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Technical Report
NREL/TP-5200-57991
April 2013

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Executive Summary

Photovoltaic (PV) system performance depends on both the quality of the system and the weather. One simple way to communicate the system performance is to use the performance ratio (PR): the ratio of the electricity generated to the electricity that would have been generated if the plant consistently converted sunlight to electricity at the level expected from the DC nameplate rating. The annual system yield for flat-plate PV systems is estimated by the product of the annual insolation in the plane of the array, the nameplate rating of the system, and the PR, which provides an attractive way to estimate expected annual system yield. Unfortunately, the PR is, again, a function of both the PV system efficiency and the weather. If the PR is measured during the winter or during the summer, substantially different values may be obtained, making this metric insufficient to use as the basis for a performance guarantee when precise confidence intervals are required.

This technical report defines a way to modify the PR calculation to neutralize biases that may be introduced by variations in the weather, while still reporting a PR that reflects the annual PR at that site given the project design and the project weather file. This resulting weather-corrected PR gives more consistent results throughout the year, enabling its use as a metric for performance guarantees while still retaining the familiarity this metric brings to the industry and the value of its use in predicting actual annual system yield. A testing protocol is also presented to illustrate the use of this new metric with the intent of providing a reference starting point for contractual content.

List of Acronyms

AC	alternating current
DC	direct current
EPC	engineering, procurement, and construction
PAC	provisional acceptance certificate
POA	plane of array
PR	performance ratio
PV	photovoltaic
RTD	resistance temperature detector
STC	standard test conditions
TMY	typical meteorological year

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Introduction: The Performance Ratio

The performance ratio (PR) is defined in IEC 61724 [1] and is a metric commonly used to measure solar photovoltaic (PV) plant performance for acceptance and operations testing. The PR measures how effectively the plant converts sunlight collected by the PV panels into AC energy delivered to the off-taker relative to what would be expected from the panel nameplate rating. This metric quantifies the overall effect of losses due to: inverter inefficiency, wiring, cell mismatch, elevated PV module temperature, reflection from the module front surface, soiling, system down-time, shading, and component failures. Because many of these factors are indicators of build quality, this metric is popular with some companies and financiers for contractual acceptance testing. However, some of these factors are also weather dependent. Most notably, weather affects the PR by affecting the module temperature. To many financiers, this is an attractive feature of the metric because it helps to understand which locations will provide the most productive plants. For example, a colder site will provide a higher PR, implying more electricity generation if everything else is equal. Unfortunately, associated with this dependence on the weather is a *bias error* in the metric that introduces unnecessary risk in contractual acceptance testing. The PV system electrical output changes as weather varies; for example, system output changes with temperature (typically ~ 0.5%/°C), irradiance (typically can vary by as much as 5%–10%, especially for modules with high shunting or series resistance), and spectrum (typically varies by up to ~3%, depending on the difference in responses of the irradiance sensor and the PV module). As shown in Figure 1, the PR can swing radically over a single day. The contract must specify a PR that is representative of the annualized performance at the site, but the season of the measurement is seldom defined, leading to unnecessary risk for both parties. Before proposing a method for reducing this risk, we give some background on PR.

PR values for new systems typically range from 0.6 to 0.9 [2-9]. A recent paper summarizing the performance of ~ 100 German PV systems concluded that the cool climates in Germany helped some systems approach, or even exceed, 0.9 [2]. The strong dependence of PR on temperature results in a large seasonal variation in PR, which can be as large as ±10% [3-6, 9]. PR is often corrected to a common temperature of 25°C (standard reporting conditions) [4, 5]. Correction to a cell temperature of 25°C usually results in a higher PR because modules more frequently operate at 45°C. Thus, while correction to 25°C essentially solves the problem of seasonal variations, it may overstate the actual performance and thus does not allow the financier to assess the effect of local climate on the expected performance. Therefore, correction to 25°C is not an acceptable method for removing the seasonal variability in the PR metric because it would change the PR value stated in the contract.

Given the goal of removing the seasonal variability of the PR metric without changing the PR value that is stated in the contract, we assert that it is possible to define a site-dependent average cell temperature to which the PR can be corrected. We will call this a “weather-corrected” PR because it corrects for most of the weather-related effects. Although it would be useful to correct the PR for every aspect of the weather, we propose here to correct only for weather variations that affect the module temperature (ambient temperature, wind, and irradiance). We do not attempt to correct for snow coverage, soiling, or irradiance variations that affect the PV efficiency (with the assumption that a high-quality installation does not suffer greatly from shunt and series resistance effects). While system tests could be corrected for snow or soiling, it is unlikely that a contractor would choose to run the test while the system is covered with snow or is heavily soiled. By using a semiconductor reference-cell sensor in the plane-of-the-array, the seasonal spectral biases for the irradiance measurements are also minimized.

The purpose of this report is to 1) present the importance of using weather-corrected PR instead of uncorrected PR as a binding performance metric, 2) propose a method for applying the weather correction so as to remove the seasonal bias associated with variations in temperature, and 3) define a sample test protocol that can be referenced for contractual content. The report starts by quantifying the variability in PR that results from variation in temperature and by showing how this variability causes risk to all parties of the test, but can be removed by defining an annualized average temperature. Next, the report provides more detail about how the weather correction is constructed so as to remove the seasonal variability without changing the annualized PR and gives examples from plant acceptance testing around the world, showing how using the weather-corrected PR reduces the variability in the reported PR value. Finally, the report concludes by giving a step-by-step test protocol.

