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Review of yield increase of solar panels through soiling prevention, and a proposed water-free automated cleaning solution

Dipankar Deb[a,*], Nisarg L. Brahmbhatt[b]

[a] Department of Electrical Engineering, Institute of Infrastructure, Technology, Research and Management, Ahmedabad 380026, Gujarat, India
[b] Department of Electrical Engineering, Institute of Infrastructure, Technology, Research and Management, Ahmedabad 380026, Gujarat, India

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ABSTRACT

Solar Energy is available in abundance and can be easily extracted using solar cells along with regular maintenance of solar panels. However, the efficiency of solar cells which is fairly low, is further affected by factors such as orientation of the panel, shade, wind speed, ambient temperature, precipitation and dust deposition. Especially, the maintenance of solar panels is challenging on account of soiling. Presently, manual and water-based cleaning solutions are generally used to remove the debris accumulated on the panels. In this paper, a detailed review of soiling prevention methods is presented with a view to increase the energy capture from solar panels. The technical details of an indigenously developed automated water-free cleaning device to remove soiling over the solar panels, is then discussed. The energy capture over the course of a month for PV panels regularly cleaned using automated solar panel cleaning solution is compared with that of the energy capture using soiled panels in a local solar panel installation, and the increased yield is measured.

1. Introduction

Solar energy is an efficient renewable resource due to its wide availability and ease of generation, but due to soiling, the yield from solar panels invariably reduce. Accumulation of dust on the surfaces of photovoltaic modules decreases the incoming irradiance to the solar cell, obscures solar flux and causes power loss. Studies in dry areas show that these losses could reach up to 15% of total capacity of generation per day. In such cases, the common solution is to clean the panels with water. In large-scale PV plants, water-based cleaning is expensive, especially when there is limited water supply. Given that solar panel installations are expected to provide 25% of world's total electrical power needs, the PV installations are more likely to be in non-agricultural or semi-arid regions and deserts, which together cover a third of the world's land mass. Projections indicate that even with installations of PV plants in just 4% of the net viable arid regions, the total global energy requirement can be fully met with close to zero CO_2 emissions when compared with the alarming levels of greenhouse gases which lead to increased global warming [1].

Almost half of solar irradiance is scattered away and absorbed in atmosphere before striking the Earth's surface. Annual amount of solar radiation is concentrated in arid regions near 25 ° N and also near 25 ° S of equator, and falls off sharply close to equator or the poles [2]. In these regions, the cloud cover considerably contributes to the variation of insolation and the resulting mean annual global irradiation data is determined in energy units of kWh (1 kWh = 3.6×10^6 J) which is highest in the Sahara Desert at 2685 kWh/m^2/year, followed by the Great Sandy Desert, and the Thar Desert. About 90% of present estimated energy requirement, that is, 474×10^{18} J is contributed by fossil fuels. Assuming a world in future with about 10 billion people, each using an average of 10 kW, a total of 100 TW power would be needed. The foreseeable global needs can be met by installing PV power panels of around 14% generation efficiency in a landmass of approximately 3.5×10^5 km^2 which is a small fraction of total landmass in the seven major deserts where vegetation cannot grow [3].

Suspended dust (in atmosphere) in the direct optical path of incident irradiance of solar panels, and also the dust deposited on the panels, both obscure the impending solar radiation, particularly in dusty, arid or semi-arid regions, or near highways, and therefore greatly impacts the power capture capacity of solar panels. Goossens et al. report that large amounts of dust generally get deposited on panels due to powerful westerly winds in the afternoons, and southwesterly winds in the evenings [4]. Remote measurements of suspended atmospheric particulate matter from many different regions indicate higher levels of light obstruction from particles of diameter 0.3–0.6 mm as these sizes are similar to the visible light wavelength. The rate of dust deposition widely varies. For instance, some desert regions in the Middle East have 0.36 g/m^2 rate of dust deposition per day, whereas 0.5 g/m^2 a day in

* Corresponding author.
E-mail addresses: dipankardeb@iitram.ac.in (D. Deb), nisarg.brahmbhatt@rediffmail.com (N.L. Brahmbhatt).

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the Negev Desert, and 0.17 g/m^2 a day in Mojave Desert have been reported [5].

Desert storms followed by light rains, is a common phenomena which results in formation of a thin layer of mud on the exposed PV panel surface. Efficient cleaning of the dust layer after the storm is needed to remove this barrier to the incident irradiance. Many such PV panels are cleaned with water, a costly labor intensive process especially when clear water is scarcely available. Most PV panels are covered with tempered borosilicate glass which are easy to clean with water. In recent advances, textured glass is found to help trap light and have lower reflection losses, but such textured surfaces also attract microscopic particles to deposit and therefore need efficient cleaning.

Existing solutions include manual and semi-automated cleaning methods that require water in excess amounts and are labor intensive, thereby further decreasing their cost effectiveness and eco-friendliness. Some autonomous solutions wherein an electrodynamic screen (EDS), placed atop a PV panel, removes dust with the help of an electric field that is generated from a high voltage supply to the electrodes of EDS, is discussed further [6]. These screens may not always be efficient due to their heavy weights and uneconomical services, thereby reducing commercial feasibility. In general, cleaning of PV panel surface has only been emphasized recently as rainfalls in regions of PV installations were considered adequate to clean the PV panel surface. However, recent studies prove that soiling can severely affect energy yield of PV panels even in regions receiving sufficient rainfalls.

