

# THE IMPACT OF OUTDOOR METEOROLOGICAL PARAMETERS ON THE PERFORMANCE OF DYE-SENSITIZED SOLAR CELLS

Cristina Cornaro<sup>1,3</sup>, Angelo Spina<sup>1,3</sup>  
Thomas M. Brown<sup>2,3</sup>, Aldo Di Carlo<sup>2,3</sup>, Andrea Reale<sup>2,3</sup>

<sup>1</sup>Department of Enterprise Engineering,  
<sup>2</sup>Department of Electronic Engineering,  
<sup>3</sup>CHOSE

University of Rome Tor Vergata  
Via del Politecnico 1, 0133 Rome, ITALY

## ABSTRACT

The paper presents a first study of the impact of meteorological parameters on outdoor performance of DSC. A DSC cell has been tested in real operating conditions while located in the University of Rome Tor Vergata ESTER outdoor facility, where global, direct, diffuse and reflected solar radiation, air and cell temperature, wind speed and direction, humidity are continuously monitored.

Outdoor measurements have been performed on cloudless days at normal incidence of the incoming solar beam radiation, mounting the cell on a sun tracker.

Cell performances have been expressed in terms of solar radiation intensity and cell temperature. Thanks to the complete set of environmental data it has been possible to fully explain the temperature behaviour of the cell. Wind conditions have shown to play a fundamental role, together with radiation intensity.

## INTRODUCTION

The great interests arising from the potentialities of Dye-Sensitized Solar Cell (DSC) technology [1, 2] has been mainly concentrated on the analysis of the cell performances in conventional indoor measurement conditions. Less attention has been paid to systematically monitoring the behaviour of DSC and organic cells in realistic outdoor operating conditions and few works can be found in the literature [3, 4]. This is generally a key point for a correct evaluation of the actual performances of any photovoltaic technology. Especially for some innovative devices such as thin film, DSC or fully organic photovoltaic systems, indoor characterization at Standard Test Conditions (STC) can be a limiting factor.

This paper presents a first study of the impact of meteorological parameters on outdoor performances of a dye-sensitized solar cell while operating in the ESTER outdoor test facility [5] of the Environmental Technical Physics laboratories of the University of Rome Tor Vergata, in the framework of a systematic outdoor test activity that is going to be carried out at ESTER on dye-sensitized solar cells and modules.

## EXPERIMENTAL SET UP

The cell has been tested on the ESTER meteorological station where global, direct, diffuse and reflected solar radiation, air and cell temperature, wind speed and direction, humidity are continuously monitored.



Fig. 1. Sun tracker with the cell support plate at ESTER facility.

The solar device has been mounted on a support plate fixed to the station sun tracker where a pyrheliometer measures direct solar irradiation and a shaded pyranometer measures horizontal diffuse irradiation (fig. 1). Global Irradiation on the test plane has been calculated with the simple geometrical model transposing the available data of the separate irradiation components (direct, diffuse and reflected). Combined standard uncertainty on radiation intensity measurements has been estimated as  $\pm 2\%$ . A custom made and calibrated k-type thermocouple has been positioned on the rear side of the cell to monitor its temperature. Cell temperature measurement accuracy is  $\pm 1^\circ\text{C}$ .

First outdoor measurements have been performed on cloudless days at normal incidence of the incoming solar radiation beam during the central hours of the day from 16<sup>th</sup> of April till the 19<sup>th</sup> of April 2007.

The cell has been maintained at MPP conditions using a Keithley 2612 source-meter and dedicated Labview® VI routines and every minute current, voltage, power and cell

temperature have been measured. Every 15 minute I-V curve has been traced. During night the cell has been stored in the dark and I-V curves in indoor conditions have been traced before and after the outdoor exposition. I-V measurements are affected by  $\pm 1\%$  uncertainty due to instrumentation. Great care has been also devoted to the interlock between cell measurements and irradiation measurements from the meteorological station.

