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Solar Photovoltaic Panels Cleaning Methods A Review

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Abstract

The Solar Photovoltaic panel cleaning technology can considerably increase the efficiency of electricity generated and also increase the durability of Solar panels. The various cleaning methods, such as electrostatic cleaning system, super hyperbolic coating methods, mechanical method, microcontroller based automatic cleaning method, self-cleaning nanodomes and various characteristics of dust particles are discussed in this paper. This paper throws light on various cleaning methods for solar photovoltaic panels.

***Key Words*:**Solar panel; Self-cleaning; Electrostatic cleaning; Super hyperbolic coating.

1 Introduction

Photovoltaic panel is one which generates electricity from solar radiation. Photovoltaic panel consist of semiconductors, with the help of which, solar radiations are converted into direct current. As this technology is pollution free, renewable and safe, it has rapid growth in the recent past. Mega solar power plants are already installed in various countries like Australia, the Middle East, USA, Europe, China He et al [1]. Mega Solar power plants are installed at deserts where the sun shine is brightest at low altitudes [2]. The on-site issues which usually overlooked are bird droppings, deposition of dusts and water stains, which would reduce the solar panel efficiency significantly. Also there is 10-25% of efficiency reduction due to losses in wiring, module soiling and inverter [3]. It has been analyzed that the dust accumulation is mainly depending on the slope, orientation, type of coating, surface roughness etc. Factors influencing dust settlement are shown in Fig. 1 It is reported that energy loses are huge in fixed horizontal panels, which is around 8-22%, than compared to tilted panels (45°), here the losses around 1-8% only. Also, other external parameters like humidity, temperature, wind speed and regional characteristics like traffic, air pollution and plants play crucial role in dust deposition. Further the biological, electrostatic and chemical properties of dust, also shape, size and weight of the dust particles influence the accumulation of dust on the surface of panels [4]. A large number of studies conducted on the process of dust deposition on PV modules. It is observed that the dust accumulation density is mainly depending on the angle at which the PV module is

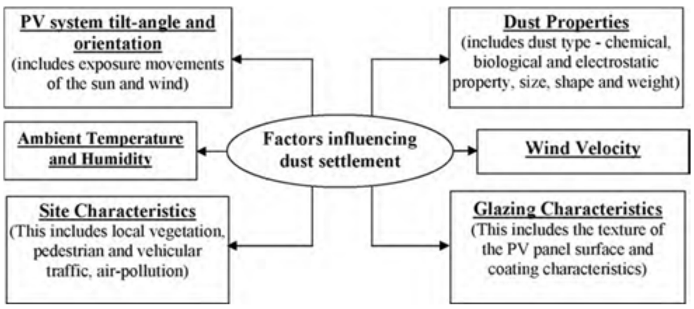

Fig 1 Factors influencing dust settlements [3]

installed [5]. Sunlight penetration through the photovoltaic module glass cover was obstructed by the dust deposition, due to which reaching of sunlight to the solar cell is affected drastically

[6]. The power loss due to soiling would vary based on physical and chemical properties of dust particles and also would vary depending on geographic locations [7]. The Solar cell cleaning process will produce slurry residue due to sticky dust, cleaning fluids etc [8]. With the help of wind cleaning process, Jiang et al. [9], came to the conclusion that the velocity of the wind varied from 0.82 m/s to 2219.8 m/s, and the shear velocity to wind velocity ratio ranged between 0.04 -0.06. They did the calculation for the diameter of particles ranging from 0.1 m up to100 m. Hussain et al. [10] made a comparative study of 7 different dust samples on PV panels under the three different radiation levels as 650, 750 and 850 W / m^2. They observed that more sunlight is blocked by smallest particles. Saidan et al. [11] recommend that scheduled cleaning of solar panels is very important, otherwise the magnitude of dust impact will be very high. Margaret K. S. et al. [12] discuss about robot cleaning system where the robot control system consists of arduino microcontroller. Gaier et al. [13] did experiment to know the martian dust particles effect on photovoltaic cells at varying wind velocities (23 to 116 m/s). Solar photovoltaic panel covered with the super hyperbolic micro-shell Polydimethylsiloxane (PDMS) array would reduce the degradation of efficiency of Solar panels by airborne dust [14]. Various dust removing methods for solar collectors is shown in Fig. 2 [15].The dry cleaning method remove dust particles from the surface, but it is observed that wet cleaning method is more effective [16]. Accumulation of dust on the solar panel affects performance. Due to this it is observed that the performance of the photovoltaic panel reduced by up to 85% [17]. As compared to flat photovoltaic panels, the automated cleaning and 360° sun tracking system generates 30% more power output[18]. The anionic and cationic surfactants are used for dust removal from the solar panels. For the deposited sand particles anionic is most effective surfactant while compared to cationic surfactant [19]. Spraying water on the photovoltaic cells increases the photovoltaic efficiency of the system [20]. Gheitasi et al.[21] made a experimental set up which consists of wireless sensor network for collecting data related to

