IDENTIFICATION OF A GENERAL MODEL FOR THE MPP PERFORMANCE OF PV-MODULES FOR THE APPLICATION IN A PROCEDURE FOR THE PERFORMANCE CHECK OF GRID CONNECTED SYSTEMS

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ABSTRACT: To assure the maximal energy yield of grid connected PV systems, system faults have to be identified as quickly as possible. For this task several procedures that offer an almost continuous performance check are in development or application. One of them is the EU-funded project PVSat2. In the framework of this project, a model, able to reflect the efficiency characteristics η(G,T) at MPP of both the classic crystalline silicon and the various thin film technologies is analysed. The applicability of this model for the application to grid connected PV systems using cSi, aSi and CIS modules is demonstrated.

1 INTRODUCTION

To assure the maximal energy yield of grid connected PV systems, system faults have to be identified as quickly as possible. For this task several procedures that offer an almost continuous performance check are in development or application (see e.g. [1], [2]). They are mostly based on the identification of reference values of the performance that are estimated from information on the meteorological conditions (irradiance, temperature) that may either be gained by on site measurements or be remotely sensed, i.e. derived from the images of meteorological satellites. Within the project PVSat-2 (see. [3]), a continuation of the PVSAT project [1] funded by the European commission, a respective procedure based on remotely sensed hourly irradiance data is subject to further improvements. One field of improvements is the modelling of the performance of the generators.

Whereas in PVSAT, main emphasis was put on the modelling of modules with cells of the crystalline Silicon (cSi) type, PVSAT-2 aims to cover the whole range of different cell technologies. Thus a model, able to reflect the efficiency characteristics of both the classic crystalline silicon and the various thin film technologies is required. In the following a simple procedure for the estimation of the efficiency of PV-generators operated under MPP conditions in dependence of irradiance and module temperature η(G,T) is proposed. The application of this model is tested for Generators with cells made of crystalline silicon (cSi), amorphous silicon (a-Si) and copper-indium-diselenite (CIS).

2 A SIMPLE PROCEDURE FOR THE SIMULATION OF THE PERFORMANCE OF GRID CONNECTED SYSTEMS

The modeling of the DC-output of the PV generator with a physical model either calls for a large effort devoted to the identification of the parameters of a 2-Diode model (if cells made of crystalline silicon are concerned) for each module type or – as was done within PVSAT – the use of a `standard` parameter set, referring to the module that is most commonly applied. The errors associated with the use of this standard set for the modeling of crystalline cells had been discussed e.g. by [4].

In view of a broader application of thin film technologies, the 2-Diode model has its limitations and has to be modified (see [5]). This modification, even for the most simple thin film technologies (single active layer) increases the number of model parameters and the complexity of the parameter identification scheme.

In [6] an approach which consists of the use of a set of semi-empirical equations to characterize the dependence of the MPP current and voltage on irradiance and temperature was presented. It has its advantages in a straightforward (no iterative fitting) procedure for the identification of the model parameters from data sheet information and has proven its applicability for the modeling of the MPP performance of crystalline silicon cells and modules (see e.g. [7]). This model is however not exactly transparent. Therefore another approach for the modeling of the DC performance of grid connected, MPP-tracked PV generators is analyzed here.

Based on the analysis of the characteristics of modules made from both crystalline and amorphous silicon, and suggestions in [8], a model for the dependence of the efficiency in MPP operation on the Irradiance G at an operation temperature of 25ºC is proposed by [9].

$$\eta_{MPP}(G,25°C) = a1 + a2\cdot G + a3\cdot \ln(G\cdot 1/[Wm^2]) \quad (1)$$

a1 - a3 are device specific parameters.

The performance at operation temperatures other than 25ºC may then be modeled by the standard approach using a single temperature coefficient α:

$$\eta_{MPP}(G,T) = \eta_{MPP}(G,25°C) \cdot (1+ \alpha(T-25°C)) \quad (2)$$

Thus this model has in total 4 parameters which may be determined in straightforward manner from e.g.:

- the MPP-power at STC
- 2 values for the MPP power at other irradiances and at 25ºC
- the MPP-power at 1000 W/m² and a temperature other than 25ºC.

