PHOTOVOLTAIC GLASS CLEANING METHODS: AN OVERVIEW

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Abstract

The development of solar technologies in Middle East and North Africa regions is restricted by their regional surrounding high temperature and density of dusts. High temperatures and sandstorms always occur at these regions which reduce light transmission on solar photovoltaic panels. Light transmission refers to the percentage of radiation that can pass through the glazing glass. As the density of dust on the glass surface is higher, some of light i.e. visible light and UV-light is blocked by the dust thickness, thus reduce the light transmission. Hence, no enough light energy can be converted to electrical energy therefore, reduce the photovoltaic efficiency. In this paper, the attempt has been made to discuss about the dust factors that influence the photovoltaic performances which have been observed by the researchers including human activities, climate change, built environment characteristics and etc. Thus, there must be the alternative to cleaning photovoltaic glass to reduce dust deposition and enhance photovoltaic efficiency. The cleaning method of photovoltaic panels such as natural method, electrostatic method, mechanical method and self-cleaning nanofilm method has been discussed in detail to provide an insight of the dust effect and its preventions.

1 Introduction

According to the International Standardization Organization (ISO 4225-ISO , 1994) : Dust can be defined as small solid particle with particle size below 75 micrometer in diameter, which settle out under their own weight but which may remain suspended for sometimes [1]. While according to Atmospheric Chemistry terms (IUPAC, 1990), dust is small, dry, solid particles projected into the air by natural forces, such as wind, volcanic eruption, and by chemical or man-made processes such as crushing, grinding, milling, drilling, demolition, etc. Dust particles are usually in size range from about 1 to 100 micrometer in diameter, and they settle slowly under the influence of the gravity [2]. Hazard Prevention and Control in the Work Environment (WHO/SDE/OEH/ 99.14) refer dust as solid particles, ranging in size below 1 micrometer up to at least 100 micrometer, which may be or become airborne, depending on their origin, physical characteristics and ambient conditions [3].

Dust deposition enhances the thickness of dust with several millimeters on the PV panels. With the thick layer of the dusts, it becomes harder for the sunlight to penetrate through photovoltaic cover and reach the PV cell. Hence, dusts build shading region and increase the temperature on the PV panel. The shading region ceases PV cells from generating electricity, in sudden, PV cells become reverse-biased to other PV cells. Looking towards the problems come out from the dust deposition, the researchers have studied the factors that affecting dust settlement. There are two main factors: dust properties and local environment as shown in table 1.

FACTORS AFFECTING DUST DEPOSITION	
DUST PROPERTIES	LOCAL ENVIRONMENT
Dust-type Electrostatic properties Sizes Shapes Weight	Human Activities Photovoltaic Installation Design Weather Condition/Climate Change

Table 1: The factors affecting dust deposition.

As can be seen from figure 1.0, the sub-factors of dust properties are dust-type, electrostatic properties, sizes, shape and weight which are differently affected the PV panel. Refer to airborne dusts from (WHO/SDE/OEH/ 99.14), dust can be classified as chemical type and biological type. Dust with chemical type are like mineral dusts (coal, free crystalline silica and cement dusts), metallic dusts (lead and nickel dusts) and others chemical dusts (bulk chemicals). While, biological type dusts are like organic dusts (pollens), vegetable dusts (flour, tea dusts), biohazards (moulds and spores) and fibrous dusts (asbestos) [3]. Electrostatic properties of dust refer to electrostatic potential energy of dust grains charge occur at the solid-gas interfacial energy.

High density of dust produce more electrostatic energy on the PV panel surface, thus it enhance strong adhesive force. High electrostatic potential energy dust easily attracts on the PV surface depending on their geometries, sizes and shapes. Dust with smaller size and large weight tend to have larger adhesive force and hardly to remove.

