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LIFESPAN OF PV SYSTEMS OPERATING FOR OVER 30 YEARS IN HIGH-LATITUDE REGIONS

Summary

Photovoltaic (PV) module warranties typically assume a degradation rate of 0.8% per year over a 25-year lifespan, with some premium manufacturers offering up to 30-year warranties and industry efforts pushing toward 50-year guarantees. As PV adoption expands, particularly in high-latitude regions, module longevity is increasingly critical for project bankability and environmental sustainability. However, long-term performance data remain scarce, especially in these regions, where over 85% of installed modules are less than 10 years old. This study reports a 0.5% annual power degradation over 30 years for a PV system installed in Sweden in 1994. Visual inspection and electroluminescence testing revealed no major defects, while near-infrared spectra indicated no significant degradation of the encapsulants or backsheet. Additionally, we report on a second legacy system currently being installed on-site, incorporating modules over 40 years old. These results offer valuable insights into the long-term PV reliability in Nordic climates.

Keywords: Photovoltaics, Reliability, High-latitude, Long-Term Performance, Nordic Climates.

1. Introduction

Long-term degradation studies in European Nordic countries have been limited, especially considering that the photovoltaic (PV) market in this region only gained momentum in recent years [1]. While certain investigations have reported low annual degradation rates (<0.2%) [2] in Nordic climates, others have shown rates exceeding 1% [3]. To address these concerns and ensure the safe and reliable performance of PV modules under real-world conditions, indoor accelerated stress testing—outlined in the IEC 61215 standard for terrestrial PV modules—has proven to be a valuable methodology. This approach helps identify fault mechanisms and estimate degradation rates, allowing module and cell manufacturers to detect and mitigate issues during the development phase [4], ultimately reducing the time to market for new products.

However, it is important to note that these standardized tests may not capture all fault mechanisms observed under actual field conditions [5], as they are primarily designed and updated based on data from outdoor testing [6]. For this reason, indoor testing should not replace long-term outdoor testing—especially when assessing new types of modules or accounting for variations in environmental conditions. Continued outdoor testing remains crucial for a comprehensive evaluation of PV module performance and reliability [7], particularly as the industry moves toward 50-year warranties. Additionally, with the growing deployment of PV systems, end-of-life concerns have gained relevance, and extending module lifespan is one of the most effective ways to address this challenge.

In this study, we examine a grid-connected Building-Attached Photovoltaic (BAPV) system that has been in operation for 30 years in Sweden. We also report on a second legacy system, a 2.1 kW installation currently being deployed on-site, incorporating modules that are over 40 years old. These two systems are among the oldest still in operation in Nordic climates.

2. PV Systems Description

The BAPV system was installed on a rooftop in Sweden in 1994, as shown in Figure 1. It comprises 72 monocrystalline silicon PV modules manufactured by Gallivare PV in 1992, each rated at 45 W. The system is grid-connected and consists of two arrays, each with 36 modules, and has undergone various configuration changes and interventions, including upgrades to power electronics and system reconfigurations. In 2013, the PV system was upgraded with new inverters and reconfigured for improved performance. In early 2014, one of the arrays was adjusted to maximize energy yield under low irradiance conditions. Field tests showed that

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this array, with two sub-arrays in parallel (each comprising 18 modules in series, with lower input voltage and higher input current), outperformed the others in low irradiance conditions.

Fig. 1: The BAPV system installed on a rooftop in Sweden in 1994.

The second BAPV system was originally installed in 1984 in Sweden. It comprises 48 multicrystalline silicon modules manufactured by Kyocera, each rated at 44 W, for a total capacity of 2.1 kW, with a module area of 20.5 m². The system is now being relocated near the first system described.

3. Results and Discussion

Figure 2 shows the maximum power for 53 PV modules measured in 1992, 2016 and 2024. The average power (P) in 1992 was 43±3 W, in 2016 was 39±2 W and in 2024 was 37±3 W. The average degradation rate for the modules measured in 2016 and 2024, were very similar and around 0.5%/year. This rate falls significantly below the maximum degradation rates typically guaranteed by manufacturers at that time. The current-voltage (I-V) characteristics were measured in the field were translated to Standard Test Condition (STC) following the standards IEC 60904-1 for I-V measurement and IEC 60891 for temperature and solar irradiation corrections [8].

