Impact of Dust Deposition on PV Panels and Cleansing Methods

Isha Arora
Electrical Engineering Department
Punjab Engineering College
Chandigarh

Dr. Jaimala Gambhir
Electrical Engineering Department
Punjab Engineering College
Chandigarh

Dr. Tarlochan Kaur
Electrical Engineering Department
Punjab Engineering College
Chandigarh

Abstract—**There is continuous day-to-day rise in the demand of electricity, which is one of the present day basic necessities of humankind. Researchers have been inspecting for substitute energy sources as prevalent fossil fuels are hazardous and creating critical menace by intensifying green-house effect. Large portion of solar radiation hitting the earth surface can be utilised to produce electrical energy through photovoltaic (PV) panels.**
Accumulation of dust also referred to as soiling, on the surface of PV panels results in diminishing the energy productivity of the panels. The effect of dust poses as major issue for PV plants in various regions across the world, especially in the areas with dust storms or dusty surroundings. Dust accumulation on the PV panels and solar concentrators result in productivity loss from 10% to 30% relying on the surface mass concentration of the dust. They need to be cleaned regularly to exploit to their maximum designed potential. Various techniques employed for cleansing PV panels have been reviewed.

Keywords— Dust; dust elimination; PV panels; power output; solar radiation.

I. INTRODUCTION

Renewable Energy is the energy deduced from naturally occurring resources that can be restored likewise solar energy, wind energy, wave energy and biomass energy etc. Solar radiation is crucial driving power of the Earth. Various types of energies such as hydroelectric, wave, wind energies are result of inequitable heating of the Earth by Sun [1]. There are various energy systems that utilise solar energy directly. Solar technologies are mainly classified as active or passive dependent on the manner they trap, transform and scatter sunlight and allow solar energy to be used at various extents around the world. Active solar technologies are comprised of solar photovoltaic, concentrated solar power, solar thermal collectors, etc. Passive solar technologies constitutes of material selection with beneficial thermal characteristics and drafting spaces. PV systems employed are quite unalike other electric power production mechanisms, the basic dissimilarity being it is devoid of any moving constituents such as prime mover as present in steam operated or wind generators [2].

Amount of solar insolation received at the Earth's upper atmosphere is around 174000 TW. Total installed capacity of solar energy (solar panels and solar concentrators) worldwide by the end of year 2017 as quoted by IRENA is around 390 GW.

Solar arrays normally comprises of PV cells in the combination of series and parallel, shielded by a protective glass layer. As enough amount of solar radiation falls on the surface of PV panels, energy of solar radiation is consumed by the cells and thereupon transformed into electricity. Solar energy is source of green and clean energy as it decreases harmful CO_2 emissions and therefore, secure the surrounding location. PV power plant production may be adversely influenced by the dust deposition on the array surface. The optical loss produced by aggregation of dust and other pollutants on PV panels is the third most significant input parameter after solar radiation intensity and air temperature that governs the energy production of the PV power plant [3]. PV panel conversion efficiency is considerably lowered by dust, soil, pollutants, pollen grains and other particulates. Dust accumulation on the solar panels and concentrators result in productivity diminution from 10% to 30% relying on the surface mass concentration of the dust. Typically, there is 1% deterioration in efficiency of panels after every one year.

Elimination of contaminants and dusty molecules is required for effective performance of these equipments. The prime emphasis of this paper is on efficiency enhancement of PV panels by reviewing the various techniques used for cleaning the surfaces of PV panels.

The paper is organised as follows. In the second section, we introduce the concept of soiling and its effect on performance of PV panels. Section 3 describes the details of various techniques employed for cleaning PV modules such as by natural means, utilising water, electrostatic approach, robotic means or using nano film technology. The conclusions of the work presented are given in Section 4.

II. PV PANELS, DUST DEPOSITION AND LOSSES

According to the International Standardization Organization (ISO 4225 - ISO, 1994), "Dust: small solid particles, conventionally taken as those particles below 75 m in diameter, which settle out under their own weight but which may remain suspended for some time"[4]. According to the "Glossary of Atmospheric Chemistry Terms" (IUPAC, 1990), "Dust: Small, dry, solid particles projected into the air by natural forces, such as wind, volcanic eruption, and by mechanical or manmade processes such as crushing, grinding, milling, drilling, demolition, shovelling, conveying, screening, bagging, and sweeping. Dust particles are usually in the size range from about 1 to 100 m in diameter, and they settle slowly under the influence of gravity" [5].

