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Assessment of PV generation based on spherical irradiation measurements

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Abstract. In this paper spherical irradiation measurements are exploited and compared to power output in order to assess PV system generation potential. Not the spherical irradiation as a sum is measured, but irradiation referred to a specific solid angle. This approach enhances generation forecasting for predefined panel orientations within urban areas. In urbanised regions sophisticated shadowing and reflexion patterns result generally in complicated generation predictions.

Key words

Irradiation Measurement, Photovoltaic System, Optimisation

1. Introduction

Operators need simple, quick, and reliable information about operational conditions of their PV systems [1]. Therefore, a robust monitoring system concept includes synchronised, instantaneous measurements of received solar irradiation and active power output (AC side) of the PV plant. The comparison between irradiation and produced power indicates the operational condition of the PV system [2]. Possible damage can be identified and the energy output can be more accurately assessed. In some urban locations it is not feasible that the sensor and PV cells have the same geographical orientation. Thermoelectric radiation sensors give information which can't be quickly compared to produced power due to different spectral sensitiveness. The same material should be used in the sensor and the PV installation for practical monitoring purposes.

Conducting measurements with a set of sensors evenly covering the half-sphere significantly enriches the analysis possibilities. Energetic contributions from various directions can be analysed.

Surfaces available for PV installations in urban areas are in many aspects not optimal for energy generation. There are numerous reflected components and sophisticated shadowing patterns. The location of panels follows the lines of a façade or roof. Therefore, each panel with a different irradiation pattern should, theoretically be monitored separately. This approach is not optimal.

One way to avoid difficulties is to use spatial measurement and select directional components which optimally describe the total irradiation. Such an attempt is presented in this paper.

Firstly, a PV test installation and measurement equipment are described. They are followed by a brief characterisation of recorded irradiation curves and active power curves.

Two approaches of constructing a relation between irradiance and power output are proposed: a long term approach, taking daily values as input and an instantaneous model based on one second values.

Generally, PV performance models are used to predict how much energy an installation will produce at a location [3]. Irradiance measurements were used to optimise the PV system performance [4] or just to characterise the performance [5]. Detailed analysis of mpp at various locations is given in [6]. Linear regression was applied to figure out the irradiance values [7].

In this paper a linear model correlating irradiance and PV system power output is obtained through an optimisation procedure. It is assumed that such approach can be used for sophisticated arrangements of modules in urban areas. Optimisation process is focused on the minimisation of the squared error between power output given by the model based on radiation measurements and true measured values of output active power.

2. Test Installation

The 110 kW installation is located at BTU University Campus (Fig. 1). It consists of polycrystalline cells.

Fig. 1. PV Test Installation

The PV Roof Installation is composed of 530 modules from ALGATEC Solar AG with 220 W_{peak} of power each, so that the resultant power amounts to 116.6 kW_{peak}. The installation is located on the rooftop of the Laboratories of research and material testing (FMPA) at the BTU Cottbus-Senftenberg. It is distributed over the main roof, the projecting roof and the facade (368 modules with an angle of incidence of 30°, 162 modules with an angle of incidence of 70°; the building is oriented 12° to the south-west). The installation's currents and voltages are registered every second and can be retrieved anytime for evaluation and analysis. The installation consists of 368 panels with an inclination of 30 degrees and 162 panels with an inclination of 70 degrees. All of this panels are tilled by 12 degrees from the South orientation towards the West.

3. Irradiation measuring equipment

The irradiation data was collected using a multi-channel measurement device consisting of 33 reference cells

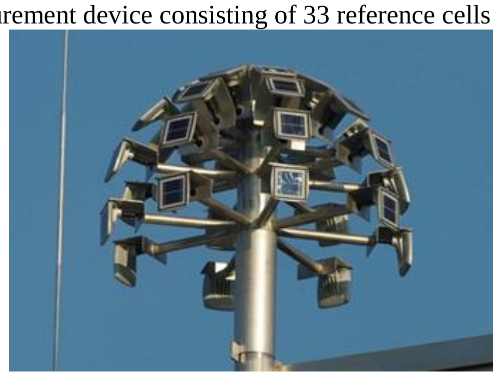

Fig. 2. Irradiation measurement equipment

distributed evenly on the surface of a half-sphere (Fig. 2). The vertical cross-section is shown in Fig. 3 and the top-view in Fig. 4.
In the solar radiation sensor (ISET sensor 01274) [2] the solar radiation is converted into a proportional current by an exact defined solar cell. The output voltage signal is given through a specific shunt resistance with a thermic coupling to the aluminium casing.
Accurate measurement results are possible due to the geometric construction of the reference cell close to PV modules dimensions and specially formed casing enabling a link to outside temperature. The sensor is waterproof and can work in temperatures between -25°C and 80°C.
The calibration of every ISET sensor is achieved with a reference element constructed in identical fashion by an accredited test laboratory in W/m^2 and is documented on a quality assurance calibrating certificate. The calibration is conform with EN 17025. The relative measurement uncertainty is <±4% for crystalline material.