### Dye-Sensitized Cell description

The scheme together with a picture of the cell built in the CHOSE laboratory is shown in fig. 2. The cell built is of the Graetzel type [1]. A nano-structured  $\text{TiO}_2$  film is deposited in the form of liquid suspension by means of blade coating on a TCO substrate ( $R_s = 8 \text{ Ohm/square}$ ). After sinterization at  $450 \text{ }^\circ\text{C}$  the  $10 \text{ }\mu\text{m}$  thick  $\text{TiO}_2$  is dip coated with N719 Solaronix  $\text{Ru}$ -based dye for twelve hours. The counter-electrode is covered by a Pt-catalyst film and the cell is assembled in the form of a sealed structure. The DSC cell is then filled with  $\text{I}^-/\text{I}_3^-$  liquid electrolyte solution (Solaronix R150 $\text{@}$ ) through vacuum assisted liquid injection technique.

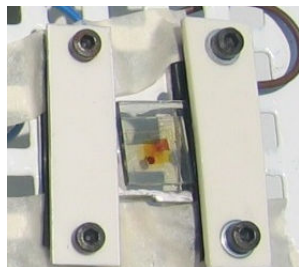
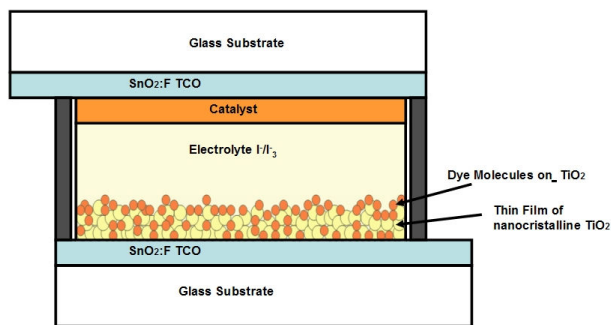


Fig. 2. Scheme of the DSC cell (top) and picture of the cell mounted on the test plate (bottom).

## RESULTS

### Meteorological conditions

Climatic conditions and solar radiation availability for the days of test have been evaluated using data from the meteorological station. Fig. 3 shows the wind speed and average air temperature trends from 16<sup>th</sup> till 19<sup>th</sup> of April. Quite high temperatures values have been experienced especially during the first day of test; average wind speed

in the prevalent direction reached 6 m/s in the central part of the days and only on the 19<sup>th</sup> of April a maximum of 3 m/s has been measured.

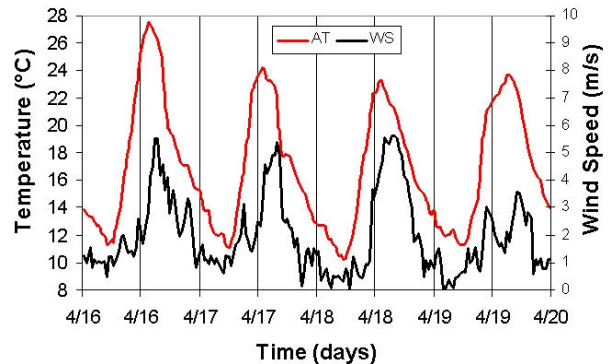


Fig. 3. Average air temperature (AT) and wind speed (WS) in the prevalent direction for the days of test.

Fig. 4 shows global irradiation (GR) on a horizontal plane together with the direct (DR) and diffuse (SR) components on the same plane. All days were almost clear even if some instability in the solar irradiation trend can be observed due to some irregular cloud cover. During the central part of the day irradiation values as high as  $800 \text{ W/m}^2$  have been experienced on a horizontal plane.

