PV INSTALLATIONS BASED ON VERTICALLY MOUNTED BIFACIAL MODULES EVALUATION OF ENERGY YIELD AND SHADING EFFECTS

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ABSTRACT: Bifacial solar modules promise an increased energy yield, compared to systems with standard, monofacial panels, and also offer new opportunities with regard to the installation. One particular approach is the vertical mounting of PV modules, which is reported to be an effective measure to avoid soiling or dust deposition and is an option to obtain a broadened energy generation profile. In spite of the general interest in this type of installation, the amount of published data is very limited, especially with regard to arrays, for which pronounced shading effects can be expected.
In this work we present an analysis of the energy yield and the respective losses for arrays of vertically mounted bifacial solar modules with varied installation conditions.

Keywords: Bifacial, PV Array, Shading, System Performance, Evaluation

1 INTRODUCTION

A major motivation for bifacial PV is an expected additional power yield, compared to monofacial panels, due to the two sided light sensitivity. Bifaciality also enables interesting opportunities, such as a broadening of the energy generation profile or alternative mounting concepts.

Bifacial PV technology is known since long, but up to now there was no real breakthrough with regard to the installed capacity. Currently however, this technology attracts considerable interest in the PV community [1, 2]. Due to technical progress, such as improved bifacial cell concepts or the availability of thin solar glass, the technology gets increasingly attractive. Also, some of the PERC solar cell technologies, which are currently implemented in industrial production, allow a comparatively simple adaption to a bifacial lay-out [3]. The general trend towards glass/glass-modules with superior reliability, as well as the interest in “peak shaving” and customized solutions for specific applications, further supports the development towards bifacial technology.

Nevertheless, the installed capacity of bifacial systems is still negligible. The lack of reliable field data of this new technology still deters possible investors. Even in the PV community there is considerable uncertainty about the real benefit due to bifaciality, as reflected by the numerous publications dealing with this issue.

The potential for an improved module power output was repeatedly demonstrated by simulations [4, 5, 6] and measurements on single modules [7, 8, 9, 10, 11, 12, 13, 14] or installations [15] in various orientations. In real, extended systems however, the arrangement of multiple modules and the specific mounting conditions will have multiple effects which have to be taken into account. Data of larger systems are rare [15, 16, 17, 18], and the results are linked to a specific mounting and / or the respective orientation.

The vertical, or close to vertical, installation of bifacial modules may be a promising approach for several applications. Besides the options to broaden the generation profile and to minimize dust deposition (e.g. in desert applications), simulation data and measurements on single, vertically installed modules are very promising [11, 19, 20, 21, 22, 23]. Especially for vertically installed systems however, also shading is obviously very pronounced and the energy yield will heavily depend on the specific lay-out of the PV installation [20, 23]. At the ZHAW we currently implement a test system in order to measure and compare the actual energy yield of bifacial systems with differing mounting conditions. In the course of the prearrangement we simulated several arrays, in order to obtain a valuation of the conditions which have to be expected.

In this paper we present the simulation results for arrays based on vertically mounted PV modules. There are numerous simplifications and assumptions in the calculations, the results can thus not be considered to be a real quantitative analysis. However the data is suitable for a rough estimation and should reflect the general trends.

2 SIMULATIONS AND MEASUREMENTS

In order to get an appraisement of the software’s suitability for bifacial applications, measured data were compared to simulation results. As an example in Fig 1 the measured data of a single bifacial module (nominal power 255.6 / 232.6 Wp - front / rear side, 90° tilt angle, east/west orientation) is compared to the simulated data for a specific day with clear sky conditions in May.

