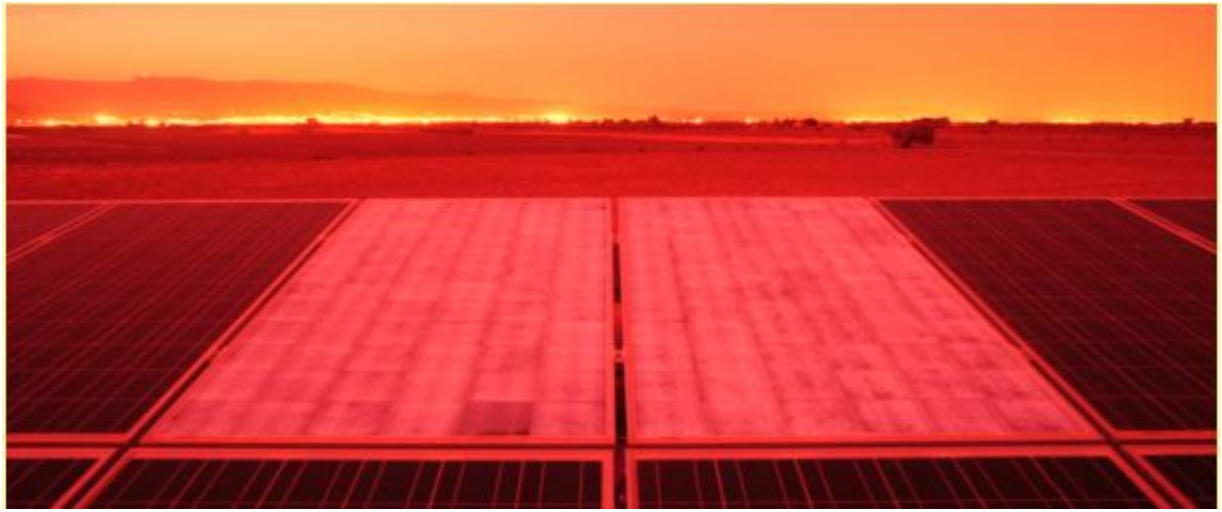


Towards a Predictive Model for Potential-Induced Degradation (PID) Based on Climate Data

Simon Koch,

J. Berghold, P. Grunow

PI Photovoltaik Institut Berlin AG

Photovoltaik-Modultechnologie

Testing | Consulting | Development | Research

Wrangelstr.100, 10997 Berlin, Germany

Overview

1. Introduction
2. Phenomenological PID model
3. Application examples
4. Current work
5. Summary

Introduction

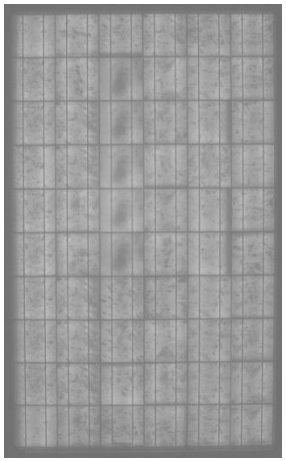
- PID is comparable to a growth process
- A growth process is usually limited
- There are countless examples of limited growth processes:
    - An epidemic which covers a city or a country
    - A product which is newly introduced in the market
    - Growth of a fungus in a petri dish
- A common feature of these growth processes is that they describe highly complex systems with a large number of influencing factors

- The current notion assumes that sodium ions accumulate into stacking faults and thus short-circuit the cell.
- A cell can therefore be regarded as a space with a finite number of stacking faults.
- More and more stacking faults are affected or „infected“ by sodium ions

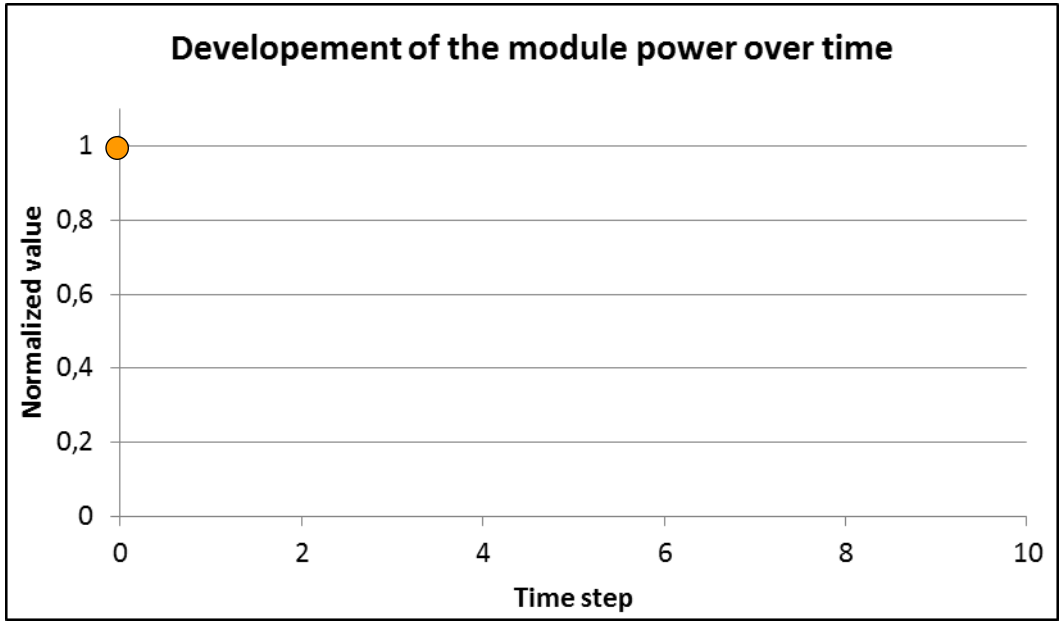
The potential induced degradation process

Damp heat 85°C/85% r.H. -1000V (PID Test)

Electroluminescence



STC Power

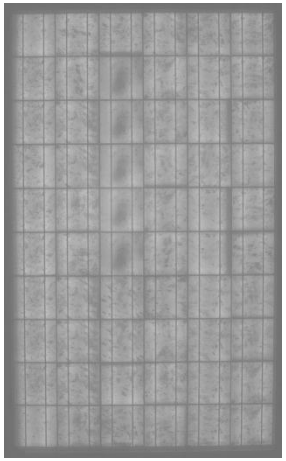


- Slow degradation at the beginning
- Develope to an exponentiale like grows in the middle
- Flattens at the end

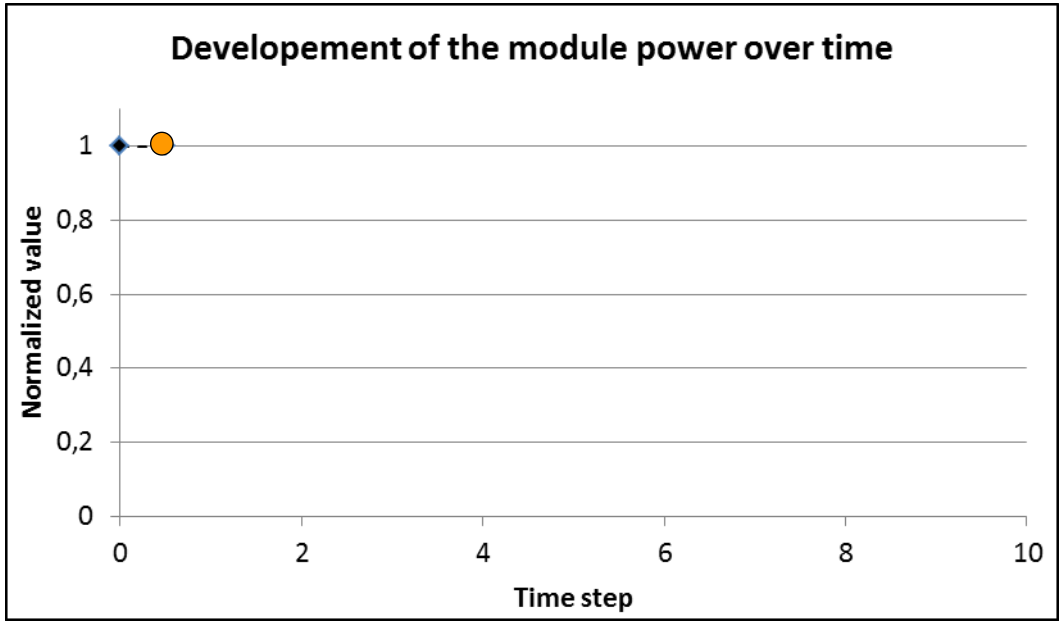
The potential induced degradation process

Damp heat 85°C/85% r.H. -1000V (PID Test)

Electroluminescence



STC Power

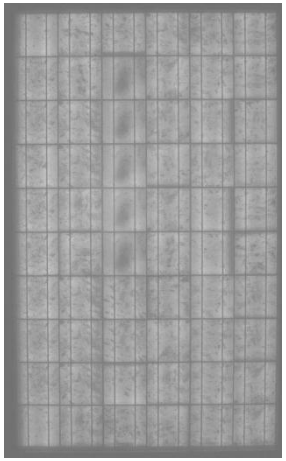


- Slow degradation at the beginning
- Develope to an exponentiale like grows in the middle
- Flattens at the end

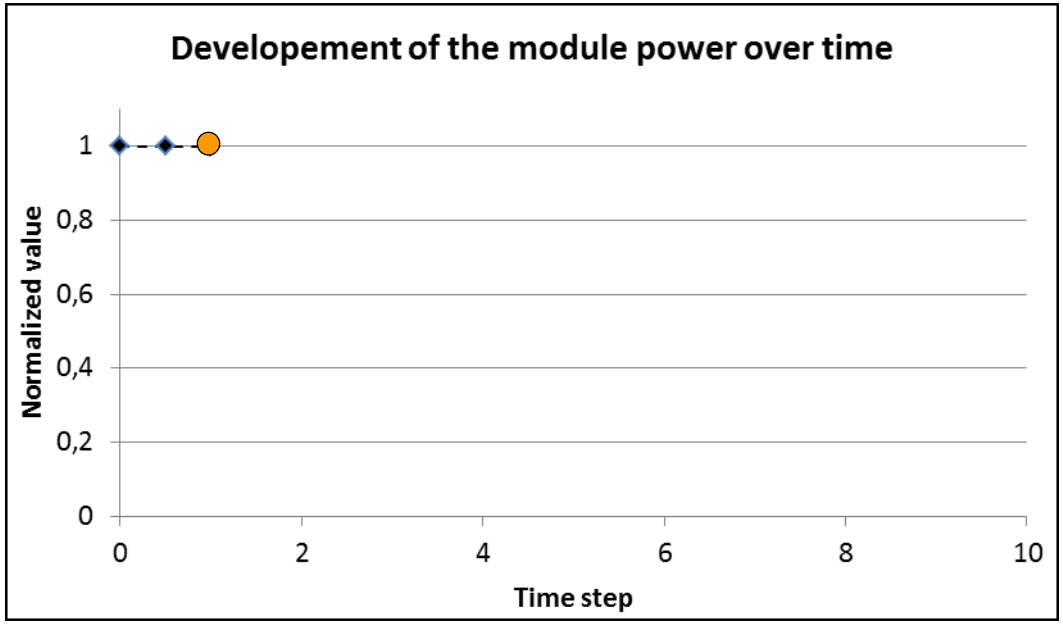
The potential induced degradation process

Damp heat 85°C/85% r.H. -1000V (PID Test)