Variability of PR with Weather

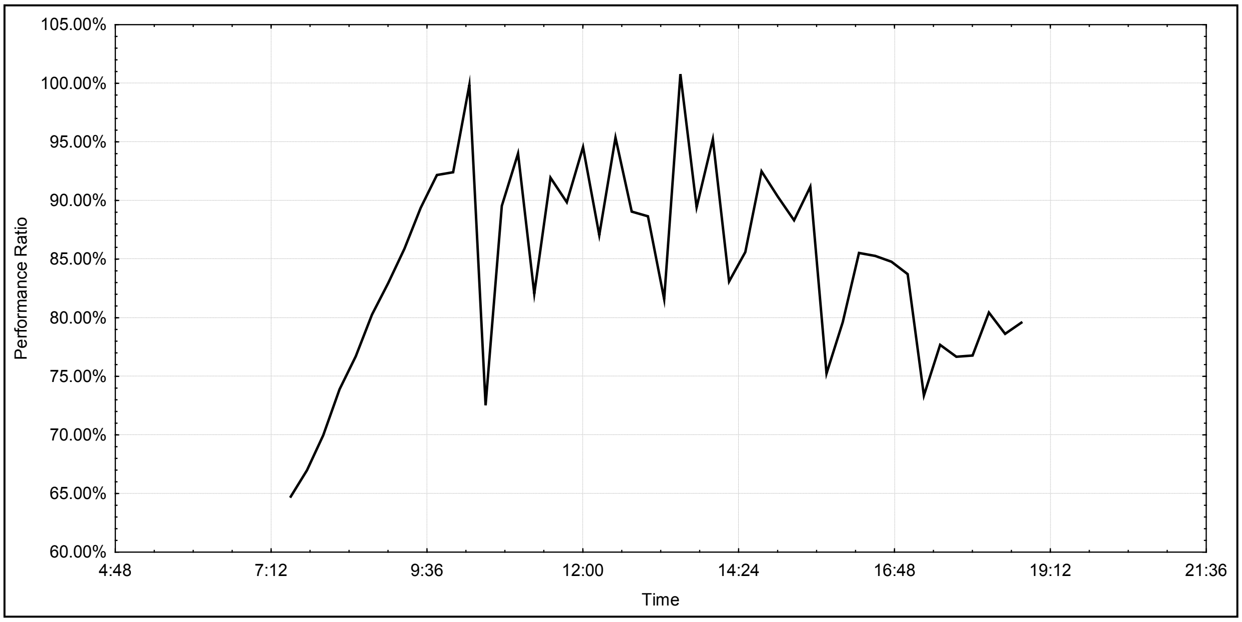


Figure 1. Performance ratio (PR) calculated from measured data over 15-minute periods from a 24-megawatt (MW) facility.

The annual PR is not a stable function of the project weather file. The project weather file is the annual weather file of record used to determine energy generation expectations and set performance guarantees. The source may be a typical meteorological year (TMY) file or a combination of any other sources. It is recommended that all parties to the project agree to the data stored in the project weather file.

A project's PR will change if a different weather file is used in the annual simulation — even though the plant design is unchanged. Table 1 shows the effects on PR as a result of changing either ambient temperature or wind.

Table 1. Effects of Annual Ambient Temperature or Surface Wind on PR

Weather File	PR	Difference
Baseline weather file	84.9%	
3° C Higher Annual Temperature	84.0%	-0.9%
3 m/s Higher Annual Wind Speed	86.6%	1.7%
The modeling assumed single-axis tracking and a temperature coefficient of -0.38%/°C, providing an example of how the PR may be expected to vary with variable weather.		

The lack of constancy of the PR as the weather file is varied is readily apparent. It is recommended that practitioners repeat this exercise of changing weather files on their own projects. The important recommendation is to have all parties to a project agree on a weather file (based on either historical data or data measured specifically for the project) before establishing PR guarantees.

Theoretical Approach

As described in the introduction, the PR varies with changes in meteorological conditions (and thus throughout the year). Yet, the PR is an important metric to the industry. The goal of this report is to mitigate risk caused by the inexact nature of the PR by defining a modified metric: the weather-corrected PR.

To quantify this variability and show how it can be reduced or removed, we calculate PR using two different methods: the method outlined in IEC 61724, and a new method that corrects PR for site-dependent meteorological conditions. Simulations are presented for a facility located in the southwest United States. Equation (1) shows how the PR is traditionally calculated. Equation (2) shows the modifications to become a weather-corrected PR. The difference between the two is that the weather-corrected PR contains a term to translate modeled power to the average operating cell temperature. The operating cell temperature accounts for the effects of both the ambient temperature and wind (as well as the heating from the sunshine). The use of a matched reference cell to measure irradiance avoids the need to also correct for spectral variations. There is no attempt made here to correct for other weather effects, such as snow losses, soiling losses, or the effects of variable irradiance on efficiency. While corrections for these additional weather effects could produce more consistent results, Equation (2) provides a simple way to account for the primary effects.

