# PV System Performance Assessment

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# Metrics and methods to assess performance of existing systems to aid bankability of PV asset class

## Determining and evaluating system performance based on actual weather and actual system characteristics is

Stakeholders of existing photovoltaic (PV) solar energy systems are typically interested in system performance for operation and maintenance planning, commissioning, performance guarantees and for making investment decisions. Monitoring companies are developing data analysis methods to process real-time data for their specific systems and performance metrics. However, a literature review of metrics in common use by companies found that various analytical methods are used to calculate the same metric, or they are using one analytical method with varied results due to the environment of the system. Both are problematical because they result in different interpretations

For example, the commonly used metric of Performance Ratio (PR), as defined by IEC61724 and NREL, may be appropriate for annual comparison of systems with the same climates but is not appropriate for shorter term or system comparisons in differing climates. Specifically, if PR is used to evaluate a system in San Francisco, CA, compared to a similar system in Daggett, CA, incorrect conclusions would be reached. Using PVWATTS to represent an actual system, a 100kW system in San Francisco with latitude tilt has a calculated PR of 0.73 with an output of 145,000 kWh/year, while a 100kW system in Daggett with latitude tilt has a PR of 0.69 with an output of 171,000 kWh/year. Even with a lower PR, the Daggett system has higher output and therefore higher performance.

If PR is used to make an investment decision in one of these systems, all other factors being equal, the investor would choose San Francisco with a lower ROI due to significantly lower annual energy production.

Bankability of PV assets requires that investors understand the reliability of modeling and actual performance data in support of their investment decisions and how it is related to:

- Equipment
- Location
- Design
- Contractor and Installation Technique
- Maintenance

It would be desirable for stakeholders to have consistent definitions, methods, and agreement regarding the objective of the metric. This would enable better classification of the performance of solar assets across technologies and location. Consistent performance standards would also help streamline the bankability assessment for solar assets.

This article identifies representative metrics in current use, summarizes the method and level of effort to calculate the metrics, reviews the objective of the metrics, estimates the metric uncertainty level, and recommends which metric is appropriate for which purpose/objective.

The following four performance metrics are the focus of this article:

- Power Performance Index (PPI) of actual instantaneous kW AC power output divided by expected instantaneous kW AC power output.

- Performance Ratio with temperature corrected final yield using weighted-average cell temperature (CPR). Note that Performance Ratio is commonly defined without temperature correction.

- Energy Performance Index (EPI-SAM) of actual kWh AC energy divided by expected kWh AC energy as determined from an accepted PV model, such as SAM, using actual climate data and assumed derate factors.

- Energy Performance Index (EPI-REGRESSION) of actual kWh AC energy divided by expected kWh AC energy as determined from a polynomial regression equation having coefficients determined from actual operating and climate data collected during the model "training" period.

Some conclusions of this study show how the above four metrics are applicable for the following performance assessment objectives:

- Monitoring of a specific PV system to identify degraded performance and need for condition based maintenance. Recommendations, including varied levels of uncertainty, are to use EPI-SAM or EPI-Regression or CPR.

- Commissioning of a new system, re-commissioning, or assessment after major maintenance and to set a baseline for future performance measurements and comparisons. Recommendation is to use PPI and EPI metrics.

- Determination of specific industry parameters, such as Yield or Performance Ratio, to allow comparison of systems in different geographic locations for design validation or investment decisions. Recommendation is to use Yield, PR, CPR and/or EPI depending on the level of effort and level of uncertainty. In some cases, depending on the objective, combinations of these metrics are most useful.

Although this study was intended for metrics that apply to fixed flat panel PV module technology used on systems of greater than 100kW DC, the metrics are actually helpful for any fixed flat plate panel PV system size. Further explanations are shown on the application map of Figure 1.2.

Calculations were performed to evaluate the uncertainty range for various metrics. Data was obtained from exiting systems which had weather stations and had accessible data through on-line monitoring sites.

## Performance Assessment Objectives

The objectives for performance assessment can best be summarized from an owner's perspective by the questions that are often asked:

- How is my system, or a portion of my system, performing currently in comparison to how I expect it to perform at this point in its life?
- How is my system performing for both the short-term and long-term in comparison to how it is capable of performing with its given design, site location and baseline performance?
- How is my system performing over an assessment period in comparison to other, similar systems in similar climates?
- How is my system performing compared to the last assessment periods? This trending model is useful for maintenance objectives.
- How can I develop metrics in support of accurate prediction of future energy yield and ROI for reliable investment assessment.
- During commissioning, what metrics should be used to set a baseline for future performance assessments?

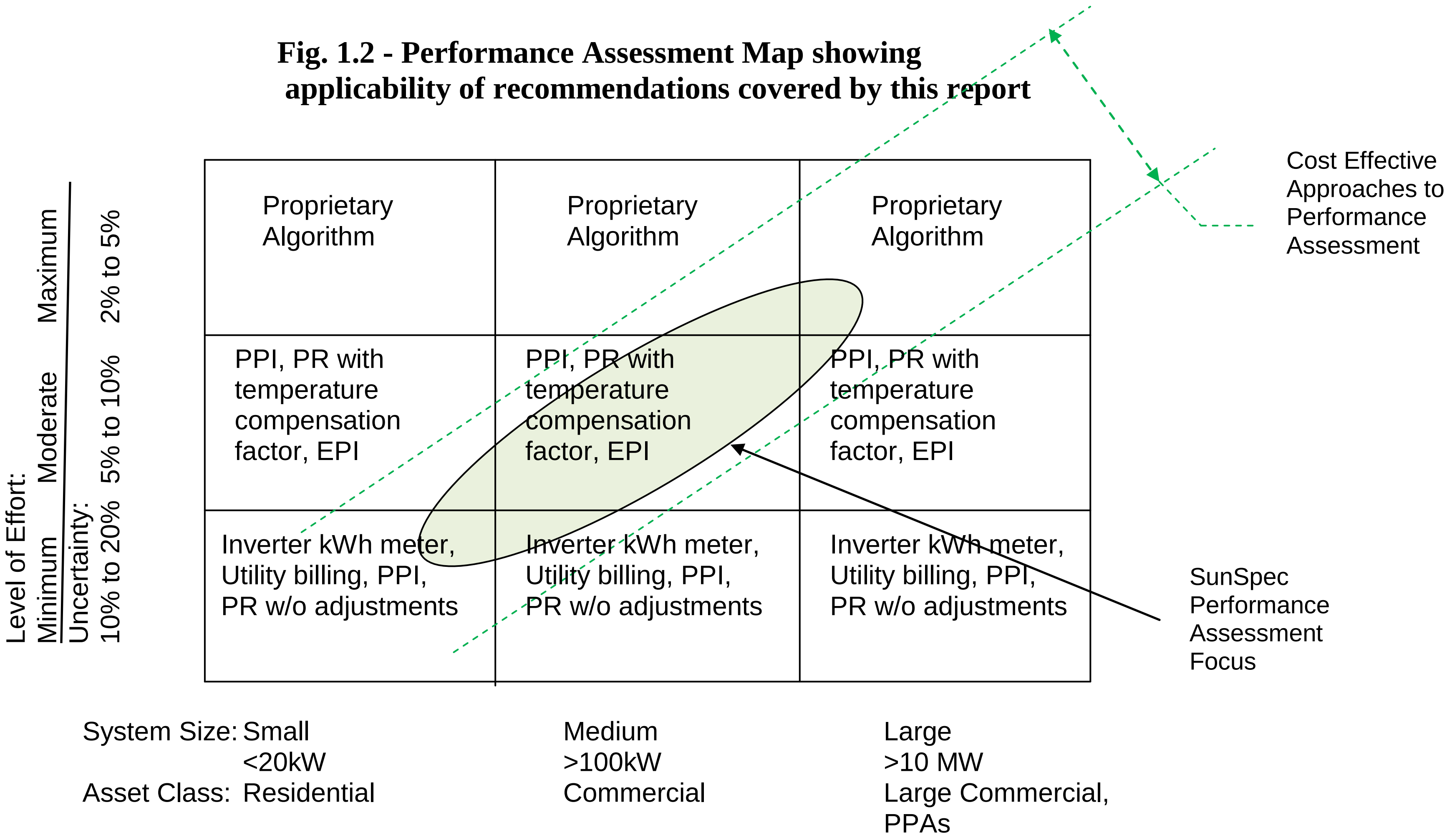
One objective of a performance assessment is to detect changes in system performance; usually decreases in performance, to allow the system owner to investigate and potentially perform cost effective maintenance. This can be done best on a relative scale where the specific performance of the system is compared to itself which reduces adverse effects of modeling input assumptions and uncertainty.

Another objective is to determine if a new system, or an existing system having completed major maintenance, has instantaneous power output and a 0 to 6 month energy output consistent with predictions by the design model. This is also considered a commissioning activity and since there is no long-term operating data, the results are directly dependent on the validity of the model and input assumptions which both increase uncertainty.

It should be noted that system performance is different than system value or system reliability. The performance of a system is indicated by the actual AC energy or power output relative to its as-designed or as-built capability. Deviations from 100% can be caused by many factors, including errors or incorrect assumptions during design, poor installation workmanship, equipment failure or degradation, etc. The value of a system is related to the system lifetime cost relative to the AC energy output, often referred to levelized-cost-of-energy (LCOE). Also, performance is different than reliability although performance is dependent upon reliability.

Figure 1.2 shows the relative types of assessment and the applications.

**Fig. 1.2 - Performance Assessment Map showing applicability of recommendations covered by this report**




The recommendations were developed to be applicable to fixed flat panel PV module technology.

## Current Industry Performance Metrics – Literature Survey

The review of currently used performance metrics included information from NREL, Sandia, IEC, equipment suppliers, and other organizations. Some metrics appropriately use a ratio of actual performance divided by expected performance, called Performance Index (PI). Some methods have established acceptance criteria which define the minimum output and are used primarily during commissioning. Inputs used in calculating expected performance included as-build system component ratings and technology, irradiance, ambient temperature, wind, mounting, module temperature, and typical condition dependent derate factors.

