How to Assess Energy Yield and Degradation with Operational Power Curves

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Background

This study examines the use of SCADA data to calculate energy yield and degradation of operational solar PV plants. Wood formulated this methodology in response to a request to assess degradation and drop in energy yield following an extended outage when the plant was shutdown and disconnected from the grid. This unique situation presented several obstacles:

- A trend analysis to analyse degradation was not possible since the plant was not operational.
- A traditional operational energy yield could not be performed due to limited operational data in the post-shutdown period.

The novel methodology developed by Wood to overcome these obstacles is presented below. Even though this methodology was developed to overcome a specific set of constraints, Wood opines that this same methodology could be used in other circumstances.

Methodology

Period Selection

Wood assessed the data available to decide on appropriate periods of analysis for the pre- and post-shutdown periods. In a typical operational energy yield, one full year of consistent operational data (i.e. without any material changes to site characteristics) is required to fully capture seasonal effects. However, this was not possible due to limited operational data in the post-shutdown period. Therefore, Wood examined the data available in the post-shutdown period and, after excluding one month of data due to teething issues caused by the plant restarting operations, settled on a period of four months between August and November. To allow a like-for-like comparison, Wood selected the same four-month period in the pre-shutdown period.

Flagging and Filtering SCADA Data

Wood screened meteorological data from the two data periods so that only valid data was used for calculations. Accurate plane of array irradiance (POAI) and temperature measurements are essential in the formation of reference operational power curves and, therefore, there is great value in applying high quality screening techniques. An example of a failed irradiance sensor is shown in Figure 1.

Wood then filtered SCADA data according to the ASTM E2848-13 standard to ensure that only representative data was taken forward for developing reference operational power curves. This included, but was not limited to, filtering out data points with:

- Less than 100% availability.
- Inverter clipping or point of interconnection (POI) clipping.
- Highly variable irradiance (i.e. cloudy conditions) using the standard deviation of the POAI measured at various sensors across the site.

This is an essential step as failure to adequately filter the data can result in noisy power curves and, ultimately, uncertain results. An unfiltered power curve is shown in Figure 2.

