Generic, accurate annual yield calculation for PV modules based on fingerprint method

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PV Efficiency & Annual Yield

PV Power Conversion Efficiency (η)

$$\eta_{STC} = \frac{P_{max}}{A\ Pin}$$

P_{max} = max. generated power
A = device area
P_{in} = incident power per m²
(1000 W/m² at STC)

As P_{in} is well-defined, P_{max} is reasonably well-defined

$$J = J_{ph} - J_0\left(e^{\frac{q(V+JR_s)}{nkT}} - 1\right) + \frac{V + JR_s}{R_{shunt}}$$

$$V_{oc} = \frac{nkT}{q} ln\left(\frac{J_{Ph}}{J_0} + 1\right)$$

Annual (Electricity) Yield:
Y (in kWh)

Specific Yield (Y_p)

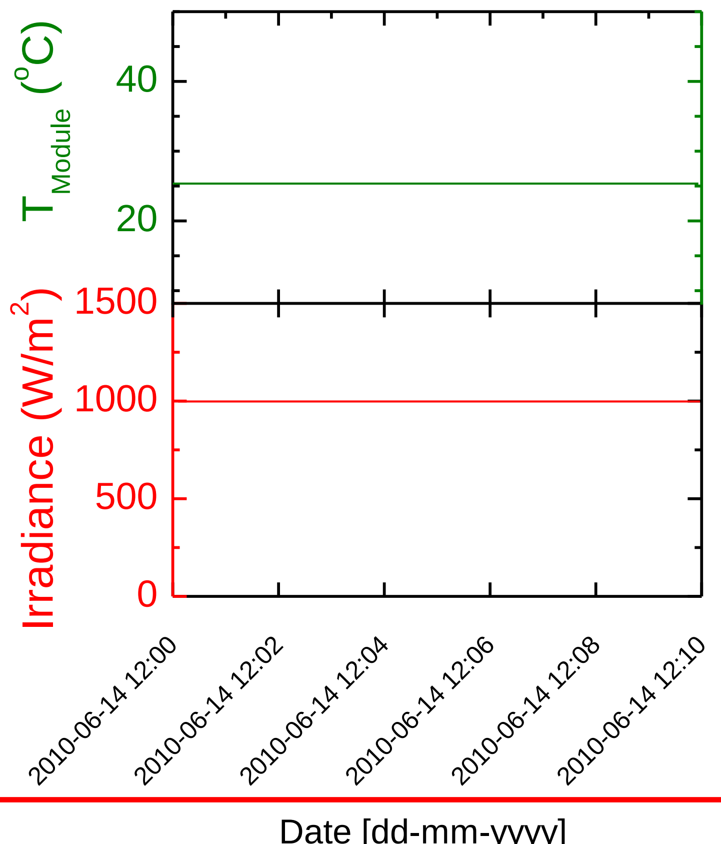
$$Y_p = \frac{Y}{P_{max}}$$ (in kWh/W_p)

Y depends on device efficiency η(S,T,G) &outdoor conditions (T,G):

