# ACCURATE YEARLY YIELD CALCULATION USING PV MODULE FINGERPRINT METHOD APPLIED FOR MWT, H-PATTERN AND THIN FILM MODULES

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ABSTRACT: The yearly yield of a module in kWh/kWp depends on the module, the mounting of the module and the location. Accurate models for the calculation of the yearly yield can be very detailed and require many parameters. The parameters of these models are often difficult to determine. Simple models are often not very accurate. In this paper, a method will be described which is simple and accurate for x-Si (MWT back contact and H-pattern) and triple junction a:Si thin film modules.
The method consists of 2 stages. First a so-called fingerprint is made of the module at given location. The input for the fingerprint is the irradiance, ambient and module temperature and power output of the module during a limited timeframe. No IV curve, open cell voltage or short circuit current is required. Secondly the power output is calculated with ambient temperature and irradiance data as input, from which the yearly yield in kWh/kWp can be calculated.
The accuracy of the model was determined from the comparison of the calculated and measured module temperature and power output. For the x-Si modules, the deviation of the yearly yield was <0.1%, while for the a:Si the deviation was 2%. The higher deviation of the a:Si was due to the lower stability of the thin film module during the year of operation.
Keywords: Back Contact, Thin Film, Modelling, Stability, Yearly Yield, Fingerprint

## 1 INTRODUCTION

The power of a PV module in Wp is often only given at Standard Test Condition (STC). The yearly yield field performance of a module in kWh/kWp depends on many more factors, like the module characteristics (such as low irradiance power output, temperature coefficients, spectral response, anti reflective coating and location characteristics (such as irradiance distribution, ambient temperature, AM, ratio of direct and diffuse light and angle of incidence). Every module has its own characteristics, resulting in a different yearly yield in kWh per kWp per location. For these reasons, it is impossible to calculate the field performance accurately on only STC power output.

Hence, it is important to know the characteristics of the module, which can be described in many different ways. Some models are very detailed, based on the physics of the modules and require many parameters [1]. Other models are less detailed and often not very accurate. In this paper a simple, yet accurate method will be described for the calculation of the yearly yield of a module. The required fingerprint of the module is determined from outdoor measurements during a week up to a month depending on the sample rate, temperature and irradiance distribution. The method is proven to be accurate for different types of modules, such as thin film modules and wafer based H-pattern or MWT back contact x-Si modules. The yearly yield can be calculated for every type of module by the fingerprint method,, given the irradiance and ambient temperature during a year.

## 2 EXPERIMENTAL

### 2.1 PV Modules

In this paper, the results are shown for three types of PV modules. The first module is an in-house made foil based 60 cell MWT back contact x-Si module. The second module is a commercial available 54 cells H-pattern module. The third module is a commercial thin film a:Si triple junction module.

### 2.2 Measurements

The measurements were done with the outdoor IV tracer facility at ECN in Petten [2]. By this facility every 10 minutes the irradiance (Gi), module temperature (Tmod), ambient temperature (Tamb) and IV curves were measured at exactly the same time which appears to be the key factor for the quality of the dataset. At the moment, the system consists of 54 individual IV tracers and measurements are fully synchronized with the irradiance, temperature and wind sensors.

From the IV curve, the maximum Power (Pmpp) was derived. For the check of the accuracy and stability of the module during the fingerprint measurements, the open cell voltage (Voc) and short circuit current (Isc) are recommended to be measured but this is not necessary for the application of the method. Therefore a module connected with an MPP tracker could also be used for the fingerprint method.

## 3 METHOD

### 3.1 Principle of the method

First a so-called fingerprint of the PV module is made, which describes the module characteristics at given location recorded in a limited timeframe. Secondly the power output and yearly yield is calculated using the fingerprint of the module and a dataset consisting of ambient temperature and irradiance data of a whole year.

### 3.2 Fingerprint

The input of the fingerprint is the irradiance, ambient temperature, module temperature and power of the module during a certain timeframe. The required number of data points depends on the temperature and irradiance range.

First, the temperature coefficient of the power ($\gamma_P$) and the temperature corrected power at 25°C (Pmpp25) are calculated (see Fig.1).

From this data, 2 characteristic fingerprint relations are derived, namely:

- FP1: The relation between the module temperature, ambient temperature and the irradiance. In this case, a linear relation between the module and ambient temperature was assumed with the irradiance excluding the influence of wind or heat capacity of the module.
- FP2: The relation between temperature corrected power and the irradiance. In this case a fourth order polynomial was used (see Appendix A).

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

**Figure 1**: Fingerprint (FP) of the module

The relations FP1 and FP2 are the input for the yearly yield calculation.

3.3 Yearly yield calculation

The input for the yearly yield calculation is the irradiance, ambient temperature and the fingerprint relations FP1 and FP2 (see Fig. 2).

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 $\gamma_P$.