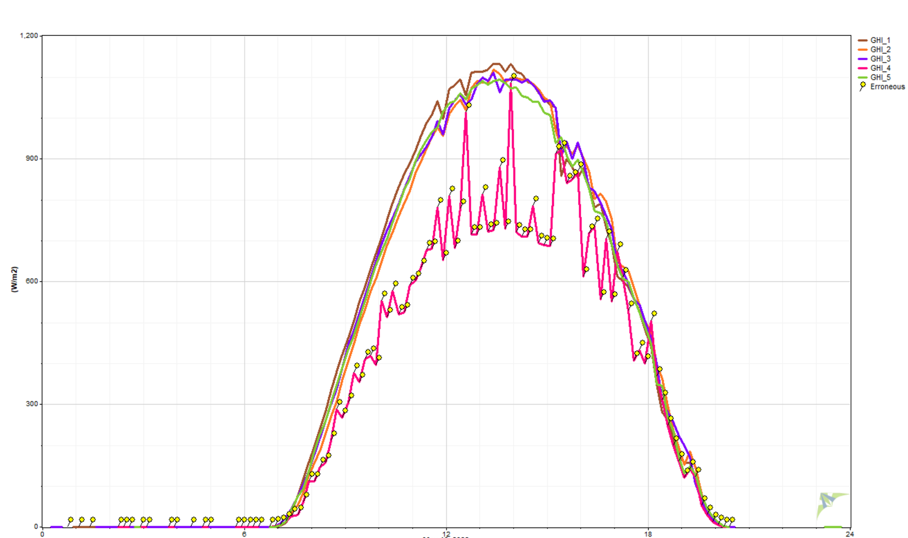

Figure 1: Failed Irradiance Sensor

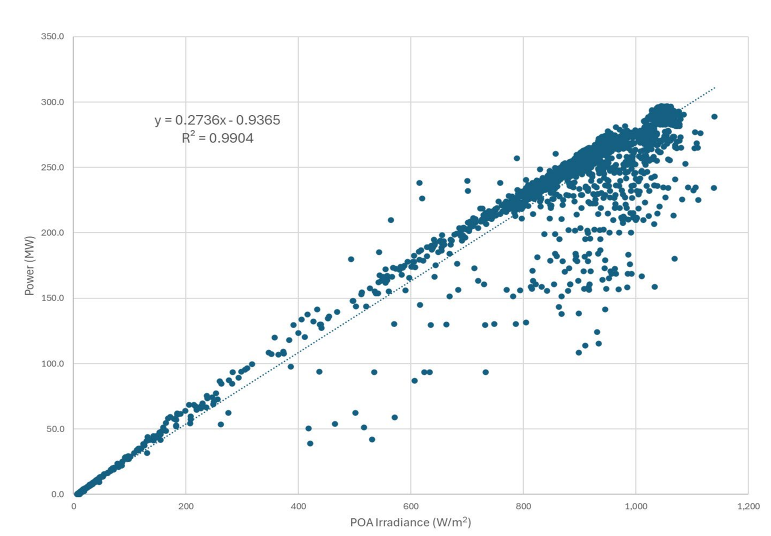

Figure 2: Unfiltered Power Curve

Developing Reference Operational Power Curves

Wood developed a site level reference power curve using the screened and filtered SCADA data, which reflects the operation of the equipment in-situ. The POAI was also temperature corrected using the formulas provided in NREL's Weather-corrected Performance Ratio paper (NREL/TP-5200-57991, April 2013) to find the most accurate relationship between power and POAI.

A filtered power curve is shown in Figure 3, with final reference power curves shown in Figure 4. The power performance drop at the annual average POAI is highlighted by the purple arrow in Figure 4.

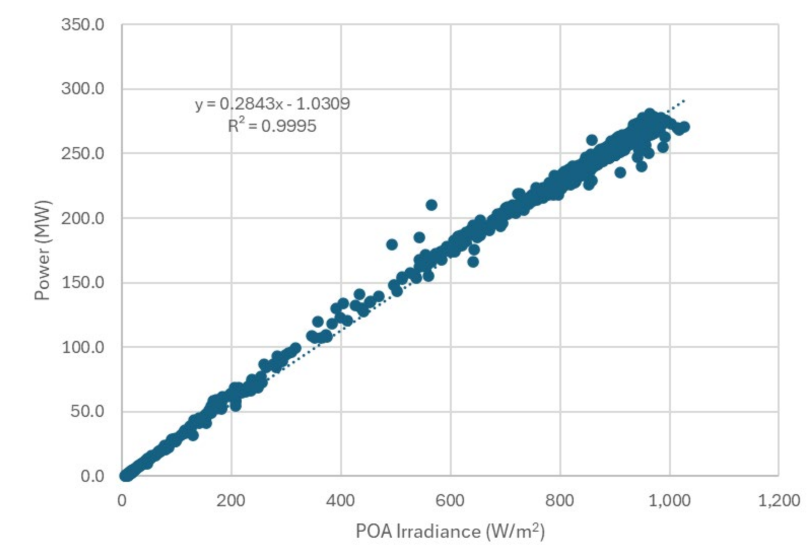

Figure 3: Filtered Power Curve

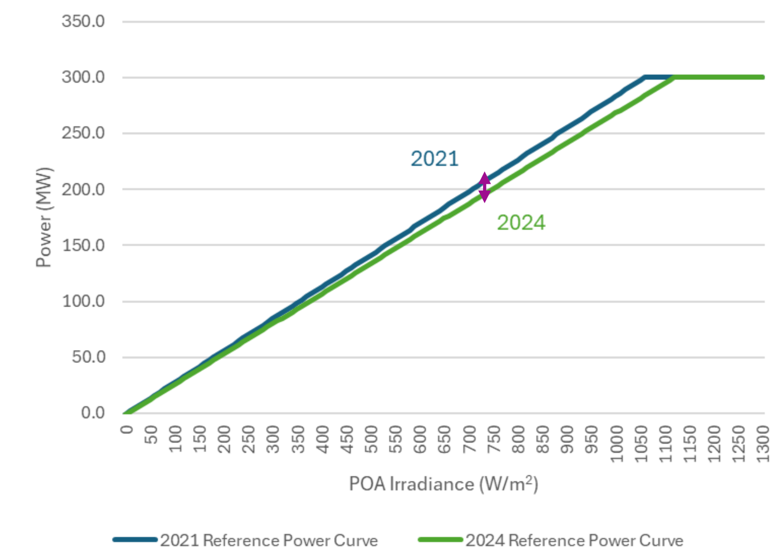

Figure 4: Reference Power Curves

P50 Energy Yield and Calculation of Degradation

Typical meteorological year (TMY) data, the as-built PVSyst model, and the operational power curves developed above were used to calculate an energy yield for the pre- and post-shutdown periods as follows:

- TMY data was input into the as-built PVSyst model to obtain a typical POAI timeseries.
- The typical POAI timeseries was input into the operational power curves to obtain power timeseries for the pre- and post-shutdown periods.
- The power timeseries were:
  - Temperature corrected using TMY data.
  - Adjusted for the capacity limit at POI.
  - Summed to calculate the gross annual yield.
- Expected degradation was incorporated into the pre-shutdown annual yield.