Proportion of the radiation that can get past the coated glass is known as Light transmission. As thickness of dust on the surface of panels is higher, a part of the light is interrupted by the dust density, hence, decreasing the transmission of light. Therefore, no sufficient light can be transformed to electrical energy, thereby decreasing power productivity.

Solar energy entirely is dependent on the light intensity and radiation emitted by the Sun. So to produce large power, PV arrays need to be subjected to maximal light and radiation [6]. Weather performs significant part in electricity generation from solar cells. An overcasted and hazy weather results in decreased exposure of arrays to solar radiation, therefore, leading to reduction in plant production.

Taking in account above mentioned parameters, the apt location for wide-scale PV power plants are the deserts, where the weather is quite hot and large intensity of solar radiation is easily accessible. Moreover, there are comparatively lesser possibilities for the weather to change. However, such locations have to face the issue of dust and sand. This is mainly because of sandstorms, which leads to formation of layer of dusty particles, soil and pollutants. This layer then acts as obstruction to the light radiation falling from the Sun on the surface of arrays, eventually leading to less electricity production of power [7].

Fig 1. Left - clean panel and right - dusty panel

It is essential to come up with a method to approximate losses as a result of soiling. Mani F. *et al.* have proposed a Neural Network based model of dusty PV panel that is useful for enhancing reliability of panels as soiling is unavoidable situation. Power losses have been forecasted using particle size structure as quantifying factor, in addition to solar radiation for training of Multilayer Perceptron model using Levenberg-Marquardt Algorithm. As particle size of soil has straight impact on the portion of sunlight received by panel from real incident sunlight. Sieve analysis has been used to estimate and classify particle size structure on the scale from 2.36 mm to 75µm. Sequences of experiments have been performed on 5 varieties of soil from the Shekhawati area of Rajasthan, India. Voltage and current readings have been noted down manually for different irradiance values from 100-1200 W/m^2 for 5 soil types, and thereafter power productivity is computed.

On analysis, it has been concluded that smaller sized constituents leads to increased losses at higher irradiance levels; soil particles with relatively larger particle size contribute to losses at lower irradiance levels, whereas, medium sized particles have quite less impact on power losses of PV panels [8].

Javed *et al.* have deduced the depletion in daily energy output, as effect of dust aggregation on PV panel surfaces, estimated the rate of soil deposition, learnt about the physiochemical attributes of dust on panels, and their correlation with PV performance and environmental circumstances [9]. Analysis conducted depicts average dust accumulation rate as 260±10mg m^{-2}day^{-1} with more deposition in winters in contrast to summers. Baras *et al.* have performed 3-year soiling measurement experiment in Rumah, Saudi Arabia and thorough study of soiling losses from one year long data. Losses calculated are then applied for cost-effective evaluation of price of soiling for optimum cleaning intervals. Total cost has been computed as addition of cost of lost energy and cost of cleaning mechanism. It has been realized that machine employed cleaning produces greater than 80% cost trimming in contrast to hand-operated cleansing [10]. Boyle *et al.* have studied the influence of natural soiling on the light transmission by solar panels by subjecting tempered glass plates with dimensions 10cm*10cm*0.48cm to environment for different amount of time. Only dry accumulation has been taken into account, as plates are sheltered by small roofs to obstruct any cleaning or contamination by precipitation. ASD Field Spec Pro spectroradiometer has been employed to check for light transmission for various dust samples. It has been observed that in Commerce, Colorado, for each 1g/m^2 of dust aggregated on the panel's top, leads to drop in light transmission by 5.8% [11]. Guo *et al.* have defined a parameter 'cleanness index' as ratio of temperature-corrected performance ratio of dusty PV module to that of clean PV module placed in similar arrangement and surroundings, to measure influence of dust on PV power production. Results computed conclude that cleanness index of solar modules installed in Doha, Qatar cleansed after every 2 months reduce 0.45% points per day, due to dust deposition only [12].

Deceglie *et al.* have suggested an approach for determining median daily soiling rates from PV productivity data. This approach can be utilised on a large range of sites in a direct, uniform and resilient way using the robust Theil-Sen estimator [13]. Boyle *et al.* have computed dust deposition velocity, location specific transmission losses, PV power production and overall losses. Results have depicted that location has insignificant part in deposition velocity value so; same value can be employed over various sites without amendments [14]. Pradhan A. *et al.* have performed experiment on 0.136m^2 area of polycrystalline panel in Bhubaneshwar, India to analyse the impact of varieties of soil on panel's behaviour. Various soil kinds accounted are

1. Sand
2. Clay
3. Mixture.

Influence of soiling on PV curve, IV curve, fill factor and efficiency has been computed using following equations:

$$\eta = \left(V_m * I_m \big/ I * S \right) \quad (1)$$

$$FF = V_m * I_m \quad (2)$$

Where, V_m is maximum voltage (V), I_m is maximum current (A), I is radiation intensity W/m^2, S is area of cell (m^2), FF is fill factor.

