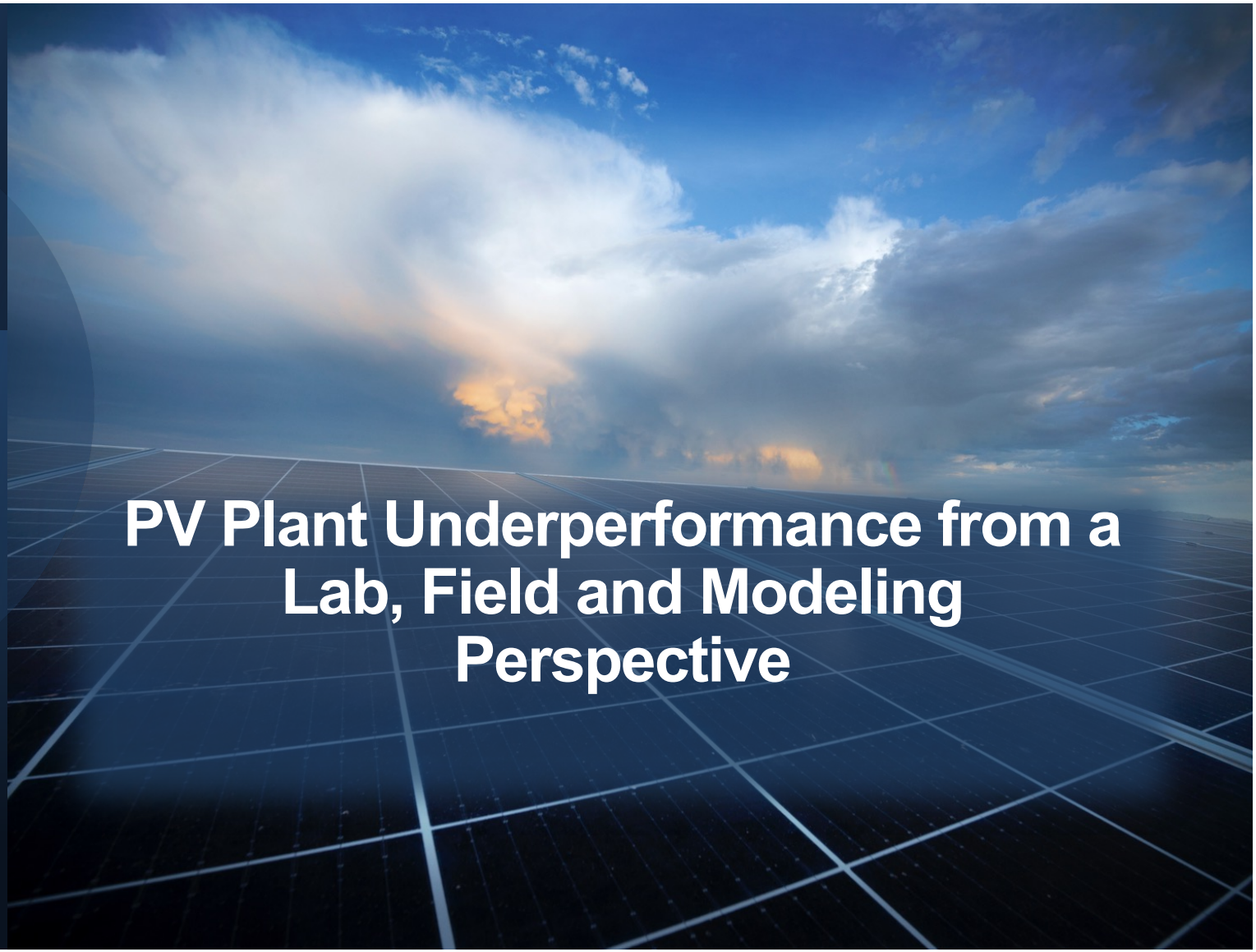
CFV Labs
Albuquerque, NM



PV Plant Underperformance from a Lab, Field and Modeling Perspective

Jim Crimmins, CEO
2023-05-09

CFV Labs

CFV Labs

PVPerformance
MODELING COLLABORATIVE

- PV Test and Research Lab in Albuquerque, NM.
- Co-Sponsor of PVPMC since 2018.