Local environment factors include human activities, weather condition or climate change, and photovoltaic installation design. Human activities that contribute to dust environment are like driving vehicles on the road, air-pollution from factories, local vegetation and others man-made process [4]. Industrial areas have more dust on PV panels. Pandey et al. [5] exposed the sun has unlimited power supply but the collection of solar energy including atmospheric attenuation and weather condition can restrict the efficiency of PV despite the dust effect. Bashar et al. [6] placed their pilot PV station with thin film modules at HU whereas its area is near a major industrial and free-trade zone. Their experiments have been done for 60 days and they found that PV modules at that area were covered with accumulated dust. Their daily efficiencies increase from below 7% to above 7.5% after cleaning the system. Hottel and Woertz [7] observed that 1 % degradation in collector performance from the horizontal inclined plate in industrial area of United States of America .Weather condition or climate changing like sandstorms, high temperature humidity, rainfalls, spring/summer/autumn/ winter etc also affect the PV performance. Wakim [8] observed that a reduction in photovoltaic power by 17% due to sand accumulation on panels after 6 days at Kuwait City. He also studied that dust reduces photovoltaic performance is higher (20% in 6 months) in spring and summer compared to autumn and winter. Mani and Pillai [9] stated that PV installation design also contribute to higher amount of dust on PV panel itself like Sun-tracking devices, solar reflectors, photovoltaic system tilt angle, photovoltaic system geometry and photovoltaic coating surfaces. A sticky coating photovoltaic surface is more likely to accumulate dust than a less sticky, smoother surface. Horizontal tilt angle tend to attract a gravity dust compared to vertical tilt angle. Garg [10] analyzed a vertical glass plate have 88% transmittance light value compared to horizontal glass plate have 30% light transmission. Another PV system tilting angle research has been done by Eliminir group from Institute of Astronomy and Geophysics in Egypt [11]. They revealed a reduction in dust deposition from 15.84 g /m^2 for 0^{8} tilt angle to 4.48 g / m^2 for 90^{8} tilt angle. Yoon et al. [12] observed the temperature of BIPV window was found to be increased for vertical plane in winter season while the surface temperature increased for horizontal and inclined plane for summer season.

The dust reduces the performance of PV panels drastically which are exposed in the outdoor conditions [13], in this study attempt has been made to present a brief review on cleaning methods for PV panels. Section 1 presents the introductory part of the dust and its effect on panel, section 2 presents the different methods of cleaning the PV panel. Finally, the conclusions obtained from the study have been presented in section 3.

2 Photovoltaic Panels Cleaning Methods

Several methods have been proposed to clean the PV glass like natural method, mechanical method, self-cleaning nano film method and electrostatic method. As can be seen in figure 1, all these methods have their sub-method which is discussed here in this review articles.

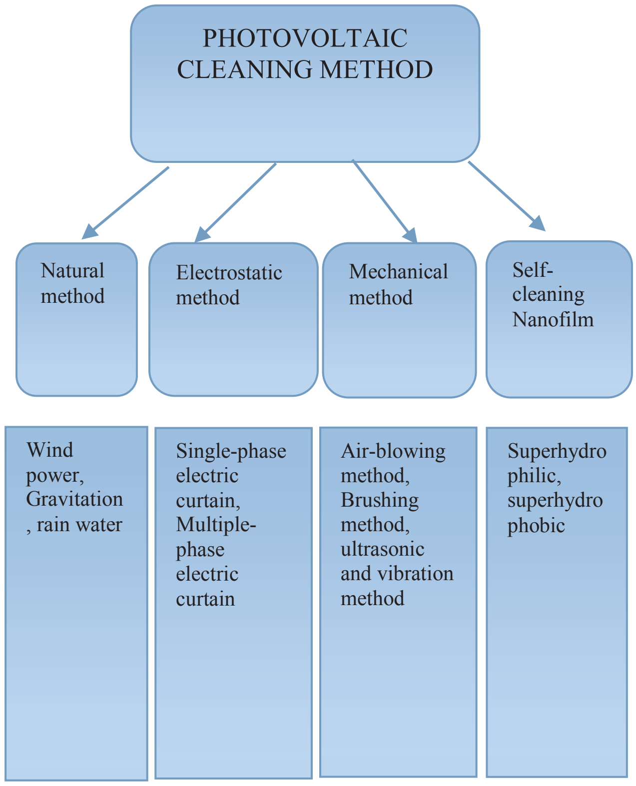

Figure1: Photovoltaic Panels Cleaning Method

2.1 Natural Method

Natural method is a cleaning method which uses a nature as their cleaning agent. These natural agents are wind powers from wind, rainwater from rainfalls, and gravitation from earth. High wind velocity can blow out the dust from the panel surfaces. A water droplet from rainwater roll-off the dust on the surfaces while low gravitation area like less-gravity moon can “float” the dust naturally from PV panels. Sometimes, less gravitation occur at night and early morning. Gair et al. [14] reported that the dust removal can be easily if the solar panel arrays can be turned to vertical position during early morning, late evening, night and rainy day. The advantages of this method are low-cost, clean energy and easily achieved from the environment. The problems with this method are difficulty in tilting rotation for the large solar cell arrays, not function well at high humidity area in Africa and Middle East region, and very nature-dependable.