Electroluminescence



STC Power

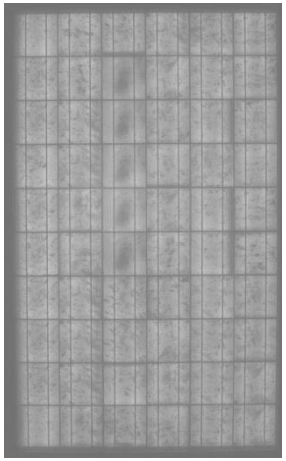


- Slow degradation at the beginning
- Develope to an exponentiale like grows in the middle
- Flattens at the end

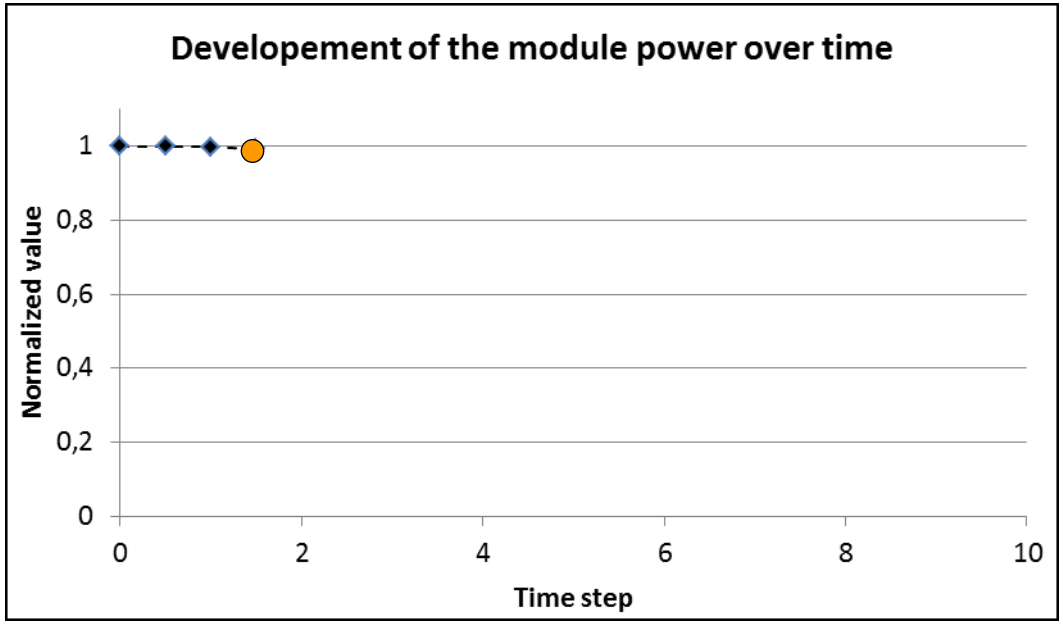
The potential induced degradation process

Damp heat 85°C/85% r.H. -1000V (PID Test)

Electroluminescence



STC Power

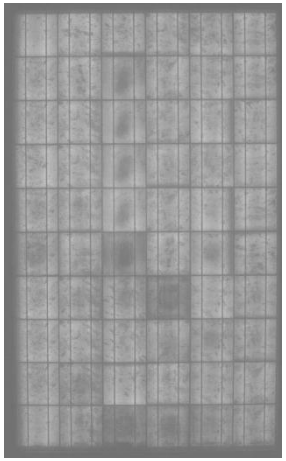


- Slow degradation at the beginning
- Develope to an exponentiale like grows in the middle
- Flattens at the end

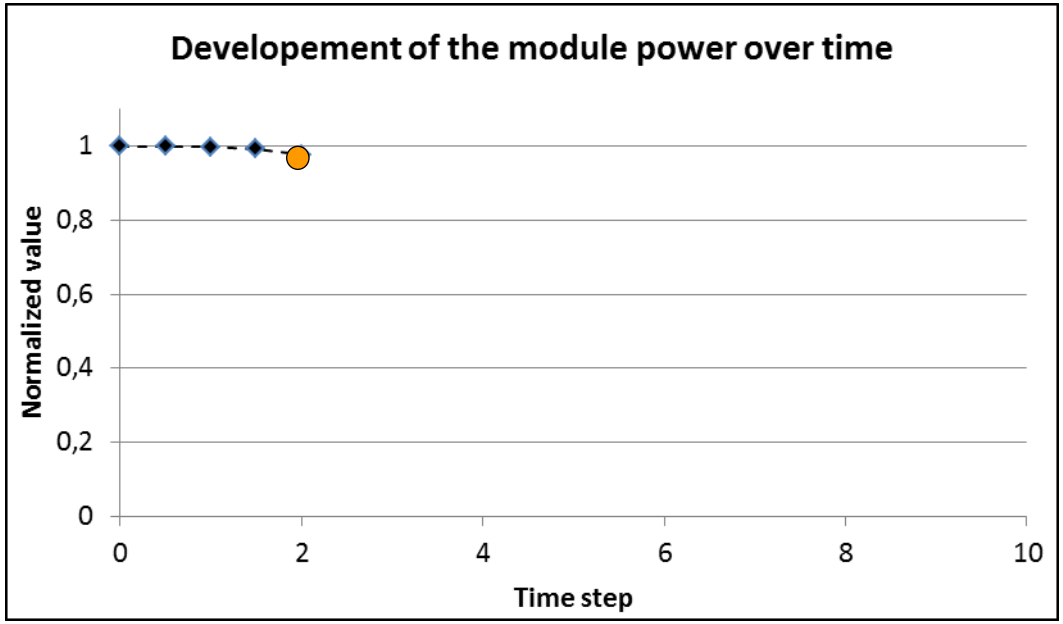
The potential induced degradation process

Damp heat 85°C/85% r.H. -1000V (PID Test)

Electroluminescence



STC Power

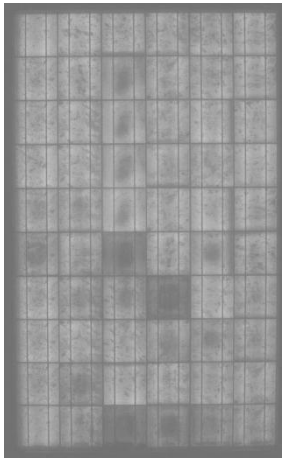


- Slow degradation at the beginning
- Develope to an exponentiale like grows in the middle
- Flattens at the end

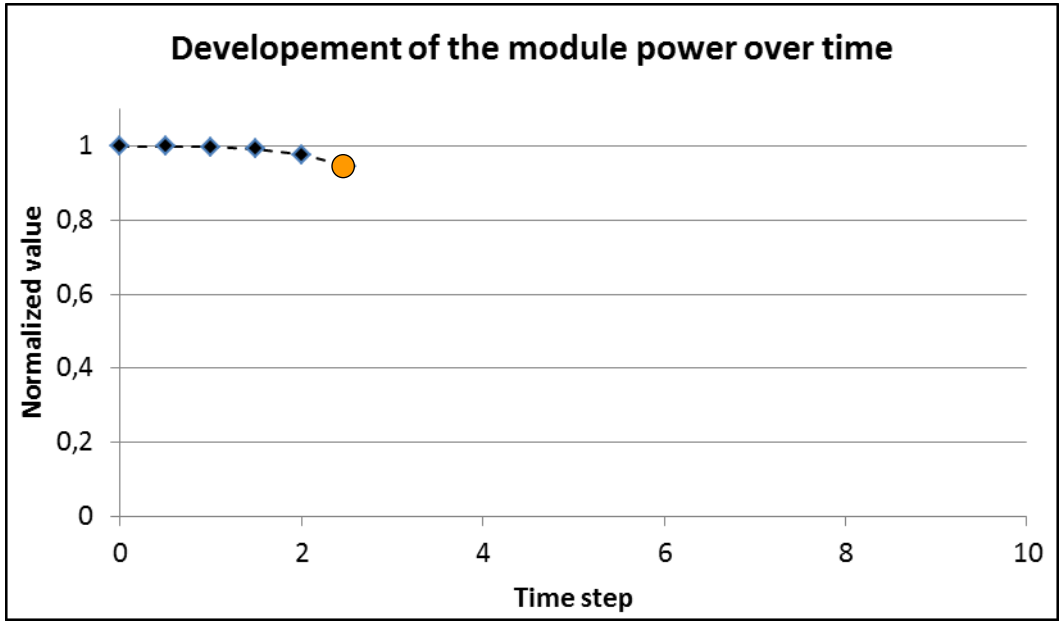
The potential induced degradation process

Damp heat 85°C/85% r.H. -1000V (PID Test)

Electroluminescence



STC Power

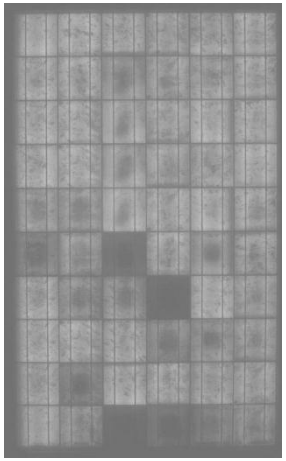


- Slow degradation at the beginning
- Develope to an exponentiale like grows in the middle
- Flattens at the end

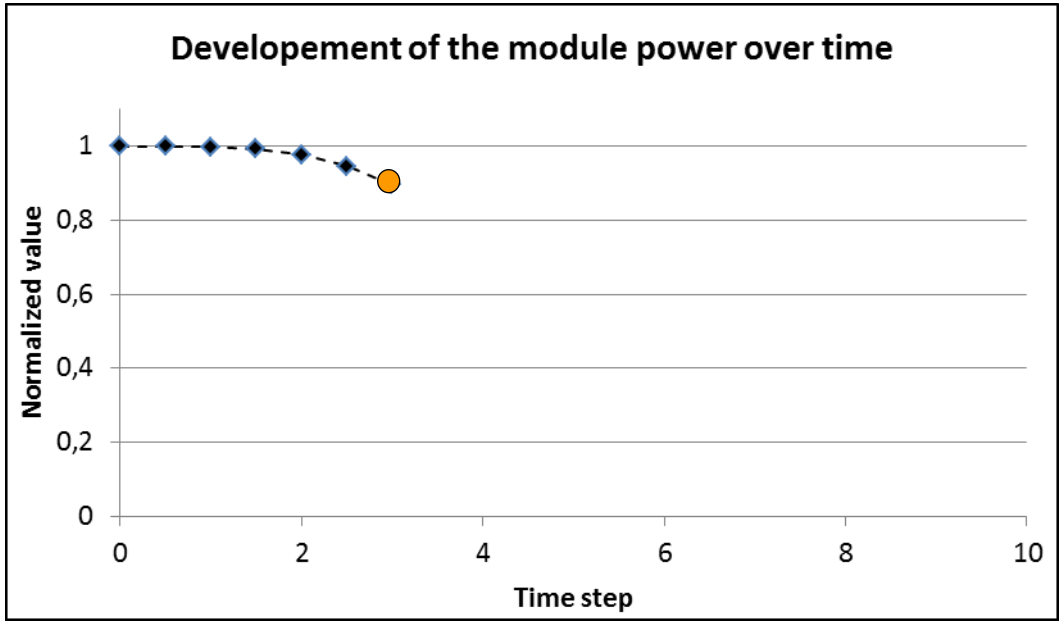
The potential induced degradation process

Damp heat 85°C/85% r.H. -1000V (PID Test)

