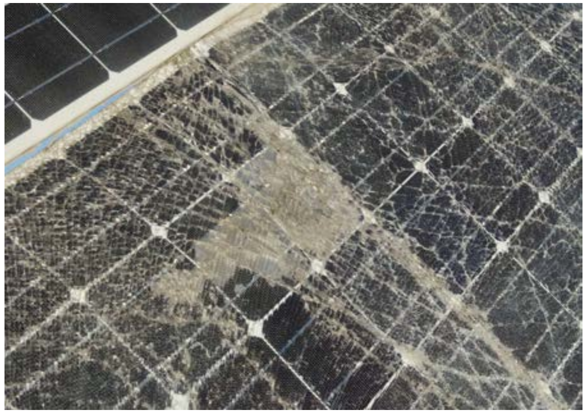
1.1 Discoloured solar cells – yellowish (c-Si)	1.2 Discoloured solar cells – yellowish (p-Si)	1.3 Discoloured solar cells – purple (p-Si)
		
1.4 Discoloured solar cells – purple (a-Si)	1.5 Cracking of solar cells (c-Si)	1.6 Cracking of solar cells (a-Si)
		

1.7 Snail trails	1.8 Solar cell edge degradation and discoloration	1.9 Encapsulant delamination (c-Si)
		
1.10 Encapsulant delamination (a-Si)	1.11 Front surface soiling	1.12 Blackening at the bottom edge of the module (ingrained dirt not possible to remove)
		

1.13 Busbar oxidation and discoloration	1.14 Busbar oxidation and discoloration	1.15 Hot spots (hot cells)
		
1.16 Hot strings	1.17 Sealant infiltration	1.18 Insufficient stability of frame
		

1.19 Physical impacts (fracture, glass breakage)

1.20 Physical impacts (fracture, glass breakage)



1.21 Delamination of the back polymer

1.22 Junction box corrosion

1.23 Damaged diodes

1.24 Back sheet polymer cracks

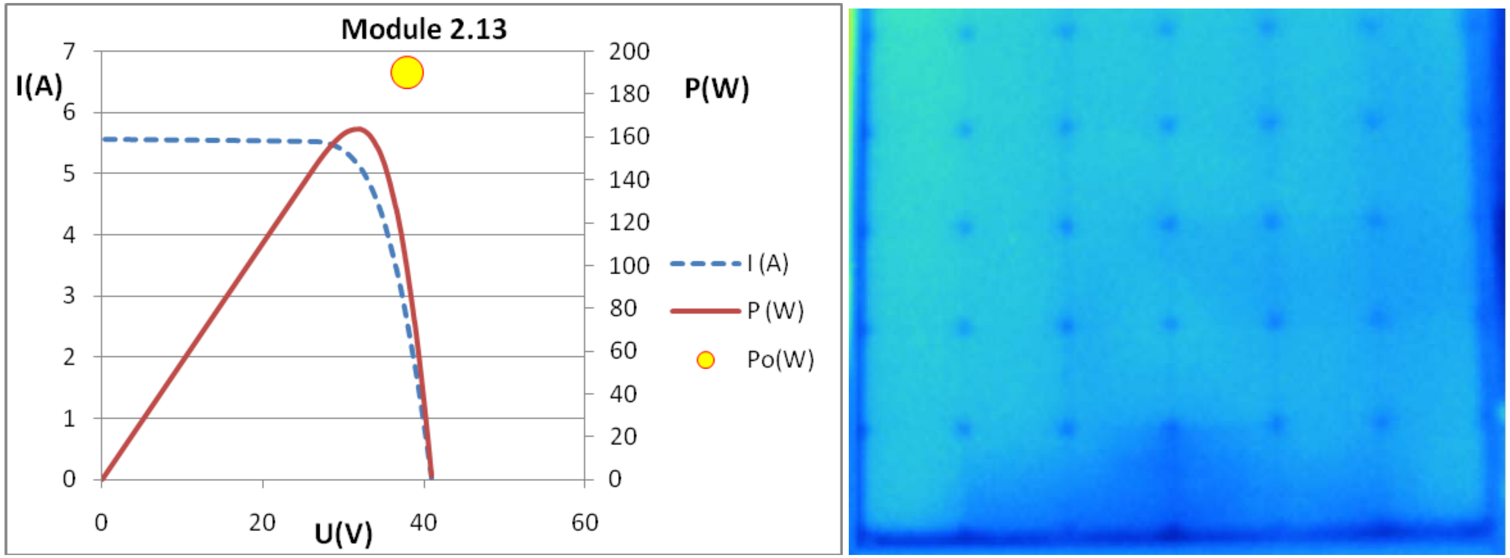


Figure 1 – A module with small degradation in power (P_m from 190 W_p to 165 W_p) and no IR signs of hot spots