2.2 Electrostatic Method

Electrostatic method is a method which uses an electrostatic charge from the electric curtain on PV panel to remove dust. This electric curtain have been developed by F.B. Tatom and collaborators [15] at NASA in 1967 , later , further developed in 1970 by Masuda and Aoyama at the University of Tokyo [16]. Calle et al. [17] have studied the action of electrostatic and dielectrophoretic forces in removing the dusts. The electrodes used to generate electrostatic and dielectro-phoretic force to transport charged and uncharged particles on PV panels. Stable electrostatic force occurs as the value of charge is nearly balance between the particle and the surface in the uniform electric field. While, in the non-uniform electric field, the unbalance charged particles between the particle and the surface insists the particle to create its own force. This own force generate a movement of particle on the surface which called dielectrophoretic forces. The transportation of dust particles are shown in figure 2.

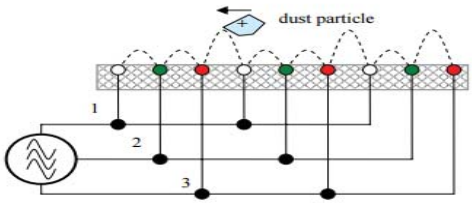

Figure 2: The Transportation of Dust Particle

Figure 2 showed that three wire electrodes (white dot, green dot, and red dot) in series connection used as electrode and connected to multi-phase of AC voltage. As the AC voltage is turned on, these electrodes generates travelling wave to transport dust particles in forward or backward direction in combination with dielectro-phoretic force. Their analysis showed that the Dust Shield can remove dust at low humidity with the absence of water and high vacuum at $5.0 \pm 2.0 \times 10^{-6}$kPa like same as lunar condition. Thus, the dust particles are removed out from the panel surfaces. Kawamoto [18] have improved the single-phase rectangular voltage to the screen electrode configuration. The results showed improvement where more than 90% of the dust was repelled from the clearance under the high-speed microscope camera observation.

2.3 Mechanical Method

Mechanical method is a method which uses mechanical systems to clean the PV panels, either manual mechanic systems like brushing or automatic mechanical systems like air-blowing, ultrasonic and vibrating. Manual mechanic system need the human energy, cost and time. Brushing the PV panel using robot, wind screeen-wiper, broom and brush definitely require high cost and more energy for the large PV panel installations. Automatic mechanical systems have been developed by Williams et al. [19] using piezoelectric effect for ultrasonic self-cleaning PV panels. The generating power of PV cells up to 95% in their initial test using their nine distributed piezoceramic actuators. Minu [20] using forced air flow of return air from air conditioning system. Figure 3 showed the air blowing method using forced air flow of return air from air conditioning system