Electroluminescence



STC Power

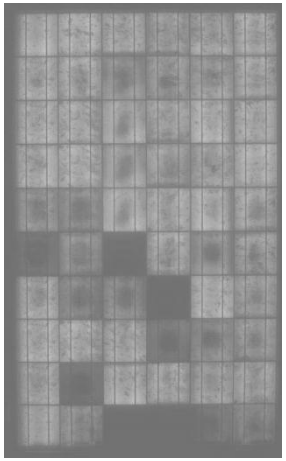


- Slow degradation at the beginning
- Develope to an exponentiale like grows in the middle
- Flattens at the end

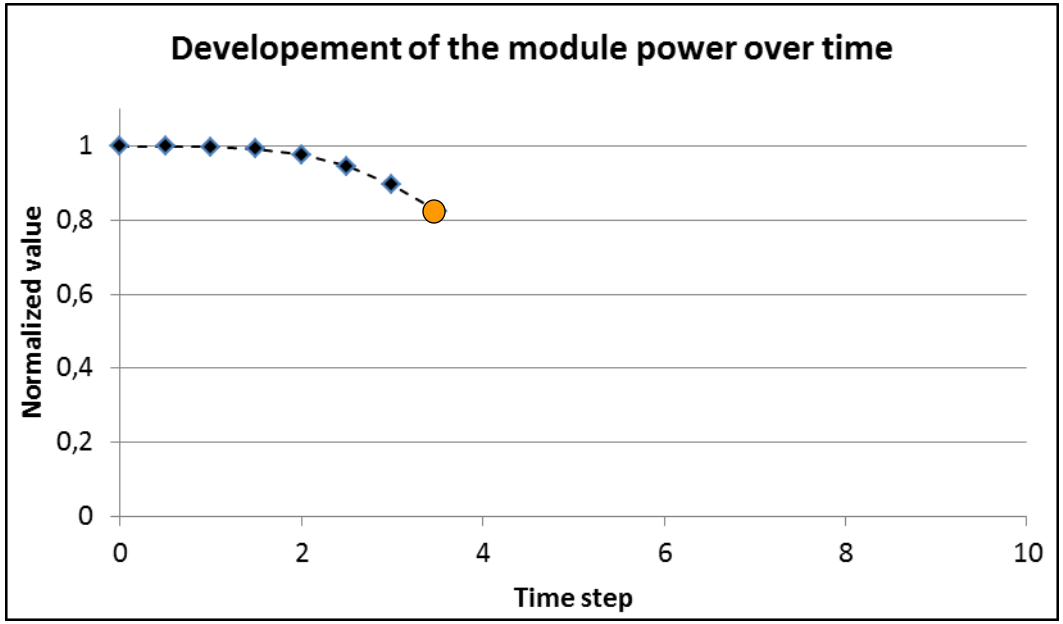
The potential induced degradation process

Damp heat 85°C/85% r.H. -1000V (PID Test)

Electroluminescence



STC Power

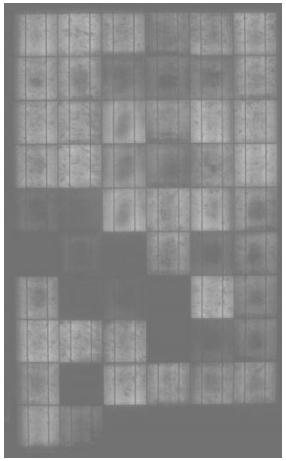


- Slow degradation at the beginning
- Develope to an exponentiale like grows in the middle
- Flattens at the end

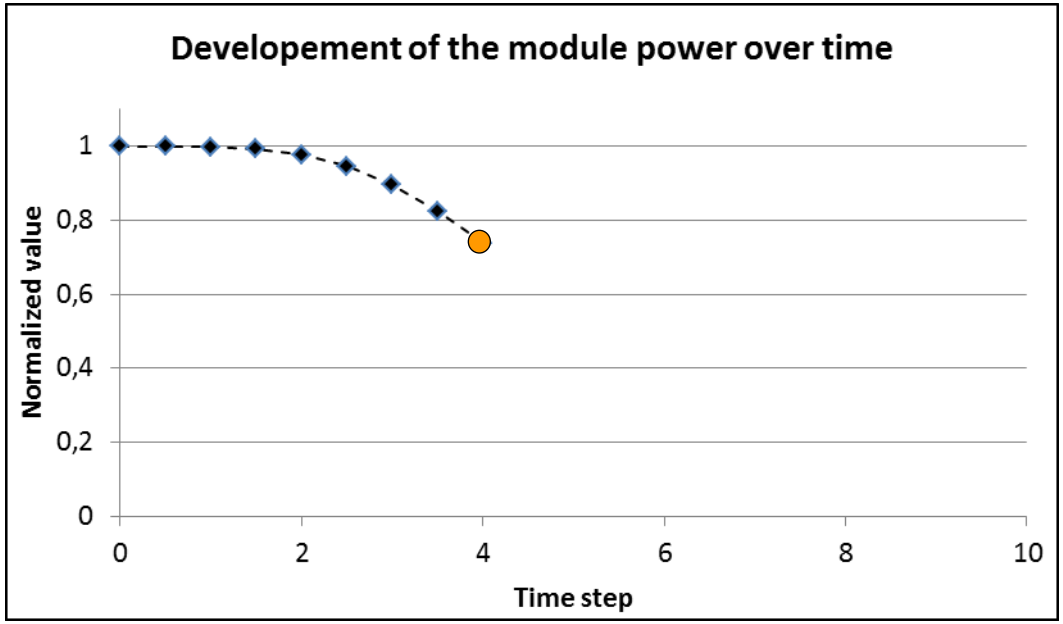
The potential induced degradation process

Damp heat 85°C/85% r.H. -1000V (PID Test)

Electroluminescence



STC Power

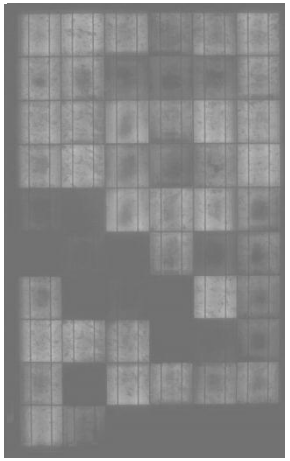


- Slow degradation at the beginning
- Develope to an exponentiale like grows in the middle
- Flattens at the end

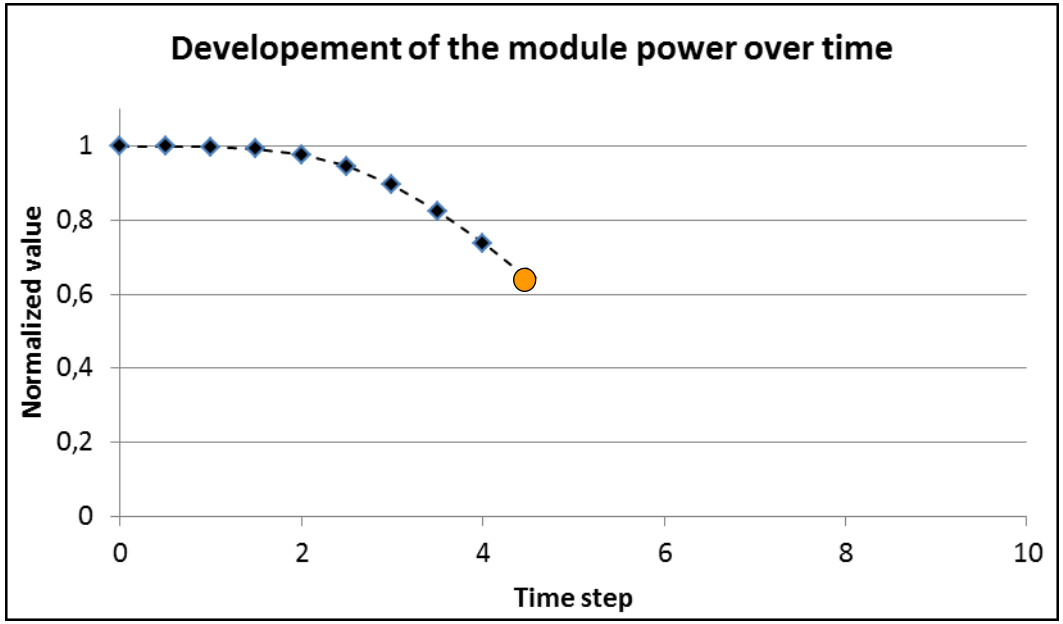
The potential induced degradation process

Damp heat 85°C/85% r.H. -1000V (PID Test)

Electroluminescence



STC Power

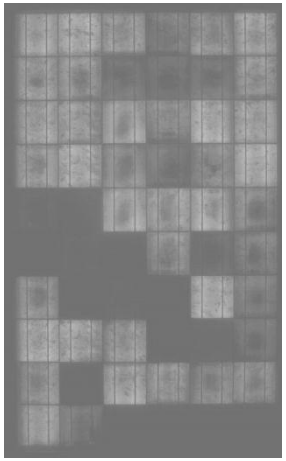


- Slow degradation at the beginning
- Develope to an exponentiale like grows in the middle
- Flattens at the end

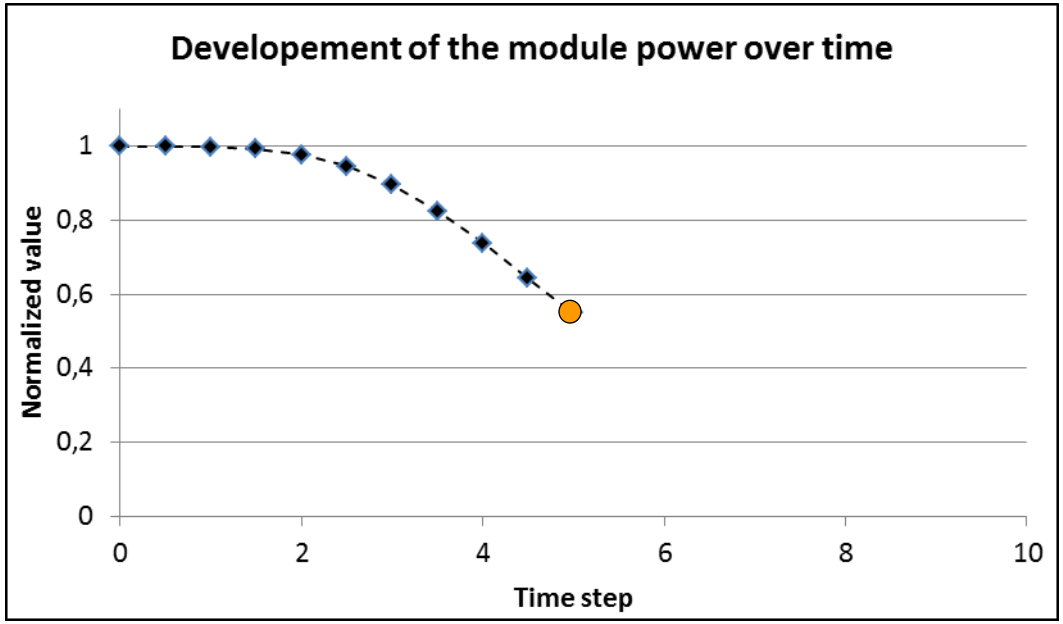
The potential induced degradation process

Damp heat 85°C/85% r.H. -1000V (PID Test)

