Solar Energy 162 (2018) 597–619

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

Review

Advances in approaches and methods for self-cleaning of solar photovoltaic panels

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ARTICLE INFO

Keywords:
Dust density
Efficiency
Photovoltaic panels
Self cleaning methods
Solar cells

ABSTRACT

Photovoltaic (PV) installations in desert areas such as Middle East, Africa, four-season countries and industrial areas suffers from loss in efficiency due to accumulation of dust, snowfall and airborne dirt (both organic and inorganic) from factories. The resultant soiling through dirt accumulation hinders the conversion of light into electricity, consequently degrading the PV performance. Hence, in order to maintain a steady performance, PV panels must be cleaned regularly. However, traditional manual cleaning of the panels is an energy and time consuming process. Moreover, manual cleaning can also create cracks on the PV panel surface due to harsh brushing which will further deteriorate PV performance. In addition, very small particles cannot be removed effectively by manual cleaning process. Therefore, researchers around the globe are promoting the self-cleaning methods, viz., electrostatic method, mechanical method and coating method for PV panel surface cleaning. In this article, attempt has been made to review the progress and achievements in all kinds of self-cleaning methods for PV panels with special focus on super hydrophobic coating based methods for self-cleaning. In this connection, future focus research areas such as development of mini robots and spray coating on self-cleaning have been pointed out.

1. Introduction

Solar energy provides heat and electricity for useful real life applications abundantly and free of cost. Moreover, in contrast to the non-renewable sources of energy, solar energy is environment friendly producing almost zero emission. Therefore, solar energy is considered as the most sustainable solution to energy crisis all over the world. Although state-of-the-art technology is available for solar thermal conversion, solar electricity from photovoltaic (PV) modules still grabs the major focus due the higher grade of the harvested energy. Application of PV modules, both in standalone and grid-tied mode, is growing day by day. In addition, large scale PV power plants are also becoming popular, especially in the tropical and desert oriented countries. However, several glitches are hindering the optimum power harvest from PV modules. Accumulation of dust on the PV module surface has been identified as one of the major problems with PV power generation (Hales et al., 2002; Landsea et al., 1999; Magnuson et al., 1997; Nardone et al., 2010; Nazeeruddin et al., 2011; Pandey et al., 2016; Rauschenbach, 2012; Trenberth, 1990; Tyagi et al., 2013; Zavaleta et al., 2003).

Dust depositions shield the sunlight from penetrating through the PV module glass cover and obstruct to reach the solar cell. Photon from sunlight radiation cannot excite free electron to conduction band and hole-electron do not separated. Consequently, no electric current generated from the PV cells. On the other hand, the shaded cells become reverse-biased to other PV cells. The resultant effect creates a drastic drop in PV performance (Alonso-Garcia et al., 2006; Bidram et al., 2012). Hence, in order to recuperate the rated performance, researchers are trying to develop appropriate and effective technique for cleaning the PV module glass surface. The effect of dirt deposition on the operation of solar cells.

In order to maintain the efficiency, solar panel should be cleaned every few weeks which needs very hard work for the large solar panel arrays. Cleaning dusty panels with several detergents can be time-consuming, costly, and hazardous to the environment or even corrode the solar panel frame. Because of that, researchers and scientists are trying to develop self-cleaning facility for glass surface through practicable and feasible methods. There are three self cleaning methods viz. Electrostatic, Mechanical and coating methods which are widely being used for cleaning the outdoor exposed PV surfaces. Electrostatic method expels the dusts especially lunar dusts outside from electric curtain through electrostatic's standing and travelling wave. Standing wave

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https://doi.org/10.1016/j.solener.2017.12.023
Received 12 May 2017; Received in revised form 21 November 2017; Accepted 12 December 2017

waves the dusts upward and downward while travelling wave waves the dusts horizontally. The electric curtain consists of the parallel electrode which are only suitable for top low iron-glass of PV panel. Mechanical method has four techniques to expel the dusts which are robotic method, air-blowing method, water-blowing method and ultrasonic vibration method. Air-blowing method and water-blowing method also reduce the temperature of PV panel and avoid excessive heat on the panel surfaces. Coating method requires nanotechnologies research and development to build super hydrophilic and super hydrophobic thin film on the PV panel glass. Super hydrophilic coating diminishes the dirt through photo catalytic reaction while super hydrophobic coating rolling the water droplet to carry away the dirt from the surfaces.

As discussed above, dust accumulation decrease the PV performance and also hampers the life span of the module. Hence, cleaning the PV panels regularly is obligatory to get rated performance from the module. There are basically four different methods (mechanical, electrostatic, manual and coating method) of cleaning the dust and every method has its own merits as well as shortcomings. Mechanical method has moving parts which consumes a substantial amount of power. Electrostatic method also needs electrical power to operate and manual cleaning is not technically feasible at all. Nonetheless, hydrophilic and hydrophobic coatings are capable options to clean the dust from PV panels at large scale with reasonable reliability and low cost. These methods require no power consumption, nor do they create scratches on the module glass cover during the cleaning which also reduce the power production. Therefore, in this article attempt has been made to give an overview on different PV cleaning methods with special emphasis on coating methods. This paper has been divided into seven different sections; Section 1 gives an introduction about the issues regarding low efficiency when put in real outdoor conditions. Section 2 presents the research methodology followed in conducting the review, different factors affecting the efficiency of PV panels has been discussed in Section 3. Section 4 details the different types of cleaning methods and recent advancements in different cleaning methods. Section 5 presents the conclusions obtained from the study and the recommendation for future work is suggested in Section 6. Finally, the publication trend has been presented in Section 7.

