POWER GENERATION AND ENERGY YIELD USING DOUBLESUN® PHOTOVOLTAIC SOLAR CONCENTRATION

F. Reis[1,2], V. Corregidor[1], M. C. Brito[2], R. Rodrigues[1], J. Wemans[1], G. Sorasio[1]
[1] WS Energia.Lda / [2] Faculty of Sciences of the University of Lisbon
[1]Taguspark Ed. Tecnologia II Pavilhão 46, 2740-257 Porto Salvo, Portugal, +351 214 212 190
[2]SESUL, Ed C8 Campo Grande, 1749-016 Lisbon, Portugal,

ABSTRACT: DoubleSun® technology is a V-trough concentration system that makes use of commercial photovoltaic monocrystalline silicon modules. The system integrates a 2-axes tracking system and increases the amount of radiation falling upon the modules by using two flat mirrors. The purpose of the present work is to demonstrate the power and energy increase of commercial modules when integrated in a V-trough system as to a fixed flat-plate system. A theoretical model was developed to estimate such improvement. This model was validated by on-field data, which was acquired during an experimental campaign performed from June to August and also during November of 2008 in WS Energia laboratory, Portugal. DoubleSun® technology, with 1.9x concentration, showed an increase of 50% on the DC power of commercial modules at solar noon.

Keywords: Concentrators, Simulation, System performance

1 INTRODUCTION

Since the beginnings of terrestrial photovoltaic (PV) applications, concentrating sunlight has been considered as a shortcut to significantly reduce the cost of PV electricity [1-3]. Such savings in system cost are achieved by using additional optics (mirrors or lenses) which boost the amount of radiation per m^2, allowing a considerable reduction of the expensive solar cells area [4]. However, it is important to take into acount that the saving costs achieved in concentrators, due to the reduction of cell area, should be balanced with: the additional optics; the very often associated tracking system; and the loss of diffuse light.

Tracking systems are usually associated to concentrator systems to assure an homogeneous illumination pattern on the cells. Such measure is important to avoid mismatch losses or even premature failure of the modules. Such tracking systems demand for a more complex structure with movable parts, which increases the cost of the structure and the need of regular maintenance.

Regarding diffuse light, it is important to notice that concentrator systems makes use of additional optics to concentrate the light. Since such optics only redirects direct radiation (i.e. radiation that is not scaterred by the atmosphere) it is important to take into acount that diffuse radiation should be disregarded when estimating the extra radiation due to the concentration.

Another additional cost may arise for the necessity of active cooling. Since concentrator photovoltaic (CPV) systems boost the amount of radiation falling upon the modules it is likely to observe an increase of the temperature of the modules. However, such device is unecessary for concentration systems up to a few suns, as we shall discuss below.

Today several concentration photovoltaic configurations are ready to commercialization. CPV technologies are usually classified into three main categories: low, medium and high concentration systems. This work will focus on low concentration system, the DoubleSun®, a patented low concentration technology developed by WS Energia. More details about this technology will be found in section 2. The performance of this system will be compared with a fixed system, both systems installed in WS Energia laboratory, also described in section 2.

The theoretical performance of the system was predicted by a Matlab simulation in section 3 and its validity was confirmed by on field data, which will be presented in section 4. Also in this section we will discuss the reliability of the system.

2 LABORATORY AND ANALYSED SYSTEMS

In this paper we present experimental data of two different systems: a CPV system (DoubleSun®) and a fixed system. The systems were installed in WS Energia laboratory which is located in Taguspark, Oeiras, Portugal (38º41'50''N, 9º18'30'' W). This location presents a sunny climate with a yearly average global irradiation of 4.5 kWh/m^2 in a horizontal plane and annual average ambient temperatures of about 16.6ºC. Global radiation, ambient temperature, module temperature and wind velocity were locally recorded by an experimental set-up described in section 2.1.

2.1 DoubleSun® technology

This technology was conceived as a shortcut to reduce the PV electricity cost by making use of commercial PV modules available in the market. Such compromise has limited the concentration level up to a few suns because we are dealing with conventional modules which were manufactured to operate at 1 sun, i.e. with unconcentrated radiation.

DoubleSun® consists on a low concentration V-trough system based on two flat mirrors (reflective optics) that are placed along the commercial modules, as showed in Figure 1. The mirrors are produced by Aluminium Veredlung GmbH & Co. KG (Miro Sun) and its main features are its lightweight (4 kg/m^2), high reflectivity and optimal resistance to outdoor conditions. The mirrors have a total area of 8.8m^2.

The technology integrates a 2 axes tracking system that follows the sun during the day and year. Dual axes tracking is achieved by using two linear actuators, one moving along the polar axis and the second correcting the seasonal variation. The annual power consumption of the tracking is about 10 kWh/year, which corresponds to about 0.3% of the expected production.

The PV modules are tipically high efficiency monocrystalline commercial modules with low temperature coefficient, since they are to operate under concentrated radiation. Depending on modules size, the system can integrate 3 to 4 PV modules. For a typical configuration of 1.5 kWp the solar modules occupy an active area of 6.3 m^2.

