Minimizing Variation in Outdoor CPV Power Ratings

CPV-7, Las Vegas, Nevada

Matthew Muller

4/4/2011

NREL/PR-5200-51370

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Outline

- An overview of 6 months of CPV and tracked PV power data
- Analyze NREL's data set in an attempt to answer 3 questions:
  - 1) How much variation is actually seen in outdoor power measurements if tight filtering is placed on meteorological and spectral conditions?
  - 2) How much variation is seen in monthly power ratings using a regression based approach?
  - 3) Are there alternative methods to regression that result in less variation?
- 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 available

- A unique data set of various CPV lens and module architectures
- Understanding CPV performance variation and supporting standards development

IEC 62670, Outdoor or Indoor CPV Power Ratings

Concentrator Standard Test Conditions
(CSTC)

Tcell = 25C
DNI = 900 W/m^2
G173/AM 1.5

Cell Temperature Fixed

Temperature Coefficients

Concentrator Standard Operating Conditions
(CSOC)

Tambient = 20C
DNI = 900 W/m^2
Wind Speed 2m/s
G173/AM 1.5

Calculate Cell Temperature

Power Ratings at CSOC but How?

- IEC62670 describes CSOC but has not established a clear method
- ASTM-2527 regression
- ISFOC translation
- Consider other approaches
- Goal of work is to find the method that minimizes variation

Power Ratings, Autonomously Collected MONTHLY Data

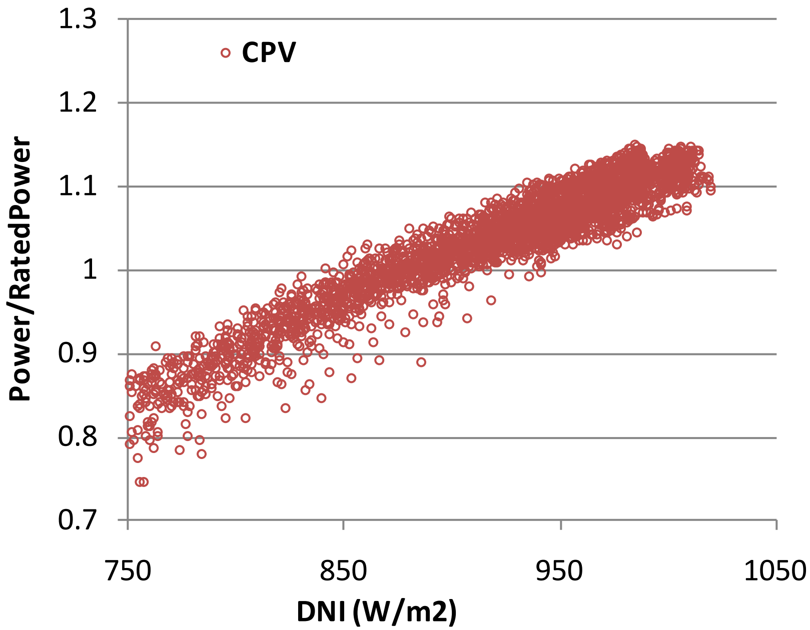
- Filtering is applied to all data (based on ASTM-2527 data restrictions)

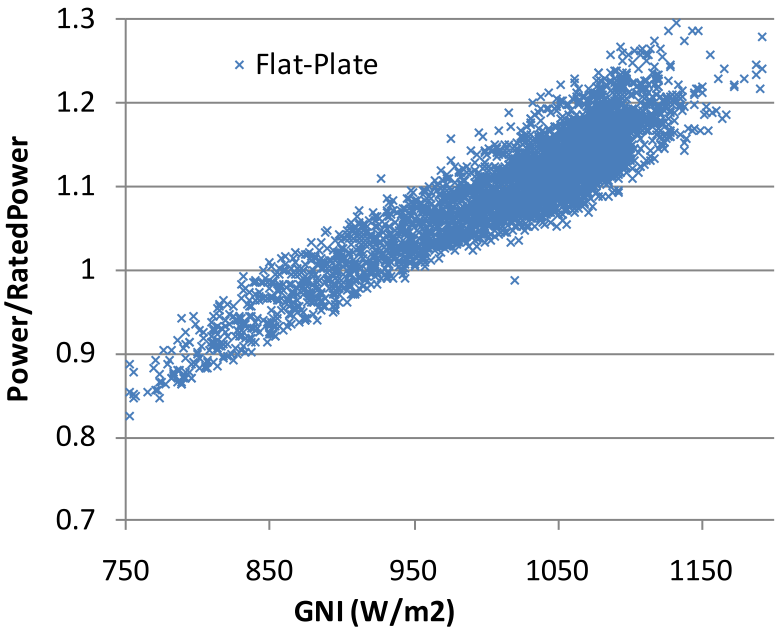
- ASTM-2527 calls for the following:
  - 10C <= T_{amb} <= 30C
  - DNI >= 750W/m^2
  - The average wind speed for the 5 minutes prior to a measurement is <= 5m/s
  - Reject if visible clouds are within 10 degrees of sun
- Cloud restriction approximated by rejecting a 10 minute DNI deviation>2%