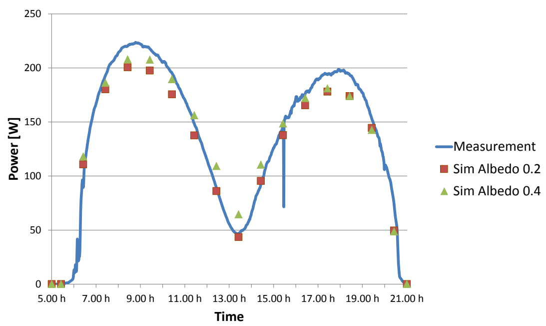

Figure 1: Measurement data (May, clear sky conditions, ZHAW/Winterthur) of a vertically mounted, east/west oriented, bifacial module compared to simulations with two differing albedo factors.

2.1 Simulation of a single bifacial module

The bifacial module was simulated by two modules with nominal power similar to the front and rear side of the measured one (250 / 235 Wp). The simulation of the modules DC output was carried out by means of the widely used PVsyst [24] software (PVsyst 6.3.0, standard configuration, linear shading, Perez model, one microinverter per module).

While the general course of the simulated power generation (albedo 0.2) is in fairly good correspondence to the measured values, the two peak values are underestimated by a factor close to 10%. Choosing a higher albedo factor of e.g. 0.4 is a reasonable approach due to the mounting situation with concrete ground, but does not significantly increase the simulated peak values. Instead, it has a more pronounced effect on the dip region at noon. The latter is plausible due to the albedos impact for conditions with low direct insolation (east/west-orientation at noon). The too low peak values may indicate a discrepancy between the assumed and the real irradiation conditions of the solar cells, e.g. due to the used model for insolation [25, 26].

The calculated annual yield can be compared to the yield of an also simulated monofacial module, with optimal orientation (Winterthur – orientation: 37° South) and the same efficiency as the front side of the bifacial device. With an assumed albedo of 0.2 there is a gain of 15% due to bifaciality for the above considered specific date in May and a gain of 5% in the course of one year for a single, verticaly mounted bifacial module.

Thus, the concept of vertically mounted east/west orientated bifacial modules seems to be an obviously beneficial approach, however also additional aspects have to be considered. The actual energy yield of a solar module is heavily dependent on the orientation and the shading conditions. Obviously shading is in particular a crucial factor for vertical installations, since the shaded areas are considerably more extended than in standard arrays.

2.2 Simulation of arrays

It is obvious that the shading is very much influenced by the area utilization and thus by the distance between the rows of PV modules, if PV arrays instead of single modules are considered.

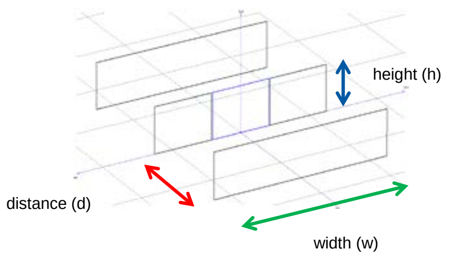

Figure 2: Simulations were performed for of a vertically mounted bifacial module in the center of an array. The distance (d) between the rows is varied as well as their width (w) and the array`s orientation.

Below we will present simulations for arrays with varied distance, width and albedo, as indicated in Fig. 2. The simulations were respectively carried out for installations with east/west and south/north orientation.

In order to obtain more general results, the calculations are based on a single bifacial module within a varied array of vertically installed shading elements. For simplicity the module height h is considered to be 1m, the width of a single module plus spacing is close to 1.7 m, with the long side parallel to the ground. Irrespective of the module tilt angle the area utilization of continuous arrays can be expressed by the ratio of the module height and distance between the rows ($f = h/d$), as indicated in Fig. 2. For a tilt angle of 0° a ratio of 1 would thus represent an area fully covered with flat lying solar modules. Due to the fix module height of 1 m, the results can be directly related to this utilization factor (f), neglecting the unused area outside the module field, such as roof margins of a PV plant mounted on top of a building.

2.3 Error analysis

In spite of the fairly well matching simulation results for the single module, only a rough estimation of the output can be expected for arrays as described above. Several factors which are of particular importance for bifacial installations are not or imprecisely represented [25].

