Novel Dry Cleaning Machine for Photovoltaic and Solar Panels

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***Abstract*—Accumulation of dust (also known as soiling) on the surface of solar panels decreases the amount of sunlight reaching the solar cells underneath and thus the efficiency of the solar panel is severely impacted. To harness their designed capacity to its fullest, they need to be cleaned periodically, usually with water. The Middle East region is a very suitable region for harvesting solar energy due to abundance of sunlight, but there is also a profusion of sand and dust. Due to water scarcity in this area, cleaning becomes difficult, challenging and subsequently costly. Here, a novel four-stage automated 'dry cleaning' method is reported for solar panels. The proposed cleaning process is carried out in four stages with no involvement of liquids. The cleaning process involves compressed air spray, followed by cleaning through a foam roller and a polywool synthetic duster. An electronically controlled mechanical assembly holds the rollers and guides them along the solar panels. A set of servo motors and a stepper motor is installed on the assembly to rotate and guide the cleaning structure. The system is very useful for small and large installations alike, especially in dry areas where there is little or no rain throughout the year.**

Keywords-component; solar panels; dust effects; autonomous dry cleaning; mechanical design

I. INTRODUCTION

Whilst energy demands grow exponentially, scientists are looking for alternate green energy resources. The conventional petroleum products are neither truly cost-effective nor environmental friendly, as they are posing a serious global threat by enhancing global warming [1]. Various alternative energy sources have been considered around the globe to reduce the dependency on such conventional energy sources [2].

Solar energy is highly suitable alternative energy source owing to its natural existence and can potentially replace the conventional fossil resources [3]. The available Sun energy at the surface of Earth is approximately 3.6×10^4 TW_{awg}. However, only 50 TW_{avg} are being consumed [4]. The solar energy production is very suitable for the areas where the weather remains hot throughout the year, especially the areas near equator. A lot of research has been done in the field of semiconductor technology to create highly efficient and long lasting solar cells [5].

A. Dust Effect on Solar Panels Efficiency

It is a common practice to install Photovoltaic (PV) panels (or solar panels) for domestic and commercial applications. The amount of sunlight falling on a solar panel is then dependent on various factors like local radiation levels, panel's orientation and its tilt. Solar panels generate electricity by capturing the sunlight and the electric current produced is directly proportional to the amount of sunlight.

As solar panels face upwards and are generally static, they are more prone to collect debris from the surrounding environment. This gradual and continuous build-up of dust layer reduces the quantity of sunlight reaching the solar cells embedded inside the panel and ultimately reduces the power output. Dust layer thus adversely affects the panel's output and reduces its optimum performance. Usually, the manufacturers rate their solar panels efficiency, according to lab environments, which does not account for real life efficiency inhibitors like dust. So, it is very crucial to clean the solar panels on a regular basis in order to maintain ones' investment.

Dust is one of the most prominent limiting factors that hinder the performance of a solar panel. The power output of the panel degrades up to 50% due to dust accumulation. Hence, it is necessary to clean panels periodically [6]. The dust settlement is caused by various factors that are reminded in Fig. 1 and the details of these factors can be found in literature [7]. As seen from the figure, type of dust and surrounding environment are very important factors. It can be assumed that in deserts, mainly sand and fine dust accumulate on the panel.

Dust accumulating factors include:

- Dust properties,
- PV panel composition,
- PV panel orientation,
- Surrounding environment,
- Wind velocity,
- Temperature and humidity.

Figure 1. Factors influencuing dust build-up on PV panels [7].

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B. *Prevailing Cleaning Techniques*

In the dusty areas where it rains, the PV panels get covered by a layer of mud that requires a thorough cleaning. Alternatively, for those areas where there is little rain, a dry cleaning process can be used which is cost-effective and self-sufficient as it requires no water supply. A research work on this topic [8] shows how dust accumulation affects the efficiency of PV panel as illustrated in Fig. 2. It can be observed that the efficiency drastically reduces as the dust starts accumulating on the panel. The efficiency is reduced by 60% with only 1 g of dust randomly spread on a PV panel of size 12 cm × 8 cm.

