SELF-SHADING IN BIFACIAL PHOTOVOLTAIC NOISE BARRIERS

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ABSTRACT: There is a large market potential for Bifacial Photovoltaic Noise Barriers (PVNB) due to their high energy output for any road orientation. A crucial parameter affecting their energy output is the so-called 'self-shading'. In this research we evaluate the effect of self-shading on the energy production of both an east and west facing bifacial PVNB. We followed an approach consisting of 1) Experimental investigation by accurately monitoring the power output of two bifacial PVNB prototypes, 2) Shading simulation using in-house developed simulation methods. Results show that in particular noise barriers on north-south aligned roads suffer from self-shading because the support structure of the noise barrier itself casts a shadow on the PV modules around noon. A strong correlation is found between clearness index and energy yield loss. On sunny days the energy loss can be as high as 5%. The year average for the loss is about 3%. Clear design guidelines for minimizing the impact have been derived. We conclude that our measurement method, simulation tools and derived design guidelines provide a way to assess and minimize the effect of self-shading on the energy output of bifacial photovoltaic noise barriers, leading to better energy yields and more market success for this type of application.

Keywords: BIPV, Bifacial, Field Testing, Performance

1 Introduction

This paper evaluates the performance of a bifacial photovoltaic noise (PVNB) barrier and more in particular the effect of self-shading on the performance of a bifacial PVNB along north-south aligned roads.

There is a growing interest in photovoltaics in the built environment and placing solar modules on or in noise barriers is an attractive option. Whereas most photovoltaic installations are oriented southward, the orientation of a PVNB cannot be chosen freely, but is governed by the orientation of the adjacent road. For roads running from north to south using bifacial PV modules for PV noise barriers will result in a large increase in electrical output. A system facing east and west will show a minimum in electricity output at solar noon, as no direct light can reach the solar modules. Around this time, the carrying structure of such a system will cast a shadow on the solar system itself, which is called self-shading. How much this has a negative effect on the electricity output depends on the design of the system; The size of the supporting structure, the placement of the cells within the module and the string layout will influence the power output of the modules. The negative effects of self-shading can be mitigated by smart solar cell placement within the modules, a smart design of the string layout and an optimal design of the supporting noise barrier structure. Nevertheless, optimal cell placement and stringing might limit the cell density (or cell area coverage ratio) within the module. Furthermore, in general the supporting structures for noise barriers are rather large. Because of the noise blocking functionality of the noise barrier, the barrier will need a certain mass. Furthermore, the nature of the noise barrier structure will induce high wind loads on the structure. For these reasons, noise barriers will need larger support structures than would be ideal for the solar modules.

Although the use of bifacial solar cells in solar noise barriers has been demonstrated before [1], the role of self-shading has not been studied in detail. In this paper we evaluate the effect of self-shading on the electrical output of a bifacial solar noise barrier pilot system built in 's Hertogenbosch, the Netherlands.

Figure 1: (left) The SONOB Living Lab test site, showing two differently oriented noise barriers. The third row from the top holds the bifacial solar cells. (Right) Self-shading by the carrying structure on the rear side of the bifacial cells.

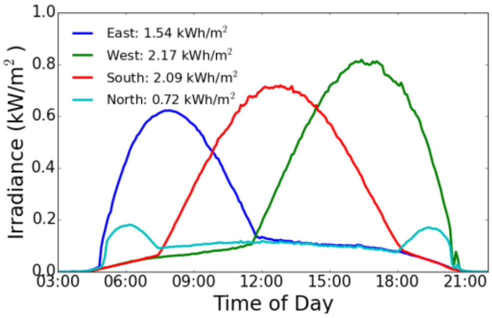

Figure 2: Irradiance in-plane for both sides of both barriers on 30 June 2015, an almost completely clear day.