Electroluminescence



STC Power

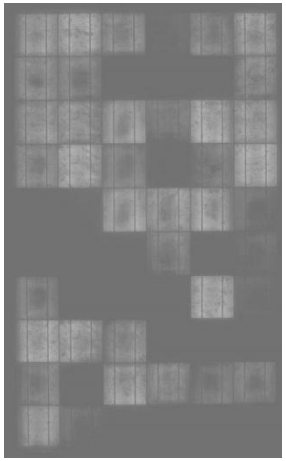


- Slow degradation at the beginning
- Develope to an exponentiale like grows in the middle
- Flattens at the end

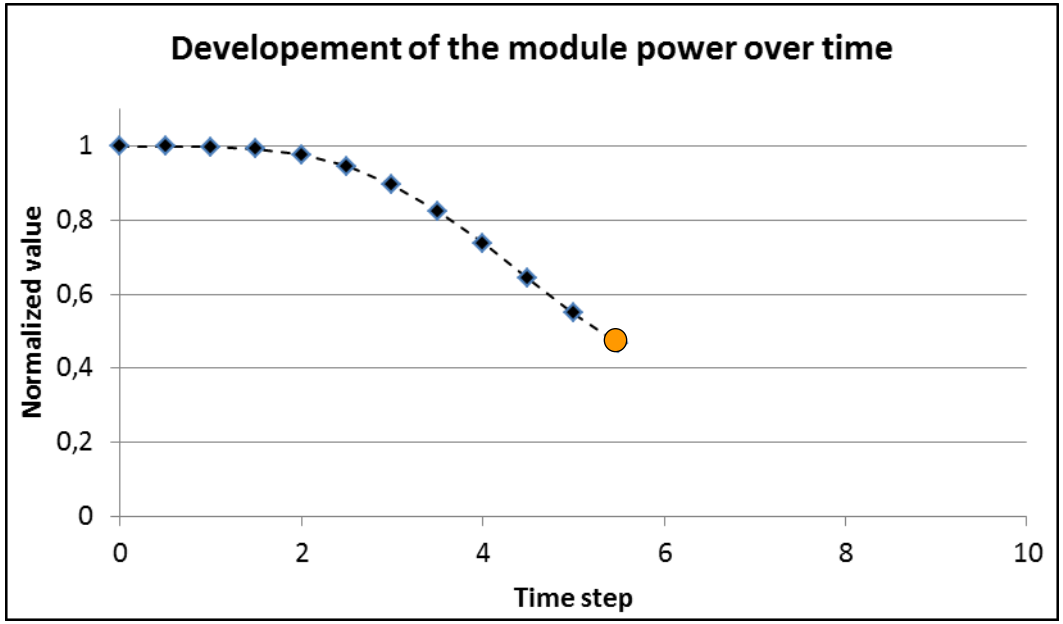
The potential induced degradation process

Damp heat 85°C/85% r.H. -1000V (PID Test)

Electroluminescence



STC Power

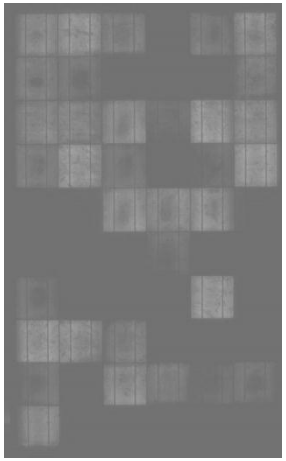


- Slow degradation at the beginning
- Develope to an exponentiale like grows in the middle
- Flattens at the end

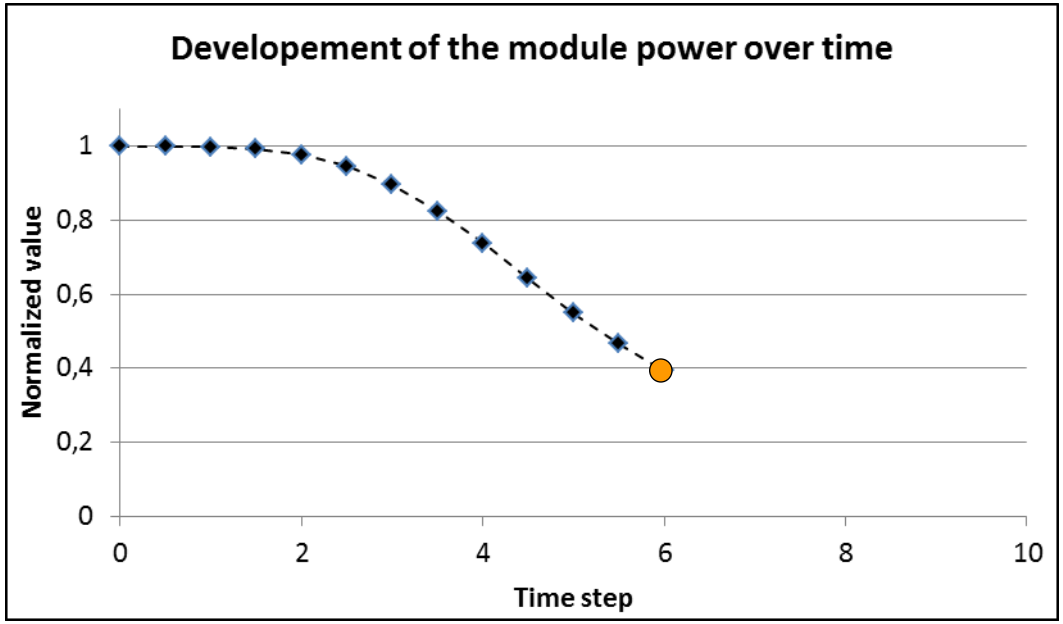
The potential induced degradation process

Damp heat 85°C/85% r.H. -1000V (PID Test)

Electroluminescence



STC Power

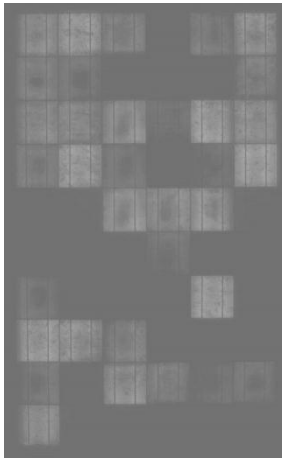


- Slow degradation at the beginning
- Develope to an exponentiale like grows in the middle
- Flattens at the end

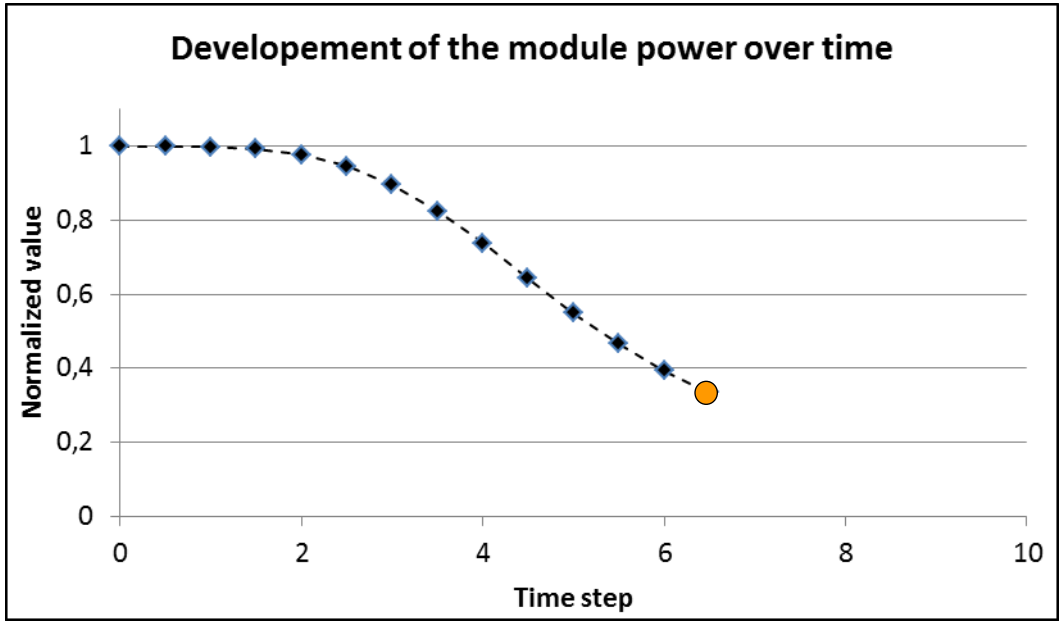
The potential induced degradation process

Damp heat 85°C/85% r.H. -1000V (PID Test)

Electroluminescence



STC Power

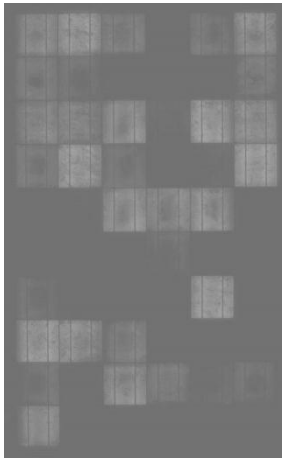


- Slow degradation at the beginning
- Develope to an exponentiale like grows in the middle
- Flattens at the end

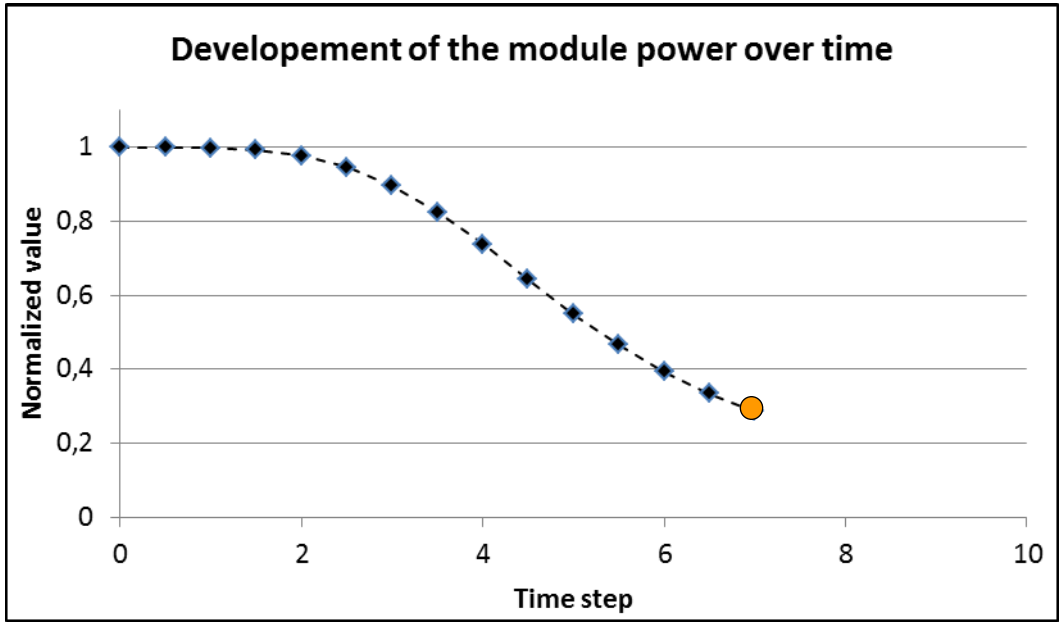
The potential induced degradation process

Damp heat 85°C/85% r.H. -1000V (PID Test)

