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PV MODULE LIFE TIME FORECAST AND EVALUATION

Prediction of the Remaining Useful Lifetime of PV Modules

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INTRODUCTION

- The remaining useful lifetime (RUL) of a system or a component is defined as the length from the current time to the end of its useful life. Prediction of the remaining useful lifetime of PV modules and system is of great importance to all PV stakeholders. It could be used as a key factor for operation and maintenance decision making. Here a simplified approach to predict the RUL of PV modules with a better accuracy is presented.

DEGRADATION MODEL AND RUL OF PV MODULES

- In this study degradation is defined as the gradual loss of the module maximum power. This loss of power is modelled as:

$$\frac{P_{MPP}(t)}{P_{MPP}(0)} = 1 - exp\left(-\left(\frac{B}{kt}\right)^{\mu}\right) \quad \text{Eq:1}$$

k is the rate constant, μ is a shape parameters and B model parameter

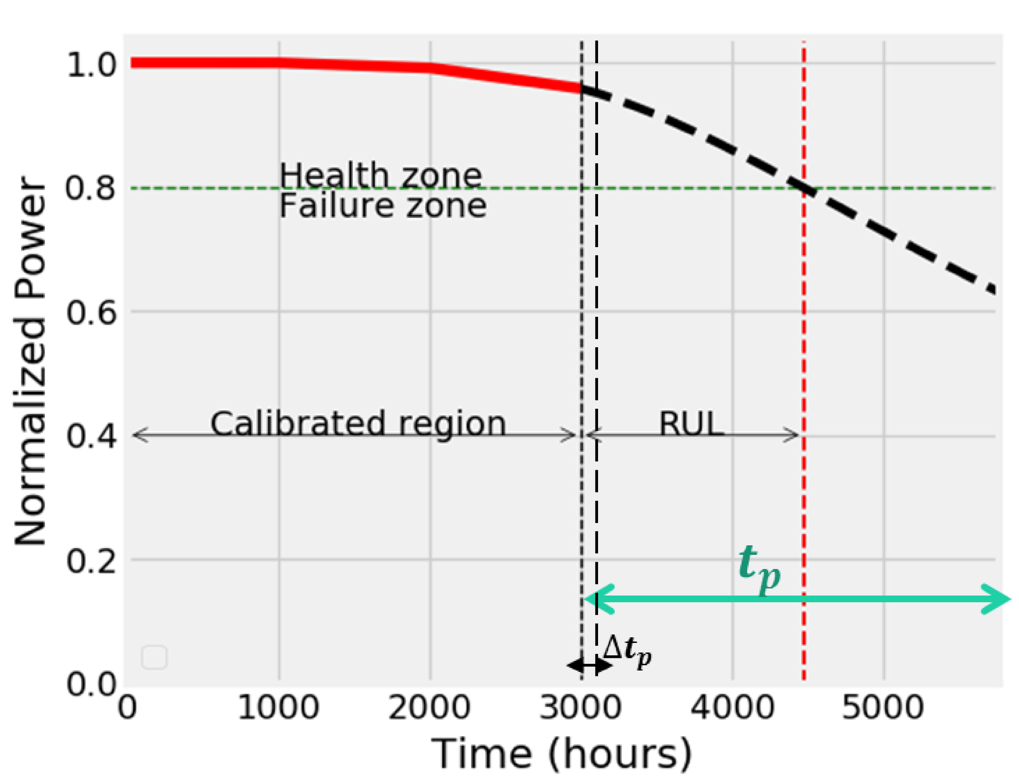

Fig.1. Remaining useful lifetime

Remaining useful lifetime (RUL)
The duration from calibration time to the time when the initial power has reduced by 20%.

