Using Meteorological Data to Evaluate Worldwide PV Degradation Rates

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Introduction and Background

In assessing the durability of PV modules, the PV community frequently can mathematically describe the kinetics in a way that lends itself to extrapolation to the field for specific degradation pathways. In the past we would pick specific reference environments and plot tables of expected performance.

Here we automate the process to enable the creation of world maps for specific PV durability metrics. The end goal is to create a tool for the creation of world maps predicting the sensitivity of modules to degradation to inform the development and utilization of module testing standards and to provide information to module designers.

TMY (Typical Meteorological Year) Data was aggregated from sites around the world to render insight into factors contributing to the degradation of solar modules. The focus of aggregating data was to create a single dataset to work with utilizing **Solar Irradiance values** combined with **Ambient Temperature**, **Relative Humidity**, **Wind Speed** and **Dew-Point Temperature**.

Module Environment Database

Aggregated Data Sets

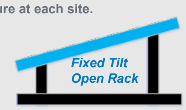
•Ground–based weather stations were first analyzed, and missing holes were filled with Satellite-based data.

- **3 Ground-based Weather Station databases** (4,524 total sites)
  - **TMY3**: (United States) 1961-1990 and 1991-2005
  - **CWEC**: (Canada) 1953-1995
  - **IWEC2**: (Global) 12-25 years of data, dependent upon site location
- **2 Satellite-based** (1,573 total sites)
  - **PVGIS-NSRDB**: National Renewable Energy Laboratory (NREL) and is part of the National Solar Radiation Database (2004-2014)
  - **PVGIS-CMSAF**: CM SAF collaboration for the area covering Europe and Africa (2007-2016)

The King Model provided module and cell temperature at each site.

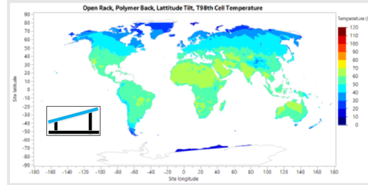
Mounting Configurations

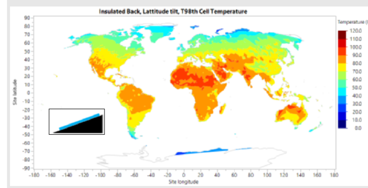
- Open Rack Cell Glass Back
- Roof Mount Cell Glass Back
- Open Rack Cell Polymer Back
- Insulated Back Polymer Back
- Open Rack Polymer Thin Film Steel



William F. Holmgren, Clifford W. Hansen, and Mark A. Mikofski. "pvlib python: a python package for modeling solar energy systems." Journal of Open Source Software, 3(29), 884, (2018). https://doi.org/10.21105/joss.00884
D. King et al, "Sandia Photovoltaic Array Performance Model", SAND2004-3535, Sandia National Laboratories, Albuquerque, NM

IEC 63126, High Temperature Modules

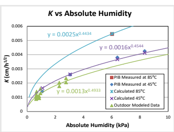




The standards IEC 61730 and IEC 61215 currently refer to rack and roof mounted arrays having different testing requirements. However, the real problem is not in the mounting but a combination of mounting and environment that result in high temperature. IEC hopes to remedy this by defining IEC 61730 as applying to systems where the 98th percentile temperature is less than 70ºC and then IEC 63126 defines more tests for a system with a 98th percentile upper limit of 80ºC or 90ºC.

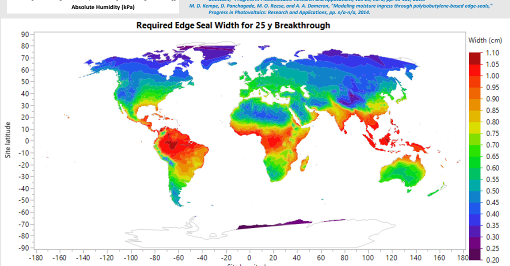
These plots will be part of IEC 63126 and serve to help people quickly assess the potential need for additional high temperature testing.

Edge Seal Ingress



By noting the loose correlation between average **ambient absolute humidity** and **moisture ingress for edge seals**, a map of **required edge seal width** can be created.

M. D. Kempe, D. L. Nobles, L. Postak, and J. A. Calderon, "Moisture ingress prediction in polyisobutylene-based edge seal with molecular sieve desiccant," Progress in Photovoltaics: Research and Applications, vol. 26, no. 2, pp. 93-101, 2018.
M. D. Kempe, D. Panchagade, M. O. Reese, and A. A. Dameron, "Modeling moisture ingress through polyisobutylene-based edge-seals," Progress in Photovoltaics: Research and Applications, pp. n/a-n/a, 2014.