Electroluminescence



STC Power

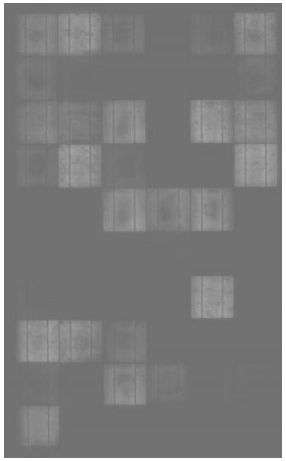


- Slow degradation at the beginning
- Develope to an exponentiale like grows in the middle
- Flattens at the end

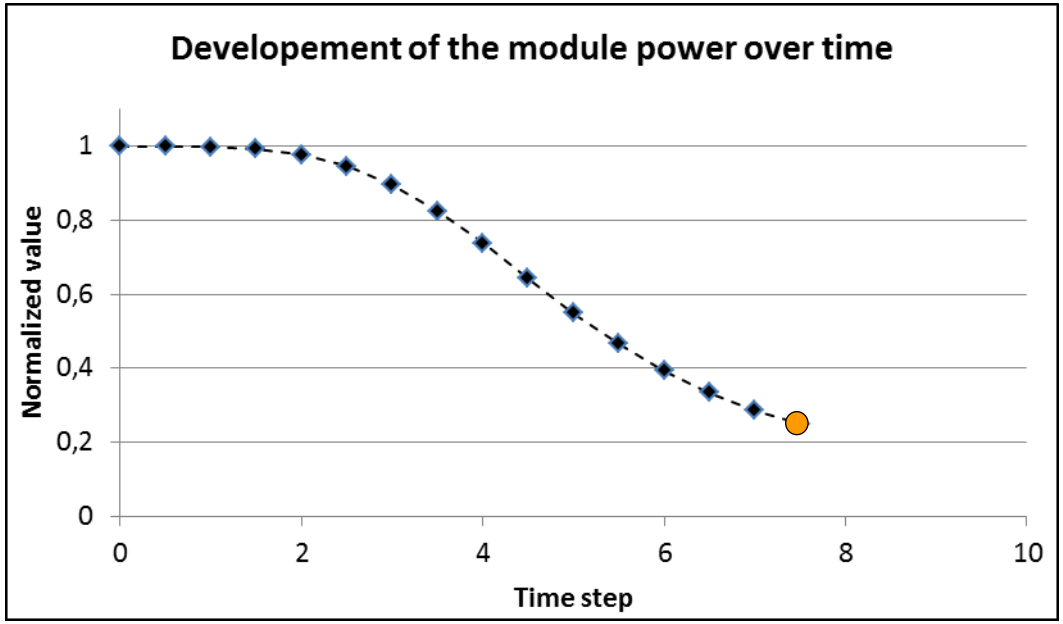
The potential induced degradation process

Damp heat 85°C/85% r.H. -1000V (PID Test)

Electroluminescence



STC Power

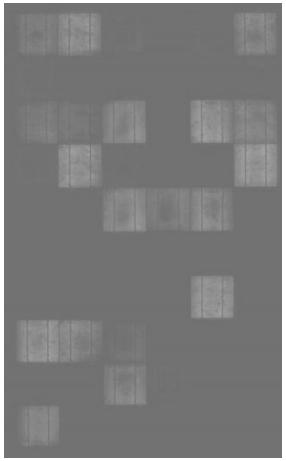


- Slow degradation at the beginning
- Develope to an exponentiale like grows in the middle
- Flattens at the end

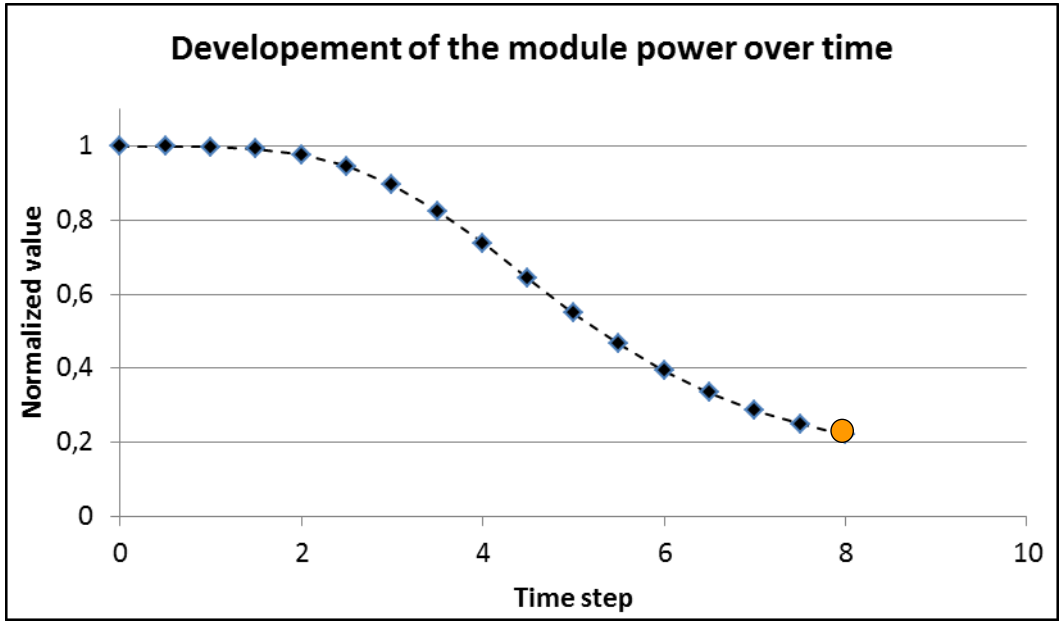
The potential induced degradation process

Damp heat 85°C/85% r.H. -1000V (PID Test)

Electroluminescence



STC Power

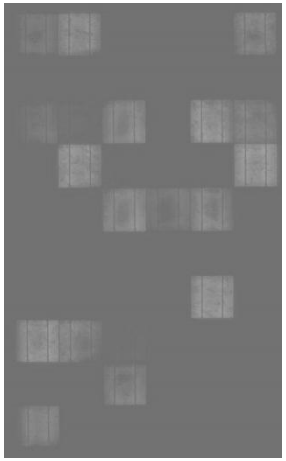


- Slow degradation at the beginning
- Develope to an exponentiale like grows in the middle
- Flattens at the end

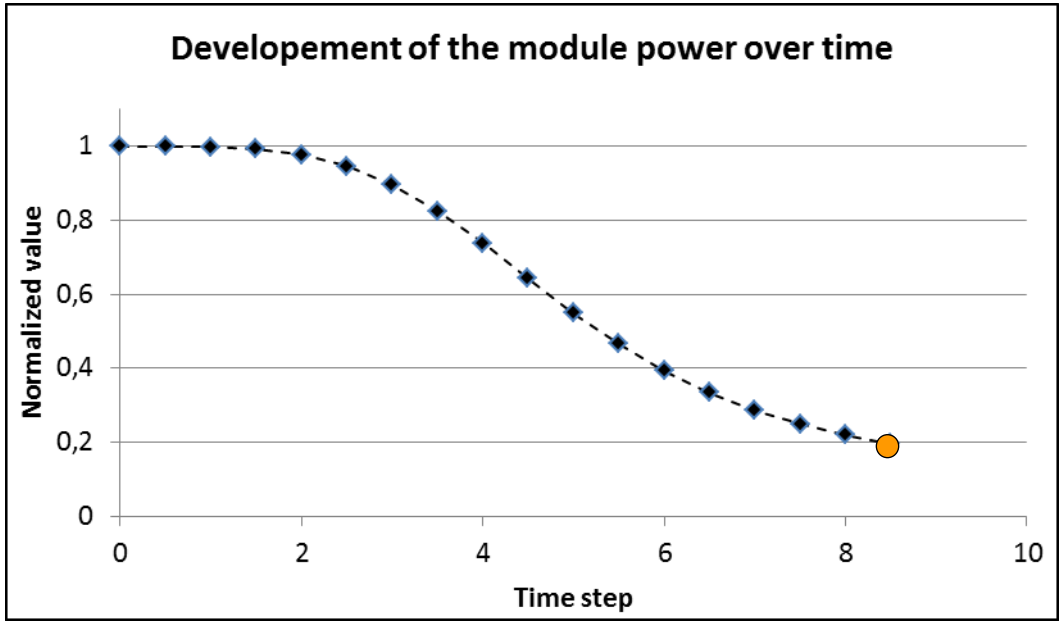
The potential induced degradation process

Damp heat 85°C/85% r.H. -1000V (PID Test)

Electroluminescence



STC Power

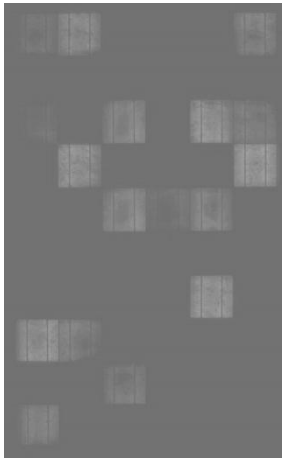


- Slow degradation at the beginning
- Develope to an exponentiale like grows in the middle
- Flattens at the end

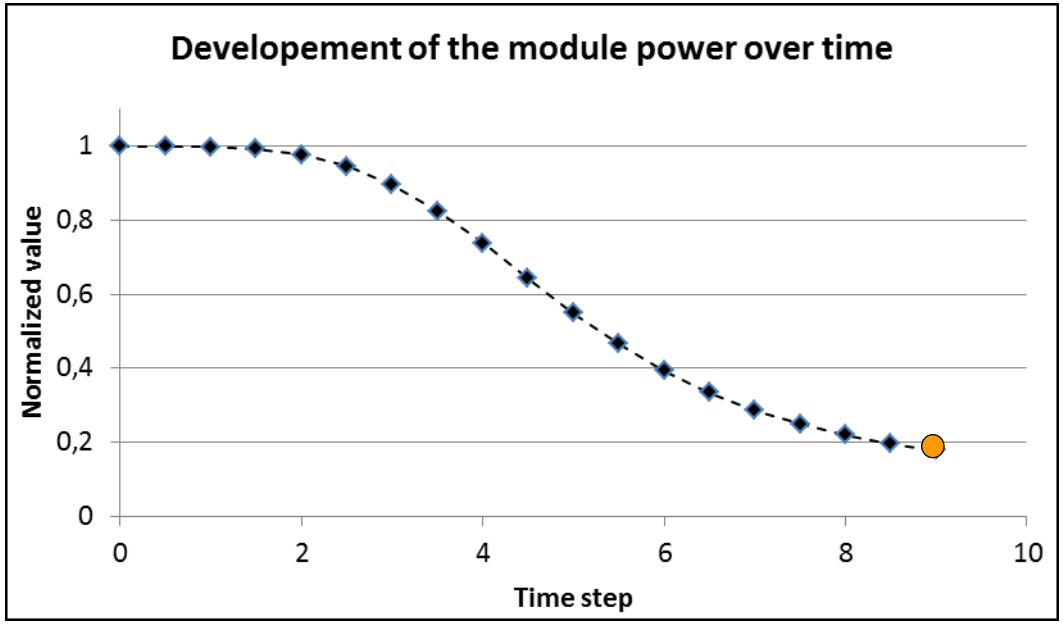
The potential induced degradation process

Damp heat 85°C/85% r.H. -1000V (PID Test)

Electroluminescence



STC Power

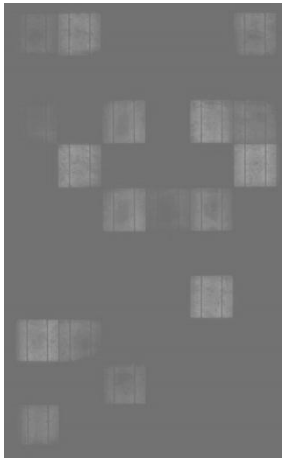


- Slow degradation at the beginning
- Develope to an exponentiale like grows in the middle
- Flattens at the end

