2018 International Conference on Smart Grid and Clean Energy Technologies

A Low-Cost and Energy-Efficient Smart Dust Cleaning Technique for Solar Panel System

Nithin Sha Najeeb, Prashant Kumar Soori
School of Engineering and Physical Sciences
Heriot Watt University
Dubai, UAE
e-mail: nnv2@hw.ac.uk; p.k.soori@hw.ac.uk

T. Ramesh Kumar
Senior Engineer, Phoenix Contact
Middle East
Dubai, UAE
e-mail: rkumar@phoenixcontact.com

***Abstract*—Dust accumulation or soiling is a major challenge faced by the solar farm which are in the desert areas where the solar resource is available in plenty. Dust can be classified as any particles on the panels which blocks the sun's irradiance from reaching the solar cell. Soling is more prominent in solar farm which are placed in non-arid environment (Desert Regions). The performance of the Photovoltaic Systems is greatly affected by dust accumulation or soiling. Current methods used in the markets are costly, labour based, involves periodic battery replacement, more water usage, immense mechanical components and requires cyclic maintenance. This paper presents a low cost, energy efficient, smart dust cleaning technology for PV Panels, which shall mitigate the local climatic challenges in solar farm. The cleaning system is designed, automated using Programmable Logic Controller (ILC 131 ETH) which controls the devices used in the cleaning system and tested successfully. Particularly, the proposed solar cleaning system is expected to enhance the system efficiency of the Solar panels in the United Arab Emirates (UAE) and other Gulf Cooperation Council (GCC) countries which have climatic conditions of dusty weather conditions.**

Keywords—dust accumulation; human machine interface (HMI); nozzle; Programmable Logic Controller (PLC); soiling

I. INTRODUCTION

Solar energy is the cleanest, inexhaustible, easily available and an abundant energy resource available on the earth. Solar energy can suffice the present and future energy demands of the world. The energy industry is also keen on moving towards providing the electricity in green and sustainable manner. Despite the huge initial cost for deployment, photovoltaic systems are being used widely to meet the growing electricity demand. The life-time of Photovoltaic panel is around 30 years [1]**.** Photovoltaic systems are being used widely to fulfill the growing demand for electricity. Despite, the huge cost of initial deployment, the solar panel installation is increasing day by day. Photovoltaic modules are growing day by day, both in standalone and grid tied mode. The large-scale installation is usually in desert and semi-arid regions because of sun's irradiance is stronger in these regions. Although Photovoltaic systems are used more in common and ease of use, they are affected by a major challenge in the large-scale installation: Dust accumulation or Soiling.

Soiling reduces the output of PV panels in the range of 5- 20% per month in most desert areas [2]. The performance of the solar panel is highly dependent on the amount of irradiance reaching the solar cell. Due to dust accumulation or soiling, the irradiance reaching the solar cell is significantly reduced, resulting in the reduced performance. There are a lot of factors which determine the soiling. The surface of the panel whether it is smooth or rough, the position of the panel (if placed horizontal it is easier for dust to accumulate), wind velocity (Breeze will help in dust accumulation) and geographical location [3]. The external factors such as temperature, humidity, wind speed and air pollution also play an important role in dust deposition on the solar panel. If soiling is prevalent during the sunny days, the power output of the panel will be similar as that of the cloudy days resulting in wastage of free energy available to us. The solar cell, to work at the maximum output, there should not be any particles on the solar panel which obstruct the irradiance from reaching the solar cell. In non-arid environments, sandstorm is very common and it leads to build up of dust (fine and sand particles) to accumulate on solar panels thereby blocking the radiation from reaching the solar cell leading substantial power loss [4].

The solar panels being fixed in a place and facing upwards, they are more prone to dusting from the surrounding environments [4]. The gradual builds up of dust over time will lead to reduce in the power output from the solar panels. The dust accumulation on solar panel decreases the performance of the module and also reduces the life span of the solar panel. The suspended dust in the air which is in the direct path of the Solar panel receiving the irradiance and the deposited dust in the solar panel both acts as a hindrance from the sun irradiation reaching the solar cell, which are placed in the semi-arid areas. Solar panel should be completely free of any particles on the panel to fully absorb the sun's radiation. The soling rate will vary according to geographical site condition due to change in physical and chemical properties of dust particles from region to region.