The amount of radiation that falls upon the modules in this kind of systems is usually characterized by the concentration factor. The most common definition is the geometric concentration factor (C), which, for this system, is calculated by the ratio between the effective area (the area seen by the sun) and the active cell area. The geometric concentration factor is defined by the following equation:

$$C = \frac{A_{eff}}{A_{modules}} = \frac{A_{modules} + A_{mirrors}}{A_{modules}} = 1 + \frac{A_{mirrors}}{A_{modules}}$$

where A_{eff} is the effective area, $A_{mirrors}$ is the area of the mirrors that is seen by the sun, and $A_{modules}$ is the total area of the modules. According to this definition the gemoetrical concentration factor of DoubleSun® system is 1.9x. However, we should notice that this value is higher than the real concentration factor, since we are disregarding the efficiency of the mirrors, reflective losses and the percentage of direct radiation. Such factors were taken into account by the theoretical model, which is discussed in section 3.

2.2 Fixed flat-plate system

The fixed flat-plate system was mounted on a fixed structure which was optimized to the yearly production according to the laboratory location. Thus, the system was tilted by 35º. The system peak capacity is 525 kWp. It consists of 3 modules from the same manufacture of the modules mounted on the DoubleSun concentrator under analysis.

2.3 Experimental setup

To better understand the performance of the systems in analysis it is important to know the local atmospheric conditions. The laboratory was eqquiped with a Sunny WebBox, a web enabled data logger and controller. This is a SMA product which allows to get information of the inverters and also from the Sunny SensorBox. The former provides the output power data while the latter has integrated sensors which allow a continuous monitoring of the solar radiation, ambient temperature, module temperature and wind velocity of the local. Such data is very important since it makes possible to predict the PV output power as well as to understand unexpected changes in system performance.

3 MODEL PREDICTIONS

In this section we briefly describe the theoretical model [5], implemented in a Matlab® simulation, that predicts the performance of a fixed, tracking and concentrator PV system. Comparison between theoretical and experimental data has validated the model.

3.1 Model

The input parameters of the model are: local coordinates, ambient temperature, percentage of direct radiation and wind velocity. These parameters may be an average value or in case of specific days we have used the data measured at the laboratory with the system described in section 2.

As input parameters we should also define the characteristics of the system that we aim to analyse. For example, if we are simulating DoubleSun® technology it is important to define the optic efficiency, which was estimated at 0.84. Characteristics of the modules (such as area, temperature coefficient and efficiency) are also input parameters.

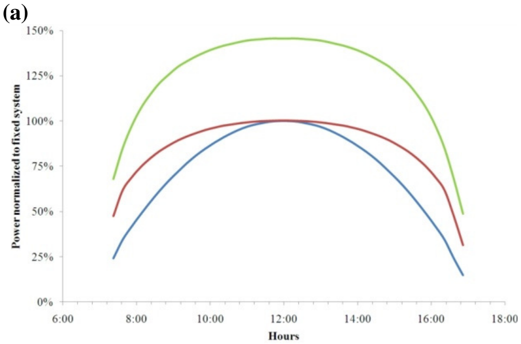
As output, the model estimates the output power, the output energy and the module temperature. The latter is a very important parameter, which should be thoroughly analysed in concentration systems, since modules tend to warm more when integrated in concentrators than when integrated in conventional systems due to the extra irradiation incoming from the mirrors.

Figure 1: Photograph of DoubleSun solar concentrator in WS Energia laboratory in Portugal (38º41'50''). This system has a peak capacity of 1.0 kWp.

3.2 Model results

Figure 2 (a) shows the predicted output power for the DoubleSun® system compared with a flat-plate and a 2 axes tracking system. This figure highlights the benefits of a tracking system in the earliest and latest hours of the day as to a conventional fixed flat-plate system. The tracking system eliminates the cosine losses in the previously referred hours since it directs the modules towards the sun allowing a higher use of the available radiation. On the other hand, DoubleSun® increases the overall output power in 45%. Such power increase is due to both tracking and optical concentration. As mentioned above, the tracker eliminates the cosine losses while the concentration increases the amount of energy that falls upon the models. However, such extra radiation is only significant for locations where the direct radiation is a significant part of the global radiation and the ambient temperature tends to remain below the 45ºC, which is the ambient temperature guaranteed by modules manufactured for normal module operation.

(a)



(b)

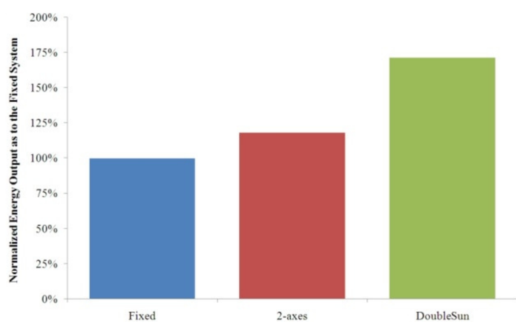


Figure 2: Predicted (a) power output and (b) energy output for a typical winter day. Normalized output for fixed flat-plate system (blue), 2-axes tracking system (red) and DoubleSun® system (green).

