SIMULATION OF IRRADIATION AND TEMPERATURE DEPENDENT EFFICIENCY OF THIN FILM AND CRYSTALLINE SILICON MODULES BASED ON DIFFERENT PARAMETERIZATION

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ABSTRACT: For reliable energy yield predictions an accurate modeling of the PV module behavior is essential. In this analysis we compare two different possibilities for acquiring the necessary parameters: indoor measurements and data sheet values. We found that temperature coefficients of power given in data sheets can be used for yield prediction without introducing higher uncertainties. On the other hand the derivation of model parameters for the modeling of irradiation dependent efficiency of PV modules based on data sheets is associated with high uncertainties. In a sample of 50 PV modules only for 15 modules parameters from data sheets could be derived with a sufficient accuracy.
Keywords: Energy Rating, Modeling, Module

1 INTRODUCTION

For reliable energy yield predictions an accurate modeling of the PV module behavior is essential. In this analysis we compare two different possibilities for acquiring the necessary parameters: indoor measurements and data sheet values.

All simulations are based on the model developed by Heydenreich [1]. The model requires at minimum three module efficiencies at different irradiation conditions at a temperature of 25 °C to derive the parameters for the irradiation dependency and the temperature coefficient of power. So it can be parameterized using the information given in a data sheet according to EN 50380 [2].

2 AVAILABLE DATA

For the investigation we used a sample of 50 different modules measured at the Fraunhofer ISE CalLab. Each module is measured in steps of 100 W/m^2 from 100 to 1000 W/m2 at 25 °C and in steps of 1 °C from 35 to 65 °C at 1000 W/m^2. The parameters of the model can be derived from these measurements.

For the data sheets the necessary efficiencies can be derived from the given power at Standard Test Conditions (STC) and Nominal Operating Cell Temperature (NOCT) and the given deviation of efficiency at 200 W/m^2 compared to 1000 W/m^2. The temperature coefficient of power can be taken directly from the data sheet. For 26 of the 50 modules in the sample the necessary information was given in the datasheet.

Table I: Analyzed PV modules sorted by module technology

Technology	Number of modules
Monocrystalline Silicon	7
Polycrystalline Silicon	14
CdTe	3
CI(G)S	2

3 PARAMETER DERIVATION

3.1 Relative efficiency dependent on irradiation according to measurements

For all 26 modules with data sheet information available the relative efficiency dependent on irradiation were derived from measurements and from data sheets.

With the parameter derived from measurements the model in general agrees well with the measured data (see Figures 2-4). All errors are in a range of ±1%.

However the histogram of the residuals (Figure 1) shows a non normal distribution. This is due to the fact, that there is an over estimation of the model at 100 W/m^2 and an under estimation at 200 W/m^2 for most of the modules in the analysis. At the time of writing it is not clear if this is the result of measurement uncertainties at low irradiation or if it is a problem of the model itself. A test of the simulation procedure without using the 100 W/m^2 efficiencies showed that there is now significant influence on the results of this paper.

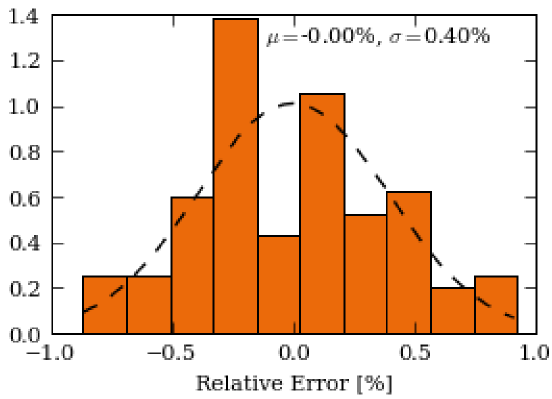

Figure 1: Histogram of relative errors between measured and modeled irradiation dependent efficiency for all measured points

3.2 Relative efficiency dependent on irradiation according to data sheets

For the parameter derived from data sheets the model agrees exactly with the data as there are three parameters and three data points available. 15 of the 26 data sheets are in good agreement with the measurements (see Figure 2). For 7 modules the difference between measurements and data sheet is relatively high (Figure 3) and for 4 modules the information in the data sheet do not represent an efficiency characteristic which appears to be physically reasonable (Figure 4).

