THE EFFECT OF BIFACIAL SLIVER® MODULE ORIENTATION ON ENERGY PRODUCTION

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ABSTRACT: The Sliver® solar cell technology has the principal features of reduced silicon consumption (down by a factor ~12), a reduced number of wafers that need to be processed per kW (down by a factor of ~30), high efficiency (~19%) and perfect bifacial response. The bifacial response of cells allows a wide range of innovative Sliver® module designs that cannot be achieved using conventional technology (monofacial modules). This work examines the relative performance of monofacial and bifacial modules in a variety of mounting configurations.

Keywords: PV Module, Bifacial

1 INTRODUCTION

There are substantial niche markets for transparent and bifacial PV panels as sound barriers, as building facades or as semi-transparent, power-producing windows. The relatively small dimensions of Sliver® cells allow modules with any desired degree of transparency (e.g. by leaving out every second Sliver® cell) to be produced [1]. The optional transparency and bifacial response of Sliver® modules allows for novel applications in buildings, sound barriers and niche applications.

The mounting configuration of a PV module depends on whether it is monofacial of bifacial or on its application. Conventional modules are normally mounted facing the equator with the tilt equal to the latitude angle. However, for some applications a different mounting configuration may be optimum.

- If winter output is to be optimized, then a mounting angle equal to the latitude angle plus about 20° is optimum;
- If the panel is to be used as a transparent window or a building facade then vertical mounting (preferably facing the equator) is usually required;
- If the panel is to be used as a sound barrier on a motorway then vertical mounting is usually required. The orientation with respect to the equator will depend on the orientation of the motorway.

A panel mounted vertically on a building will receive illumination on one surface only, whereas one used as a motorway sound barrier can receive illumination on both surfaces. Sliver® modules can be perfectly bifacial and so will have an advantage over monofacial (conventional) modules in this respect. Another feature of Sliver® modules is that they can be semitransparent if desired, although this will reduce the energy output of the module.

Global solar radiation has two components: direct beam (and circumsolar) radiation, which comes directly from the sun, and indirect radiation, which comes from the sky, clouds and the ground. The direct beam component is generally in the range 60-80% of the total. Places with high levels of cloud, haze or smog have a lower proportion of direct beam radiation than clear, dry places like central Australia. The electrical output of modules in places with a low proportion of direct beam radiation is less dependent upon the module orientation because indirect light comes from every direction, not just from the direction of the sun.

The radiation received by a module will depend to some extent upon the reflectivity (albedo) of nearby objects and the ground. This is particularly important for vertical modules around noon in summer, when direct beam sunshine is most intense but when the angle of the sun means that the direct beam sunshine received by the modules is relatively small.

As the illumination intensity on a PV module is reduced, the intrinsic efficiency also declines slowly. This is partially offset by a drop in the operating temperature of the module. The operating efficiency of a typical module will decline by 10-20% (relative) for a drop in solar intensity of 90%. However, to a first approximation, the energy output is proportional to the solar radiation input.

The purpose of this work is to examine the relative performance of monofacial and bifacial modules in a variety of mounting configurations.

2 METHODOLOGY

We have used data from the Australian Solar Radiation Data Handbook [2] that contains information for 28 Australian cities in all States and Territories. It contains information about the average hourly direct beam and indirect irradiance for each month on surfaces that are fixed at the latitude angle and surfaces that are oriented with a variety of elevation and azimuth angles. Well-known algorithms can be used to determine this information without taking into account details of local weather embodied in the Australian Solar Radiation Data Handbook. However, the ratio of direct beam light to indirect light, which varies from city to city, makes a significant difference to calculated outcomes. In this study the solar radiation received for various module configurations is analysed.

For example, Figure 1 shows average hourly irradiance for Hobart (latitude 43 degrees) for summer, winter and the equinox for north-facing vertical, east-facing vertical and south-facing vertical monofacial modules and for a monofacial module fixed at the
Figure 1: Hourly irradiance data for Hobart for several monofacial module orientations.