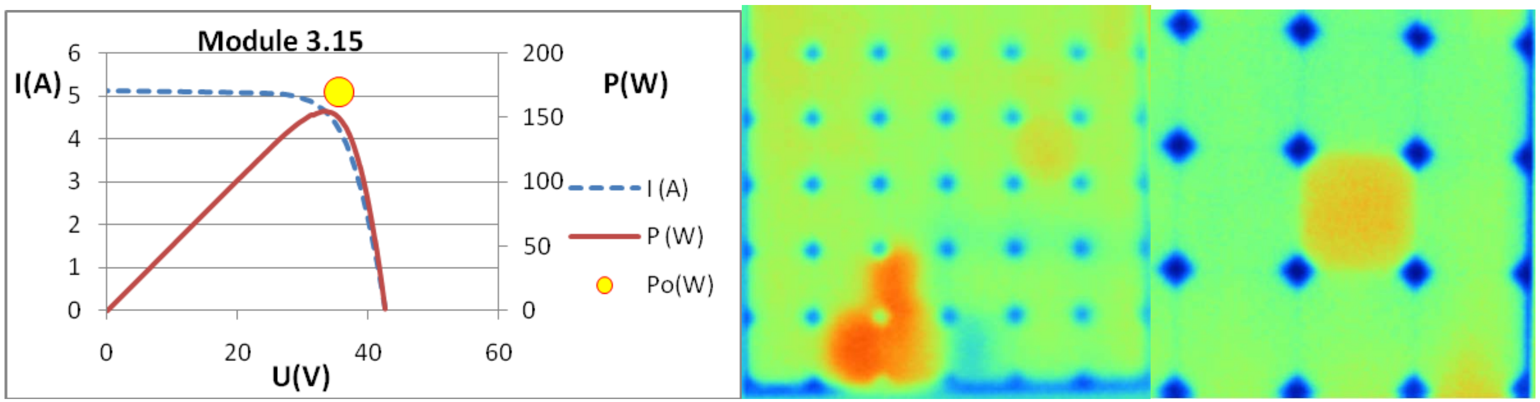


Figure 2 – A module with a small degradation in power (P_m from 170 W_p to 155 W_p) and first IR hot spots

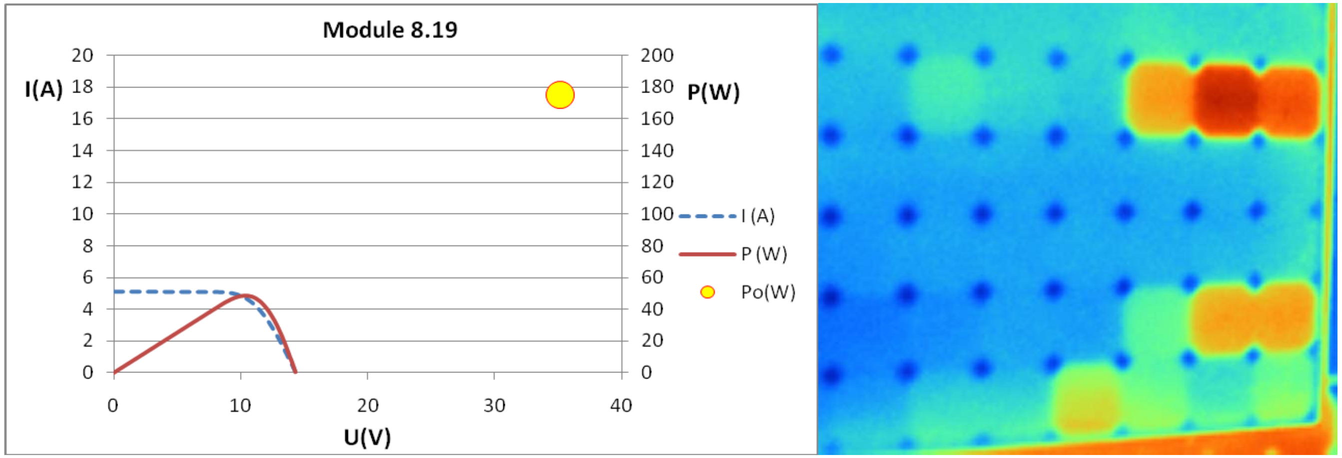


Figure 3 – A module with significant degradation (practically failed) in power (P_m from 175 W_p to 50 W_p) and different IR hot spots

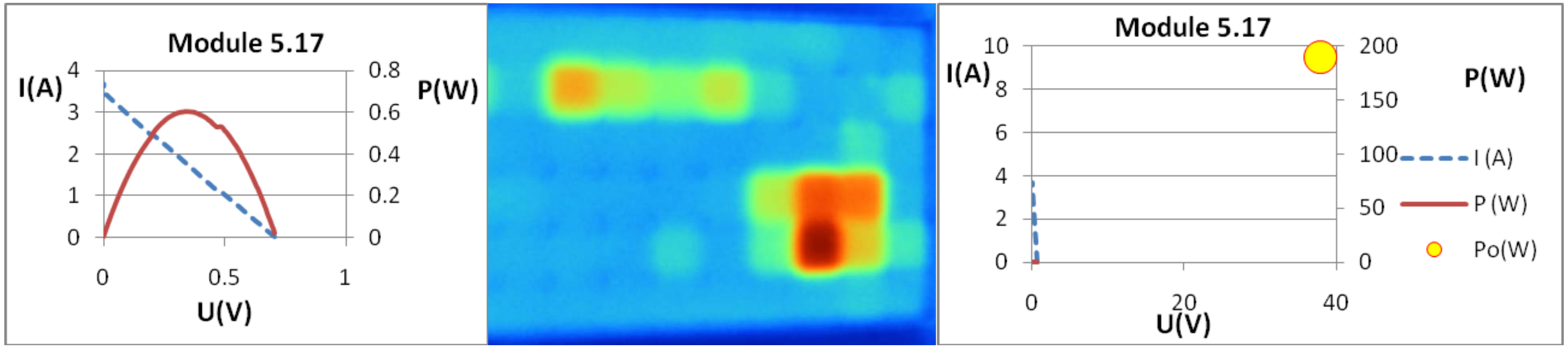


Figure 4 – A module with complete failure in power (P_m from 190 W_p to 1 W_p) and IR hot spots of failed solar cells