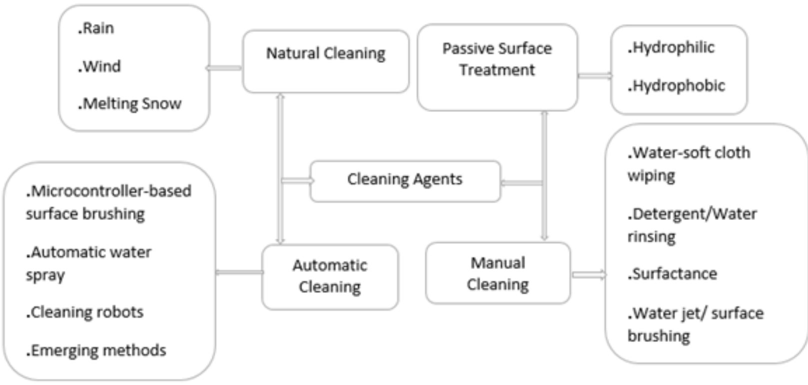

Fig 2 Different cleaning methods for removing dust from solar collectors [15]

dirt level from each solar panels. Then the robots clean the dirty panels system with the help of collected data. The electric curtains along with standing waves could be used for removing particles from the surface [22]. Carlson et al. [23] studied the inorganic hyperbolic coatings for self-cleaning surfaces. Chen et al. [24] invented a multifunctional coating with various properties of antireflection, super-hydrophilicity etc. For Solar photovoltaic panel cover glass TiO2 / SiO2 composite are used to reduce soiling accumulation [25]. The tilt angle of Photovoltaic panel influences the dust deposition density. The dust deposition density is in the range of 15.84 to 4.48 g/ m2 [26]. Cao et al. [27] discuss about possibilities of anti-icing super-hydrophobic coated surfaces changing the surface textures. Gagila et al. [28] with their experimental analysis calculated the mean annual photovoltaic efficiency as 8.7% under outdoor conditions in Athens, Greece. To solve the cloud covering over the photovoltaic panels Gandoman et al. [29] propose a model which has advantage of cloud cover support during all seasons. Ganesh et al.[30] highlights peeling-off effect in self-cleaning surfaces. Due to the Brighton regional weather in UK, the dust deposition effect on the solar photovoltaic module was found to be smaller. But the performance was much affected due to local problem of bird droppings [31], which would result in dropping inefficiency. The performance of nanocryltalline solar cell reduced with increase in air mass. It is around 94.18% , 81.86% and 37.47% for direct, global and diffuse solar radiation respectively[32]. Gwon et al. [33] demonstrate antireflective and super-hydrophobic photovoltaic cells with significant power conversion efficiency with the use of super-hydrophobic nanograss-coated glass.

2 SELF-CLEANING AND TRACKING SOLAR PHOTOVOLTAIC PANELS

Bandam et al. [34], have developed a prototype system for improving efficiency by incorporating solar panel self- cleaning and tracking mechanism. This model consists of 1000 rpm and 10 rpm DC motors for cleaning and tracking purpose respectively. A threaded rod is connected to the DC motor, which is used for cleaning. And a wiper is connected to the threaded rod, as the motor rotates in forward direction the wiper moves downward and vice versa. The system also has a microcontroller which helps for automatic tracking and cleaning the panels. The microcontroller receives information from the LDR (Light dependent resistors) and based on that it passes command to the dc motors which clean the panel and track the sun. The LDR value is based on light illumination, if it is dark the resistance increases and with the illuminated light there is a drastic reduction in resistance. The LDR has very high resistance sometimes as 10 M. Also they have written algorithm for cleaning the panels and tracking the sun. The final increase in the efficiency proves that the success of this prototype. The following Table 1 gives details of efficiency under different test conditions.

