Journal of Electrostatics 91 (2018) 28–33

Contents lists available at ScienceDirect

Journal of Electrostatics

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

Improvement of an electrostatic cleaning system for removal of dust from solar panels

Hiroyuki Kawamoto[a,*], Bing Guo[b]

[a] Department of Applied Mechanics and Aerospace Engineering, Waseda University, 3-4-1, Okubo, Shinjuku, Tokyo 169-8555, Japan
[b] Mechanical Engineering Program, Texas A&M University at Qatar, Texas A&M Engineering Building, Education City PO Box 23874, Doha, Qatar

ARTICLE INFO

Keywords:
Cleaner
Electrostatic force
Mega solar
Sand
Solar panel

ABSTRACT

An improved cleaning system has been developed that uses electrostatic forces to remove dust from the surface of solar panels. A two-phase high voltage is applied to the parallel wire electrodes embedded in the glass plate of a solar panel. It was previously demonstrated that the adhering dust can be repelled from the surface of a slightly inclined panel by applying a low-frequency high-voltage. However, the performance is low for extremely small dust particles. The proposed system improves the performance by the application of a high voltage, reduction of adhesion force, utilization of natural wind, and frequent operation before the deposition of dust. In addition to the cleaning performance, the frequency response and actual power consumption of the high voltage source was investigated to provide data for the design and efficiency evaluation of the system. It was demonstrated that the energy consumption is extremely small with a simple and potentially low-cost high voltage source. This technology is expected to increase the efficiency of the mega solar power plants constructed in deserts at low latitudes.

1. Introduction

Mega and giga solar power generation plants are being constructed in deserts at low altitudes where the sun shines the brightest. However, solar panels get covered by the stirred-up dust, especially during dust storms, causing a drastic decrease in the output power of a plant [1–7]. In dry months with no rain, the capacity utilization of the plant can be greatly reduced without cleaning. For example, a soiled photovoltaic module in Doha will only be able to provide approximately 85% of the electricity if it is not cleaned for one month [7]. The most primitive and secure method is manual cleaning with brush and water. However, a manual operation is tough in the harsh desert environment and water is costly in deserts. Robotic cleaning is an alternative solution. However, it needs the operation and maintenance of the machine. In both cases, a future labor cost is indefinite.

Electrostatic dust-cleaning systems have been developed to mitigate the above-mentioned problem by utilizing the technology developed for space application [8,9]. The lunar and Martian surfaces are covered with small regolith dust, which is easily lifted by a disturbance, and it covers the solar panels and optical elements such as the lenses and mirrors of a spacecraft, causing degradation of their optical performance. In order to overcome this problem, automatic cleaning systems that employ electrostatic traveling-waves for removing dust have been developed based on the novel concept first proposed by Masuda et al. [10] This system has no mechanical moving parts and is, therefore, highly reliable. One of the authors has also developed the method of removing dust using the electrostatic traveling-wave generated by four-phase voltage applied to a transparent conveyer consisting of parallel ITO (indium tin oxide) electrodes printed on a glass substrate, as shown in Fig. 1 (a) [11]. However, this technology developed for space application is not suitable for commercial mega solar systems because it requires expensive ITO electrodes and three-dimensional electrode-end construction to accommodate the multi-phase scheme. The high voltage source and interconnections would also be complicated and expensive for the large-scale commercial plants. In order to mitigate these issues, we have developed a modified system that consists of a dust-repelling glass plate with parallel fine wire electrodes embedded in the cover glass plate of a solar panel and a high voltage source that generates a two-phase rectangular voltage as shown in Fig. 1 (b) [12]. The alternating electrostatic field generates a standing wave that cannot transport particles in one direction but causes a "flip-flop" motion of the dust particles on the plate, and when airborne, the dust particles are transported downward by gravity [12–14]. High performance was demonstrated in this system for relatively large particles such as the Namib sand; however, the performance is low in case that the particles are small such as the Doha dust [15]. Several effective methods are

* Corresponding author.
E-mail address: kawa@waseda.jp (H. Kawamoto).

https://doi.org/10.1016/j.elstat.2017.12.002
Received 18 October 2017; Received in revised form 1 December 2017; Accepted 4 December 2017

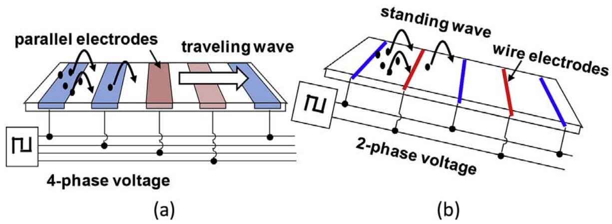

Fig. 1. Schematic diagrams of the electrostatic cleaning systems that use a (a) traveling wave and (b) standing wave.

proposed in this report to improve the practical performance of the system.

Another concern is the high voltage source for the cleaning system. We have designed and manufactured a proto-type high voltage source that generates high voltage of standing wave, and the frequency response and actual power consumption of the high voltage source was investigated for realizing a simpler and more efficient design in the future.

2. System configuration

The proposed cleaning system shown in Fig. 1 (b) consists of a dust cleaning plate with parallel wire electrodes embedded between a thin cover glass and a glass substrate, and a high voltage source used to generate the two-phase high voltage.

