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Performance analysis of photovoltaic systems of two different technologies in a coastal desert climate zone of Chile

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Abstract

This paper reports on the performance of photovoltaic systems in the coastal zone of Antofagasta, northern Chile. This region is one of the most suitable places in the world for the use of solar energy due to the high solar radiation levels. However, this location is influenced by a coastal desert climate where the environmental effects on solar technologies are not well known. Therefore, we study the performance ratio of photovoltaic systems in a period of 16 months, in which solar radiation and ambient temperature were quantified. The technologies were modules based on amorphous/microcrystalline silicon tandem thin films and mono crystalline silicon solar cells. The global tilted solar irradiation reached mean values of 8.5 kW h/m^2 day in summer and 6 kW h/m^2 day in winter demonstrating the high radiation available here. We analyzed how the performance ratio is influenced by the dust accumulation and the ambient temperature associated to this place. It came out that the difference of energy yield between the technologies became larger for summer and smaller for winter, and that the performance ratio decreased due to the dust accumulation between −0.04%/day up to −0.13%/day for positive ambient temperature gradient, and between −0.13%/day up to −0.18%/day for negative ambient temperature gradient.

Keywords: Photovoltaic systems; Performance ratio; Soiling; Dust accumulation; Real conditions

1. Introduction

The performance of a photovoltaic (PV) system depends on both the selected technology and also on the environment. The impact of ultra violet solar radiation, corrosive surroundings, temperature, humidity, ventilation and dust can strongly affect the energy prediction of the PV system. The losses due to these factors can be determined by using models based on field measurements (Kaldellis and Kapsali, 2011; Caron and Littmann, 2013) and different approaches summarized in(Sayyah et al. (2014). Another method for energy predictions is the use of a mathematical expression (Mulcué-Nieto and Mora-López, 2014).

Regarding general recommendations to mitigate the effect of soiling on PV modules, investigations have been reported in Mani and Pillai (2010). However, the environmental conditions can strongly differ even in the same region. An example is the Atacama Desert. The Atacama Desert is a plateau in South America, covering a 1000 km strip of land on the Pacific coast, west of the Andes Mountains. It covers an area of approximately 105,000 square kilometers that extends mostly in Chilean land but even partly Peru, Bolivia and northern Argentina. It is the driest non-polar desert in the world (Mckay et al., 2003). As a consequence, calculations of energy yield which consider the effect of dust and other climatic variables must be

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complemented by studies of the specific place, e.g. (Kaldellis et al., 2011).

In order to study and evaluate the behavior of PV systems, the performance ratio (PR) is a common indicator which will be used in this work. This measure determines how effectively a PV system converts sunlight collected by the PV modules into electricity considering the availability of the solar resource and relating to the name plate power (Decker and Jahn, 1997; Jonathan et al., 2011).

In the following, the quantities to calculate the performance ratio are defined according to (IEC, 1998). The reference yield (Y_r) is the quotient between the total in-plane irradiation H [kW h/m^2] and the irradiance at standard testing conditions or STC (G_{STC}), i.e. 1 [kW/m^2] as expressed in Eq. (1).

$$Y_r = \frac{H}{G_{\mathrm{STC}}}\ [\mathrm{h}] \tag{1}$$

The energy yield (Y_f) is the normalized energy to the size of a PV system as Eq. (2) shows.

$$Y_f = \frac{E_{\mathrm{dc}}}{P_{\mathrm{STC}}}\ \left[\frac{\mathrm{kW\,h}}{\mathrm{kWp}}\right] \tag{2}$$

where E_{dc} is the total DC energy produced by the PV system in kW h and P_{STC} is the DC power capacity of the PV system at STC. If considering the energy converted by the PV modules in AC to include inverter losses, the value of E_{dc} must be replaced by E_{dc} in Eq. (2). The performance ratio is then calculated as Eq. (3) describes. For this work, DC measures will be used.

