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Photovoltaic performance degradation due to dust accumulation

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ABSTRACT: *PV module performance can be significantly affected by both environmental conditions, such as outside temperature, wind velocity, and humidity, as well as the accumulation of dust on the module surfaces. Climatic factors can also influence the amount of dust accumulation directly. In this paper, the effect of long-term soiling on the PV module performance for one year of outdoor exposure in a Tropical Savanna climate and the influence of manual cleaning method was investigated. It was observed that a manual cleaning was effective at improving the output of the PV module. However, overall improvements in Pmax after cleaning ranged from 3.5% to 19.4%, with an average value of 9.8% and an average improvement in Isc of 6.7% were obtained.*

KEYWORDS: *photovoltaic system, dust accumulation, module performance, cleaning.*

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I. INTRODUCTION

The future of the world lies with renewable energy resources, and solar energy is one such type of sustainable energy resource since it relies mainly on an abundant and clean source. The environmental parameters have a significant impact on both the power productivity and the performance of photovoltaic (PV) system [1-7]. Some of the environmental parameters are temperature, wind speed and direction, humidity, solar radiation and the presence and amount of dust. Soiling or dust accumulation on the PV modules is one of the most significant environmental factors that affect the performance of PV modules by reducing the incoming solar radiation received by the PV module. Dust is a general term for any particulate matter less than 500 lm in diameter, which is about the dimension of an optical fiber used for communications or 10 times the diameter of a human hair [8]. Dust can comprise various matters like vegetation pollens, animal cells, carpet and textile fibers and generally minerals from geomorphic fallout such as sand, clay or eroded limestone [9]. Atmospheric dust (aerosols) is attributable to various sources, such as soil elements lifted by wind (Aeolian dust), volcanic eruptions, vehicular movement, and pollution [10]. The particle size, constituents of dust and their shape vary according to region throughout the world. 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 [11].

Weather conditions such as rainfall, relative humidity, wind speed, and ambient temperature play a significant role in determining the accumulation of dust on the panel surface and the resulting PV performance loss [12-13]. The rain naturally helps to improve PV performance by washing away the deposited dust or dirt from panel surfaces. However, the effectiveness of cleaning varies with the amount of rain and dry period for dust accumulation before a rain event. The impact of soiling on PV module performance firstly depends on the mass of dust accumulated on module surface and secondly on the characteristics of dust [14-18]. In general, an increase in dust accumulation leads to a decrease in PV module performance [19-28]. The objective of this study was to determine the loss of energy output caused by dust accumulation on PV modules.

II. METHODOLOGY

2.1 **Meteorological and climatic characteristics of the site**

Modules were installed in Noida, northern India situated in between latitude 28.4744° N and longitude 77.5040° E of 202m height above the sea level. As Tropical Savanna Climate, it has three main seasons: summer, monsoon and winter season. In summer, which is from March to June, the temperature ranges from a maximum of 45 °C to a minimum of 23 °C. Monsoon season prevails during mid-June to mid-September with an average rainfall of 932 cm. The cold waves from the Himalayan region make the winters in Greater Noida very chilly. Temperatures fall down to as low as 3 to 4 °C at the peak of winter. In January, a dense fog envelopes the city, reducing visibility on the streets.

1.2 Module characteristics

The array was composed of a set of 12 crystalline silicon PV modules which were subjected to long-term continuous outdoor exposure for one year without cleaning. The modules SS320P (each of 310 Wp capacity) having 72 solar cells made up of polycrystalline silicon having 16.15% efficiency are used. The modules are free from any of shading effect and are fixed with tilt angle of 28° (equal to the latitude of the corresponding location to get maximum solar radiation) facing south at an azimuth angle of 0°. 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.

1.3 Cleaning procedure

The modules were dismantled in October 2016 and different characterizations were performed, prior to cleaning the surface of the modules, in order to assess the extent of long-term soiling. The PV array was never cleaned during the outdoor exposure period and the PV modules were subjected to manual cleaning, one by one, after removal from the field using a soft sponge with a standard commercially available glass cleaning detergent sprayed on the cover glass and a final clean with a cloth. Times of approximately 10 min were employed for each module during the manual cleaning.

