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Solar PV Panel Cleaning Methods: A Comparative Study

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***Abstract*: Solar energy has emerged as one of the most go-to sources of power in this century. Installations have been setup all across many countries in and around the globe. However, there exists various problems such as cleaning the PV panels which hinder the energy conversion. This study is an attempt to throw light on the various methods that exist to lower or eliminate dust accumulation on solar panels in harsh conditions. This might also serve its role as a comparative analysis on the electro static cleaning and super-hydrophobic anti-soiling coating methods that are used to eliminate the same problem.**

***Keywords*: Electrostatic cleaning, PV panels, Super hydrophobic coating, Solar energy.**

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. Mega Solar power plants are installed at deserts where the sun shine is brightest at low altitudes. 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. It has been analysed 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. 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. 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 installed.

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. 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. 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%. The Solar cell cleaning process will produce slurry residue due to sticky dust, cleaning fluids. Various dust removing methods for solar collectors is shown in Fig. 2.

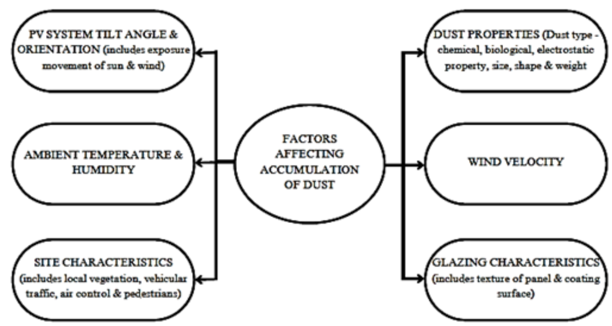

Fig. 1. Factors affecting dust accumulation

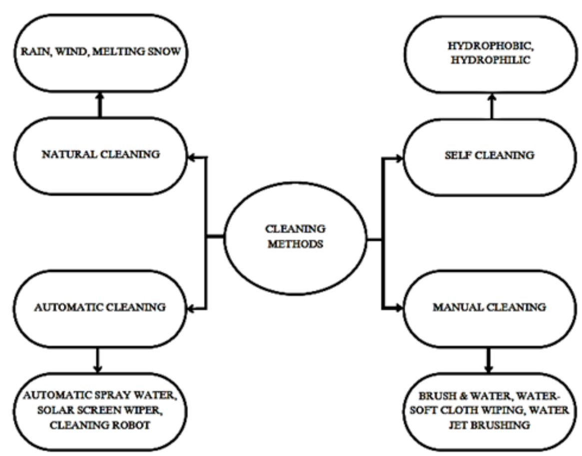

Fig. 2. Various cleaning methods

2. Literature Survey

The recent upsurge in the demand of PV systems is due to the fact that they produce electric power without hampering the environment by directly converting the solar radiation into electric power. Solar energy is completely natural; it is considered a clean energy source. So the study on improving

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the efficiency of solar panel is very necessary. Various methods of efficiency improvement of solar panel, we can improve efficiency of solar panel by using solar tracker with panel which continuously tracks sunlight throughout the day to get maximum solar energy. Second method to improve the efficiency is dust cleaning. Dust is barrier between sunlight and solar panel. Third method is cooling technique. As panel temperature increases output voltage of solar panel decreases so cooling of panel is necessary for improvement of efficiency.

Shading and overheating of photovoltaic cells can result in a significant energy reduction of PV systems. Tilting and natural ventilation allows the buildup offline sand to be blown off from the PV array's surface. However, dust particles tend to gradually accumulate on the PV surface making the cleaning task more difficult and reduces the overall PV panel efficiency due to the combined effect of shading and heating.

Accumulation of dust from the outdoor environment on the panels of solar photovoltaic (PV) system is natural. There were studies that showed that the accumulated dust can reduce the performance of solar panels, but the results were not clearly quantified. The objective of this research was to study the effects of dust accumulation on the performance of solar PV panels. Experiments were conducted using dust particles on solar panels with a constant-power light source, to determine the resulting electrical power generated and efficiency. It was found from the study that the accumulated dust on the surface of photovoltaic solar panel can reduce the system's efficiency by up to 50%.