2.1. Cleaning plate

A cross-sectional drawing of the cleaning device is shown in Fig. 2. Parallel wire electrodes, 0.3 mm in diameter made of copper, were embedded in the borosilicate glass substrate (100 × 100 × 3 mm, Asahi Glass Company, Tokyo, Japan) with a 7-mm pitch between the wires. After the wires were arranged on the substrate, a thin borosilicate glass plate (Asahi Glass Company, Tokyo, Japan) was adhered on the substrate using a transparent adhesive to prevent the insulation breakdown and accidental electric shock. Because the metal wire electrodes create a shadow on the solar panel and reduce the output power of the photovoltaic panel, a fine wire and wide pitch configuration are employed to minimize the light shielding. Details are reported in reference [12].

2.2. High voltage source

A two-phase rectangular voltage was generated by using a set of positive and negative amplifiers switched by Photo-MOS relays (AQV258, Panasonic, Tokyo, Japan) that were controlled by a microprocessor (MPU, PIC16F1827, Microchip) [13,14]. A block diagram of the high voltage source is shown in Fig. 3. We adopted the low-capacity amplifiers (HUR6-4P and HUR6-4N, Matsusada Precision, Tokyo, Japan) to generate negative and positive high voltages.

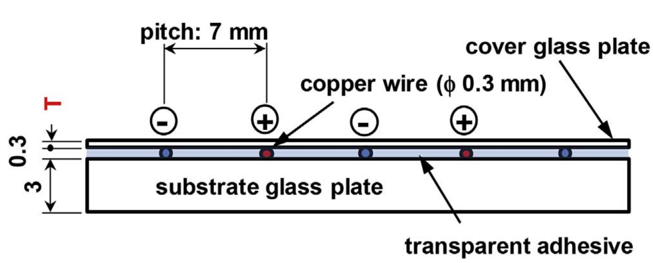

Fig. 2. Cross-sectional drawing of the cleaning device (adapted from literature [12]) with cover glass plate thickness T.

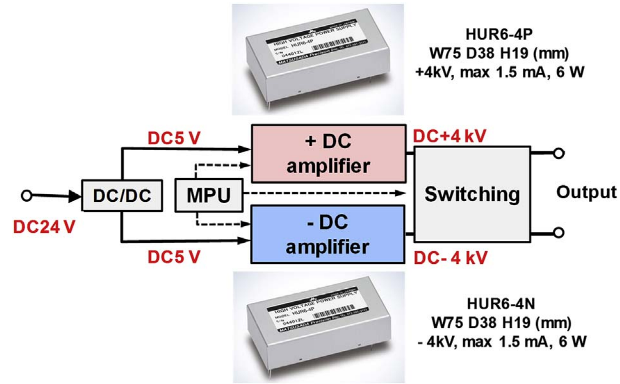

Fig. 3. Block diagram of the high voltage source.

2.3. Dust used for experiments

Two kinds of dust particles, the Namib sand and the Doha dust, were used. The physical, chemical, and dielectric properties of these particles are summarized in Table 1. The Namib sand, collected from the Namib Desert in Africa, is dark red in color and the main component is silica. On the other hand, the Doha dust, collected from the deposited dust on the solar panel installed at Doha, Qatar, is light gray in color and the main component is calcium carbonate [15]. The most significant differences between them is the particle size. As shown in Fig. 4, the typical diameter of the Namib sand is 200–300 μm, whereas that of the Doha dust is approximately 6–10 μm. Although one of the authors had evaluated the performance of the electrostatic cleaning system using the Namib sand [12], the Doha dust is more realistic because it is collected from the actual environment.

2.4. Experimental procedure

The plate was inclined at 20°, which is the typical inclination angle of solar panels installed in the Middle East, and dust was uniformly scattered on the cover glass. A two-phase rectangular voltage was then applied to the parallel electrodes. The frequency of the applied voltage was fixed at 1 Hz, because low frequency, less than 10 Hz, operation is preferable [12]. The cleaning performance decreased at higher frequencies because particle motion cannot follow the high-speed change of polarity. The low frequency operation is preferable with the objective of the design of the high voltage source because low-capacity DC amplifiers can be used in the high voltage source. The cleaning rate—the weight of dust removed divided by that fed initially on the plate—was determined. The experiment was conducted in an air-conditioned laboratory (20–27 °C, 40–60% RH). Because the PV output loss is quantitatively related to dust loading on the surface (and the type of dust), it is common to quantify the cleaning rate as the ratio between the weight of the sand fed onto the panel and that after the cleaning operation. The effectiveness of the cleaning system for improving PV performance can be evaluated by using the relation between dust mass loading and PV performance loss [15].

3. Effect of sand characteristics

Fig. 5 shows the cleaning rate vs. the applied voltage. Approximately 15% particles of the Namib sand slipped down from the inclined glass plate without the application of voltage, and a high performance, approximately 90%, was realized by applying a high voltage. On the other hand, almost no Doha dust slipped down before applying the voltage. Moreover, the plate could not be cleaned with a low applied voltage (2 $kV_{p\text{-}p}$), because the adhesion force between the particle and the glass plate was larger than the electrostatic force applied to the particle. The relatively large adhesion force caused low cleaning