CFV Labs

Let's Read The News on Underperformance

US solar assets underperforming, says kWh Analytics

The 2022 Solar Generation Index report shows that solar asset performance is falling below estimates.

NEWS

Built solar assets are 'chronically underperforming' and modules degrading faster than expected, research finds

NEWS

PV module underperformance is costing US$2.5 billion globally, says Raptor Maps

Sizing up shortfalls: Underperforming assets are plaguing the solar industry

Underperforming solar assets shade the entire industry. Here is how to fix it

CFV Labs

Should We Be Skeptical of These Underperformance Claims?

- **YES - BE SKEPTICAL**
  - Press outlets like provocative stories.
  - Bias is generally toward negative news rather than positive news.
  - Some organizations may have interests in making these claims.
- **NO – IT'S TRUE**
  - PV Power Plants are complicated entities – lots of things can go wrong – especially in times of extreme cost pressures and high supply chain and component technology volatility.

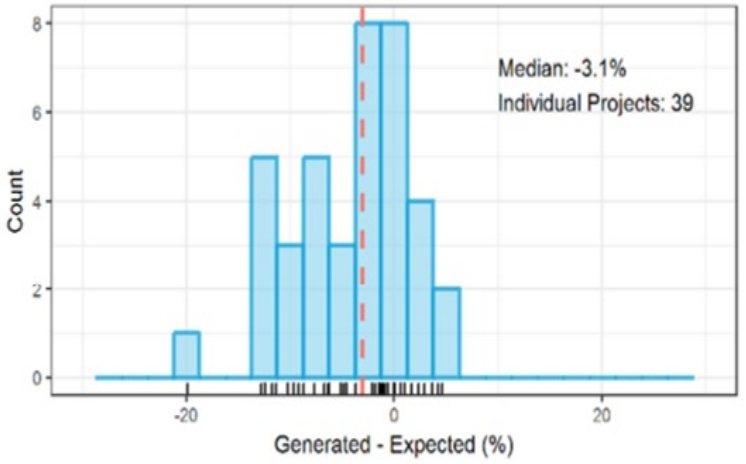


Fig. 1. Project-average validation results for solar energy assessments. Each project-year was adjusted for interannual variability by scaling production by the ratio of TGY to historical monthly insolation.

Figure from DNV via NREL Paper "Validation of Subhourly Clipping Loss Error Corrections "