Soiling is one of the greatest challenges faced in the solar farm especially in the Middle East and North African Regions. However, the performance of the Photovoltaic panels in the region which have climatic conditions of dusty weather are significantly affected by dust accumulation or soiling. In these regions, the dust issue is further complicated by build of salt and moisture which enhances the layers of

978-1-5386-6410-0/18/$31.00 ©2018 IEEE

cemented particles on the panels. Desert storms followed by a light rain is a common phenomenon in desert environments and this will result in the formation of cemented layers on the top of the solar panel. It is required to have an efficient cleaning system to remove these cemented particles which have formed on the top of the solar panel [7].

The solar panel performance is highly dependent on the sun's irradiance which reaches the solar cell. Due to dust accumulation or Soiling, the irradiance which reaches the solar panel is drastically reduced, leading to reduced performance. There are a lot of factors which determine the soiling. Depending on the degree of dust accumulated, the open circuit voltage, short circuit current and other parameters will change from the manufactures specification. This justifies the need for a well-designed cleaning system to clean the panels in the solar farms. In order to improve or enhance the efficiency of the solar panel, it should be cleaned which is a tedious job in the large solar arrays. The solar panels have to be kept clean with the help of an efficient and a controlled cleaning process to ensure the maximum capture of energy.

There are numerous methods to clean the solar panels. Some of the methods are Manual cleaning, Robotics, Anti-soiling coating (Hydrophobic and Hydrophilic Coating), Dielectrophrosis and Electrodynamic Screens [5].

- Manual cleaning is a labour intensive and time-consuming method [6]. There is a high chance of scratches due to frequent brushing on the solar panel. There will be huge wastage of water as the water has to be carried in large truck and must be jetted on to the solar panels. The scrubbing and washing happens simultaneously, since the brushes relate to water. In a Gigawatt Scale, manual cleaning is not at all a viable option, since this involves lots of people walking inside the farm to clean the solar panels.
- Robotics system go by principle of brushing away the dust on the solar panel without using water. However, types of devices take twice as long as to clean the dust due to the fact that it should move horizontally and vertically. The power consumption and capital cost tend to be very high for robotic installation. Some of the robotic system consume power from the solar panel installed on the device and yet they need to find a way to clean those solar panel associates with the devices They also have lot of mechanical moving parts and their reliability is a concern [7].
- An electrodynamic screen placed on the solar panel that can automatically remove dust from the dusty solar panel without any usage of water or any other mechanical moving parts. This technique uses high voltage to power up their electrodes, the high voltage is used for generating high electric field, thereby using electric field to push the dust particles to the edge of the Photovoltaic panels. The voltages applied are phase shifted to create a travelling wave. Transparent electrodes are incorporated into the solar panel. The transparent electrodes are made up of indium tin oxide, which is a major drawback because of the indium tin oxide electrodes are very expensive and also a three dimensional structure is required for isolating the phases. Within a span of two minutes almost 90 % of the dust is removed which is very much useful in the dry, arid areas where the PV panels are installed [8].
- Anti-soiling coating is another method used to clean the PV panel. There are two types of coating which are used in the market.
  Hydrophobic coating: A transparent super-hydrophobic coating is applied on the solar panel. This approach uses very less water, which is very much attractive to the industry. The challenge, this type of cleaning system still faces is that the coating still needs to be cleaned frequently with water as they cannot remove the dust which sticks on the coating. In these type of coatings, reflection loss also tends to increase which is not good for PV operation. The coating also needs to be changed if it is not cleaned with water often. If the coating must be re-applied frequently, it increases maintenance and labour cost and it also raises the question of reliability [9], [10].
  Hydrophilic coating: This method of solar panel cleaning uses chemically made hydrophilic coating for soiling. This plane can be achieved by Nano-film of titanium oxide, chemical coating and Nano-patterned glass surfaces. These coatings have the same benefit of super hydrophobic coating but in this case, the coating can break down the dust particles with the reaction of sunlight and the process is known as the photocatalytic effect. Super hydrophilic coating is more durable since it does not come with polymer coating and can perform more than super hydrophobic coating [11]. The major drawback of this cleaning system is that it accumulates more dust due to degradation of the coating because of the ultraviolet radiation. It needs regular washing in dry areas and moderately efficient during the rain. This form of cleaning is inappropriate in dry regions.
- In Dielectrophrosis technique of cleaning the PV panel, a high voltage is applied between the electrodes to repel the dust from the solar panels. The electrodes are then moved into the adjacent section and the process is again repeated. This technique does not use water which is attractive. However, the challenge is that it is time consuming since the electrodes must be moved into the adjacent section of the panels. Moreover, at one place of cleaning, it must apply pulse three times to remove the dust. Also, it is not that easy to attain such high voltages and is dangerous for the working staff [5].