If data for the measured power output of systems in operation are available, the parameters may as well be fitted for that set. Due to the structure of the model simple linear fit procedures may be applied. A similar model proposed by [10], in which instead of the term $a_1+a_3\ln G$ the term $a_1 \cdot G^{a3}$ is used, calls for nonlinear fit procedures.

In the following we will present the application of this model for both, different module types and different input data sets.

3 EXAMPLE FOR THE APPLICATION TO THE MODELING OF A C-SI GENERATOR BASED OF DATA SHEET INFORMATION

Using data from systems out of the WEBlog supervision scheme [2] the model for the $\eta_{MPP}(G,T)$ performance is applied to c-Si generators.

For these generators, the necessary input data for the 3-point evaluation of the model parameters are available due to the application of the SolEm modeling tool [7] (except one: the MPP-current, necessary for calculating the MPP power the at the intermediate radiation level (500 W/m²) had to be estimated from the values of the MPP-current at 1000 and 100 W/m²).

Figure 1 shows an example for the estimated efficiency characteristics of a standard cSi module at 25ºC together with the 3 efficiency values used for the model determination.

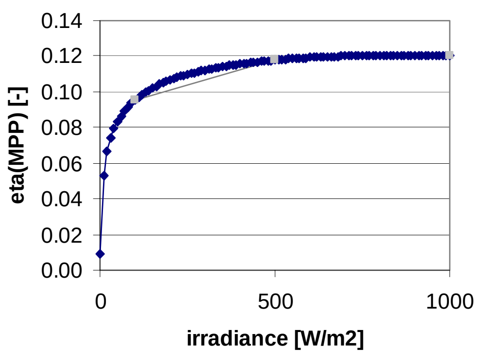

Fig. 1: Example for an efficiency characteristic of a cSi module at 25°C extrapolated from three sample values (single points connected by straight lines), using the efficiency model discussed here.

For the modeling of the temperature dependence (see eqn. 2) a default temperature coefficient of 0.45%/ºC is assumed.

As within the WEBlog scheme only data of the AC performance are available, a model for the simulation of the complete system performance was implemented using the INSEL simulation tool. Hereby the inverter efficiency is simulated according to the standard model [11] based on the respective manufacturers data. For the system losses it is assumed that 2% of losses have to be accounted for both, the mismatch and MPP-tracking errors. The maximum losses in the cables are assumed to be 4%. Due to these rough estimates in absence of more detailed information, the results have to be interpreted with some care.

Fig. 2 gives examples for the comparison of the performances of the new η (G,T) model and the SolEm procedure. Monthly sets of measured data (hourly averages) from 2 generators using modules of different manufacturers are shown. The performance of the new model is equivalent to slightly superior to the one of SolEm.

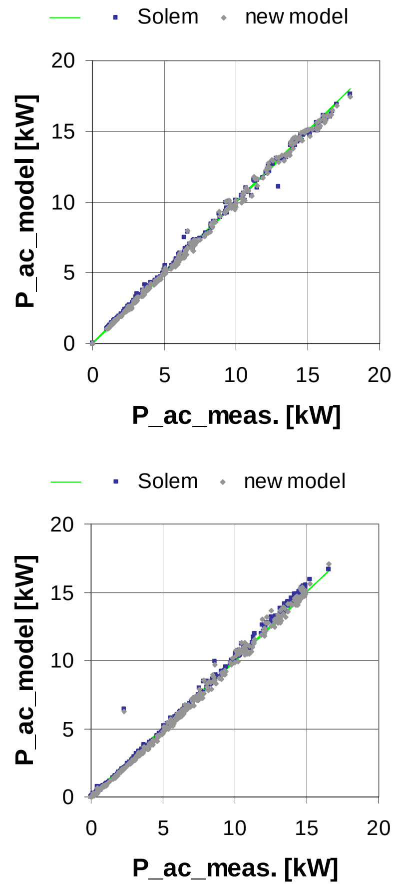

Fig. 2 a,b Scatters plot of simulated and measured power output of two PV generators with cSi modules taking part in the WEBlog supervision scheme. As simulation schemes, the SolEm procedure [7] (dark points) and the model described in the present paper (light points) are applied.