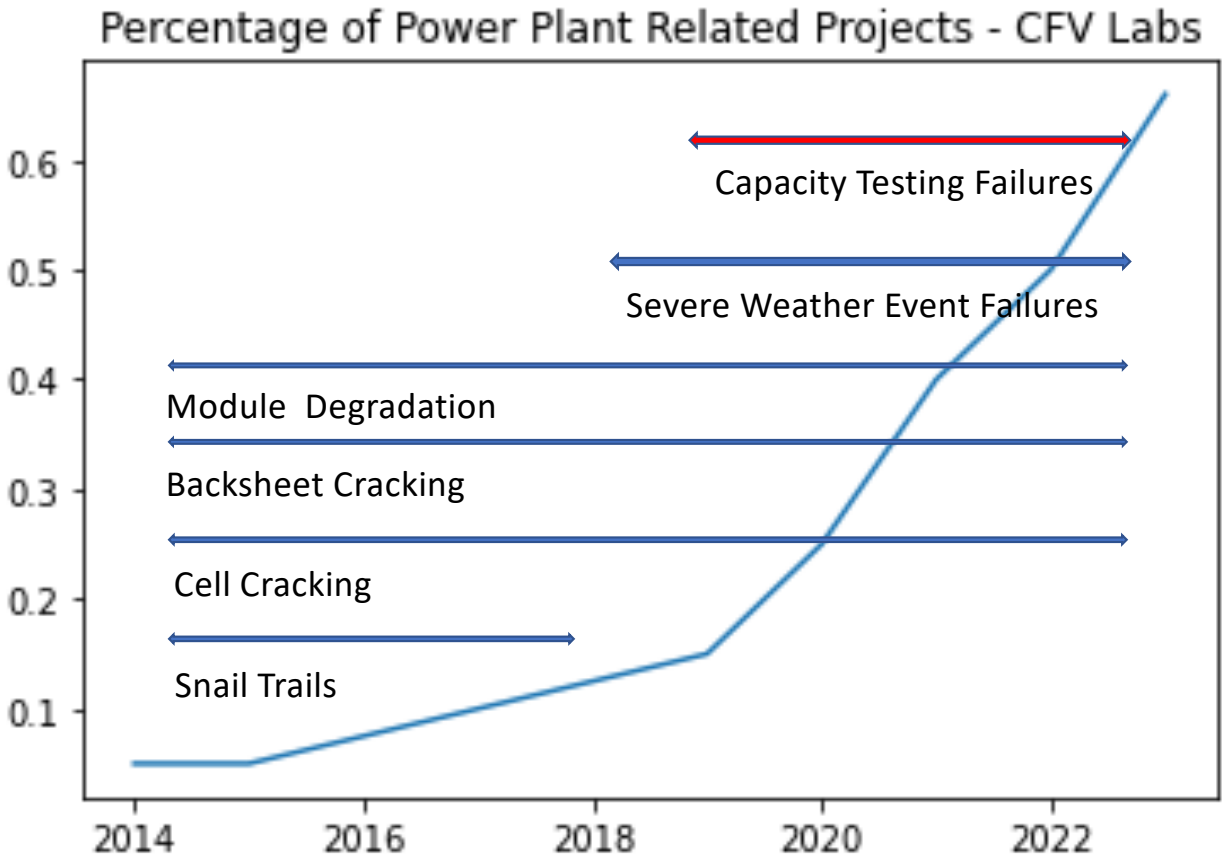
CFV Labs

Experience from CFV Labs:

Many more incoming plant performance requests.

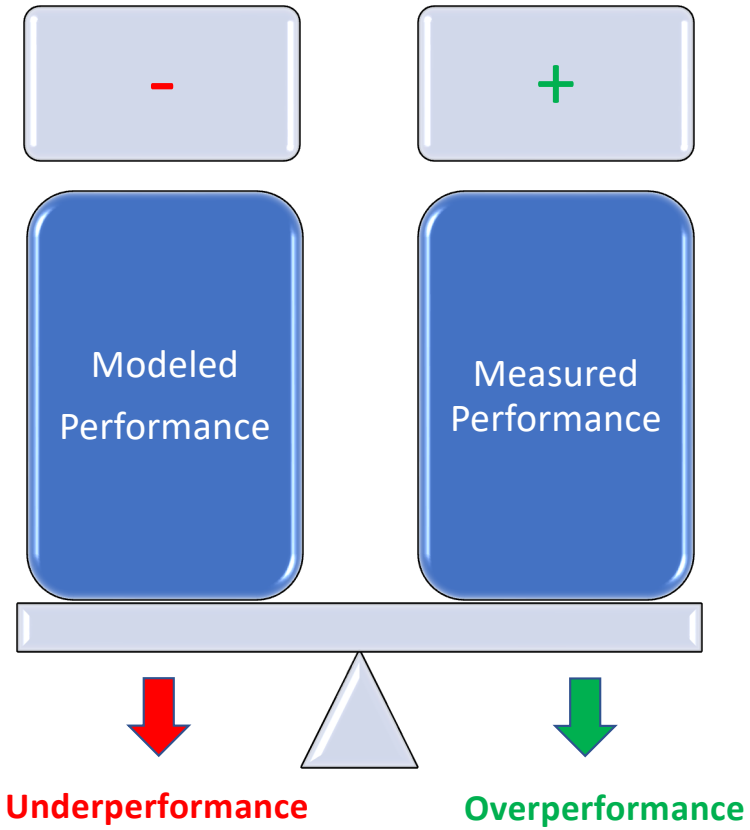
Some old failure modes. Some new issues.