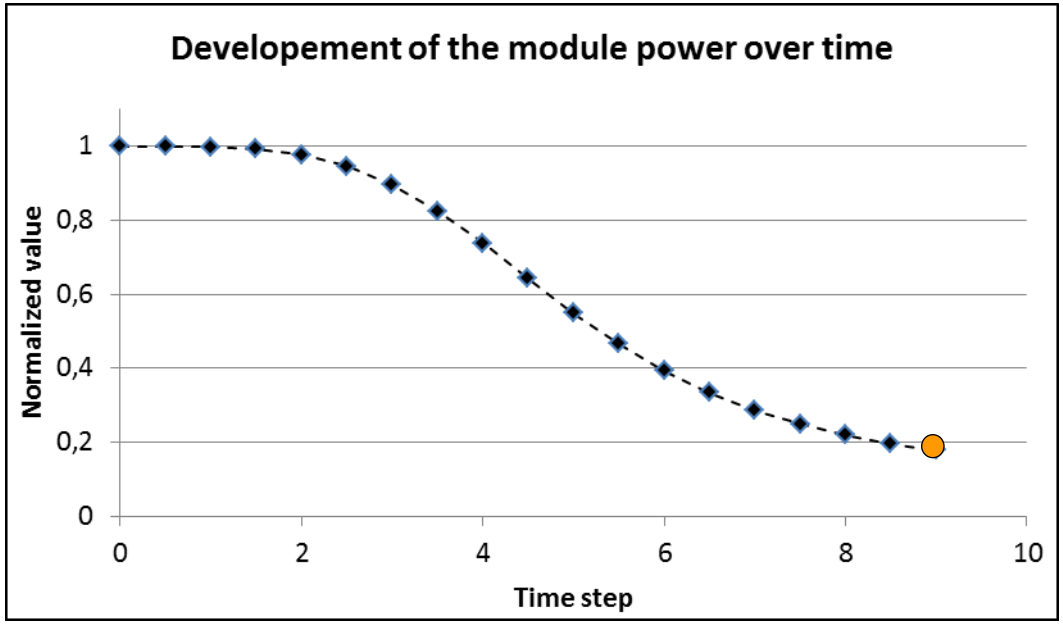
The potential induced degradation process

Damp heat 85°C/85% r.H. -1000V (PID Test)

Electroluminescence

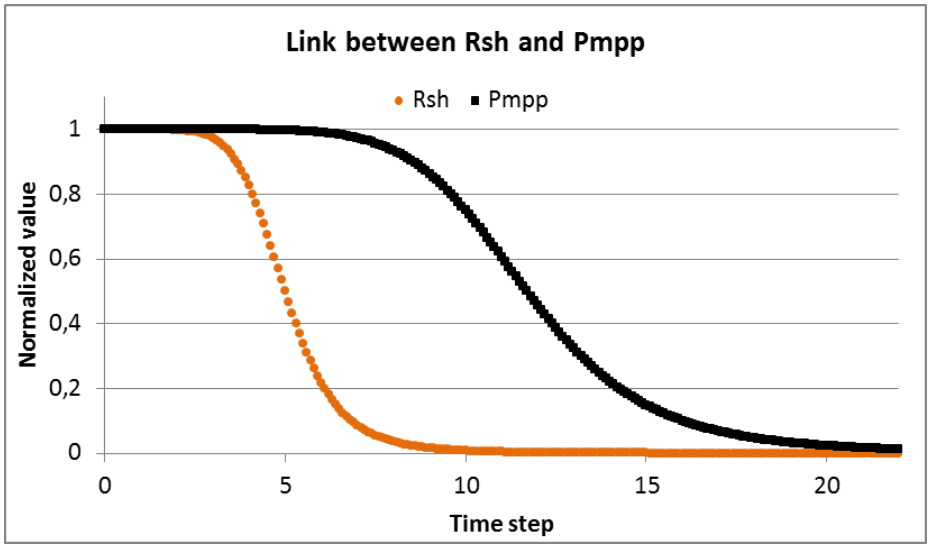


STC Power

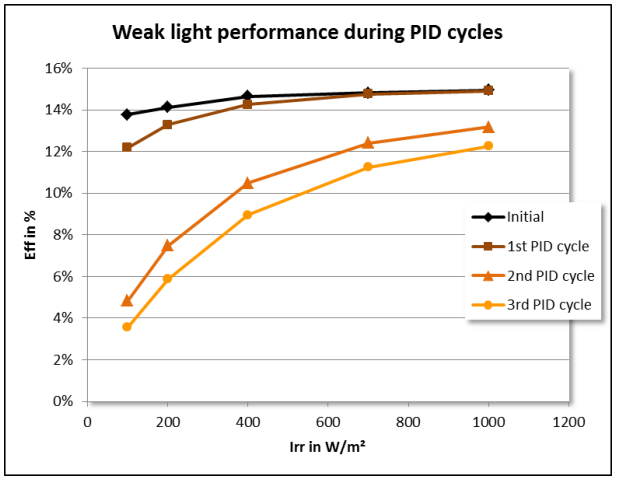


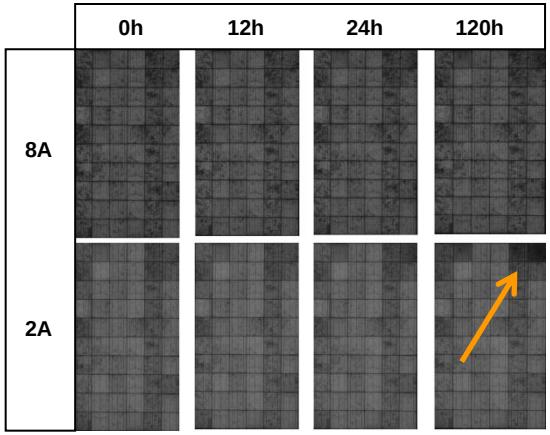
- Slow degradation at the beginning
- Develope to an exponentiale like grows in the middle
- Flattens at the end

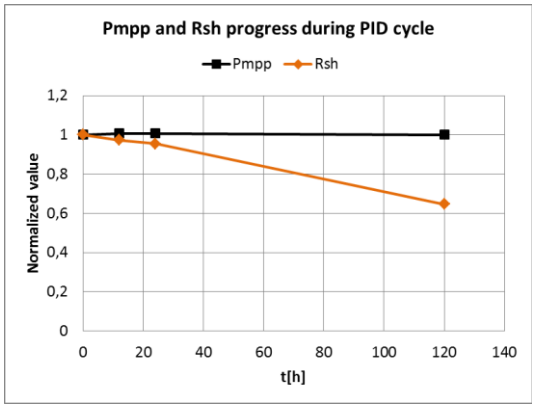
The link between Rsh and Pmpp



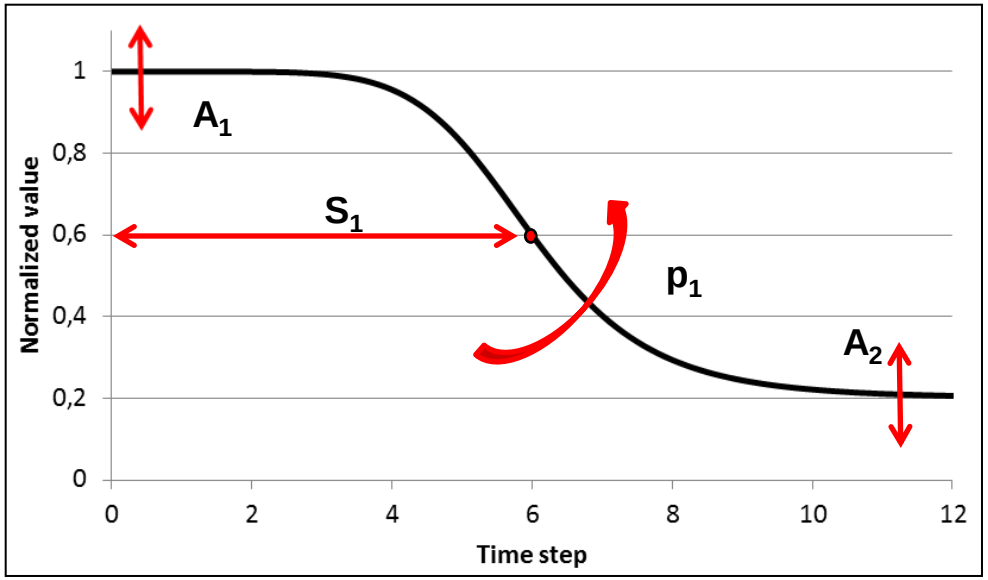
- Rsh is connected with the Pmpp of a cell or module according to the two diode model
- The Rsh is an indicator for PID
- This can be visualized with weak light graphs or electroluminescence images
- **Both progresses are following a logistic function**







The PID model based on a logistical function



$$f(x) = \frac{A_1 - A_2}{1 + (\frac{x}{s_1})^{p_1}} + A_2$$

Power function

Alternative notation:

$$f(x) = \frac{A_1 - A_2}{1 + e^{p_1 * (x - s_1)}} + A_2$$

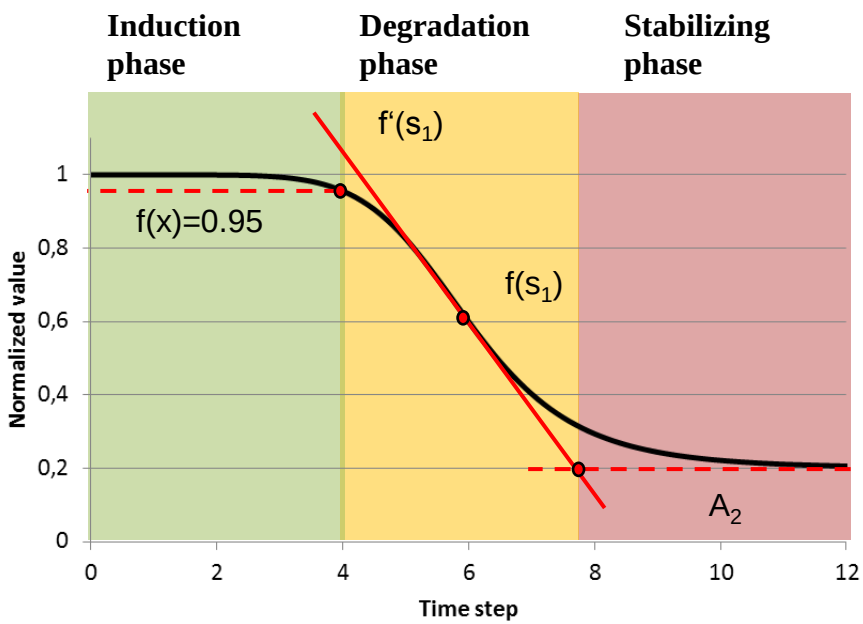
Exponential function

- First presented by Pierre Verhulst (1804 - 1849) to describe the grows of the population in Paris

Main characteristics of the functions

- A_1 gives the start value (it will be 1 when looking at normalized values)
- s_1 gives the position of the inflection point
- p_1 gives the power of the function
- A_2 gives the end value of the function
- $f'(s_1)$ gives the slope in the inflection point