1.4 Data collected

TheI–V characteristics of the modules were measured indoor using a PASAN IIIB solar simulator at 1000 W/ m2 and 25.0 ± 0.1 C, with all measurements corrected to 1000 W/m2. The spectral responsivity of one module of each type was measured using the differential spectral response technique with a large area pulsed solar simulator equipped with a number of filters to obtain illumination of modules with monochromatic light. No mismatch factor correction was applied to the resulting I–V curves due to that its effect in the comparison of electrical performances before and after cleaning (which was the purpose of this work) was found to be less than 0.15%. Different defects such as cracked cells, dark areas in cells corresponding to inactive areas, finger interruptions and scratches on the cell surface were observed by Electroluminescence (EL). EL images were obtained in the dark with the module biased at Isc and at 0.1Isc with an exposure of 300 and 600 s, respectively, using a Sensovation digital camera SVSB14-M. However, no relevant information was obtained from the images taken at 0.1Isc due to the noise produced by the long exposure times. Infrared thermography images were obtained with FLIR E-60 IR camera with the module biased at Isc mounted in a fixed vertical.

III. RESULTS AND DISCUSSION

The average change in modules parameters and standard deviation (SD) of the whole array are listed in Table 1. Despite the full set of modules exhibiting small module design differences; the study of the complete array can provide information of non-uniform systems. On average, Pmax increases by 9.8% and Isc by 6.7%, after the cleaning procedure for the whole set of modules. The average annual soiling rate is calculated as an average of the Pmax (also for Isc) values of each module divided by the number of years exposed outdoor each type. An average yearly soiling rate of 0.31% in Pmax and 0.20% in Isc was obtained. However, only a small average change between the different cleaning procedures is observed (within the measurement uncertainty band). A slight trend can also be observed in that those modules mounted at the top of the system are more soiled as evident from the greater increase in the change on the Pmax (greater soiling, greater Pmax increase after cleaning). This may be due to the fact of an increase in the amount of water on the lower modules which receive water directly from the rain and also water flowing from the modules mounted above. Most of the literature reports on the loss in the Isc with the soiling for crystalline Si-based modules.