Calculations have been carried out with reference to a clean PV panel and its output is taken as $Reference_{yield}$. System has been operational from 9 am to 4 pm and output of dusty panels is taken as $Array_{yield}$. Power output and losses for 3 kinds of dust are computed as:

$$Output(Wh) = P_{\max} * timeofoperation \quad (3)$$

$$Captureloss = Reference_{yield} - Array_{yield} \quad (4)$$

Results have concluded that dust mixture leads to less efficient panel relative to other cases, as it blocks Sun's radiations from entering interior of panels [15]. Caron have discovered location specific soiling rates and amount of rainfall needed for thorough retrieval of PV plant's productivity. It has been found out that 0.5mm of rainfall is enough to entirely clean a dusty frameless module in areas with milder soiling rates. Patil *et al.* have carried out performance analysis of clean and dusty panels to evaluate deterioration in efficiency due to contaminants and soiling on top of panels. Experiment has been conducted for 30 days on per hour basis and values of output voltage across sense resistor, output current and power are determined. It has been recorded that because of dust aggregation on panel's top, efficiency falls by 50% [16].

There are number of dust aspects that have impact on PV power plant performances such as human actions, climatic alterations, environmental features, PV panel design and positioning etc. Human actions that lead to dusty surroundings are such as moving vehicles on road, air pollutants from industries, other man-made systems. Climatic modifications and weather changes such as dust storms, elevated temperatures, humidity, changing seasons, rainfalls etc. all influence PV performance.

Considering gravitational effect, horizontal panels normally aggregate more dust than tilted surfaces. Sticky surface tend to assemble more soil than smooth surfaces. Moreover, dusty surfaces are more susceptible to dust accumulation [17].

Ibrahim A. has stated that solar cell efficiency determines prices associated trade-off between storage modules and lifespan, panel and its efficiency, load side profile. Shadow and dust effects have been evaluated using a solar-simulator that is Halogen lamp rated 100 W and silicon solar cell with 10cm*6cm and 100 cm^2 area as specifications. Correlation between layer of aggregated dust on top of cell and I_{SC}, short circuit current and V_{OC}, open circuit voltage of solar cell with t as time of exposure is formulated as:

$$I_{SC} = -5.5612t + 211.85 \quad (5)$$

$$V_{OC} = -0.0192t + 2.2 \quad (6)$$

Equations depict that I_{SC} reduce with rising exposure time to a greater extent than V_{OC} [18]. Numerous factors have impact on dust accumulation such as panel orientation and tilt angle, atmospheric temperature and humidity, wind speed and direction, properties of dust and location specific attributes. Chamaria *et al.* have computed and expressed the power loss as a result of dust accumulation in kWh units. PVsyst software has been employed for determination of tilt and azimuth angle for year around optimisation. It has been computed that low lying locations should be cleaned on daily basis as they have high dust aggregation rates. Weekly cleansing cycles are ample for medium latitude areas. Higher latitude areas have almost vertical tilt angles, so dust might not be a significant issue as compared to difficulty caused by snow [19]. Model for forecasting output power depletion rate of PV panels has been developed based on back propagation neural network model taking PM accumulated concentration and tilt angles as the model inputs [20]. Effect of dust accumulation on the PV panels has been studied using data loggers and LABVIEW software. 2 panels with similar specifications have been installed at similar location out of which one has been regularly cleaned and maintained, and the open circuit voltage, short circuit current and power produced by both have been analysed over a period of 55 days. It has been reported that power output of the dirty panels reduces by 9% in comparison to the clean panel [21]. The effect of dust accumulation on the PV panel's surface because of sandstorms, in the desert area of Ouargla city has been studied. Impact of dust on electrical attributes of PV system has been studied by comparing a dusty and a clean panel. Results have depicted that there are huge negative consequences of dust on short circuit current, whereas less on open circuit voltage [22]. Analysis of the impact of dust aggregation on the performance of the panels has been carried out based on an experimental study. Different dust patterns have been simulated by varying lightness% and density% of 4 incandescent lamps used [23]. A model has been developed to forecast soiling losses of PV panels using PM_{10} , $PM_{2.5}$, tilt angle and rain database as input parameters. The rain data used is real-time recorded, that has been extracted from Oregon State University's PRISM database, and the results have been then compared for 7 sites [24]. The impact of wind and sand on the PV power production has been observed. Sand not only blocks the Sun rays from reaching the panel's surface, but also raises the panel's temperature, that results in efficiency deterioration. 3D model of FLUENT has been utilised to examine dust aggregation on panels. Wind field has been forecasted based on k-e turbulence technique, and it has been reported that panels installed in high wind velocity locations, may not need cleaning frequently but they may get damaged by winds [25].