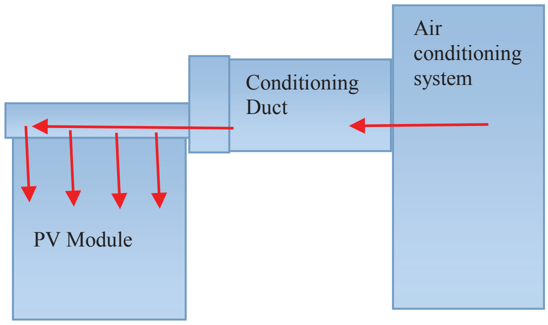

Figure 3: Force Air Flow of Return Air from Air technique

Figure 3 showed that air conditioning system flow the air to the PV module through the air conditioning duct. The removal of dust on the PV module depends on the airflow rate, lenght/ second (*1/s*) from the air conditioning duct. Minu [20] state that there are three air changes generates air flow through convection process occur which are central chiller, return duct and roof area. This air blowing method can remove dust and excessive heat on PV module. They observed that 73% of huge thermal energy can be removed in Al Ain dessert places at UAE. Albaqawi et al. [21] using another mechanical method alternative which they developed an automatic robotic self-cleaning system for PV panels. The robot have sensor to detect dust, small vacuum drives for cleaning process, servo DC motor to drive the robot and the cleaning brush which is spun by DC motor. The robot move in zigzag motion and at one point or dust-detected point, it turn move in spiral motion like figure 4. From figure 4, when the sensor give a signal of dust on PV panel surfaces, the robot move to the dust, and spin the brush in spiral motion. The developed software reduced the cleaning time for a 1x 2.20m panel from 8 minutes to 2 minutes by modifying the path on the PV panel surface compared to semi random movement. Old software only can clean 11 panels while the new programs achieved 37 clean panels in 90 minutes.

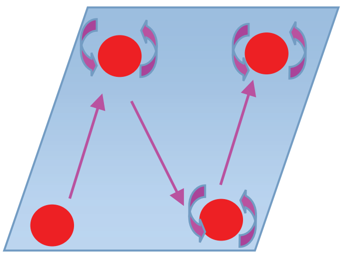

Figure 4: The Motion of Automatic Robotic Self-Cleaning System of PV panels

2.4 Self-Cleaning Nano film

Self-Cleaning Nano film method is the method uses any coating process to build Nano film layer on the PV panel. Several coating process have been innovated by the researchers are vapor deposition, chemical vapor deposition (molecular beam epitaxy, electrostatic spray assisted vapor deposition (ESAVD) , physical vapor deposition (sputter deposition, magnetron sputtering) , chemical and electrochemical technique (electroplating, ion beam mixing) , spraying (plasma spraying) and roll-to-roll coating process (inkjet printing, roller coating), dip-coating and spin-coating. This method objects to modify the normal surface turning to superhydrophobic surfaces and superhydrophilic surfaces by coating superhydrophobic and superhydrophilic nanofilm. Superhydrophobic nanofilm have nanostructres and microstructures on their nanofilms that tend to roll-up the water droplet and carry the dusts away from their surface above 150° water contact angle. It has been inspired by the lotus leaf structure shown in figure 5.

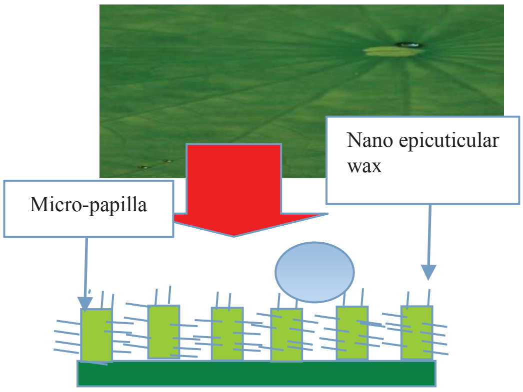

Figure 5: Water Droplet on the Lotus Leaf

Refer to figure 5, the lotus leaf have nano epicuticular wax which attach on every micro-papilla on lotus leaf epidermis. Nano epicuticular wax increase the surface roughness of the lotus leaf which in sudden increase lotus leaf's superhydrophobicity. The presence of air-gap between every micro-papilla repel the water droplet from lotus leaf surface, hence water cannot go underneath of the micro-papilla. Several researches have been done to develop superhydrophobic coating using many techniques. Annaso et al. [22] have built superhydrophobic coating using methyl-modified silica (methyltrichlorosilane) particles using simple dip-coating method. The substrates used is glass micro-glass substrates which results showed that a water contact angle is 153°±2° with sliding angle 8°±1° .Mahadik et al. [23] used methyltrimethoxysilane, oxalic acid and ammonia base catalyst for sol-gel dip-coating method to develop superhydrophobic silica coating . Their superhydrophobic coating have ultra-high water contact angle up to 168°±2° with sliding angle 3°±1°. Liu et al.[24] studied their raspberry-like superhydrophobic silica coating using the mixture of hydrophobic silica particles suspension and tetraethylorthosilicate (TEOS). Under dip-coating technique, their superhydrophobic glass substrates obtain the water contact angle at 152° with sliding angle 10°. Differ from others superhydrophobic coating observations, this superhydrophobic glass endured against the scratch under applied force 150mN.

