Minimizing Variation in Outdoor CPV Power Ratings

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Outline

• NREL CPV testbed and its use in examining outdoor CPV power ratings

• IEC 62670, outdoor CPV power ratings, motivations and challenges

• ASTM E2527, a method for rating CPV module power outdoors

• Month to month variation in power ratings using ASTM method

• Attempts to improve the ASTM regression or develop an alternative

• Results to modifications to regression filtering and additional approaches

• Conclusions/Recommendations
NREL CPV Testbed & Outdoor Power Ratings

- 2-axis tracker (+/-0.15 degree sun pointing error)
- Data acquisition provides module peak power tracking
- IV sweeps, 5 minute intervals
- DNI, GNI, wind speed, Tambient, Tmodule, and tracking error are measured
- Spectral data (SRRL)
- A unique data set of various CPV lens and module architectures
- Understanding CPV performance variation and supporting standards development
IEC 62670 and Outdoor CPV Power Ratings

Concentrator Standard Operating Condition (CSOC)
Tambient (20°C), DNI (900 W/m²), Wind speed (2 m/s) G173/AM 1.5 Spectrum

**STC-based measurements**
(T_{module} = 25 °C, DNI = 850 W-m²)

**SOC-based measurements**
(T_{ambient} = 20 °C, DNI = 900 W-m², wind speed = 2 m-s⁻¹)
Outdoor Power Ratings, WHY? HOW?

• A need to characterize module thermal performance
  • Flat plate, ~25C above ambient at 1sun
  • CPV, ?? Degrees C above ambient
    • 300-1300X concentration varies the heat dissipation needed
    • Not all heat sinks are created equal
  • Outdoor temperatures → module/lens expansion/contraction
    • Does this impact performance?

• A need to characterize module spectral performance
  • It is well know that performance of triple junction cells is dependent on spectrum but how does this play out in a module and can it be quantified without specialized data

• If the above is the WHY? What about HOW?
  • IEC62670 describes CSOC but has not established a clear method
  • Method must provide consistent results from lab to lab (<5% variation)
  • Method must work for various CPV architectures without specialized information from the manufacturer
• Measure module maximum power and meteorological parameters
• Apply the following regression to the data set, reject if standard error too high
  \[ P_{\text{max}} = \text{DNI}(a_1 + a_2 \text{DNI} + a_3 T_{\text{ambient}} + a_4 \text{Wind}) \]
  Report \( P_{\text{max}} @ (T_{\text{amb}} = 20\degree C, W = 4\text{m/s}, \text{DNI} = 850\text{W/m}^2) \)

• In this presentation CSOC or \((T_{\text{amb}} = 20\degree C, W = 2\text{m/s}, \text{DNI} = 900\text{W/m}^2)\) is used

• ASTM calls for the following restrictions on data for the regression
  • 10C <= \( T_{\text{amb}} \) <= 30C  
  • \( \text{DNI} \geq 750\text{W/m}^2 \)  
  • The average wind speed for the 5 minutes prior to a measurement is <= 5m/s  
  • Reject if visible clouds are within 10 degrees of sun

• Cloud restriction is approximated by rejecting a 10 minute DNI deviation >2%

• Other restrictions applied above and beyond ASTM criteria
  • Reject if Diffuse radiation is > 140W/m²
  • Reject if Tracking error is > 0.15 degrees
How much will the Rated Power for a CPV module if this procedure is applied over multiple months??

The answer not only depends on outdoor conditions but also on the module technology!
The graph shows the % variation in a modules monthly power rating as compared to lowest monthly rating over the 2 years.

For example, CPV1 had its lowest rating in month 12, while the rating in month 11 was almost 6% greater.

Note that CPV2 appears to be degrading in the 2nd year.

WHY so much variation with the regression results?

• AM neglected?
• Lens performance neglected?
• Moisture in modules, soiling, alignment varies?
• Regression gives too much weight to outliers?
Can other variables improve the regression?

Efficiency correlates with the following:
- \( T_{ambient} \)
- \( T_{module} \)
- \( DNI \) and \( GNI \)
- \( AM \)

Efficiency (after temp correction) correlates with:
- \( DNI \) and \( GNI \)
- \( AM \)
- Precipitable water vapor (moderate to weak)
- Turbidity (weak)
- In some cases there is positive correlation with \( T_{ambient} \), consistent with lenses that go out of alignment at low temperatures
Regressions examined

• New regressions were tested on yearly data sets using linear and nonlinear combinations of the variables on the previous slide.

• The “best fit” for yearly data, judged by lowest standard error and the Tstat on the included variables, was: \( \text{Power}_{\text{temp corrected}} = a_1 \text{DNI} + a_2 \text{DNI}^2 + a_3 \text{AM} + a_4 \text{WaterVapor} \)

• The existing ASTM regression with AM included also performed well.

• When the “best fit” and the modified ASTM regression were tested on monthly data the monthly variation in power became worse. (Graphs show one reason why.)
• The graphs on the previous slide show how monthly regressions can fail to accurately model spectral performance variations

• As an alternative, can spectral filtering (specifically limiting airmass from 1.3 to 1.7) reduce variation in the ASTM power rating?

• As another alternative, would variation be reduced if monthly data is corrected for temperature, airmass, and precipitable water vapor before running a simple regression using DNI and DNI^2?

  • Only accept airmass values less than 2
  • Assume efficiency increases 1% absolute per unit of AM
  • Assume efficiency increases 0.6% per cm of PWV
  • Exclude any data points that have a PWV below 0.4cm
  • Exclude ambient temperatures below 15C
Regression modification results CPV1

- The tight filter on airmass eliminates Dec, Jan but there is still ~9% variation.
- The simple regression with corrected data reduces variation to ~4%.

**CPV1 (filtering and regression changes)**

- **ASTM**
- **ASTM (1.3-1.7AM)**
- **TEMP & SPECTRAL correction**

% change in power rating vs Months 0=Jan2009
Regression modification results CPV2

- Airmass filtering again removes Dec, Jan but variation is still high
- Ignoring 2010 degradation, corrected data has a variation of ~6%

![Diagram showing CPV2 (filtering and regression changes)]
Regression modification results CPV3

- Again airmass filtering removes Dec, Jan with only a slight reduction in variation
- Corrected data still has a variation of 6.5%, June 2009 looks questionable
Conclusions and Recommendations

• Data sets for outdoor CPV power ratings should not include data points with a geometric airmass greater than 2
  • Performance begins to decline at airmasses greater than 2 or 3
  • This does little to help predict performance at AM1.5

• Ambient temperatures below 15 C have the potential to skew power ratings due to lens misalignment at low temperatures (true for some modules)

• Monthly regressions as a method for calculating CPV outdoor power ratings show too much variation (At least for data collected in Golden Colorado)

• Correcting outdoor data for temperature and spectral variation shows some potential to reduce month-to-month variation in outdoor CPV power ratings.