III. CLEANSING METHODS FORPHOTOVOLTAIC PANELS

Various mechanisms have been presented for cleaning the PV panels such as natural means, water-based, electrostatic approach, robot-mechanical means, nanofilm technology etc.

A. *Natural Process*

Natural process indicates methods which utilises nature as their cleansing factor. These factors are earth's gravitation, rainwater from rainfalls, wind powers from wind [26]. Winds with higher speeds can sweep out dust from glass surfaces. Water drops of rainfall can roll-off dusty particles from surfaces. Gaier *et al.* have described that dust elimination can be done easily if PV panels can be tilted to vertical orientation during early mornings, late evenings, night and showery days. This technique has different merits such as low-priced, clean energy and simply available from environment [27]. This method has demerits too associated with it such as complication and problems in turning rotation for huge PV panels and quite nature-dependent.

B. *Water*

At small level, hand wash are used to clean PV modules. For wide scaled installations, fire trucks have been employed for dust elimination with water sprays from hoses. This procedure demands for massive water supplies, substantial manpower and considerable amount of time all raising up maintenance cost. Tucker pole mechanism has been implemented too, though better than abovementioned methods, but has similar challenges.

Water if used as cleansing medium, cannot entirely eliminate dust after huge time span. Water pressure can be raised to improve cleaning method, but it will be quite expensive. Increase in cleaning regularity results in reduction of rate of dust accumulation but cannot be entirely prevented, also increases unavoidable maintenance charges incurred. Prudhvi P. have designed model for active cooling and cleaning of PV panels based on underground tunnelling. A very thin layer of water is made to flow on front surface of PV panels to decrease temperature losses that washes away the accumulated dust too. Enhancement in efficiency by 7.75% is attained.

Fig 2. Panel Cleaning

C. *Electrostatic Technique*

Electrostatic technique is the process which utilises electrostatic charge from electric screen on solar panel to eliminate dusty particles. Transparent electrodynamic screens (EDS), comprising of series of see-through parallel electrodes implanted within a transparent dielectric film are employed for dust elimination. No water or any mechanical means is used. Dust constituents charge up for their eradication by electrostatic forces and scrub away by moving electric field. EDS approach needs dry ambient surroundings and is hence pertinent in semi-arid and desert regions.

Three phase ac voltage with peak to peak value of 700-1000V actuates electrodes. Analysis unveils that energy needed to make surfaces dust free is less than 1Wh/m^2/cleaning cycle, that is smaller than 0.1% of energy yielded by PV panel with 1m^2 of area.

Mazumder *et al.* have examined EDS film technique for regular water-free cleaning with low energy needs. Electrodes are excited by 3-phase high voltage (1.2kV), current (in μA) and low frequency pulses. Analysis has unveiled that high optical efficiency on average is retained by EDS film in comparison to water cleansing mechanism [28].

Sayyah *et al.* have surveyed the effect of dust aggregation on concentrated PV and concentrated solar power systems. Experiments employing EDS screens, activated by low power, 3-phase pulse voltage with frequency of 5-20 Hertz is conducted. Number of experimental runs have depicted that around 90% of reflective restoration is realizable after EDS excitation for few minutes [29]. Mazumder *et al.* have created EDS for solar collectors, in Iraq utilising Fresnel lens against accumulation of dirt of solar radiation incident surface. It eliminates dust with 90% effectiveness in less than 2 minutes with minute portion of energy created by solar collectors [30]. This practice keeps surfaces dust free and is cost-effectual, economical, devoid of manpower, water usage and any robotic equipment even in large scale dust accumulation with less power consumption and firm capability for its widespread implementation and has been experimented successfully in Mojave Desert, North America. [31].

D. Robot Mechanical strategy

Mechanical strategy signifies the ones that employ mechanical arrangements for cleaning, either manually or automatically. Manual system uses manpower, large amount of cost and time for wide scaled panels. Automatic system involves controlling motor driven robots, vacuums via sensors, timers, software programming etc.