Superhydrophilic nanofilm have a smooth surface nanofilm which easily to spread water to entire nanofilm surface. Thus, the entire surface of the glass always wet. Dislike superhydrophobic nanofilm, there are a photocatalytic process to remove dirt from the nanofilm surfaces by using photocatalyst chemicals inspired by the photosynthesis process. This explanation has been shown in figure 6. Refer to figure 6, light is the important source to break up the photocatalyst into radical and electron. This radical and electron then destroy the dirts into carbom dioxide and vapors. Same like photocatalysis, light react with the carbon dioxide, water and chrolophyll to produce starch and oxygen. The popular photocatalyst chemicals are titanium dioxide. Nowadays, scientists have modified this titanium dioxide nanofilm by doping with others materials or polymers to enhance the speed rate of photocatalysis. Choi et al. [25] observed the titanium dioxide-dopped with WO_3 can degradate the C/C_0 of Methylene blue from 1.0 to 0.4 within 30 minutes compared to titanium only which have 60 minutes. Nitrogen doped titanium dioxide/ WO_3 degrade C/C_0 of methylene blue from 1.0 to below 0.3 within 30 minutes and below 0.1 wiithin 60 minutes. Lee et al. [26] investigated at% of tungsten enhance the highest photocatalytic activity. WO_3 also improves the charge separation and reduce charges carrier recombination. Meanwhile, Jesus et al. [27] have developed titanium dioxide/ silicon dioxide of superhydrophilic self-cleaning surfaces give high transparency above 85% in visible-NIR range. Titanium dioxide turn to hydrophobicity after 2 weeks while titanium dioxide/ SiO_2 slows this conversion. Jumeri et.al [28] studied their titanium dioxide doped reduced graphene oxide (RGO) thin film have higher photcurrent response (80.2µ A) than bare titanium dioxide (13µA) which indicated increasing of electron transport and minimized charge recombination process.

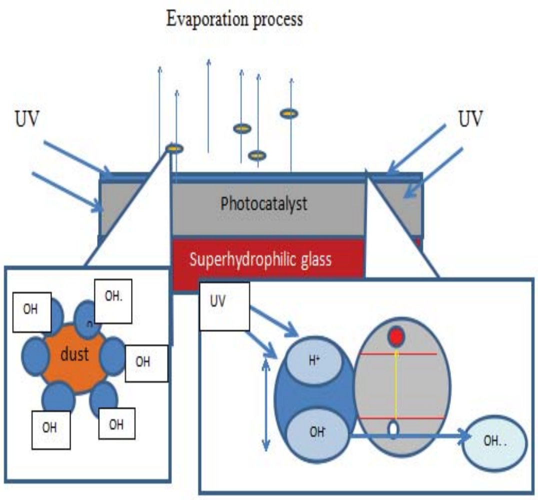

Figure 6: Photocatalysis Process

3 Conclusions

The deposition of any type of biological and chemical dusts on the PV panel affected the PV performances, hence decrease the the solar PV output power. By cleaning the high density of dust deposition, the PV performances can be increased again. There are 4 types of PV cleaning method which are electrostatic method, mechanical method and self-cleaning Nano film method. The electrostatic method uses electrode as electric curtain which connected to single phase or multiple-phase AC voltage to transport dust particle via standing wave or travelling wave. Good results obtained from this method like 90% of dust repelled by screen electrode configuration [18]. The development of automatic mechanical method like robotic-brushing method, blowing method and vibration method enhance the PV cleaning and cooling like 73% thermal energy removed in Al-ain dessert by air-blowing method [20] and enhance the generating power of PV cells up to 95% in their initial test using their nine distributed piezoceramic actuators [19]. Self-cleaning Nano film method is the only method using a chemicals coating on the PV panels by various coating techniques. There are two types of self-cleaning Nano film which are superhydrophobic Nano film and superhydrophilic Nano film. Superhydrophobic Nano films need a small roll-water angle to roll- out the dust from the film like lotus leaf concept. Large water contact angle easy to slide as its sliding angle is small [22, 23, 24]. Superhydrophilic Nano film undergoes a photocatatalysis process like photosynthesis to remove dust in the presence of the UV light. The modified photocatalyst can enhance the photocatalysis rate reaction like research [25], [26] and [28]. The modified photocatalyst can slow down hydrophobicity of titanium dioxide [27]. Compared to others method, self-cleaning nanofilm is the best method among them because it is not affected by the climate changing, less energy consumption, clean energy, and can be used for large scale solar PV panel.