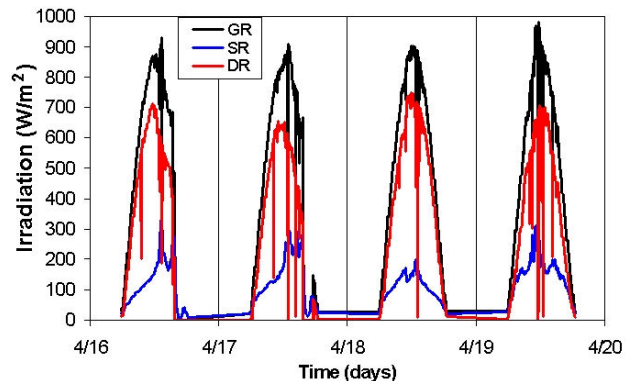


Fig. 4. Global (GR), direct (DR) and diffuse (SR) irradiation on a horizontal plane for the days of test.

### DSC performance and environmental parameters

Cell performance has been expressed in terms of solar radiation intensity and cell temperature. Fig. 5 shows cell efficiency (black) and radiation intensity (red) versus time expressed in minutes from the beginning of the experiment. An average efficiency of approximately 5% has been observed. During the first day an efficiency decrease has been noted. After a partial overnight recovering a subsequent decrease can be observed in the second day, while the last day of test shows an unexpected efficiency growth. This behaviour does not

appear correlated just to the radiation intensity but rather to the cell temperature.

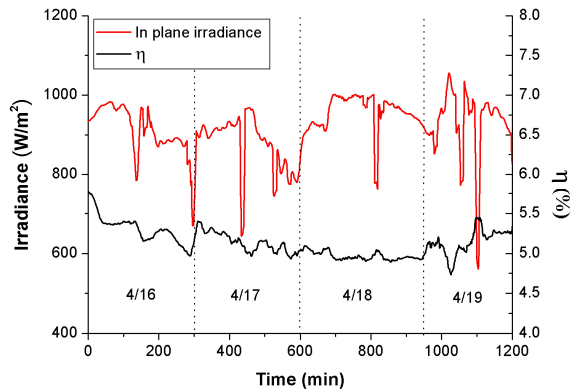


Fig. 5. In plane irradiance and cell efficiency versus time.

Figure 6 shows a good correlation of the cell efficiency with the cell temperature trend.

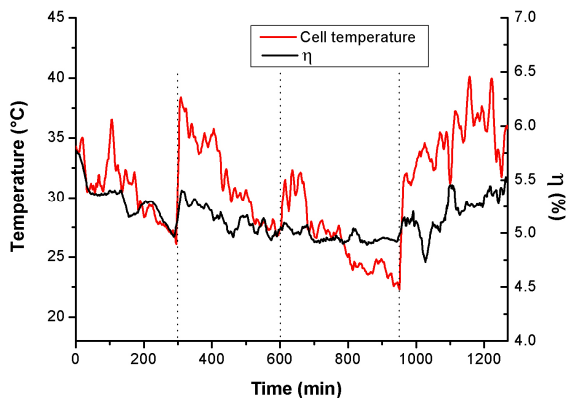


Fig. 6. Cell temperature and efficiency versus time.

The increase in efficiency of the last day could be due to the temperature increment of the cell. To confirm the link between the two parameters, data have been correlated at a fixed value of irradiance ( $910 \text{ W/m}^2$ ), as shown in fig. 7.

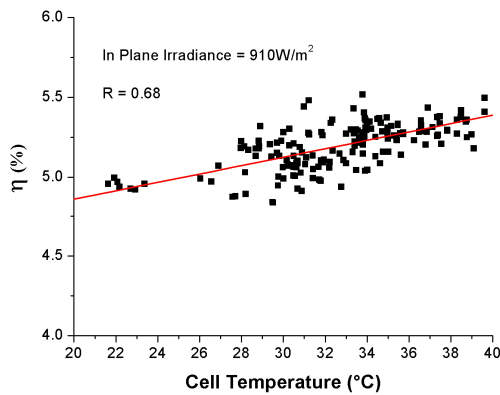


Fig. 7. Correlation between cell temperature and efficiency

The trend confirms an efficiency increase with increasing cell temperature. The linear correlation results in a quite good correlation coefficient of 0.68.

From fig. 6 it can also be noted a high variability of cell temperature with time. This behaviour can be explained by analysing the influence of wind conditions on the cell.