Most of these factors will cause an underestimation of the power output, because relevant beneficial effects due to bifaciality are not comprehensively considered. The modules in the array are simulated as being completely opaque. Thus, shading effects, due to direct and self-shading, as well as the related reduced reflected intensity from the ground, will be more pronounced than in reality. This also affects the impact of an increased installation height. A beneficial influence of elevated mounting is frequently reported [4, 5, 25], but showed no effect in our simulations (PVsyst 6.3.0).

Moreover, the reflected light intensity from modules in adjacent rows [23] is not considered. On the other hand, we did not choose the option to simulate shading on the basis of a specific module lay-out, but assumed a linear effect on the power of the shaded module. This may result in reduced losses compared to real conditions.

A comprehensive simulation of bifacial PV installations would require by far more sophisticated calculations, including e.g. self-shading [4, 5], semi-transparency, improved models for diffuse radiation [26] or inhomogeneous illumination on the front and backside.

In summary it can however be assumed that, due to the described major loss effects, the calculated power output may be considerably lower than for corresponding real power plants.

2.4 Simulation results for arrays

In Fig. 3 the simulated output of the central bifacial module, expressed by the annual yield (DC) in kWh, is depicted for the above described arrays.

Separate data sets represent the respective variation of width (w) and orientation, while the horizontal axis indicates the distance (d) between adjacent rows at a fix height (h) of 1m. The variation of the widths is calculated for 5 values respectively, ranging from 5 m and 50 m. The smaller values (5 m, 8.4 m and 11.8 m) represent rows of 3, 5 and 7 modules. The adjustments in the software are as described for the single module in section 2.1, with an albedo of 0.2.

When examining the results of the simulations in Fig. 3 the distinct separation between the two orientations is ocular. The east/west orientation (front side pointing to the east), is always advantageous, but the difference is diminishing for smaller distances between the rows. For the east/west orientation an increased annual yield in the range of 4% to 12% was calculated, relative to the respective south/north orientation, dependent on the distance between the rows. There is only a small influence of the array`s width in this regard (not shown).

For 1 meter distance the value for the annual yield is almost pinned to a specific value, independent on orientation, distance between the rows and their width.

The impact of the array`s width first increases towards larger distances. Then, according to the simulation, the delta remains at a similar level, up to comparatively large distances between the rows. Infinite distance will resemble the unshaded case.

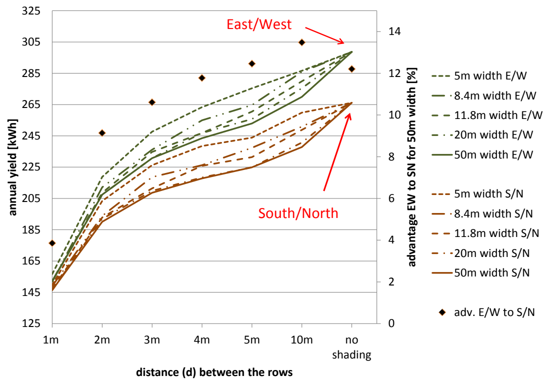

Figure 3: Simulation results (annual yield, DC, albedo factor 0.2) for a specific single, vertically mounted, bifacial solar module in the center of an array with varied installation conditions. The variation is carried out for east/west (E/W)- and south/north (S/N)-orientation (h=1m). Also depicted is the relative advantage of E/W- compared to S/N-orientation in percent.

In Fig. 4 the losses due to the installation conditions are depicted, the respective losses refer to the unshaded case.

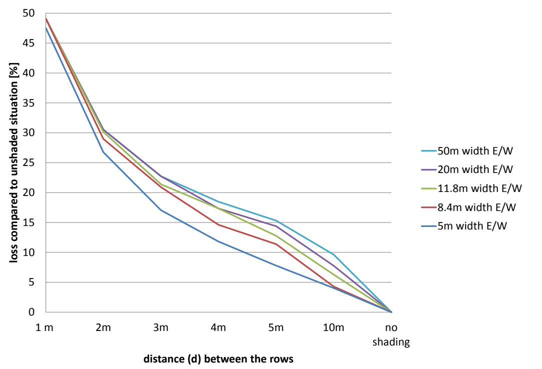

Figure 4: Loss in annual yield compared to the unshaded situation for a bifacial module (East/west orientation, vertically mounted, albedo 0.2).