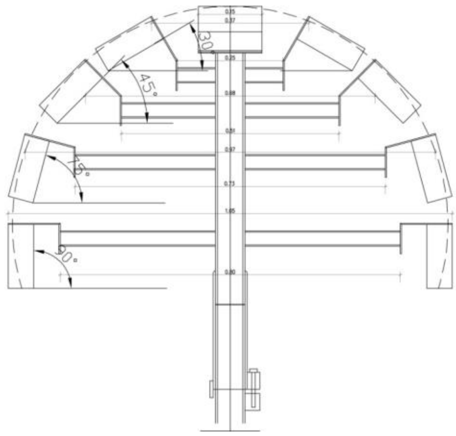

Fig. 3. Vertical cross-section of the measurement sensor

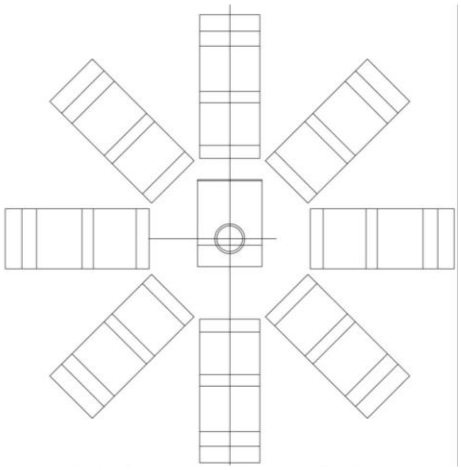

Fig. 4. Horizontal view of the measurement sensor (from top)

For the energetic rating and monitoring of a PV system the same cell technology should be applied in sensor and cell production to guarantee same spectral sensitivity. Furthermore, using the same cells results in comparable physical characteristics regarding temperature reflection and degradation.

4. Measured Irradiance and Power

The irradiation and active power values were averaged over the period of one second and then recorded. The research results are shown for one month values (July).

C. Active Power Curves

Relatively high variations in the value of active power given as one second averages can be observed not only during a measurement day, but also in the shape of the daily curves (Fig. 5). The first three days in July are significantly different, with a maximum of active power around 90 kW.

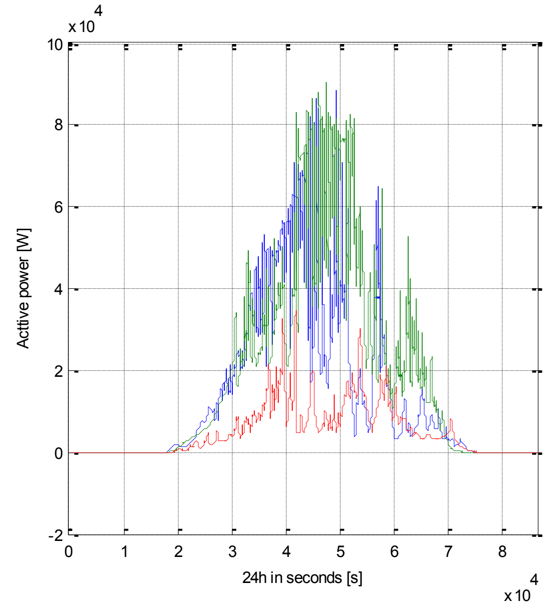

Fig. 5. Active Power on three first days in July

D. Irradiance correlated to Active Power

Firstly, the power curves and irradiation values were normalised in order to find an irradiation shape similar to power curve.

The sum of squared errors between normalised irradiation and normalised powers (compare Fig. 5) is shown in Fig. 6 to Fig. 8.