***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

**Figure 2**: Yearly yield calculation

In this way, the expected power output Pmpp is directly calculated from the irradiance and ambient temperature, using the relations FP1 and FP2 as characteristics of the modules.

## 4 RESULTS

### 4.1 Fingerprint of the module

The fingerprint is given by the description of the module temperature and power output as function of the irradiance.

#### 4.1.1. Module temperature

In Figure 3, the relation between the difference of the module and ambient temperature is given as function of the irradiance. The line is the linear relation as derived from the data. Irradiance above 1000 W/m² is due to cloud enhancement and will therefore only occur during days with fast moving clouds. This requires a relative high reflectance of the clouds and will therefore only occur during cloudy days. During cloudy days the module temperature will be lower, resulting in a drop of the temperature for irradiance above 1000 W/m².

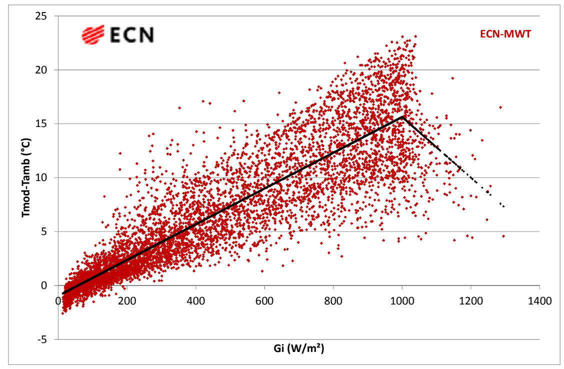


**Figure 3:** FP1: Tmod-Tamb as function of the irradiance of the 60 cells MWT module (points are measurements, line = model)

#### 4.1.2. Temperature corrected power output

In Figure 4 the temperature corrected power output is given as function of the irradiance of the x-Si modules.

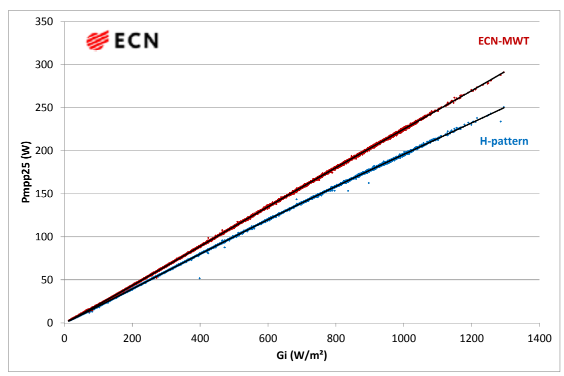


**Figure 4:** FP2: The temperature corrected power output (25°) as function of the irradiance for the x-Si modules (points are measurements, line = model)

The foil based ECN-MWT power output is almost linear with the irradiance. This is due to the very low series resistance of this type of module. The deviation from linearity of the H pattern module by the series resistance is very well illustrated by the model.

4.2. Yearly yield calculation

For the yearly yield calculation, the module temperature and power output are calculated from the ambient temperature and irradiance.

4.2.1. Module temperature

The module temperature is calculated from the Fingerprint of the module (Fig 3), the ambient temperature and the irradiance. The module temperature was also measured. The difference between the calculated and measured module temperture is given in Figure 5.

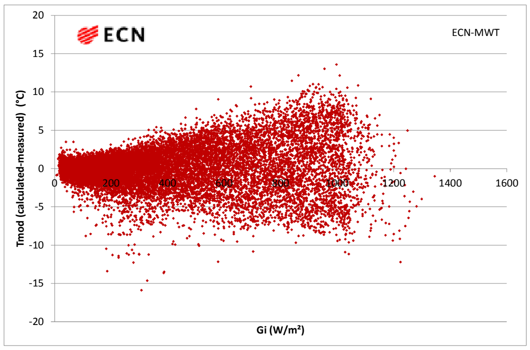


**Figure 5**. The difference between the calculated and measured module temperature as function of the irradiance (60 cells ECN-MWT module)

From this figure it is clearly seen that the difference between the calculated and measured temperature is evenly distributed around 0. The deviation increases with the irradiance up to 10°C. This is problably due to the effect of wind which is not taken into account in the model. The average deviation is <0.1°C, which shows that the fingerprint description on average is sufficiently accurate.

4.2.2. Power output

The temperature corrected power output at 25°C is calculated from the fingerprint of Figure 4 and the irradiance data. The power output is calculated from the temperature corrected power output, the module temperature and the temperature coefficient of the power ($\gamma_P$). In Figure 6, the difference of the calculated and measured power output is given as function of the irradiance for the ECN-MWT module.