4 Recommendations for Future Study

The future of this study can raise the contribution of energy development into large scope in PV cleaning method. The cleaning method like electrostatic method, mechanical method and self-cleaning Nano film method is important to increase the efficiency of PV panel. In this review article, it highly recommended to:-

1- Enhance the transparency of self-cleaning Nano film either superhydrophobic film or superhydrophilic film under UV-light or visible light. The high transparency of the self-cleaning Nano film is important to gain the amount of light energy and produce large output energy. Thus, increase the PV efficiency of conversion energy.

2- Develop high technology electrostatic curtain t remove the small particle of dust and others type of soil in outer space. The small particle of dust which is in micrometer size has larger charged compared to large dust and it is hardly to remove.

3- Increase the ability of the piezoelectric actuator and robotic-brushing method to clean the large snow particles and high density of dust during winter season.

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References

[1]. ISO (1995). Air-Quality - *Particle Size Fraction Definitions for Health-Relating samples*. ISO Standard 7708. International Organization for Standardization (ISO), Geneva.

[2]. IUPAC (1990). *Glossary of atmospheric chemistry terms. International Union of Pure and Applied Chemistr*y, Applied Chemistry Division, Commission on Atmospheric Chemistry. Pure and Applied Chemistry 62 (11) : pp. 2167-2219

[3]. OEH/WHO (1999). *Hazard Prevention and Control in the Work Environment, Airborne Dust*, International Occupational Health publication, WHO, Geneva chapt. 1 : pp. 1- 3

[4]. Green, M.A., Emery, K., Hishikawa, Y., Warta,W., and Dunlop, D.E., " *Solar cells efficiency tables (version 45)", Progress in PV : Research and Applications*, Prog. Photovolt: Res. Appl., 2015, 23, pp. 1-9

[5]. Pandey AK, Tyagi VV, Selvaraj Jeyraj A/L, Rahim NA, Tyagi SK, *Recent Advances in Solar Photovoltaic Systems For Emerging Trends and Advanced Applications,* Renewable and Sustainable Energy Review, 2016, 53: pp. 859-884

[6]. Bashar,K.H, Shaher, M. R., Mohammad, A. A., Ahmed, M.G., *"Performance study of on-grid thin film PV solar station as a pilot project for architectural use*", Jordan Journal of Mechanical and Industrial Engineering, 2013, 7 (1), pp. 1-9

[7]. H.C. Bottel , B.B.Woertz, *The Performance of Flat Plate Solar Heat Collectors* , ASME Trans, 64 (1942) : pp. 91-104

[8]. F.Wakim, *Introduction of PV Power Generation to Kuwait*. Kuwait Institute for Scientific Researchers, Kuwait (1981). [Report No. 440]

[9]. Monto Mani, Rohit Pillai, *Impact of Dust on Solar Photovoltaic (PV) performance : research status, challenges and recommendation*, Renewable and Sustainable Energy Reviews, 14 (9), Dec (2010) : pp. 3124-3131

[10]. H.P. Garg, *Effect of Dirt On Transparent Covers in Flat Plate Solar Energy Collectors*, Solar Energy 15 (4) (1974) : pp. 299-302

[11]. H.K.Elminir, A.E. Ghitas, R.H.Hamid, F.El.Hussainy, M.M.Beheary, K.M.Abdel Moneim*, Effect of Dust on the Transparent Cover of Solar Collectors* Energy Convers Manage, 47 (18-19) (2006) :pp.3192-3205

[12]. Yoon, J.H, Shim S.R., An, Y.S, and Lee, K.H, "*An experimental study on the annual surface temperature characteristics of amorphous silicon BIPV window*", Energy Build, 2013, 62, pp. 166-175.