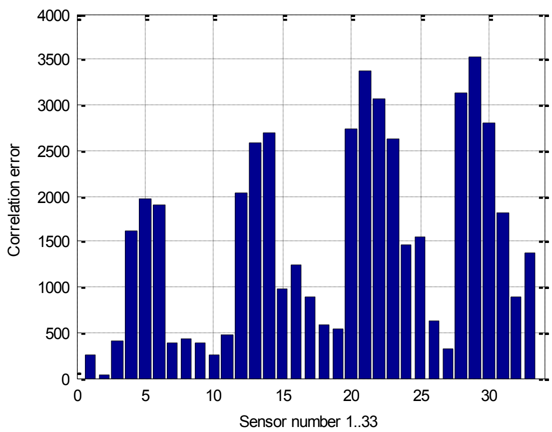

Fig. 6. Squared errors between power and irradiance, 1. July

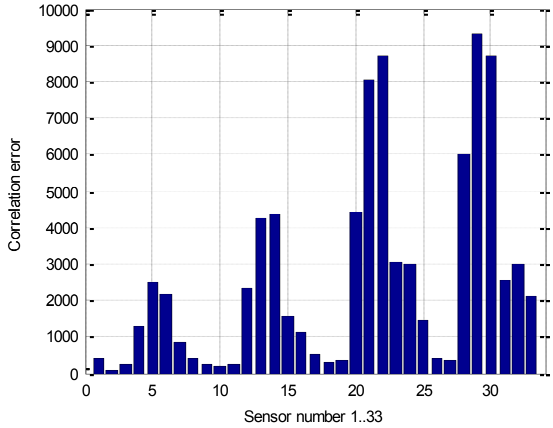

Fig. 7. Squared errors between power and irradiance, 2. July

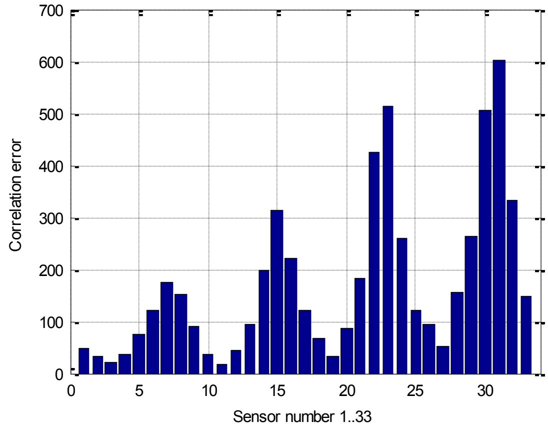

Fig. 8. Squared errors between power and irradiance, 3. July

The Fig. 5 to 7 show different values on various days, even for the same sensor number. There is a difficulty, to figure out a single plate or a group which most accurately and linearly describe the active power production of the entire installation. An opposite approach is to consider all sensors, i.e. all directions as equally significant.

5. Modelling the power curves with selected irradiation components.

A. Daily curves approach

In this case the sum of some measured irradiance components was considered proportional to the power output of the installation

$$P_{sum} = \alpha_{global} \sum_{i=1}^{n} irr_{sum,i} \qquad (1)$$

Moreover, the daily sum of power values and irradiances was considered. The number of components used could vary between 1 and 33.

Computation results with accordance to (1) and using all 33 components show variation of the alpha-global parameter over all days in July is shown in Fig. 9.

Reduction to three significant components (Fig. 10) resulted in increased spread of the coefficients is given as standard deviation in Table I.

All parameters were obtained through an optimisation approach minimising the squared error between model prediction and real measurement.