The condition dependent derate factors are difficult to determine and they have a large influence on the performance calculation, and also introduce significant uncertainty into the calculations.

In principle, performance assessment could be based on any of the following:

- Actual output divided by actual solar input. This metric is representative of overall system efficiency and a normal system would have a value on the order of 0.1, largely dependent on the module efficiency. No analytical PV model is needed in this case. This metric has limited use most likely due to the negative perception of a low value around 0.1.
- Actual output divided by expected output. This metric is largely dependent on the system design, quality of installation, and the accuracy of the PV model. A normal system would be on the order of 1.0. This metric is used and can be based on either power or energy.
- Actual output normalized divided by actual input normalized. An example of this metric is Performance Ratio and it is used regularly to compare systems. However, it may result in incorrect conclusions if the systems being compared are in different locations with different irradiance and temperature.

Performance metrics can first be divided into instantaneous, short-term, and long-term assessment periods. Various degradation mechanisms and intermittent anomalies develop and occur over long-term periods so both periods are needed to complete an assessment. Instantaneous output is based on power and is denoted by kW (power). A long-term assessment period, such as weekly, monthly, or annually is based on energy and yield, and is denoted by kWh (energy).

Performance metrics can also be divided into absolute and relative values. An absolute value can be used to evaluate a system by comparing it to industry-wide values resulting in a figure of merit for the system. A relative performance metric can be used to trend a specific system using trend plots of the metric and associated parameters. Both the absolute and relative metrics provide input to troubleshooting of degraded systems. Measurement uncertainty and error analysis should be used to define a tolerance band to avoid reaching inappropriate conclusions.

Some metrics, such as Yield and Performance Ratio are independent of a PV model, whereas Performance Index is the actual performance divided by the calculated expected performance and is therefore dependent upon an accurate PV model.

Initial review of industry practice found various performance metrics as shown in Table 2.1 in the Appendix.

## Yield

The standard Yield metric is considered to be the "bottom-line" indication of how well a system is performing since the purpose of the system is to maximize energy output for a given system size; however, it does not account for weather conditions or design and can only be applied for a consistent assessment period (such as annually). Since Yield increases proportionally with hours of operation, insolation, and lower temperature, a high yield due to unusually high insolation can be misleading and potentially even mask a case of a degrading system. Conversely, a system with an unusually low insolation may be incorrectly judged to have poor performance. If systems are being compared using Yield, the hours of operation, insolation, and cell temperature should be equivalent for a fair comparison. The basic Yield equation is shown below as equation 1:

$$\text{Yield} = \frac{\sum_{Start}^{End} kWh_{AC}}{kW_{DC\,STC}} \qquad (1)$$

The value of a system ultimately comes down to annual AC energy output relative to system cost. Therefore, Yield is a measure of system value rather than performance.

## Performance Index

Performance Index (PI) as typically used by the industry represents the ratio of actual output (either power or energy) of a system divided by the expected output. The expected output was calculated using an accepted PV model, such as the NREL System Advisor Model (SAM), or a regression model, therefore, the accuracy and uncertainty of the PI value is dependent on the accuracy and uncertainty of the model.

## Summary of Effective Performance Metrics

The industry has used various metrics, often with similar names but different calculation methods, or with different names and similar calculation methods. Some metrics and calculations presented in technical papers are not effective for the purpose intended. As the industry has evolved, data has become more available, and analyses easier to perform; newer methods have been proposed and used. Based on evaluation of these various metrics, those that are considered appropriate for assessments are summarized in Table 2.2.

In general, performance assessment is the process of measuring or monitoring actual performance and comparing it to expected performance.

Either the actual performance or the expected performance must be adjusted to account for the actual weather and derate factor conditions. One approach is to adjust the actual system kW AC output "up" to STC (e.g. apply a ratio of 1000 W/m$^2$ / $G_{actual}$) and compare this to the expected STC system output from PV model calculations.The other approach is to adjust the STC output from PV model calculations "down" to the actual condition (e.g. apply a ratio of $G_{actual}$ / 1000 W/m$^2$). The second approach is appropriate and more commonly used by the industry.

Performance Index (PI) is typically the direct ratio of actual output divided by expected output, and is obviously different than a ratio of output divided by input such as is used in an efficiency equation. Performance Ratio (PR), as defined by NREL and IEC, is a normalized version of output divided by input so its value is not similar to a system efficiency of around 10% but rather is around 70%. The normalizing approach of including the DC STC rating and irradiation ratio, effectively converts the PR to a ratio of actual output divided by a "rough estimate" of expected output. If compensation factors in addition to actual irradiation are added to PR, such as temperature, balance of system losses, etc., it converts PR to a ratio with expected value in the denominator and is then similar to PI. The simple algebra is shown later.

Energy Performance Index (EPI) is a ratio of actual kWh AC divided by expected kWh AC using actual climate data over the assessment period as input to an accepted PV system model, such as SAM with all relevant derate parameters included, or as input to a "trained" regression model. "Trained" refers to the process of using actual system historical data to solve for regression equation coefficients. Therefore, EPI (either SAM or Regression methods) incorporates the most complete metric for performance assessment.

In the paragraphs that follow, the four metrics which are considered to be appropriate for performance assessment are discussed.

## Table 2.2- Summary of Performance Metrics

| METRIC | PURPOSE | METHOD | UNCERTAINTY |
|---|---|---|---|
| PR-Performance Ratio | Maintenance | (kWh/Rated $kW_{DC}$) / (kWh/1000) | High - 15% to 20% |
| CPR – Temperature Corrected PR | Maintenance | [kWh/(Rated $kW_{DC}$*Temp Corr. )] / [$kWh_{sun}$/1000] | Moderate - 10% to 15% |
| EPI – Energy Perf. Index SAM model | Maintenance, Commissioning, Financial | Actual $kWh_{AC}$ / Calc. SAM $kWh_{AC}$ | Moderate - 10% to 15% (model dependent) |
| EPI – Energy Perf. Index Regression model | Maintenance & Commissioning, Financial | Actual $kWh_{AC}$ / Calc. Regression $kWh_{AC}$ | Low - 5% to 10% |
| kWh Production | Maintenance | Compare AC kWh Period to Period | High - 15% to 20% |
| Yield | Financial only | kWh per DC Watt | Low - 5% to 10% |
| PPI – Power Performance Index | Commissioning & Troubleshooting | Measured kW power Output vs. Calc. kW power Expected | Low to Moderate - 5% to 15% (model and measurement dependent) |

Acronyms:
PI = Performance Index, ratio of actual divided by expected
PPI = Power Performance Index, instantaneous actual power divided by expected power
PR = Performance Ratio
CPR = Temperature compensated Performance Ratio
EPI = Energy Performance Index
$kWh_{AC}$ = AC Energy at system output at utility meter
$kW_{DC}$ = DC rating of array at standard test conditions (STC)
SAM = System Advisor Model, from NREL
$K_{Temp}$ = Temperature compensation factor based on ($T_{Cell}$-$T_{STC}$)

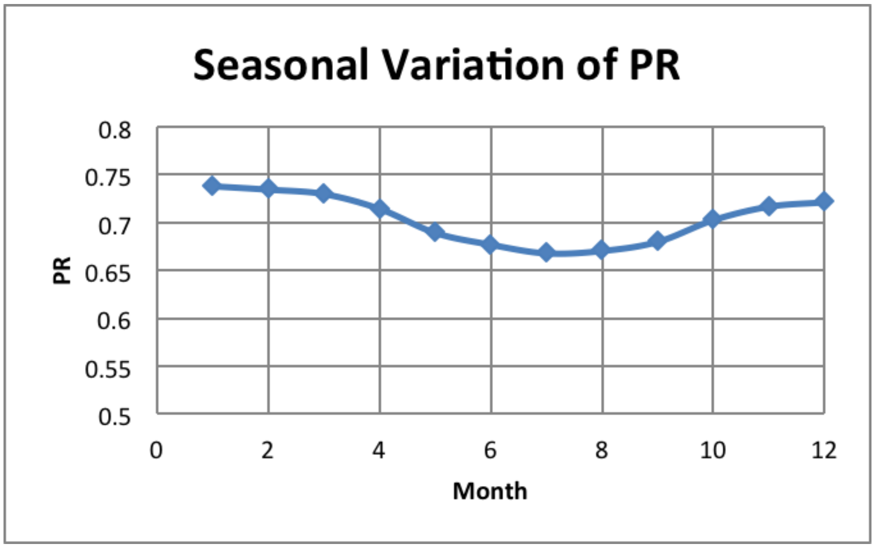
$kWh_{Sun}$ = Total in-plane solar irradiance

## Performance Ratio

Performance Ratio (PR), as defined by IEC61724 and NREL, is a metric commonly used, however one shortcoming in the basic PR is that normal temperature variation influences PR and is not included in the basic equation. Specifically, cases with low temperature and moderate irradiation (such as late winter) result in higher PR and cases with high temperature and moderate irradiation (such as late summer) will result in lower PR. A normally operating system typically has a declining PR in the spring, which could potentially be misinterpreted as a degrading system. Hourly data also has variation from morning to afternoon that is difficult to interpret.

The seasonal variation of PR can be illustrated using PVWATTS to represent an actual system to calculate monthly AC kWh and monthly irradiation. A 100kW system with latitude tilt in Sacramento was arbitrarily selected and analyzed resulting in the plot shown in Figure 2.1. It would appear that the system performance was degrading February through July.

**Figure 2.1 – Basic PR Seasonal Variation Without Temperature Correction**




Also as discussed above, PR is more appropriate to trend a specific system or to compare systems in similar geographic locations. If PR is used to evaluate a system in San Francisco, CA, compared to a similar system in Daggett, CA, incorrect conclusions would be reached. Even with a lower PR, the Daggett system has higher output and therefore higher performance.

