EXPERIMENTAL EVALUATION OF THE SOLAR RADIATION GAINS OVER PHOTOVOLTAIC CELLS DUE TO THE USE OF TiO_2 TREATED SURFACES. APPLICATIONS TO PHOTOVOLTAIC SYSTEMS WITH MICRO-INVERTERS

Isidoro Lillo[1], Rocío Domínguez[2], Miguel Larrañeta[2] and Manuel Silva[1]
1 Department of Energy Engineering. University of Seville. Spain
2 Andalusian Association for Research and Industrial Cooperation. Group of Thermodynamics and Renewable Energy.
Camino de los Descubrimientos s/n, 41092, Seville, Spain. Phone/Fax number: (+34)954487236/(+34)954487233.
E-mail: isidorolillo@etsi.us.es

ABSTRACT: In building integrated photovoltaic (PV) systems, the reflection of the solar radiation by the walls of the buildings may cause a non-uniform distribution of the incident radiation on the different PV modules. However, by using micro-inverters at strings levels, electricity production may increase instead of provoking losses by mismatching. For this purpose, the maximum possible solar gain due to reflections is required.

The annual profit of the solar radiation depends on factors such as climate, latitude and the relative position of the cell to the reflective surface. In the location of Seville (Spain), the gain on a PV cell generation due to radiation reflected by a TiO_2 treated perpendicular surface reaches a 13% for an entire year. Therefore, it is well demonstrated that using micro-inverters not only involves a loss reduction of a solar installation but also to obtain a profit from the solar radiation that cannot be achieved with centralized inverters.

Keywords: TiO_2, Solar radiation, Photovoltaic.

1 INTRODUCTION

In building integrated PV systems, the solar radiation distribution on the different PV modules can be inhomogeneous. This is due to the presence of partial shadows, dirt and/or PV modules with very different orientations and inclinations.

The inhomogeneous distribution of the solar radiation on a PV module usually produces significant reductions on the electrical production of the installation due to mismatching. A way to reduce these energy losses due to partial shadows and dirt is using micro-inverters at cell, string or module levels [1-7]. The benefits of micro-inverters against of centralized inverters have been extensively analyzed in the scientific literature [8-20].

Nevertheless the use of micro-inverters can encourage another phenomenon that occurs in the building sector. Sometimes due to structural elements of the building and its surrounding the reflection of the solar radiation occurs on the PV modules. These reflections of radiation produce a gain of the global total radiation on cells, strings or modules. If mismatching losses between cells, string or modules are avoided by using micro-inverters, the electric production of the PV system can be increased due to its increased solar radiation gains.

To achieve the maximum reflections is necessary to dispose of superficially treated surfaces with highly reflective materials. Among the most common reflective materials used on the exterior of the buildings include aluminum, galvanized steel, white cement or coatings finished with white paint highlight.

One of the pigments that have better reflective qualities is the TiO_2. This is the whitest pigment available in the market. With a low price, it has very good reflective properties in the visible range, reflecting around 90% of the incident radiation. It has a high refractive index, making it a material with a high opacifying power. TiO_2 also has a wide range of application in nano-technology field, as it shows photocatalytic and super-hidrophilic properties that make it a self-cleaning material, used in plenty of solar applications like PV or building integration [21-35].

The goal of this study is to evaluate the use of TiO_2 as a reflective pigment to increase the gain of reflective incident irradiance on PV modules that have micro-inverters at string or module level. To this the solar radiation gain of a cell that receives reflection respect of other that not receives has been experimentally measured. Besides this gain, the spectral distribution of reflection radiation by the TiO_2 treated surface is analyzed.

As Figure 1 shows, it has been dealt a vertical surface facing with TiO_2 towards south over a horizontal monocrystalline silicon calibrated solar cell (cell 2) located outside. Simultaneously another identical calibrated cell (cell 1) was placed on a horizontal surface without reflection. We assessed the gain of solar radiation that receives the reflected cell (cell 2) versus the non-reflected cell (cell 1) in different types of days.

