Understanding Modeling Errors for Module Models Using Residual Analysis and Application to the Results of the Model Intercomparison

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Goal

• Examine selected participant model results using residual analysis
  – Each participant will be given a personalized model validation report (hope to have this available within a month of the meeting’s conclusion)

• Models used as examples:
  – Sandia PV Array Performance Model
  – PVSyst
  – 5-Par Model
  – PVWatts
What Can Be Learned? (Caveats)

• Residual analysis examines both model and input parameters as a set.
  – Non random residuals can reflect problems with the model and/or problems with the input parameters.

• Used iteratively, residual analysis is a powerful tool for model development and validation.

• The examples shown here are meant as an example of the approach only.
  – Do not generalize these results
  – They apply to the specific system and installation
  – When patterns are repeatable with multiple systems, generalizations may be appropriate.
Total Measured Energy = 1932830 Whr
Total Modeled Energy = 1875467 Whr
Percent Energy Difference Before Derate = -2.9678%
Derate1 (minimize Sum LSE) = -1.7682%
Derate2 (Sum of Residuals = 0) = -3.0586%
Distribution of Residuals (SAPM)

Probability Plot of Daytime Residuals

Histogram of Daytime Residuals

Residual Run Plot
Slight correlation in 1-hr lag plot suggests residuals are autocorrelated at 1-hour. This pattern indicates a systematic bias associated with time in the model. Since it disappears at 6 hours, it is probably related to a diurnal process. Interesting but not all that informative because nearly every variable is diurnally-controlled.
SAPM by Hour

Difference Between Modeled and Measured AC Energy by Hour

Box Plot of Power Differences per Hour
SAPM by Month

Difference Between Modeled and Measured Energy by Month

Box Plot of Power Differences per Month
SAPM by GHI

Difference Between Modeled and Measured Energy by Irradiance

Box Plot of Hourly Power Differences per Irradiance Bin
SAPM by AOI

Difference Between Modeled and Measured Energy by Angle of Incidence

Box Plot of Hourly Power Differences per Angle of Incidence Bin
5-Par Model

Measured vs. Modeled DC Power

Measured vs. Modeled DC Power with Derate2

Model Residual and Irradiance with Time for 8-Day Example Period

Total Measured Energy = 1932830 Whr
Total Modeled Energy = 1952765 Whr
Percent Energy Difference Before Derate = 1.0314%
Derate1 (minimize Sum LSE) = 1.115%
Derate2 (Sum of Residuals = 0) = 1.0209%
Distribution of Residuals (5-Par)

**Probability Plot of Daytime Residuals**

- X-axis: Day-Time Residual [Whr]
- Y-axis: Probability

**Histogram of Daytime Residuals**

- X-axis: Day-Time Residual [Whr]
- Y-axis: Frequency

**Root Mean Square Error = 29.9768 Whr**

**Mean Bias Error (derated) = 2.4074 Whr**

**Correlation Coefficient = 0.99775**
5-Par by Month

Difference Between Modeled and Measured Energy by Month

Box Plot of Power Differences per Month
5-Par by Temperature

Difference Between Modeled and Measured Energy by Ambient Temperature

Box Plot of Hourly Power Differences per Ambient Temperature Bin
5-Par by GHI

Difference Between Modeled and Measured Energy by Irradiance

Box Plot of Hourly Power Differences per Irradiance Bin
PVWatts(a) Model

Measured vs. Modeled DC Power

- Measured vs. Modeled DC Power with Derate2

Model Residual and Irradiance with Time for 8-Day Example Period

Total Measured Energy = 1932830 Whr
Total Modeled Energy = 1924835 Whr
Percent Energy Difference Before Derate = -0.41365%
Derate1 (minimize Sum LSE) = -0.84158%
Derate2 (Sum of Residuals = 0) = -0.41537%
PV Watts Model

Measured vs. Modeled DC Power

Measured vs. Modeled DC Power with Derate 2

Model Residual and Irradiance with Time for 8-Day Example Period

Total Measured Energy = 1932830 Whr
Total Modeled Energy = 1932876 Whr
Percent Energy Difference Before Derate = 0.0023865%
Derate 1 (minimize Sum LSE) = 0.70584%
Derate 2 (Sum of Residuals = 0) = 0.0023865%
Distribution of Residuals (PVWatts)

Probability Plot of Daytime Residuals

Histogram of Daytime Residuals

Root Mean Square Error = 20.9807 Whr
Mean Bias Error (derated) = -1.8025 Whr
Correlation Coefficient = 0.999

Residual Run Plot
PV Watts by Month

Difference Between Modeled and Measured Energy by Month

Box Plot of Power Differences per Month
PV Watts (a) by Temperature

Difference Between Modeled and Measured Energy by Ambient Temperature

Box Plot of Hourly Power Differences per Ambient Temperature Bin
PVWatts(b) by Temperature

Difference Between Modeled and Measured Energy by Ambient Temperature

Box Plot of Hourly Power Differences per Ambient Temperature Bin
PVWatts by GHI

Difference Between Modeled and Measured Energy by Irradiance

Box Plot of Hourly Power Differences per Irradiance Bin
Conclusions

• For the system examined, several models exhibited correlation between power residuals and temperature.
  – SAPM, PVsyst, and 5-Par models overpredict power at low temperatures (below 20 C) and underpredict at high temperatures (above 20 C)
  – This might suggest the temperature coefficient is too large?
  – PVWatts did not exhibit this pattern (but not all PVWatts model runs are identical)

• Residual Analysis provides important information that can be used for model refinement and model validation.