Considering human safety's, there are chances of electric shock during hand-operated cleaning of solar panels, also health issues from exposure to severe outside conditions.

Therefore, automation of this operation would eradicate these issues. Memon has presented modeling of PV power station (Doha, Qatar) by applying Virtual Robot Experimentation Platform (V-REP) and Robot Operating System (ROS). This principle can be utilised to use automatic vehicles for dust elimination. Various in-built libraries for navigation, mapping, obstacle prevention, localization, perception and path planning have been utilised. The shortcoming of this technique is that obstacle prevention method is that it cannot track dynamic swiftly moving hurdles, which would be problematic if there are several robots/vehicles around station [32].

Trancă *et al.* have designed a customised, low power, economical, non-complex, sturdy, light, customer-friendly automatic IoT controller for PV module cleansing (Romania). Functions carried out are governing working of mechanical equipment, remote handling, and web configuration and providing with security attributes, not executed by other present-day equipments [33]. Jaradat *et al.* have designed a movable robotic system that has versatile attributes and can move across complete length of solar panels, employed in Gulf Cooperation Council (GCC) countries. It has been constituted of 2 brushes, 4 wheels, 4 motors, sensors and control system. Controlling of robot has been executed by employing Arduino Microcontroller. No water wastage has incurred as brushes dry clean the module. Microcontroller, motor controller and sensors generate feedback signals to robot about PV panel borderlines, and shift robot to next line of module in automated layout [34]. Abhilash B. have analysed the consequences of soiling and solar radiation on the efficiency of PV arrays installed on building's rooftop. Design and fabrication of cleansing and tracking arrangement has been concisely described, comprising of 2 dc motors of 1000 and 10 rpm for cleaning and tracking process respectively. Microcontrollers have regulated the motors on receiving signals from LDR. Different cases of with and without tracking, with and without cleaning have been compared with the clean panels and it is observed that efficiency of system falls by 50% even if trackers are used on dirty panels [35].

Aly *et al.* have proposed innovative, simple and sturdy 4 level automatic dry cleaning equipment for PV panels, without any inclusion of fluids. It has been devised to operate for flat as well as tilted PV modules. The process of cleaning is as follows -

1. Spraying the compressed air using nozzles for eliminating deposited dust and dries out any sort of humidity present.
2. Polyurethane foam roller operated for scratch free dust removal
3. Spraying of air jet again, this time with speed faster than the previous.
4. Spinning of polywool synthetic duster (with static charge) for eliminating very quiet fine contaminants.

The device is effortless on installation, operator-friendly, flexible, automatic, light-weight, less power exhausting, undemanding on maintenance, economical, with easily accessible and deployable units and apt for Saudi Arabia, Qatar and Middle East countries [36].

Robotics are propelling means for PV panel cleansing as it has less of human involvement, water wastage and more effective. But such techniques utilises wipers or scrapers for cleaning that could result in scratching of panels, there are chances of dispersing and averting away of light from panels. Hassan *et al.* have devised low-priced and non-complex robotic cleaner for making Quaid-e-Azam Solar Park dirt-free. It has been constituted of roller brush, ducted fan, and differential drive motors, running wheels and blower fan. Structure has been composed of different segments for speed controlling, sensing, movement, data handling. Algorithm has also been designed to regulate robot's motion, rotation and to control adhesion of ducted fan. [37]. Wang *et al.* have created and tested a wind driven process for cleaning of panels, and used this technique for testing on panels employed in Taiwan. The basic rule is: a bi-directional reciprocating modular cylindrical linear cam is employed to convert the rotation into linear motion. Wind propels the turbine and turbine further powers cleaning brush. This technique is electricity-free, as unlike other presently accessible cleansing mechanisms involves operating electric motors. This wind turbine can further be utilised to produce electric power and can perform cleansing operation when required. The diameter and length of the cam can be modified accordingly as per the specifications of PV panel [38].

For street light solar panels a wet and dry self-cleaning structure, that utilises little or no water, non-complex, low-priced, easy on maintenance, transportable, face environmental conditions, long lifespan and coordinated automatically by remote control or timer has been suggested by Mustafa F. *et al.* Study has been performed on panels before cleaning and after cleaning dry, with water or with solution (Isopropanol, Mono Butyl Glycol and water). Least and highest efficiencies achieved of the structure proposed are 76%-81%, 77%-84%, 78% - 83% on dry cleaning, with water and solution respectively. On cost analysis, PV system owner would receive about 4 times more as compared to installation, maintenance and cleaning charges [39].