2. Research methodology

For conducting the review, Science Direct database has been used and the articles were searched using different keywords related to the study. The articles were refined using Science Direct interface, original research, review articles, encyclopedia and book chapters were taken into consideration for studies. Total number of publications for superhydrophobic glass studies from 2009 till 2018 were found to be 2574.The published hydrophobic glass studies from 2009 till 2018 were found to be 129,417. However, total number of articles from 2009 till 2018 for hydrophilic and superhydrophilic studies were found to be 95,557 and 1335 respectively. Therefore, it can be said that more efforts are being made in developing and characterizing hydrophobic glass as compared other types of coating methods. However, most of these published papers focus on hydrophobicity or hydrophilicity behavior rather than self-cleaning ability. Therefore, keyword of "self-cleaning glass" was used for search and in total 58, 583 of self-cleaning glass researches have been published from 2009 till 2018 which can be seen in Fig. 1. Patents on the related studies were also included and "Google Patents" data base was used using "Self cleaning glass" keyword. Based on the their suitability and merits as per the review topic, 255 papers and 24 patents were selected for rigorous review.

3. Factors affecting efficiency of PV panel

Outdoor conditions such as module temperature, irradiance level, ambient temperature, wind speed, dirt/dust accumulation and

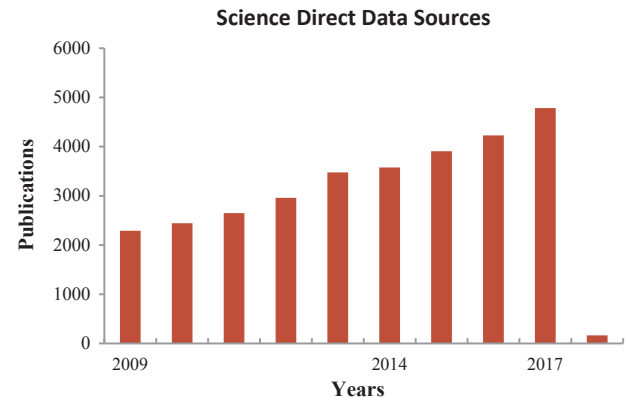

Fig. 1. Year-wise articles published of self-cleaning glass (Data Source Science Direct).

particular installing conditions influence the performance of solar cells and solar panels. For example, high ambient temperature reduces the band gap of semiconductors consequently lead to reduction in open circuit voltage and output power (Meral and Dinçer, 2011). The carrier concentration of cells increase due to high ambient temperature which leads to internal carrier recombination. High humidity issues resulted by accumulation of heat causes excessive grid corrosion and later deteriorate the PV module performances. Corrosion has been defined as the destructive chemical or electrochemical reaction of metals with its environment (Park et al., 2013). The previous studies have reported that the efficiency of solar panel has been reduced by 4.5% at temperature range between 40 and 61 °C during indoor testing (Malik et al., 2010). Ramli et al. (2016) observed more than 43% of output power losses for PV panel due to high humidity effect in Surabaya, Indonesia. The result obtained by Ye et al. (2014) showed 6% of power losses in PV panel (CIGS module) each year in high humidity and cloudy climate of Singapore. The output power of PV panel installed in Island of Crete and Greece also exhibited 5% of power loss during summer (long-lasting rainfall) (Kymakis et al., 2009).

Wind-blowing can repel accumulated thermal energy on the panel's surface. As the wind moves on the PV surfaces, the energy is transferred to environment by convection and conduction. The movement of air-stream at high speed causes large interchange circulation between the temperature of solar cell and surrounding temperature due to convection heat transfer. At this state, the cell temperature being reduced and the PV performance was upgraded (Mekhilef et al., 2012). However, a strong winds significantly deposit the dust on the cell; carries a high dust concentration on the cell surfaces (Goossens and Van Kerschaever, 1999). High dust acumolation is a major factor of PV degradation especially in desert areas. Several research studies proved the loss in performance due to dust on the PV panels; for example the loss in efficiencies by 32% (after 8 month) (Salim et al., 1988), 11% (after 3 days) in Riyadh (Sayigh, 1978). 17% (after 6 days) in Kuwait City (Wakim, 1981), more than 65% (after 6 months) in desert areas, Egypt (Hassan et al., 2005) and about 40% (after 6 months) in Saudi Arabia (Nimmo and Said, 1981) have been reported.

Dust is known as small, dry, solid particles projected into the air by natural forces, such as wind, volcanic eruption, and by chemical or man-made processes (crushing, grinding, milling, drilling, demolition, etc.). Dust particles are usually in size range from about 1 to 100 μm in diameter, and they settle slowly under the influence of the gravity (Calvert, 1990). Hazard Prevention and Control in the Work Environment (WHO/SDE/OEH/99.14) refer dust as solid particles, ranging in size below 1 μm up to at least 100 μm, which may become airborne, depending on their origin, physical characteristics and ambient conditions (WHO, 1999). The dust deposition rate on the PV panel was influenced by the property of dust such as its sizes, electrostatic forces and local environment especially at industrial regions or desert areas. For example, a small size particles of dust are hardly removed