Costa et al. have discussed many publications relating to soiling prevention, inspection and different ways to clean PV panels [7]. Sarver et al. have suggested several steps for dust mitigation such as (1) preventive, durable and non-toxic coatings for different conditions of dusty environment may be applied (or reinforced) either during actual use or at the time of manufacture, (2) automated mechanical cleaning systems (air, water, solution) for large collector fields: (a) waterless or water conserving (recycling); and (b) mobile operated or attached to the arrays, (3) sensors to detect the critical point for cleaning of surfaces (that is, to initiate automatic cleaning techniques or to alert for problems with loss of dust coating effectiveness) [8].

This paper is organized as follows. In Section 2, we present a review of different solar panel cleaning methods so as to determine a method that is most suitable for a particular geographical region, with the help of a comparison table describing the requirements of different cleaning methods, and the benefits and drawbacks of each of these methods. In Section 3, we present an indigenously developed water-free solar panel cleaning system, its working principle and technical specifications. In Section 4, we have quantified and compared the yield with and without the automated cleaning system, over a period of one month for a locally installed set of solar panels. Section 5 presents the concluding remarks and the possible future work.

2. Methods of cleaning solutions

From review of literature like [8] and [9], PV module cleaning methods are broadly categorized as:

2.1. Forced flow from air conditioning systems

A method proposed by Assi et al., mostly applied in the United Arab Emirates (UAE), and could also be implemented in various other developed countries with wide availability of air conditioners, uses air flow from the fan of air-conditioners to force the flow on solar panels for dust removal [10]. Fig. 1 depicts a conceptual diagram of the system.

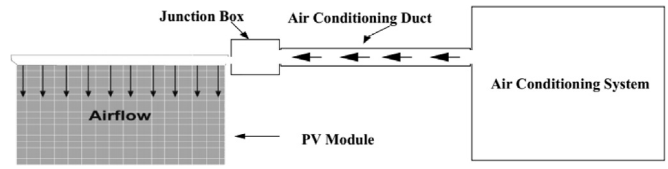

Fig. 1. Conceptual diagram of forced air flow based cleaning [10].

2.2. Rainfall cleaning

In this method of natural cleaning, the rainwater incident on the tilted (for optimal solar irradiance capture efficiency) solar panels to clean the loose dust on panel surface. This process usually leaves behind the dust that is stuck onto the panels due to moisture, and generally requires heavier rainfall to remove it. Reliability of such a method to wash off the deposited soil is debatable when there is intense soiling and inadequate rainfall. As stated by Kimber et al., 2006, sharp decline in production was noticed following a light shower [11]. To avoid mud formation on PV panel surface and optimal power generation, rainwater-based cleaning shall be avoided. However, wind can be of assistance to reduce dust deposition. Although rains are not accurately predictable, panel surface property can be improvised to increase the efficiency of this soiling prevention method. Such improvisations will increase capital costs, but would be effective in remote areas where maintenance is not always feasible.

2.3. Water-based cleaning

This method requires water in large amounts and under continuous high pressure to ward off any soiling particulate matter stuck on the PV panel surface. The pressurized water is sometimes mixed with a special cleansing agent that will help ward off dust and can also be useful for cooling down the PV panels installed in semi-arid regions and deserts. This method can be considered as a significant improvisation of rainfall cleaning. There are many drawbacks of this method, such as lack of reliability when applied in water scarce regions, loss of water in huge quantities, chances of chemical deposition on PV panel edges, reduced efficiency as the pressurized water system consumes significant amount of power, risks of water clogging, refilling of water tanks (if any), a fear of thermal shock in the hot PV panels because the water is cooler than the panel surface, and the attraction of more dust particles when the PV panel surface is wet after cleaning. These drawbacks are avoided by regulating the timing of cleaning to avoid thermal shocks and by using power efficient pumps to facilitate pressurized water.

2.4. Manual cleaning

This method is analogous to the procedure one uses in the cleaning of high-rise building windows/glasses. Dust particles are scrubbed using special brushes equipped with bristles to avert any scratches. Brushes connected with a direct water supply enable simultaneous scrubbing and washing. It is considerably more efficient in reinstating the solar panel surface to cleaner condition than rainfall cleaning. However, since the movement of brushes over panel surface is uneven, a risk is always there that the direct contact of brush with PV panel may have an abrasive effect. It is also an expensive cleaning method as it requires skilled labor to clean off the soiling. Abrasion risk of PV panels may be reduced by using soft cleaning cloth or brush with soft bristles.

2.5. Mechanized cleaning

A set of mechanical apparatus like motors or robot are required to operate the brushes or wipers and a water storage tank with sprinklers is used to clean the PV panel surface [12]. Mani et al. advocated cleaning the panel once a week in dry periods, and daily when rate of dust accumulation is intense [13]. This method uses automation where the system is controlled by a micro-controller with the help of sensors. It is a reduced labor system of cleaning panel surfaces. However, it becomes very helpful under conditions when water-based cleaning is