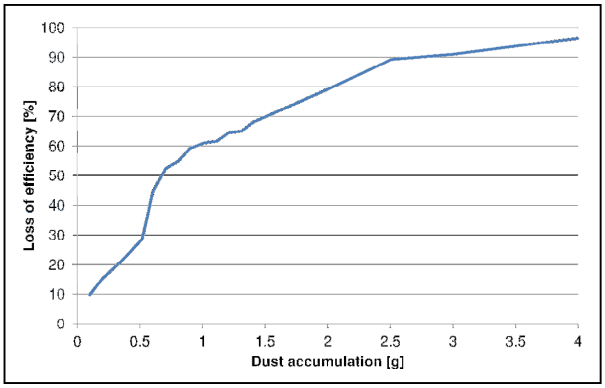

Figure 2. Reduction in efficacy of solar panel by dust accumulation, derived from [8].

Due to dust deposition, an average daily power loss can be up to 4.5%. While, long periods of drought can also induce it up to peaks at 20% [9]. The latter is the more prevalent is scenario for the desert areas in the Middle East region. Other studies suggest a decrease in the efficiency of the solar panels by 6% in a weeks' time [10].

Solar panel cleaning has always been present, but techniques and approaches are evolving. Relying only on rainfall to clean the solar panels is an unwise approach, as already settled dust after mixing with water blemishes the surface, and later on even hardens to further aggravate the soiling issue. A large workforce is usually required to clean the solar panels especially in large industrial installations, where the cleaning requirements are based on the environmental conditions. Most common methods of cleaning require an extensive amount of labor and water. Although research is being done to reduce the amount of water needed [11], it still does not completely eradicate the water need for cleaning, which stacks on the costs of maintenance of field installations.

The need for efficient dry cleaning techniques are under study by designers, which eliminate the use of water. Some experimentation has been carried out on using electrostatic charges to repel the dust [12] and consequently decreasing the dust settlement. The technique is applicable in theory, but requires very high voltages to work efficiently, which is practically difficult and is hazardous for working staff. Moreover, it only works on unbound loose debris and not to the one that clings on the surface.

Robotics, like in many fields, is also making its way to solar panel cleaning. Such robotic cleaning machines [13] without human intervention are efficient in not wasting water for cleaning purposes and can increase the efficiency of panel by 15%. Similarly, there are robotic wipers [14] that can wipe off dust without any need of water (only for low mass particles). Several designs of fully autonomous solar panel cleaning machines have been tested [15]. Their effectiveness and use of water varies from design to design. Robots though more autonomous and precise, generally have high initial cost. Most also make use of water to some extent, while displaying complicated structure and electronics.

There are also many commercially available cleaning systems [16]. Although partly automated, these systems still use quite an amount of water in their cleaning solution. On similar footsteps, several other robotic devices have been proposed to clean the PV panels [17]. These robotic cleaning devices make use of a scraper to wipe off the excess solution from the panel, which puts the panel under the risk of being scratched. Such scratches, even if they are of microscopic size, can scatter the entry of light on the PV panel and divert it away from the solar cells. This in turn can affect the output of the panel significantly. One the most recent popular commercial dry cleaning machine is "NOMADD" [18]. This commercial system is very efficient in the current market, yet the electronics it uses requires almost 150 W. Without energy storage capability, it is equivalent to the output of a full efficient common solar panel.

A lot of research has been carried out on the microstructure level to make hydrophobic and super-hydrophobic surfaces [19]. The surfaces minimize the settlement of dust and if any does accumulate, it is usually cleaned by least amounts of water, compared to other existing systems. This is particularly suitable for places where rain falls periodically. But in dry places with very little and infrequent rainfalls, the use of external water source (even in small amounts) adds up to the expenditure over a period of time, especially if there are large number of installations.

As seen above, various solar panel cleaning processes have been proposed. At small scale, hand wash is still used to clean the panels. On the other hand, for the larger scale, fire trucks are used to clean PVs with water spray from the hoses. This method for instance requires huge water supplies and a sizeable team force under supervision. These manual methods are very time consuming and increase the maintenance costs. Tucker pole system is also being used by a considerable number of consumers [20]. Though comparatively better than the aforementioned techniques, it still has the same issues as them.

II. Objectives

Currently no "feasible" dry cleaning method prevails that can clean the glass surface of panels. Nearly all systems in practice make use of the water, which is cumbersome and expensive when applied to large scale. The systems which do not use water are either not very efficient, have certain limitations, are expensive and/or have high power consumption.

In view of pros and cons of general designs discussed above, this research work reports an automatic, fully autonomous dry cleaning system for solar panels. It is equally attractive for small as well as large and unattended installations in desert and dry areas, where there is little rain throughout the year. Regions like Saudi Arabia, Qatar and other Middle East countries in general are typical examples. The proposed system is self-sufficient and works automatically at preset timings. Hence the authorities no longer will have to worry about the water supply in there. With its use, the solar cells will give their maximum (nominal) output.