Hobart, N-facing vertical

Hobart, S-facing vertical

Hobart, E-facing vertical

Hobart, latitude angle

Figure 2: Hourly irradiance for Hobart averaged over the year for several module configurations.

The United States cities insolation data were collected from the National Renewable Energy Laboratory’s (NREL) Solar Radiation Resource Information database at the Renewable Resource Data Center (RReDC) [3]. The European and African insolation data were taken from SoDa (1975 data from MARS database for Europe) [4].

In the present study, the bifacial module output is normalised to that expected from a monofacial module fixed at the latitude angle of the city. Further, the bifacial modules are assumed to be 100% covered with cells. A 50% transparent module would have a correspondingly reduced output.

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3 RESULTS AND DISCUSSION

The results of our simulations are given in Figure 3. The scatter in the plot is caused by varying values of the direct beam to indirect ratio. It is clear that a vertically mounted bifacial PV panel that receives relatively unobstructed sunlight on both surfaces performs well compared with a conventional monofacial module mounted at the latitude angle. The following pertinent remarks can be made regarding the results depicted in Figure 3:

- A vertical, unobstructed bifacial module that faces East-West will provide a greater annual energy output than a monofacial module mounted at the latitude angle. However, this orientation is susceptible to substantial losses from shading to the east and the west;
- For latitudes greater than about 40 degrees a vertical, unobstructed bifacial module that faces North-South will match the annual energy output from a monofacial module mounted at the latitude angle. In this orientation, a bifacial module is only slightly more prone to losses from shading than a monofacial module mounted at the latitude angle;
- For unobstructed vertically mounted modules facing the equator, a bifacial vertical module is likely to provide an annual energy output about 40% larger than a monofacial vertical module.

The data points for the vertically mounted monofacial panel facing the equator show that the higher the latitude of the site the less difference there is between vertical orientation and orientation at the latitude angle for a monofacial module smoothly to the limit where the latitude angle orientation is the same as the vertical. A vertically mounted bifacial module oriented along E-W does well relative to a monofacial module fixed at the latitude angle. The relative performance of a module in the E-W orientation is almost independent of latitude. It is worth noting, however, that a module in this orientation is prone to large reductions in output if there is significant obstruction of light to the east or the west. An E-W bifacial module receives much of its illumination in the early morning and late afternoon. For example, in Hobart (Figure 2) an E-W bifacial module will lose one third of its potential illumination if shading from buildings and trees is such that direct sunlight is prevented from reaching the module except for the 7 hours between 08 30 and 16 30. In many cases shading would be even more severe than this.

A vertical bifacial module, oriented facing N-S, does well at high latitudes relative to a monofacial module fixed at the latitude angle, but less well at low latitudes. This module orientation is only marginally more susceptible to shading from buildings and trees in the morning and evening than a monofacial module mounted at the latitude angle.

![Figure 3: Relative module performance for several module configurations compared with a monofacial module mounted at the latitude angle. The data points correspond to cities in the regions shown in the legends.](image)
4 FUTURE RESEARCH

The preliminary results presented in this paper form part of an ongoing study of the orientation dependence of the energy output of Sliver® modules. We plan to widen the scope of the current study to include the following additional work in the future:

- Make use of algorithms to determine the latitude-dependence of various module configurations independent of actual weather (direct beam / indirect ratio) data;
- Model and experimentally determine the effect of reflected radiation from nearby surfaces (albedo);
- Detailed examination of the orientation-dependence of output on shading from objects near the horizon such hills, trees and buildings;
- Examination of the orientation dependence of output of bifacial modules in which one face has a higher conversion efficiency than the other.

5 CONCLUSIONS

Vertical mounting of modules on buildings or as sound barriers is an alternative to mounting modules at the latitude angle. The higher the latitude the better will be the relative performance of a vertical module. Bifacial modules mounted vertically can perform as well as a monofacial module mounted at the latitude angle - the higher the latitude the better. An East-West facing vertical bifacial module requires a clear view (i.e. no shading) to the east and west to obtain good performance. Further work is required to include the effects of albedo and shading in our modeling.

6 ACKNOWLEDGMENTS

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7 REFERENCES