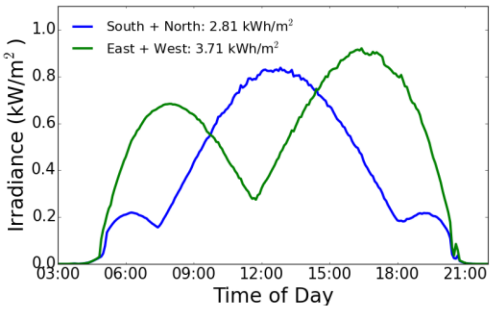

Figure 3: Added in-plane irradiances for both barriers. The legends also show the total amount of irradiance received.

2 Experimental Setup

For the SONOB project [2,3] a 'Living Lab' for testing a diversity of solar cell techniques in a solar noise barrier was set up by a consortium of companies and knowledge institutes consisting of Heijmans, Van Campen industries, Airbus Defence and Space, Scheuten, TU Eindhoven, ECN and SEAC. The pilot setup consists of two noise barriers of 5 meters wide and 4.5 meters high, one facing south and north, and one facing east and west. Both barriers are inclined 15° backwards, to the north and east, respectively. While in the project we investigate the performance of a number of different solar cell technologies and orientations, this paper will focus on the behavior of bifacial modules in the barrier facing east and west. The row holding bifacial solar cells consists of two modules that both contain 48 NSP NS6MN '1960' bifacial solar cells, produced by Scheuten glass. The cells are placed approximately 20 cm away from the sides and top of the modules to mitigate the effect of self-shading. Flash tests at Scheuten showed a front side STC rated power of 207 Wp and a rear side rated power of 190 Wp. The setup is presented in figure 1 (left), showing both barriers and the different PVNB solar concepts. The third row from the top contains the bifacial solar modules. Figure 1 (right) shows an instance of self-shading by the carrying structure on the rear side of the bifacial solar cells, in this case the east facing side of the PVNB facing east and west.

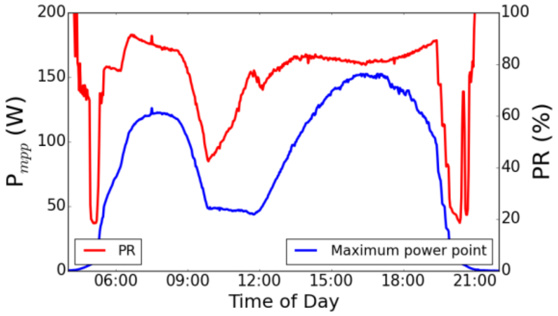

Figure 4: Measured maximum power point and performance ratio of the east-west facing barrier.

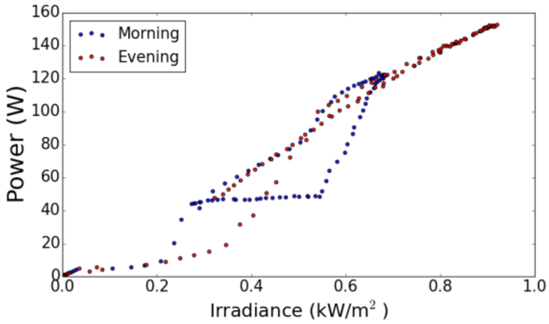

Figure 5: Measured maximum power point plotted against the irradiance. The self-shading-periods in the morning (blue) and evening (red) hours are easily identified.

On top of both barriers, two EKO MS-802 secondary standard pyranometers are placed in-plane to measure the irradiance in the four planes of the barriers. A separate pyranometer is used to measure the global horizontal irradiance, to be able to determine the clearness index. An on-site weather station measures ambient temperature and wind speed. Every two minutes an IV-curve is measured using an EKO MP-160 IV-tracer, while in between the measurements the modules were in open-circuit.

3 Results

As a case study, we analysed the performance of the east and west facing PVNB on a sunny summer day, showing an almost unclouded sky during the complete day. Figure 2 shows the irradiation measured by the in-plane pyranometers on June 30, 2015. The figure shows the irradiation in all planes of the two differently oriented barriers. The irradiation on the south facing side shows a peak around noon. Because in summer the sun rises in the northeast and sets in the northwest, the irradiance on the north facing barrier shows two peaks: in the early morning and in the late evening. The east and west facing side receive a peak in the morning and evening, respectively. For all faces, there is a significant diffuse contribution to the total irradiance throughout the day.