This paper is about the design and fabrication of low cost, fully-automated, efficient and innovative dust cleaning system. Compressed air and water is used to clean the solar panels. The water when used for cleaning serves dual purpose. Firstly, it will help in cleaning the panel. Water will also act as a coolant and was found to decrease the solar cells temperature by 8°C and increase the panel efficiency by 3% [12]. In this work, cleaning system is automated using Programmable Logic Controller ILC 131 ETH and an Interface using Human Machine Interface (HMI) Panel for the Operator is provided [13], [14]. Automation of cleaning

process proposed in this prototype, shall increase safety factor as compared to manual cleaning and other forms of cleaning, where technicians are required to move along with the cleaning system. Hence using the proposed technology, the technicians are not exposed to harsh environmental conditions in the solar farm.

The proposed method of cleaning does not have any moving parts, no battery replacement, doesn't need any coating, no guard rails, less water consumption, does not require any self-cleaning, and a fully automated cleaning system for deployment in the solar farm.

II. Proposed Methodology

The pictorial representation of the developed prototype solar panel cleaning system is presented in Fig. 1.

Figure 1. Pictorial representation of the proposed solar panel cleaning system.

In the proposed method, a mixture of pressurized air and water is used to clean the PV Panels. The air and water is fed into a nozzle where it is allowed to mix in a designed proportion before spraying on the dusty solar panel. The mixture is sprayed through a specially designed Nozzle resulting in flat-fan spray to achieve the desired result. The pressure maintained for both air and water is 3 bars to achieve the desired spray to clean the solar panel.

The main components of the proposed methodology are Air compressor, Water pump and Pneumatic Nozzle which produces flat fan spray. The pressure for air and water is regulated using air and water pressure regulators.

The air compressor chosen for testing is a silent air compressor (550 W, 2.8 A, 220 V AC), the water pump is a micro diaphragm pump (80W, 3.3 A, 24V DC). The pressure regulator chosen is a mechanical device and is adjusted manually and fixed into the air line and water line by manually adjusting the knob to set the designed pressure to be regulated. The nozzle produces a flat fan spray as shown in the Fig. 2. In flat fan spray nozzle, the fluid is molded into a fan formed sheet of liquid. The fluid will consist of droplets of water which are more or less consistent like sheet of waterfall. The angle of spraying will range from 15-145 degrees. The range of the spray angle and the fluid concentration is shown in Fig. 2.

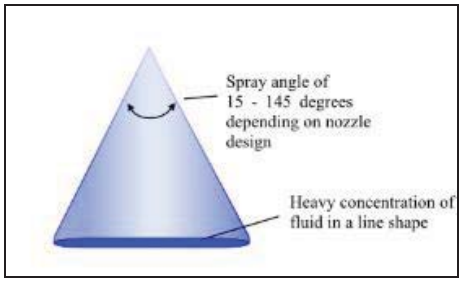

Figure 2. Flat Fan Spray.

The designed and fabricated system is fully-automated using Phoenix Contact Programmable Logic Controller (PLC) ILC 131 ETH. The following logics were developed to perform the cleaning process. A Human Machine Interface (HMI) Panel is used as an interface to control the devices in operation. An automatic clock is set using PLC module to start the cleaning process automatically without the intervention of the operator as shown in Fig. 3. The advantage of this technology is that without an operator giving a command, the process will still take place at the programmed time to the PLC ILC 131 ETH. Hence, operator doesn't need to be in the control room or there is no requirment for the operator to be physically present.

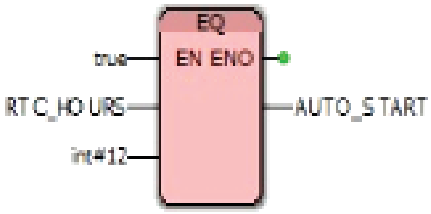

Figure 3. Real time clock from PLC Program (Noon 12 Clock).