CONCEPT OF TIME DEPENDENT DEGRADATION RATES

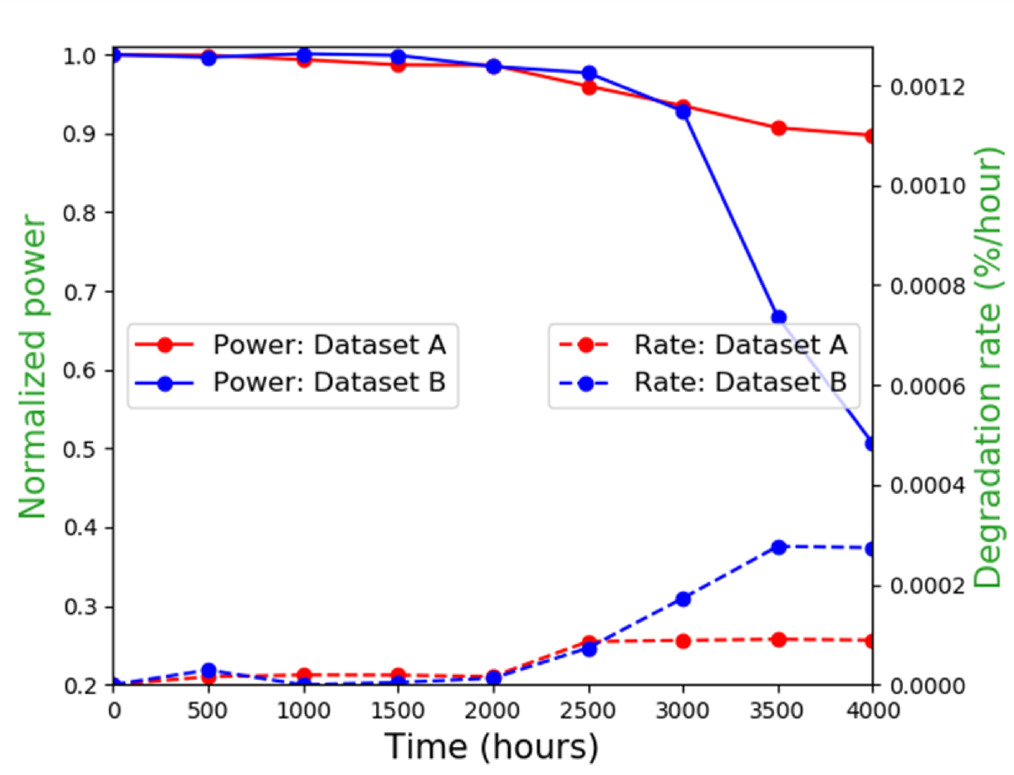

Fig.2. Extracted rates by fitting equation 1 to the measurements at different intervals

- Increasing degradation rates with increasing testing time was observed using different sets of damp heat measurements.

- Hence a time dependent degradation rate model was proposed to take into account the changing degradation as in eq: 2.

$$k(t) = k_{fit}.\left(1 + k_{fit}.t_p{}^{\gamma}\right) \quad \text{Eq:2}$$

k_{fit} is the derived rate at calibration, t_p is the time from the calibration and γ is the model parameter derived from the power loss function as:

$$\gamma = \left|\frac{1}{\Delta t_p}\left[\ln(k_{fit}) + \ln\left(\frac{-\mu B}{t_{fit}.\ln\left(1-\frac{P_{fit}}{P_0}\right)}\right)\right]\right| \quad \text{Eq:3}$$

Δt_p is the very small change at $t_p = 0$, $t_p = t_{fit} - t_{fin}$, t_{fit} is the time of calibration, t_{fin} is the time of prediction and P_{fit} is the power at t_{fit}

