Non-linear power degradation detected from massive real-world power plants data

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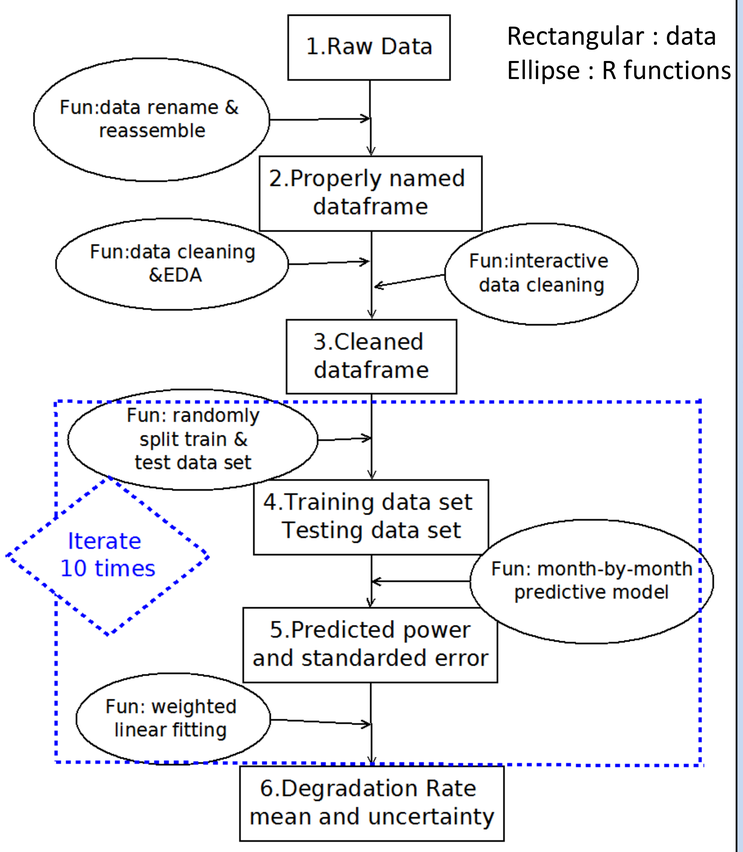
Objective

- Estimate photovoltaic power degradation rate from real-world data
- A case study of 7 power plants
- Using identical **non-SunPower** front contacted multi-crystalline silicon modules
- Brand: e725*9a0, model: 5e2a*2f2
- Located in 5 different Koppen-Geiger climate zones
- Climate conditions affect on degradation rate
- Degradation rate of silicon modules is assumed to be constant over their lifetime
- Month-by-month prediction approach check the trend of power changes in time

Data analysis procedure

Month-by-month prediction approach:

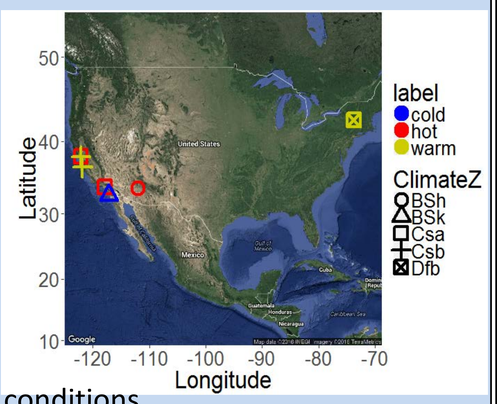
- Underlying assumption is PV system's degradation within a month is negligible
- 90% cleaned data set train regression model
- 10% test set estimate predictive error
- Regression fitting weighted on inverse of predictive error
- Monte Carlo approach estimate uncertainty
- Data pipeline enables application on multiple systems



Results

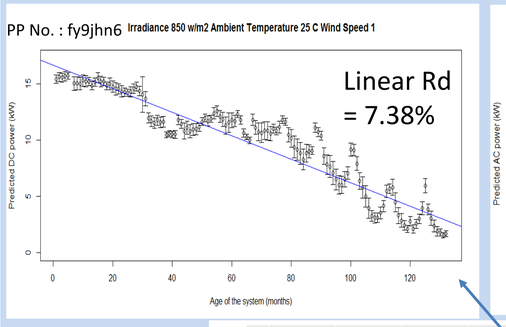
1 : PV systems degrade faster then warranty in hot climate

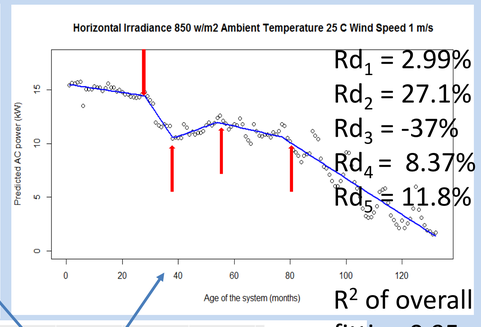
- Seven PV systems
- Identical PV module model
- Distributed in 5 climate zones
- BSh, BSk, Csa, Csb and Dfb,
- as classified by Koppen-Geiger system
- Assumed linear degradation rate varies a lot in different climate conditions
- Systems in "hot" climate (BSh, Csa) degrades faster



2 : Assumed linear degradation is not sound in some cases , Non-linear power degradation is detected