One of the advantages of using PR is that the expected performance is not calculated, therefore, a PV computer model is not needed and the inaccuracies and uncertainty introduced by the model and the derate-factor assumptions are avoided.

Long-Term assessment is needed to identify system degradation due to intermittent faults, out-of-service time (outages), unavailability, low light performance, angle of incidence effects, solar spectrum effects, light or potential induced degradation, and other conditions that cannot be detected during the Short Term assessment period using methods such as those used for commissioning..

The basic PR calculation uses the standard yield equation in the numerator and the actual measured plane of array (POA) irradiation summed over the assessment period divided by standard irradiation in the denominator. The units work out to be hours divided by hours. The numerator is equivalent to the number of hours the system operated at the DC STC rating and the denominator is equivalent to the number of peak sunhours of irradiation. Both the measured irradiation and standard irradiance are in terms of meter$^2$, and cancel directly.

$$PR = \frac{\frac{kWh_{AC}}{kW_{DC\ STC}}}{\frac{kWh_{Sun}/m^2}{1kW/m^2}} \qquad (2)$$

Both the numerator and denominator are summations of the measured increment data over the assessment period. The assessment period can be daily, weekly, monthly, annually. Calculation of hourly PR is a problem since some hours of the day with zero irradiance result in division by zero and is undefined. Since hourly data is commonly available, hourly PR was calculated and plotted for interest.

Analysis of hourly data required filtering to eliminate hours with zero irradiance. The Excel filter function was used in various scenarios such as to include mid-day hours and for irradiance greater than a defined value, such as 600 $kWh/m^2$. Effectively, this was a "mid-day flash test". Filtering levels raise questions and doubts about the calculated PR value; therefore it is preferred to calculate daily or longer periods. The Excel function of SUMIFS is useful to calculate the total values for the period, and AVERAGEIFS is useful to calculate average values such as daily temperature if temperature correction is being used in CPR.

**Instructions for Calculating Long-Term Performance Ratio**

$PR = (kWh_{AC}/DC_{Rated})/(kWh_{Sun}/1kW)$

1. Install Plane of Array (POA) irradiance datalogger, or obtain access to existing POA data, or use data from another local site adjusted from horizontal to POA using NREL DISC Excel spreadsheet and an anisotropic sky model such as the Perez or similar model.
2. Read inverter kWh total on inverter display at beginning of assessment period, or obtain access to existing monitoring data.
3. Read totals for irradiation from datalogger and kWh from inverter (or from monitored data) at end of assessment period; calculate differences to obtain actual kWh of irradiance and kWh of AC energy over the assessment period. For simpler approach for annual PR estimate, use PVWATTS total annual POA irradiation value. Annual PVWATTS irradiation is typically less discrepant from actual than monthly PVWATTS POA irradiation values, however if the weather during the assessment year is different than the typical year, uncertainty is increased.
4. Calculate Performance Ratio (PR). Calculate the hourly PR using the IEC61724 formula, Equation 2 above.
5. Compare PR value to typical industry values, or to similar systems in other locations, or to previous PR values of the same system to establish trend of performance depending on the purpose of the assessment.
6. Evaluate PR. If PR ± uncertainty is within Long-Term criteria, system performance is acceptable. Otherwise proceed to investigate performance shortfall of individual components.

## Performance Ratio, Compensated

The basic Performance Ratio (PR) is directly influenced by energy (kWh) output, which is directly influenced by irradiation (kWh/m2) and inversely influenced by module temperature. Since the basic PR equation accounts for irradiation, changes in irradiation will have little direct effect on PR, however, since changes in temperature are not accounted for, the basic PR will decrease as temperature increases.

In order to use a metric which is more indicative of system condition rather than design or environmental conditions that are outside the control of the owner, compensation factors can be added to the basic PR equation. One method to include temperature compensation is to adjust the DC rating in the numerator using the power temperature coefficient provided on the module manufacturer's data sheet relative to the STC temperature of 25°C. Other methods used for hourly calculations weight the compensation factor by the irradiance or energy output for the hour, or to use factors based on average annual ambient temperature.

Other factors besides temperature also affect PR and are also outside the control of the owner, such as design, shading, degradation, balance of system, and could be included as compensation factors; however the basis for estimating these factors to compensate PR is impractical. Therefore, if compensation other than temperature is desired, it is more practical to calculate Long-Term Energy Performance Index (EPI) using actual irradiation and temperature in one of the accepted models, such as SAM or regression model.

If the purpose of the assessment is only to evaluate a specific system, trend analysis using a temperature compensated PR is reasonable because it is not influenced by the accuracy and/or uncertainty of a PV model.

Compensation for factors such as cell temperature, $K_{Temp}$, can be applied to the basic PR to adjust the DC power rating from Standard Test Conditions (STC), however since temperature varies continuously with irradiance and weather, an averaging technique must be performed at each time increment (such as, hourly) and used to calculate a daily average temperature.

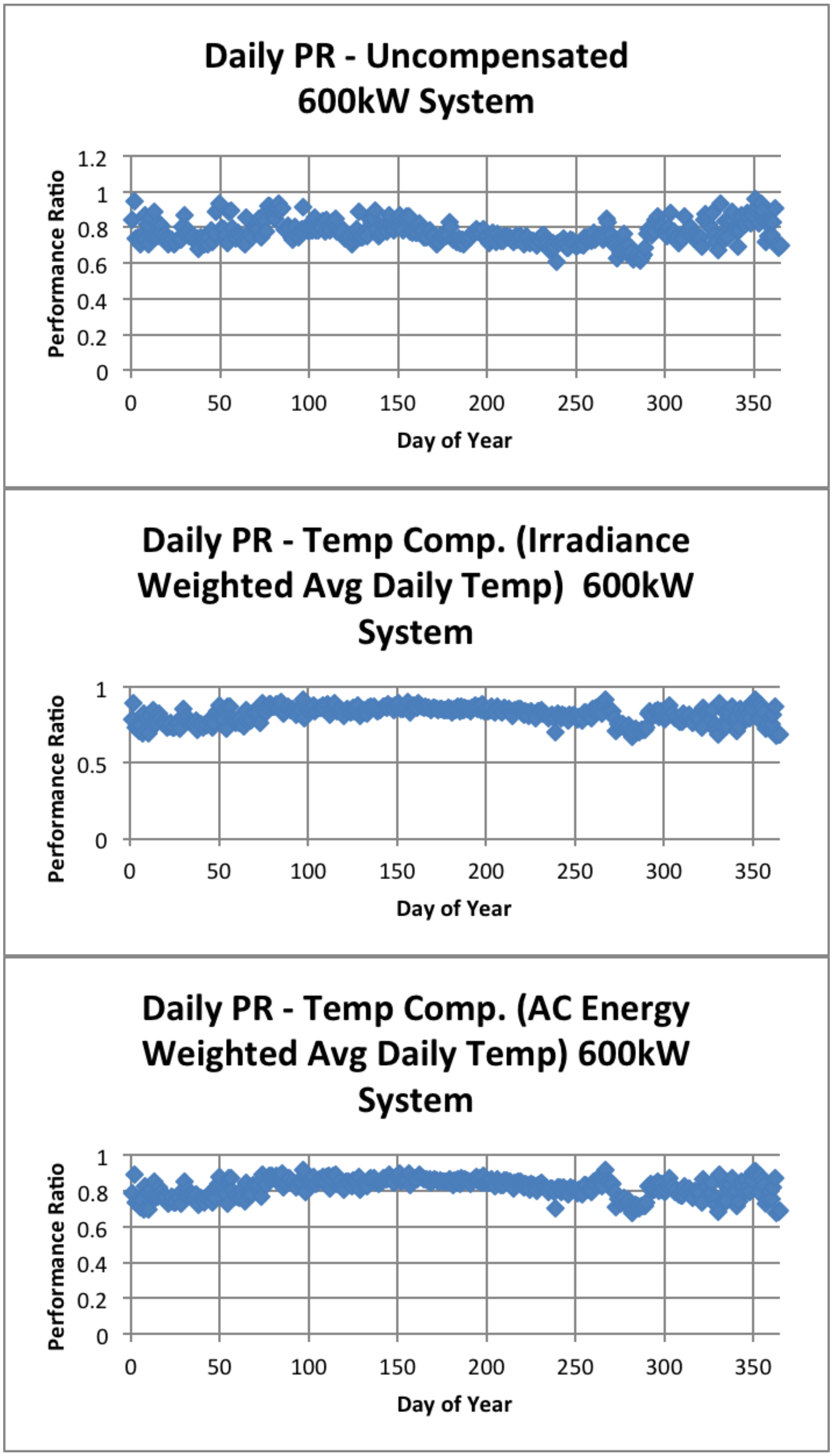
$$PR_{Temp\ Comp.} = \frac{\dfrac{kWh_{AC}}{kW_{DC\ STC} \times K_{Temp}}}{\dfrac{kWh_{Sun}}{1kW}} \qquad (3)$$

Typical hourly data includes night hours when the energy production and irradiance are zero. Dividing by zero is undefined; therefore, Daily PR should be calculated using the SUMIF function in Excel to sum the hourly values to obtain the daily sum of $kWh_{AC}$ and $kWh_{Sun}$. A daily PR would then be obtained using equation (3). Hourly PR values vary from zero to a maximum either before or after noon depending on conditions and are considered to be of little use for performance assessment. Averaging hourly PR to obtain daily PR was tried and not recommended versus summation of the hourly $kWh_{AC}$ and $kWh_{Sun}$ values for the day.

Because irradiance and temperature change continuously, it would be beneficial to use a time increment less than an hour, however for practicality an average hourly temperature is considered acceptable unless the assessment is for a large critical system. The 2004 King paper, suggests that hourly averages is acceptable for most assessments, although other experts say hourly average under-predicts performance due to the thermal lag when irradiance increases.

If additional compensation factors are of interest to be included, such as balance of system losses, angle of incidence, soiling, shading, long-term degradation, etc, it is more practical to include them in the Energy Performance Index (EPI) using an accepted PV model, such as SAM, to incorporate the compensation factors rather than complicating PR.