- Other restrictions applied above and beyond ASTM criteria
  - Reject if Diffuse radiation is > 140W/m^2
  - Reject if Tracking error is > 0.15 degrees

6 Months of Data with Basic Filtering in Place

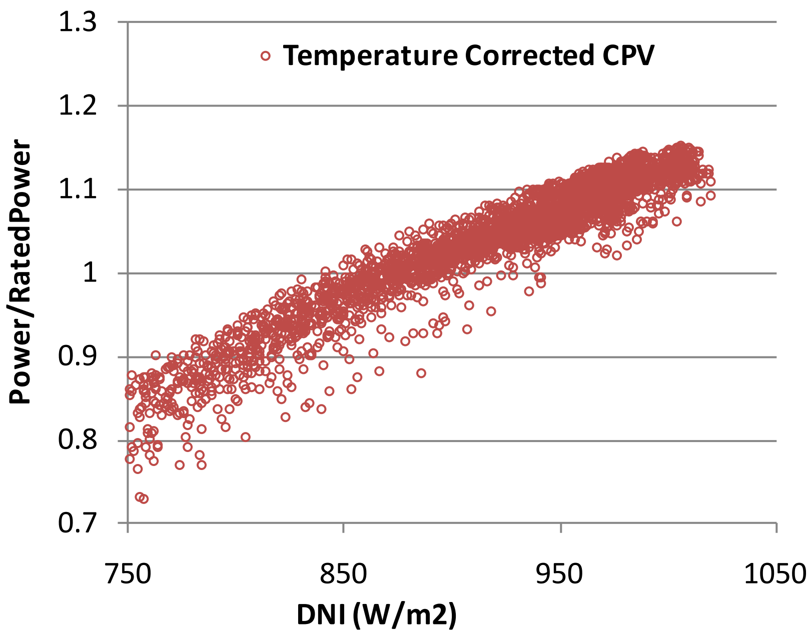
- The plots below show about a 10% variation in the power produced at a given DNI for both flat-plate and CPV for a July – December

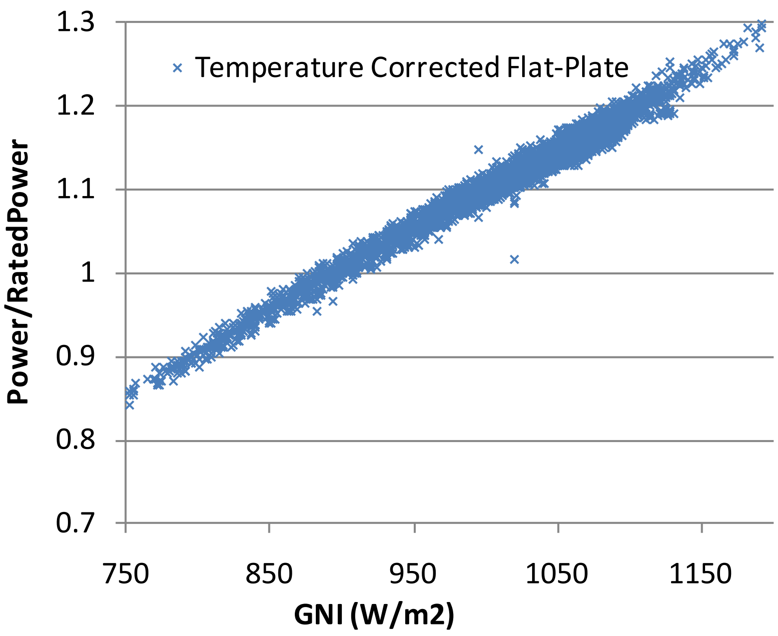




Same 6 Months of Data but Apply Temperature Correction

- The flat-plate variation is now < 5% while CPV variation decreased slightly at high DNI, increased for the lowest DNI and a bend is now more prominent at 850W/m^2

