Published in: Proceedings of the 24th European Photovoltaic Solar Energy Conference and Exhibition, Valencia, Spain, 1-4 September 2008.

SHADING LOSSES OF BUILDING INTEGRATED PHOTOVOLTAIC SYSTEMS

Catani, A., Gómez, F., Pesch, R., Schumacher, J., Pietruschka, D., Eicker, U.
zafh.net – Centre of Applied Research Sustainable Energy Technologies
University of Applied Sciences Stuttgart, Schellingstr. 24, 70174 Stuttgart, Germany
ursula.eicker@hft-stuttgart.de, Tel. +49 711 8926 2831, Fax +49 711 8926 2698

ABSTRACT: A building integrated photovoltaic façade has been analysed with partial shading through thin objects such as an antenna or through larger neighbouring buildings. The influence of irradiance distribution modeling and accuracy of the PV generator model is discussed in this work.

Keywords: simulation, modeling, shading, power losses

1 INTRODUCTION

Shadowing effects due to tree leafs, dust or opposite house antennae in urban street canyons are common factors which lead to non negligible power losses of PV-generators. The exact prediction of such losses is crucial for energy yield certification and has to be included in system simulations and data analysis.

Ray-tracing techniques to determine the power losses have already been reported by Kovach and Schmid [2]. Already twenty years ago, models have already been reported to categorize tree shapes and to understand their shading effects in relation to buildings [3]. Many mathematical models have already been developed up to now in order to understand and simulate the behavior of shaded PV-arrays [4,5,6,7].

For building integrated photovoltaic systems, especially photovoltaic facades, the simulation of power losses is required to evaluate the economical viability of the installation. Most simulation tools can calculate direct beam shading for far away objects by reducing the total irradiance to the diffuse component only, if the direct beam is blocked by objects on the horizon. In this case, height and azimuth angles of the shading objects are simply compared with the sun angles and the complete generator is assumed to receive diffuse irradiance only.

It is far more complex to calculate the geometrical shadow projection for near shading objects and additionally to properly calculate the power loss, if the generator is partially shaded. A correct simulation would need to consider the exact irradiance distribution on every module or even cell within the module, calculate the IV curves for the different irradiance and sum the cell or module IV curves including the bypass diodes. If only power losses are calculated linearly with irradiance, the losses are usually strongly underestimated.

In this work, a geometry model has been developed and implemented using INSEL, which calculates the shadow projection of near shading projects.

2 GENERAL SCOPE

2.1 System of study

The object of study was a 4,95 kWp south oriented facade located in Ostfildern near Stuttgart, in Germany. The façade consists of 45 solar modules Engcotec 1000 with 110 Wp that are connected to a SMA-SB 4200TL inverter with 4 kW nominal power. The data logger records the input power from both strings and the output total power every 5 minutes. In order to minimize shadowing effects in winter, the PV-generator was split into two independently strings, the upper with 27 modules and the lower with 18 as seen in figure 1. The measured weather data (horizontal radiation & ambient temperature) was taken from a weather station nearby with a time resolution of 1 minute.

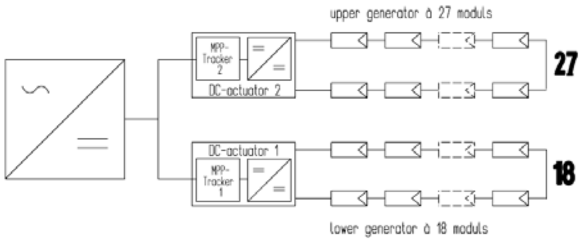

Figure 1: Two independent strings connected to a multi-string inverter SB4200TL

The irradiance was converted to the tilted plane using diffuse fraction correlations according to Erbs/Klein/Duffie and the conversion from the horizontal to the tilted radiation was calculated following Hay's model.

The photovoltaic generator was simulated for different detail levels, for example using either average module irradiance or irradiance on each cell string connected to a bypass diode.

2.2 Geometrical model

The idea of the developed algorithm goes back to basic computational geometry and uses the technique of point projections using a Sun-vector to hit the vertex-points of the obstacles onto a finite plane.

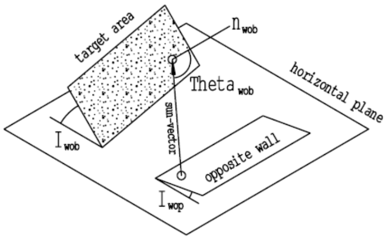

Figure 2: Sun-vector hitting the receiver

The program deals with the geometrical problem of generating the shadow projected by an opposite wall onto a target wall as depicted in Figure 2. The parameters of the presented algorithm are the solar azimuth and elevation, the dimension of the target area and the orientation of the target and the obstacle areas which are described by their vertex-points in a horizontal plane reference system. The rotations and transformations between the reference systems (horizontal plane, obstacle plane, target wall plane and a finite section plane) are programmed in FORTRAN and implemented as an INSEL-block.