Table 1 Efficiencies of different conditions [34]

System	Cleaned Panel With Tracking	Cleaned Panel Without Tracking	Dusty Panel with tracking	Dusty panel without tracking
P_{max}	7.48W	6.39 W	3.99 W	2.819 W
% Efficiency	7.13%`	6.08 %	3.8 %	2.653

3 MICROCONTROLLER BASED AUTOMATIC CLEANING OF SOLAR PANELS

Robot working as an auto cleaner for the solar panel is proposed by Halbavi et al. [35] as shown in Fig. 3. The robot has brushes, in accordance with the size of the solar panels. Also the robot has the compatibility to fix with different sizes of the panels. DC-motors connected with belt arrangement drives the brushes. There is a dust sensor LDR, which senses the dust and in accordance with that a microcontroller which sends signal to control the brushes. With the help of a belt the rotational motion of the DC-Motor is converted into linear motion. Under various pollutants (sand, ash, red soil) the solar panel performance has been tested. It is observed that due to dust accumulation, there was drop in voltage and power output. Also it is observed that when there is increase in temperature of panel, drastic reduction in power output.

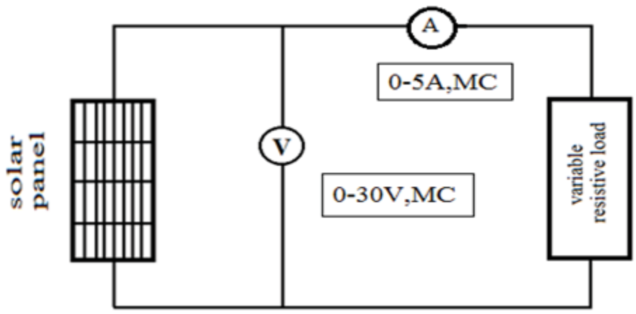

Fig 3 Block diagram of Microcontroller based Automatic cleaner [35]

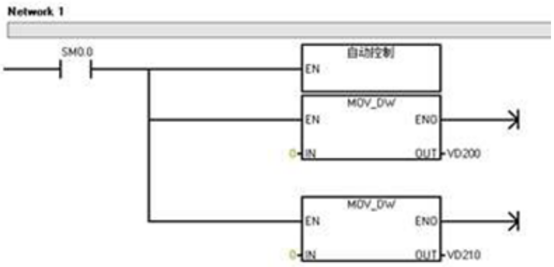

Fig 4 Parts of PLC ladder diagram program [8]

Zhen, et al. [8] have developed a control system for cleaning the panels. It consists of cleaning robots which includes water supply equipment, cleaning device, adjustable bracket and walk across device. As shown in Fig. 4 robot is controlled by a PLC control system. The characteristics of the PLC are, it has high reliability of 50,000 hours, strong environmental adaptability, simple programming language, easy installation and maintenance.

4 ELECTROSTATIC DUST REMOVAL

One of the samples of electric method is the electrostatic dust removal. Gaofa et al[1] have suggested two mechanisms for charging particles on moon. 1) From surface of particles electrons emitted through photoemissions due to UV radiation 2) Triboelectric charging. When there is a high potential on the solar panel surface, the panel will attract the uncharged and charged dusts due to electrostatic forces. The solar panel will charge the dust particles. They will have repulsion among them due to electrostatic forces among them, because they have same electric charge. Finally the dust particles fly away from solar panels. Due to effect of rain, this method has limitation on the PV system. The other well known electro dust removal method is the electric curtain method.

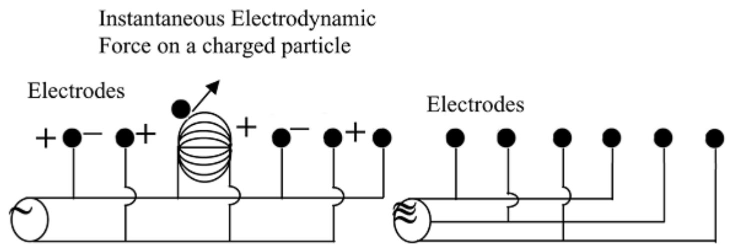

Fig 5 Single-phase electric curtain (Left side) Three-phase electric curtain (Right side)[36]