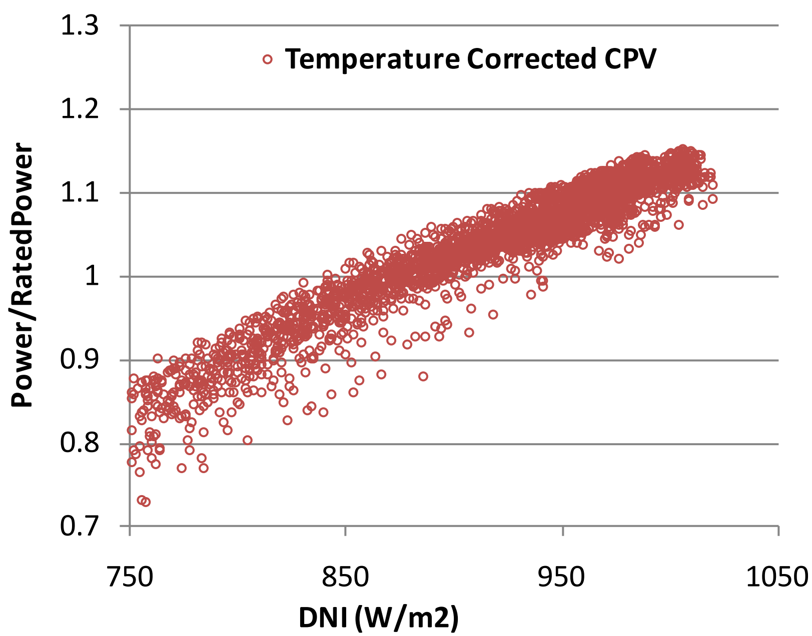


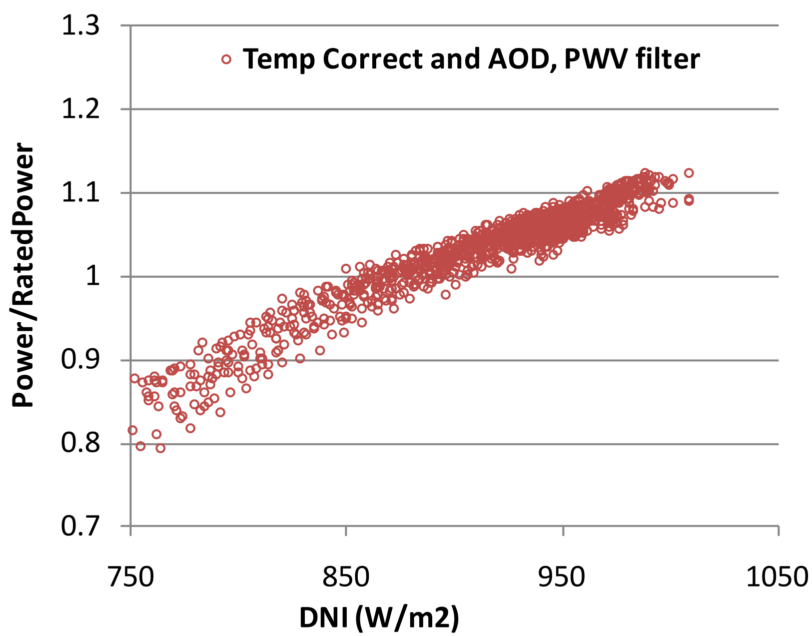


Apply Spectral Filtering in Combination with Temp Correction

- Filter the CPV data to only accept Precipitable Water Vapor (PWV) between 1-3 cm and Aerosol Optical Depth (AOD) between 0.06-0.135

- Now the variation for CPV is about 5%. Additional filtering was considered based on geometric airmass (AM). Excluding AM>2 removes almost all data below the bend or below 850 W/m^2