$$(1) \qquad PR = \frac{\sum_i EN_{AC\_i}}{\sum_i\left[P_{STC}\left(\frac{G_{POA\_i}}{G_{STC}}\right)\right]}$$

$$(2) \qquad PR_{corr} = \frac{\sum_i EN_{AC\_i}}{\sum_i\left[P_{STC}\left(\frac{G_{POA\_i}}{G_{STC}}\right)\left(1-\frac{\delta}{100}\left(T_{cell\_typ\_avg} - T_{cell\_i}\right)\right)\right]}$$

Where:

The summations are over a defined period of time (days, weeks, months, years)

PR = performance ratio (unitless)

PR_{corr} = corrected performance ratio (unitless)

EN_{AC} = measured AC electrical generation (kW)

P_{STC} = summation of installed modules' power rating from flash test data (kW)

G_{POA} = measured plane of array (POA) irradiance (kW/m^2)

i = a given point in time

G_{STC} = irradiance at standard test conditions (STC) (1,000 W/m^2)

T_{cell} = cell temperature computed from measured meteorological data (°C)

$T_{cell\_typ\_avg}$ = average cell temperature computed from one year of weather data using the project weather file (°C)

δ = temperature coefficient for power (%/°C, negative in sign) that corresponds to the installed modules.

The motivation for amending the PR metric into a weather-corrected number is evident in **Figure 2**. This shows the uncorrected and corrected PR calculated from a simulation. (A simulation is used because it represents an ideal system where all aspects that contribute to electrical generation are controlled. This is required to show that a performance metric is not a consistent value. The reader is encouraged to repeat this analysis.)

In this plot, the PR is calculated for each month in the year's simulation. The blue markers are the PR values calculated using Equation (1), and the red markers show the corrected PR for the same time computed using Equation (2). Note that the uncorrected PR changes by 10% over the year. This bias will result in false high values during the winter months (causing risk for the PV customer because a poor-performing plant might falsely pass the test during this time) and false low values during the summer months (causing risk for the PV installer). It is this instability in the metric that is the motivation for a corrected PR. Without the weather correction, PR is not consistent throughout the year.

Some have attempted to address this error by producing a table that states PR for each month. However, this is still a biased metric if the month is unseasonably warm or cool — resulting in a possible falsely high or low result. All parties to an agreement will carry weather risk during testing periods that may result in a false pass or fail if uncorrected measurements are used.

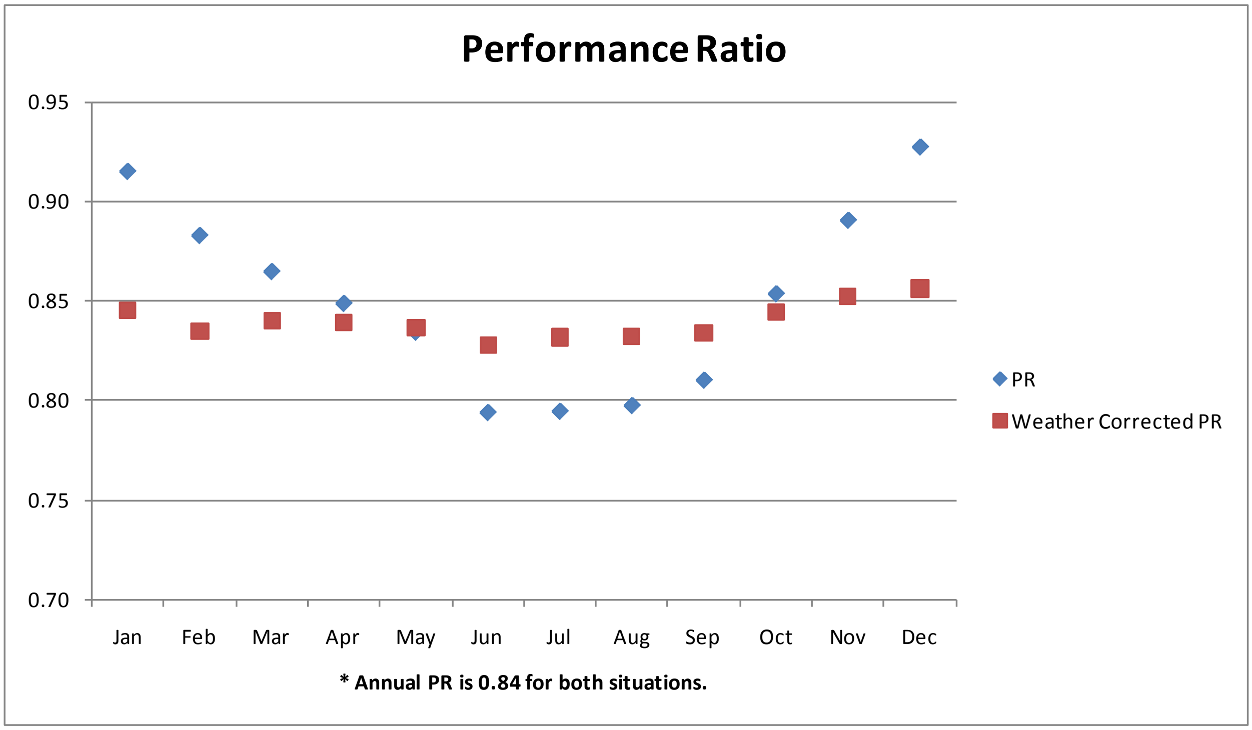


Figure 2. Corrected and uncorrected PR from simulated results.