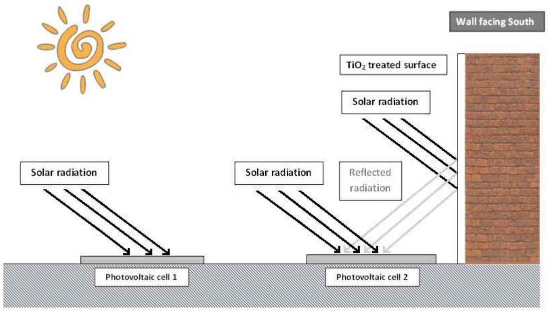

Figure 1. Experimental installation.

2 RESULTS

The solar radiation gain received by the cell depends on geometrical considerations defined by the relative position between the sun, the reflecting surface and the solar cell. Climatic considerations as the level of irradiance at each time, the value of the direct solar radiation and the composition of the atmosphere also affect to the value of the solar radiation gain. The existing combinations are limitless.

By way of example, Figure 2 and Figure 3 show the incident solar irradiance between cell 1 and cell 2 along a cloudy day and another clear day. The vertical plane of the reflecting surface is facing south.

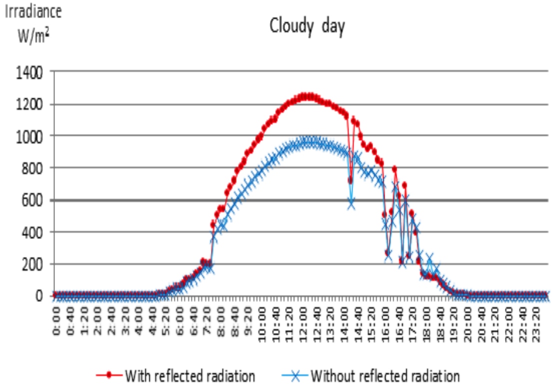

Figure 2. Solar radiation on the reflected and non-reflected cell for a cloudy day.

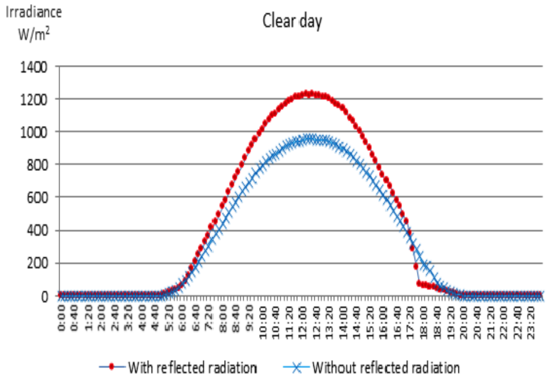

Figure 3. Solar radiation on the reflected and non-reflected cell for a clear day.

On the basis of the results obtained of solar radiation gain for each relative position, the results have been extrapolated for a typical meteorological year of Seville (Spain). It is regarded that the analyzed cell is in a horizontal position and the reflecting surface of TiO_2 is facing south.

Furthermore, it has been experimentally established that in the Northern Hemisphere for solar altitudes between 10º and 35º, in the morning and with vertical reflective surfaces south-east facing, the gains reach maximum values of 150%.

Solar radiation gain not only has been measured in absolute value, since reflected radiation presents a specific spectral distribution in function of the reflective material. Figure 4 ans Figure 5 show, in function of waveleength, the behaviour of the reflecting surface treated with TiO_2.

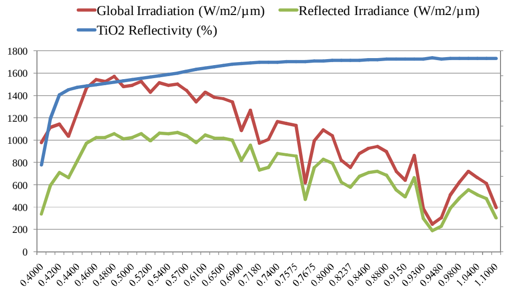

Figure 4. Spectral reflectivity of the surface treated with TiO_2.