The outcome of these calculations was a pre- and post-shutdown gross energy yield (i.e. independent of availability effects) based on the performance of the plant in the two time periods analyzed. Comparing the yields after incorporation of the expected degradation reveals the accelerated degradation of the plant. This is shown in Figure 5, with all values presented as a percentage of the pre-shutdown annual energy production (AEP).

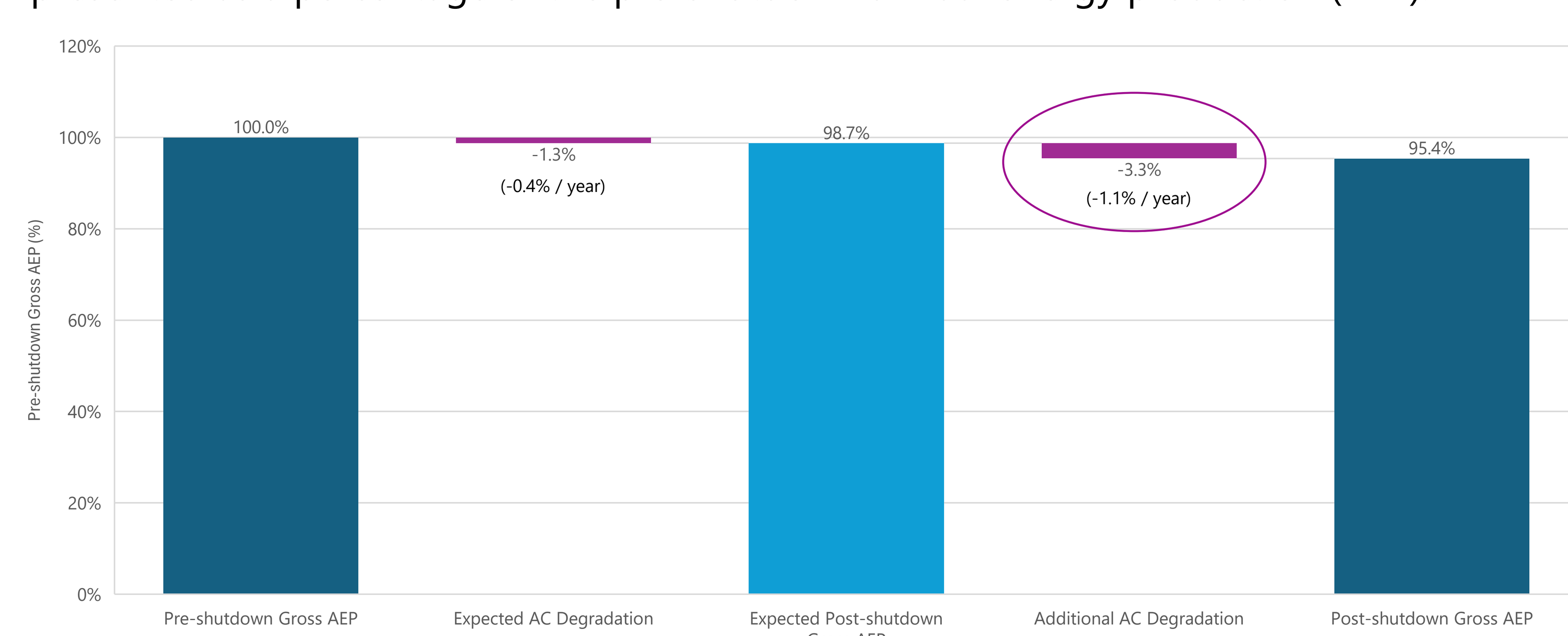

Figure 5: AEP and Degradation Waterfall Chart

Uncertainties

Wood calculated the uncertainty of the energy yields using the categories presented in Figure 6, color-coded into parameter and model uncertainty, respectively.