2.3 Shading situation

In winter months the solar facade is partially shaded by two TV-antennae and two solar collectors as well as by the PV-modules placed on the opposite roof. The current shading situation can be described using approximately 170 parameters.

Fig. 3: 4,95 kWp BIVP in Ostfildern, Germany

3 METHODOLOGY

3.1 Assessment of the luminance over the cells

In order to validate the geometrical part of the algorithm, the opposite obstacles displayed on a carpet plot were compared against pictures from four different days in winter 2008. A highly sensitive Rollei camera with special lens and shutter speed of about 1/1000 was used to assess the luminous intensity on the target area. To know the luminance distribution on the PV generator, three different cases were considered. The first case evaluated the luminance of fully shadowed cells, the second case the luminance of the cells located in the crossing area between the fully shadowed and the partially illuminated cells and the third case the luminance of fully illuminated cells. The luminance [cd/m²] is displayed on the ordinate axis against the distance [pixels] on the abscissa.

3.2 Geometrical model validation

The simulation output was compared against the photos and videos taken every minute from 7:00 a.m. until 14:00 p.m. in January and February 2008. The algorithm plots the obstacles onto the façade mirror inverted in comparison to the observer's view in front of the BIPV.

3.3 Inhomogeneous irradiance distribution

The solar façade, which comprises 1620 cells from 45 solar modules, was split into 180 cell strings with 9 cells each. The algorithm calculates the inhomogeneously distributed radiation for every cell. The simulation considers each cell strings illuminated averagely with the same radiation. Two cell strings are protected by one bypass-diode as shown in Figure 4.

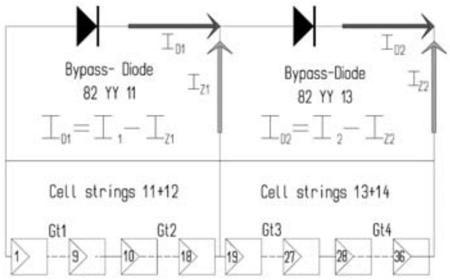

Figure 4: Bypass-diodes connected in parallel to two cell strings with 9 cells each.

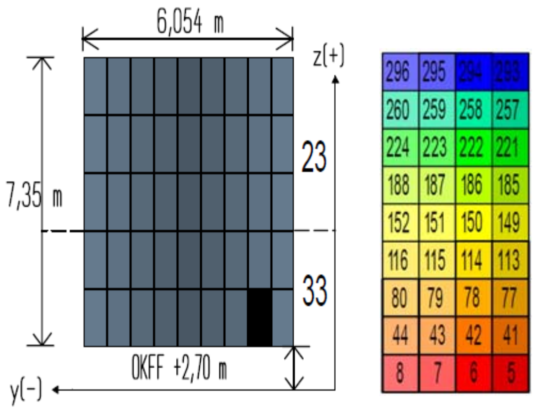

Figure 5: PV generator split off into two partial generators (left) and second solar module (right)

The written routine follows the motion pattern displayed in the right side of Figure 5 in order to compute the radiation for every single solar cell. The algorithm sweeps the target area from the right to the left and from the lowest to the highest row of cells of a PV-array in order to calculate the radiation.

4 SIMULATION RESULTS

4.1 Luminance assessment

The luminance is plotted across the cell surface on the height of the line drawn across the cell. On average the fully shaded cells receive a luminance between 130 and 150 cd/m² as displayed in Figure 6. The peaks are caused by reflection of the metallic cell contacts.

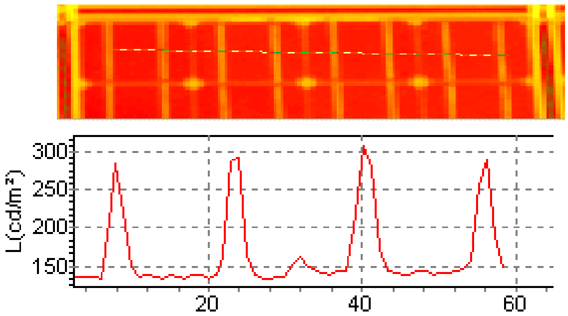

Fig. 6: Luminance of fully shaded cells.

The cells located between both fully and partially shadowing effects were averagely radiated with 300 cd/m².