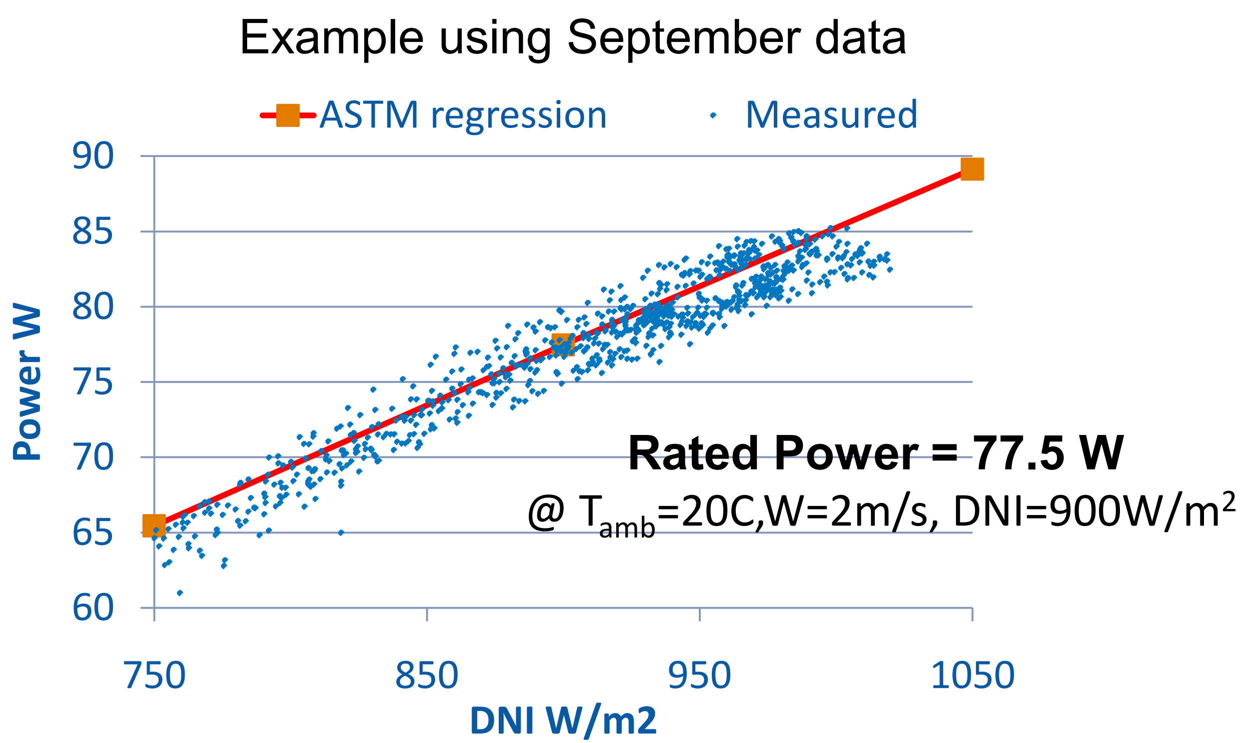


ASTM E2527 as an Example

- Apply the ASTM regression to the data set, reject if standard error > 3%

$$P_{max}=DNI(a_1+a_2DNI+a_3T_{ambient}+a_4Wind)$$

Report at CSOC (T_{amb}=20C,W=2m/s,DNI=900W/m^2)

