# Ageing of Standard PV Module when Integrated in a V-trough Concentration System

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## ABSTRACT

Concentration photovoltaic (CPV) systems are seen as a shortcut to achieve lower photovoltaic (PV) electricity costs/kWh. Within the available CPV configurations, V-trough systems are likely to succeed in the short term since they are less demanding in terms of tracking accuracy and due to their ability to make use of standard PV modules, a well-known and developed technology. However, silicon standard modules were initially designed to operate under 1 sun conditions, facing some challenges when integrated in CPV systems. The present work aims to demonstrate that such application is efficient up to a few suns and also to analyze possible accelerated modules degradation rates. For such analysis we have used a prototype based on the DoubleSun® technology: a 1.9x concentration V-trough system, integrating 2-axis tracking system and making use of conventional silicon modules.

## INTRODUCTION

The growing interest on concentration photovoltaic (CPV) technologies begins with its potential to significantly reduce the PV electricity cost/kWh. The concept behind CPV is to use optical materials that enhance the radiation falling upon the cells which allows a reduction of its area for the same output power. It can be understood as a shift from the expensive PV converter material to reasonably priced optical solutions.

Within the wide variety of CPV configurations that are on the table today, V-trough arrangement is highlighted as a short term solution. Two main reasons should be noticed: the optical configuration (generally reflective mirrors) which allows high homogeneity with moderate tracking accuracy avoiding prohibitively high costs of the final product; and the use of standard silicon solar cells, a technology with many years of given proofs and a well standardized industrial manufacture, benefiting from scale production. Based on these premises, the DoubleSun® technology consists on a 1.9x V-trough concentrator, with two flat mirrors (lightweight, highly reflective and outdoor resistant) placed along the standard PV modules (high efficiency monocrystalline technology with low temperature coefficient, since they are to operate under concentrated radiation), as showed in Figure 1. The system integrates a 2 axes tracking system that follows the sun, with an annual power consumption that corresponds to 0.3% of the annual expected system production [1].

The efficient application of standard modules in CPV systems is limited to a few suns. Ideally, as the radiation flux is enhanced through concentration, the current density increases, leading to a higher performance of the cell. However , such boost on radiation flux will lead to new challenges: higher operating cells temperature, which diminishes the open circuit voltage ($V_{oc}$); high series resistance losses, due to the higher transverse flow of current from the solar emitter to the front grid (initially designed to work under a maximum irradiance of 1000 $W/m^2$); and possibly accelerated modules' degradation rate originated by a higher exposure to the sunlight [6].

In the present work we report on the behavior of standard 1-sun silicon modules when integrated in a reduced scale prototype similar to the DoubleSun® technology. As far as ageing is concerned, the concentrator qualification standard IEC 62108 [2] procedures were applied. This norm is the first standard developed exclusively for CPV systems, consisting on a mixture between the IEEE 1513 and IEC 61215 standards [2-4]. It aims to provide reasonable assurance that CPV systems may perform reliable and safety for a long period of time by determining electrical, mechanical and thermal characteristics of CPV modules [4]. In this report particular attention is devoted to outdoor exposure test, ultraviolet conditioning test, and off-axis beam damage test.

## EXPERIMENT

### Outdoor exposure test

The purpose of the outdoor exposure test is to make a preliminary assessment of the ability of the module to withstand exposure to outdoor conditions. The present test also aims to find power degradation that may occur joining different outdoor effects and that may be undetectable by laboratory tests [2, 4]. This test requires one full-size module or assembly, described in detail in Table I.

**Tabela I.** Electrical parameters of the modules used in the outdoor exposure test.

| | |
|---|---|
| Open circuit voltage - $V_{oc}$ (V) | 44.6 |
| Short circuit current - $I_{sc}$ (A) | 5.43 |
| Peak power voltage - $V_{mp}$ (V) | 35.4 |
| Peak power current - $I_{mp}$ (A) | 4.95 |
| Peak Power - $P_{mpp}$ (W) | 175.0 |

The module was integrated in DoubleSun® technology, as shown in Figure 1, and exposed outdoors. The period of exposure was 6 months, corresponding to a cumulative direct normal irradiation (DNI) higher than the value required by the standard, 1000 $kWh/m^2$. To evaluate the module's power degradation, an I-V measurement was performed with a solar simulator *Spi-Sun Simulator 460i* before and after the outdoor exposure test.

**Figure 1.** DoubleSun® system installed at WS Energia laboratory in Oeiras, Portugal (38º41'50''N, 9º18'30''W).

## Ultraviolet conditioning test

The goal of the ultraviolet (UV) conditioning test is to reveal possible premature failures of physical and electrical integrity due to limited UV exposure [2]. This test was conducted in the testing lab, in an UV chamber, where the sample was exposed to a total accumulated dosage of 50 $kWh/m^2$ ±10% in the wavelength below 400 nm.