A means to improve the yield of bifacial systems is to increase the diffuse radiation amount by choosing a reflective surface with higher albedo factor. Fig. 5 depicts the simulation results for an array as described above, with a fixed width of 20 meter.

The simulation results show that the impact of an enhanced albedo factor is dependent on the spacing between the rows. This indicates that the application of e.g. reflecting foil material is particularly effective for low area utilization.

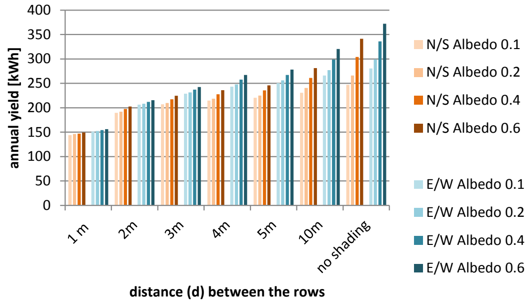

Figure 5: Simulation results with varied albedo factor for an array with a fixed width of 20 meter. The impact of an enhanced albedo factor is dependent on the spacing between the rows.

Based on the assumptions in section 2.1, the calculated gain in annual yield (DC) for an unshaded bifacial module is again compared to a monofacial one with optimum orientation and no shading.

The gain due to bifaciality can be increased from 5% to 30% by switching the albedo factor from 0.2 to 0.6. This is no unrealistic assumption, if for example reflective foil material is applied to the surrounding area. Again however, the advantage compared to non-vertical mounting quickly diminishes in installations with high area utilization factor.

In order to fully exploit the beneficial properties of vertically mounted bifacial modules the lay-out of the installations has to be carefully considered. This is reflected by the simulations shown in Fig. 6. A higher yield than for optimally oriented monofacial modules with the same front side efficiency can be obtained, but only for installations with high albedo factor and comparatively low area utilization.

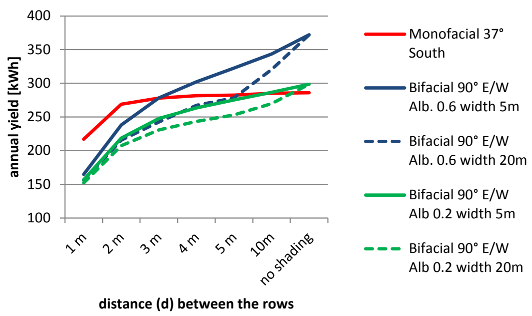

Figure 6: An improved yield compared to arrays with optimally oriented monofacial modules (same front side efficiency and area utilization) can be obtained by installations with high albedo factor and comparatively low area utilization.

The presented arrays are no exhaustive summary of potential arrangements for vertically mounted bifacial modules. Approaches as depicted in Fig. 7 are an alternative to the simulated variants with continuous rows. Because of the larger spacing in the direct surrounding of the module it might be reasonable to assume an increased yield due to reduced shading and an enhanced albedo effect. Though, for the specific arrangement in Fig. 7 no advantage compared to the simulated systems with the same area utilization was found. This might however be related to the fact, that effects which are beneficial for bifacial applications are suppressed in the simulation.

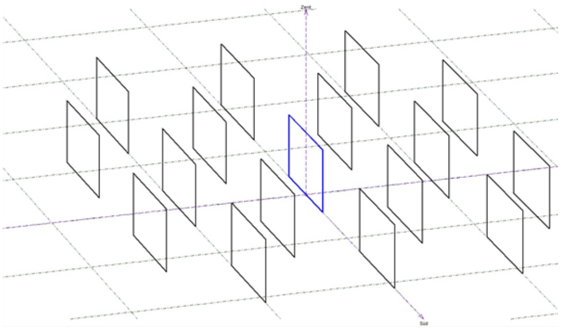

Figure 7: Alternative arrangement to the simulated variants with continuous rows.