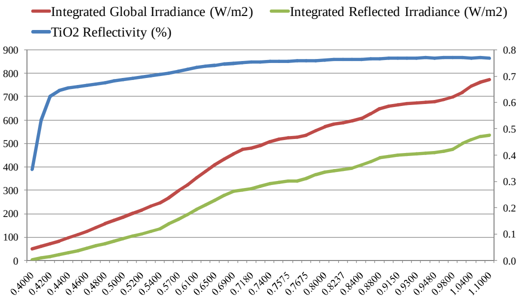

Figure 5. Accumulated values of solar irradiance and reflected irradiance of a surface treated with TiO_2.

It is noted as above a wavelength of 700nm the reflectivity of the surface is between 75% and 80%. For wavelengths of 400nm the reflectivity decreases in order of 35%, that is, the reflectivity of the reflecting surface improves as the wavelength increases.

On the other hand, each PV technology has its own spectral response and thus their behaviour varies depending on the spectral distribution of the incident solar radiation, both radiation reflected and radiation directly reflected.

Figure 6 shows a comparative analysis of the intensity that would be generated for the same reflected solar radiation for five different PV technologies, monocrystalline, polycristalline, amorphous, CdTe and CIGS due to the spectral response of each technology in function on the spectral distribution of the incident solar radiation.

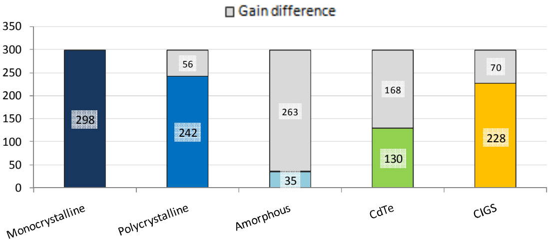

Figure 6. Comparative analysis of the intensity produced by each technology to the same spectral radiation emited by a surface treated with TiO_2.

Figure 6 shows that the monocrystalline silicon PV technology presents the best response. In contrast, the amorphous silicon PV technology presents the worst response with a decrease of 88% of net gain in the conversion of incident solar radiation into electrical production.

3 CONCLUSIONS

The results show that the use of these painted surfaces can significantly increase the PV production in buildings. The use of TiO_2 pigment as reflector achieves an homogeneous distribution of the additional solar radiation reflected with appreciable results and without incurring in huge costs.

The annual profit in solar radiation depends on the relative sun-surface-cell position and the amount of direct solar radiation and weather conditions.

The electrical production gain at the output of the module depends on the solar radiation gain and the spectral response of the PV technology.

Monocrystalline silicon technology obtains higher electrical production gains compared to other PV technologies.

Therefore, it is well demonstrated that using micro-inverters not only involves a loss reduction of a PV solar installation, but also allows to obtain a profit from the solar radiatoin that cannot be achieved with centralized inverters.

4 REFERENCES

[1] Micro-inverter improves array reliability. Limpscombe, Gail. 2008, Solar Today, Volume 22, Issue 7, p. 58.

[2] Performance comparison between micro-inverter and string-inverter Photovoltaic Systems. Fabio Famoso, Rosario Lanzafame, Simone Maenza, Pier Francesco Scandura. 2014. 2014, Energy Procedia,Volume 81, pp. 526-539.

[3] Control and circuit techniques to mitigate partial shading effects in photovoltaic arrays . Ali Bidram, Ali Davoudi, Robert S. Balog. 2012. 2012, IEEE Journal of Photovoltaics, 2 (4), pp. 532-546.

[4] Micro-inverters Promising solutions in solar photovoltaics. Hadeed Ahmed Sher, Khaled E.Addoweesh. 2012. 2012, Energy for Sustainable Development 16 , pp. 389-400.