**Figure 2.2 –PR Without and With Temperature Compensation**



## Energy Performance Index (EPI) – SAM or equal:

When compensation factors are added to the PR equation, the equation is equivalent to Performance Index of actual energy divided by expected energy for the assessment period.

Note that the PR equation which includes compensation for temperature or other factors is identical to the equation for Energy Performance Index (EPI), based on the following algebra:

$$PR = \frac{\frac{kWh_{AC}}{kW_{DC\ STC}}}{\frac{kWh_{Sun}}{1kW}}$$

$$PR_{Comp.} = \frac{\frac{kWh_{AC}}{kW_{DC\ STC} \times K_{Temp} \times K_{Derate} \times K_{Misc\ Comp}}}{\frac{kWh_{Sun}}{1kW}}$$

$$PR_{Comp.} = EPI = \frac{\sum_{Start}^{End} kWh_{AC}}{kW_{STC} \times \sum_{Start}^{End} \left( \frac{kWh_{Sun}}{1kW} \times K_{Temp} \times K_{Derate} \times K_{Misc\ Comp} \right)}$$

This equation is of the form of the Power Performance Index (PPI) presented later, however in this case it is in terms of energy and is EPI.

Acceptable models (e.g. SAM) inherently include “compensation factors” as part of the model. It is necessary to input actual weather data in a climate file. In the case of SAM, actual hourly data for GHI, DNI, DHI, dry-bulb temperature, and wind speed can be incorporated into TMY3 format file and read by SAM. Other parameters included in the TMY3 file, such as dew-point, relative humidity, pressure, and albedo can be assumed to be acceptable from the original TMY3 file for the specific location.

The rate of change of the compensation factors affects the time frame over which the summation is performed.

**Instructions for Calculating Long-Term Energy Performance Index**

EPI = Actual energy output / Expected energy output

When calculating the expected energy output, System Advisor Model (SAM), or equal, requires actual weather conditions to be formatted in a Typical Meteorological Year format.

Procedure:

1. Download a TMY3 file in the vicinity of the PV array.
2. Click and open the function "Create a TMY3 File"
3. Obtain one year of hourly data for actual weather conditions at the PV array.
4. In order to calculate the Direct Normal Irradiance (DNI), the Direct Insolation Solar Code (DISC) model developed by Dr. E. Maxwell of the National Renewable Energy Laboratory, available on-line can be used.
5. The Diffuse Horizontal Irradiance (DHI) was also calculated through DISC data. Using the DNI, and $\Theta_z$ zenith angle, calculated by DISC, and the relationship between GHI, the direct horizontal irradiance (dHI), and DHI, were able to be calculated.

$$DHI = GHI - dHI$$

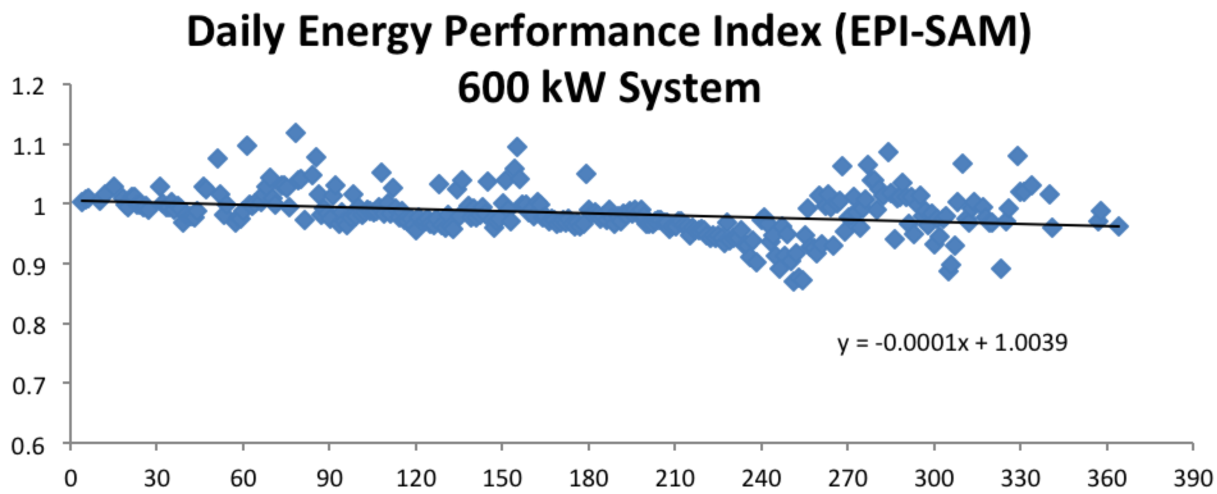
Where:

$$dHI = DNI \times \cos\theta_z$$

6. Using the SAM Create a TMY3 Function, create a TMY3 file for your PV system.
7. Input system design characteristics and assumed derate factors into SAM and calculate an expected hourly generation ($kWh_{AC}$).
8. Calculate an hourly performance index using the measured energy generated and expected energy generation from SAM.
9. Apply a filter removing all hours where less than a threshold was generated.

A plot of EPI is provided below from the 600kW PV system applying the above method. It shows a potential performance problem in late summer that could be investigated, such as soiling.

**Figure 2.4: Daily EPI-SAM for One Year Using Actual Weather and SAM**




## Energy Performance Index (EPI) - Regression Method:

The Energy Performance Index (EPI) is calculated using a polynomial regression analysis method to develop an equation relating actual irradiance, temperature, and other relevant parameters (such as inverter efficiency) to the actual AC energy output at each sample time. The general equation shown below has four unknown coefficients, and in principle they can be determined with four equations. Considering that each row of data represents each hour of operation with values for each of the input and output parameters, therefore there is enough data to use statistical methods to find the "best fit" equation for a combination of the input parameters in the regression equation. Deviations between the calculated expected AC output and the actual output are called residuals and are minimized as the model is improved.

General regression equation:

$$\text{AC Output Energy} = A + \text{Temp} \times \text{Irrad} \times B + \text{Irrad} \times C + \text{Irrad}^2 \times D$$

Coefficients (A, B, C, D) are determined by pseudo-inverse matrix operations in Excel or MatLab. Automated processing of the regression method is available in statistical programs such as MiniTab, JMP, SPSS, etc.

Data is needed from an "equation training period" where it is assumed that the system operates properly and data collected for use in developing equation coefficients. The data needed consisted of the actual metered hourly kWhAC output, and actual hourly weather (GHI or POA irradiance, ambient temp, wind, inverter efficiency, etc) input.

An advantage of using the regression analysis method is that an accurate PV model (e.g. SAM) and correct derate factor are not needed.

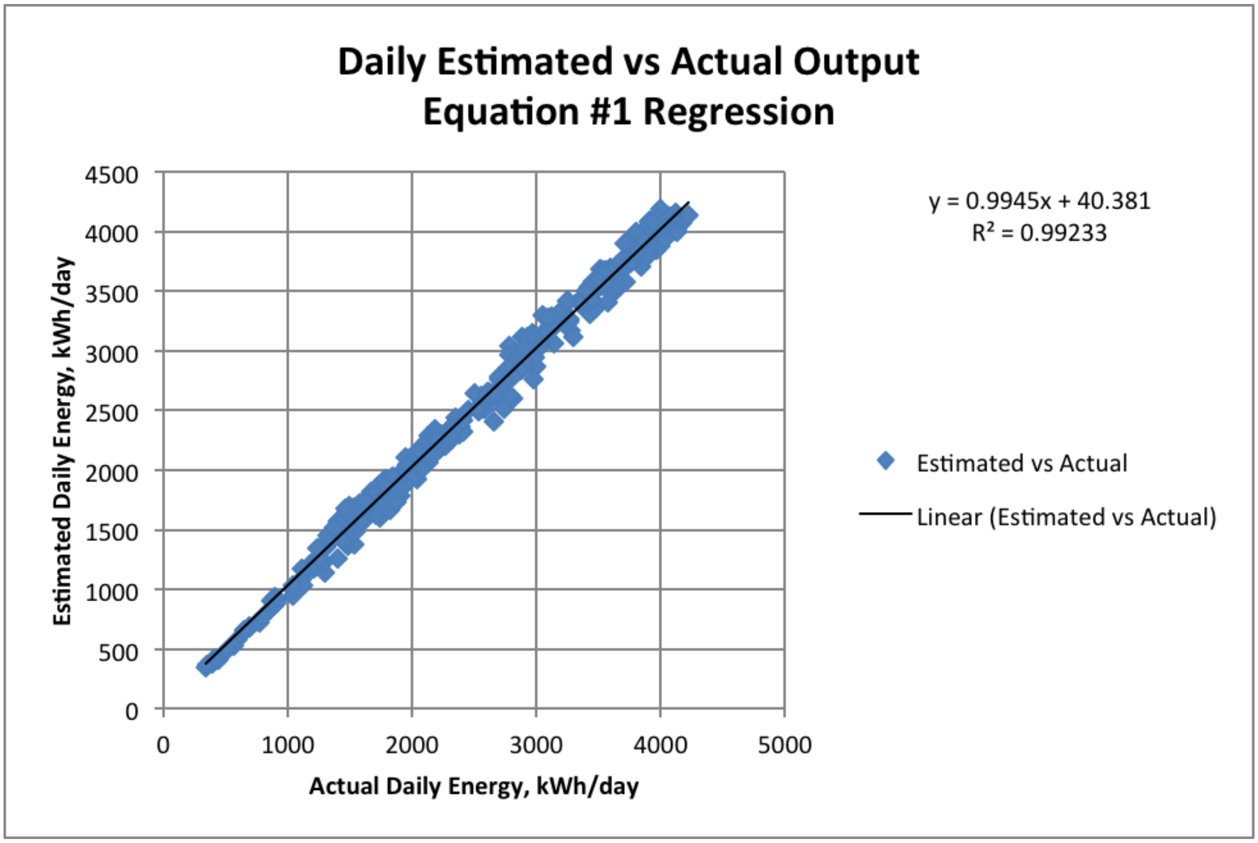
The value for EPI is calculated based on actual kWhAC / Expected kWhAC from regression model using coefficients from actual hourly weather and hourly energy output data over the previous year.