Zulkefli M.Z. *et al.* have presented 2 PV systems (Malaysia): a PV system combined with several fixed concentrating mirrors along with cooling system, and another PV system implanted with upgraded robot cleansing structure. Cleaning system has been formed to evaluate power output of 3 different panel situations:

1. PV panel with clean surface
2. PV panel with moss on the surface
3. PV panel with sand on the surface.

Cleaning robot has been linked to panels and its working is dependent on Arduino Microcontroller, which is further attached to resistors (acting as load) and LVDAC software for gathering output in values of voltage, current, power for every minute in 2 hours. The least voltage of 1.7 V across Light Dependent Resistor (LDR) is set to prevent the operation of robot particularly at the time of cloudy weather or during the night and voltage lower than 5V initiates the cleaning process, hence, enhancing performance of system. 12V battery drives the motor, coordinated by IC L293 [40].

The primary aim of the work has been to come up with a simple and accurate ANN model dependent on kind of day (dim or bright) and data of soil deposition [41]. Control signals are received by windshield wiper placed on sides of 250 $_p$ Si-polycrystalline panel from the model to clean the PV surface. Results attained depict about 90% accuracy for aggregated dust assessment.

Liu *et al.* have designed an innovative robotic system that could vertically climb up the surfaces with numerous curvatures in horizontal direction and is tested in Gyeongsan, Korea. Robot 'AnyClimb' has utilised flat dry adhesives to stick to the surfaces. Complaisant method based on asymmetric 4-bar mechanism (for vertical motion) has been applied for adaption as per surface geometry. Kinematic and compliant specifications have been computed mathematically [42]. On analysing the impact of dust aggregation of the top of PV panels, low-cost, autonomous model has been proposed and designed to clean off the dust using compressed air and water from air compressor and water pump respectively, that have been fed through the nozzle. System has been controlled using PLC and a human machine interface (HMI) [43]. Low cost cleaning model for biaxial tracker of Helioslite has been designed. Tracker prototype has been considered for carrying out and validating cleaning tests and for cleansing model improvement [44].

E. Nanofilm Technology

Nano film technology is the technique that employs any coating methodology to create layer of nano film on PV panel's surface. Usual panel surfaces are customised to superhydrophobic surfaces or superhydrophilic surfaces by covering with superhydrophobic or superhydrophilic nanofilm. Selfcleansing nanofilm is the most advantageous process as it is not influenced by climatic changes, also it uses up not as much energy, clean energy process and can be employed for higher rating PV arrays.

A fine coat of photoactive crystalline Titanium Dioxide (TiO_2) is laid on the top of the glass sheet. When Sun rays falls on the TiO2-covered glass layer, the film becomes conducting and really hydrophilic. The high surface energy of the film makes it so wettable. At the time of rain showers, the wetting features of the glass surface aids the cleaning operation.

These surfaces transform the front glass cover plates of modules to non-sticky, thus, reducing the settlement of dirt, and if any aggregates, it is normally washed away by minimal amount of water in comparison to other techniques. This technique is specifically apt for location with periodic rains.

Prime shortcomings of this mechanism is

1. Water or rain showers are required for dust removal.
2. TiO_2 layer raises the reflection loss of solar radiation by 20% which deteriorates the PV performance.
3. Longevity of nanofilmed surfaces is quite small, usually order of months.

Soiling doesn't only lead to energy losses but also incur financial losses. Solar system owner need to decide when cleaning should be carried out to fetch significant financial revenue on their entire investment. Dolan *et al.* have formulated 2 location specified techniques in California for possessor to cost efficiently decide appropriate schedule of panel cleaning [45]. Technique 1 has utilised Solmetric PVA-1000S PV Analyzer for daily IV curve computations of panels cleaned biweekly and panels left uninterrupted. Technique 2 has isolated strings of a module and performs direct energy measurement, where one has been cleansed bi-weekly and other remains dusty. It involves calculating the drop in energy productivity without the need of some energy model or another test system.

IV. CONCLUSION

Extracting Sun's energy through PV technology is of great potential worldwide. But the accumulation of any type of dust on the surface of PV panels, severely affects the panel performance and therefore, the solar power production. The paper has provided with concise overview of the deterioration effect of soiling on top of PV panels. It has been then accompanied by brief review of numerous cleaning methodologies such as cleansing by natural means, water-based cleaning, embedding EDS screens, employing automated processes, and implementing nano film technology.

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