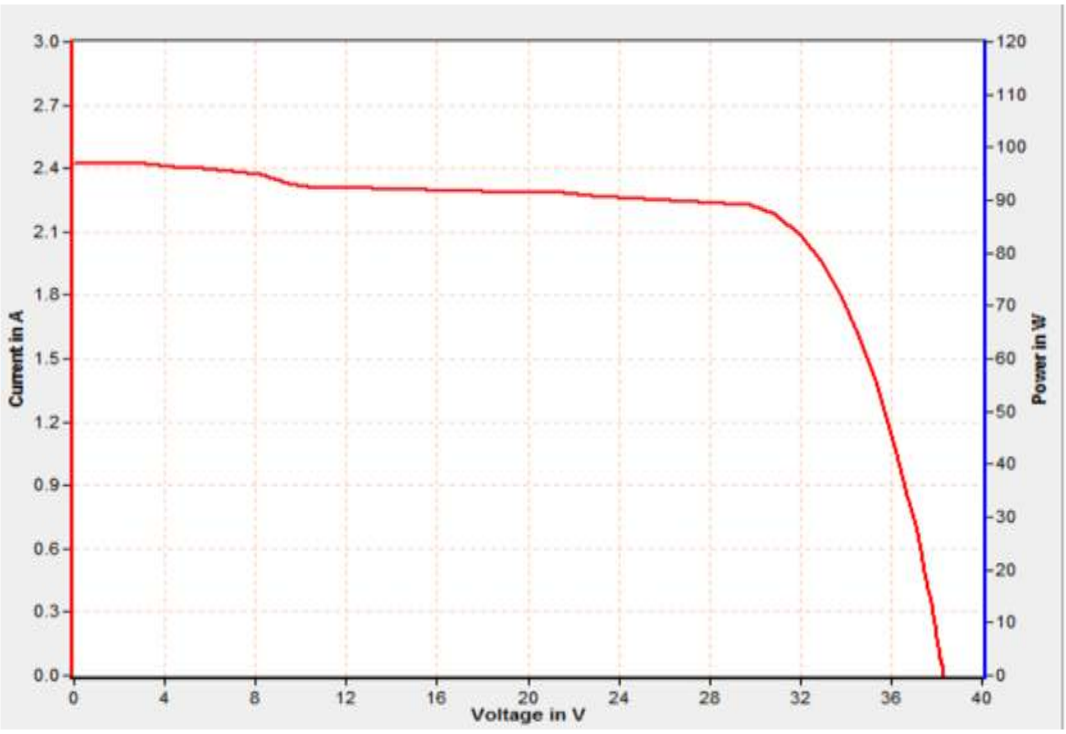

Fig. 1: I–V curves of a module before cleaning

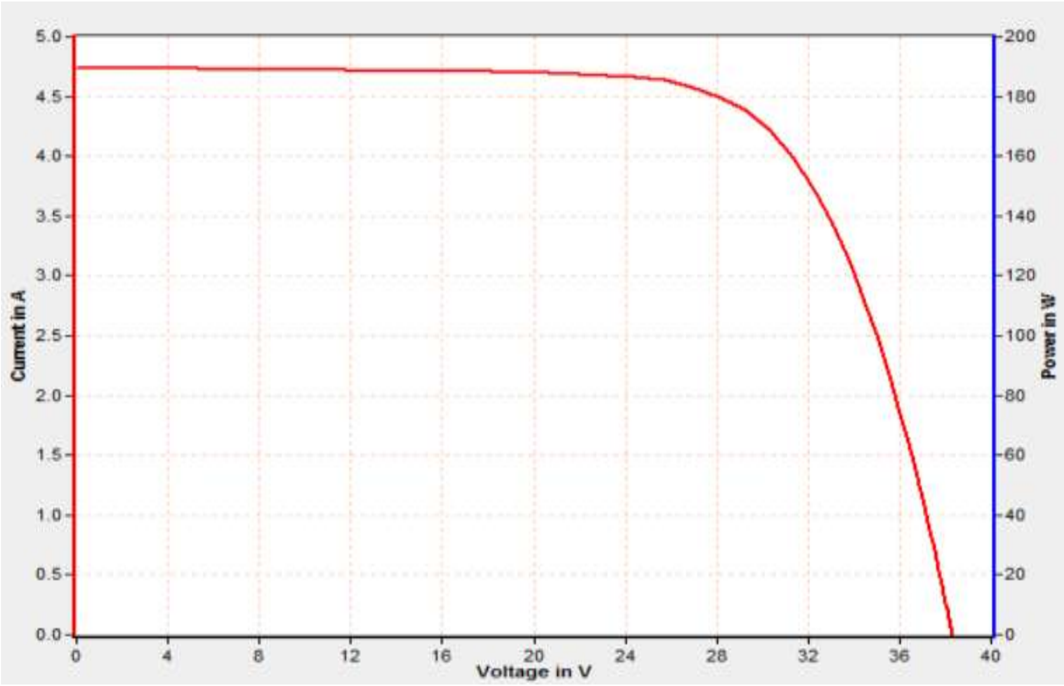

Fig. 2: I–V curves of a module after cleaning

Table1. Average change (%) and standard deviation (SD) of the electrical parameters of the whole set of modules

	Before cleaning				After cleaning			
Parameters	Isc	Voc	Pmax	FF	Isc	Voc	Pmax	FF
Average (%)	6.68	0.30	9.80	2.67	0.19	-0.09	0.13	-0.05
SD (%)	2.17	0.09	3.03	4.05	0.31	0.08	0.53	0.33

IV. CONCLUSION

The accumulation of outdoor environmental dust on solar PV modules is a natural phenomenon. Accumulated dust reduces PV module performance. In this study, the effects of long-term soiling on the performance of Silicon-based PV modules which have been exposed outdoor for one year without cleaning in a Tropical Savanna Climate were investigated. The influence of the manual cleaning method is analyzed. More uniform soiling behavior was observed for the flat glass modules whereas those with textured glass exhibited a greater variation in soiling. It was observed that manual cleaning was effective at improving the output of the entire module.

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