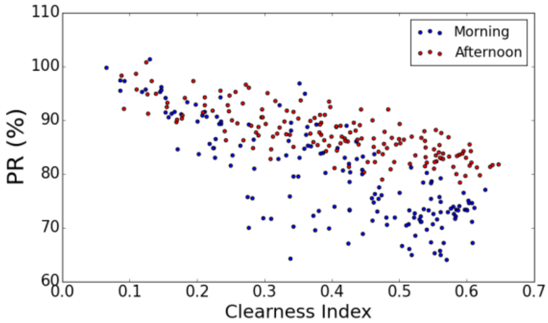

Figure 6: There is a correlation between PR and clearness index that is stronger in the morning (self-shading) than in the afternoon.

Figure 3 shows the added in-plane irradiances as 'seen' by the bifacial modules. The bifacial irradiation profile for the east and west facing barrier shows a double peak structure, showing a peak in the morning and a peak in the afternoon. Around midday, the irradiation is parallel to the barrier and no direct light is received by the modules, but there is still a substantial contribution by diffuse light. The asymmetry in morning and afternoon illuminations is caused by the tilted angle of the barriers. The south and north facing barrier shows a more conventional irradiation profile.

Figure 4 shows the maximum power points (P_{mpp}) of the east and west facing barrier together with the corresponding DC performance ratio (PR). The power output profile also shows a double peak profile, but at 9:30 the P_{mpp} reaches a minimum and is stable to 12:00, whereas the irradiation profile does not show this 'flat zone'. If we look at the PR, we see a significant dip during this period. This dip in PR is caused by shading of the support structures. In this particular case, the self-shading by the side support and the top support occur simultaneously. Another large dip in PR is observed around 5:30, which is caused by the support structure on the north side, as in summer the sun rises in the northeast. A third dip in PR at 20:00 is caused by an external shading source.

In figure 5 we plotted the P_{mpp} plotted against the bifacial irradiance of the east and west facing module. In this way we can easily identify the periods in which the installation suffers from self-shading, where the points deviate from a linear dependence.

The effect of self-shading is most pronounced in sunny conditions. In overcast conditions, the diffuse nature of the irradiation will mitigate the negative effects. To make an assessment of the year-round effects of this self-shading, we divided the measured performance data in two parts: morning performance, when self-shading occurs and afternoon performance, when there is no self-shading. The resulting PRs as a function of the clearness index are presented in figure 6. We clearly see a negative correlation between PR and clearness index. This can partly attributed to the temperature effect of crystalline silicon; in sunny conditions, the cells heat up. The fact that this correlation is stronger in the morning can be attributed to the presence of self-shading in the morning. Throughout the year the average morning PR was 72.9%, whereas the average PR in the afternoon was 86.3%.

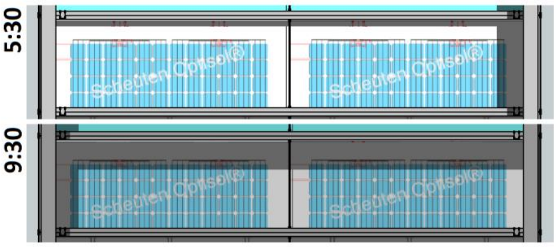

Figure 7: Images from a Sketchup model showing rear-side self-shading pattern at 5:30 and 9:30 of the east and west facing barrier.

Taking into account the lower rear side efficiency of the bifacial solar cells, the total irradiation on the front and back side and the lower morning PR, we estimate the loss of energy yield due to self-shading to be 3.0% in this configuration.

To visualize the self-shading, a model was created in Sketchup. By using the shadow feature of the program we can see when self-shading becomes a problem. Figure 7 shows the modelled self-shading of the east and west facing barrier on June 30 at 5:30 a.m., about an hour after sunrise and at 9:30 a.m., when the south support structure casts a shade on the rear side of the bifacial modules. We see that both the vertical and the horizontal support structures cause self-shading. Using this visualization we can derive design guidelines for bifacial installation in the built environment or infrastructure in any orientation.

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References

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