3 EXAMPLE FOR THE APPLICATION TO THE MODELLING OF A-SI GENERATOR BASED ON MEASURED DATA

At the Universidade Federal de Santa Catarina at Florianopolis, Brazil a PV generator made of amorphous silicon modules is in operation and monitored since 1997. Its initial nominal power output was 2 KW (see. e.g. [12]).

The model for the irradiance dependence of the MPP power was applied while testing the applicability of the PVSAT procedure for South America [13]. As no significant temperature dependence of the MPP-power could be identified (see [12]), the operation temperature was not taken into account by this fit (i.e: $\alpha = 0$).

Figure 3 shows measured hourly MPP-DC-efficiencies (month May and June 2002) as a function of the irradiance together with the efficiency model. The irradiance data are measured by a cSi-sensor (Matrix). A correction is applied to transfer these data to a set that presents values equivalent to pyranometer measurements. It can be remarked, that for irradiances >200 W/m² the efficiency of the generator is almost constant, with a small tendency to decrease with higher irradiances. The model performs reasonably for this data set.

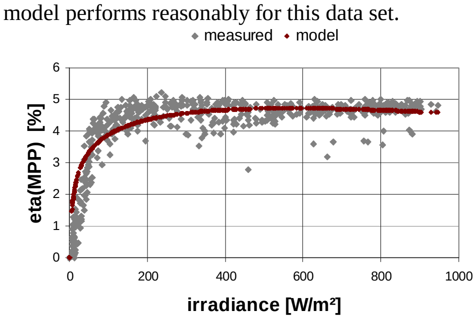

Fig. 3: One month of measured MPP-DC-efficiencies for the 2kW a-Si generator of the UFSC at Florianopolis, Brazil (grey diamonds). The dark squares indicate the efficiency according to the model fitted to this data set.

It should be remarked, that the DC data presented already include the losses due to the wiring and mismatch, which are therefore implicitly taken into account by the fitted model.

The use of the model with the parameter set identified on the basis of the data set for the month of May and June 2003 is tested for the months July 2002 to March 2003. Fig.4 gives the scatter of the measured and modeled monthly DC-yields for these 9 months. The deviations for these months are less then about 4% of the measured DC-yield.

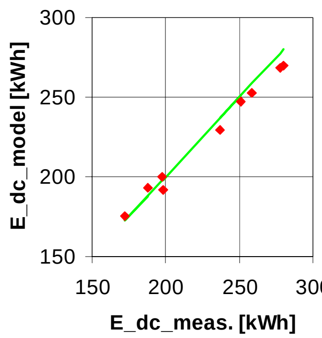

Fig.4 Comparison of the measured and modeled DC-yield of the aSi generator analyzed for the month July 2002 - March 2004. The model was adapted to data for May-June 2003. The maximum deviation is about 4%.

It can be seen, that the deviations show a systematic trend with increasing irradiances. This may however be due to an effect of the change of the predominant spectra from the winter (here: June, month used for model identification) to the summer months. The inclusion of a model to correct for these spectral effects has to be tested.

4 EXAMPLE FOR THE APPLICATION TO THE MODELLING OF A CIS GENERATOR BASED ON MEASURED DATA

For the analyses of the performance of a generator using modules with CIS technology a data set had been made available by the University of Applied Sciences Frankfurt. These data (5 min. averages) stem from a generator with a nameplate rating of 513 W, but is supposed to have a real rating of about 600 W. The measuring system uses a reference cell for the registration of the irradiance. These data are directly used in the following. Two month of data had been analyzed (February and August 2003). Due to the increased relative uncertainty of the radiation sensor at low radiation levels (G < 100 W/m²), the respective data are skipped.