CFV Labs



What Is Going On?
Underperformance is Always and Everywhere Relative

- **Models: PVSyst, SAM, Plant Predict, Solar Farmer, ASTM E2848/IEC 61724.**
- **Components: PAN Files, OND Files, Tracker parameters, etc.**
- **Weather Data: Real Time On-Site, Satellite, TMY, Long Term Historical Resource Data**



- **Measured: DC Side / AC Side Meter Performance Data.**
- **Components: Actual Component Performance**
- **Weather Data: Real Time On-Site**

CFV Labs

What is Going On?
Long Term Solar Resource Estimation – A Separate Issue

- Long term PV plant energy yield will depend on average long term solar irradiance at the site.
- This is a different issue than plant underperformance normalized to real time irradiance data.

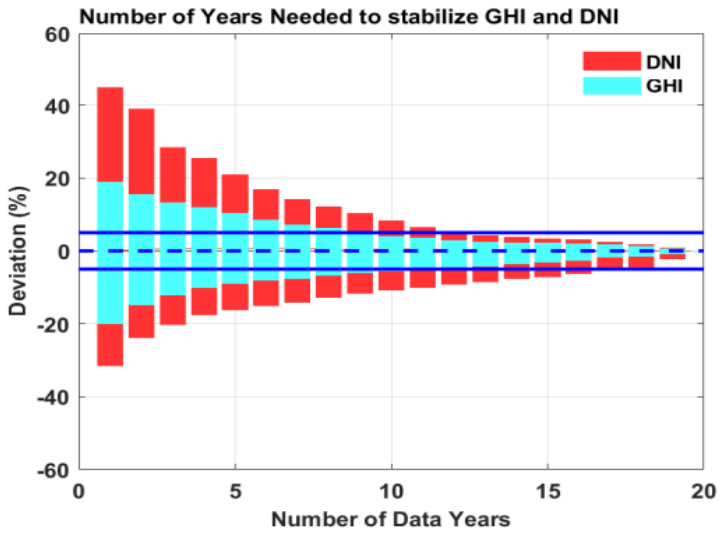


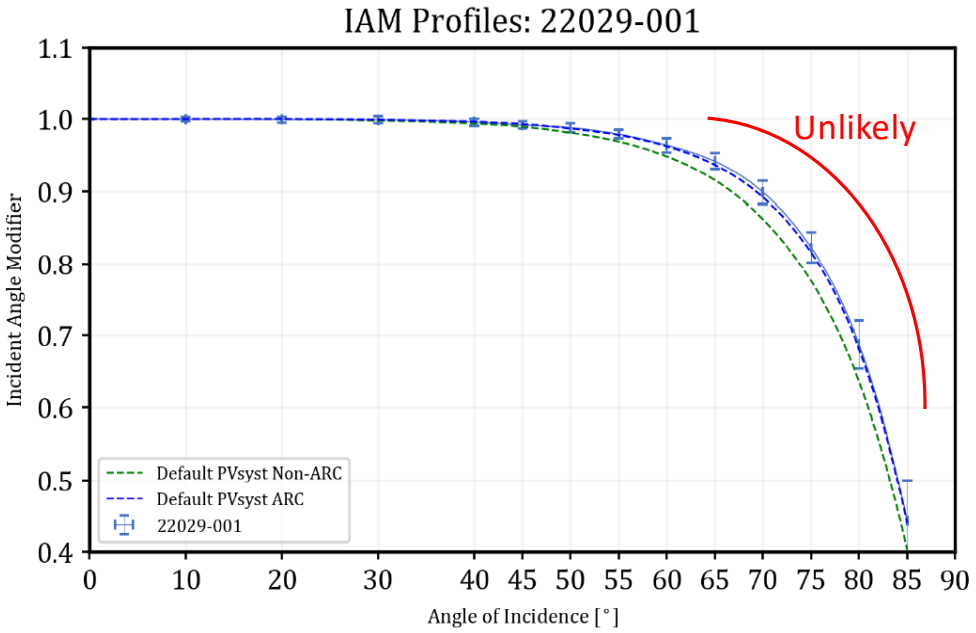
Figure 16. Number of years needed to stabilize GHI and DNI over the whole NSRDB domain. The two blue lines represent the ±5% range. A period of 20 years is assumed to represent the "true" climatological average.