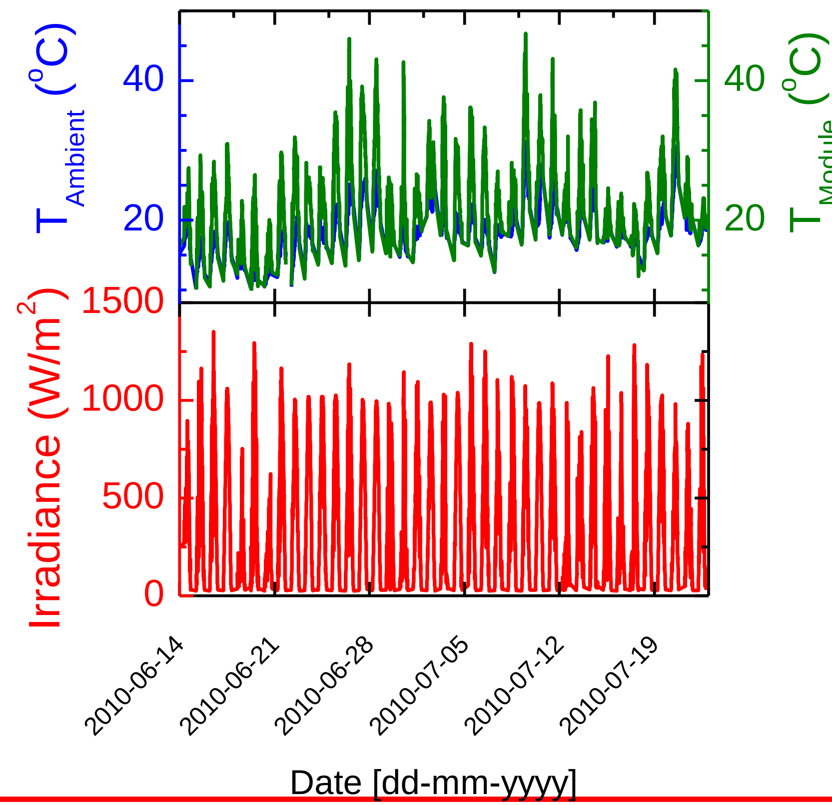
- $S(\lambda)$: Spectral response device
- T : Temperature
- $G_i(\lambda,\varphi,\delta)$: Irradiance (in W/m²) specified by:
  - Spectral distribution (λ)
  - Intensity
  - (Angle of incidence (φ,δ))

PV Efficiency & Annual Yield

Example A: Conditions during *IV* measurement



Example B: Conditions during yield measurements (NL, 1000 hr.)



PV Efficiency & Annual Yield

PV Power Conversion Efficiency (η)

- Relatively easy and fast to determine (see RRs)
- Gives a 'unique' value under steady-state conditions
- Directly correlated to system price (Euro/Wp)

Annual (Electricity) Yield:

- Time-consuming to determine
- Strongly depend on location
- Correlated to PV system revenue

  (kWh produced over lifetime)

Objective:
To provide a simple and accurate method for calculating the annual yield, based on outdoor IV characteristics of the module ("Fingerprint"), irradiance and ambient temperature data.

Outdoor test facility in Petten

Example A: south oriented
Azimuth angle = 170^{o}C

Example B: facade mounted PV modules

Measure simultaneously every 10 minutes:
- IV characteristics: Power output
- $T_{ambient}$ and T_{module}
- Irradiance (pyranometer and reference cells

Method

1. The irradiance (G_i), ambient temperature (T_{amb}), module temperature (T_{mod}) and power output (P_{mpp}) of a module is measured during a limited timeframe
2. A “Fingerprint” is made of the module based on these measurements
3. The yearly yield is calculated based on the Fingerprint of the module and annual data set of irradiance and ambient temperature.

Method

Fingerprint (FP) of module

Input: G_i, T_{amb}, T_{mod}, P_{mpp}

Calculate:

$\gamma_P = f(P_{mpp}, T_{mod}, G_i)$

$P_{mpp25} = f(P_{mpp}, T_{mod}, \gamma_P)$

Output:

FP1: $T_{mod} = f(G_i, T_{amb})$

FP2: $P_{mpp25} = f(G_i)$

Yield calculation

Input: G_i, T_{amb}, FP1, FP2

Calculated on base of FP:

$T_{mod} = FP1(G_i, T_{amb})$

$P_{mpp25} = FP2(G_i)$

Output:

