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Effect of soiling and sunlight exposure on the performance ratio of photovoltaic technologies in Santiago, Chile

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ABSTRACT

The performance, yearly degradation, and annual yield of photovoltaic systems have been studied in outdoor exposure for two years period 2014–2015 in Santiago, capital of Chile. Photovoltaic panels performance degrades daily in a rate between −0.13% and −0.56% under soiling in highly polluted Santiago, Chile. Yearly degradation of the arrays system was found to be in the order of 1.29% for the polycrystalline array, 1.74% for the monocrystalline array, and 2.77% for the thin film system array. The annual production yield reached 1419–1373 kW h/kWp for Poly, 1459–1444 kW h/kWp for Mono, and 1248–1236 kW h/kWp for TF, in 2014 and 2015, respectively. The annual in-plane irradiation measured reached 1981.3 kW h/m^2 and 1943.2 kW h/m^2, for 2014 and 2015, respectively. A weather-corrected performance ratio is presented showing a yearly performance ratio of around 75% for all technologies. Monthly cleaning and random rain fall have shown positive effects as primarily solutions. Furthermore, we studied the optimal strategies of cleaning for different energy prices and we defined a critical cleaning period of 45 days for a real case, independent on cleaning cost and energy prices. This work contains novel results for the Chilean capital city and can be applied to future installations in the area and serve as further insights for the development of solar energy in Chile.

1. Introduction

Chile has become a promising country for photovoltaic (PV) plants installations since 2012. Following the growth of the electricity market, more than 0.74 GWp of Solar PV are under operation and around 2 GWp are under construction up to date [1]. Also, another motivation for PV worldwide is that the total cost of a fully installed utility PV system (fixed-tilt) is already below $1.5 per watt [2]. Although 80% of the performance is guaranteed by the solar panel manufacturer up to 25 years, the output power generated by a solar plant strongly depends on the climate parameters and the ambient aggressiveness of the specific field. Qualification of solar panels is the key for long term reliability, stability and guaranteed output power. Out in the field however, certified solar panels have shown failures mainly lying on interconnect breakage, solar cell cracks, and corrosion [3].

It is of paramount importance to follow a PV plant after installation in order to understand and characterize its failures in the field over long periods of time. Real conditions mean measuring the output power and *I–V* characteristics of solar panels under parallel incident radiation, recording the ambient and real module temperature together with the velocity of wind (speed and direction), and recording periods of cleaning and rain. A common drop on PV performance is produced by shadowing the incident sunlight due to soiling. Since the 80s it has been already known that testing PV panels under long periods of outdoor exposure is the most effective way to evaluate soiling [4].

Although the first PV plant in Chile began to operate in late 2012, solar energy research in Chile had previously started in the 60s. One of the first published works on Solar Energy in Chile was done on solar-heat collectors by Federico Santa Maria Technical University in Valparaiso [5]. The first solar radiation data was registered in Chile back to 1973, also by the same author [6]. After that, the solar energy resource data available in Chile was collected and published a few years ago on a review paper [7]. Later on, monthly means of radiation were published recently from satellite image available in Chile between 1995 and 2005 [8]. First studies on a panel prototype specifically designed for the Atacama desert have shown that glass to glass is a good solution for

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extremely high solar irradiation [9]. Furthermore, the Atacama Solar Platform project has started as an initiative for research of solar energy in north Chile [10]. Finally, the levelized cost of energy (LCoE) [11] and the performance of various solar panels have been analyzed in northern Chile showing the detrimental effects of high temperature on the performance ratio [12].

This work focuses on the soiling analysis for a PV grid-connected plant installed in Santiago Chile, where pollution and dust are heavily present and are a main problem during cold seasons. We select an optimal period for the analysis of two years. Irradiation and performance of different PV technologies are presented for this period. Also the yearly degradation of our PV system is discussed under real conditions as soiling, rain and shadowing. From our knowledge, this is the first time the performance of crystalline and thin film PV arrays are compared for two years period in Chile, where the effect of soiling and regular periods of cleaning on the non-corrected and weather-corrected performance ratio are presented.

2. State of the art: soiling and degradation

2.1. Soiling

Natural dust (soil) is a contamination source for PV panels mainly formed by airborne particulates. Soiling is the effect of particles deposition during a period of time where no external cleaning is present. The size of dust particles may vary from 1 μm to 500 μm, depending on the source. Particles from an industrial source include concrete, fibreglass, carbon fibres, brick among others, and particles from anthropomorphic pollution causing health risks (10 μm). If high relative humidity is present, the stickiness of soiling particles on the PV panel will increase and the effect of cleaning by wind will be reduced. In other words, low moisture present in the particles influences on a suspension by wind [13].