It is recommended to use the weather-corrected calculation and the mutually agreed-upon project weather file if the PR is to be used for a contractual metric. This avoids the risk that the weather would produce erroneously high or low readings. As can be observed, the corrected data are more consistent through the year — a better choice for demonstrating contract guarantees.

To further demonstrate the variability of the PR, **Figure 3** shows the hourly values of corrected and uncorrected PR for the entire year (from the same simulation used in **Figure 2**). Note that the extreme variance in the uncorrected PR values is drastically reduced with the weather correction.

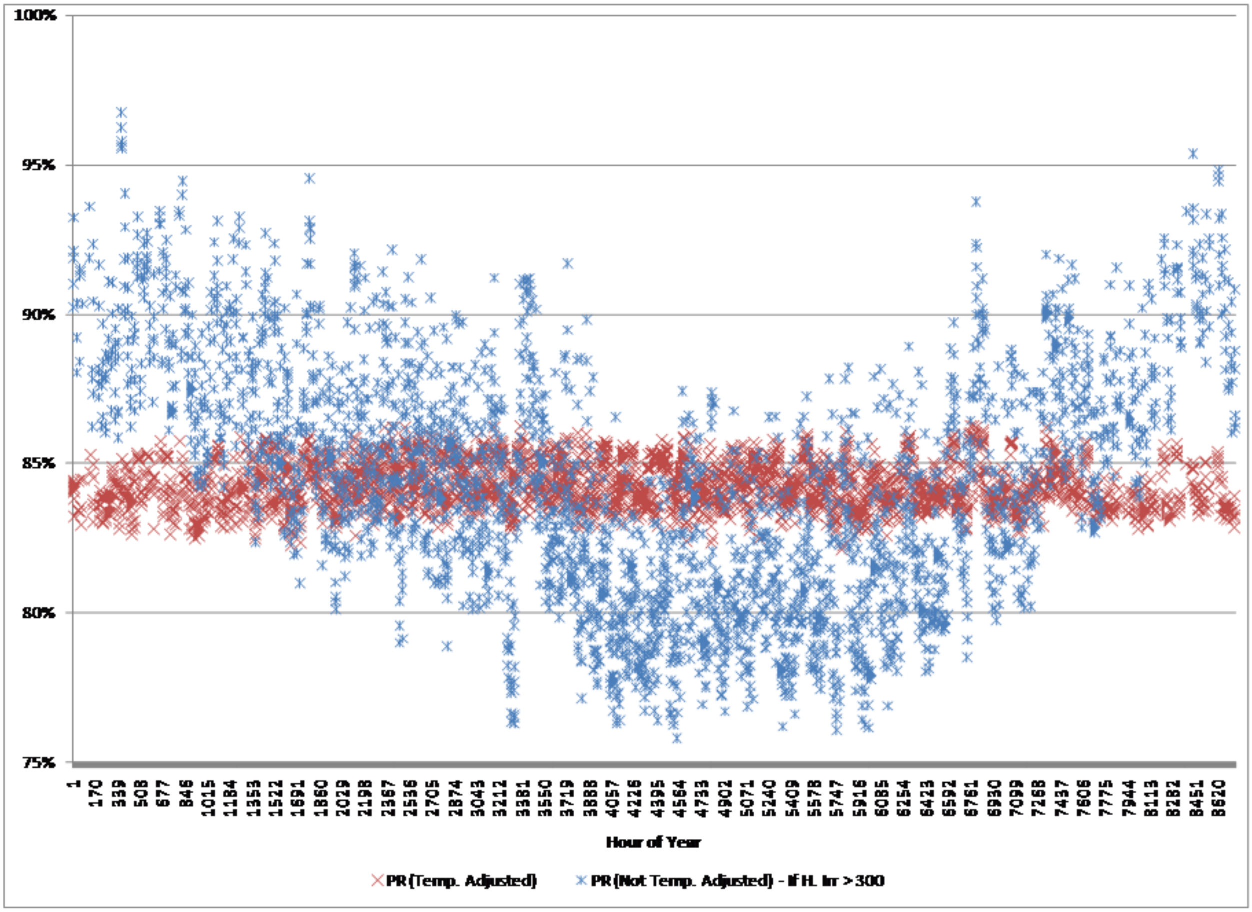


Figure 3. Corrected and uncorrected PR calculated for each hour of the year for the same simulation described in Figure 2.

Average Annual Cell Temperature

The important parameter for the corrected PR is the annual average cell temperature. In Equation (2) this is the variable "$T_{cell\_typ\_avg}$." This value is carefully determined such that the annual PR and annual weather-corrected PR are the same for this location. While the PR shows systematic seasonal variations as shown in **Figure 2** and **Figure 3**, the weather-corrected PR provides a consistent assessment of the annual PR with very little seasonal variation if the "$T_{cell\_typ\_avg}$" is chosen correctly.