The process to calculate EPI is:

1. Obtain hourly metered kWhAC  for assessment period.
2. Sum hourly kWhAC, for each day using Excel SUMIF.
3. Calculate DNI, DHI, DiffHI from GHI using NREL DISC, or use POA data if available.
4. Calculate POA irradiance using Isotropic Sky model.
5. Calculate coefficient matrix using polynomial equation.
6. Use matrix pseudo-inverse to calculate hourly kWhAC .
7. Sum hourly kWhAC for day using Excel SUMIF.
8. Calculate EPI for day, plot daily trend.

Using the regression analysis method, the estimated daily energy can be calculated for comparison to the actual, Figure 2.5 shows how the calculated and actual compare.

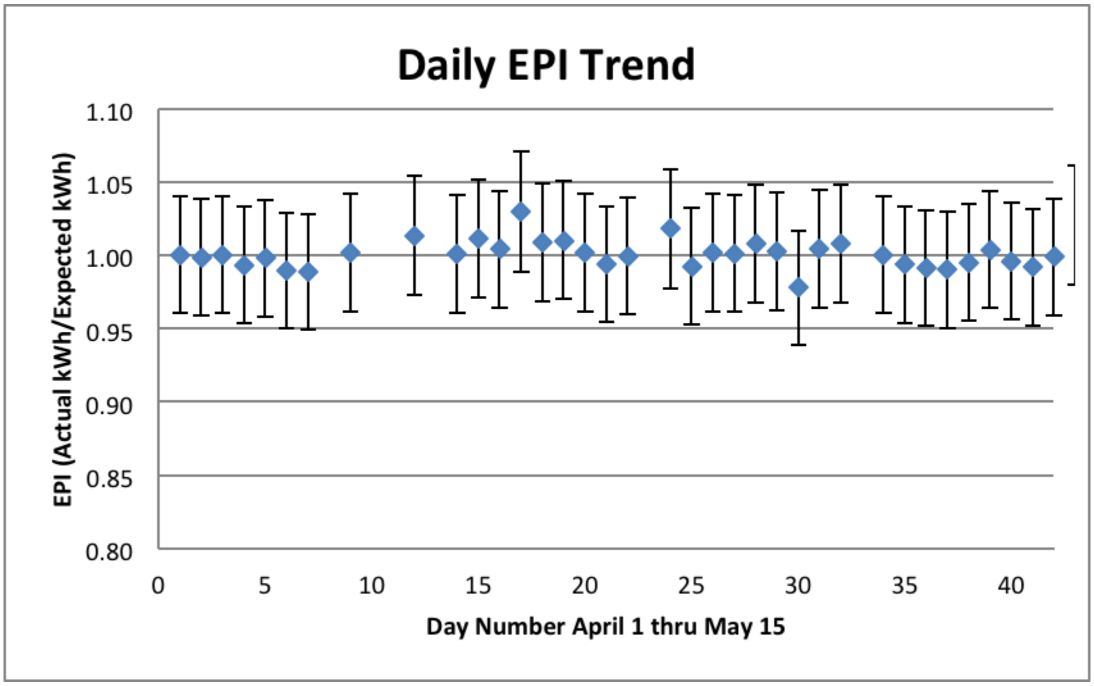
**Figure 2.5:  Plot Showing Agreement of Regression Equation**




Different variables in the general regression equation were tried, such as inverter efficiency which played a role to reduce the uncertainty. By analyzing weather data, it was found that at high ambient temperatures the inverter shuts down even though the insolation was optimal for high power output. Hourly data was used to determine the regression coefficients from the general regression equation. The POA irradiance was calculated using the NREL- DISC program using GHI data.

Using the general regression model and adding the inverter efficiency to the equation as a new parameter reduced the uncertainty. With this new parameter, the uncertainty with a GHI greater than 800 (W/m²) is 4.1%.

**Figure 2.6: Plot Showing Result of Regression Method with 4% error bars.**




Quarterly data was also used to see if any anomalies or trends existed. Quarterly data would be used to define a regression equation for a particular season. Further work is needed on this topic to fully assess its usefulness.

The same technique and method was used for 15-minute data. The reduction of averaging over a longer period of time (for an hour) was the motive for using 15 minute data so that there would be less averaging involved. For 15-minute data there were more wild points to be considered, however, by taking into account more variables, 5% uncertainty was achieved.

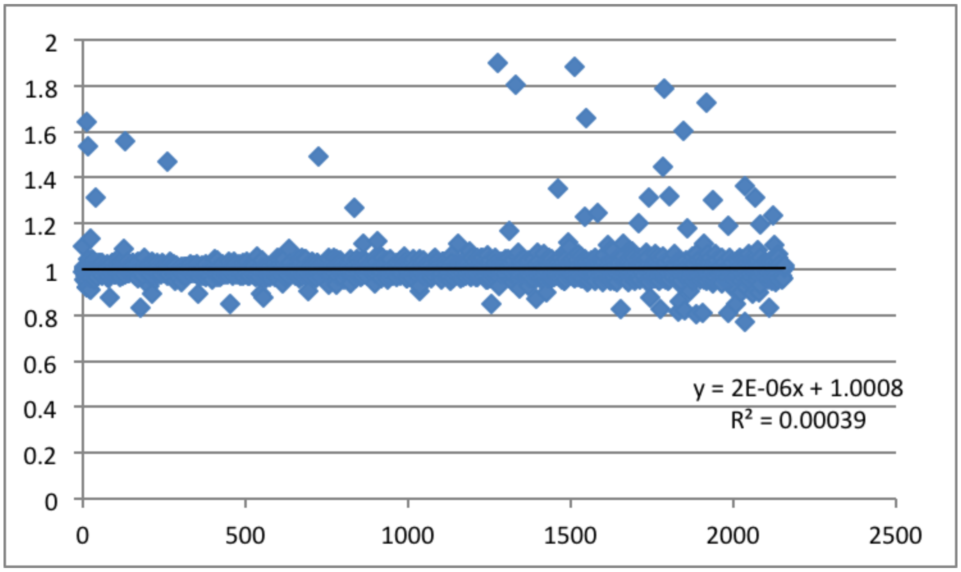
The data has a range of points. There are more than 10,000 data points which have been graphed on this chart and there are many more wild points that need to be taken into account. Yet, the regression was able to predict the outcome within 5% of the actual power output.

For the year of 2011, the chart below shows the EPI obtained. The confidence is high in this case since the generic model described above was altered to include more variables.

$$P = \boldsymbol{A} + T\,H\,\boldsymbol{B} + H\,\boldsymbol{C} + H^2\boldsymbol{D} + T\boldsymbol{E} + N\,\boldsymbol{F} + T\,N\boldsymbol{G} + D\boldsymbol{H}$$

Where T = Temp, H = Irradiance, N = Inverter Efficiency, D = Humidity.

**Figure 2.7: Plot Showing Wild Points Adversely Affecting EPI .**

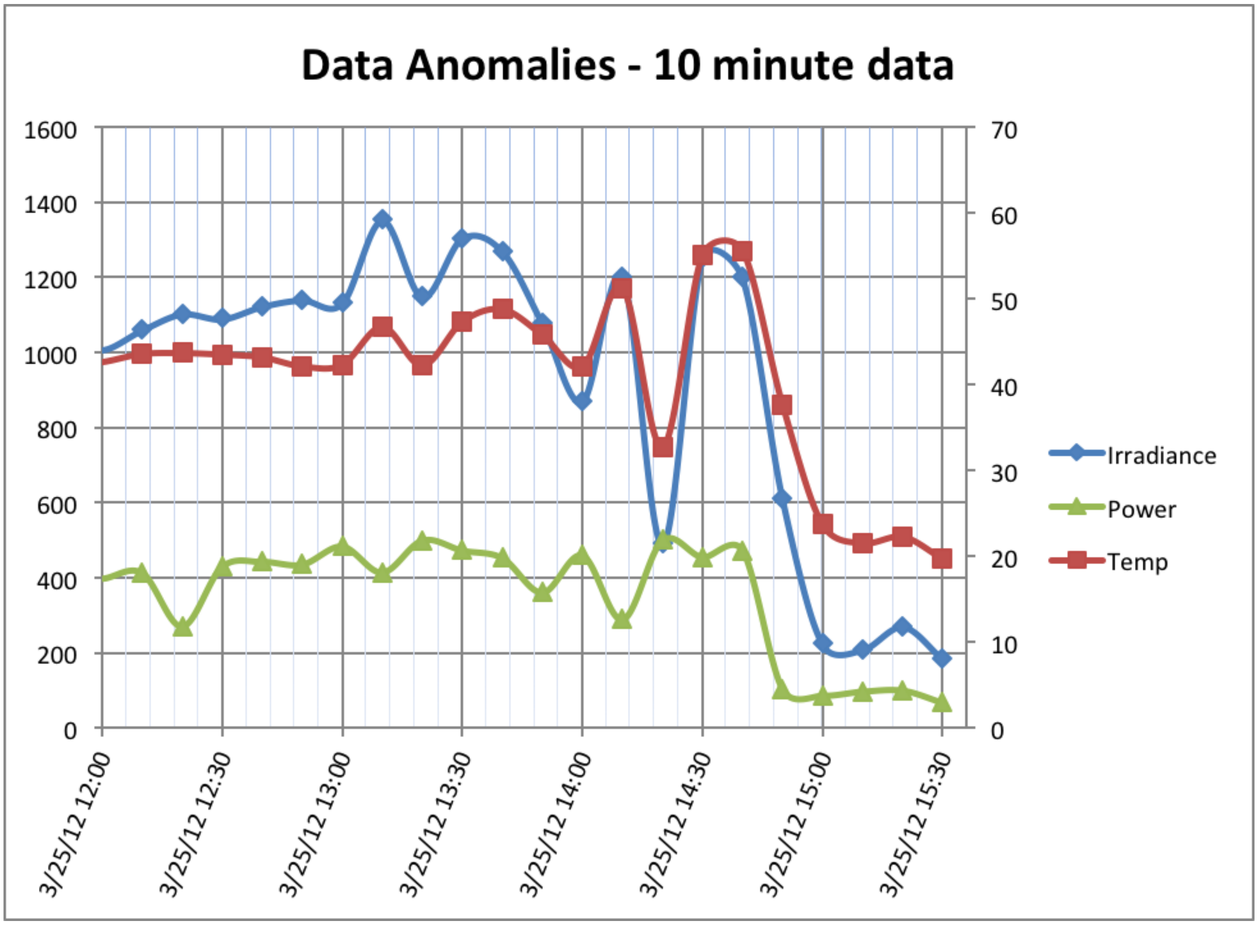



## Data Quality Issues and Uncertainty

Methods to reduce wild-points and condition data for analysis were applied. One area that can be improved is the manner in which data is collected or monitored. Currently the provided data is an average of data during a one hour time period. In doing so the hourly averaging of data underestimates the actual energy production during high irradiance conditions. This occurs due to averaging the fluctuations of irradiance over an hour. With large fluctuations the power generated will adjust quickly, however the module operating temperature will adjust slowly and remain at a lower temperature.