The electrical performance of the PV panel is strongly affected by partially shadowing the front surface module glass due to particle deposition. The main factor is that particles of soiling can behave as dielectrics, absorbing incident light and reducing transmission or even produce reflection by changing the angle of incidence of light into the module. It has been shown that the performance degradation of solar panels can range from 2% to 60% power loss, depending on time and site of particle accumulation, and that the effectiveness of cleaning by rain heavily depends on material properties [4].

Although soiling is not standardized as a PV module failure [14], its detrimental effect on reducing the electrical output of Photovoltaic (PV) solar panels is well known. PV panel performance has been compared before and after cleaning [15]. Particles present in soiling are normally water-soluble, so that a short cleaning process is sufficient to remove the coating from the surface and bring the panels to original state. However, in some desertic areas, cleaning by water is no sufficient and chemicals have to be added to the mixture to improve cleaning and water saving [16]. After a very dry period some particles are resistant and sequential cleaning procedure is needed. Thus, the effectiveness of cleaning by rain depends on the amount of rain and the humidity present in the day.

Several studies can be found worldwide, and depending on the location site the electrical performance degradation has different rates. In Europe, the mean daily production losses in Malaga (Spain) caused by the accumulation of dust deposited on the surface of the PV module was around 4.4% and in long dry periods of dust accumulation this value was higher than 20% [17]. In Belgium, the power loss was between 3% and 4% in a period of 5 weeks [18]. In Crete, the annual soiling losses were estimated to be 5.86% [19]. In the countryside of Southern Italy a 6.9% and 1.1% monthly power losses were found for a plant built on a sandy soil and a plant built on a more compact soil, respectively [20]. In Gran Canary Island, relative efficiencies dropped to 20% of the initial values within 5 months, and recovered their initial value after rainfall [21]. In Kuwait, soiling losses amounted 45.8% over three months period without cleaning [22]. In California, soiling losses averaged 0.051% per day of conversion efficiency during dry seasons [23] and 7% annually [24]. In Brazil, the chemical properties of soiling particles are primary silicates critical for the adhesion [25]. In the Atacama Desert (Chile), PR decreased at a rate of 4.8%/month for thin film technology and at a rate of 6.2%/month for multicrystalline, due to the dust accumulation and extreme temperatures [11], although none weather-correction of the data has been performed so far in Chile [26].

The pollution coming from nearby highways or cities is a critical factor influencing soiling and cleaning [27]. The detrimental effects of hydrocarbon fuels enhanced the bonding of soiling particles to the surface; soiling properties related to Na, Mg, and Cl have been reported from near traffic highway [25]. In Santiago, Chile, the pollution is heavily present [28]. Although we have not yet performed chemically analysis of the soil present on our modules in Santiago, nevertheless, the soiling losses can be directly related to the polluted air from urban and industrial environment, since our plant is installed close to heavily trafficked roads.

All this studies show that it is indeed worth focussing on preventing soiling or developing anti-soiling technologies.

Nowadays there are methods developed from different authors which are trying to predict soiling effects [20,29–33], showing the benefits in terms of revenues for the PV industry. Besides this, anti-soiling techniques have been developed as self-cleaning glazing products [34] and anti-soiling photocatalytic coating [35].

2.2. Degradation

Panel degradation occurs directly after light exposure. Rapid initial degradation correlates to oxygen contamination in the silicon material and long time degradation is attributed to long ultraviolet exposure [36]. Both, crystalline and thin film technologies suffer directly after light soaking: For crystalline, this phenomena is known as light induced degradation (LID); For thin film technology, the process occurs faster than in crystalline due to defects and vacancies in the amorphous material. This light induced phenomena is also known as Staebler Wronski Effect (SWE), which describes the decrease of photoconductivity of the solar cells based on a-Si [37]. Another degradation of solar panels can be found depending on many factors, from solar cell and manufacturing procedures, to PV plant electrical design and polarization of panels. This phenomena is called potential induced degradation (PID): at the cell level, parasitic positive charges can approach to the cell due to sodium diffusion from encapsulant to the cell [38]; at the PV plant level, wrong electrical configuration of the whole system may produce negative potential relative to earth. Thus, PID can be avoided by hard grounding the inverter/transformer to earth or soft grounding the transformerless inverter. Also, humidity and temperature have been shown as a detrimental effect to increase PID [39]. Furthermore, delamination and discoloration has been in deserting climates zones [40].

Degradation rates of solar panels can change for different climate conditions. It has been shown that these rates can vary from 0.17%/year in Sweden to more than 0.5%/year in USA [36]. Most of failures lie on interconnect breakage, solar cell cracks, and corrosion [3], although electrical solar cell parameters can be affected due to a lack of high quality processing. A correct degradation analysis needs to cover a long period of time above at least 2 years [15,36], and should be performed comparing *I*–*V* data before and