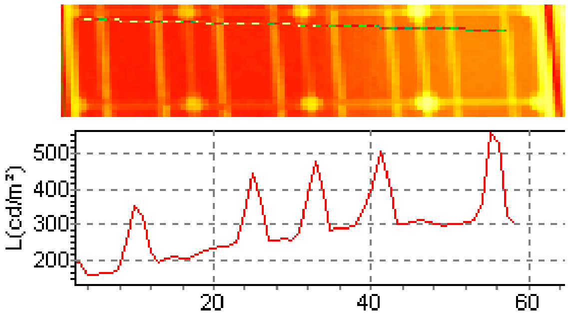

Fig. 7: Luminance of partially illuminated cells.

The luminance over the fully illuminated cells amounted to 450 and 500 cd/m² on average as shown in the next figure.

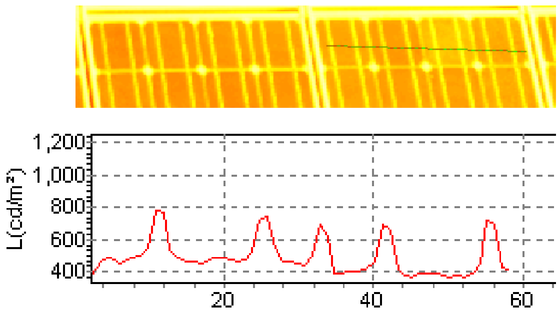

Fig. 8: Luminance of fully illuminated cells.

In the following, photos takes with the luminance camera are compared with simulations for the same time step.

4.2 Validation of the geometrical model

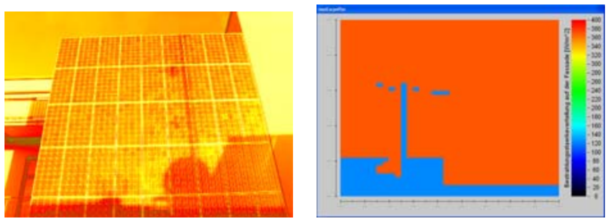

Fig. 9: Luminance-photo dated 24.01.08 at 9:30 a.m. (left) and corresponding INSEL-simulation (right).

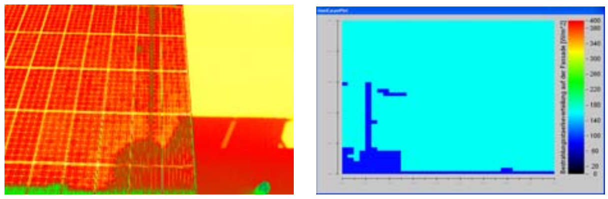

Fig. 10: Luminance-photo dated 24.01.08 at 9:40 a.m. and corresponding INSEL-simulation.

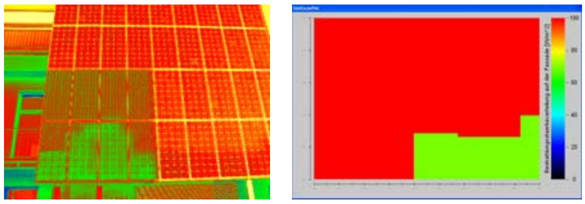

Fig. 11: Luminance-photo dated 19.02.08 at 7:55 a.m. and corresponding INSEL-simulation.

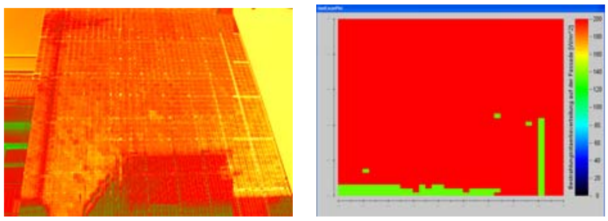

Fig. 12: Luminance-photo dated 19.02.08 at 9:00 a.m. and corresponding INSEL-simulation.

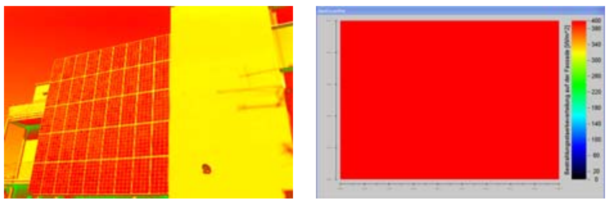

Fig. 13: Luminance-photo dated 19.02.08 at 11:00 a.m. and corresponding INSEL-simulation.