MODEL VALIDATION WITH INDOOR MEASUREMENT

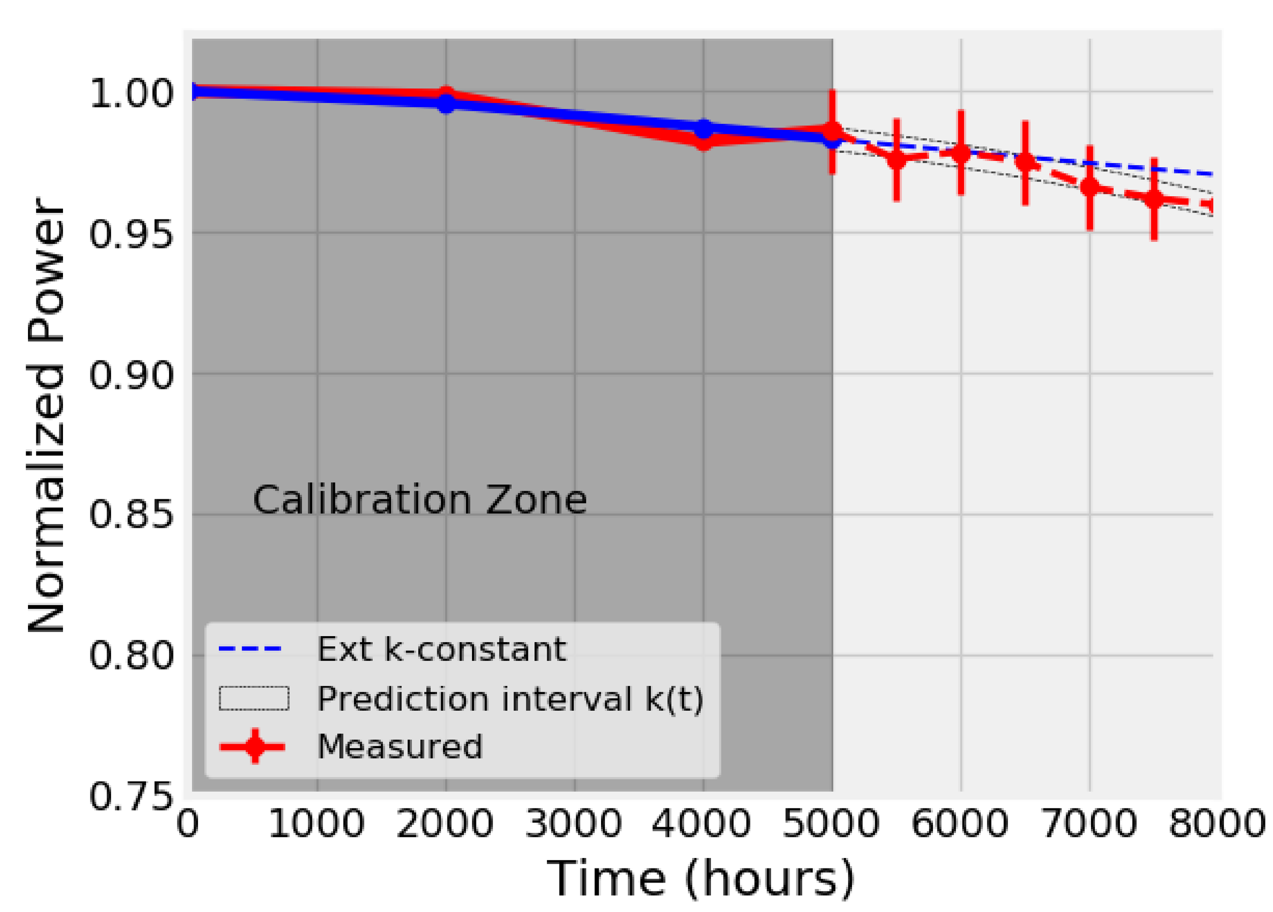

Fig.3. RUL prediction using a constant degradation rate (blue dotted) and a time dependent rate (black dotted) and in red is the measured power

Different data sets were used to validate the model. A time dependent rate showed very good agreement with the measured data. This can be seen by the evaluated uncertainties in the table below.