CFV Labs

What is Going On?
Some Energy Model Inputs May Be Overestimating Performance

- **Manufacturer generated PAN files are not as reliable as third-party lab generated PAN files. Developers should be more invested in generating their own PAN files from modules sampled from the project supply.**

- **Reliable IAM measurements of production AR coatings used in PV modules will almost always resemble the PVSyst default ARC IAM profile. Any data implying significant outperformance of these Fresnel models is likely illusory.**



CFV Labs

What is Going On?
Models Using Hourly Data May Be Overestimating Performance

- Energy models using hourly data may overestimate performance by missing inverter clipping at sub-hourly frequencies.
- This is especially important for plants with high DC:AC ratios, and sites with highly variable irradiance on a sub-hourly time scale.
- The order of magnitude of this effect seems to be on the order of ~ 0.0%-3.0% depending on site parameters.
- There are several posters on this topic this year.

TABLE IV
RESULTS SUMMARY BY SYSTEM, AFTER FILTERING

System	Metric	Before Correction	After Correction	Change [%]
System A	Overall MBE	2.3%	1.8%	-0.5
System A	MBE (High VI)	10.7%	9.0%	-1.7
System A	MBE (Medium VI)	3.1%	2.2%	-0.9
System A	MBE (Low VI)	1.1%	0.8%	-0.3
System B	Overall MBE	3.6%	2.8%	-0.8
System B	MBE (High VI)	8.7%	5.9%	-2.8
System B	MBE (Medium VI)	4.4%	2.9%	-1.5
System B	MBE (Low VI)	2.8%	2.3%	-0.5

NREL Paper "Validation of Subhourly Clipping Loss Error Corrections ". Abhishek Parikh,1 Kirsten Perry,2 Kevin Anderson,2 William B. Hobbs,3 Rounak Kharait,1 and Mark A. Mikofski1

CFV Labs

What is Going On?
Soiling

- Soiling losses may be much larger than reported visual estimates from the field, or model estimates, even for newly built plants.
- Soiling can be highly variable across a power plant and multiple stations are needed.
- It is important to calibrate the soiling stations accurately.
- New innovations are coming with combinations of soiling measurements with module performance degradation.

CFV Labs

What Is Going On?
Modules Performing Below Nameplate

- It is very difficult to diagnose module degradation or underperformance from operating plant data due to issues like clipping, curtailment, etc. Although on-site string IV testing is possible, lab flash testing is the best option to accurately determine module health.
- We still see large projects that do not have independent flash data.
- A large fraction of the plant underperformance projects we are involved in will have modules flash 3%-4% under nameplate after less than 6 months in the field, so they are underperforming model LID estimates.