Since the full-size assembly is too large to fit into the available UV chamber test, we have constructed a reduced-scale prototype similar to DoubleSun® technology, as shown in Figure 2. The design of the prototype was manufactured in order to achieve maximum similarity to the full-size component. The construction of the small scale module (see electrical parameters in Table II) has followed the same procedures as a conventional full-size product. The mirrors were made with MIRO-SUN® product (for more detail about this material see [5]) with a total area of 0.22 $m^2$. The adjustment of the position of the mirrors with respect to the module allows for the test of concentration factor between 1x and 1.9x.

To evaluate the module's power degradation, the prototype was inserted in the solar simulator (this time we have used the *Berger Lichttechnik* simulator) and the I-V curve was measured before and after UV exposure.

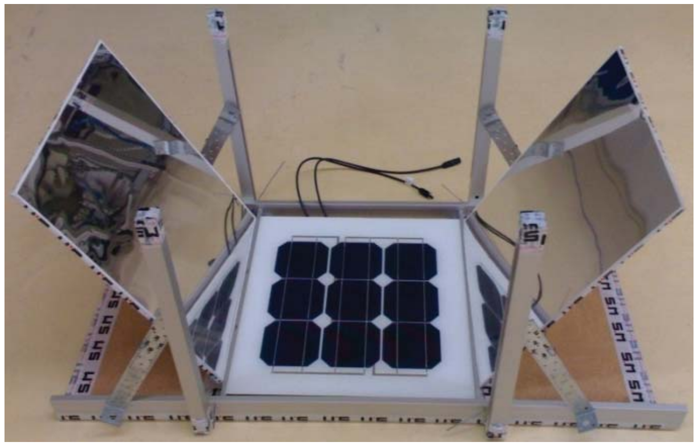

**Figure 2.** Prototype similar to DoubleSun® technology.

**Tabela II.** Electrical parameters of the module used in UV conditioning test

| | |
|---|---|
| Open circuit voltage - $V_{oc}$ (V) | 5.54 |
| Short circuit current - $I_{sc}$ (A) | 5.16 |
| Peak power voltage - $V_{mp}$ (V) | 4.40 |
| Peak power current - $I_{mp}$ (A) | 4.91 |
| Peak Power - $P_{mpp}$ (W) | 21.63 |

**Off-axis beam test**

The objective of the off-axis beam damage test is to evaluate that no part of the module could be damaged by concentrated solar radiation during conditions of misalignment or malfunctioning [3]. Since the DoubleSun® technology uses a fully redundant and failsafe protection system to manage misalignment, the system is exempt from the requirement of the present test.

## DISCUSSION

**Outdoor exposure test**

Visual inspection was performed revealing that physical changes were imperceptible. Comparison between the I-V measurements performed before and after outdoor exposure showed that the maximum power has decreased (see Table III) by 1.7%. This value is below the maximum value required by the IEC 62108 standard, which is 5%.

**Table III.** Maximum power ($P_{max}$) of the module before and after 6 months of outdoor exposure an Power degradation ($\Delta$).

| Electrical parameters | Before outdoor exposure | After outdoor exposure | Δ (%) |
|---|---|---|---|
| $P_{max}$ (W) | 172.38 | 169.45 | 1.7 |

**Ultraviolet conditioning test**

As in the previous test, visual inspection was performed and the evidence of major defects was undetected.

Regarding electrical parameters, the evaluation of the I-V curves measured before and after UV exposure highlighted the occurrence of a drop on the short circuit current ($I_{sc}$). Such preliminary results suggest a degradation of the mirrors, and therefore the power of the system, within the limits of the norm.

**Off-axis beam test**

Preliminary tests on the 2-axis tracking system, which is integrated in DoubleSun® technology, revealed that the protection system had responded to forced misalignments. The protection against high wind speed as well as against modules overheating was also tested showing correct reaction to such harsh conditions, according to the manufacturer's product definition.

## CONCLUSIONS

Outdoor exposure, with DNI higher than 1000 kWh/m$^2$, has showed that standard silicon modules undergo 1.7% of power degradation when integrated in a V-trough system with 1.9x concentration. Preliminary results of ultraviolet exposure, under lab conditions and with a reduced-scale prototype, have shown a decrease of the short-circuit current, suggesting a decrease on the concentration factor due to mirrors degradation. However, power degradation remains within the requirements of the norm. Major physical defects of the assembly were unnoticed in both previous tests.

DoubleSun® system may be exempt of the off-axis beam test, since all the requirements and manufacturer's specification were previously verified.

The successful results of the tests performed according IEC62108 standard suggest that, for the range of concentration factors tested, standard silicon modules may be eligible for concentration. The present work provides reasonable assurance of system reliability for a long period of time and opens the path for product successful certification according to the IEC 62108 standard.

## ACKNOWLEDGMENTS

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