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On site renovation of degraded PV panels – Cost and environmental effective technology

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A B S T R A C T

The encapsulation of photovoltaic (PV) panels determines the trouble-free lifetime of the panels. The quality of PV panel encapsulating components has significantly decreased over the last 25 years. Consequently, large quantities of PV panels worldwide are experiencing degradation or damage much earlier than expected.

To address this issue, an on-site renovation technology for PV panels has been developed, which involves pre-deposition diagnosis and polydimethylsiloxane (PDMS) film deposition. This technology substantially prolongs the real field lifetime of PV panels. In terms of carbon footprint, PV panel renovation is over a hundred times more effective compared to PV panel replacement. It is also a profitable solution.

1. Introduction

The trouble-free lifetime of PV panels is determined by their encapsulation by lamination process. However, due to intense market competition for the production of the cheapest modules, both the quantity and quality of encapsulating components have decreased over the past 25 years. For instance, 25 years ago, the front glass thickness of PV panels ranged from 4.0 to 3.2 mm. Recently, it has been decreased to 3.2–2.8 mm range despite the PV panel area being four times larger. At glass/glass PV panels the usual front glass thickness was 3.2 mm but it was decreased to 2.0 mm or even to 1.6 mm. Similarly, the height of typical PV panel frames was 40–50 mm 25 years ago, but it now ranges from 30 to 35 mm, despite the PV panel area being four times larger. Additionally, the use of less durable films such as PVDF (polyvinylidene fluoride), PET (polyethylene terephthalate), PA (polyamide), etc., has become common for the polymer-based backsheets, whereas it originally used the best quality polyvinyl fluoride (PVF) film. Moreover, the typical PV array system voltage has increased from about 600 V DC to 900 V DC, and more recently, up to 1500 V DC. Therefore, the quality of insulation and encapsulation materials should be increased rather than decreased. Furthermore, many new PV plants have been installed in demanding tropical locations, leading to a decrease in ground impedance (Risol) in real field conditions due to PV panel back sheet degradation.

It should be noted that laboratory simulations and accelerated testing are not equivalent to real field tests. Authoritative declarations about a 25–30 year lifetime of PV panels based on a few years of real field tests are also not relevant. Additionally, our experiments confirm that the ground impedance (Risol) of PV panels in field conditions (wet and dirty) is typically reduced by more than 1000 times compared to laboratory tests of the same PV panel after cleaning and drying. Although reduced ground impedance is a major factor, it is not the only source of PV panel degradation. However, this article does not focus on describing all PV panel degradation models.

Moreover, it is important to note that PV panels are connected in series to inverters (usually 20 panels), where a failure of a single PV panel causes the disconnection of the remaining 19 panels in the string, resulting in a multiplication effect [1]. Consequently, the failure of 5% of PV panels in a PV power plant can cause a substantial reduction in energy production.

Recently, reports have been published indicating that many IEC 61215 certified PV panels, particularly those located in demanding or tropical climates, have a lifespan of less than 12 years [2–5]. In some cases, this lifespan is even shorter, lasting less than 4 years [6–10], with an annual degradation rate exceeding 2% (see Table 1). These panels reach a total output power degradation limit of 80%, despite commercial leaflets declaring a PV panel lifetime of 25–30 years until 80% degradation. Table 1 illustrates two degradation groups: the first group

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Table 1
Degradation of usual design glass/polymer-based backsheet c-Si PV panels in demanding climate.

Location Ref.No.	Ghana [2]	India [3]	Algeria [4]	Algeria [5]	Morocco [6]	India [7]	Thailand [8]	Senegal [9]	S.Africa [10]
Annual degradation	3.19%	2.5%	3%	2.6%	2.6%	20%	2.7%	2.96%	5.5%
Outdoor exposure	12 years	10 years	11 years	11 years	3 years	2.5 years	3 years	4 years	3 years

Fig. 1. Picture of renovation PDMS film on back side of PV panel.

with a panel lifetime of up to 12 years and the second group with a lifetime of up to 4 years. There are numerous additional reports on degradation, but they often remain unpublished due to the confidential nature of the data following early failures in PV power plants. An example of such rapid degradation occurred in an 86 MW PV power plant in South Africa, where substantial output power reduction was observed just 3.5 years after the plant's opening, caused by PV panel back sheet degradation. This example aligns with the second degradation group, although exact data remain confidential [11]. Another valuable source of degradation data was measured and calculated in Qatar [12,13].