Anomalies were found as illustrated in Figure 2.8, whereby irradiance, cell temperature, and system output varied counter intuitive to known PV principles.

**Fig. 2.8 Data Anomalies Which Are Inconsistent With PV Operating Principles:**
Between 12:20 and 12:30 - Irradiance decreases, cell temp constant, power increases
Between 13:10 and 13:30 - Irradiance decreases, cell temp increases, power increases
Between 13:50 and 14:00 - Irradiance large decrease, cell temp small decrease, power increases




Uncertainty estimates for the measured data were based on literature consensus. Uncertainty for calculations was based on principles of propagation of uncertainty, such as using square-root-sum-of-squares combination when products were calculated.

## Power Performance Index (PPI)

The Power Performance Index (PPI) is the instantaneous actual AC kW power output divided by the instantaneous expected AC kW power output. The instantaneous expected AC power depends on many factors, including the instantaneous irradiance and cell junction temperature, the module technology including STC ratings and spectral and angular response, and the derate factors. The actual irradiance absorbed by the module cells (referred to as "effective irradiance" by Sandia) can depend on a number of factors, including the POA irradiance just above the glass surface, incident angle, glass coatings, soiling, encapsulant, etc.

A desirable module temperature measurement results in the average cell junction temperature across the array under test. The average cell temperature depends on a number of factors, including ambient temperature, irradiance, wind speed and direction, mounting geometries, etc. Uncertainty results from the specific model used to calculate the expected power. Neglecting some of the factors mentioned above increases uncertainty, but generally simplifies the calculations and measurements. A detailed PPI analysis could be performed using SAM or other PV design software to calculate the expected power output considering all relevant factors. A simple model for the calculation of expected output uses the rated DC STC power (P) times adjustment factors (Ks) which include instantaneous irradiance and temperature, and is called the PKs method in this article. The actual power is then compared to the resulting expected power in the PPI ratio.

Latency between the irradiance and temperature measurements and the actual power reading should be minimized. Instantaneous measurements are ideal. If irradiance and temperature measurements are taken manually, it is important to carefully timestamp actual power readings and irradiance and temperature readings and note how steady the values are so that the actual power value is correlated to the actual irradiance and actual temperature values. Experience has shown that apparently clear sky conditions can result in significant variations of irradiance over a short time. It should also be noted that the uncertainty in the actual power reading shown on an inverter can vary from inverter to inverter. A revenue grade AC power meter is usually the best method.

**Instructions for Calculating Power Performance Index (PPI) using the PKs method**

1. Visually inspect system - Determine as-built configuration, identify conditions affecting performance, estimate typical derate factors per PVWATTS description or similar documentation and combine to obtain derate K factor ($K_{Derate}$).
2. Measure Plane of Array (POA) irradiance. If only horizontal data is available (GHI), convert to POA using NREL DISC spreadsheet to calculate DNI, DHI and use Isotropic model to convert to POA irradiance. Note that converting from GHI to POA will introduce error into the irradiance measurement, especially at steep incident angles seen early or late in the day. The Isotropic model formula is:

$$I_T = I_b R_b + I_d \left(\frac{1 + \cos\beta}{2}\right) + I\rho_g \left(\frac{1 - \cos\beta}{2}\right)$$

3. Calculate irradiance K factor, $K_{Irrad}$, from:

$$K_{irrad} = \frac{I_T}{1000}$$

4. Measure module backside temperature and add an offset to account for temperature difference between backside and cells, such as 3°C × $K_{Irrad}$, per King 2004 paper shown below. If backside temperature is not available, you can measure ambient temperature and calculate cell temperature using Sandia model or NOCT value on module datasheet

using one of the following formulas. Note, this method will generally be less accurate than directly measuring the backside temperature.

$$T_{cell} = T_{ambient} + \left(\frac{T_{NOCT} - 20°}{800}\right) I_r$$

or, per Sandia model:

$$T_{cell} = I_r e^{(a+b\,WS)} + T_{ambient} + \left(\frac{I_r}{1000}\right)\Delta T$$

where, ΔT is temperature rise over ambient, such as 3°C.

5. Calculate temperature K factor ($K_{Temp}$) for temperature relative to STC using the following formula, where μ is the power temperature coefficient and is a negative number, such as typically - 0.005/°C.

$$K_{Temp} = [1 + \mu(T_{cell} - 25°C)]$$

6. Calculate expected AC output power (kW):

$$P_{Expected} = P_{DC\,STC} \times K_{Irrad} \times K_{Temp} \times K_{Derate}$$

7. Measure actual AC output power (kW) or use inverter displayed value at a time which is correlated with the irradiance and module temperature measurements.
8. Calculate ratio of measured actual AC power to expected power, define values as Power Performance Index (PPI)

$$PPI = \frac{P_{Actual}}{P_{Expected}}$$

9. Estimate uncertainty values for measured and calculated values (apply propagation of uncertainty method using square root sum squares of each relative uncertainty in %).
10. Evaluate PI. If PI = 1.0 ± uncertainty, short-term system performance is acceptable, proceed to Long Term Assessment.

**Uncertainty of PPI**

As noted above, the uncertainty associated with the PPI is highly dependent on the model used to determine the expected power and the methods used for determining instantaneous irradiance and module cell temperature. The PKs method trades-off uncertainty for simplicity. This method results in an uncertainty of 10-15%. More sophisticated measurements and models will reduce the uncertainty of the expected power and therefore reduce the uncertainty of the PPI. Some industry tools and models have been shown to have uncertainty less than 5%. To reach

such accuracy levels requires care. For example, a better method for determining the average cell junction temperature across the array is to use the Voc of the array as described in IEC 904-5. This is generally a better method than backside temperature measurements plus offset or calculations that take into account wind speed because in general it is nearly impossible to determine the typically non-uniform distribution of wind flow over an array. It should be noted that the Voc method has limitations at low irradiance values.
Accurate irradiance measurements can be achieved by using a matched reference cell or a model-corrected reference cell oriented in the POA. This will give a good estimate of the effective irradiance actually absorbed by the cell, taking into account angular and spectral response, glass coatings etc and will generally be superior to inexpensive irradiance meters. These kinds of irradiance meters are fairly accurate when oriented directly at the sun to give the direct normal irradiance, however direct normal readings are only valid when the sun is directly normal to the plane of array which in practice is only a few times during the year. Therefore angle-response effects are not accounted for like when a reference cell is used oriented in the POA.

## Conclusion and Recommended Performance Assessment Methods

Literature review and discussions with industry experts suggested focusing on the following four metrics:

- Power Performance Index (PPI) of actual instantaneous kW AC power output divided by expected instantaneous kW AC power output.
- Performance Ratio (PR) of final yield divided by reference yield over an assessment period.
- Performance Ratio with final yield corrected for cell temperature (CPR) over an assessment period.
- Energy Performance Index (EPI) of actual kWh AC energy divided by expected kWh AC energy as determined from an accepted PV model, such as SAM (EPI-SAM), using actual climate data input to the model over the assessment period, or a regression model using operating data to “train” the model (EPI-REGRESSION) resulting in reduced uncertainty since derate factors are not needed.

The three primary objectives for performance assessments of existing systems and the associated recommended metrics are listed below. A guideline summary is provided in Table 2.2.

- Monitoring of a specific PV system to identify degraded performance and need for maintenance based on condition. Use EPI metric and trend EPI for the specific system.
- Commissioning, re-commissioning, troubleshooting, or assessment after major maintenance. Use PPI and EPI metrics.
- Determination of specific industry parameters, such as Yield or Performance Ratio, to allow comparison of systems in different geographic locations for design validation or

investment decisions. Use PR, CPR and/or EPI depending on the level of effort and level of uncertainty.

Additional work is recommended to develop specific procedures for each of the four metrics summarized above and for making Excel spreadsheets available for general use. Additional long-term data should be analyzed to investigate the ability of metrics to meet the stated purposes, and to determine best practices for obtaining reliable inputs with currently available industry products such as monitoring systems and IV curve tracers. An industry standard would also be useful to improve consistency in calculating and interpreting these performance metrics across the industry.