The average annual cell temperature should be determined from the project weather file and the simulated plane-of-array irradiance that is used to set the expected power generation. The project weather file represents the nominal annual meteorological conditions hour by hour. As noted above, when the "$T_{cell\_typ\_avg}$" is chosen correctly, the annual PR is the same number as the annual weather-corrected PR. The "$T_{cell\_typ\_avg}$" is chosen by applying Equations (1) and (2) until the annual PR and annual corrected PR are equal, or (equivalently) using the equations provided in this report.

Calculated Cell Temperature

It is important that the computation method used to determine the average annual cell temperature from the project weather file is also used to compute the operating cell temperature during the PR test. It is very important to follow this requirement because it mathematically assures a link between the PR calculated from measurements and the PR predicted by the project weather file and the plant design parameters (loss factors). *This linkage is broken if the cell temperature is measured directly or determined by a different method.*

It should also be noted as an aside that directly measuring the operating cell temperature may hide design or construction issues that result in higher than expected operating temperatures — and thus a false pass of a performance test using the weather-corrected PR.

Therefore, the solution is to compute cell temperature from the weather data. If the computation is consistent for (a) the annual average cell temperature and (b) the current operating cell temperature, then this approach will result in consistent values throughout the year. As stated, the result is also tied back mathematically to the value calculated using the project weather data. With this method, we have a consistent basis for the weather-corrected PR. The corrected PR calculated from the field measurements is consistent with the performance guarantee.

Precise methods based on a Sandia [10] heat transfer model are used in this report for calculating PV operating cell temperature. This method was previously validated [10], so is not validated here, but it is noted that the coefficients used for this calculation may need to be chosen to match the operation expected for the system being measured. This method may be replaced with a different heat transfer model as long as identical methods are used to compute both the annual average cell temperature (from the historical weather data) and the cell operating temperature (from the measured weather data during the assessment period).

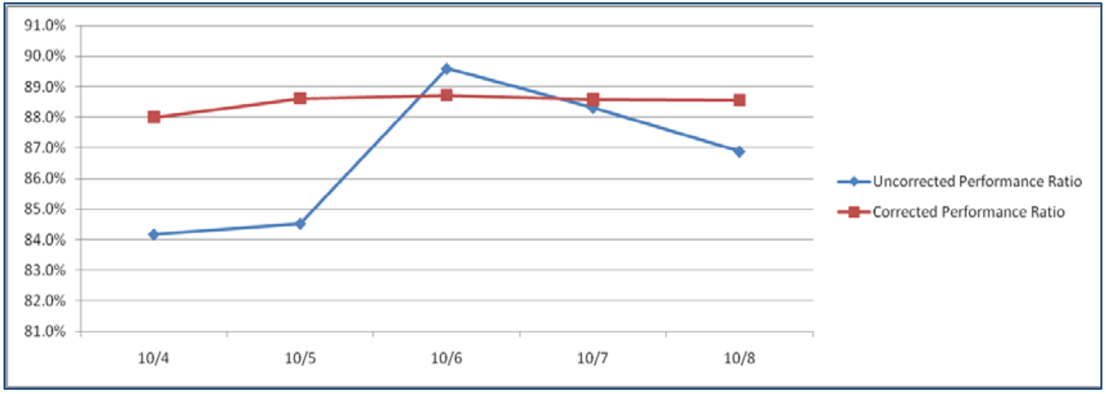
Example Data

Thus far, this report contains a theoretical presentation with some simulated data examples. A logical question to ask is: does this method actually work? Real-world results are presented.

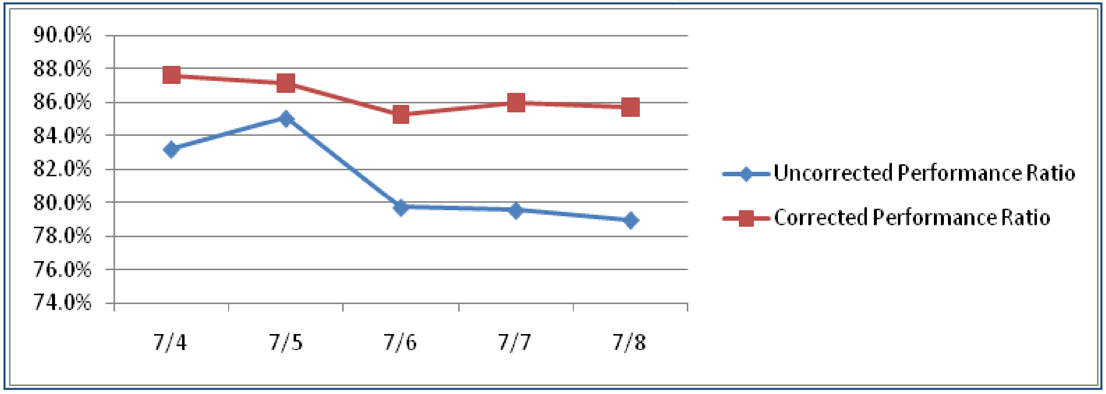
Corrected Performance Ratio from Measured Data

The plots shown in **Figure 4** show the uncorrected (raw) and weather-corrected PR from a Provisional Acceptance Certificate (PAC) used to confirm engineering, procurement, and construction (EPC) project guarantees from around the world. Notice how the weather-corrected PR provides stability to this volatile metric.

