Assessment of Performance Loss Rate of PV Power Systems

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Executive Summary

This IEA PVPS Task 13, Subtask 2.5 reports on a benchmarking study of the various approaches for calculating the Performance Loss Rate (*PLR*) of commercial and research photovoltaic (PV) power plants in diverse climatic zones. PLRs are calculated with data from the PV systems' power and weather data. The PLR is used by power plant owners, operators, and investors to determine the expected power output of a PV system over its installed life. Therefore, discrepancies in various calculation methods can greatly impact the financial around a PV installation. This benchmarking study is necessary due to the inconsistency in reported *PLR* results based on the many different approaches currently used to calculate *PLR* of PV systems. This study is focused on identifying which of the various approaches produce similar results and what causes inconsistencies between these different methods.

The findings of the study lead to a *PLR* framework which defines the basic four steps common to *PLR* determination. After initial exploratory data analysis and data quality grading, the four steps are 1) input data cleaning and filtering, 2) performance metric selection, corrections, and aggregation, 3) time series feature corrections, and 4) application of a statistical modeling method to determine the *PLR* value. The *PLR* of 19 high quality research PV systems and four simulated (aka "digital") PV systems using the various available PLR methodologies. These 23 datasets are now open access datasets for the PV community. This reports shows the impact of data quality and missing data on PLR calculations. Additionally, the "true value" of PLR (i.e., mean *PLR* ($\overline{PLR_i}$)) of each of the *i* systems studied is reported.

The *PLR* results were compared between the different calculation methods using statistical, data-driven, and deterministic analytical methods. These results help define which analysis methods produce results that cluster around the mean *PLR* of the individual PV systems. The results of the PLR framework for each PLR calculation method are benchmarked in terms of a) their deviation from the $\overline{PLR}$ value, and b) their uncertainty, standard error and confidence intervals. Of the 19 systems studied, nine systems had $\overline{PLR_i}$ values between -0.4%/annum to -1%/a, 3 systems showed lower $\overline{PLR_i}$ values, and six had larger $\overline{PLR_i}$ values in the range from -1%/a to -4%/a.

Various statistical modeling methods can be applied for the calculation of the *PLR* of PV systems. Furthermore, the selections made at each calculation step are highly interdependent such that the individual steps cannot be assessed individually. In addition, the different methods used are impacted

by the quality and missingness of the specific dataset in a complex manner such that one cannot identify particular methods as more relatively more robust.

The key findings of this report are:

- Data quality of the research and commerical PV systems impact the calculated PLR results. Exploratory data analys is important to assess, quantify, and grade the input datasets in order to understand the reliabilty or bias of reported results and to make choices on the appropriate methodology. If more than 10% of the daytime data is missing, then data imputation techniques are recommended.
- The degree of data filtering can impact the stability of the PLR results. Heavy data filtering can introduce strong bias in the *PLR* results, enabling a user to raise or lower the reported PLR of a PV system. When calculating and reporting PLR, an exhaustive report on filter selection and data cleaning is vital to better comprehend the steps in the PLR calculation. Reported PLR values need to be reproducible by others and have clearly reported confidence intervals, so that results among systems are comparable at a 5 % significance level.
- The choice of Performance Ratio *(PR)* or Power (*P)* in the calculation does not strongly influence the PLR results and give comparable results; therefore, either metric can be used.
- The uncertainity of the PLR is determined by the quality of data (power and weather). When there is high quality of data to compare between different types of PLR calculations on a single PV system, the results should be standardized on 95 % confidence intervals. When comparing *PLR* results between multiple systems, the results should be standardized at 83.4 % confidence intervals. In both of these cases, this standardization corresponds to a p-value, capture ratio, and significance level of 0.05 and is suggested be best practice. If a time series decomposition is used in the statistical modeling, then the residuals should be retained with the trend in order to report comparable confidence intervals.
- In cases where local weather data is not available, it is possible to use satellite-based weather data.
- Higher order time series data such as *I-V*, P_{mpp} (max power point) datastreams, by virtue of containing more information, represent an important opportunity for advanced analytics of PV system performance and degradation.

Careful data filtering is an essential foundation for reliable PLR analysis. Filtering can be divided into two categories: threshold filters and statistical filters used to remove outliers in power-irradiance pairs. High irradiance threshold filters tend to lower the reported *PLR* which is not necessarily representative of real system performance. Statistical filtering (to remove the anomalous power-irradiance data pairs) in combination with low to medium irradiance thresholds (to retain a larger amount of the system's data) provides the most reliable datasets for the next steps in *PLR* determination and produces the most accurate results.

These results will inform standards development for *PLR* determination, which was previously attempted with an initial proposal for a new IEC 61724-4 standard. However, the results reported here suggest that proposing a specific standardized method is still premature.

Even if we have not yet defined a single way to calculate the *PLR* of a PV system, this study suggests that the preference aggregation approach may itself represent an accurate ensemble approach for *PLR* determination. By calculating *PLR* using many filters, performance metrics corrections, data aggregations, time series corrections, and statistical modeling approaches, we can provide consistent and robust estimates of $\overline{PLR}_i$ for PV system *i*. This ensemble multiple method approach may serve as the best model for minimizing the inaccuracies found in the different approaches for determining $\overline{PLR}_i$.