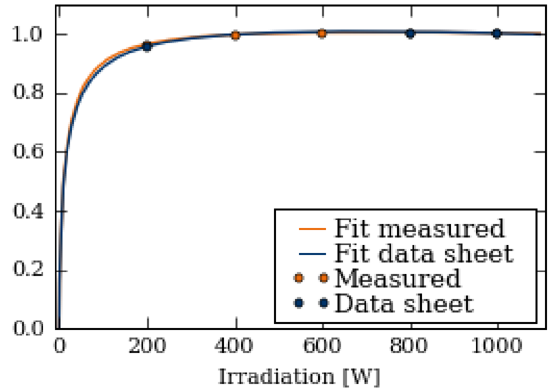

Figure 2: Example of a good agreement between measurement and data sheet for a polycrystalline module.

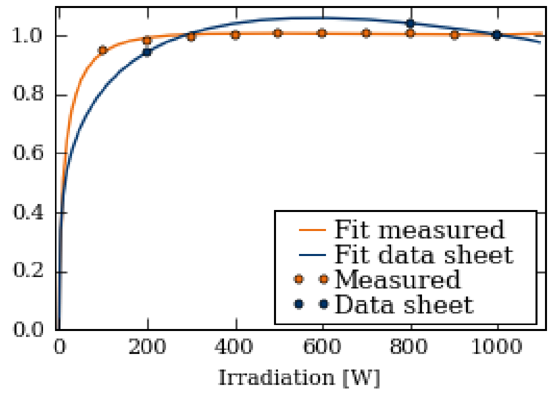

Figure 3: Example of a relative high deviation between measurement and data sheet for a monocrystalline module. In most cases the efficiency at NOCT is higher than the measurement, while the efficiency at 200 W/m^2 is lower than the measurement.

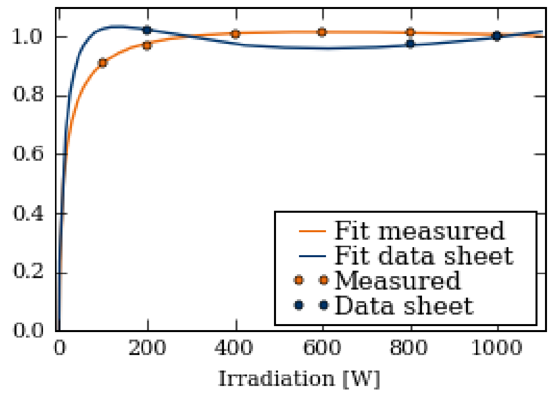

Figure 4: Example of a CdTe module where the information in the data sheet gives an efficiency characteristic which appears to be physically not reasonable

3.3 Temperature coefficients

As for the irradiation dependent efficiency the temperature coefficients of power for all 26 modules were derived from measurements. Here the residuals are smaller and seem to be normal distributed (Figure 5).

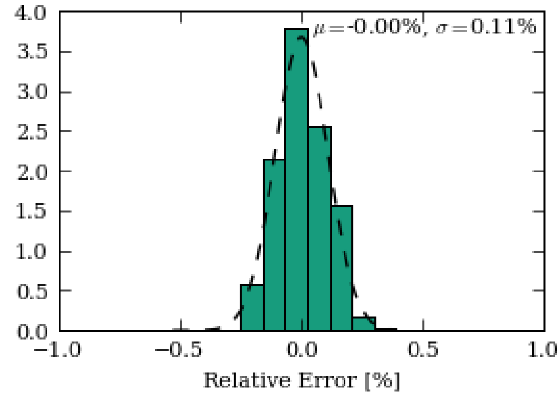

Figure 5: Histogram of relative errors between measured and modeled efficiency for all measured points

Figure 6 shows the absolute deviation between measured temperature coefficients and temperature coefficients given in the data sheet.

