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Outdoor Module Reliability

The ability to accurately predict power delivery over the course of time is of vital importance to the growth of the PV industry.¹ Two key cost drivers are the efficiency with which sunlight is converted into power and how this relationship changes over time. An accurate quantification of power decline over time, also known as the <I> degradation rate, <I> is essential to all stakeholders—utility companies, integrators, investors and researchers alike.

Outdoor field testing has played a vital part in determining PV field performance and lifetime for at least two reasons: it is the typical operating environment for PV modules²; and it is difficult to correlate indoor accelerated testing to outdoor results to forecast field performance.³ In this article, we present degradation rates for more than 40 modules tested under the same environmental conditions at National Renewable Energy Laboratory (NREL) and compare them with results from other publically available sources, such as research institutions, testing laboratories and professional organizations.

<a> Literature <a>

Figure 1 shows a compilation of degradation rates reported in the extensive literature regarding outdoor field testing of PV modules. While this histogram needs to be constantly updated as new information becomes available, some general insights can be drawn from it.

First, the distribution is highly skewed, with the most frequently occurring degradation rates below 1% per year. One possible reason is that modules with a large power loss are often considered to have failed and therefore are not included in calculations of degradation rates. Second, Figure 1 also shows a few occurrences of “negative degradation rate” points—modules that appear to exhibit improvement. Short field exposure in combination with seasonal performance variation can result in this observation (see the description of thin film performance transients on p. XX). Negative degradation rate points are not sufficiently addressed in the Photovoltaics for Utility Scale Applications (PVUSA) methodology.⁴ The third, and most important, observation is that the most frequently reported degradation rate is about 0.50% per year.

<figure 1>

<a> Field Testing at NREL <a>

It is difficult to extract more details from the module field test literature due to the wide variety of testing conditions, module types, manufacturers, dates of installation, length of monitoring times and geographical locations. The Performance and Energy Rating Testbed (PERT) at NREL is ideally suited for such a task because it can accommodate a large variety of modules in a limited footprint. More than 40 modules from more than 10 different

manufacturers were compared for their long-term outdoor stability on this system, side-by-side under the same atmospheric conditions. Module installations varied greatly, with the earliest installations occurring in 1993. There was an equally large variation in the monitoring times, from merely a few months to more than 16 years of continuous data. Due to increased uncertainty, no degradation rates were calculated for monitoring times below two years. Module technologies tested included amorphous silicon (a-Si), monocrystalline silicon (mc-Si), and polycrystalline silicon (pc-Si), cadmium telluride (CdTe) and copper indium gallium selenide (CIGS).

The modules, mounted at a latitude tilt of 40° facing south, are held at maximum power with IV curves taken every 15 minutes. The PVUSA method was used to translate the measured power to the PTC reference state.⁵ The PVUSA test conditions are: irradiance = 1,000 watts per square meter; ambient temperature = 20°C; wind speed = 1 meter per second. Subsequently, the monthly normalized data are graphed as a time series, and the degradation rates are determined from a linear least-square fit, as shown by the example in Figure 2.

<figure 2>

Figure 3 shows the results for the modules installed on the PERT system partitioned according to technology and date of installation. Modules were divided by installation date as pre-2000 and post-2000. The choice of the year 2000 is somewhat arbitrary and was driven by the decision to have a roughly equal number of modules for each category. The top and the bottom of the shown boxplots shown in Figure 3 represent the <I> interquartile range, <I> the range from 25% to 75% of the data. The line in the center is the median or the middle point of the data. The median is shown rather than the average because it is less sensitive to outliers, making the analysis more robust.

<figure 3>

It appears that the long-term degradation rates of the CdTe, CIGS and pc-Si technologies were reduced in the post-2000 category, while the a-Si category shows roughly the same distribution. Unfortunately, no new mc-Si modules were installed after 2000, making a direct comparison impossible. Furthermore, three categories contained only one data point, making the analysis less convincing.

Figure 4 shows a similar analysis of the reported degradation rates summarized in Figure 1. No statistically significant difference between pre- and post-2000 modules could be detected for a-Si, mc-Si, and pc-Si modules. However, a significant reduction was found for CdTe and CIGS modules, paralleling the findings from the NREL system. When all the rates in the pre-2000 category across all the technologies are statistically analyzed by an analysis of variance, the thin-film technologies—a-Si, CdTe and CIGS—show significantly higher degradation rates compared to their crystalline silicon counterparts. This observation has historically been associated with thin-film products. A similar analysis for all degradation rates in the post-2000 category, however, revealed that there is no longer a significant difference between the thin-film and crystalline silicon technologies. This suggests that

thin-film technologies have caught up to crystalline technologies in terms of reliability. In addition, the median degradation rate for monocrystalline and polycrystalline silicon nudged up slightly in the post-2000 category, although the difference is not statistically significant. This could be due to the influence of new products in the market place.⁶

<figure 4>

In conclusion, the combined findings based on observation of 40+ modules located at NREL and reported literature results increase the confidence that long-term stability has improved in the past decade, particularly for thin-film modules. As data is collected from more systems and the field exposure of existing systems increases, leading to smaller uncertainties in degradation rates, confidence in the analysis will continue to improve.

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Figure 1

Caption: Figure 1 This histogram summarizes publically available degradation rates for 780 field-tested PV modules. The median reported degradation rate is 0.5%/year; the average reported rate is 0.7%/year.

Credit: Courtesy NREL

Figure 2

Caption: Figure 2 The linear degradation rate for an a-Si PV module is statistically derived, using a standard least-square approach, based on normalized field measurements.

Credit: Courtesy NREL

Figure 3

Caption: Figure 3 Degradation data from NREL's Performance and Energy Rating Testbed are partitioned here according to technology and pre-2000 or post-2000 year of manufacture.

Credit: Courtesy NREL

Figure 4

Caption: Figure 4 Degradation data from PV field test literature, as shown in Figure 1, are partitioned here according to technology and pre-2000 or post-2000 year of manufacture.

Credit: Courtesy NREL

¹ Kurtz S, Granata J, Quintana M. Photovoltaic Reliability R&D toward a Solar-Powered World. Proceedings of the SPIE, San Diego, 2009, 7412.

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