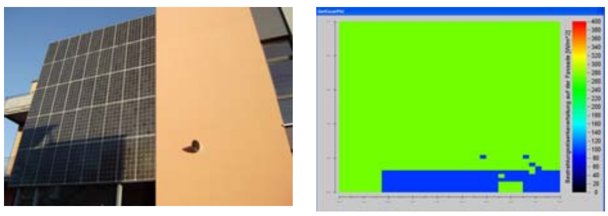

Fig. 14: Photo dated 24.02.08 at 8:20 a.m. and the corresponding INSEL-simulation.

4.3 Validation of the inhomogeneous radiation model

If shading losses are neglected, the monthly energy yields overestimate the measured values with about 20% during the winter months.

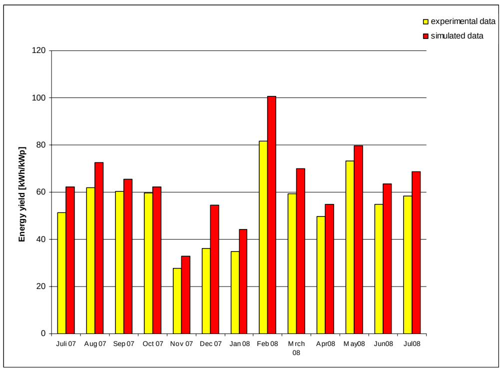

Fig. 15: Comparison of measured and simulated monthly energy yields without considering shading losses.

Attached below are the simulated and experimental DC-power curves of each partial generator as well as the curves of the horizontal and tilted radiation for representative days of every season. While there are only small deviations between measurement and simulations during the summer months with no shading, there are significant differences during the morning hours in winter, spring and autumn even for the upper string, which is only shaded by the antenna.

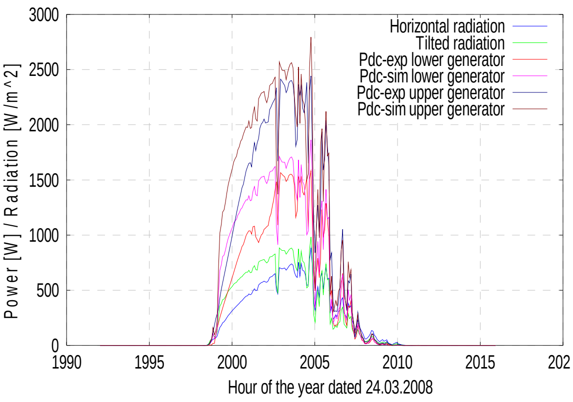

Fig. 16: Power and radiation of the BIPV dated 24.03.08

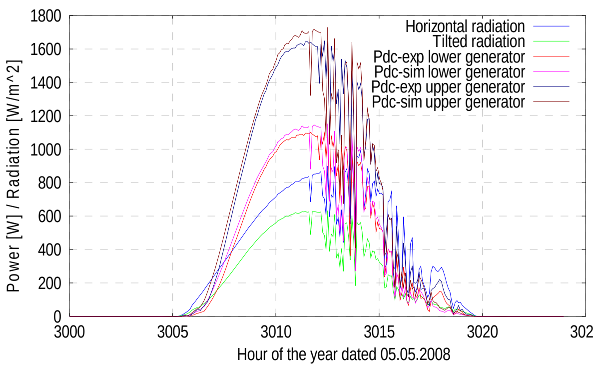

Fig. 17: Power and radiation of the BIPV dated 05.05.08

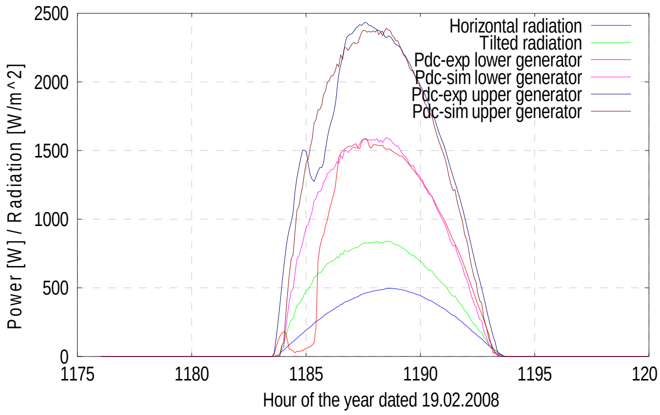

Fig. 18: Power and radiation of the BIPV dated 19.02.08

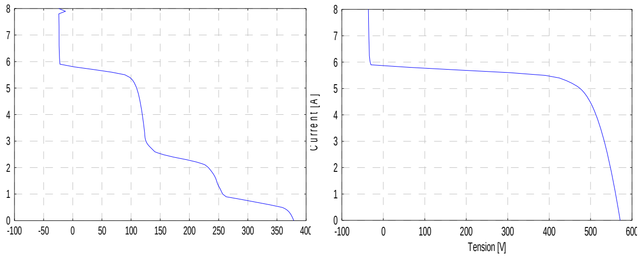

Fig 19. Lower and upper generator dated 19.02.08/8 a.m.