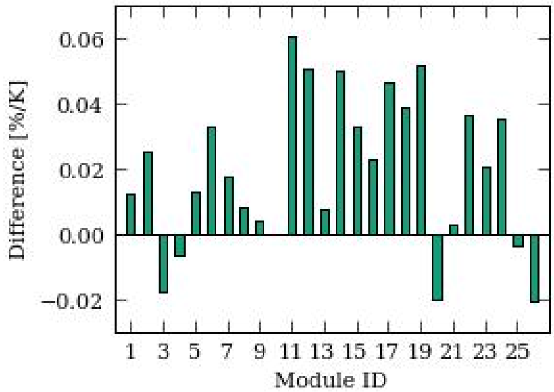

Figure 6: Difference between measured temperature coefficient of power and temperature coefficient from data sheet.

The mean difference is 0.02 %/K with a standard deviation of 0.02 %/K. So although the temperature coefficients in data sheets are slightly less negative than the measured coefficients, the differences are quite small and may possibly arrive from measurement uncertainties or module to module variations.

4 SIMULATION OF ENERGY YIELDS

To reflect the different module behavior based on the location we performed a simulation for a sample location with low irradiation / low temperature in Northern Germany and a sample location with high irradiation / high temperature in Southern Spain. From these simulations the losses or gains due to deviation of irradiation and temperature from STC over one year are calculated.

As expected the gain or loss for the irradiation dependent efficiency is relative small for Spain while the temperature dependent losses are high (Figure 7 and 8) and dominate the overall loss. For Northern Germany the picture changes: the temperature losses are small while the irradiation dependent losses dominate.

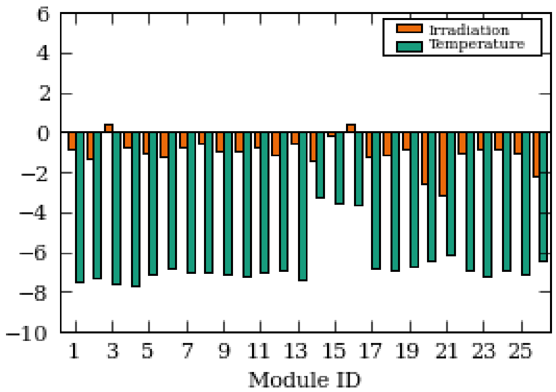

Figure 7: Gain or loss [%] due to deviation from STC for a location in Southern Spain simulated with the parameters derived from measurements

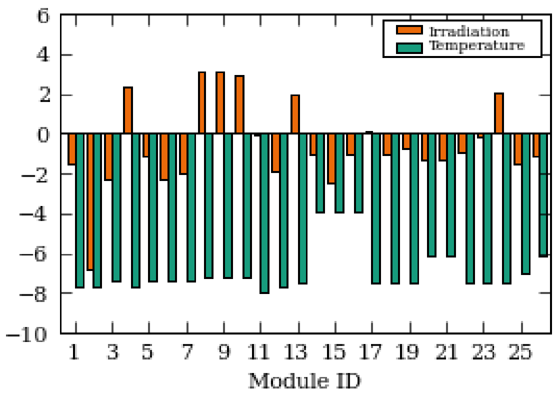

Figure 8: Gain or loss [%] due to deviation from STC for a location in Southern Spain simulated with the parameters derived from data sheets

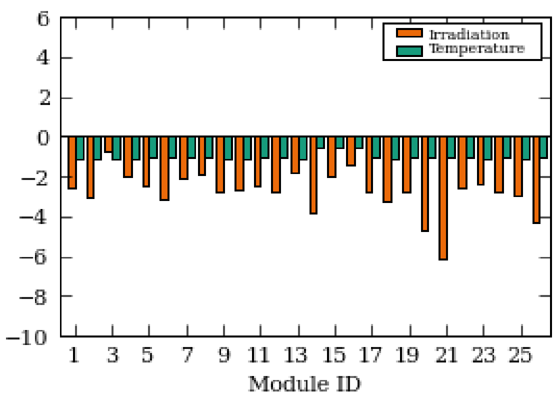

Figure 9: Gain or loss [%] due to deviation from STC for a location in Northern Germany simulated with the parameters derived from measurements