Unlike other designs, this system has been designed to be simple, user-friendly, robust, light weight, precise and credible. Due to being fully autonomous, it eliminates the demand of large workforce. It has extremely low power consumption, because of the choice of components, which gives it an edge over prevalent machines. The cleaning mechanism gets rid of any type and mass of dust, as long as it is dry (or moist within certain limits to be dried off with its on-board compressor).

It can easily be installed on new solar panels or retrofitted with older ones and using its on-board controller it can be programmed according to users' needs. It is designed to work well for both flat and tilted solar panels. Also the design is simple yet robust. All these features make it a very viable machinery with hopes of a promising future.

III. Proposed System

The following breakdown explains in detail about the working mechanism, the mechanical design with its associated components and assumptions, on which the claims are made.

A. *Working Mechanism*

The proposed design consists of three separate cleaning mechanisms which are used one after the other in the process. The onboard processor can initiate itself automatically after the sunlight detectors (well covered so they only pick the rays from the sun) detect the beam from the sun. After the pre-set time (in-built timer of the on-board processor), if the humidity level is within acceptable range the cleaning process can commence.

In the 'first stage' compressed air is sprayed on the panel with the help of nozzles which removes sand and coarse dust accumulated on the panel. At the same time during this stage this air dries out any unlikely presence of humidity layer over the cover of panel at early hours of the day. A compact on-board D.C. compressor can be used which is readily available from market. The cleaning structure moves along the panel on the guiding rails which are installed beneath the panel. There are two limit switches (proximity type) installed on both ends which signal the completion of respective stage. The limit switches get their input from sensing specified points along the path. When it detects the first point that is placed few centimeters before the end of track, the machine slows down and similarly when it senses the second point it signals the controller about completion of the track. The controller in return signals the servo motors to stop. Along with the structure, the compressor is also shutdown. This marks the completion of one complete cycle.

After cleaning the panel thoroughly with air jet spray, the 'second stage' is initiated. In this stage, the machine starts moving backwards towards its initial starting point. For this phase, low density flexible polyurethane foam roller (or for that matter any commercial material that does not scratch the panels' glass and is easily available) is deployed. The roller cleans the dust and sand stuck to the surface of panel. The cleaning structure is guided back to the starting point by spinning foam roller on the surface of panel. The cleaning structure is now back to its initial position at the end of stage 2.

Following that, the 'third stage' starts. The compressor is started again and the air jet is sprayed again to blow the dust that has been rubbed off the surface by the polyurethane foam roller. Speed of servo motors guiding the structure during this stage is slightly faster than that in first stage. Motive for slow rpm (revolutions per minute) during the first stage is to make sure that the initial expected humidity layer, during early hours of the day is properly evaporated and fried out.

Finally the polywool synthetic duster (with static charge) is deployed in the 'fourth stage' which spins on the surface to remove very fine dust particles.

It is possible to install multiple panels in a row on guiding rails and the structure then can clean all of them in one cleaning phase. The complete process takes two complete runs, where the cleaning structure is guided all the way to the end of panels twice and taken back at the starting point. The procedure for marking the end of all stages is similar to first stage with the use of limit switches. And the speed by which the structure advances laterally is same for all stages except that of third stage that is slightly faster, see the third stage. The cleaning process is explained in the flow chart shown in Fig. 3.

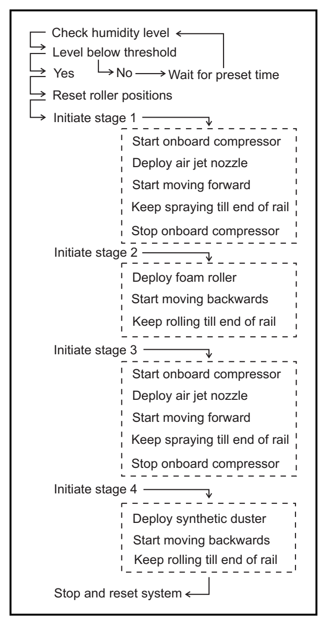

Figure 3. Flow chart of the four stage automatic dry cleaning system.