4,700-kWp Facility



2,300-kWp Facility



1,300-kWp Facility

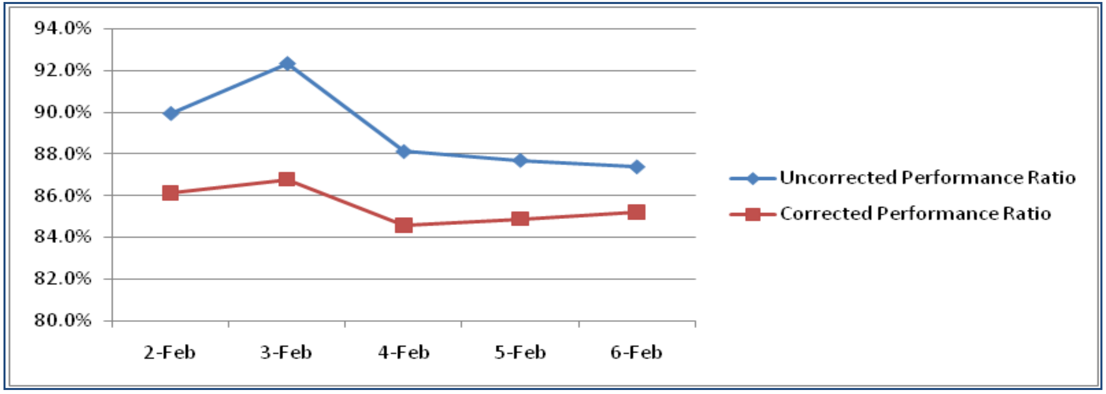


Figure 4. Weather-corrected PR compared with uncorrected PR during acceptance testing.

Figure 5 shows the daily PR for a 24-MW facility over a year. This is for day-to-day operation. There is increased scatter because this data was not collected during a controlled performance test. The weather-corrected PR significantly removes the seasonal bias. Actual operating issues such as soiling or derated equipment are more apparent when considering the corrected PR.

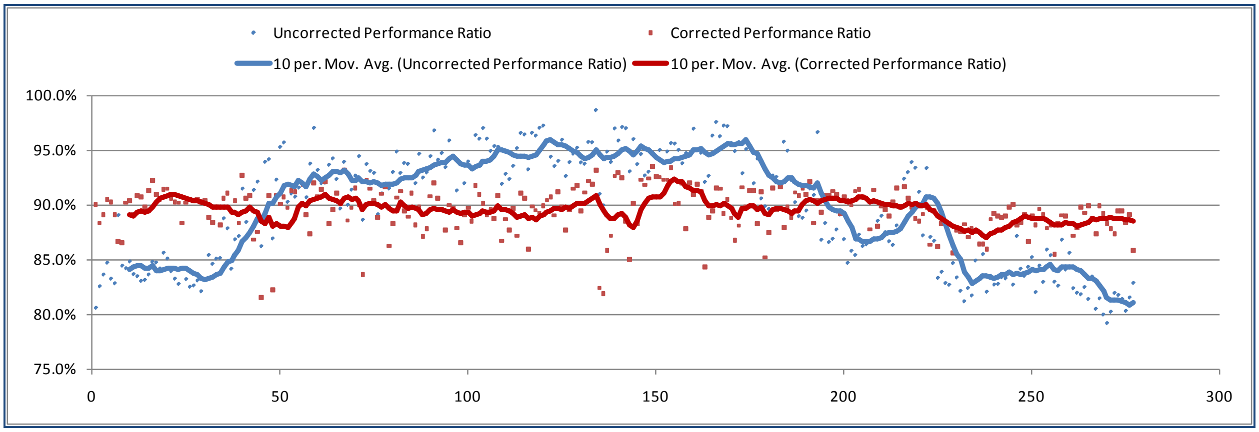


Figure 5. PR (weather-corrected and uncorrected), annual trend, 24-MW facility.

Corrected PR Test Protocol

The remainder of this report presents a sample protocol for a weather-corrected PR measurement. It is recommended that practitioners fully adopt the mathematical approach to ensure fidelity in the final calculated PR. However, commercial terms can be adjusted as needed for items such as number of sensors, minimum irradiance criteria, and treatment of measurement uncertainty.

Purpose

The procedures below describe the calculation methodology used to determine the weather-corrected PR for a plant acceptance test. The guiding principle is that the measurement and computational approach provide a method that results in an accurate and consistent metric for determining whether performance guarantees have been demonstrated. This metric must be unbiased to test boundary conditions, and thus fair to all parties. The purpose is to measure against an annual PR guarantee.

Note that the PR should not be used as a guarantee metric if the plant is designed such that the inverter will clip during high irradiance. The PR will unfairly penalize results during these periods. Similarly, grid unavailability or other circumstances may affect the fair application of the metric, and the metric is not designed to cover reactive power requirements.

Parties to the Test and Responsibilities

Parties to the test are defined in the contract. They may be the owner, contractor, and an independent engineer. All parties must agree to this protocol before test commencement.

The test will be executed by the contractor. All relevant raw test data, spreadsheets, and computations shall be provided to all other parties to the test for their review. The contractor will supply raw data before any manipulation and highlight any gaps in the data. The final test report will be produced by the contractor in the timeline detailed in the contract.

