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Electrostatic cleaning system for removal of sand from solar panels

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ABSTRACT

An improved cleaning system has been developed that uses electrostatic force to remove sand from the surface of solar panels. A single-phase high voltage is applied to parallel wire electrodes embedded in the cover glass plate of a solar panel. It has been demonstrated that more than 90% of the adhering sand is repelled from the surface of the slightly inclined panel after the cleaning operation. The performance of the system was further improved by improving the electrode configuration and introducing natural wind on the surface of the panel, even when the deposition of sand on the panel is extremely high. The power consumption of this system is virtually zero. This technology is expected to increase the effective efficiency of mega solar power plants constructed in deserts at low latitudes.

Introduction

Solar power generation has grown drastically in recent years owing to increasing energy demand as well as the environmental and economical concerns associated with fossil fuel consumption [1], and many mega solar power generation plants are being planned and constructed, especially in deserts at low altitudes, where the sun shines the brightest. However, sand storms occur frequently in deserts, and solar panels can become covered by stirred-up sand, causing a drastic decrease in the output power of a photovoltaic power generation plant [2–7]. Because sand on solar panels is not cleaned by rain over a long period of time in an arid region, the capacity utilization of the power plant is reduced if the panels are not cleaned frequently.

To mitigate this problem, we have developed an automatic cleaning system that does not need scarce cleaning water but instead utilizes an alternating electrostatic force [8]. Transporting particles using electrostatic force was first developed and implemented by Masuda et al. [9], and many investigations of this technology have subsequently been conducted mainly as a toner supplier in electrophotography [10–21]. Numerous other applications for the electrostatic particle transport have been proposed, including control of bubbles in dielectric liquid [22], removal of radioactive dust in a fusion reactor [23], transport of liquid droplet [24], movement of blood cells in liquid [25], classification of particle size [26], separation of seed by-products derived from agricultural processes [27], and dust removal from solar panels and solar hydrogen generators [28]. Theoretical and numerical studies of electrostatic particle transport have been conducted to clarify the mechanism and to support the development by many researchers [10,12,13,21,29]. Cleaning of lunar or Martian dust on solar panels for space exploration is another potential application of this technology [30–33]. It has been demonstrated that more than 98% of the dust on a glass plate can be removed using electrostatic traveling waves generated by a four-phase rectangular voltage applied to a transparent conveyer consisting of transparent indium tin oxide (ITO) electrodes printed on a glass substrate [33].

However, this technology is not suitable for use in commercial mega solar systems because it requires prohibitively expensive ITO electrodes, the ends of the electrodes must be three-dimensional to prevent the intersection of phases, and the power supply and interconnections required are relatively complicated and expensive for large-scale commercial plants. To mitigate these issues we have developed an improved system that consists of a sand-repelling glass plate with parallel wire electrodes embedded in a cover glass plate of a solar panel and a high-voltage power supply that generates a single-phase rectangular voltage. The alternating electrostatic field generates a standing wave that causes a flip–flop motion of the sand particles on the device, and when airborne, the sand particles are transported downward by gravity [8]. This report describes a basic principle and performance of the system, and how the performance of the system was further improved by improving

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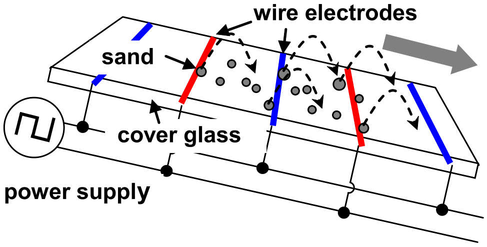

Fig. 1. Schematic diagram of the electrostatic cleaning system that uses a standing wave and gravity to remove sand from a solar panel.

the electrode configuration and introducing natural wind on the surface of the panel, even when the deposition of sand on the panel is extremely high. The power consumption of this system is extremely low compared to the output power of the solar panel. This technology is expected to increase the effective efficiency of mega solar power generation plants constructed in deserts at low latitudes.

System configuration

Parallel wire electrodes embedded in the cover glass plate of the solar panel was employed instead of ITO electrodes to reduce the manufacturing cost of the cleaning plate. Although the wire electrodes create a shadow and disturb the absorption of light, this is minimized by using a fine wire and a wide pitch configuration. The diameter chosen for the wire electrodes was 0.3 mm, and the size chosen for the pitch between the electrodes was 7 mm.