Current labor-based cleaning methods for photovoltaic arrays are costly in time, water and energy usage and lack automation capabilities. In this paper a novel design is presented for the first ever human portable robotic cleaning system for photovoltaic panels, which can clean and maneuver on the glass surface of a PV array at varying angles from horizontal to vertical. In order to regularly clean the dust, Various cleaning methods has been looked into this study. The most used cleaning methods that is being used are natural cleaning, manual cleaning, mechanical cleaning, anti- soiling coatings, electrostatic cleaning, automatic cleaning, robotic cleaning etc. In terms of daily energy generation, the presented automatic-cleaning scheme provides about 30% more energy output when compared to the dust accumulated PV module (module kept stationary on ground).

3. Cleaning Methods of Solar Panel

A. Natural Cleaning Method

The natural powers are employed to remove the dusts, such as wind power, gravitation and the scour of the rainwater. The effect of this method is not very well. It is seen that the solar cell array can be turned to vertical or oblique position to remove the dusts easily when early morning, late evening, night and a rainy day. However, the rotation of the large solar cell array is very difficult. The natural cleaning process takes place in places where rain is abundant. Places like Japan have abundant of rain. With the help of rainfall, the dust accumulated on the PV panels is cleaned automatically by rainfall. But the problem with this method is that, with this abundant rainfall, the output power produced by the solar panels is acceptably small.

B. Manual Cleaning Method

The Manual cleaning method is the most primitive and secure countermeasure cleaning method of the PV panels. The various manual cleaning methods are Brush and water wiping, water and soft-cloth wiping, water jet brushing. However, manual operation is hard in harsh environments as the labor cost is indefinite and the transportation cost of water to power plants is costly.

C. Mechanical Cleaning Method

The Mechanical dust removal system includes various methods like ultrasonic driving, blowing, brushing and vibrating. Mechanical vibrations could remove dust particles, by incorporating piezo ceramic actuators in solar panels. Due to this the efficiency of the solar panels increases up to 95%. One 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.

Another method for mechanical dust removal is a machine that 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.

D. Super-Hydrophobic Coating Method

This is also referred to as Super-hydrophobic anti-soiling coating. They are based on SH functionalized nano silica materials and polymer binders they possess the key requirements necessary to inhibit particulate deposition on, and adhesion to, CSP mirror surfaces, and thereby significantly reducing mirror cleaning costs and facility downtime. The key requirements for these coatings are excellent optical clarity with minimal diffuse reflectance, and coating mechanical and exposure durability in harsh desert environments while maintaining SH and dirt shedding properties. The surface must have low surface energy and be structured on the nano to micro scale range to minimize the water droplet surface contact area with the underlying surface. With very SH surfaces, not only does water not stick to these surfaces, but the forces binding dust and other particulates to the surfaces are also reduced.

E. Electrostatic Cleaning Method

Electrostatic cleaning equipment has been developed to remove dust from the surface of soiled solar panels. When a high AC voltage is applied to the parallel screen electrodes placed on a solar panel, the resultant electrostatic force acts on the particles near the electrodes. The reciprocatory motion of the particles between the electrodes arises due to the alternating electrostatic force, where some particles pass through the openings of the upper screen electrode and fall downward along the inclined panel owing to the gravitational force. High cleaning performance is realized by the application of low frequency high voltage, and high inclination of the panel and low initial dust loading are preferable. Although residual dust accumulates after repeated cleaning operations, the amount of accumulated dust is much smaller than that without cleaning.