Looking to Figure 2 (b), which compares the systems in terms of output energy, we conclude that the tracking system increased the daily energy in 20% while the DoubleSun® system increased the daily energy in 70% as to a fixed flat-plate system. However, such values are likely to vary along the year: on one hand the days tend to be longer in the summer, benefiting the tracking system as to the flat panel; on the other hand the amount of direct radiation changes affecting the amount of concentrated radiation and consequently varying the benefits of the CPV system. Moreover, this model disregard the effect of clouds, which has a significantly impact in systems production as we will see in section 4.

4 ON-FIELD DATA ANALYSIS

This section presents the on-field data recorded from June to August and November of 2008. During these months the ambient temperature of the local in analysis has remained below 45ºC.

First we will compare the performance of DoubleSun® system to a conventional flat-plate system, and then we will analyse the influence of clouds on the performance of both previous systems.

4.1 Comparison between flat-plate and DoubleSun® system.

The modules integrated in DoubleSun system show a significant energy increase as to the modules of the fixed flat-plate. Such improvement is mainly verified during the summer, when the ratio direct/global radiation tens to be higher.

During the 4 months in analysis, DoubleSun® system has produced 948 kWh/kWp while the tracking system has produced 511 kWh/kWp. This means an energy improvement of 86%. Regarding November, the energy of DoubleSun system as to the fixed system was increased by 85%, validating the theoretical predictions showed in Fig 2.

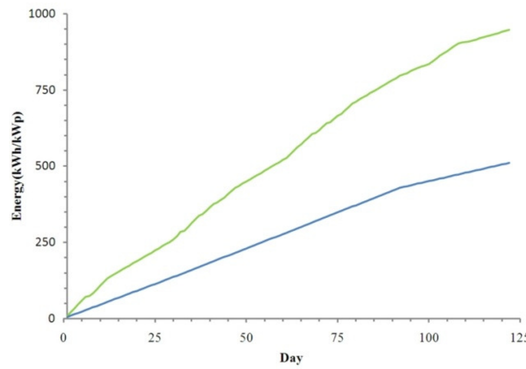


Figure 3: Measured accumulated energy. Comparison between DoubleSun® concentrator system (green line) and fixed flat panel system (blue line).

Although the system does not include any form of active cooling, the module temperature was found to be always below 80 ºC, as long as the ambient temperature is below 45 ºC, which is low enough to allow for normal module operation

4.2 Influence of clouds

The influence of clouds is an important parameter deserving a thoroughly analysis. The presence of clouds decreases the amount of global radiation and increases the amount of diffuse radiation as to direct radiation. Thus, a significant drop in the DC current of the concentration system is observed. Figure 4 shows a comparison between the profile of the DC current produced by the DoubleSun® system and a fixed flat-plate system in a cloudy and sunny day.

In the sunny day it is evident the already mentioned benefits of concentration, which increases the output current of the commercial modules up to 50% as to a conventional fixed flat-plate system. In a cloudy day, the levels reached by the concentration system are just slightly above the control flat-plate fixed system. Such small difference is due to the tracking system that eliminates the cosine losses. One should also notice that during the cloudy day, when the sun shines again, the current immediately jumps for considerable higher levels than in the fixed system. These data shows that if concentrating systems are inadequate for very cloudy climates, where diffuse radiation is a major fraction of the global radiation, for locations with wintery scattered clouds concentration may be a performance enhancer anyway.

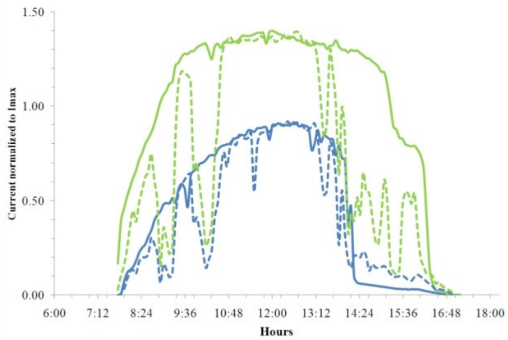


Figure 4: Influence of cloud cover. Comparison between the profile of the DC current produced by DoubleSun® system (green lines) and fixed flat-plate (blue lines) in a cloudy (18th Nov – dashed lines) and a sunny day (19th Nov – solid line)

5 CONCLUSIONS

This paper describes model and experimental data for the performance of a V-trough concentration PV system with a geometric concentration factor of 1.9, using conventional silicon modules and no active cooling.

The results have shown that the radiation increase due to the replacement of the expensive converter area by cheaper optical materials can lead to an improvement of 45% in the instantaneous output power and up to 70% in the daily energy yield. The effect of the tracking system was determined to be responsible for about 20% of the daily energy increase.

The effect of clouds was also briefly discussed. It is shown that, obviously, the effect of the concentration is less relevant in the presence of diffuse radiation, limiting the interest for these concentration systems to sunny locations. However, it is also shown that the occasional cloud does not hinder the system performance.

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