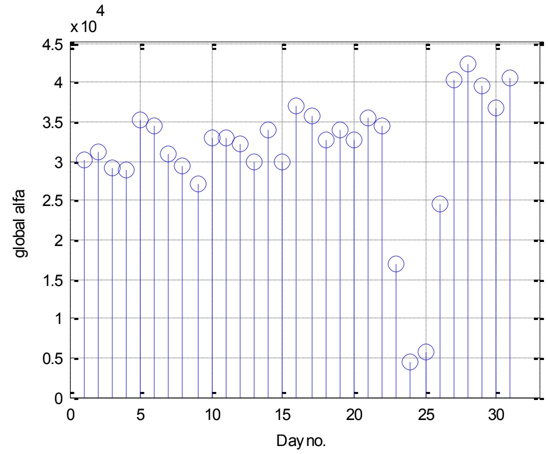

Fig. 9. Daily values of alpha-global parameter, all sensors

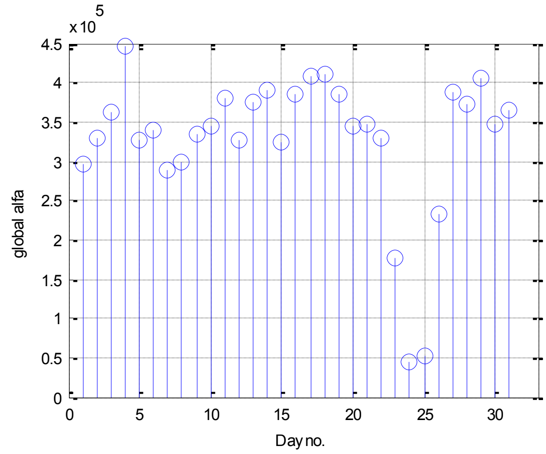

Fig. 10. Daily values of alpha-global parameter, sensor 11,19,27

Table I. – STD and MEAN of normalised alfa-global

Sensor no.	11	11 19 27	all
STD	0.2105	0.2045	0.2010
MEAN	0.7602	0.7353	0.7312

Quite accurate results were obtained even with one reference cell (Fig. 11).

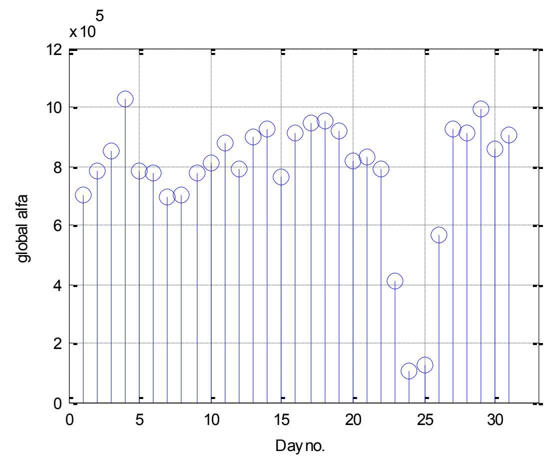

Fig. 11. Daily values of alpha-global parameter, sensor 11

B. Selection of directions

A different approach was focused on the accurate computation of instantaneous values of alfa parameters for a particular time of a day. The relation between irradiance and power is different as in (1) and given as

$$P_t = \sum_{i=1}^{n} \alpha_{t,i} \cdot irr_{t,i} \qquad (2)$$

where the number of components n can be equal or smaller than the sum of all sensors. Generally, it can vary between 1 and 33. The particular value of n should be determined in an optimisation process. The squared error between the predicted power output (2) and measured value is understood as the objective function to be minimised.

The period for which the alfa-inst parameter was computed was arbitrarily settled to five minutes, what resulted in 300 equations. For all the 300 measured data sets the alfa-inst coefficients were computed for every day separately. The same time in every day was considered (five minutes counted from noon).

Increasing the number of sensors used the standard deviation of normalised alfa values also increased (Table 2). Increasing the number of sensors did not help to achieve better performance.

Table II. – STD and MEAN of alfa-instant-norm

Sensor no.	11	11 19 27	all
STD	0.2321	0.5102	0.4162
MEAN	0.7736	-0.1419	-0.0899

The particular values of alfa-instant for sensor no. 11 only are given in Fig. 12.

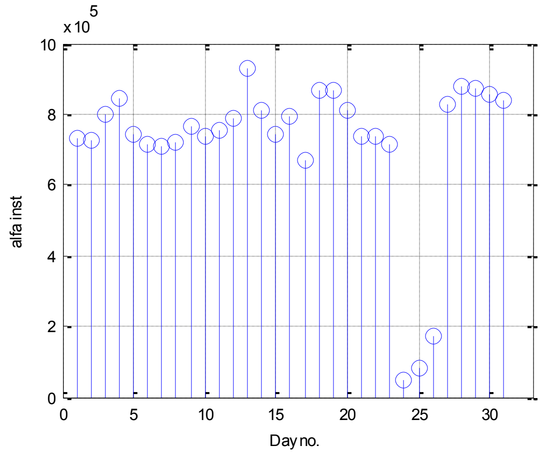

Fig. 12. Values of alpha-instant parameter, sensor 11

Using more sensors resulted in multiple alfa-insant values for every day. Fig. 13 shows these coefficients for a model with three sensors and Fig. 14 for the most complicated case with all sensors.