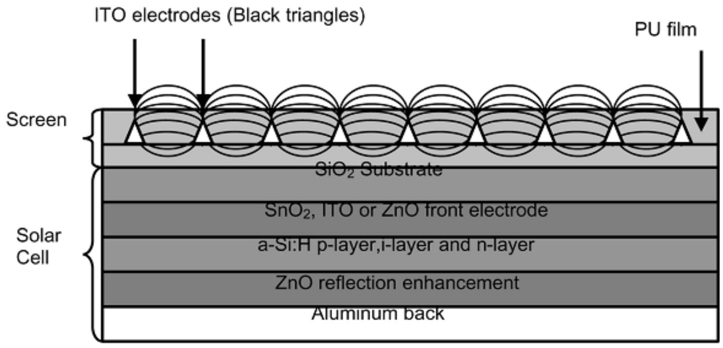

Fig 6 An electrodynamic screen placed on a solar panel [36]

Mazumder et al. [36] have taken q as electrostatic charge on a particle. As per experimental data both the particles have been removed namely charged and uncharged from screen (as shown in Fig. 5). With no initial charge (q=0) the particles deposited on the screen surface, would have a net electrostatic charge. This is either through dielectrophoresis (polarization of charge) or for a conducting particle through induction charge. Net force acts on the particle due to these processes which results in particle motion on the screen surface as shown in Fig 6. A net charge would be acquired by the particles due to dielectrophoretic-triboelectrification and it causes repulsion from the screen surface. [36]

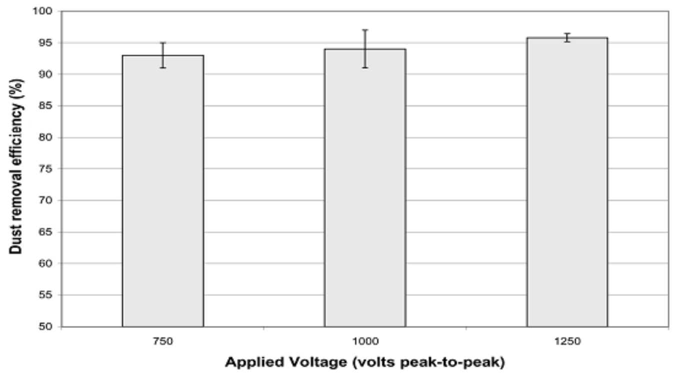

Fig 7 Dust removal efficiency of a three-phase electrodynamic screen operating at 750,1000 and 1250 volts with cleaning operation time for 30s for each experiment [36]

Results of Mazumder et al. [36] shows that the three-phase Electrodynamic screen (EDS) model has better dust removal efficiency over single-phase model. The figure shows for a Electrodynamic screen with electrode spacing of 1.27 mm, 90% dust removal efficiency was achieved. Fig. 7 discuss about the dust cleaning efficiency at various operating voltages. Most particles charge showed close to zero, when these particles were neutralized by using bipolar ions. The performance of EDS had been analyzed for both neutral and charged particles (Fig. 8). It was observed that for neutral particles the dust removal efficiency (DRE) did not deteriorate for test screens. Calle et al. [37] in their paper discussed about how to develop a dust shield(Fig . 9) and how to prevent deposition of dust particles on surfaces. They gave report on dust removal technology by using dielectrophoretic and electrostatic forces to remove dust particles in relation with NASA exploration mission.

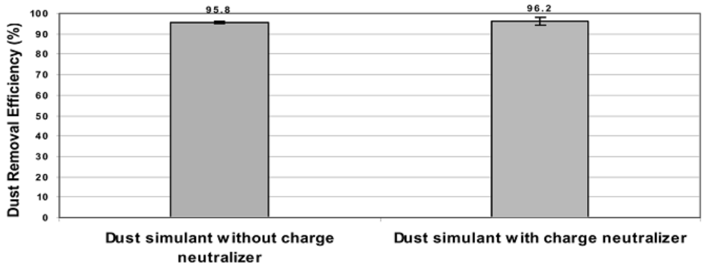

Fig 8 Dust removal efficiency of a 3-phase electrodynamic screen with and without charge neutralizer [36]

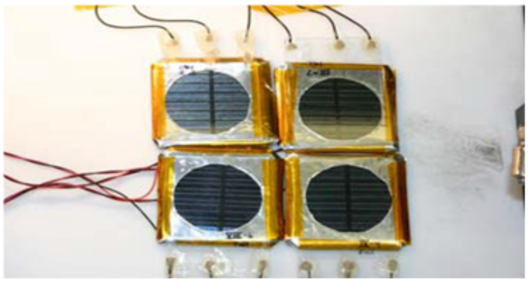

Fig 9 Solar panel-backed transparent Dust Shields used for testing at high vacuum conditions [37]

Johnson Space Center (JSC-1A) dust deposition leads to considerable reduction in output voltage for each of the solar panels. The voltage drop reaches less than 20% of the initial voltage. As soon as the electrodynamic shield is turned on, within two minutes the efficiency reaches beyond 90% and further increase gradually with respect to time. Calle et al. [37] have observed this increase in efficiency after activation of the shield and collected data as given in the Table 2.