[5] A comprehensive techno-economic review of microinverters for Building Integrated Photovoltaics (BIPV). Hanumath Prasad Ikkurti, Suman Saha. 2015. 2015, Renewable and Sustainable Energy Reviews 47, pp. 997-1006.

[6] Microinverters and power optimizers: Power conversion migrates down to the PV panel. Conner, Margery S. 2009. 2009, EDN Volume 54, Issue 24, pp. 24-27.

[7] A Review of Single-Phase Grid-Connected Inverters for Photovoltaic Modules. Soeren Baekhoej Kjaer, John K. Pedersen, Frede Blaabjerg. 2005. 2005, IEEE Transactions on Industry Applications,41 (5), pp. 1292-1306.

[8] "Partial Shade Evaluation of Distributed Power Electronics for Photovoltaic System," Deline, J. Meydbray, M. Donovan, and J. Forrest, 2012. IEEE Photovoltaic Specialists Conference Austin, Texas. NREL/CP-5200-54039.

[9] A performance and economic analysis of distributed power electronics in photovoltaic systems, C. Deline, B. Marion, J. Granata, S. Gonzales, NREL Technical Report, NREL/TP-5200-50003, January 2011.

[10] "Analaysis of potential for mitigation of building integrated PV array shading losses through use of distributed power converters," S.M. MacAlpine, M.J.Brandemuehl, R. W.Erickson, in Proc. 4Th Int. Conf.on Energy Sustinability, ES2010, May 17-22. 2010.

[11] "Characterizing Shading Losses on Partially Shaded PV Systems, C. Deline, 2010. PV Performance Modeling Workshop. NREL/PR-520-49504.

[12] "Photovoltaic Shading Testbed for Module-Level Power Electronics," C. Deline, J. Meydbrey, M. Donovan and J. Forrest, NREL Technical Report NREL/TP-5200-54876 (2012).

[13] "Analaysis of potential for mitigation of building-integrated PV array shading losses through use of distributed power converters," S.M. MacAlpine, M.J.Brandemuehl, R.W.Erickson, in Proc. 4Th Int. Conf. on Energy Sustinability, ES2010, May 17-22.2010.

[14] Performance of Mismatched PV Systems with Submodule Integrated Converters," C. Olalla, C. Deline, D. Maksimovic, "IEEE J. Photovoltaics, 2013.

[15] "Potential for power recovery: simulated use of distributed power converters at various levels in partially shaded photovoltaic arrays," S.M. MacAlpine, M.J.Brandemuehl, R.W.Erickson, in Proc. PVSEC 2011.

[16] "Control of Submodule Integrated Converters in the Isolated - Port Differential Power Processing Photovoltaic Architecture," Y. Levron, D. Clement, B. Choi, C. Olalla, D. Maksimovic, and S. Member, IEEE J. Emerg. Sel. Top. Power Electron., 2014.

[17] "Architectures and Control of Submodule Integrated DC – DC Converters for Photovoltaic Applications," C. Olalla, D. Clement, M. Rodriguez, and D. Maksimovic, IEEETrans. Power Electron., vol. -, no. -, pp. 1–18, 2012.

[18] "Generation Control Circuit for Photovoltaic Modules," T. Shimizu, M. Hirakata, T. Kamezawa, and H. Watanabe, IEEE Trans. Power Electron., vol. 16, no. 3, pp. 293–300, 2001 K. Kim, P. Shenoy, and P. Krein, "Converter Rating Analysis For Photovoltaic Differential Power Processing Systems," IEEE Trans. Power Electron., vol. 8993, no. c, pp. 1–1, 2014.

[19] "Differential Power Processing for Increased Energy Production and Reliability of Photovoltaic Systems," P. Shenoy, K. A. Kim, B. B. Johnson, and P. T. Krein, IEEE Trans. Power Electron., vol. 28, no. 6, pp. 1–19, 2013.