Comparison of time dependent with constant degradation rates

Module	k_{fit} (%/hour)	μ	γ	RMSE k_{fit} (%)	RMSE $k_{fit}(t)$ (%)
M01	1.04e-4	1.64	1.134	2.5	0.5
M02	2.22e-6	0.31	1.495	2.2e-3	3.3e-5
M03	7.29e-5	0.70	1.171	1.9e-2	1.1e-2
M04	1.16e-4	1.95	1.115	2.9	5.7e-2
M05	1.15e-4	1.03	1.125	1.0	0.01

MODEL APPLIED TO PV MODULES OUTDOOR PREDICTION

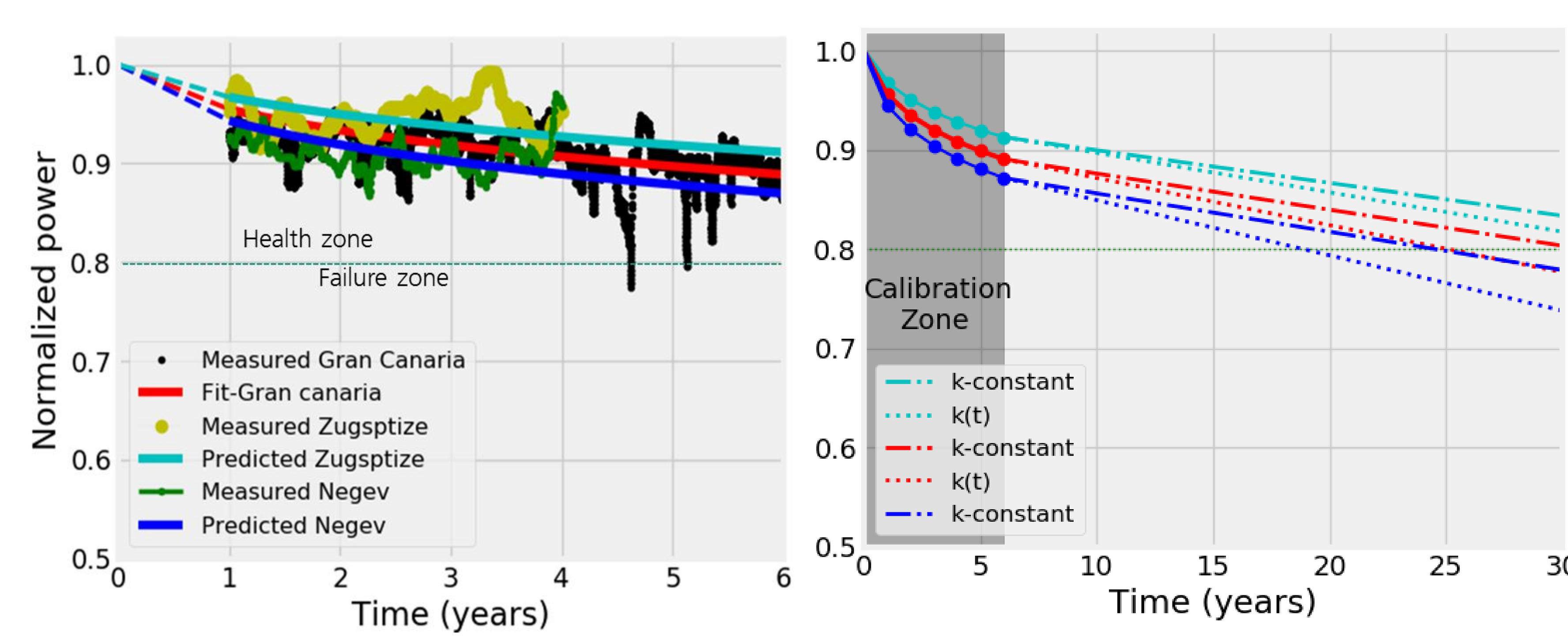

Fig.4. Outdoor calibration in three climatic zones (right), prediction of the RUL using constant and time dependent degradation rate.

Comparison of the RUL predictions using a time dependent and constant degradation rate in the three climatic zones

Location	k_{fit} (%/year)	μ	γ	RUL k_{fit} (years)	RUL $k_{fit}(t)$ (years)	Relative Difference
Negev	0.74	0.19	0.0485	15.4	12.5	13.5%
Canaria	0.50	0.19	0.0195	25.6	19.0	20.9%
Zugspitze	0.30	0.19	0.0182	46.8	33.5	25.2%

- Considering the indoor and outdoor results, a time dependent degradation rate provides more accurate prediction in comparison to a constant rate

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