[13]. V.V.Tyagi, Nurul A.A. Rahim, N.A.Rahim, Jeyraj A/L Selvaraj, "*Progress in solar PV technology : Research and achievement*", Renewable and Sustainable Energy reviews, Apr 2013 ,20, pp. 443-461

[14]. Gaier J, Davis P, Marabito M*, Aeolion Removal of Dust Types from Photovoltaic Surfaceson Mars*, 16th AIAA/NASA/ASTM/IES Space Stimulation Conference, NM (1990)

[15]. Tatom F.B, V. Siepel, R.D Johnson, N.A. Contaxes, J.G Adams, H. Seaman, and B.L Cline, *" Lunar Dust Degradation Effects and Removal/* Presentation Concepts", NASA Technical Report NO. TR-792-7-207A (1967) , p. 3-1

[16]. Masuda S, Aoyama M, *Characteristics of Electric Dust Collector on Electric Curtain*, Proceedings of the General Conferences of Institute of Electronic Engineers, Japan (1971) , NO. 821, Proc. Of Albany Conferences of Electrostatics

[17]. Calle,C.I.,McFall, J.L, Buhler, C.R., Snyder, S.J.,Arens,E.E.,Chen,.A.,Ritz,M.L.,Clements,J.L.,Fortier, C.R., and Trigwell, S., *"Dust Particle Removal by Electrostatic and Dielectrophoretic Forces with applications to NASA Exploration Mission*", Proc. ESA Annual Meeting on Electrostatic, Minneapolis, U.S.A, 2008, pp. 1-14

[18]. Kawamoto, H., "*Improved electrostatic shield for lunar dust entering into mechanical seals of equipment used for long-term lunar exploaration*" , 44th International conferences on Environmental System, Tucson, Arizona, July 2014 , pp. 1-8

[19]. Williams RB, Tonimoto R, Simonyan A, Fuerstenau S , *Vibration Characterization of Self- Cleaning Solar Panels with Piezoceramic Actuation*. Collection of Technical Papers- 48th AIIA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference (2007) : pp. 512-520.

[20]. Minu K.S, *Self-Cleaning of Solar PV : A case study for improving the performance of solar PV*, International Journal of Current Engineering and Scientific Research, Vol.2, Issue-7, 2015: pp. 188-191

[21]. Albaqawi, Nawaf and Gheitasi, Alireza and Hugan, Bebbie, *Development of An Automatic Robotic Cleaning System for PV Plants*, Wintect Walkato Institute of Technology, 2015 : pp. 1-50

[22]. Annaso ,B.G., Xu, Q., .Latthe, S.S., Vhatkar, R.S,Liu,S.,Yoon,H.,Yoon,S.S.*,"Superhydrophobic coatings prepared from methyl-modified silica particles using simple dip-coating method*", Ceramics International, March 2015, 41, (2 (B)), pp. 3017-3023

[23]. Mahadik, S.A., Parale, V., Vhatkara, R.S., Madik, D.B, Kavale, M.S., Wagh, P.B., Gupta, S., and Gurav, J., "*Superhydrophobic silica coating by dip-coating method*", Applied Surface Science, July 2013, 277, pp. 67-72

[24]. Liu, S., Latthe, S.S., Yang, H., Liu,B., and Xing, R.,"*Raspberry-like superhydrophobic silica coatings with self-cleaning properties*", Ceramics International, Nov 2015, 41, (9 (b)), pp. 11719-11725

[25]. Choi, T., Kim, J.S., Kim, J.H., "*Transparent Nitrogen doped TiO_2 / WO_3 Composite Films For Self-Cleaning Glass Applications With Improved Photodegradation Activity*", Advanced Power Technology, 2016, 27, (2), pp. 347-353

[26]. Lee, W.H. , Lai , C.W and Hamid, S.B.A., *"One-Step formation of WO_3-loaded TiO_2 nanotube composite film for high photocatalytic performance*", Materials, 2015, 8, (5), pp. 2139-2153

[27]. Jesus, M.A.M.L., Neto, J.T.D.S.,Timo, G., Silva, PRP., Dantas, M.S.S, and Ferreira, A.D.M, "*Superhydrophilic Self-Cleaning Surfaces Based On TiO_2 and TiO_2/SiO_2 Composite Films for PV Module Cover Glass*", Applied Adhesion Science , 2015, 3, (5), pp. 1-9

[28]. Jumeri FA, Zainal Z, Huang NM, Pandikumar A, *Titanium Dioxide-Reduced Graphene Oxide Thin Film for Photoelectrochemical Water Splitting*, Ceramics International, Vol.40 (9(b)) , Nov 2014 : pp. 15159-15165