During the test, any anomalies to this protocol will be documented. Resolutions to anomalies or variations to this protocol that occur during the test period will be documented and approved by all parties to the test in order to continue with the testing effort.

Requirements Before the Test

Before the test can commence, the following need to be completed:

1. Install and calibrate all primary measurement instruments.
2. A test procedure has been published and agreed to by all parties to the test.

Minimum Irradiance Criteria

The plant acceptance test period is five days long with the following minimum irradiance criteria:

- At least three days must have irradiance measured in the plane of the array that is greater than 600 W/m^2 for three continuous hours, and the daily total irradiance must exceed 3,000 Wh/m^2/day.
- If there are not five days that meet these minimum irradiance criteria, the test period may be extended until five sufficient days have been recorded. There will not be any liquidated damages triggered as a result of this weather-related test delay.
- If there are not five days that meet the minimum irradiance criteria, yet the corrected PR of the five strongest days meet the contract guarantee, then the plant acceptance test will be deemed a success.

Instrumentation

Data from the following instrumentation will be used to determine park performance:

- Power meter(s) at each delivery point as defined in the contract [kW].
- (2) Calibrated reference cells or reference modules to determine POA irradiance with a target measurement uncertainty of 3%. Reference cell/module technology (poly, crystal, or thin-film) should match installed panels, but other irradiance measuring devices may be used if agreed to by all parties. Reference cells are recommended if this device will also be used to trend long term performance [W/m^2].
- (1) Anemometer to measure wind speed [m/s].
- (2) Ambient temperature measurements with an accuracy of ± 1°C.

Data from the following instrumentation will be collected for reference only:

- (1) Calibrated pyranometer to measure horizontal irradiance with a target measurement uncertainty of ± 3%.
- (2) Type-T surface-mounted shielded thermocouple to measure module temperature (with a measurement uncertainty of ± 1° C) or an equivalent resistance temperature detector (RTD) device.
- Other backup meteorological measurements.

Data will be automatically collected using a combination of station and temporary loggers and instruments with a scan rate of at least one minute. Manual data sheets will be used for any non-functioning logger data channel if there will be no increase in test uncertainty.

All collected data will be averaged into 15-minute records, and each record will be used to calculate performance results and evaluate contract guarantees. Calculation methods are stipulated in this protocol.

Proof of Performance

The performance test will be deemed successful if the measured weather-corrected PR (PR_{corr}) is greater than the guaranteed value (within the tolerance agreed to by the parties to the test in advance of the test).

Calculation Method

Calculations involve the following major steps for every data record (or time interval) where the irradiance is sufficient for inverter operation:

1. Present method to calculate operating cell temperature from ambient and meteorological measurements.
2. Determine the average PV cell temperature for the solar park from the project weather file simulation.
3. Calculate the predicted PV cell temperature from measured meteorological data for each 15-minute period.
4. Use the measured irradiance to calculate the theoretical temperature-corrected DC energy.
5. Determine the measured weather-corrected PR.
6. Compare with guaranteed values.

1. Operating Cell Temperature

The following relations are used to calculate the module operating cell temperature from meteorological data. This heat transfer model is derived from the Sandia National Laboratories paper *Photovoltaic Array Performance Model* by King and Boyson [10]. There are other heat transfer models that can be used to calculate the operating cell temperature from meteological measurements. What is absolutely important is that the same heat transfer model is used to calculate both the:

- average irradiance-weighted cell temperature from the project weather file [°C]
- predicted operating cell temperature.

These parameters are described below.

If not separately referenced, all engineering methods presented in this report were derived from King and Boyson [10]. The calculation is done in two steps: (a) determine the module back temperature, (b) determine the internal cell operating temperature.

Based on heat transfer theory and empirical data, the PV module back temperature can be calculated with Equation (3).

$$(3) \qquad T_m = G_{POA} * \{e^{(a+b*WS)}\} + T_a \qquad [°C]$$

Where:

T_m = module back-surface temperature [°C]

G_{POA} = POA irradiance from calibrated reference cells [W/m^2]

T_a = ambient temperature [°C]

WS = the measured wind speed corrected to a measurement height of 10 meters [m/s]

a = empirical constant reflecting the increase of module temperature with sunlight

b = empirical constant reflecting the effect of wind speed on the module temperature [s/m]

e = Euler's constant and the base for the natural logarithm.

The term within the brackets {} is an empirically determined conduction/convection heat transfer coefficient and has units of [°C m^2/kW]. The empirical coefficients presented in **Table 2** are recommended by King and Boyson [10].

Table 2. Empirical Convective Heat Transfer Coefficients

Module Type	**Mount**	***a***	***b***	**Δ*Tcnd* (°C)**
Glass/cell/glass	Open rack	-3.47	-0.0594	3
Glass/cell/glass	Close-roof mount	-2.98	-0.0471	1
Glass/cell/polymer sheet	Open rack	-3.56	-0.0750	3
Glass/cell/polymer sheet	Insulated back	-2.81	-0.0455	0
Polymer/thin-film/steel	Open rack	-3.58	-0.1130	3

If needed, the values for coefficients a, b, and $\Delta Tcnd$ may be recomputed for different project designs if required data is available. The empirical method used to determine these coefficients are described in Incropera and DeWitt [11].