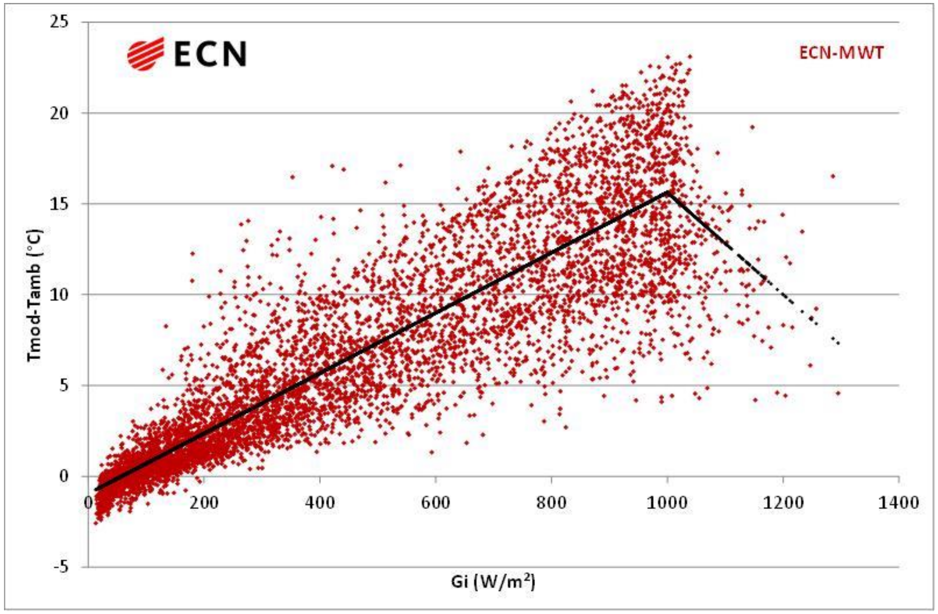
$P_{mpp} = f(T_{mod}, P_{mpp25}, \gamma_P)$

Yearly Yield

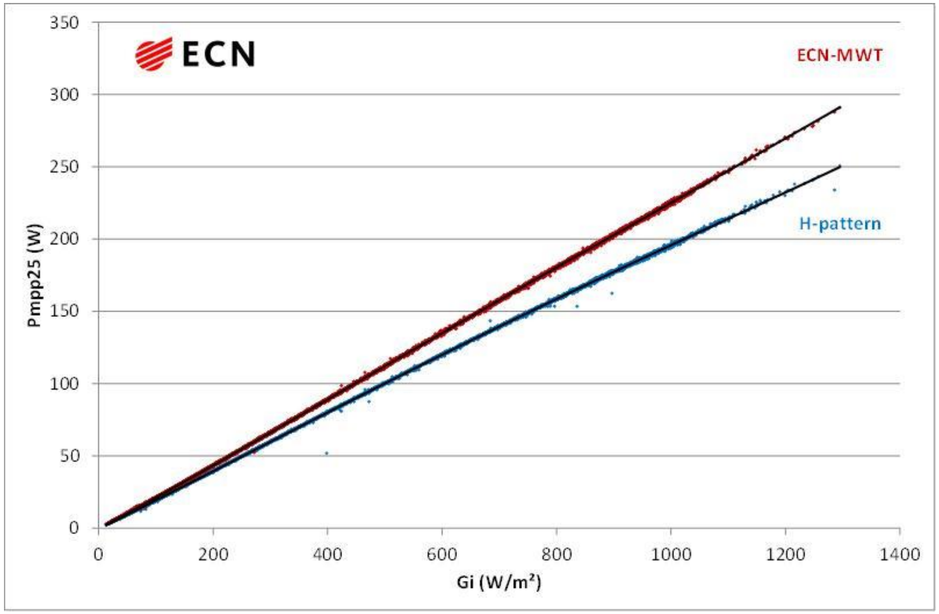
Results Fingerprint

- Example of the Fingerprint of wafer based modules (line = model)

FP1: : Tmod-Tamb vs. Irradiance



FP2: Pmpp @25°C vs. Irradiance



Yield calculation

Input: G_i, T_{amb}, FP1, FP2

Calculated on base of FP:

$T_{mod} = FP1\ (G_i, T_{amb})$

$P_{mpp25} = FP2\ (G_i)$

Output:

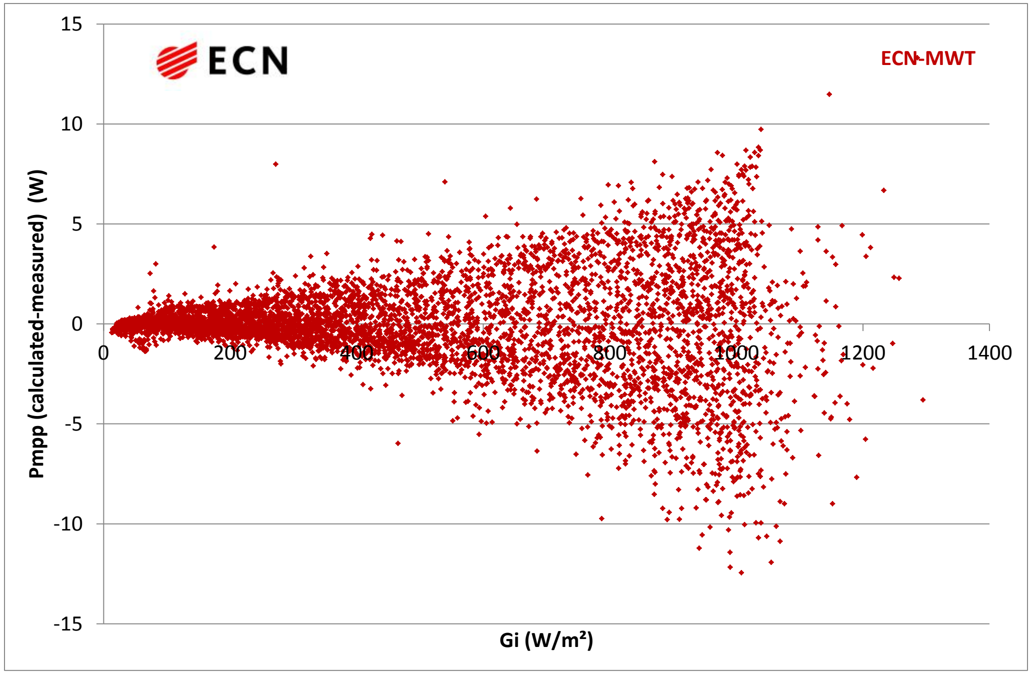
$P_{mpp} = f\ (T_{mod}, P_{mpp25}, \gamma_P)$

Yearly Yield

- The input for the annual yield calculation is the irradiance, ambient temperature and the fingerprint relations FP1 and FP2
- From FP1, irradiance and ambient temperature, the module temperature is calculated.
- From FP2 and the irradiance, the temperature corrected power Pmpp25 is calculated.
- The output power Pmpp can be directly calculated from the calculated module temperature and temperature corrected power Pmpp25 and the temperature power coefficient γ_P.

Data analysis

Pmpp(calculated - measured) vs. irradiance



Calculated / measured yield

Module	Yield
ECN-MWT	99.9%
H-pattern	99.9%
a:Si (TJ)	102%

Conclusions

- The “**Fingerprint**” method is a **simple and accurate method** for the calculation of the **yearly yield** of a module with the **irradiance** and **ambient temperature** as input parameters
- Applied for wafer based, inorganic and organic based modules
- The uncertainty can be reduced by adding wind data to the fingerprint calculations of the module temperature, which will reduce the spread of measured and calculated module temperature considerably

Reference:

N.J. Dekker et al . **ACCURATE YEARLY YIELD CALCULATION USING PV MODULE FINGERPRINT METHOD APPLIED FOR MWT, H-PATTERN AND THIN FILM MODULES.** PROCEEDINGS EUPVSEC, 2016, 5AV 6 40