The PID model based on a logistical function



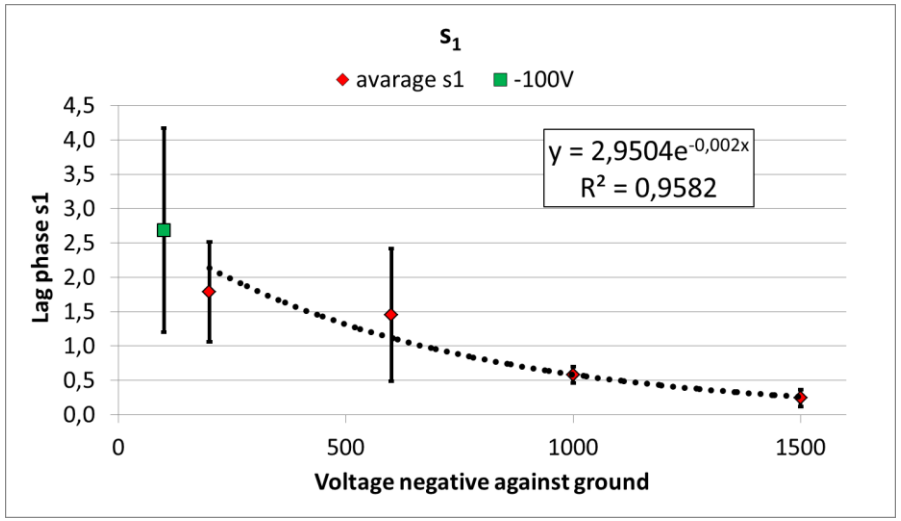
$$f(x) = \frac{A_1 - A_2}{1 + (\frac{x}{s_1})^{p_1}} + A_2$$

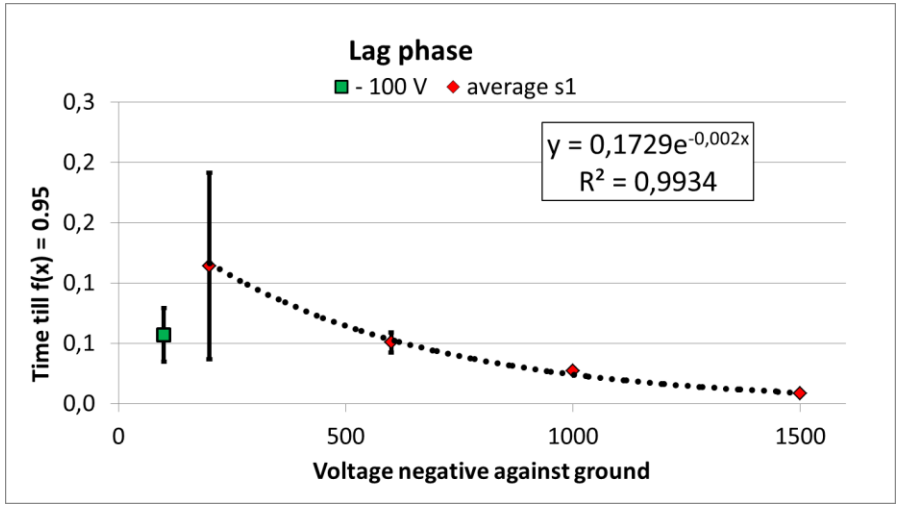
$$f'(x) = \frac{-(A_1 - A_2) \cdot p_1 \cdot (\frac{x}{s_1})^{p_1}}{x \cdot ((\frac{x}{s_1})^{p_1} + 1)^2}$$

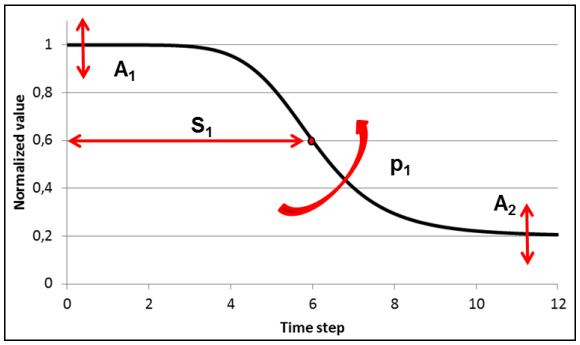
Derivative of f(x)

- The induction or **lag phase** is defined as the time till f(x) = 0.95
  - → The **lag phase** is mainly influenced by $\mathbf{s_1}$
- The **degradation phase** is defined as the time from f(x) = 0.95 till $f'(s_1)*x + a_0 = A_2$
  - → The **degradation phase** is influenced by $\mathbf{p_1}$ and $\mathbf{S_1}$
  - → The average **degradation velocity** is defined as $\mathbf{f'(s_1)}$
- The **stabilizing phase** is defined as the time after degradation phase
  - → The **stabilizing phase** is manly influenced by $\mathbf{A_2}$

Application example: Voltage and R_{SH}

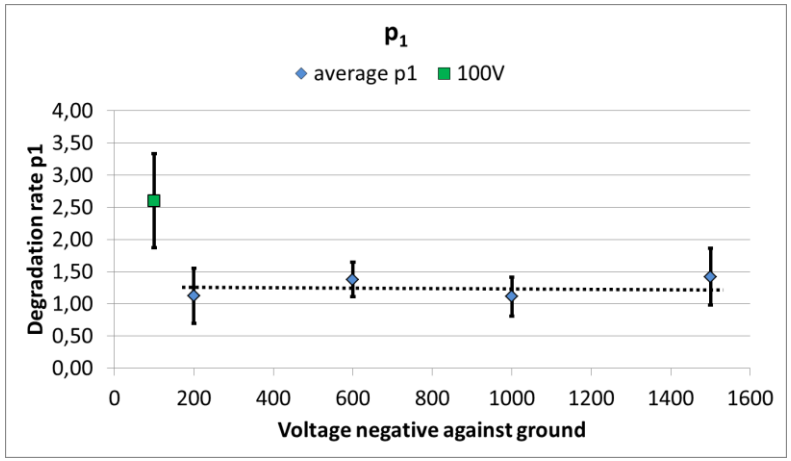


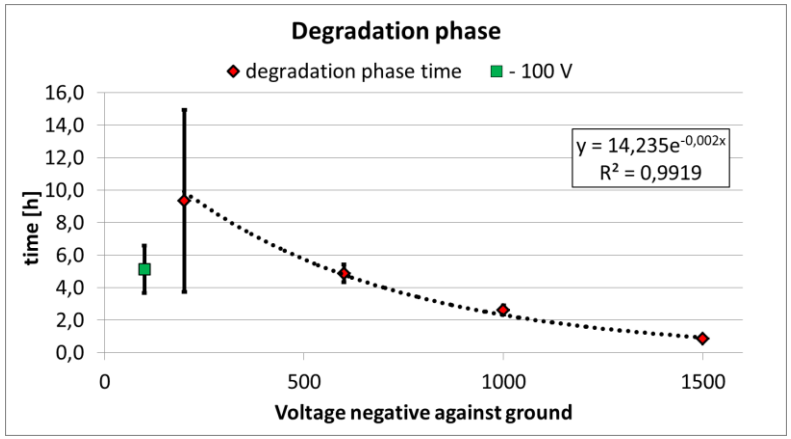


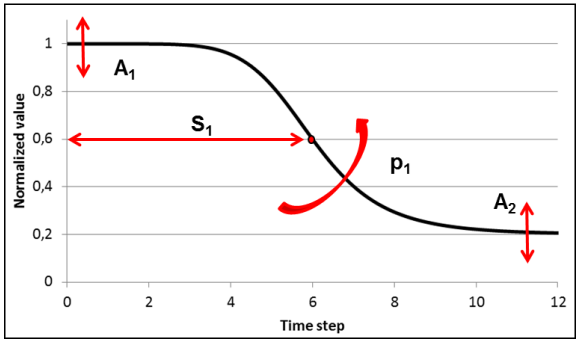


- The s_1 parameter is decreasing with the voltage
- The lag phase is decreasing as well and can be described by an exponential function
- It seems that the sodium ions need more time to reach the cell surface or to accumulate to a certain level
- The value for -100 V does not fit the other values

Application example: Voltage and R_{SH}



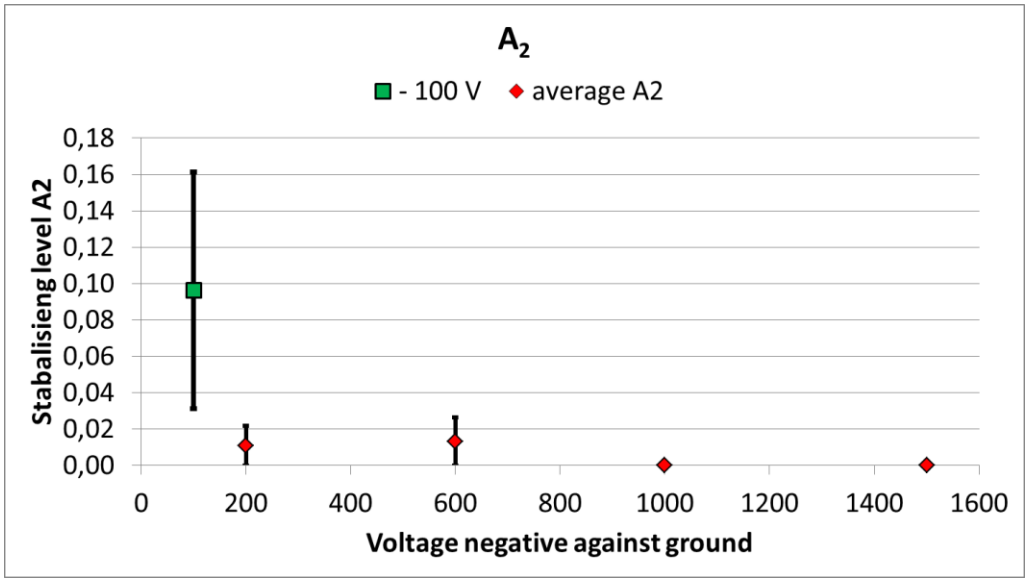


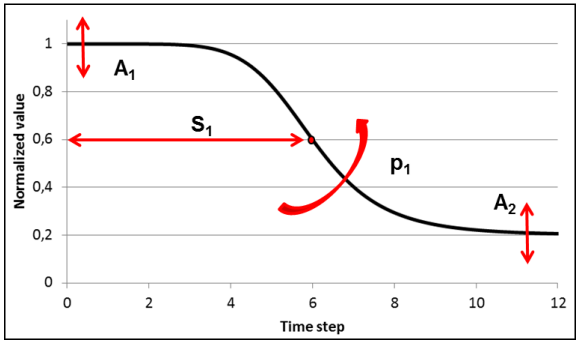


$$f'(s_1) = \frac{(A_2 - A_1) \cdot p_1}{s_1 \cdot 4}$$

- The degradation rate stays nearly stable for all voltages
- The degradation phase time is also following an exponential grows
- It seems that the accumulation along stacking faults is also highly influenced by the voltage
- The value for -100 V does not fit the other values

Application example: Voltage and R_{SH}

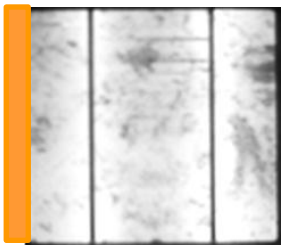




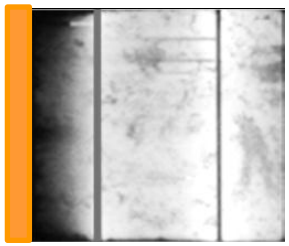
- The A_2 value is nearly zero for all voltages
- The A_2 value for -100 V does not fit the other values and the degradation progress can not readily be compared with the other voltages