A characteristic feature of the multi sensor model is the presence of positive and negative values of alfa-insant parameters for a particular day. Mutual cancellation of irradiances (sensor values) occurs.

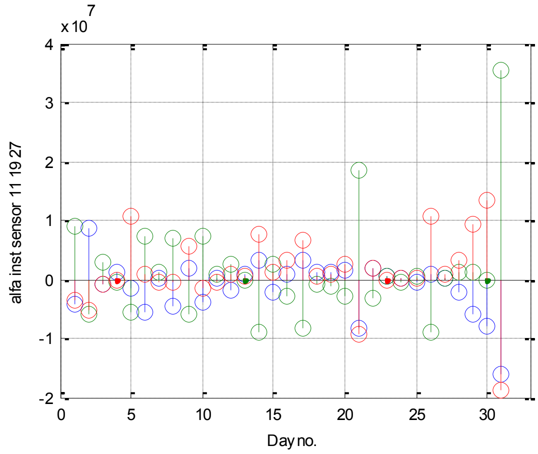

Fig. 13. Values of alpha-instant parameter, sensor 11 19 27

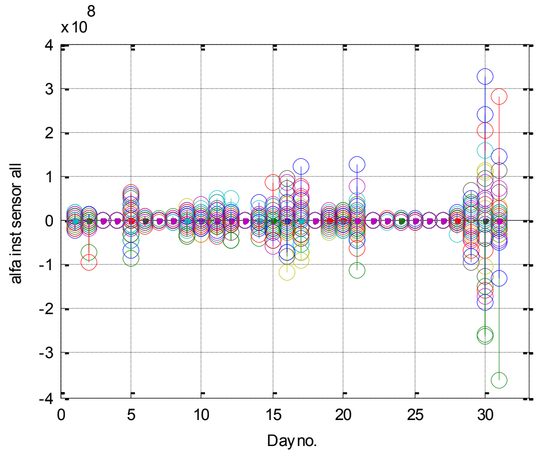

Fig. 14. Values of alpha-instant parameter, all sensor

6. Conclusion

The use of spherical measurements could give the opportunity to establish a correlation between irradiation and active power output, even for sophisticated constellation of panels and reflections. The assumption was tested on the data from a real research PV system.

Two models were presented: a global one and an instantaneous one. In both cases an optimisation routine settled the parameters of models minimising the error between real output and the model performance.

In the global approach, utilising whole day data, the usage of more (of all) irradiation components resulted in slightly better performance. However, even for one reference cell the results were quite satisfactory.

Applying the instantaneous approach a different tendency was observed.

Further research is needed. Neural networks regarding a proper tool for the modelling of produced power and further statistical analysis could strengthen the choice of components to be used in models.

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References

[1] H. Haberlin, "Photovoltaics", Chichester: John Wiley & Sons, 2012.

[2] "ISET Sensor – solar irradiation sensor", User Guide, IKS Photovolt aic GmbH, 2013

[3] J.S. Stein, C.P. Cameron, B. Bourne, A. Kimber, , J. Posbic; T. Jester, "A standardized approach to PV system performance model validation", 35th IEEE Photovoltaic Specialists Conference (PVSC), 2010, pp. 1079 – 1084

[4] N.S. Husain, N.A. Zainal, B.S.M. Singh, N.M. Mohamed, N. Mohd Nor, "Integrated PV based solar insolation measurement and performance monitoring system", IEEE Colloquium on Humanities, Science and Engineering (CHUSER), 2011, pp. 710 – 715

[5] C.M. Whitaker, T.U. Townsend, J.D. Newmiller, D.L. King, W.E. Boyson, J.A. Kratochvil, D.E. Collier, D.E. Osborn, "Application and validation of a new PV performance characterization method", Conference Record of the Twenty-Sixth IEEE Photovoltaic Specialists Conference, 1997., pp. 1253 – 1256

[6] H.G. Beyer, G.H. Yordanov, O.-M. Midtgard, T.O. Saetre, A.G. Imenes, "Contributions to the knowledge base on PV performance: Evaluation of the operation of PV systems using different technologies installed in southern Norway", 37th IEEE Photovoltaic Specialists Conference (PVSC), 2011, pp. 3103 – 3108

[7] Su Shi, Wang Zhe, Wang Fei, "Estimation of solar irradiation based on multiple stepwise regression" IEEE PES Innovative Smart Grid Technologies Asia (ISGT), 2011, pp.1-4