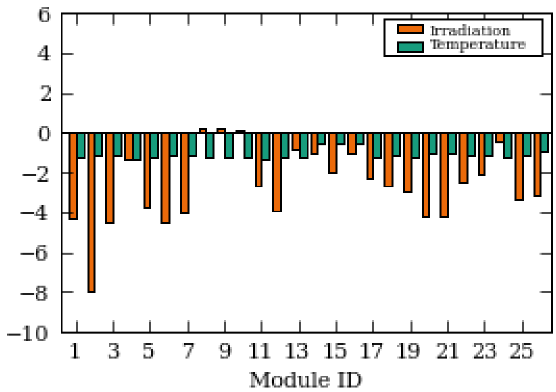

Figure 10: Gain or loss [%] due to deviation from STC for a location in Northern Germany simulated with the parameters derived from data sheets

5 RESULTS

To compare both possibilities for acquiring the parameter for PV module modeling we look at the differences between the simulation results. This difference directly reflects the difference in yearly energy yield based on both parameterizations. A positive difference means that the simulated energy yield based on the measurements is higher than the simulated energy yield based on the data sheet.

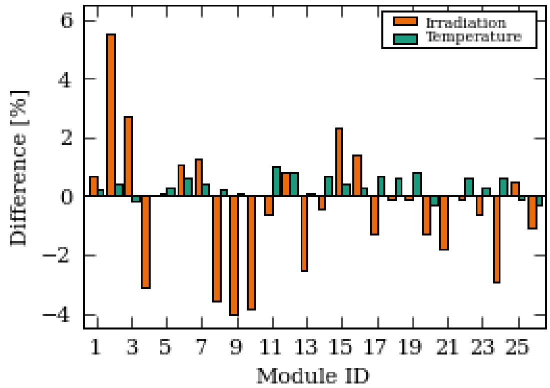

Figure 10: Differences in yearly energy yield between calculation based on measured parameters and based on parameters derived from data sheet for a location in Southern Spain

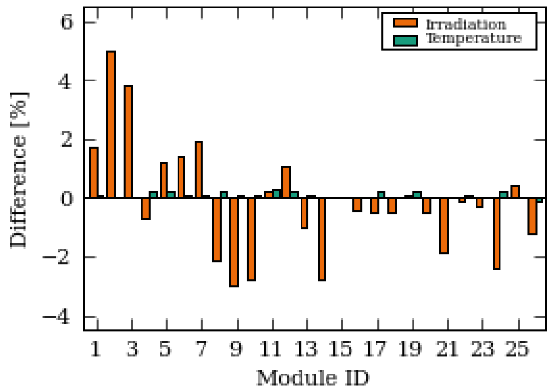

Figure 11: Differences in yearly energy yield between calculation based on measured parameters and based on parameters derived from data sheet for a location in Northern Germany

For the location in Northern Germany the mean difference for the irradiation dependency is -0.1 % with standard deviation of 1.9 %; for the temperature effect the mean is 0.1 % with a standard deviation of 0.1 %. In Southern Spain the mean difference for the irradiation effect is -0.4 % with a standard deviation of 2.2 % and the mean difference for the temperature effect is 0.3 % with a standard deviation of 0.4 %.

For the irradiance dependency the high standard deviation and differences of around -4 % to + 6 % in several cases show that using data sheet values is not appropriate for a sound energy yield prediction.

6 CONCLUSIONS

For yield predictions temperature coefficients from data sheets are sufficient. The difference between simulated yield with parameters derived from a data sheet and parameters derived from measurements is in the range of the measurement uncertainties or module to module variations.

The derivation of model parameters for the modeling of irradiation dependent efficiency of PV modules based on data sheets is associated with high uncertainties. In a sample of 50 PV modules only for 15 modules parameters from data sheets could be derived with a sufficient accuracy. For most of the modules sufficient information is either not available or not usable. The same applies to databases in commercially available simulation software without a strict check of all data [3][4].

To overcome this issue reliable information on data sheets should be required. The revision of IEC 61215 and the future IEC 61853 standard should require “matrix measurements” of module power over a broad irradiance and temperature range.

REFERENCES

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