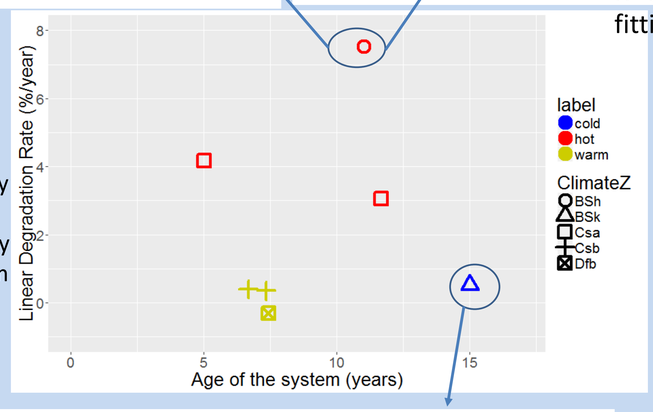
- Month-by-month prediction model approach
- Enables a view of monthly performance portfolio
- Assumed linear fitting is not sound in some cases
- Segmented fitting give a better R square value

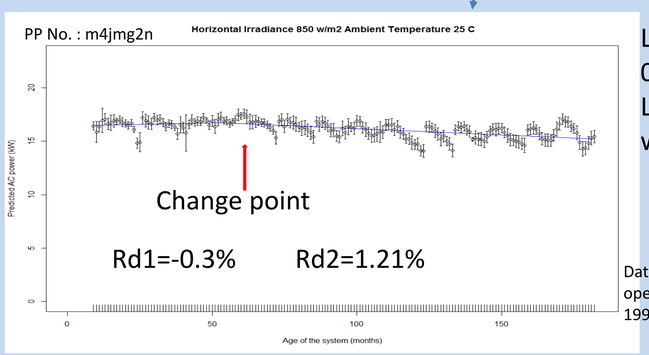




R^2 of overall fitting 0.95

Climate Zone
BSh: Arid-Steppe-Hot
BSk: Arid-Steppe-Cold
Csa: Temperate-Dry Summer-Hot
Csb: Temperate-Dry Summer-warm sum
Dfb: Cold-Without dry season-warm sum

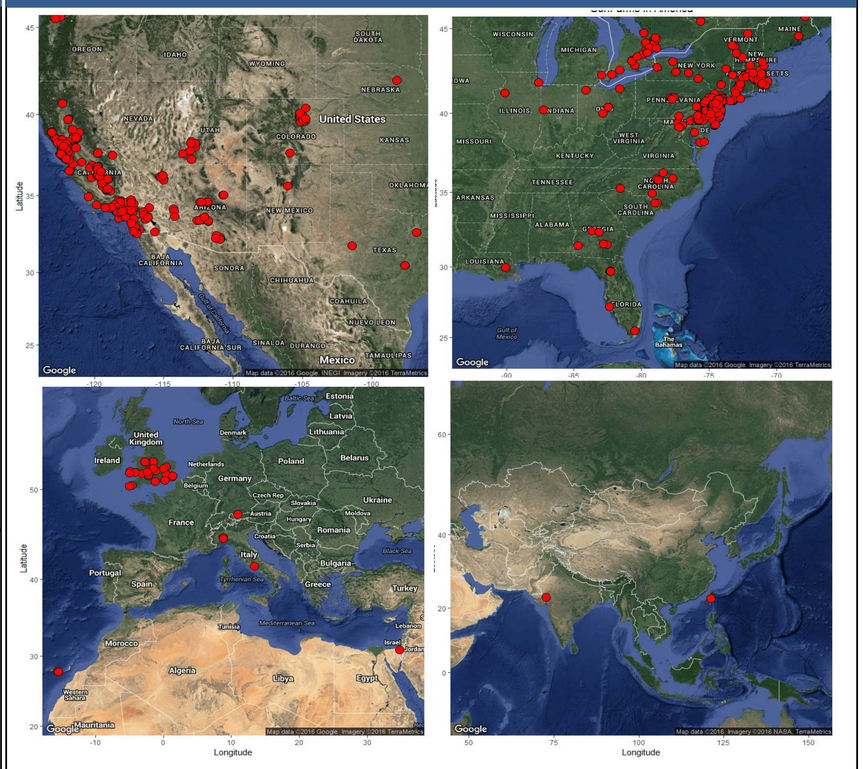




Linear Rd = 0.67%
Lower than warranty

Date of operation 1999-10-27

Global SunFarm Network [1]



SDLE PV Data Covers ~3.4 GW

- 787 PV Plant Sites encompasses 1.92% of Global PV Plants
- 5638 PV Plants (Inv. & Modules)
- Distributed in 13 different climate zones
- 60 PV Module Brands/Models
- 38 PV Inverter Brands/Models
- Single Modules to 265 MW power plants
- Going Back Up To 15 years

Future Work

Population-based Studies to Identify

- Statistically Significant Factors
- Controlling Lifetime Performance
- Impact of environmental conditions
- Real-world Degradation & Failure

Acknowledgements

- This work is supported by the Bay Area Photovoltaic Consortium Prime Award No. DE-EE0004946, Subaward Agreement No. 60220829-51077-T.
- This research is in collaboration with SunPower

References

[1] Yang Hu, et. al " Energy-CRADLE: Photovoltaic Informatics Based on Hadoop" submitted to Journal of Photovoltaics, IEEE

Process Cost Analysis

- Current manufacturer warranty on PV modules is 25 years with no less than 80% peak power
- Less than 1%/year linear degradation rate
- This work shows that this particular PV module model degrades much faster than 1%/year under "hot" climate conditions

Research to Transition Tech to Industry

- Presumed linear degradation rate: not sound
- Month-by-month prediction approach enables segmented fitting
- PV modules do not behave identically across different climate zones
- Impact of climate zones on PV modules reliability is a critical

Summary of Progress vs. Plans

- Developed data analytic procedure
- Developed a series of functions in R language
- This analytic procedure will be applied on 508 power plants in the SunFarm network

Metrics for Next Year

- The PV module being studied in this work is an older technology from an early industry leading module manufacturer
- The analytical method put this work in contact with reliability study of newer technologies, such as PERC solar cell.