Ladder logic Program is developed to program the PLC. The whole process runs on timer basis and the signal from the PLC to the field components is given based on the time. In total three commands from the PLC is given to the field components for the whole solar panel cleaning using this methodology. The first one is for Air compressor, the second one for water pump and third one is for solenoid valves. Once the Operator gives the start command through the HMI Panel, a series of command will be initiated by the PLC for cleaning the solar panels. The PLC module will give supply to the air compressor. Hence the air compressor turns on and within 120 seconds, it will build up the pressure of the air up to 8 bar. Once it reaches 8 bar, the air compressor shuts off automatically because of the inbuilt pressure switch. The supply is automatically removed from the compressor to prevent it from switching on again. Next, PLC sends a signal to turn on the Water pump. The water pump will run for 60 seconds to build the required pressure. After the completion of this, PLC then sends a signal to actuate the solenoid valves. The solenoid valves are used instead of the already built in manual valves. The valves will be open for 60 seconds. The pressurized air-water will be sprayed on the top of dusty solar panels through the customized nozzle.

The detailed block schematics is displayed in Fig. 4. The air compressor and water pump are connected through a pressure regulator to regulate the pressure and then fed into the Pneumatic Nozzle which is placed on the top of Dusty Solar Panel. The purpose of solenoid valve is for automation purpose where they remain closed during the air line and water line is getting pressurized. The valves will remain closed during the air compressor and water line is pressurized and open simultaneously for air and water to be fed into nozzle for mixing in proportion and hence the mixed proportion is sprayed on the dusty solar panel.

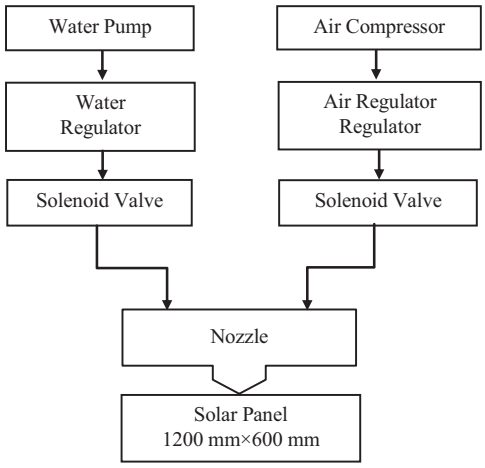

Figure 4. A detailed block schematics of the proposed system.

III. Results and Discussion

Two test benches were set up in the Heriot Watt University Dubai campus laboratory for measuring the current (A) values from the same solar panel (60 W). The first one was a cleaned solar panel and the other panel was dusty panel (by keeping it outside for a week) of the same power rating. The cleaned solar panel current reading was 2.5A and the uncleaned panel current reading was 0.3A for the same load. The readings are taken at 2 o'clock after noon. This drastic change in value of current indicates the severity in the effect of dusting of the solar panel and leads to an eye opening to keep the panels clean to ensure the maximum capture of the solar energy.

The dusty panel was cleaned using the proposed technology explained earlier and the water consumption and energy calculations were recorded.

- It was observed that, the water consumed for cleaning an area of approximately 0.76 m^2 is approximately 250 ml/per cycle.
- The energy consumption for the operation of the devices per cycle is given in Table 1. The total energy consumption for solar panel cleaning system is 0.0197 kWh per cycle which is less than compared to the existing methods, where in other methods there will be a lot of energy consumed because of the complex moving parts and other auxiliaries associated with the cleaning system.
- The proposed method of solar panel cleaning system can wash away all present-day industry facing issues and it is a promising technology which can be deployed in the solar farms.
- The operator intervention is fairly less compared to the existing technologies because of the real time clock feature of PLC module as well as there is no need for the operator to move along with the cleaning system in the solar farm.
- This proposed method of cleaning has no guard rails, no need of any periodic battery replacement, requires no self-cleaning, requires very less maintenance and it can withstand harsh climatic condition like Middle East and African regions.

