A SYSTEM DEGRADATION STUDY OF 445 SYSTEMS USING YEAR-OVER-YEAR PERFORMANCE INDEX ANALYSIS

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INTRODUCTION

Year-Over-Year Performance Index Change Analysis is a powerful and practical technique for assessing the median degradation of a large fleet of systems

- **ROBUST:** Insensitive to noise and absolute accuracy errors, uses minimal data manipulation and filtering
- **PRACTICAL:** Requires only AC inverter data and essential met data
- **RELEVANT:** Uses data from a live, real-world fleet

A system level degradation study of 445 systems representing 3.2 million module-years of monitored data has been performed using this technique:

- 266 systems (86MW) using SunPower modules as old as 5.5 years ? show median degradation rate = -0.32% ± 0.05% (95% confidence) ? per year
- 179 systems (42MW) using non-SunPower modules (conventional ? front-contact) as old as 11.5 years show median degradation rate = ? -1.25% ± 0.05% (95% confidence) per year?

MOTIVATION

- Degradation rates are generally low, but they still affect project ? economics significantly

? – 0.25%/yr on a $2B project has NPV impact of ~$50M?

PROBLEM STATEMENT

- Solar Investors and Consumers need proof of low degradation.?
  – Small changes are expensive to measure accurately
- Need <1% measurement error ?
- But small-scale experiments do not address Investor concerns:?

? – Well-controlled experiment may not represent real-world experience?
– Extensive data processing and manipulation
? – Noise and Statistical relevance, possible "hand-picked" modules?

SOLUTION STRATEGY

Obtain a massive dataset from installed fleet, use statistics to get high-accuracy median degradation rate.

YEAR-OVER-YEAR PERFORMANCE INDEX ANALYSIS METHOD

1. Minimal filtering – remove obviously spurious data

? – 400 W/m² < Irradiance < 2000 W/m²
– -40°C < Ambient temperature < 65°C
? – 0 (m/s) < Wind Speed < 50 (m/s)?
? – Communication Errors (Flat-lined data)?

Exception made for wind-speed. Bad wind-speed sensors are very common – removing this data would have significantly reduced dataset and sensitivity is low. Wind-speed was replaced with a nominal 2m/s value; this ? approximation has a negligible effect on relative degradation calculations.

2. Compute expected power from weather data + performance model

? – We used PVSim, SunPower's publicly available, state-of-the-art PV ? system simulator, based on Sandia performance model

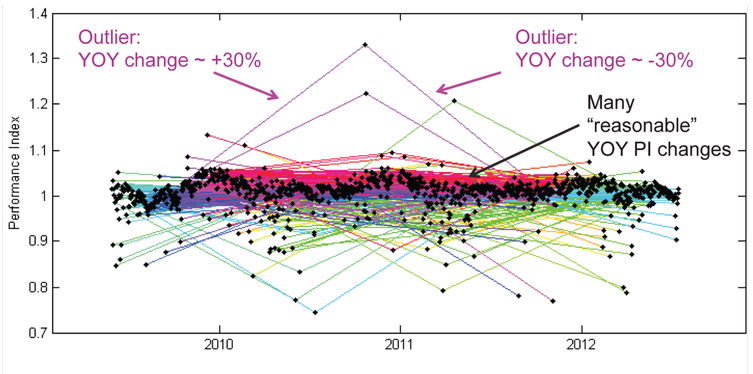
3.Compute Performance Index

P.I. = (Output) / (Expected Output) for each day

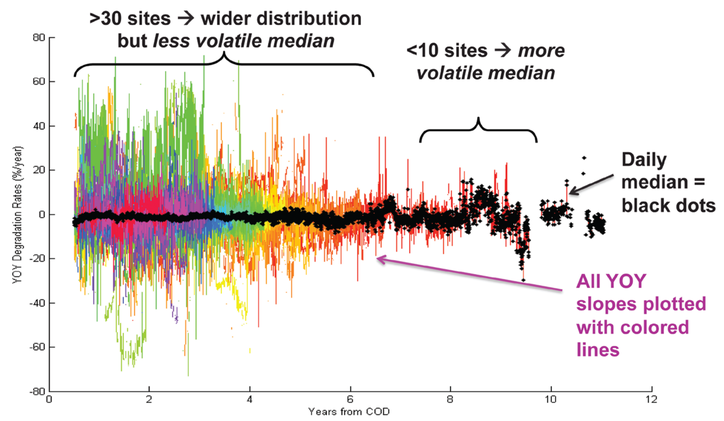
– If performance model were perfectly accurate except for degradation, then P.I. would start at unity but gradually decrease due to degradation

4. Calculate YOY change in PI: $\Delta PI_{n+365/2} = PI_{n+365} - PI_n$

? – This is a central-difference estimate of the local slope d(PI)/dt)?
– Example shown below – colored lines connect YOY PI values.
– Some of the slopes are outliers … but there are thousands of measurements per inverter