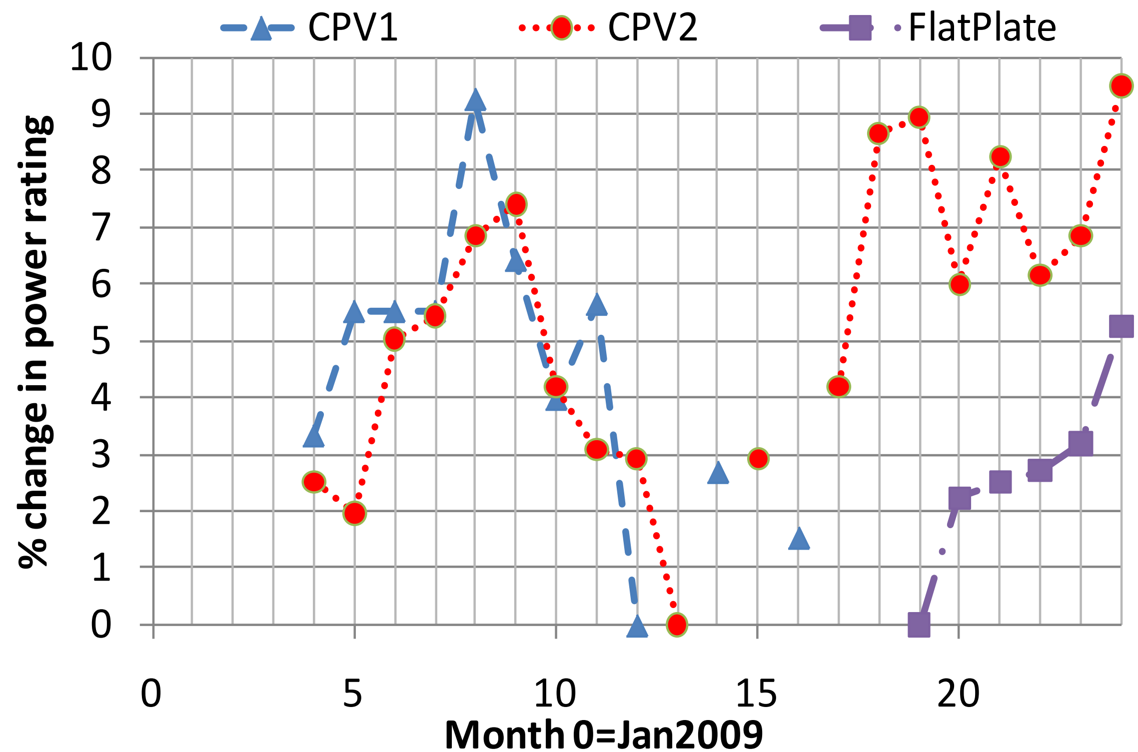


❑ **How much will these results vary if applied over multiple months??**

•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

•The ASTM power rating varies about 10% for CPV and 5% for flat-plate



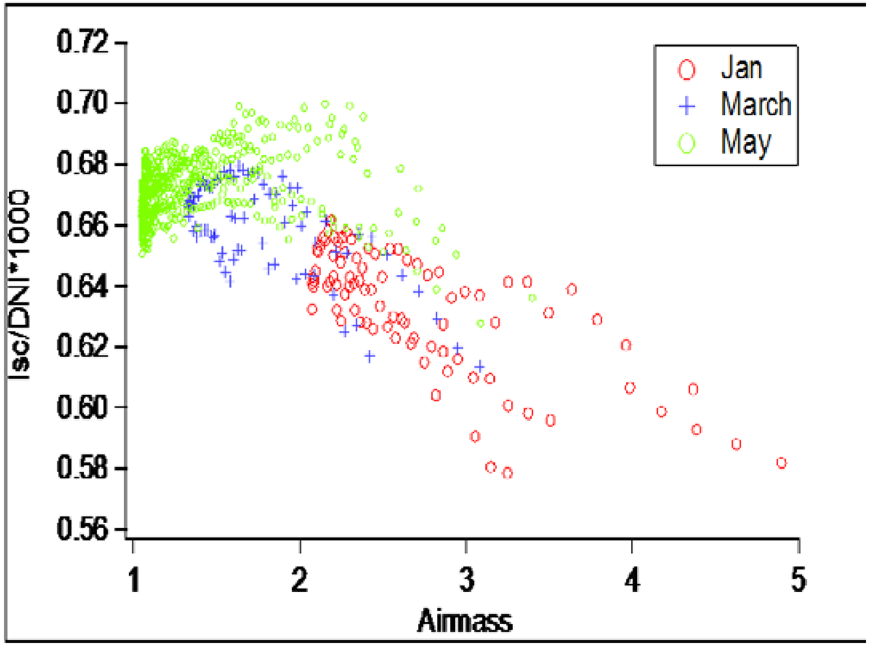
- CPV modules have their lowest ratings in the winter months
  - •(At NREL, December, January minimum AM is > 2, November, February minimum AM is > 1.7)
  - •Some modules show lens performance issues below 15C
- Even for flat-plate the regression coefficients don’t adequately model known performance variation