## Acknowledgements

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## Table 2.1- Commonly Used Performance Metrics

| METRIC | CALCULATION | REFERENCE |
|---|---|---|
| Yield | kWh / $kW_{DC\ STC}$ | NREL/CP-520-37358 |
| Performance Ratio | (kWh/ $kW_{DC\ STC}$ ) / ($H/G_{STC}$) | IEC61724 |
| Performance Ratio | kWh / (sunhours × area × efficiency) | SMA |
| Performance Ratio | ($E_{Actual}$ / $E_{Ideal}$) * 100%<br>$E_{Ideal}$ is temp. and irrad. compensated | SolarPro, Taylor & Williams |
| Specific Production | $MWh_{AC}$ / $MW_{DC\ STC}$ | SolarPro, Taylor & Williams |
| Performance Ratio | (100 * Net production / total incident solar radiation) / rated PV module eff. | NREL/TP-550-38603 |
| Performance Factor | $I_{SC,G}*R_{SC}*FF_R*R_{OC}*V_{OC,T}$ | Sutterlueti |
| Performance Index | $kW_{measured}$ / $kW_{expected}$ | SolarPro, Sun Light & Power |
| Performance Index | Actual Power / (Rated power * irrad adj. * temp adj * degradation adj * soiling adj * BOS adj) | Townsend |
| Output Power Ratio | $kW_{measured}$ / $kW_{predicted}$ | SolarPro, Sun Light & Power |
| Output power | kW > CF-6R-PV Table | CEC Commissioning |
| Output power | kW > 95% expected | SRP Arizona Utility |
| Specific Production | $MWh_{AC}$ / $MW_{DC\text{-}STC}$ | SolarPro, Taylor & Williams |
| Acceptance Ratio | $kW_{actual}$ / $kW_{expected}$ | Literature |
| Inverter comparison | kWh of multiple similar inverters | Qualitative |
| String comparison | $I_{mp}$, $V_{mp}$ of multiple parallel strings | Qualitative |
| Utility billing | Monthly comparison | Qualitative |
| Performance Ratio, temp. comp. (CPR) | (kWh/ $kW_{DC}$ *$K_{Temp}$) / (H/ $G_{STC}$) | Proposed in this report |
| Energy Performance Index (EPI) | kWh AC actual / SAM AC Expected using actual weather data | Proposed in this report |
| Power Performance Index (PPI) | $kW_{AC}$ / ($kW_{DC}$ *$K_{Irrad}$*$K_{Temp}$*$K_{Derate}$ ) | Proposed in this report |

## Sample of Excel Spreadsheets to calculate Performance Ratio (CPR)

**PR ADJUSTMENT FACTOR DEVELOPMENT**

Arizona Game & Fish 191 kW system live site data used to find PR adjustment factors to result in a PR value that has minimal variation with time, irradiance, and temp, when in normal condition. Decrease in PR would then be due to degradation.

| | | | |
|---|---|---|---|
| Plots on next tab shows results. | System DC Rated Power (kW) = 191 | Used only for comparison: | |
| Input Site Data = | Cut-off irrad (kW/M^2) = 0.75 | NOCT (C)= | 47 |
| Output for plots = | Power Temp. Coefficient (W/C) = -0.005 | Wind (m/s) = | 2 |

| ID | y | m | d | t | Hourly AC Energy (kWh) | Average Hourly Irradiance (kW/M^2) | Average Ambient Temp. (C) | Measured Average Cell Temp. (C) | Time | Week | Total Daily AC Energy (kWh) | Total Daily Insolation (kWh/M^2) | Hourly PR | Daily PR using Total Daily Energy and Insolation | Power times Hourly PR | Sum of Power times Hourly PR | Daily PR using Power Weighted Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2011 | 2 | 13 | 0:00 | 0 | 0.004 | 12.664 | 7.747 | 0.00 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 2011 | 2 | 13 | 1:00 | 0 | 0.004 | 12.711 | 7.649 | 0.04 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 2011 | 2 | 13 | 2:00 | 0 | 0.004 | 11.68 | 6.487 | 0.08 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 2011 | 2 | 13 | 3:00 | 0 | 0.004 | 11.069 | 6.128 | 0.13 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 2011 | 2 | 13 | 4:00 | 0 | 0.004 | 11.33 | 6.604 | 0.17 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 2011 | 2 | 13 | 5:00 | 0 | 0.004 | 11.268 | 5.119 | 0.21 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 2011 | 2 | 13 | 6:00 | 0 | 0.004 | 10.469 | 3.426 | 0.25 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 2011 | 2 | 13 | 7:00 | 4.24 | 0.152 | 9.838 | 6.476 | 0.29 | 1 | 0 | 0 | 0.14595 | 0 | 0.618827 | 0 | 0 |
| 9 | 2011 | 2 | 13 | 8:00 | 41.732 | 0.549 | 11.617 | 18.17 | 0.33 | 1 | 0 | 0 | 0.39791 | 0 | 16.60556 | 0 | 0 |
| 10 | 2011 | 2 | 13 | 9:00 | 85.684 | 0.851 | 15.261 | 30.12 | 0.38 | 1 | 0 | 0 | 0.527091 | 0 | 45.16328 | 0 | 0 |
| 11 | 2011 | 2 | 13 | 10:00 | 125.876 | 1.069 | 18.872 | 46.435 | 0.42 | 1 | 0 | 0 | 0.616441 | 0 | 77.59508 | 0 | 0 |
| 12 | 2011 | 2 | 13 | 11:00 | 133.224 | 1.155 | 21.793 | 52.784 | 0.46 | 1 | 0 | 0 | 0.603851 | 0 | 80.4474 | 0 | 0 |
| 13 | 2011 | 2 | 13 | 12:00 | 129.68 | 1.117 | 23.064 | 52.186 | 0.50 | 1 | 844.996 | 7.584 | 0.607782 | 0.583265 | 78.81712 | 505.3351 | 0.598033 |
| 14 | 2011 | 2 | 13 | 13:00 | 111.624 | 0.931 | 23.454 | 43.163 | 0.54 | 1 | 0 | 0 | 0.627665 | 0 | 70.06247 | 0 | 0 |
| 15 | 2011 | 2 | 13 | 14:00 | 94.496 | 0.76 | 22.913 | 35.236 | 0.58 | 1 | 0 | 0 | 0.650893 | 0 | 61.50675 | 0 | 0 |
| 16 | 2011 | 2 | 13 | 15:00 | 79.572 | 0.641 | 23.137 | 34.701 | 0.63 | 1 | 0 | 0 | 0.649832 | 0 | 51.70844 | 0 | 0 |
| 17 | 2011 | 2 | 13 | 16:00 | 33.172 | 0.284 | 22.582 | 25.096 | 0.67 | 1 | 0 | 0 | 0.611318 | 0 | 20.27863 | 0 | 0 |
| 18 | 2011 | 2 | 13 | 17:00 | 5.696 | 0.067 | 20.232 | 16.015 | 0.71 | 1 | 0 | 0 | 0.444441 | 0 | 2.531536 | 0 | 0 |
| 19 | 2011 | 2 | 13 | 18:00 | 0 | 0.004 | 18.415 | 11.741 | 0.75 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 2011 | 2 | 13 | 19:00 | 0 | 0.002 | 17.76 | 10.554 | 0.79 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

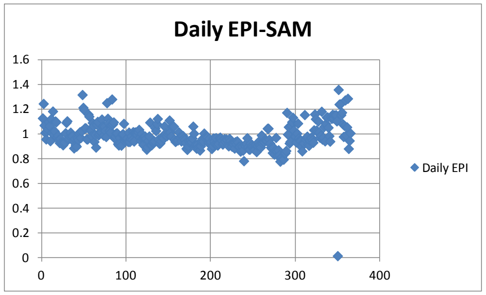
**Sample of Excel Spreadsheet to calculate Energy Performance Index (EPI-SAM)**

## CALCULATED RESULTS FROM SAM MODEL OF 600KW SYSTEM

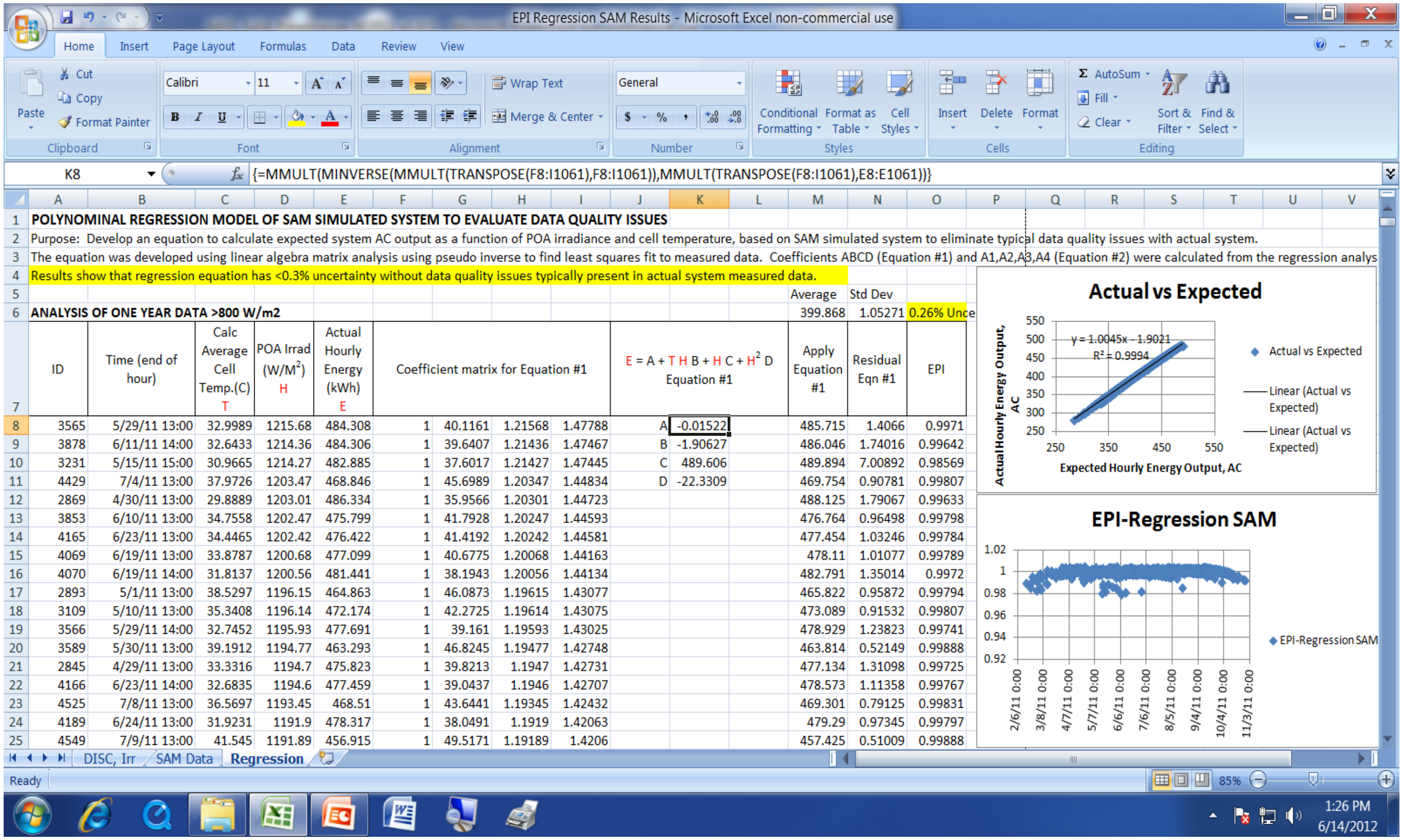
SAM results for modelled 600kW system with actual weather data