$$\mathrm{PR} = \frac{Y_f}{Y_r}[\%] \tag{3}$$

This quantity allows for comparisons between PV systems installed in different locations (Campbell et al., 2012) and for studying the degradation of a specific PV technology from year to year (Ishii et al., 2011). An investigation about the comparison of different PV technologies under same environmental and radiation conditions installed in northern India found that PR of Heterostructure with Intrinsic Thin Layer (HIT) and PR of amorphous silicon (a-Si) were 7% higher than that of multicrystalline silicon (mc-Si) (Sharma et al., 2013). Another study specified that PR ranged from 57% to 93% for mc-Si and from 54% to 88% for a-Si based PV plants in western India (Tripathi et al., 2014). The performance of four technologies from which three of them were thin films and one was mc-Si resulted to be dependent on the season due to the change in the solar radiation available and operating temperature (Cañete et al., 2014). In Europe (Italy), the variability of PR was analyzed to compare several technologies resulting also in a seasonal dependence (Del Cueto, 2002; Ghiani et al., 2013).

Regarding uncertainties, main sources of errors come out due to the measurement of solar radiation as well as the DC electrical power, current and voltage. A study reports that the error in the tilted radiation and PR is estimated to be 6%–7% (Colantuono et al., 2014) in which uncertainties associated to azimuth and elevation angles are also considered in the error propagation. In order to reduce uncertainties, a number of practices are required, such as the determination of the solar resource, considering the effects of micro-climates and improving the reliability, accurate module ratings (Carr and Pryor, 2004), and inclusion of the effects of soiling, among others (Didier and Sophie, 2013).

According to Eq. (3) the performance ratio is independent of local radiation conditions and module orientation, quantifying the overall effect of losses and external environmental factors (Reich et al., 2012). Two external factors will be considered in this work: (i) dust accumulation on the module surface and (ii) temperature. This is a first step within a larger investigation which will involve the study and impact of environment on the performance of PV systems installed in northern Chile. A further step will be the specific analysis of the optical degradation due to dust.

For (i) it has been pointed out that the presence of dust on the module surface can have detrimental effects on the available radiation which a PV device can use. Due to absorption and light scattering by fine accumulated particles, attenuation of solar radiation intensity is produced according to the mass surface concentration of pollutants, expressed in g/cm^2, its size distribution and chemical composition (El-Shobokshy and Hussein, 1993). In other words, the module glass transmittance (T), defined as the capacity of the glass to transmit radiation, is affected by dust. In this way, the available irradiation for the PV devices is calculated as follows:

$$I(\lambda) = I_0(\lambda)\ \cdot T(\lambda)\ [\mathrm{W/m^2nm}] \tag{4}$$

where $I_0(\lambda)$ is the incident spectral irradiation onto the PV module in W/m^2 nm, λ the wavelength in nm and $T(\lambda)$ is the spectral transmittance, which includes the glass spectral transmittance $T_G(\lambda)$ and the deposited dust spectral transmittance $T_D(\lambda)$ as follows:

$$T(\lambda) = T_G(\lambda)\cdot\ T_D(\lambda) \tag{5}$$

The accumulated dust on the glass decreases T regarding clean conditions and thus the available I is reduced. It is difficult to determine the spectral dependence of the transmittance due the dust deposition because it depends strongly on the particle size, the thickness of the accumulated dust layer, and chemical composition, among other local parameters. On one hand, some authors have been reported that these transmittance losses are higher in the range 300–570 nm than at longer λ (Qasem et al., 2012). On the other hand, a previous study showed that for a dust concentration higher than 19 g/cm, T does not depend on λ (Al-Hasan, 1998). A fundamental study on dust effects on PV showed a reduction in the overall plane glass transmittance of 20% for 45 days exposure (Said and Walwil, 2014). In that work, anti-reflective coated glass resulted in a lower degradation of the transmittance than non-coated plane glass.

Knowing the spectral response (SR) in A/W of the PV device, it is possible to determine the maximal theoretical