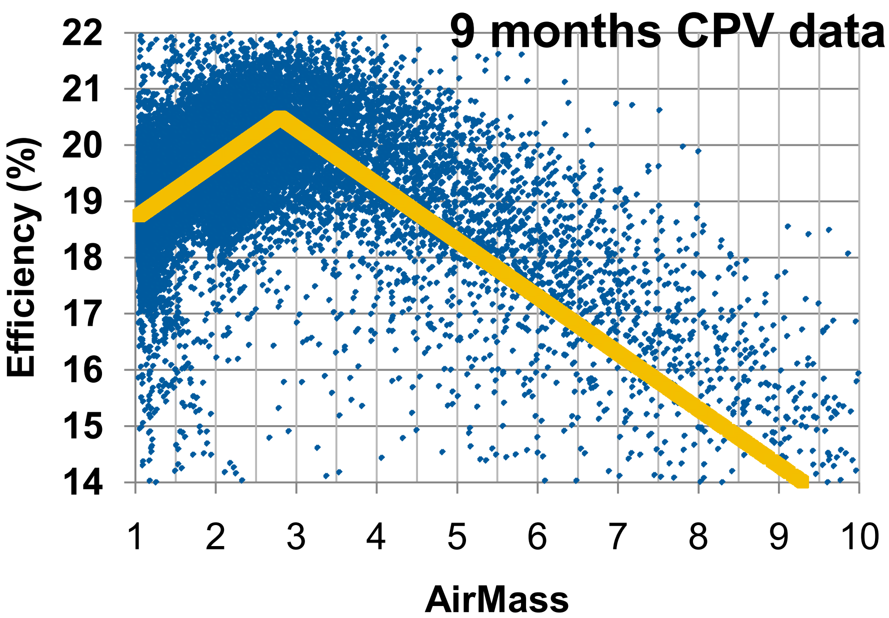
Exclude highly variable winter months in comparing Power Rating Methods

- Spectral filtering considered hereafter inadvertently removes some months leading to an unfair comparison between methods

- Excluding Nov-Feb, the ASTM variation reduces to 7.6% for CPV1 and 6.8% for CPV2

- All comparison hereafter exclude AirMass > 2 (Graphs below show why)





Approaches to Reducing Outdoor Power Rating Variation

- 1) Modify ASTM
  - ASTM1: added filtering $1.3 \leq AM \leq 1.7$
  - ASTM2: add AM term, $P_{max} = DNI(a_1 + a_2 DNI + a_3 T_{ambient} + a_4 Wind + a_5 AM)$

- 2) Build new regression from scratch considering all relevant parameters
  - The "best fit" on a year of data using statistical indicators

    $P_T = a_1 DNI + a_2 DNI^2 + a_3 AM + a_4 PWV$
  - The PWV term was not valid on a monthly basis
  - REGRESSION1: $P_T = a_1 DNI + a_2 DNI^2 + a_3 AM$

- 3) Apply more translation/correction to the data and less regression
  - REGRESSION2: $P_{T,AM,PWV} = a_1 DNI + a_2 DNI^2$
    - $P_{T,AM,PWV}$ is a translation to CSOC cell temp, airmass of 1.5, PWV of 1.4cm
    - assumes module efficiency increases 1% per AM unit and 0.6% per PWV unit
  - ISFOC: Power translation used by ISFOC
  - ISFOC1: translation with added filtering $1.3 \leq AM \leq 1.7$
  - ISFOC2: translation with above correction for AM and PWV

Comparison of Power Rating Methods

Maximum Monthly Variation in Power Rating		
Method	*CPV1*	*CPV2*
ASTM 2527	7.6%	6.8%
"ASTM1"	8.7%	8.1%
"ASTM2"	8.0%	7.3%
"Regression1"	5.4%	6.7%
"Regression2"	4.2%	5.7%
"ISFOC"	6.9%	6.2%
"ISFOC1"	6.2%	6.1%
"ISFOC2"	2.9%	5.5%

- Attempts to improve on ASTM-2527 failed as variation increased
- "Regression1" showed minor improvement, AM coefficient was positive in some months, negative in others
- "Regression2", translation for all but DNI shows even more improvement
- Both "ISFOC" and "ISFOC1" show some improvement of ASTM-2527 but are not as good as "Regression2 which include correction for AM and PWV
- The variation is the lowest for both modules when "ISFOC2" is used, ISFOC with AM, PWV corrections

Conclusions and Recommendations

- Applying filtering to a year of CPV data showed that power variation could be reduced to ~5% for a given DNI

- Regression based approaches faired poorly in attempts to minimize the variation in a monthly power rating
- Translation/Correction based approaches worked best with maximum monthly variation ranging from 2.9-5.7%

General suggestions/recommendations:

1) Exclude AM >2, PWV <0.5 from power rating data.
2) Exclude months that AM 1.5 does not occur.
3) PWV and AM should not be ignored.
4) Default to translation over regression approach.
5) Do not ignore temperature effects on lenses.

Future Work

- Apply translation based approaches to more modules and over longer time periods in order to confirm the results presented here.

- Efforts should be made to refine corrections for AM and PWV or to apply alternate corrections as data becomes available that improves ability to characterize the spectral conditions.

- Finally, corrections for variations in lens performance should be considered.

Thanks!

Questions?