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Long-term soiling of silicon PV modules in a moderate subtropical climate

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Abstract

The results of 28 silicon-based PV modules which were installed from 1981 to 1985 in a free rack configuration in the outdoor test facility of the European Solar Test Installation (ESTI) and dismantled at the end of 2014 without cleaning were analysed. The system was composed of modules with two series-connected laminates mounted in a single frame produced by the same manufacturer but using different cell layouts and cover glasses (plain glass or textured glass). The effects of long-term soiling on the PV module performance for more than 30 years of outdoor exposure in a moderate subtropical climate and the influence of different cleaning methods from manual cleaning to the use of high pressure water washing were investigated. The influence of the cover glasses and the mismatch due to the particular manufacturing design were also analysed. It was observed that a manual cleaning was effective at improving the output of all the module types. However, additional high pressure water spraying on plain glass modules showed no further improvement, but showed small improvements on the textured glass modules. Overall improvements in P_{max} after cleaning ranged from 3.5% to 19.4%, with an average value of 9.8% and an average improvement in I_{sc} of 6.7% were obtained.

Keywords: Soiling; PV performance; Silicon modules

1. Introduction

Accumulation of dirt on the surface of photovoltaic (PV) modules, referred to as "soiling", is one of the main loss factors affecting the system energy generation and this also presents a challenge to long-term performance prediction and lifetime estimates (John et al., 2014; Piliougine Rocha et al., 2008). The soiling is considered an important agent of optical losses that imply that the photovoltaic cells receive less irradiance (in the case of soiling uniformly distributed), or partial shading on the cells if it is not homogeneously distributed. Module soiling can result from various mechanisms such as pollution, particulate matter originating from agricultural activity, construction, the accumulation of dust, pollen, bird droppings or the growth of lichen (particularly at the lower edge of framed modules). Bird droppings or lichen, for example, present a serious problem as, contrary to dust, they cannot be easily washed away by rainfall (Thevenard and Pelland, 2013). The soiling is a complex phenomenon influenced by diverse site-specific environmental and weather conditions, tilt angle of the PV modules, the type of soiling agent and also the texture of the front glass (Piliougine Rocha et al., 2008; Mani and Pillai, 2010).

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The soiling effects on PV module performance have been investigated by several groups for different location, technologies, tilts and module design, with a number of papers found in the literature (Ryan et al., 1989; Caron and Littmann, 2013; Appels et al., 2013; Hammond et al., 1997; Kimber et al., 2007; Sarver et al., 2013; Schill et al., 2011, 2015; Kalogirou et al., 2013; Qasem et al., 2014). However, most of the works report on short-time soiling, from some days up to 6 years, considering that the modules are naturally cleaned by rain events or can be manually cleaned (Ryan et al., 1989; Mejia and Kleissl, 2013). An extensive review of natural soiling studies is reported by Sayyah et al. (2014). Heavy rainfall is considered to be the most efficient natural cleaning agent for removing contaminant particles from PV surfaces, demonstrating the significant restorable effects of sufficient rainfall, which make regular manual surface cleaning unnecessary. However, the build-up of dirt and dust over the years, or decades, is not so easily washed away by the rain and eventually leads to some permanent soiling. The conventional solution to the problem of soiling is to clean the PV modules with water or other standard glass cleaning products. However, this can be expensive and/or impractical at locations where water access is not feasible. The investigation on long-term soiling in PV systems should also assess the impact in economic terms (Massi Pavan et al., 2013). It has been reported, for instance, that in regions of mid-north Europe it could be uneconomic to clean the PV systems meanwhile an economical benefit can be observed in southern regions of Europe (Stridh, 2012). This study points out that with a cleaning cost of 2500 €/MW each cleaning has to recover between 1.0% (2.3%) of one year's production in Southern regions to 3.0% (5.2%) in northern European regions to give breakeven with the cleaning cost assuming industrial electricity price and (spot electricity price), respectively. Manual and automatic PV cleaning services are offered by emerging companies and PV performance losses due to soiling need to be studied to assess whether these services are cost-effective or not.

This study reports on the results of 28 silicon-based PV modules which were installed from January1981 to March 1985 in the outdoor test facility of the European Solar Test Installation (ESTI) of the European Commission's, Joint Research Centre. All of the modules were dismantled at the end of 2014 without cleaning, that is, after almost 30–33 years of outdoor exposure, depending on the installation date. The system was composed of modules with two series-connected laminates mounted in a single frame produced by a single manufacturer using either plain glass or surface textured glass. The effects of long-term soiling on the PV module performance for more than 30 years of outdoor exposure in a moderate subtropical climate and the influence of different cleaning methods were investigated. To our knowledge, this study represents the longest exposure time for soiling of Si PV modules. Despite the fact that this is a specific case and that the soiling behaviour will depend on the site, the study may be indicative of the general behaviour of dust accumulation in moderate subtropical climates with frequent rain events incorporating standard modules of the 80's and a typical tilt angle. The influence of the cover glasses and the mismatch due to the manufacturing design were also analysed.

2. Experimental method

2.1. Module characteristics

The array was composed of a set of 28 crystalline silicon wafer based photovoltaic modules which were subjected to long-term continuous outdoor exposure for more than 30 years without cleaning. The system was composed of modules produced by a single manufacturer, but they were manufactured at different times and as such incorporate different materials (e.g. modules using plain glass (6) or surface textured glass (22)). Each module is composed of two laminates incorporating round 10 cm diameter monocrystalline silicon solar cells connected in series. The two laminates can be contacted separately, thus giving the choice of connecting the two parts of the module in series or in parallel. At the beginning of the 1980s, the PV module manufacturing was in an early stage and most of the processes were performed manually. The module designs which consists of two laminates in a single frame is likely due to the fact that it was easier to manage a smaller area to place the cells manually into the liquid silicone based encapsulant.

Three different types of modules could be identified which differed in the number of cells (68 or 72), the front cover glass (flat glass or textured glass) and the cells layout. In all cases the substrate of the modules was white silicone and the encapsulant was silicone. One difference to be mentioned is the presence of a rubber gasket around the edge of each laminate for modules "Type A" and "Type B" which is not present in modules "Type C". These "Type C" modules have instead a rubber spacer between each laminate. The modules main design details are shown in Table 1. Although the modules were of three different types, they were divided into four groups for the purpose of this study, as the initial testing and installation of the 15 modules of "Type C" was performed in two separate batches, one consisting of 7 modules, with identification codes COxx, and the other consisting of 8 modules, identification code BOxx. The "Type A" and "Type B" also incorporate bypass diodes in each laminate, which have been detected by means of thermography images in reverse bias, while "Type C" do not have bypass diodes.

The array was left in an open-circuit configuration for most of the outdoor exposure period as this installation was to be used in an application requiring high DC voltage. Fig. 1 shows the view of the whole array before removal of the modules from the rack and the typical soiling distribution on a "Type C" module with the accumulation of dirt between laminates is shown in Fig. 2.