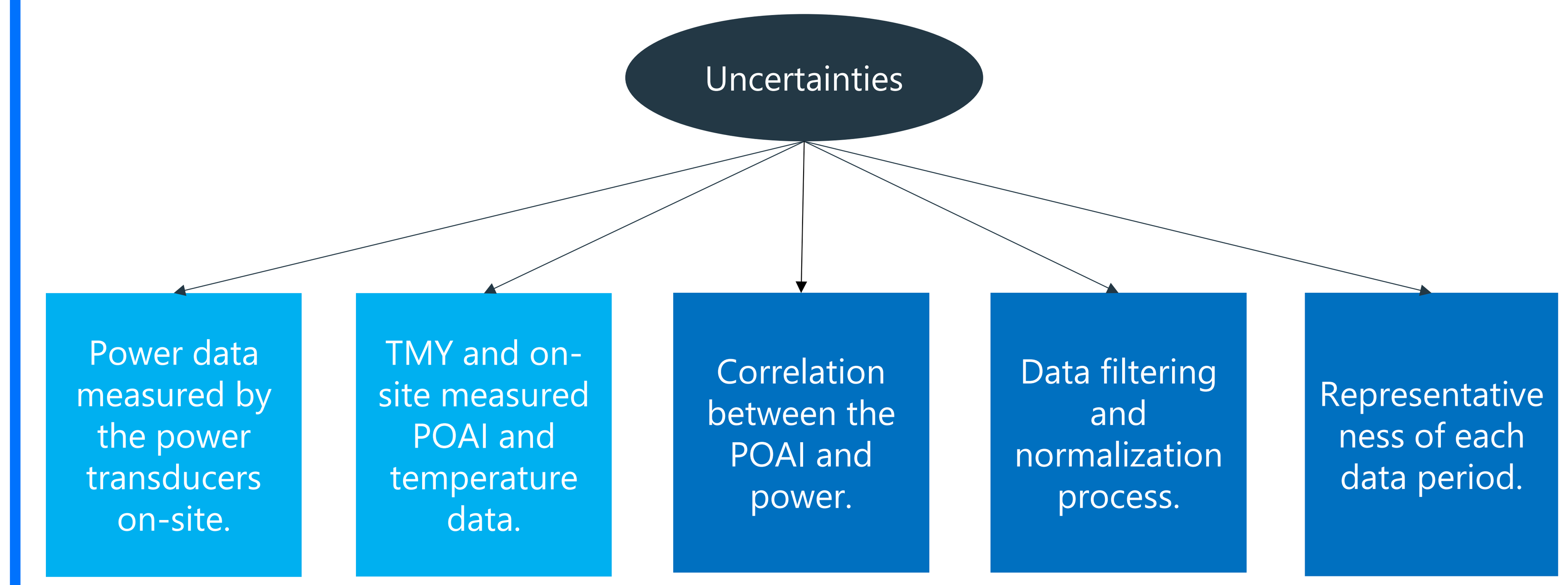

Figure 6: Uncertainties

To calculate the uncertainty of the accelerated degradation (difference in energy yields), Wood combined the uncertainties of each energy yield.

Possible Causes of Accelerated Degradation

If accelerated degradation is observed (as in this case), the same SCADA data can be utilized to investigate possible causes. On the AC side, the Inverter efficiency (Euro or California Energy Commission) and AC wiring losses (between the inverter and the POI) can be analyzed.

If the inverter efficiency and AC losses are broadly similar over the two time periods considered, that would point to a DC issue (e.g., module degradation, DC wiring losses, mismatch losses etc.) which requires further testing to pinpoint the exact cause. In this case, Wood suspects the accelerated degradation is due to higher thermal stress caused by the modules not exporting power. This could have perhaps been mitigated by covering the modules whilst the plant was offline.

Improvements

Wood sees several opportunities to refine this methodology further:

- Inverter-level reference power curves instead of site-level, allowing degradation to be analyzed at a higher resolution and pinpoint areas of the plant worst affected.
- Binned power curve approach instead of overall linear relationship, increasing the accuracy of the relationship between POAI and power.

Conclusions

- The pre- and post-shutdown periods selected should be comparable (i.e. same months of the year) to reduce uncertainty from seasonality effects.
- Robust data screening and filtering underpins robust analyses. Removing any non-linearity in the power curves is essential, including filtering out data impacted by low availability, clipping (inverter or POI) or cloudy conditions.
- Combining PVSyst modelling with operational power curves can make for a robust energy yield assessment.
- It is important to consider how the expected degradation rate is applied. If you have an expected DC module degradation rate, it must be applied prior to clipping to simulate how the plant actually performs (in terms of AC degradation). AC degradation is slower than DC degradation due to clipping masking the effects of DC degradation.
- Calculation of uncertainty can be used as a feedback loop to inform better decision-making and quality control of data.
- This methodology could be utilized to perform degradation analyses where a trend analysis is not possible, or to perform operational energy yield assessments when less than one year of operational data is available.