Halm A+/A+/A+ flasher at CFV Labs

CFV Labs

What is Going On?
Other Miscellaneous Issues

- Uneven terrain leading to tracker / module shading and underperformance.
  - Note these are usually older tracker designs as newer designs have both hardware and software means to mitigate this problem.
- Ground faults due to connector mating or design failures.
  - Can be a large performance issue if ground faults significant enough to trip breakers, fuses or inverter faults.
- Module breakage / Extreme Weather Events
  - Weaker module frames and glass are leading to increased glass breakage rates in the field and sometimes complete module collapse.
  - Glass breakage itself is not necessarily a large issue unless it causes wet leakage failures, ground faults, inverter tripping, hot-spotting, cell-cracking, etc.

CFV Labs

Typical Steps Taken in Diagnosing an Underperforming Plant

- Performance Data Review
- Model Parameter Review
- Thermographic Fly-over / Field EL Imaging / Field IV Curves
- Met Station Checks in Field
- Soiling Checks in Field / In Lab
- Module Performance Checks In Lab
- Ground Fault /Connector Checks in Field
- Inverter Availability and Performance Checks
- Tracker Availability and Performance Checks

It may be difficult to interpret field performance data due to clipping, curtailment, tracking algorithms, bifaciality issues, irradiance and temperature stability, etc.

CFV Labs

Module Performance Testing Recommendations for Power Plants

- Gather any existing flash test and EL data from manufacturer or third parties.
- Gather all serial number, module model number, BOM, date of manufacture and date of installation information that is available.
- Gather all plant performance data, thermographic or other field data and identify locations of particular concern.
- Develop a sampling plan of modules based on identification of potentially independent populations.
- Send to lab for visual inspection, EL imaging, flash testing.

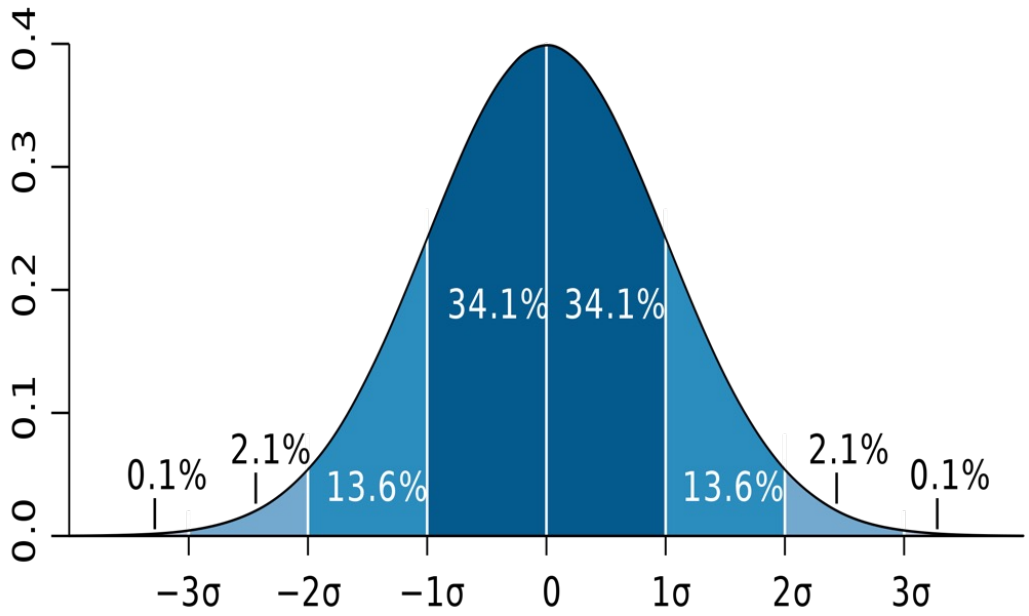
CFV Labs

How many modules to test?

Sampling from a single uniform distribution.