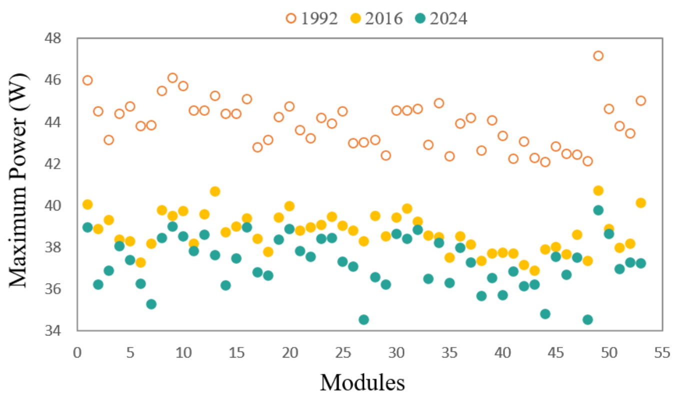

Fig. 2: The BAPV system installed on a rooftop in Sweden in 1994. Measurements from 1992 were taken prior to the system installation. All values are translated to STC conditions.

Modules exposed in Sweden for 30 years showed only slight discoloration, with no additional degradation detected through visual inspection and electroluminescence (EL) imaging, Figure 3 (Left). The near infrared (NIR) spectra confirmed ethylene vinyl acetate (EVA) as the encapsulant and a polyvinyl fluoride (PVF)-based backsheet [9, 10]. The data were then processed, including normalization, scattering and noise removal, and a Principal Component Analysis (PCA) was carried out to highlight hidden chemical information in the spectra. PCA analysis on encapsulants and backsheets attempted to correlate polymer properties with power loss, Figure 2, by categorizing modules into three classes (low, medium, and high-power loss). However, no clear trends emerged, as data from unexposed reference modules overlapped with that of field-aged modules, indicating no direct correlation between polymer degradation and power output. Similar results were observed for backsheets, supporting the idea that these modules performed reliably despite their age.

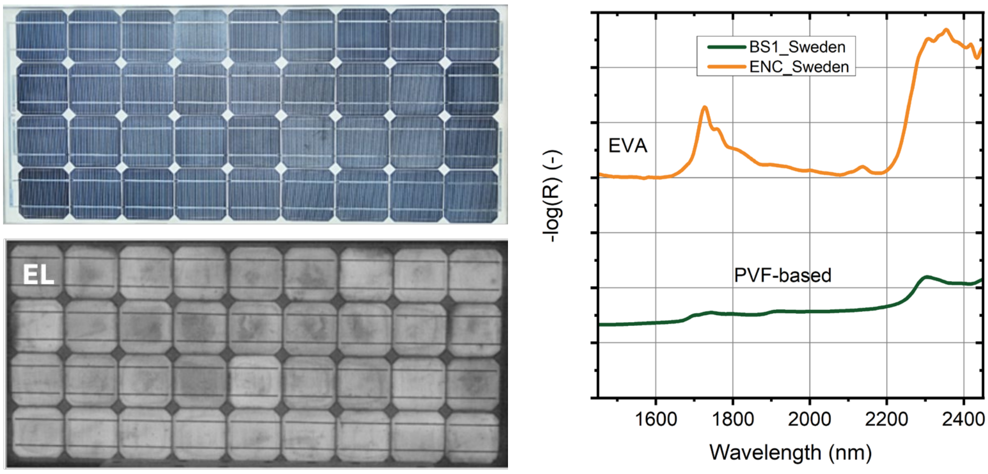

Fig. 3: (Left) Picture and electroluminescence image (EL) taken in 2024 from a representative module installed in 1994. (Right) Near-infrared (NIR) spectra of encapsulants and backsheet of the modules.

4. Conclusions

After 30 years of field exposure, the modules exhibit a degradation rate of 0.5% per year. This rate falls below the maximum degradation typically guaranteed by manufacturers. Electroluminescence imaging and near-infrared spectroscopy confirm that no significant faults are present in the modules, consistent with current-voltage measurements. A second legacy system, currently being installed on-site, features multicrystalline modules that are over 40 years old. These results provide valuable insights into the long-term reliability of PV systems in Nordic climates, where module longevity is increasingly critical for both project bankability and environmental sustainability.

5. References

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