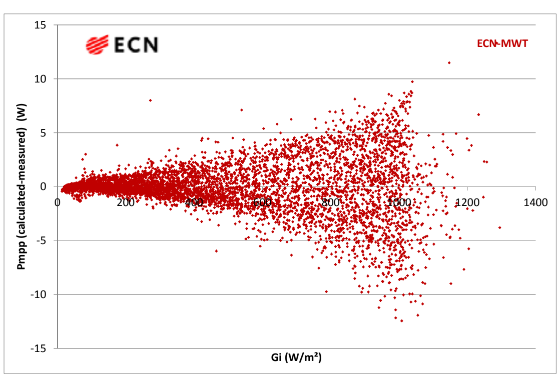


**Figure 6:** The difference between the calculated and measured power output as function of the irradiance (60 cells ECN-MWT module)

The difference between the calculated and measured power is evenly spread around 0 with a maximum difference of 10W at an irradiance of 1000W/m². The difference correlates with the deviation in temperature of Figure 5. The average deviation is <0.1W, which shows that the fingerprint description on average is sufficiently accurate.

The total power output of the three types of modules (ECN-MWT, H-attern and a:Si(TJ) were subsequently calculated using the irradiance and ambient temperature dataset of one specific year as input values. During this period, the power output was also measured.

In Table I, the ratio between the calculated and measured power output is given for the three modules.

Table I: Calculated / measured yield

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

The deviation of the calculated/measured yield for the x-Si modules is <0.1%. For the triple junction a:Si module the deviation is somewhat larger (2%), and is due to the lower power output of the modules after the fingerprint period.

## 5 CONCLUSIONS

The fingerprint method is a simple and accurate method for the calculation of the yearly yield, based on the ambient temperature, irradiance data and the fingerprint of the module as input. The method can be used for the calculation of the yearly yield for different locations and field performance in combination with weather forecasted data. The average deviation of the yield is <0.1% for the x-Si modules and 2% for the a:Si module. The larger deviation in power of the a:Si module is due to the lower power output of the module after the fingerprint method.

The mean temperature deviation of the calculated and measured temperature is small (<0.1°C) since the deviation of the temperature as function of the irradiance is evenly spread around 0. The maximum deviation was 10°C at an irradiance of 1000W/m². The deviation is probably mainly due to the effect of wind which is not taken into account in this analysis

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## 7 REFERENCES

[1] Yordanov et al, EU PVSEC (2012), 4BV 2.26.
[2] Outdoor test facility at ECN, Petten. See http://www.sophia-ri.eu/fileadmin/SOPHIA_docs/documents/Sophia_RI_description_Outdoor_PV_module_test_facility_-_ECN.pdf

## Appendix A. Fitting the power output (FP2) as function of the irradiance by a polynomial.

The power output of a module is calculated by the following formula (1 diode model, all at 25°C):

$P = V_d * I - R_{se} * I^2$ with $I = I_{ph} - I_d - I_{sh}$.

This equation can be rewritten as

$P = a_o + a_1 * I_{ph} + a_2 * I_{ph}^2$

with

$a_o = V_d * (- I_d - I_{sh}) - R_{se} * (I_d^2 + 2 I_{sh} * I_d + I_{sh}^2)$
$a_1 = V_d + 2 * R_{se} (I_d + I_{sh})$
$a_2 = -R_{se}$

Nomenclature:

| | |
|---|---|
| $I$ | output current |
| $I_d$ | diode loss current |
| $I_{ph}$ | photo current |
| $I_{sh}$ | shunt current |
| $P$ | power output |
| $R_{se}$ | series resistance |
| $R_{sh}$ | shunt resistance |
| $V_d$ | voltage of diode |

If $V_d$ at $I_{mpp}$ was independent on the irradiance, $a_0$ to $a_2$ are constants. To correct for the slight increase of $V_d$ as function of $I_{ph}$ (and therefore also $I_d$ and $I_{sh}$), the $2^e$ order power polynomial is extended to a higher order. In most cases, fitting the data with a 3th order polynomial will give a sufficient accuracy. This can be checked by a comparison of the measured and calculated $P_{mpp25}/G_i$ as function of $G_i$ (see Figure A1). In this case, a $4^{th}$ order polynominal was used for the FP2 power output curve to describe both the shunt and series resistance accurately.

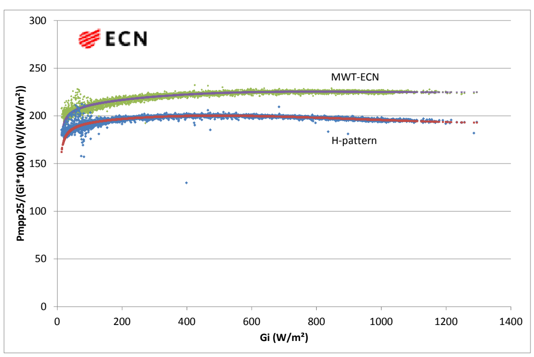


**Figure A1:** $P_{mpp25}/G_i*1000$ as function of the irradiance for the ECN-MWT and H-pattern module. (points are measurements, line = FP2 power curve based on $4^{th}$ order polynominal)