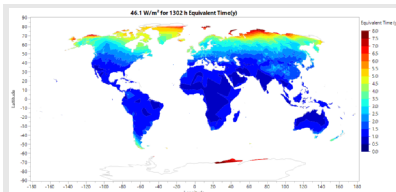
IEC 61730 UV Exposure

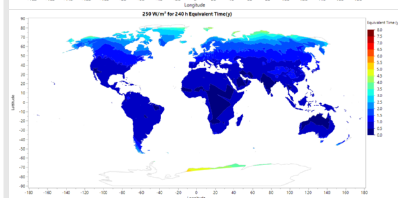
- MST 54 in IEC 61730-2 or MQT 10 in IEC 61215-2
  - 60 kWh UV exposure
  - Module Temperature of 60 ± 5 ° C
  - Irradiance uniformity of ± 15%
  - No "appreciable" irradiance below 280 nm.
  - Maximum of 250 W/m² between 280 nm and 400 nm.
  - Between 3% and 10% of the irradiance is between 280 and 320 nm.
    - ASTM G173-03
      - 46.1 W/m² between 280 and 400 nm
      - 1.52 W/m² between 280 and 320 nm (3.2%)
    - UVA-340 lamp ASTM G154-16
      - When operated at 0.8 W/m²/nm at 340 nm
      - 43.8 W/m² between 280 and 400 nm
      - 3.57 W/m² between 280 and 320 nm (8.1%)
      - Assuming significant sublinearity (x=0.64) for the same dose, this lamp irradiance setting would be 80% more damaging than the ASTM G173-03 solar spectrum
  - Assume we use a lamp with an action spectrum to match the solar spectrum damage. (e.g. irradiance equivalent to ASTM G173-03 MST 54 and MQT 10 will be met with:
    - At 250 W/m² it will take 240 h. (5.4 UV sun exposure)
    - At 46.1 W/m² it will take 1302 h. (1 UV sun exposure)
- Fischer and Ketola found that **Typical UV degradation rates** for paints and coatings could be modeled with a power law dependence on irradiance level with x=0.64±0.2 and an acceleration of 1.41±0.21 for every 10ºC temperature rise.

$$R_D \sim I^x \cdot T_f^{\frac{T-T_o}{10}} \qquad AF = \frac{n \cdot (I_{chamber})^x}{\sum_0^n \cdot (I_{POA})^x \cdot T_f^{\frac{T-T_{chamber}}{10}}}$$

R. M. Fischer and W. D. Ketola, "Error Analyses and Associated Risk for Accelerated Weathering Results," Third International Service Life Symposium, Sedona, AZ February 2004.

Application to IEC 63209 UV



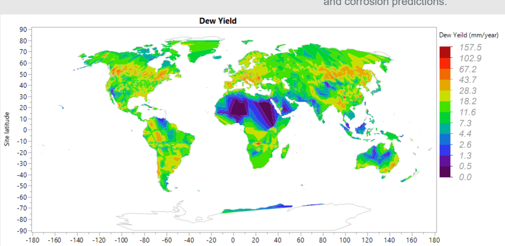


When these plots were shown to the **IEC 63209 Extended Module Testing working group** they were contemplating using a double exposure to the front side of a module. Noting that for most of the world this would be on the order **of less than 3 years equivalent exposure**, it was decided that the expense of extended front side module testing was **not worthwhile**. However, the backside could easily be getting a relevant level of exposure and was included in the extended testing protocol.

Dew Yield (total dew in a year)

$$\left(\frac{dh}{dt}\right) = \begin{cases} \{0.37 \times [\,1 + 0.204323\,H - 0.238893\,H^2 \\ (18.0132 - 1.04963H + 0.21891\,H^2) \times \\ 10^{-3}T_d] \times \left(\frac{(T_d+273.15)/}{285}\right)^4 (1 - N/8)\} + [0.06\,(T_d - T_a)] \times \\ (\,1 + 100 \times \left\{1 - exp^{\left[-\left(\frac{V}{V_0}\right)^{20}\right]}\right\} \end{cases}$$

By estimating the **Dew Yield** we can begin to model soiling effects and its relation to spectral loss. Dew Yield will also provide insight into corrosion processes. Researchers studying power loss as a factor of degradation can improve models with better soiling and corrosion predictions.



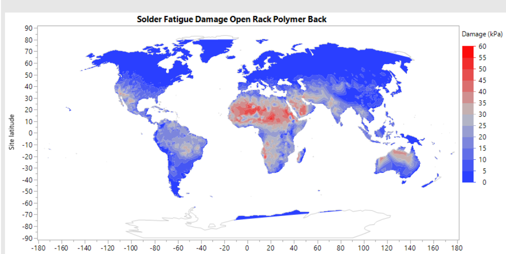
Note: Satellite data was decarded from this map due to poor cloud coverage data

Beysens, D. (2016). Estimating dew yield worldwide from a few meteo data. Atmospheric Research Volume 167, 1, Pages 146-155.

Thermal Cycling Solder Fatigue

With **Hourly Cell Temperature** data researchers can predict thermal fluctuations and the impact on **Solder Fatigue Damage** (PbSn).

$$D = C(\Delta T)^n (r(T))^b exp^{\left(-\frac{Q}{k_b T_{max}}\right)}$$



Bosco, N., Silverman, T. and Kurtz, S. (2016). Climate specific thermomechanical fatigue of flat plate photovoltaic module solder joints. Microelectronics Reliability 62 124–129

Conclusions

Utilizing typical metrological year datasets has yielded insights into the metrological effects of degradation. We are developing software to create world maps of degradation to help visualize the regions where specific degradation processes would be expected to be more prevalent.

Creating suitable solar modules for geo-specific regions can allow manufactures to improve the durability of their designs. This will aid by letting manufacturers know if additional costs are likely to result in broad or in localized improvement realizations. A system developer might note that they are building in a particularly harsh climate and focus additional testing protocols appropriately.

This aggregated dataset will be applied to single axis trackers with back row shading in as the predicted future fleeted system.

Future work will also include P10 particle data research, the effect of albedo on backside and other degradation factors.

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