It has to be pointed out again, that the results of the presented simulations can only be considered as semi-quantitative. In order to obtain real quantitative results measurements on real systems are inevitable. Due to the demonstrated sensitivity to the installation conditions, in particular when compared to standard systems, measurements actually turn out to be of extreme importance if the economic feasibility of a specific installation has to be examined.

3 CONCLUSION AND OUTLOOK

The vertical mounting of bifacial PV modules promises an increased energy yield and additional benefits compared to standard installations, such as a broader generation profile or reduced proneness to soiling and dust accumulation.

In spite of the interest in this type of installation, the amount of published data is very limited, especially with regard to arrays, for which pronounced shading effects can be expected.

The simulations as presented in this work confirm the influence of the installation conditions. The output of systems based on vertically mounted bifacial modules is heavily dependent on the distance between the rows as well as the arrays extension. For arrangements with high area utilization factors such as 1 and 0.5, there are computed losses in the range of 45% and 30%, relative to the unshaded situation.

When comparing installations on the basis of vertically mounted east/west- and south/north-oriented bifacial modules, the east/west orientation is generally superior. However, only for arrays with wide spacing the advantage due to the orientation is fully utilized.

The detrimental effect of high area utilization for arrays of vertically installed modules is not only due to direct shading, but also affects the light which is reflected from the modules surrounding, which is a significant factor for bifacial applications. Thus, also the beneficial impact of an increased albedo factor is heavily dependent on the area utilization.

An increased energy yield, compared to optimally oriented monofacial modules with the same front side efficiency, is feasible in principle. However, this is only possible for installations with high albedo factor and comparatively low area utilization. For single unshaded modules, resembling the extreme case of low area utilization, there is a 30% gain in annual yield due to bifaciality, for an albedo factor of 0.6. When comparing arrays of vertically mounted bifacial modules to arrays of monofacial ones with optimum orientation, bifacial systems are superior for area utilization factors below 0.3 (albedo 0.6). This corresponds to a minimum distance of 3m between vertically mounted, bifacial modules of 1m height. Due to the assumed underrating of bifacial systems in the simulations, the benefit may be more pronounced in real systems.

Nevertheless, systems with low area utilization are a reasonable approach for specific applications, e.g. commercial rooftops. Due to the typically elongated shape (small width) the losses can be reduced; implementing a surface with high albedo factor should be feasible. Due to the generation profile, the suitability is particularly good if not the maximum energy amount, but self-consumption without storage is in the focus. Other examples could be snowy areas with extreme albedo, exploiting also the benefits of vertical installation with regard to the snow load, or very specific installations such as noise barriers.

The above presented simulation results reflect the general conditions and trends, but can only be considered as a semi-quantitative appraisal. While the used software produces reliable results for monofacial standard applications, the actual conditions for bifacial arrays are far more complicated. Numerous factors need to be taken into account, in order to correctly include properties that are crucial for bifacial applications. Several factors which are of particular importance for bifacial installations are not comprehensively represented. Most of these factors will cause an underestimation of the power output, because relevant beneficial effects due to bifaciality are not correctly considered. A comprehensive simulation of bifacial PV installations would require by far more sophisticated calculations, including e.g. self-shading [4, 5], semi-transparency, inhomogeneous illumination or improved models for diffuse radiation based on measurement results of bifacial modules [26].

In spite of the limited quantitative validity of the present calculations, the results are important with regard to real applications. By means of the simulations the extreme sensitivity of vertically mounted bifacial modules to the installation conditions could be demonstrated. This highlights the importance of a thorough quantitative analysis in real projects in order to examine the economic feasibility.

Up to now however, significant quantitative data can only be expected by measurements on real systems, which also may be smaller test systems of reasonable size.

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