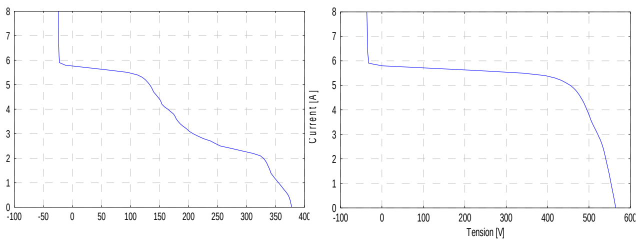

Fig 20. Lower and upper generator dated 19.02.08/9 a.m.

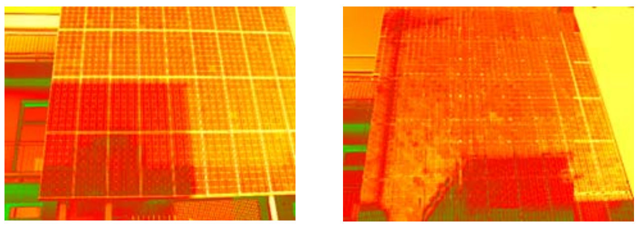

Fig 21. BIPV with shadowing effects at 8:00 and 9:00 a.m. respectively, dated 19.02.08.

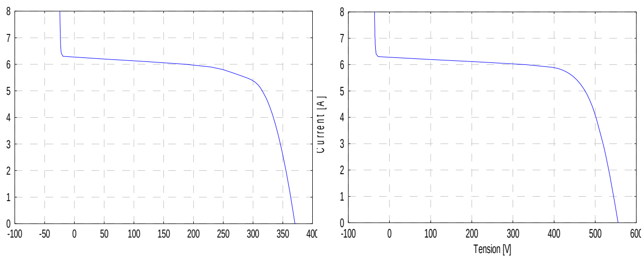

Fig 22. Lower and upper generator dated 19.02.08/10am.

5 CONCLUSIONS

The simulation results were compared with measurements of a façade photovoltaic generator installed in Ostfildern/Germany with a peak power of 4,95 kWp, which has been monitored since July 2007 with a time resolution of five minutes.

The generator is partly shaded in winter by a nearby building which includes antennae and solar collectors. To reduce power losses, the generator was split into two independent strings with 18 and 27 modules driven by a multi-string inverter.

The model clearly shows, how both bypass-diodes (connected each to two cell strings cells) switch on when the breakdown-voltage was reached by the shaded cell strings due the lack of homogeneous radiation onto their surface.

The presented shadow projection model was validated with high resolution luminance images taken on the building integrated façade. The PV simulation model correctly simulates the complete IV curve considering different irradiance levels within one module.

If shading losses are not taken into account, nearly the same energy yield is simulated and measured (for example in September and October 2007 with 62 kWh/kWp), whereas in the winter months from December until March the energy yields were overestimated by nearly 27%.

6 REFERENCES

[1] Luther, J., Schumacher, J., INSEL – A simulation system for renewable electrical energy supply systems. Proceedings 10 th. European Photovoltaic Solar Energy Conference (475-470), Lisabon, Portugal, April 1991.

[2] Kovach, A., Schmid, J., Determination of energy output losses due to shading of building-integrated photovoltaic arrays using a raytracing technique, Solar Energy Vol. 57, No2, 1996.

[3] Sattler, M.A., Sharples, S., Page, J.K., The geometry of the shading of buildings by various tree shapes, Solar Energy, Vo. 38, No.3, University of Sheffield, England 1987.

[4] Budin, R., Budin, L., A mathematical model for shading calculations, Solar Energy, Vol. 29, No.4, University of Zagreb, Croatia 1981.

[5] Quaschning, V., Hanitsch, R., Irradiance calculation on shaded surfaces, Solar Energy Vol. 62, No. 5, Berlin, Germany 1998

[6] Karatepe, E., Mutlu, B., Metin, C., Development of a suitable model for characterizing photovoltaic arrays with shaded solar cells, Solar Energy 81, 2007.

[7] Niewienda, A., Heidt, F.D., SOMBRERO: A PC-Tool to calculate shadows on arbitrary oriented surfaces, Solar Energy, Vol. 58, No. 4, University of Siegen, Germany 1996.