ORGANIC PHOTOVOLTAIC MODULES INSTALLATION: ITALY AND ALGERIA CASE STUDIES

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ABSTRACT: We here report our latest achievements regarding some installations of ASCA® by ARMOR Organic Photovoltaic Modules realized by roll to roll printing. The performances of ASCA® OPV Modules were measured in two sites, in Italy and in Algeria, and monitored over time. We found that 10-20 kWh/m2 of total irradiation are needed to reach nominal performances due to photo-stabilization behavior. Furthermore, a 1.15 kW OPV power plant was realized, vertically integrated on a building wall, and measurements data were collected for each string. Special attention is paid to compare, in terms of energy yield (kWh/kWp), the OPV Plant with a c-Si PV Plant, already present on the same site: OPV showed a gain of 12% on energy yield during the monitoring period.

Keywords: Organic Solar Cell, Energy Performance, PV System

1 Purpose of work and approach

Thanks to their properties (potential very low cost, light weight, flexibility etc.), Organic Photovoltaic Modules (OPV) have risen a remarkable interest in the last 10 years. Research has focused on continuously increasing the efficiency, mainly at lab-scale [1]. Module- and Plant-scale installations are still at an early stage, but are rapidly increasing in recent years both in Europe and abroad [2]. Measurements of I-V characteristics of OPV minimodules measured indoors were presented by G. Bardizza et al. [6]. The work presented here addresses the issue of OPV Module performance evaluation at Module-scale and Plant-scale, using two case studies in two different environments and comparing them with PV standard technologies. The performances of ASCA® OPV installations led by ENI were monitored in two different sites: Northern Italy and Algeria.
Firstly, 6 OPV Modules, each producing 17.5 Wp at Standard Test Conditions, were placed on a South-oriented structure in Northern Italy and I-V curves were collected to monitor the evolution of performances under outdoor conditions.
The Algerian installation consists of 6 OPV Modules, South-oriented at 35° tilt angle, placed in a desert area. The goal is to compare the performance evolution at different weather conditions [3] and the evaluation of the "photo-stabilization" dynamic typically required by this technology.
Furthermore, a power plant consisting of 66 OPV Modules (total peak power 1.15 kWp) was installed in Northern Italy and the energy production was monitored and compared in terms of energy yield (kWh/kWp) to a c-Si PV Plant installed in the same site. In this case, orientation is S-W (azimuth) and the installation is vertically integrated on a building wall.

2 Purpose of work and approach

Until now, only few groups were able to evaluate OPV modules performances in outdoor conditions and report data about OPV Power Plants [4]. In particular, this work will describe in detail the performance evaluation of OPV modules in real contexts (desert and building/structure integrated) in comparison with other PV technologies and report the electrical response of strings and substrings in a >1kW power plant.
Photo-stabilization data for two different sites have been also collected and elaborated to better understand the activation behavior of OPV under light exposure.

3 Results

I-V Curve measurements of 6 OPV Modules installed in Northern Italy were acquired. At the beginning, it was noticed that a certain period of "photo-stabilization" of the organic film is needed to reach nominal OPV Modules performances. This kind of initial increase in performances has been already reported previously [5]. The first measurements were done on OPV modules immediately after installation, then periodically repeated to monitor electrical parameters evolution.
As showed in Figure 1, the Fill Factor increased from 20% to 53%, most probably because of a reduced recombination within the active and transport layers after light exposure. About 10 kWh/m² of total irradiation allowed to complete the first stabilization trend. Nevertheless, after this fast initial increase, the Fill Factor continued to grow slowly, reaching a higher stabilized value (58%). About 20 kWh/m² of total irradiation were needed for completing the photo-activation process and reaching a stable value.

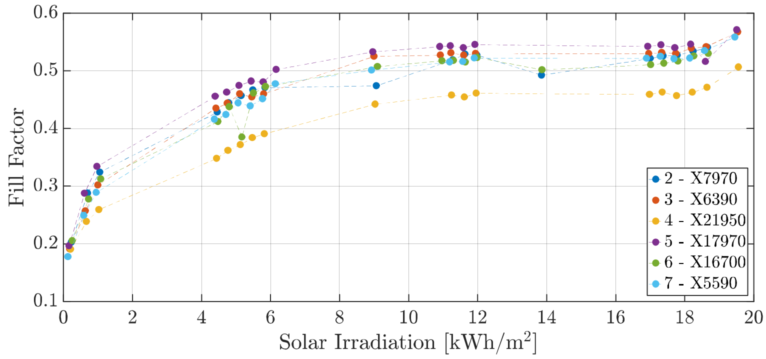

Figure 1 - OPV photo-stabilization: Fill Factor vs Solar Irradiation

In Figure 2, we reported I-V curves evolution during the photo-stabilization period: it is evident that V_{mpp} (Maximum Power Point Voltage) and I_{mpp} (Maximum Power Point Current) had a substantial increase related to curve shape modification.