Once the module-back temperature is determined, the cell operating temperature will be calculated using Equation (4):

$$(4) \qquad T_{cell} = T_m + (G_{POA}/G_{STC}) * \Delta Tcnd \qquad [°C]$$

Where:

T_{cell} = predicted operating cell temperature [°C]

T_m = predicted module surface temperature as determined by Equation (3) [°C]

G_{POA} = POA irradiance, as described above [W/m^2]

G_{STC} = reference irradiation for the correlation; constant at 1,000 [W/m^2]

$\Delta Tcnd$ = conduction temperature drop as presented in Table 2**.**

2. Average PV Cell Temperature from the Project Weather File

The project weather file (based on historical data or data measured specifically for the project) is called out in the contract as the basis for the project guarantees. Also needed is the predicted POA irradiance computed from this file. This information will be used to compute the average simulated annual operating cell temperature. This is done by computing the operating cell temperature using Equations (3) and (4) for every hour of the weather data. The next step is to calculate the irradiance-weighted average cell temperature with Equation (5).

$$(5) \qquad T_{cell\_typ\_avg} = \sum [G_{POA\_typ\_j} * T_{cell\_typ\_j}] \,/\, \sum [G_{POA\_typ\_j}]$$

Where:

$T_{cell\_typ\_avg}$ = average irradiance-weighted cell temperature from one year of weather data using the project weather file [°C]

$T_{cell\_typ\_j}$ = calculated cell operating temperature for each hour [°C]

$G_{POA\_typ\_j}$ = POA irradiance for each hour determined from the project weather file and tracker orientation [W/m^2]. This irradiance is taken as zero if the sun is not up.

j = each hour of the year (8,760 hours total).

This resulting annual average cell temperature will be a constant for all further calculations. Because this averaged value is irradiance weighted, hours with high irradiance have a larger influence than hours with low irradiance. Hours with zero sun have zero impact.

Equation (5) is developed mathematically. It is this location-specific year-average cell temperature that allows correction of the PR from measured data to that predicted when the project weather file is used in a simulation to determine the guaranteed PR. It is this value that allows the weather correction to work accurately.

One proof-of-concept test is to take the simulation and calculate the PR using the traditional method, and then calculate with the weather-corrected method described in this procedure. The values will be identical.

3. Calculate the Predicted PV Cell Temperature from Measured Meteorological Data

During the test, we will need to compute the predicted cell temperature for the measured meteorological data by using Equations (3) and (4). These equations are rewritten here for clarity:

(6) $T_{m\_i} = G_{POAi} * \{e^{(a+b*WS_i)}\} + T_{a\_i}$ [°C]

(7) $T_{cell\_i} = T_{m\_i} + (G_{POAi}/G_{STC}) * 3$[°C]

Where:

i = each 15-minute period of the test measurement period where measured irradiance exceeds minimum criteria. Any change in this averaging period must be agreed to in advance, since the choice of time period has a small effect on the calculated cell temperature.

WS_i = wind speed corrected to 10 m height for period i [m/s]

T_{m_i} = module back surface temperature for period i [°C]

T_{cell_i} = cell operating temperature for period i [°C].

4. Temperature-Corrected Theoretical DC Energy Generation

Temperature-corrected theoretical DC energy will be calculated with averaged values for each 15-minute data interval using Equation (8):

(8) $EN_{DCi} = (P_{STC}) * [G_{POAi} / G_{STC}] * [1 - \delta(T_{cell\_typ\_avg} - T_{cell\_i})] * (TimeStep_i)$

Where:

i = defined above

EN_{DCi} = temperature corrected theoretical DC energy over time step i [kWh]

P_{STC} = summation of nameplate ratings for all installed modules in given power blocks during the acceptance test [kW]

G_{POAi} = POA irradiance averaged over time step i [W/m^2]

G_{STC} = STC irradiance [1,000 W/m^2]

δ = temperature coefficient of power (negative in sign) that corresponds to the installed modules [1 / °C]

$T_{cell\_typ\_avg}$ = average annual cell temperature for the project weather file calculated by Equation (5)

T_{cell_i} = cell operating temperature for period i calculated with Equation (7) [°C]

$TimeStep_i$ = date/time interval for each data record i (15 minutes = 0.25 hour) [hr].

5. Determine Corrected Measured PR

For the test period, the temperature-corrected PR is determined by summing up the measured AC energy and the temperature-corrected theoretical DC energy over all eligible 15-minute periods (i).

$$(9) \qquad PR_{corr} = \sum [EN_{ACi}] / \sum [EN_{DCi}]$$

Where:

PR_{corr} = weather-corrected PR for the test period

EN_{ACi} = measured AC energy generation [kWh]

EN_{DCi} = temperature-corrected theoretical DC energy [kWh].

Eligible periods are defined in the contract as well as in the "Test Requirements" section of this document.

6. Compare with Guaranteed Values

The test will be deemed a success if the corrected PR is greater than or equal to the guaranteed value with 95% tolerance (or the tolerance specified in the contract) due to uncertainty applied — and if the availability guarantees have been met:

$$(10) \qquad PR_{corr} \geq (ContractTolerance) * PR_{guar}$$

Where:

$ContractTolerance$ = tolerance to account for measurement uncertainty, as specified in the contract (95% is recommended as a default value)

PR_{guar} = guaranteed PR defined in the contract.

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