CFV Labs

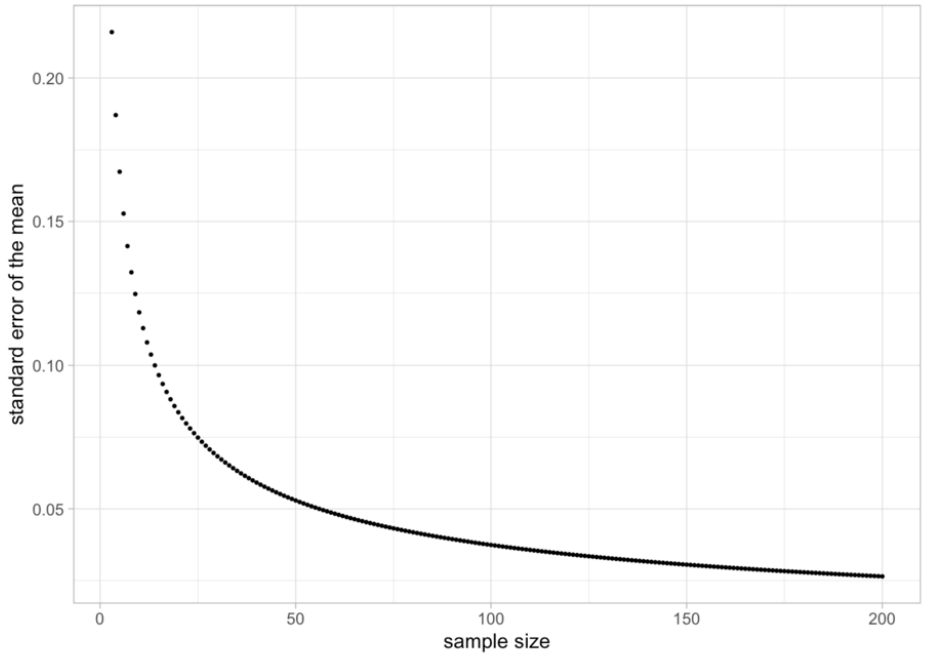
- For modules that display a normal ”bell-curve” distribution of a parameter of interest – like STC power – we don’t need a very large sample to get a good estimate of the mean, since when we choose samples they are much more likely to be in the center of the distribution:



We don't need a lot of samples to determine the mean relatively accurately. Maybe 20-40.

CFV Labs

- The error of the estimate of the mean for a normal distribution drops very quickly with sample size (1/sqrt(N)). Note that this error, and therefore required sampling, does not depend much on the population (project) size.



What sampling errors do we get for typical PV modules?

- Mean estimation errors drop with increased sample size, but slowly. Here we assume a standard deviation of module power of 2%, which is pretty typical.

Measured Mean (w)	Sample Size	95% Confidence (w)	95% Confidence (%)
450	20	[446,454]	+/- .88%
450	40	[447,453]	+/- .62%
450	80	[448,452]	+/- .44%
450	160	[449,451]	+/- .31%

- These errors also need to be evaluated against the flash testing errors for PV modules which are typically around +/-2.0%, measured in the same 95% confidence interval.

CFV Labs

For large PV Plants what are uniform populations?

Potential need to cross sample to capture different module sets.

CFV Labs

When sampling modules from the field for large projects identifying potentially different populations may matter more than sample size for estimating mean performance.

Longyangxia Dam Solar Park, China – 850MW

Sample Across:

- Module Manufacturer
- Module Models
- Module BOM – especially cell type or cell manufacturer.
- Module Factory
- Module Production Dates
- Location in Field

Conclusions and Recommendations

- PV Power Plant underperformance is a highly multidisciplinary topic.
- Because performance is measured against models, it is important to examine both sides of that difference equation.
- Many factors can affect both model output and performance in the field.
- Unclear if plant performance data alone can identify all issues easily.
- Develop a structured plan for lab and field testing even if time is short.
- **Bringing performance analysis groups together with field and lab testing assets sooner rather than later will usually make things go a bit better.**

CFV Labs

CFV Labs

Contact

Jim Crimmins

Email: jim.crimmins@cfvlabs.com
Phone Number: (505-998-0100)

CFV Labs
5600-A University Blvd.
Albuquerque, NM 87106

CFV Labs