Figure 8 shows the cell temperature and wind speed for the days of test. Cell temperature originates from the heat balance between solar radiation that heats the cell surface and forced convection that provides to remove heat from the cell; when the wind speed is high a decrease in cell temperature is observed due to efficient heat removal by forced convection. The last day of measurements have experienced a low wind intensity (below  $3 \text{ m/s}$ ) with consequent increase in cell temperature.

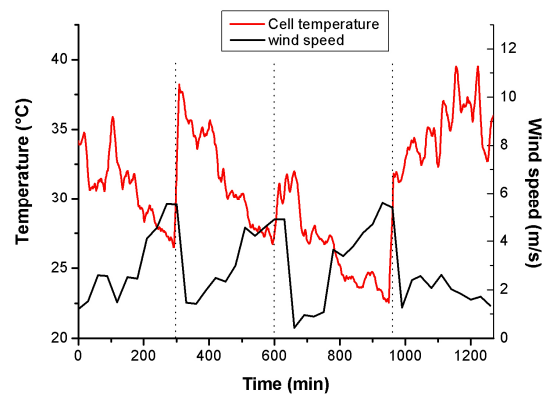


Fig. 8. Cell temperature and wind speed versus time.

Temperature measured on the cell surface can also be explained by analysing air temperature. As it can be noted from fig. 8 maximum wind intensity was almost constant during the first three days of test, consequently cell temperature should have reached approximately the same values for all days. Focusing on the 4/18 we can observe, instead, an initial abrupt cell temperature decreasing from  $36^\circ\text{C}$  registered on the 16<sup>th</sup> and the 17<sup>th</sup> to approximately  $31^\circ\text{C}$  even if the wind intensity was comparable with the previous days.

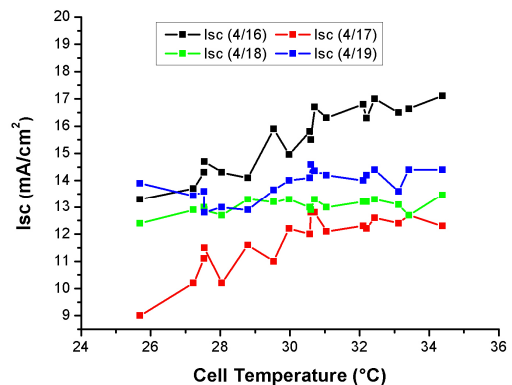


Fig. 9. Isc versus cell temperature for the days of test.

Part of this can probably be due to the decreasing of minimum air temperature registered on the 18<sup>th</sup> (see fig. 3).

Some indications of cell initial degradation has been observed during the four days of test as shown in fig. 9. Black line shows  $I_{sc}$  trend versus cell temperature for the first day in outdoor conditions: an  $I_{sc}$  increase with increasing cell temperature can be observed. The second day shows an abrupt reduction in  $I_{sc}$  with a following increase with increasing cell temperature. A sort of cell "recovery" is then observed for the last two days.

### CONCLUSIONS

A DSC cell built by CHOSE laboratories has been tested in the outdoor ESTER facility at the University of Rome Tor Vergata. The first results obtained show the importance of environmental parameter control in order to explain the cell behaviour in real operating conditions. Wind intensity have shown to play a key role.

Cell efficiency of approximately 5% have been experienced by the cell during the outdoor exposure and an initial degradation has been observed with a subsequent recovery during the test.

At fixed in plane irradiance, efficiency increase has been observed with increasing cell temperature.

As further investigation, systematic outdoor tests are planned in order to get a complete characterization of the cell in the outdoor environment.

### ACKNOWLEDGEMENTS

The authors wish to acknowledge ing. Pierluigi Braghese for the help in carrying on the measurements.

The work has been funded by Regione Lazio in the framework of the research activities of the Centre for Hybrid and Organic Solar Energy (CHOSE, [www.chose.it](http://www.chose.it)).

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