B. *Mechanical Design*

Mechanical design consists of (1) a cylinder with built in nozzles to jet spray compressed air, (2) a Polyurethane foam and (3) a synthetic duster roller (e.g. natural ostrich feathers), that is also attached to the structure. These three components are attached to three vertices of triangular plates, which hold these three components at their places. The triangular assembly is rotated by 60° clockwise or counterclockwise at the end of each stage with the help of a stepper motor. The foam roller and synthetic duster are spun with the help of servo motors attached to the triangular plates. The complete structure is guided on the metallic rails with the help of two pairs of metallic wheels which also provides direct current (D.C.) from the rails to the electronic devices. Metallic wheels are spun by a pair of servo motors (one on each side). The concept here with guiding rails is such that it consists of two separate parallel rails, like that of a train railway [21]. One of the rails is connected with a positive terminal of D.C. supply, while the other is connected with negative terminal, because all components are D.C. controlled. The power requirements of all electronic components on the structure are fulfilled through the panel itself and the whole system is controlled by an on-board microcontroller.

Since most of the components are electronics, the structure of the mechanism is made by a light weight and durable composite material. As composite materials are good insulators, it will then help reduce the electric noise in the used electronics. Moreover, the motors will be less loaded due to the light weight of the structure, which in turn decreases the overall power consumption of the system. The complete cleaning structure is shown in Fig. 4 and Fig. 5, after [22].

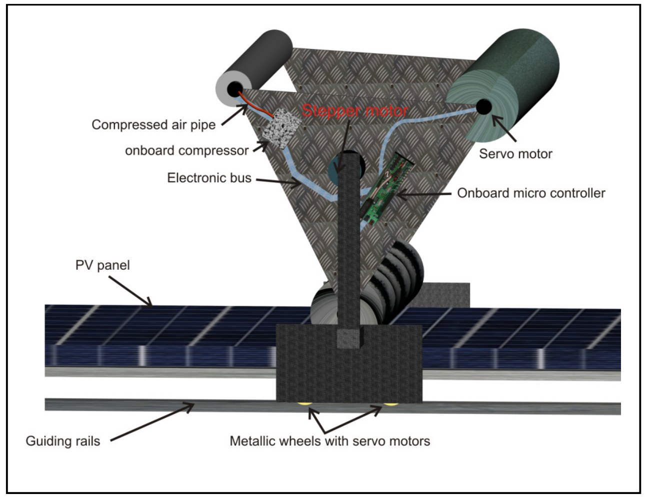

Figure 5. Side view of the assembly [22].

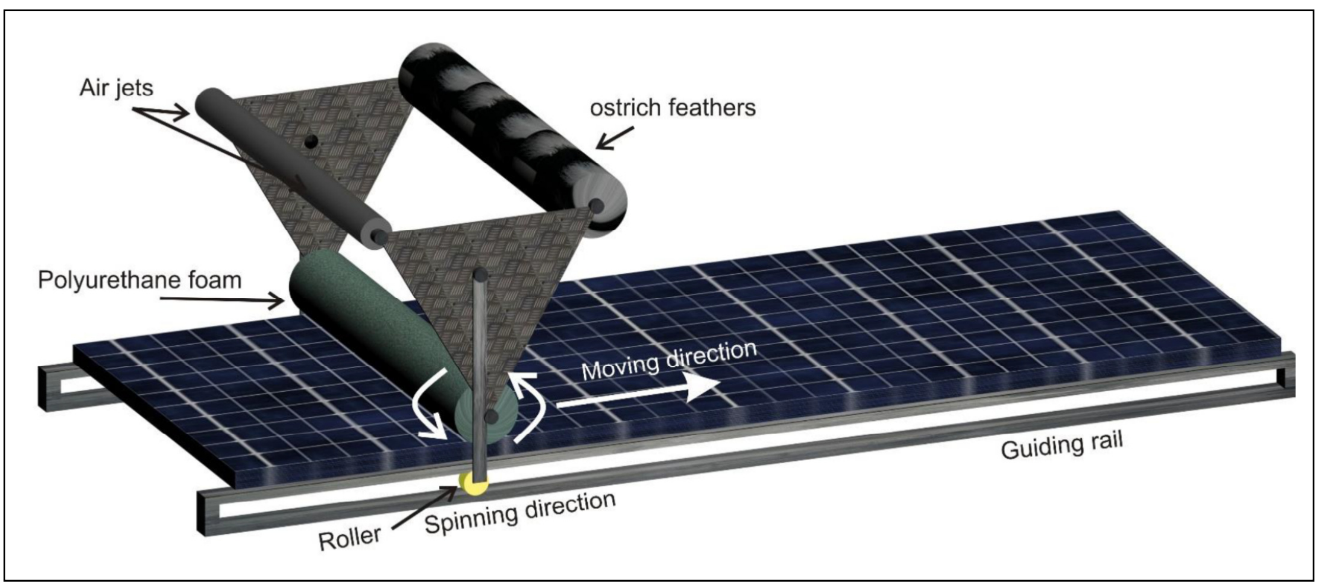

Figure 4. Overview of the dry cleaning assembly [22].