Even in the moderate climate of Europe [14–17], fast PV panel degradation ranging from 7 to 12 years is often associated with back sheet degradation, leading to a reduction in ground impedance (Risol). International Energy Agency (IEA) report [18] evaluated possibility to replace PV panels in 10 years period. The high degradation rates result in significantly increased expenses for replacing damaged PV panels in PV power plants. As a result, some panels need to be dismantled after

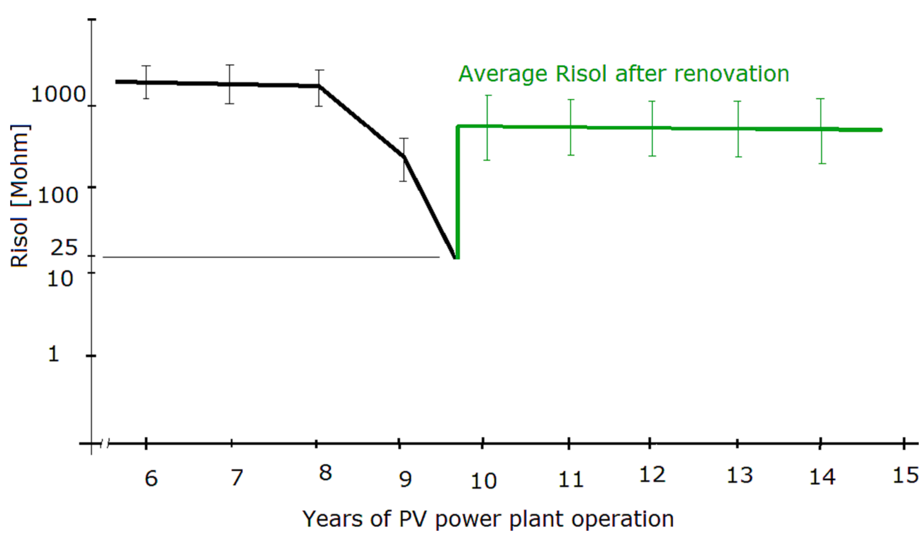

Fig. 2. Real field (wet) Risol of PV panels before and after PV panel renovation.

Fig. 3. Discharge channel between internal solar panel busbar and grounded PV panel frame.

only 3 to 12 years, which is well before the expected lifetime of 25 to 30 years. However manufacturers increased workmanship/defect warranty period from 5 years to 12-15 years within last decade. Naturally, this has corresponding economic consequences [17].

Therefore, servicing and maintaining new PV power plants, especially in harsh climates characterized by high temperatures and humidity, pose significant challenges. However, a new restoration method has the potential to address these issues.

2. PV panel renovation

The standard approach of replacing damaged PV panels with new ones is expensive and also not environmentally friendly in terms of carbon footprint. Several technologies for onsite PV panel renovation have been tested [1,16]. Some of these technologies utilize a thin polydimethylsiloxane (PDMS) film, approximately 0.1 mm in thickness, as depicted in our Fig. 1. PDMS is a hydrophobic material known for its excellent thermal stability, with a thermal resistance of 250 °C and a Relative Thermal Index (RTI) of 150 °C. It also exhibits good resistance to ultraviolet radiation. Interestingly, PDMS is the same material used in high-temperature, long-lasting PV panel lamination technology [19].