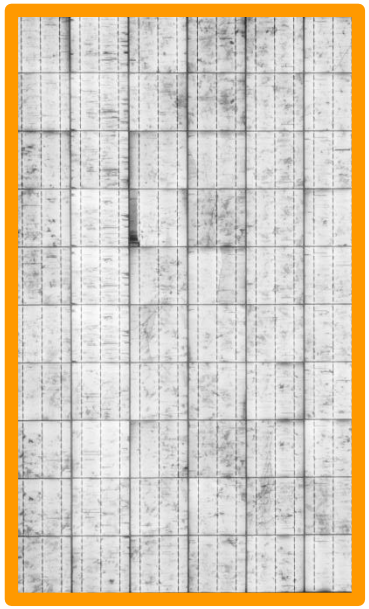
A closer look at A_2

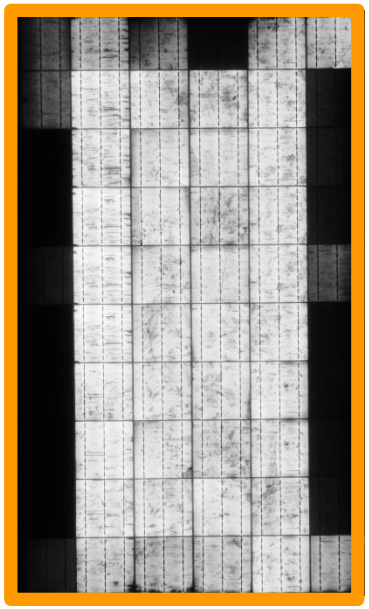
Bevore PID



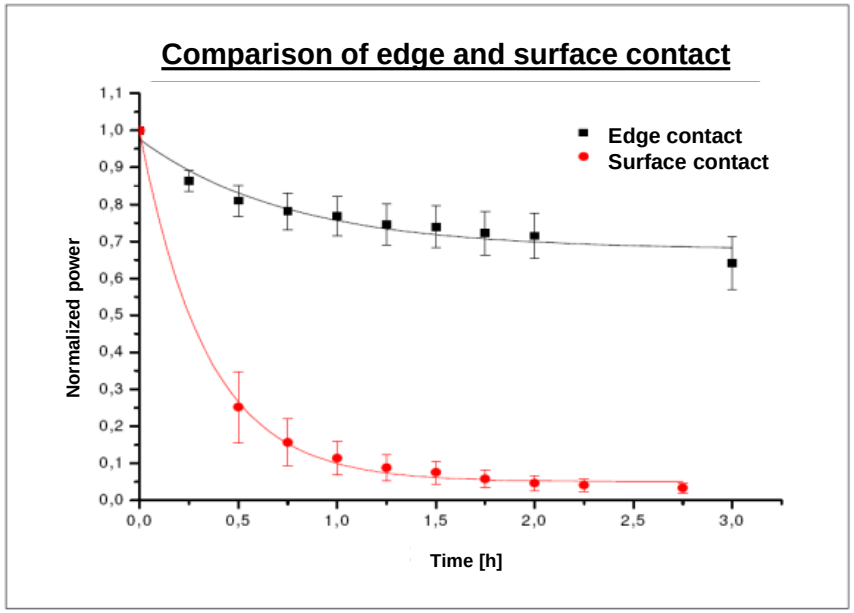
After PID degradation



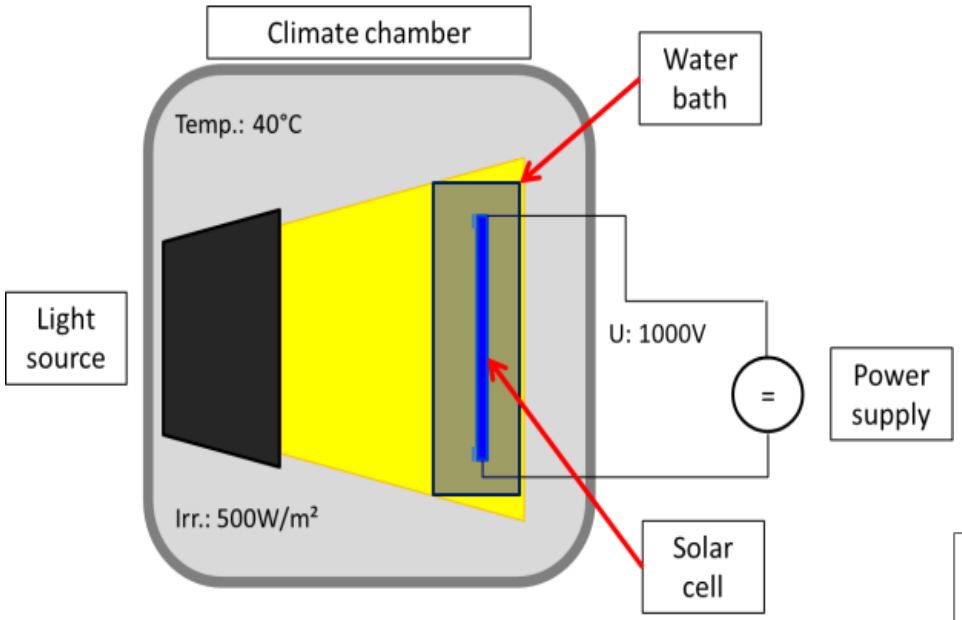




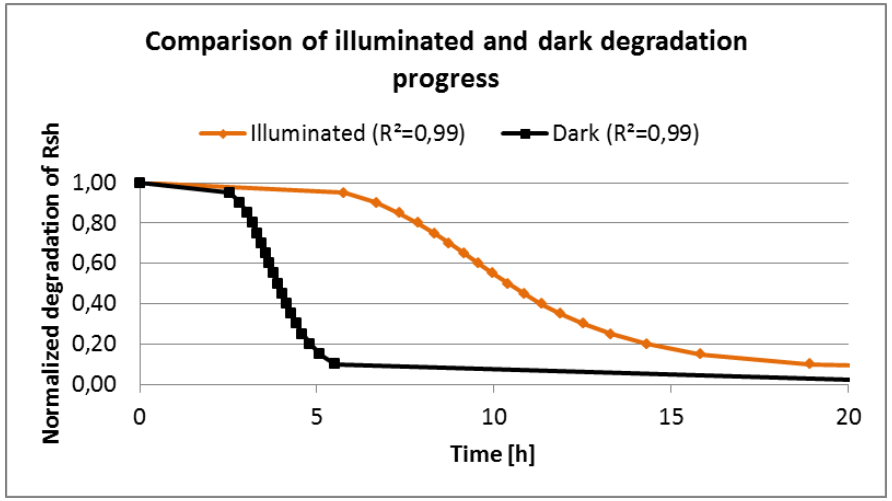
- A surface contact leads to full degradation ($A_2 = 0$)
- An edge contact leads to a degradation which stabilizes on a certain level ($A_2 > 0$)
- The voltage drops with the distance to the law of Coulomb (note: when surface is dry)



Application example: Irradiation and R_{SH}

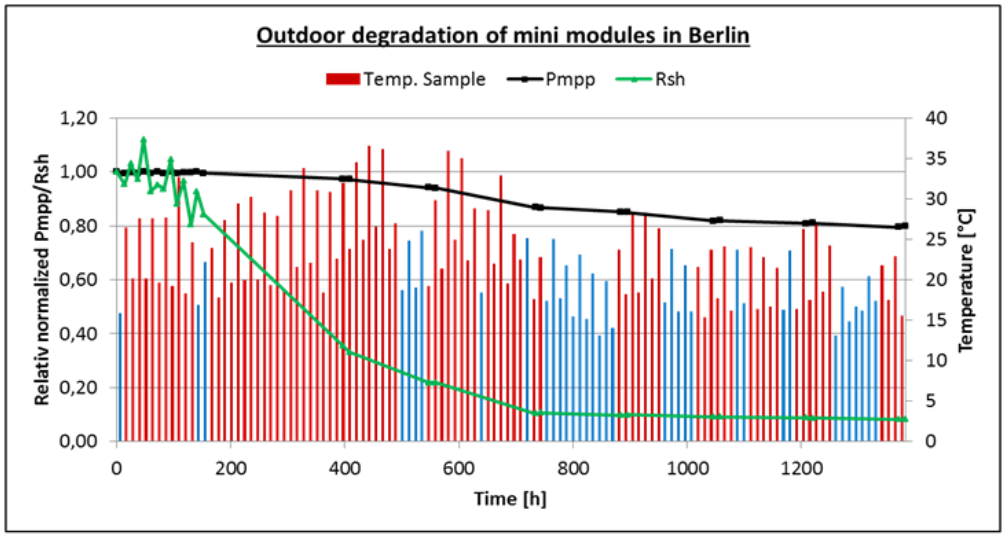


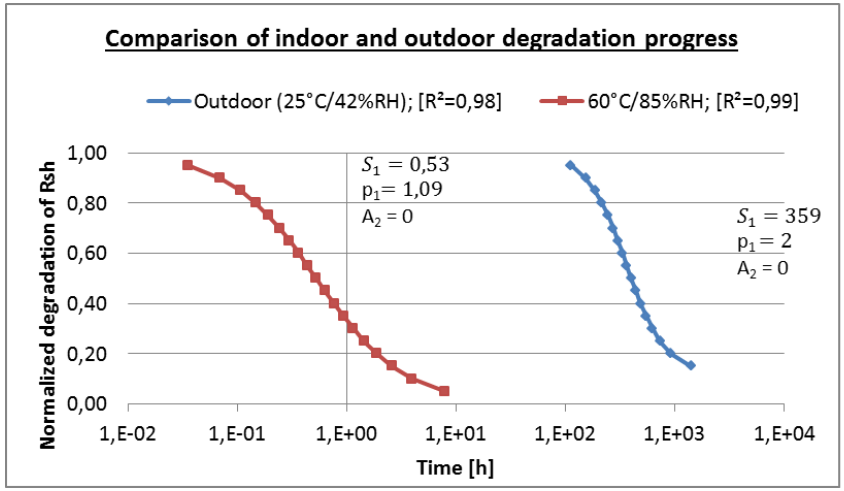
- The PID is decelerated by irradiation
- The s_1 value is 2.6 times higher
- The lag phase is 2.3 times longer
- The p_1 value is 0.7 times lower
- The degradation phase is 2.4 times longer



- It seems that the degradation is slowed down by a higher SiN_x conductivity (further investigations have to be done)

Outdoor degradation





- The outdoor degradation progress is also following a logistic function
- The acceleration between indoor and outdoor degradation was determined with 950 [note: the average module temperatures in Germany was 25°C]
- The goal of this model is to make an appropriate statement about the reliability by indoor test.
- **Indoor:** Stable temperature, humidity, contact, voltage
- **Outdoor:** Temperature gradient, humidity, changing contact area (rain, humidity, soiling), voltage relatively stable (fix string position), changing day duration
- **Additional regeneration:** Regeneration phase at night and deceleration due to irradiation

Summary

- A mathematical model which describes the degradation process was introduced
- Different degradation phases during PID were defined
- The influence of the voltage was investigated with the model
- It was shown that irradiation slows down PID
- Samples which are degraded under outdoor conditions fit also a logistic function

Thank you for you attention!