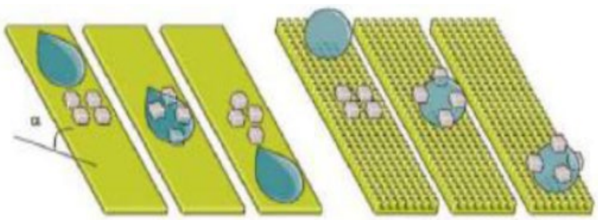


Fig. 3. Uncoated & coated panels

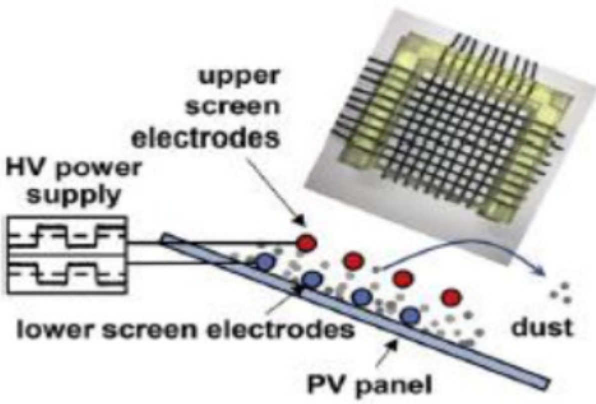


Fig. 4. Electrostatic cleaning equipment

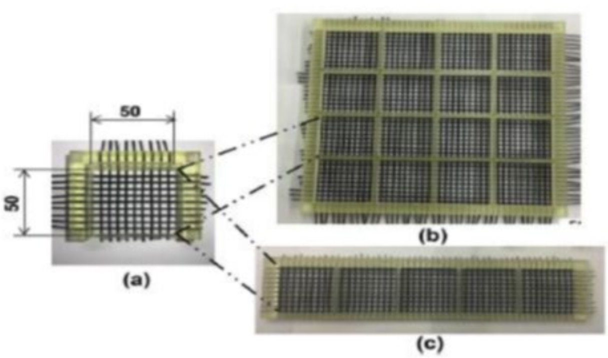


Fig. 5. Different cleaning equipment's

Small, wide, and long cleaning devices as shown in Fig. 5. The small device is used to investigate the basic performance of this system and the wide and long devices are used to demonstrate the practical performance for the actual large panel. The screen electrodes are attached to the plastic frames molded by a 3D printer. The inner width and length of the small frame are both 50 mm(a), those of the wide frame are both (b)200mm (active area: 200×200mm^2), whereas those of the long frame are (c) 250mm and 50mm (active area:250×50mm^2), respectively. The electrodes are composed of a copper wire which is 1mm in diameter and coated with a polyester film in 0.15mm thickness. The pitch between the wires of the screen electrode is 5mm and the gap between the screen electrodes is 5mm in all devices. The wires were inserted in grooves installed in the flames.

4. Comparative Study on SH Coating and Electrostatic Cleaning Method

Since there exist multiple methods of dealing with dust accumulation on solar panel, there seems to be a cloud regarding which one to go for. A comparative study is done between Super-hydrophobic anti soiling coating method and Electrostatic cleaning method. To ease out, this choice faced while installations. Any form of comparative analysis requires certain criteria to judge. The various elements on:

Factors like Particle size, Efficiency/Performance, Durability, Maintenance, Cost are used to bring about a stark contrast between the two above mentioned methods,

A. Particle Size

In electrostatic method, the small Particles collected from Doha, Qatar. The typical particle size is approximately 6-10µm in diameter and the primary component is calcium carbonate. In addition to Doha dust, Namib sand, collected from Namib deserts from Africa. Its typical size is 200-300µm in diameter and main composition is SiO_2. The Namib sand show high performance and with this particle size consideration around 80% of the dust accumulated is cleaned by electrostatic method, the residual dust particles on the panel is much smaller. In SH coatings, the particle size range is from 12-100nm, such that they would not optically scatter the UV solar radiation at wavelengths greater than 200nm. It shows that the particles with lesser size range produce an efficiency more than the particles of much higher particle size range. The silica particles of size range 12-100nm has proved to prevent significant optical scattering at the shorter solar wavelengths.

B. Efficiency/Performance

The Electrostatic cleaning depends heavily on the applied voltage and frequency. This also depends upon the insulation breakdown. Performance is also affected by the panel inclination. A small amount of residual dust accumulates on the panel. Approximately 80% of the accumulated dust is cleaned when the inclination is higher than 20°.

For SH coatings, the solar panels performance can be quantified by measuring its specular reflectance across the terrestrial solar spectrum (λ = 280 to 2500 nm). A graph showing the specular reflectance variation across coated and non-coated panels is plotted below.

C. Durability

On analyzing the durability of SH coatings, the optical transmission and scattering characteristics of the coatings are associated with the size of the silica particles. In order to fabricate coatings with a surface roughness smaller than 30nm, two different types of particles with well-defined size distributions were used. Commercially available Aerosol particles were used as received. Colloidal silica particles were functionalized in a solution of hexane and tridecafluoro-1,1,2,2-