To mitigate the complexity of the electrode wiring, power supply, and interconnections, we adopted a standing wave instead of a traveling wave [34–36]. That is, a single-phase rectangular voltage was applied to parallel wire electrodes. Because a traveling wave is not generated by the application of a single-phase voltage, particles are not transported in one direction but rather repelled from the plate, and when airborne the sand particles are transported downward by gravity. We generated a single-phase rectangular voltage by using a set of positive and negative amplifiers switched by semiconductor relays that were controlled by a microcomputer. Because a high slew-rate is not required for this system, we employed conventional low-capacity onboard amplifiers (HUR30-6, Matsusada Precision, Tokyo).

Table 1
Specification of sand used for experiments.

Item	Unit	A	B	C	D	E	F
Area		Namib	Japan	Eurasia	Oceania	North America	Africa
Relative permittivity		4.2	2.2	3.2	4.3	4.0	5.3
Elongation		0.72	0.53	0.76	0.83	0.81	0.71
Angle of repose	deg	36	38	39	31	34	35
Bulk density	g/cm^2	1.5	1.4	1.4	3.0	1.7	3.0

Fig. 1 shows a schematic diagram of the system. If the system is operated intermittently, the sand that has adhered to the cover glass of the solar panels is repelled. On the other hand, if the system is operated continuously, the sand that approaches the cover glass is also repelled, and thus, the system can protect solar panels against the adhesion of sand.

Six types of sand, collected from desert areas around the world, were used for evaluation. Photographs of the sand particles are shown in Fig. 2, and these specifications are summarized in Table 1. Sand A was commonly used in the experiments unless otherwise specified.

Results and discussion

Effect of plate inclination

We manufactured a small device for use in the basic investigation of the system. The dimensions of the substrate glass plate were 100 × 100 × 3 mm. After 0.3-mm-diameter copper wires were arranged on the plate, a thin glass plate, 0.1 mm in thickness, was adhered using transparent adhesive to make the surface smooth and to prevent insulation breakdown. Cross-sectional drawing of the device is shown in Fig. 3.

The device was inclined, and sand was uniformly scattered on the cover glass. A single-phase rectangular voltage was then applied to the parallel electrodes. The experiment was conducted in an air-conditioned laboratory (20–25 °C, 40–60 RH). As shown in Fig. 4, the sand particles on the glass plate were repelled and transported downward, as confirmed by direct observation of particle motions using a high-speed microscope camera (Fastcam-max 120 K model 1, Photoron, Tokyo) [21,33,35] and numerical

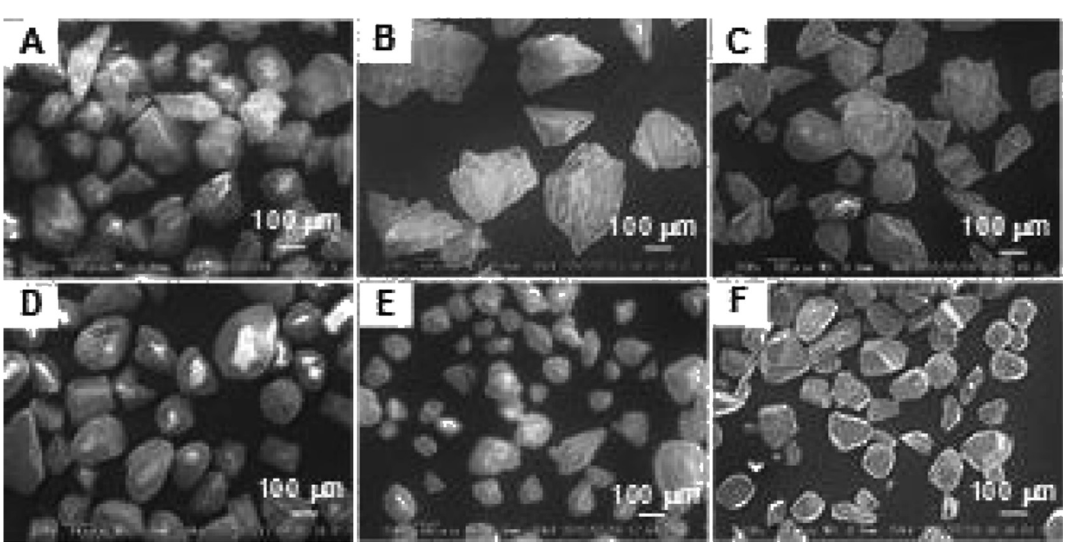

Fig. 2. Six types of sand used for experiments.