SUMIF FUNCTION:

| AC Power (kWh), Monthly from SAM | Hour | Day | Expected System Output (kWh) From SAM | SAM AC Output nonzero | Incident Total POA (kW/m2) From SAM | Incident Total POA (W/m2) | Incident Radiation (kWh) From SAM | Cell Hourly Temperature ( C ) From SAM | Actual System Output (kWh) | Day | Daily Actual kWh AC | Daily Expected kWh AC | EPI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 36061.9 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 315.9329 | 280.3982 | 1.126729 |
| 46792 | 2 | 1 | -0.13108 | 0 | 0 | 0 | 0 | 6 | 0 | 2 | 430.5748 | 346.1431 | 1.243921 |
| 56134 | 3 | 1 | -0.13108 | 0 | 0 | 0 | 0 | 5.5 | 0 | 3 | 1014.078 | 948.5689 | 1.069061 |
| 89474.7 | 4 | 1 | -0.13108 | 0 | 0 | 0 | 0 | 4 | 0 | 4 | 1392.243 | 1379.152 | 1.009492 |
| 101346 | 5 | 1 | -0.13108 | 0 | 0 | 0 | 0 | 3 | 0 | 5 | 1343.986 | 1404.672 | 0.956797 |
| 106309 | 6 | 1 | -0.13108 | 0 | 0 | 0 | 0 | 2.5 | 0 | 6 | 1280.172 | 1254.247 | 1.02067 |
| 117638 | 7 | 1 | -0.13108 | 0 | 0 | 0 | 0 | 2.5 | 0.08 | 7 | 615.9333 | 594.02 | 1.03689 |
| 105188 | 8 | 1 | 2.1934 | 2.1934 | 0.020889 | 20.8889 | 72.0133 | 3.54048 | 7.716667 | 8 | 551.3967 | 502.4821 | 1.097346 |
| 82431.3 | 9 | 1 | 29.3149 | 29.3149 | 0.074904 | 74.9042 | 258.228 | 6.43809 | 36.35 | 9 | 1025.821 | 964.2484 | 1.063855 |
| 53676.3 | 10 | 1 | 51.1864 | 51.1864 | 0.124594 | 124.594 | 429.531 | 12.9768 | 57.5 | 10 | 1308.351 | 1387.622 | 0.942873 |
| 41686.7 | 11 | 1 | 65.7219 | 65.7219 | 0.158559 | 158.559 | 546.623 | 14.1003 | 70.64286 | 11 | 377.4438 | 336.7424 | 1.120868 |
| 23056.1 | 12 | 1 | 33.1362 | 33.1362 | 0.085702 | 85.7017 | 295.452 | 13.7125 | 37.08333 | 12 | 1381.56 | 1366.975 | 1.010669 |
| | 13 | 1 | 45.4009 | 45.4009 | 0.114619 | 114.619 | 395.142 | 16.5207 | 51.55 | 13 | 501.4148 | 424.0853 | 1.182344 |
| | 14 | 1 | 29.192 | 29.192 | 0.077618 | 77.6176 | 267.583 | 16.9421 | 29.66 | 14 | 1069.255 | 1076.823 | 0.992972 |
| | 15 | 1 | 22.3394 | 22.3394 | 0.061528 | 61.5277 | 212.114 | 17.4332 | 23.85 | 15 | 1386.507 | 1356.834 | 1.021869 |



**Sample of Excel Spreadsheet to calculate Energy Performance Index (EPI-Regression)**



K8: {=MMULT(MINVERSE(MMULT(TRANSPOSE(F8:I1061),F8:I1061)),MMULT(TRANSPOSE(F8:I1061),E8:E1061))}

**POLYNOMINAL REGRESSION MODEL OF SAM SIMULATED SYSTEM TO EVALUATE DATA QUALITY ISSUES**

Purpose: Develop an equation to calculate expected system AC output as a function of POA irradiance and cell temperature, based on SAM simulated system to eliminate typical data quality issues with actual system.

The equation was developed using linear algebra matrix analysis using pseudo inverse to find least squares fit to measured data. Coefficients ABCD (Equation #1) and A1,A2,A3,A4 (Equation #2) were calculated from the regression analys

Results show that regression equation has <0.3% uncertainty without data quality issues typically present in actual system measured data.

**ANALYSIS OF ONE YEAR DATA >800 W/m2**

| ID | Time (end of hour) | Calc Average Cell Temp.(C) T | POA Irrad ($W/M^2$) H | Actual Hourly Energy (kWh) E | Coefficient matrix for Equation #1 | | | | $E = A + T H B + H C + H^2 D$ Equation #1 | | Apply Equation #1 | Residual Eqn #1 | EPI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Average | Std Dev | |
| | | | | | | | | | | | 399.868 | 1.05271 | 0.26% Unce |
| 3565 | 5/29/11 13:00 | 32.9989 | 1215.68 | 484.308 | 1 | 40.1161 | 1.21568 | 1.47788 | A | -0.01522 | 485.715 | 1.4066 | 0.9971 |
| 3878 | 6/11/11 14:00 | 32.6433 | 1214.36 | 484.306 | 1 | 39.6407 | 1.21436 | 1.47467 | B | -1.90627 | 486.046 | 1.74016 | 0.99642 |
| 3231 | 5/15/11 15:00 | 30.9665 | 1214.27 | 482.885 | 1 | 37.6017 | 1.21427 | 1.47445 | C | 489.606 | 489.894 | 7.00892 | 0.98569 |
| 4429 | 7/4/11 13:00 | 37.9726 | 1203.47 | 468.846 | 1 | 45.6989 | 1.20347 | 1.44834 | D | -22.3309 | 469.754 | 0.90781 | 0.99807 |
| 2869 | 4/30/11 13:00 | 29.8889 | 1203.01 | 486.334 | 1 | 35.9566 | 1.20301 | 1.44723 | | | 488.125 | 1.79067 | 0.99633 |
| 3853 | 6/10/11 13:00 | 34.7558 | 1202.47 | 475.799 | 1 | 41.7928 | 1.20247 | 1.44593 | | | 476.764 | 0.96498 | 0.99798 |
| 4165 | 6/23/11 13:00 | 34.4465 | 1202.42 | 476.422 | 1 | 41.4192 | 1.20242 | 1.44581 | | | 477.454 | 1.03246 | 0.99784 |
| 4069 | 6/19/11 13:00 | 33.8787 | 1200.68 | 477.099 | 1 | 40.6775 | 1.20068 | 1.44163 | | | 478.11 | 1.01077 | 0.99789 |
| 4070 | 6/19/11 14:00 | 31.8137 | 1200.56 | 481.441 | 1 | 38.1943 | 1.20056 | 1.44134 | | | 482.791 | 1.35014 | 0.9972 |
| 2893 | 5/1/11 13:00 | 38.5297 | 1196.15 | 464.863 | 1 | 46.0873 | 1.19615 | 1.43077 | | | 465.822 | 0.95872 | 0.99794 |
| 3109 | 5/10/11 13:00 | 35.3408 | 1196.14 | 472.174 | 1 | 42.2725 | 1.19614 | 1.43075 | | | 473.089 | 0.91532 | 0.99807 |
| 3566 | 5/29/11 14:00 | 32.7452 | 1195.93 | 477.691 | 1 | 39.161 | 1.19593 | 1.43025 | | | 478.929 | 1.23823 | 0.99741 |
| 3589 | 5/30/11 13:00 | 39.1912 | 1194.77 | 463.293 | 1 | 46.8245 | 1.19477 | 1.42748 | | | 463.814 | 0.52149 | 0.99888 |
| 2845 | 4/29/11 13:00 | 33.3316 | 1194.7 | 475.823 | 1 | 39.8213 | 1.1947 | 1.42731 | | | 477.134 | 1.31098 | 0.99725 |
| 4166 | 6/23/11 14:00 | 32.6835 | 1194.6 | 477.459 | 1 | 39.0437 | 1.1946 | 1.42707 | | | 478.573 | 1.11358 | 0.99767 |
| 4525 | 7/8/11 13:00 | 36.5697 | 1193.45 | 468.51 | 1 | 43.6441 | 1.19345 | 1.42432 | | | 469.301 | 0.79125 | 0.99831 |
| 4189 | 6/24/11 13:00 | 31.9231 | 1191.9 | 478.317 | 1 | 38.0491 | 1.1919 | 1.42063 | | | 479.29 | 0.97345 | 0.99797 |
| 4549 | 7/9/11 13:00 | 41.545 | 1191.89 | 456.915 | 1 | 49.5171 | 1.19189 | 1.4206 | | | 457.425 | 0.51009 | 0.99888 |