tetrahydrooctyl trichlorosilane, particle with very low surface energy. Coating durability studies have been performed, using an industry standard Taber abrasion instrument. The technique involves using two wheels, approximately 2” in diameter, with varying levels of surface roughness that are rotated over the sample to be abraded. Varying levels of force, applied by weights attached to the wheel arms, can also be maintained between the wheels and the surface under investigation. The surface abrasion and wear is assessed in our experiments by observing the super hydrophobicity and optical clarity of the anti-soiling surface before and after set numbers of abrasion cycles. The optically transparent coatings based on the double silane functionality in this test retained their super-hydrophobic properties over 20 single-wheel abrading cycles when using two standard abrading CS-0 rubber wheels used specifically for testing optical surfaces. This value is 4 times higher than the corresponding value of the same coating without double functionality. The load on each abrading wheel was set at 75 g. The anti-soiling coatings demonstrate moderate to high mechanical durability under standard Taber abrasion testing, with recently developed coatings surviving 30 times longer than earlier ones. Those based on multifunctional silica particles and polymeric binders have shown outstanding abrasion and accelerated weathering resistance when the average size of the particles is less than 200 nm.

Electrostatic cleaning endures a much-expanded lifespan as it is less susceptible to wear and tear which seems to be the major threat for SH coating. Moreover, it also irradiates the need for re-installation or application over long periods of time.

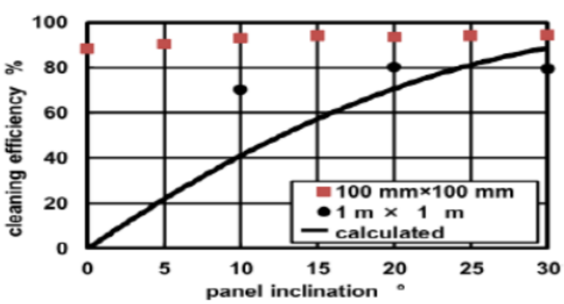


Fig. 6. Cleaning efficiency vs panel inclination

D. Maintenance

Detachable cleaning equipment for the removal of dust that accumulates on the PV panels using electrostatic standing wave has been developed, and high performance was demonstrated. High cleaning performance is realized by the application of low frequency high rectangular voltage. The applied voltage is limited by the insulation breakdown. High inclination of the panel is preferable, but approximately 80% of the accumulated dust is cleaned when the inclination is higher than 20°. Although residual small particles are not efficiently cleaned and are accumulated after repeated cleaning operations, the amount of the accumulated dust is much smaller than that without cleaning. However, because the operation of this system is not fully automatic, integrating it with the proposed cleaning equipment and a robotic system will be required to compensate for this disadvantage. The robotic system that can sweep automatically all over PV array has been commercially available.

Coatings based on multifunctional silica particles and polymeric binders have shown outstanding abrasion and accelerated weathering resistance when the average size of the particles is less than 200 nm. This technology is scalable and can be easily applied to CSP collector mirrors and heliostats already installed in the field.

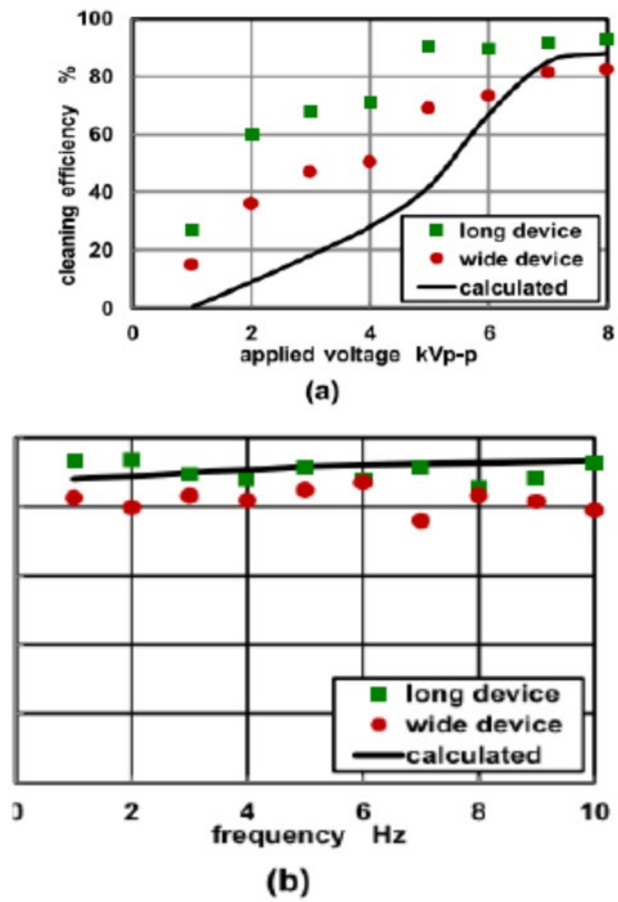
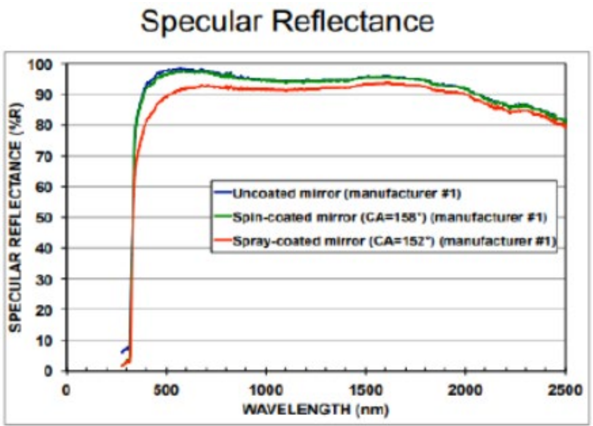