[20] "Performance of Power Limited Differential Power Processing Architectures in Mismatched PV Systems," C. Olalla, C. Deline, D. Clement, S.Member, Y. Levron, M. Rodriguez, D. Maksimovic, and S. Member, IEEE Trans. Power Electron., pp. 1–13, 2014.

[21] TiO2 pigment technology: a review. Juergen H.Braun, Andrejs Baidins, , Robert E.Marganski. 1992. 1992, Progress in Organic Coatings 20, pp. 105-138.

[22] Mini review on photocatalyst of titanium dioxide nanoparticles and their solar applications. Yucheng Lan, Yalin Lu, Zhinfeng Ren. 2013, Nano Energy , págs. 1031-1045.

[23] Nanostructured Titanium Dioxide Materials: Properties, Preparation and Applications. Alireza Khatase, G.Ali Mansoori. 2011, World Scientific.

[24] Titanium Dioxide Photocatalysis: present situation and future approaches. Akira Fujishima, Xintong Zhang. 2006. 2006, C.R. Chimie 9, pp. 750-760.

[25] TiO2 photocatalysis: Design and applications. Kazuya Nakata, Akira Fujishima. 2012. 2012, Journal of Photochemistry and Photobiology C: Photochemistry Reviews 13, pp. 169-189.

[26] Influence of TiO2 nanoparticle synthesis on the properties of thin coatings. Nina Barth, Mandy Zimmermann, Andre Erek Becker, Tobias Graumann, Georg Garnweiter, Arno Kwade. 2015. 2015, Thin Solid Films, pp. 20-27.

[27] TiO2 photocatalysis and related surface phenomena. Akira Fijishima, Xintong Zhang, Donald A.Tryk. 2008. 2008, Surface Science Reports 63, pp. 515-582.

[28] TiO2 photocatalysis Design and application. Kazuya Nakata, Akira Fujishima. 2012. 2012, Journal of Photochemistry and Photobiology C: Photochemistry Reviews 13, pp. 169-189.

[29] Photocatalytic activity of TiO2–SiO2 nanocomposites applied to buildings. Luis Pinho, Maria J.Mosquera. 2013. 2013, Applied Catalysis B: Environmental 134-135, pp. 205-221.

[30] The effect of process parameters on the structure, photocatalytic and self-cleaning properties of TiO2 and Ag-TiO2 coatings deposited using reactive magnetron sputtering. P.Navabpour, S.Ostovarpous, J.Hampshire, P.Kelly, J.Verran, K.Cooke. 571, Manchester : s.n., 2014, Thin solid films 571, págs. 75-83.

[31] Studies on photokilling of bacteria on TiO2 thin film. Kayano Sunada, Toshiya Watanabe, Kazuhito Hashimoto. 2003. 2003, Journal of Photochemistry and hotobiology A: Chemistry 156, pp. 227-233.

[32] Preparation of a highly-reflective TiO2/SiO2/Ag thin film with self-cleaning properties by magnetron sputtering for solar front reflectors. Y.J.Xu, J.X.Liao, Q.W.Cai, X.X.Yang. 2013, Solar Energy Materials & Solar Cells 113, págs. 7-12.

[33] Comparison of self-cleaning properties of three titania coatings on float glass. Minna Piispanen, Leena Hupa. 2011. 2011, Applied Surface Science 258, pp. 1126-1131.

[34] The effects of TiO2 pigmented coatings characteristics on temperature and brightness of a coated black substrate. Mehdi Baneshi, Shigenao Maruyama, Atsuki Komiya. 2012. 2012, Solar Energy 86, pp. 200-207.

[35] Applications of TiO2 nanotube arrays in environmental and energy fields: A review. Qingxiang Zhou, Zhi Fang, Jing Li, Mengyun Wang. 2015. 2015, Microporuos and Mesoporous Materials 202, pp. 22-35.