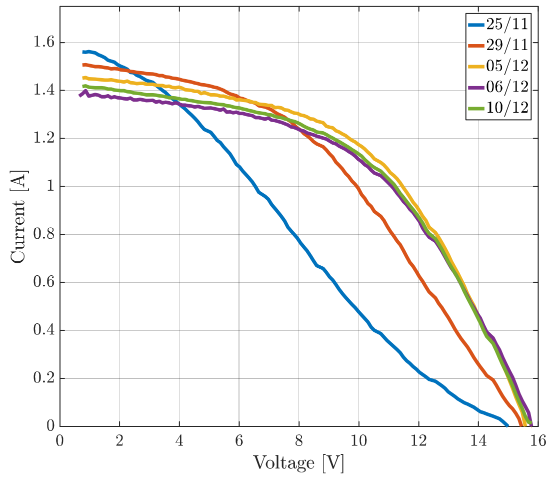

Figure 2 - I-V curve evolution during the outdoor photo-stabilization period in Northern Italy

In order to evaluate the photo-stabilization period in a different location, 6 OPV Modules were placed in Algeria on a structure with 35° tilt angle South-oriented. These modules were mounted on two different substrates: polycarbonate and aluminum. Short-circuit current and open-circuit voltage, irradiance and module temperature were measured twice a day.

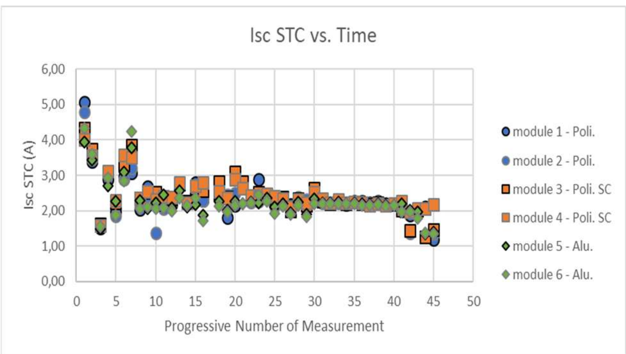

Figure 3 – OPV Modules Isc stabilization over time in Algeria

To make the current values independent from the irradiance, the short circuit current has been normalized at STC, as reported in Figure 3.

Its value resulted to be stabilized after 4 days (8 measurements) and the photo-stabilization process was accomplished.

We estimated that at the site latitude the average irradiation is about 5 kWh/m² per day, so photo-activation was completed after about 20 kWh/m² of total irradiation, a comparable value with respect to the one obtained in Northern Italy.

Evaluating the stabilization dynamic is extremely important to properly quantify the period of light exposure needed for reaching the nominal performances at plant-scale. According to our findings, an outdoor exposure equivalent to 10-20 kWh/m² of total irradiation is required for complete photo-activation of OPV modules.

A 1.15 kW power plant consisting of OPV Modules vertically mounted and South-East oriented was installed on a building wall in Northern Italy: layout is reported in Figure 4, with 3 Strings in parallel of 22 OPV Modules serially connected.

Figure 4 - OPV Plant: strings and substrings (1-8) scheme

Main parameters values (corrected at STC) have been summarized in Table 1 for each OPV String and for the total plant after proper photo-activation period. All strings showed homogeneous performances and the plant resulted as a linear addiction of them.

Table 1 - OPV Strings and Plant main parameters expressed at STC

VALUE @STC	1ST STRING	2ND STRING	3RD STRING	PLANT
I_{sc} [A]	1.87	1.86	1.84	**5.22**
V_{oc} [V]	344.3	345.1	345.1	**344.3**
Fill Factor	57%	58%	56%	**59%**
P_{max} [W]	367.0	374.77	356.24	**1055.8**
I_{mpp} [A]	1.46	1.46	1.42	**4.05**
V_{mpp} [V]	250.77	256.13	250.0	**260.7**

The OPV plant, 90° S-W oriented, was compared with a c-Si PV plant with a 35° S orientation on the same site in terms of daily energy yield (kWh/kWp).