Table 2 Solar Panel Efficiencies [37]

Solar Panel	Efficiency with dust deposition	Efficiency after 2 minutes of shield activation	Efficiency after 30 min of shield activation
0.48 mm	20.3%	99.4%	98.3%
0.55 mm	19.3%	98.7%	98.6%
0.6 mm	11.0%	91.6%	99.1%
0.67mm	22.5%	98.4%	98.1%

It is apparent from Table 2 that the dust shields could be made transparent and work successfully under extreme loading and higher vacuum conditions. Also Fig. 10 gives graphical representation of rate of dust deposition and removal at different vacuum conditions.

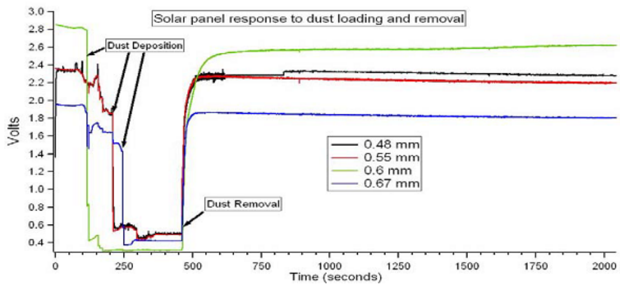

Fig. 10 Solar Panel response to 50-75μm JSC-1A dust deposition and removal under high vacuum conditions. [37]

5 NANODOME SELF-CLEANING SOLAR CELLS

Zhu et al [38] propose a nanodome solar cell model as shown in Fig. 11. As per their research the nanodome solar cell absorbs 94% of the light, where as flat film device absorbs only 65% of light. Due to this the short circuit current generated is 17.5 mA/cm^2. The nanodome concept is demonstrated by Zhu et al. [38] by using hydrogenated amorphous silicon (a-Si: H). Compare to crystalline silicon absorption depth, a-Si: H has several hundred times thinner depth, which is around 1μm only.

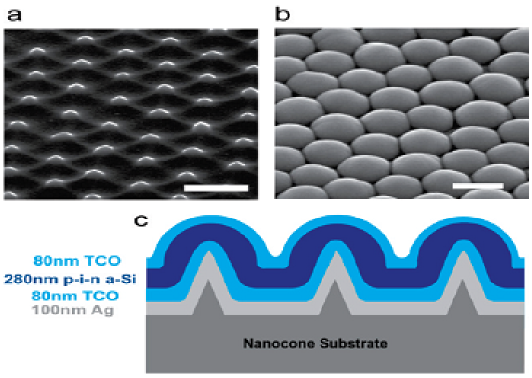

Fig 11. Nanodomea-Si:H solar cell structure. SEM images takenat 45° on (a) Nanocone quartz substrate and (b) a-Si: Hnanodomesolar cells after deposition of multilayers of materials on nanocones.Scale bar 500 nm. (c) Schematic showing the cross-sectional structure of nanodome solar cells[38].

6 MECHANICAL DUST REMOVAL SYSTEM

The Mechanical dust removal system includes various methods like ultrasonic driving, blowing, brushing and vibrating [1]. Mechanical vibrations could remove dust particles, by incorporating piezoceramic actuators in solar panels. Due to this the efficiency of the solar panels increases up to 95One of the methods of cleaning system blowing method cleans the solar cell with wind power. It has the advantage of effective cleaning, but simultaneously it has drawbacks as well, like high energy-consumption, low efficiency and difficulty in maintenance of blower[1].A machine consists of brush wipes on the solar panel just like a windscreen-wiper. This method has the challenges like, the solar cells working environment is abominable, due to this there is more difficulty in maintenance of the machine. Also this method is inefficient due to strong adhesive nature of dusts and they are small in size. The solar panel might get damaged due to brush wiping and as the solar cell area becomes larger, the cleaning machine must be more powerful.

7 CONCLUSION

Much research has been done on various solar photovoltaic panels cleaning methods and many papers published, particularly on Martian and lunar mission. By analyzing various systems, in which some are in practice and many are under research, the best one is Electrostatic cleaning method.

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