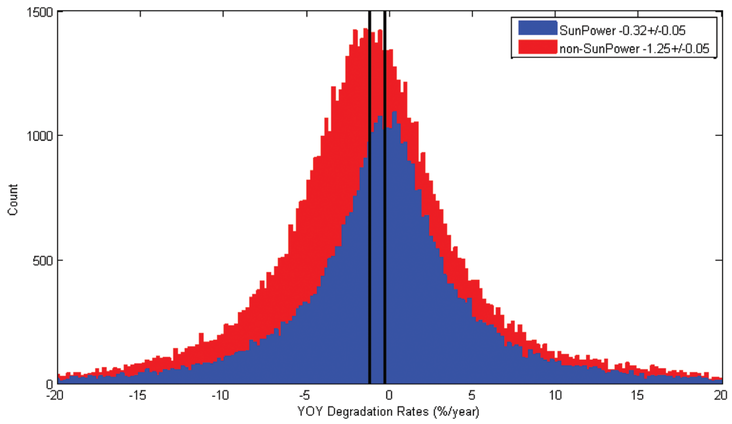


5. Obtain median degradation rate from distribution

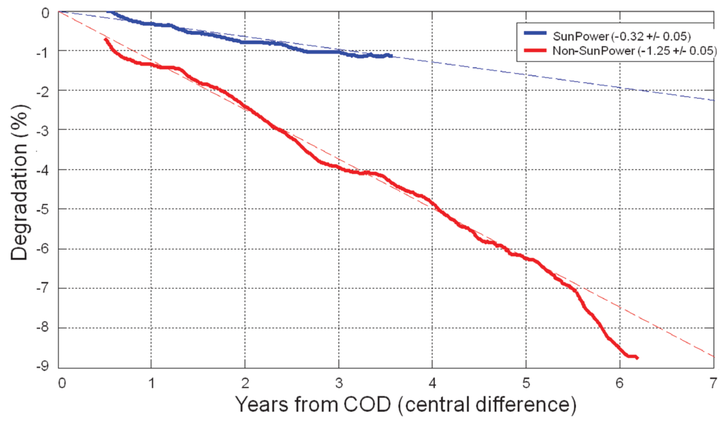


RESULTS AND DISCUSSION

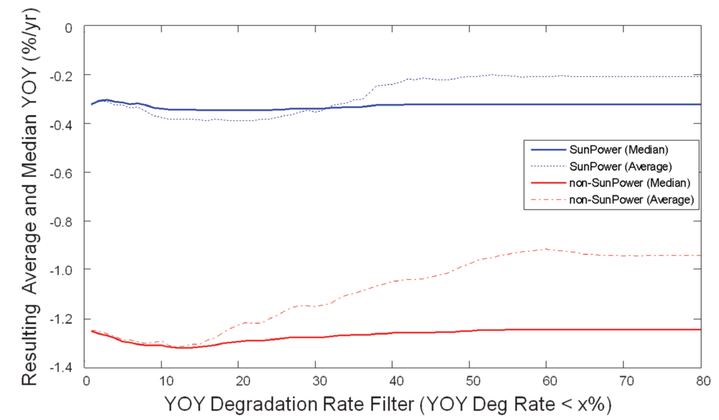
(1) Behavior with system age can be obtained by calculating median)? YOY slopes for all fleet data grouped by system age



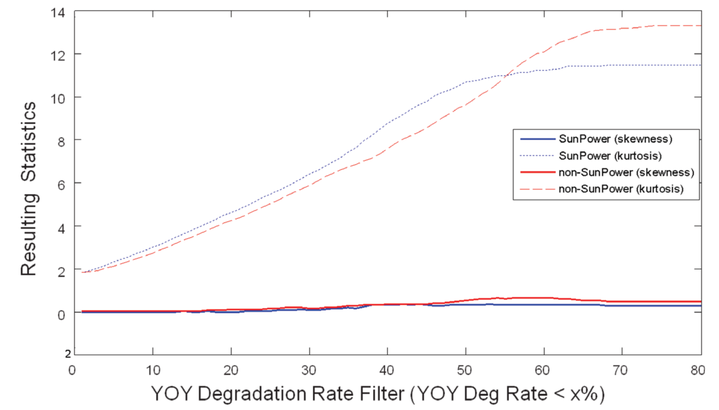
… and these Daily median YOY slopes can be integrated to yield imputed degradation curve:



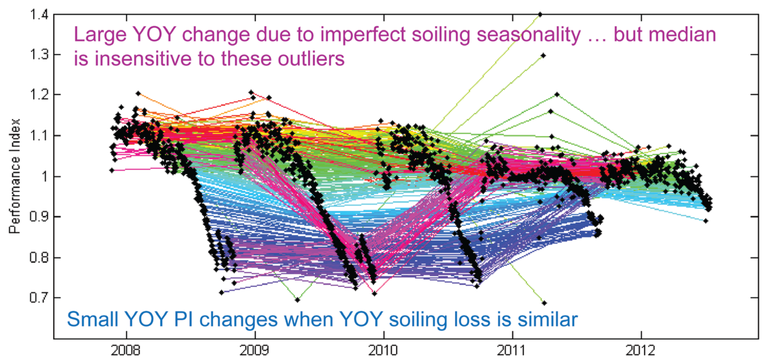
2) Median appears stable even when filtering "outlier" degradation)? rates. Average is not as stable.



3) Skewness is near zero, and stable to filtering of outliers?
(4) Kurtosis, as expected, is affected by outlier filtering?



5) What happens at heavy seasonal-soiling sites?
Soiling is not captured in the performance model. However, YOY approach is still accurate to the degree that soiling is seasonally repeatable.



CONCLUSION

Year-Over-Year Performance Index Change Analysis is a powerful and practical technique for assessing the median degradation of a large fleet of systems

- **ROBUST:** Insensitive to noise and absolute accuracy errors, and soiling

? – Median is stable to filtering of "outliers", skewness is near zero?

- **PRACTICAL:** Requires only AC inverter data and essential met data
  – No need for module removal, cleaning and flash testing, or curve)? tracing
- **RELEVANT:** Uses data from a live, real-world fleet
  – Module manufacturers can prove their real-world track record

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