Despite its lower efficiency, the OPV Plant showed 12% higher energy yield on average with respect to c-Si PV plant during the three months of monitoring period.

Results for the energy yield comparison have been reported for OPV Plant and c-Si PV Plant with same orientation and module tilt angle (vertically mounted), showing a higher gain with respect to the actual installation conditions, as reported in Figure 5. Despite the lower efficiency, the OPV plant revealed a good capacity to perform better than Silicon PV plant in unfavorable conditions as a vertical building integration and a non-optimized module orientation (South-West).

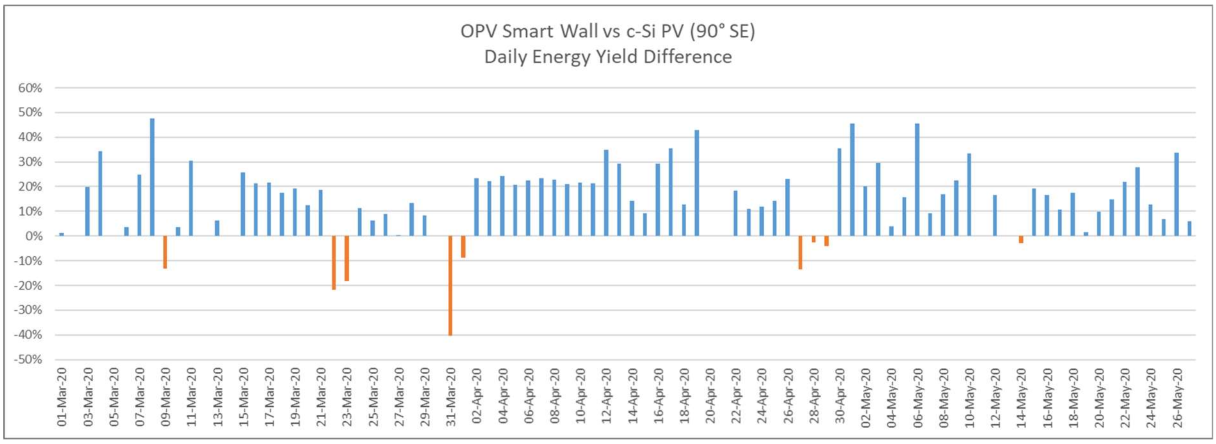

Figure 5 – Daily Energy Yield difference between OPV Plant and c-Si PV Plant

In order to compare OPV performances with other PV technologies (CIS and c-SI) at module level, an outdoor measurement campaign was accomplished by periodically measuring I-V curves. OPV and PV modules were installed on the same structure with a fixed tilt angle and orientation during the monitoring period.
Relevant electrical parameters were extrapolated and compared in relative terms, as the ratio between the measured value at actual irradiance and the nominal value of each PV module at STC conditions. In this way, the normalized Fill Factor of the different technologies was compared.
The results showed for OPV modules a more uniform performance under variable irradiation and temperature conditions with respect to Silicon PV and CIS, as reported in Figure 6, with a higher relative Fill Factor, especially under low irradiation conditions.

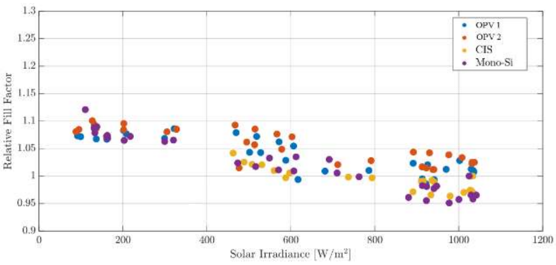

Figure 6 – Normalized Fill Factor versus Solar Irradiance for OPV, CIS and c-SI PV modules

4 References

[1] B.Fan et al. Nature Commun 2019, 10, 4100
[2] www.asca.com; www.opvius.com; www.heliatek.com; www.sunew.com
[3] C.J.M. Emmott et al. Sol Energy Mater Sol Cells 2016, 149, 284; A.M. Gracia-Amillo et al. Renew Sus Energy Rev 2018, 93, 76
[4] S. Berny et al. Adv. Sci. 2015, 1500342
[5] S.A. Gevorgyan et al. Adv Energy Mater 2016, 6, 1600910
[6] G. Bardizza et al. 10.4229/EUPVSEC20172017-3BO.12.3