Fig. 7. Cleaning efficiency vs applied voltage & frequency

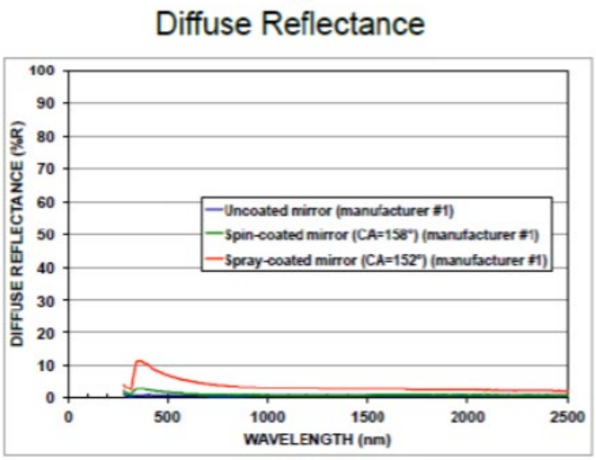
E. Cost Analysis

Initial costs are higher in installation of electrostatic cleaning equipment. Usually, all PV panels must be covered by electrode-embedded glass plates along with long wiring as well. The power consumption of this system is negligibly low. This system is suitable for use in mega solar power plants constructed in deserts at low latitudes because it is potentially inexpensive, and requires virtually no power, water, or any other consumables.

Comparatively, SH coating possess a lower cost alternative being able to be produce somewhat a similar effect with much lesser infrastructural costs. It also remains cost effective given the fact that it requires close to no power for its functioning with respect to its counterpart. This technology is scalable, inexpensive and can be easily applied to CSP collector mirrors and heliostats already installed in the field.



(a)



(b)

Fig. 8. Performance graph of SH coating

Solar-weighted reflectance	*Reference Mirror #1*	*Spray-coated Mirror #1*	*Reference Mirror #2*	*Spray-coated Mirror #2*	*Spin-coated Mirror #2*
Specular	**94.8**	89.0	**95.4**	90.1	94.8
Diffuse	**0.60**	5.65	**0.51**	4.85	1.06

Fig. 9. Specular & Diffused measurements of uncoated and SH mirrors

5. Conclusion

In SH anti- soiling coatings, the Coatings based on multifunctional silica particles and polymeric binders have shown outstanding abrasion and accelerated weathering resistance when the average size of the particles is less than 200 nm. This technology is scalable, inexpensive and can be easily applied to CSP collector mirrors and heliostats already installed in the field. In electrostatic cleaning method, the power consumption of this system is negligibly low. This system is suitable for use in mega solar power plants constructed in deserts at low latitudes because it is potentially inexpensive but costlier than SH unit soiling coatings, and requires virtually no power, water, or any other consumables. Large scale projects might benefit from electrostatic cleaning process as the costs turn out to be negligible compared to no cleaning solutions. Long term installations should go for electrostatic cleaning processes as they involve lesser maintenance and re-applications. Cost seems to be the key and the reason for the wide acceptability of SH coating solutions. Both seems comparable in terms of productivity and efficiency. Optically transparent, anti-soiling and anti-reflective coatings offer a promising route for breakthrough energy savings in concentrated solar power electricity generation facilities.

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