The DC performance for these months is given in fig.5. The differences in the performance for these two months may be partly traced traced back to variations of the operating temperatures (max. values: February: 42ºC, August: 69ºC).

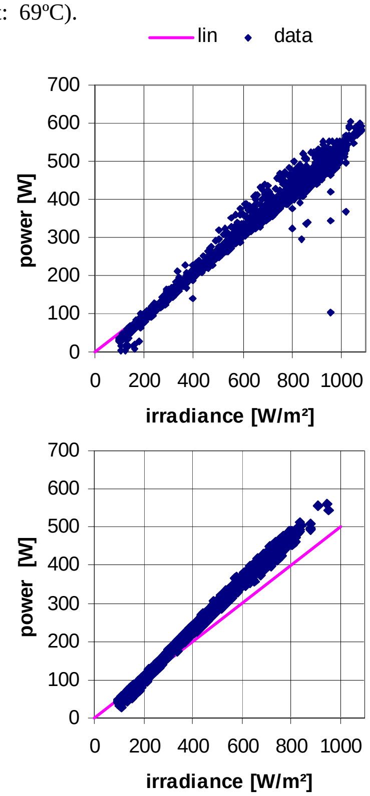

Fig. 5 a,b: Measured DC-performance of a generator using CIS modules. 5a (upper) refers to August 2003, 5b to February 2003. The straight line - identical in both plots - is added for orientation.

The data for the month of August are used for the identification of the model parameters a_1- a_3 and α by a least square fit. The results of the fit are given in fig. 6, showing normalized efficiency curves $\eta(G)/\eta_{STC}$ for the DC output at operation temperatures of 25ºC, 50ºC and 75ºC.

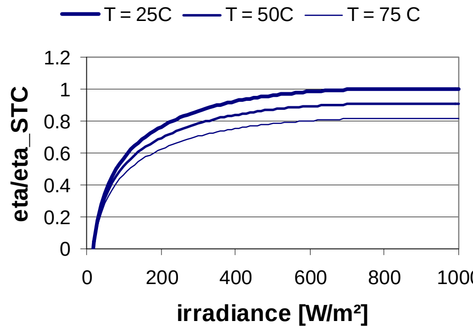

Fig. 6: Normalized DC-efficiency curves of a CIS generator as identified by a fit to the data presented in fig. 5a (month of August), calculated for operation temperatures of 25ºC(uppermost curve), 50ºC and 75ºC (lowest curve).

Applying this parameter set to the data of February results in the comparison of modeled and measured power output as given in fig. 7. The bias is 3.4 % (for the month of August, the month used to derive the model parameters the bias is less than 1%). The applicability of the model is also confirmed by the fact, that the value for temperature coefficient α (-0.36% / ºC) is in close agreement to the value of -0.3% / ºC that was determined under constant irradiance conditions (800 W/m² ± 10%) by [14].

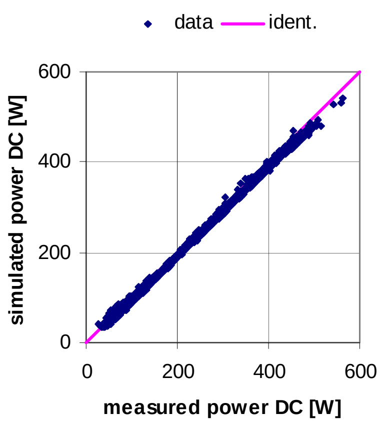

Fig. 7: Comparison of measured and simulated DC performance of the CIS generator for the February 2003. The straight line indicates the identity. The model parameters are derived from the data for August 2003.

5 CONCLUSIONS

The simple η(G,T) model for the MPP performance of PV generators has proven its applicability to PV-generators with cSi, aSi and CIS modules. It is intended to apply this model as standard within the PVSAT-2 project. For the case of non-cSi modules, requirements concerning the inclusion of spectral corrections to derive the effective radiation and an aging model have still to be checked.

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