TABLE I. Energy Consumption of Various Auxiliaries

Equipment	Power Rating (Watts)	Operating Time (min)	Energy consumed (kWh)
Air Compressor	550	2 Minutes	0.018
Water Pump	80	1 Minute	0.0013
Solenoid Valve 1	12	1 Minute	0.0002
Solenoid Valve 2	12	1 Minute	0.0002
Total Consumption			0.0197/per cycle

IV. Conclusion

The effect of dust on PV panel is studied on the dusty solar panel (60W). From experimental results, it is concluded that dust plays a very vital role reducing the performance of the solar panel. By understanding the current market trends for cleaning the panels, a new innovative approach for cleaning has been designed. This system is designed in such a way to operate in the solar farms as this requires less maintenance and involves very less human involved in the operation for cleaning the panels in solar farm. Future work will be done in operating system using a mobile phone and also an addition of a water level sensor to indicate the operator to refill the water in the reservoir.

Acknowledgment

The authors would like to express sincere thanks to Expo Live University Innovation Programme, Expo2020 Dubai Initiative for providing the funding for the development of this project. Special thanks to Ms Fatma Ibrahim, Assistant Manager EXPO Live and her colleagues for their help and support.

References

[1] P. Vasiljev, S. Borodinas, R. Bareikis and A. Struckas, "Ultrasonic system for solar panel cleaning," *Sensors and Actuators A: Physical*, vol. 200, pp. 74-78, 2013.

[2] N. K. Memon, "Autonomous vehicles for cleaning solar panels," presented at International Renewable and Sustainable Energy Conf. Marrakech, Morocco, 2016.

[3] M. Reza Maghami, H. Hizam, C. Gomes, M. A. Radzi, M. I. Rezadad and S. Hajighorbani, "Power loss due to soiling on solar panel: A review," *Renewable and Sustainable Energy Reviews*, vol. 59, pp. 1307-1316, 2016.

[4] S. Pamir Aly, ., N. Barth, and S. Ahzi, “Novel dry cleaning machine for photovoltaic and solar panels,” presented at the 3rd Int. Renewable and Sustainable Energy Conf., Marrakech, Morocco, 2015.

[5] S. Nami, N. Khan, Y. Elgendi, *et al.*, “Power architecture of a high-voltage dielectrophoresis-based contactless cleaning system for solar panels,” presented at 2017 IEEE 18th Workshop on Control and Modeling for Power Electronics, Stanford, 2017.

[6] Z. L. Chuande Zhou, “Review of Self-Cleaning Method for Solar Cell Array,” *Procedia Engineering*, vol. 16, pp. 640-645, 2011.

[7] D. Deb and N. L.Brahmbhatt, “Review of yield increase of solar panels through soiling prevention, and a proposed water-free automated cleaning solution,” *Renewable and Sustainable Energy Reviews*, vol. 82, no.3, pp. 3306-3313, 2018.

[8] T. S. H. Kawamoto, "Electrostatic cleaning system for removal of sand from solar panels," presented at IEEE 39th Photovoltaic Specialists Conference (PVSC), 2013

[9] M. Mazumder, M. N. Horenstein, J. W. Stark, *at al.*, “Characterization of Electrodynamic Screen Performance for Dust Removal from Solar Panels and Solar Hydrogen Generators,” *IEEE Trans. on Industry Applications*, vol. 49, no. 4, pp. 1793-1800, 2013.

[10] M. A. Jaradat, M. Tauseef, Y. Altaf, *et al.*, “A fully portable robot system for cleaning solar panels,” presented at 2015 10th Int. Symposium on Mechatronics and Its Applications, Sharjah, United Arab Emirates, 2015.

[11] L. K. Verma, M. Sakhuja, J. Son, *et al.*, "Self-cleaning and anti reflective packaging glass for solar module," *Renewable Energy,* vol. 36, no. 9, pp. 2489-2493, 2011.

[12] K. A. Moharram, M. S. Abd-Elhady, H. A. Kandil, and H. El-Sherif, “Enhancing the performance of photovoltaic panels by water cooling,” *Ain Shams Engineering Journal*, vol. 4, no. 4, pp. 869-877, 2013.

[13] Phoenix Contact, [Online]. Available: https://www.phoenixcontact.com/online/portal/us?uri=pxc-oc-itemdetail:pid=2700973.

[14] Phoenix Contact, [Online]. Available: https://www.phoenixcontact.com/online/portal/ae?uri=pxc-oc-itemdetail:pid=2913645&library=aeen&tab=1&requestType=product&productId=2913645&productDetection=true&redirectTarget=country&redirectTo=AE.