IV. COMPONENTS

The main components used in the design of this mechanism are shown in Table 1.

TABLE I. COMPONENTS FOR THE PROPOSED MECHANISM.

Components	Details	Quantity
1. Microcontroller	AVR Microcontroller (5V- Dc)	1
2. Humidity Sensors	DS18B20 (Max Detect Technologies) (5V- Dc)	1
3. Light Sensors	LED Light Sensors Circuit	1
4. Compressor	NEW Lifeline AAA (300 PSI) (12V- Dc)	1
5. Motors	a) Stepper Motor (12V- Dc)	1
	b) Servo Motor (12V- Dc)	4
6. H-Bridge	Circuit to control speed and direction of motors	5
7. Rollers	a) Polyurethane(for coarse sand) b) Synthetic duster(for fine dust)	1 each
8. Wheels	Rust Free Aluminum wheels	4
9. Limit Switch	Proximity Switch(12V- Dc)	1
10. Wiring	Low Voltage flexible wires	N.A.
11. Tubing	Flexible light weight tubes for compressed air	N.A.

A. Assumptions

Few assumptions are considered within the design concept for optimum working conditions of this machinery, as follows:

- The system is to be used in arid areas with little or no rainfall.
- In case of rare rainfall an alternate optimum system of cleaning should be used temporarily.
- Solar panels should be placed in a row and as much as possible in close proximity each from the other, so that a maximum number can be cleaned without interruption.
- Wheels on the rails are properly secured, so that they do not cause unwanted vibrations, and – at the same time – so they never break the contact with the tracks.
- No shading is provided by the structure on completion of the task (this is made sure by extending the rails few feet further from the end of the array).
- Both roller dusters are frequently cleaned, in order to avoid the scratching of the glass surface.
- Microcontroller and both sensors (i.e. humidity and light sensor) are in proper redundant configuration. (So, if one fails the redundant pair automatically takes its place, without stopping the system.)
- Wiring used is of high quality so it can counter any extra electric noise signal from a distant or nearby power source.
- Connections are properly tightened, so that there is no extra power consumption due to loose ends, which cause high resistance in circuit.

V. DISCUSSION

The foam used in the design is a polyurethane foam, it is widely and cheaply available in the market and is available in vast variety with rigid and flexible types. Low density flexible foam is best suited for the dry cleaning application.

The guiding rails are made longer on each side to ensure that the shadow of cleaning structure does not reduce the efficiency of the panel. The rails are extendable like railway tracks so a large number of panels can be attached in a line to use the cleaning structure in an optimum way.

The assembly can be programmed with different routines, like in case of humid weather the foam and synthetic duster roller will not be deployed and instead the whole panel is blown with jet air only. Similarly, based on different atmospheric conditions, various routines can be programmed. The foam and duster rollers are detachable for easy cleaning and replacement. The complete assembly can be realized using lightweight aluminum or composite materials to reduce the energy requirements.

Most importantly the dimensions of the structure are to be varied by the consumer's demand, because solar panels from different companies are available with different specific dimensions. The size also depends on power output of the panel. As the system is designed to be generic, no specific dimensions were reported in this proceedings paper.

VI. CONCLUSIONS AND RECOMMENDATIONS

An efficient and self-sufficient dry cleaning system has been proposed. The system consists of onboard compressor which sprays jet air on the panel. It is followed by a panel cleaning using spinning foam roller and synthetic duster roller. The system is controlled with an on-board microcontroller and very low electrical power requirements can be met directly using the panel itself. Since it involves no supply of liquids at all, it is very cost effective and efficient for the dry and hot environmental conditions as these of Saudi Arabia, Qatar and the Middle East countries. The system is easy to install, is fully autonomous and it also provides the flexibility to connect multiple panels in a row via a generic rail system, to fully exploit the optimum use of the cleaning system. The detachable rollers and readily available components, which make the maintenance easy and very cheap. All these features make this system user-friendly. It is not to be confined to large industrial plants, and can equally be used at the small scale for home and buildings PVs and solar panels.

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