We have developed a new PV panel renovation process that includes not only on-site thin 0.1 mm PDMS film deposition technology but also a comprehensive on-site PV panel diagnosis, including measurements of ground impedance (Risol), delamination, and other factors, both before and after the protective film deposition. The two component PDMS has been deposited on site by spraying method. Fast cure (30 min at temperature 25°Celsius) PDMS was used. The film thickness was measured by micrometer gauge. The main method to check the renovation film quality has been regular testing of ground impedance (Risol) in real field (wet) conditions. To double check the renovation quality early morning inverter switch on time was monitored. Once there are troubles with low Risol the inverters are switched on several hours later as the inverters have internal Risol safety control [1]. Besides Risol tests visual check of chalking and edge delamination was performed.

To evaluate the effectiveness of our renovation process, we selected two test sets comprising 40 first-tier (bankable) PV panels rated at 250 W each. These panels were installed at a 2 MW PV power plant situated in a moderate climate region of central Europe. The first set consisted of damaged PV panels that were repaired using a 0.1 mm thin PDMS film with fast curing properties. The repaired panels were observed for a period of 5 years. As shown in Fig. 2, the real-field (wet) PV panel ground impedance (Risol) was successfully restored after the renovation and remained nearly unchanged throughout the 5-year observation period.

The tests demonstrate that the lifetime of repaired PV panels could be extended by 5 years or even more. The low cost renovation can be performed repeatedly in 5–7 years period. In contrast, the second set of PV panels without renovation experienced significant degradation after 5 years, leading to non-repairable failure. This failure was characterized by the presence of electric discharge channels between the PV panel's internal busbars and the grounded PV panel frame (Fig. 3), with Risol values falling below the critical threshold of 25 Mohm. At the beginning of the test (10 years of operation) Risol of 18 panels was below 25Mohm. At the end of the test (15 years of operation) Risol of all 40 PV panels was well below 25Mohm. Furthermore, delamination of the panel edges occurred, allowing water penetration and degradation of the back-surface laminate, resulting in cracks and chalking. It is crucial to conduct PV panel renovation within approximately one year after a rapid decrease in Risol is observed. Once an electric discharge channel is formed, the PV panel becomes irreparable. To date, a total of 41 MW of PV panels have been successfully repaired using the thin siloxane film method.

3. The carbon footprint

The carbon footprint is increasingly becoming an important criterion. We can compare the carbon footprint of a new replacement PV panel with the carbon footprint of the PDMS renovation film as follows:

a) The manufacturing carbon footprint [20] of a typical first-tier (bankable) PV panel, sized 1 × 1.6 m and with a power output of 300 W (weighing approximately 20 kg), results in 120 kg CO2 eq. More recent report [21] on c-Si PV panel carbon footprint shows similar results.

b) The manufacturing carbon footprint of a typical 0.1 mm thin polydimethylsiloxane film [22], sized 1 × 1.6 m (weighing 0.15 kg), results in 0.94 CO2 eq.

The replacement/renovation carbon footprint ratio is 121 to 1, and the replacement/renovation weight ratio is 133 to 1 (see Table 2). PV panel renovation is also significantly less expensive compared to PV panel replacement, with a replacement/renovation cost ratio of 11 to 1. Please refer to Table 2 for more details.

4. Conclusion

A brief review of publications on the reliability of photovoltaic modules reveals that the modules' service life is often shorter than the manufacturer's warranty. One of the factors contributing to the reduced service life of solar modules is the quality of materials used on the back side of the modules.

The proposed technology for on-site upgrading of solar PV modules is

Table 2
PV panel replacement and renovation comparison (size 1x1.6 m, power 360 W.

	Weight of replacement/ renovation item	Carbon footprint of replacement/ renovation item	Estimated lifetime of replacement/ renovation item	Replacement/renovation cost (material, labor, transport….)
PV panel replacement by new one	20 kg	**~ 120 kg CO_2eq**	About 7–10 years	**~ 120 USD**
PV panel renovation by PDMS film	0.15 kg	**~ 0.94 kg CO_2eq**	About 5–7 years	**~ 11 USD**

approximately 11 times more cost-effective than replacing the entire modules and about 120 times more effective in terms of carbon footprint reduction. The PDMS coating is stable for more than 5 years of exposure and allows the modules to restore their electrical insulation properties. Therefore, for PV power plant owners (end users), renovating PV panels proves to be a profitable and environmentally sound solution.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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