Removal of Dust from the Solar Panel Surface using Mechanical Vibrator

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Abstract. Soiling and its effect on the performance of solar modules are generally of high concern for regions with a high deposition of dust and low frequency and less intensity of rainfall. The procedure of removing dust using traditional methods is capital and labour intensive. Additionally, most of the cleaning methods consumed power from the energy produced by the solar system. Therefore, the main objective of this study is to investigate the effect of vibration magnitude on the dust removal index of solar panel. In this work, wind energy was transformed into mechanical energy i.e. vibration. The mechanical vibrator attached to a panel produced harmonic excitation force to overcome the adhesive force between the dust particles and the surface of the solar panel. The generated vibration force has a linear relationship with the air velocity. This new designed and fabricated system was able to remove 3.5 gram of dust out of 5 grams on the panel with a vibration force of 3.128 N at a tilt angle of 15°. The new system has effectively proven that wind energy if being converted into vibration force can be used for dust removal from the solar panel surface.

1. Introduction
Solar energy as one of the sources of energy is environmentally friendly and does not in any way contribute to the global warming [1-2]. The amount of energy radiation from the sun in one second is more than what the people have used since the beginning of time [3]. Solar energy most often is called “alternative energy” when compared to coal and oil [4]. The solar radiation varies from one country to others [5]. Solar panels (PV) are ideally located in regions with high insolation levels such as desert, remote desert areas, and un-shaded areas [6]. The locations of the installation and environmental parameters (ambient temperature, wind, rainfall, and water scarcity) have a direct bearing on the performance of the solar panels [7-8]. The performance was usually affected by soiling and high cell temperatures. In nutshell, the performance is highly dependent on installation conditions [9].

Dust deposited on the solar panels resulted in energy losses [10]. Therefore, identifying a specific techniques or methods to remove dust becomes necessary. This will further ameliorate the performances of the solar system [11]. The technique or method to adopt depends on the site of the solar panels, environmental parameters, and mechanical parameters [12]. Several methods were employed to remove dust from PV system via the main concept; i.e. ability to overcome the adhesive force between dust particles and panel surface. The various methods usually fall as either natural, mechanical, or electrical technique [13]. Some of the techniques are combinations of mechanical and electrical like the one saw in the work of Mazumber, Zahn, Sharma, Zhang, Calle, Immer and Mardesich [14], which focused on
electrodynamics system to remove the dust. The technique doesn’t require water and manual labour and it continuously keeps the solar collectors clean [15]. In some situation with help of wind and presence of cover glass, the PV panels can be free from falling dust particles [16]. Also, Piliougine and his Nanophysics group at the Institute for Nano Energy developed a self-cleaning nano-hydrophobic material which will be used to coats the solar panel in order to maintain peak efficiency over long periods of time [17]. While [18] used piezoceramic actuators to remove the dust from solar panel. All these methods above consuming power and increasing the cost of electricity that produced. Therefore, this study produces a conversion of renewable energy (wind energy) into mechanical vibration for dust removal from PV surface without consuming power from the solar system and thereby improving its performance.

2. Experimental Procedure

2.1 Experimental rig set up
The experimental rig fabricated for converting wind energy into vibrating force, which used to remove dust from the solar panel surface. The experimental rig fabricated from the locally available materials and it has two major parts. The first part consists of a ducting box and mechanical vibrator (MV) with its rotating mechanism, while the second part comprises of solar panel and its frame structure with measurement instruments attached.

2.1.1 Air ducting box
A ducting box fabricated in order to obtain a streamline flow of air for the effective rotation of the impeller. The fabricated ducting box was shown in ‘figure 1’ and it comprises steel table fabricated using steel right angle (75×75×3mm) and a box fabricated from 12 mm thick plywood with a dimension of 1200×1010×900mm. A leather tarpaulin used to connect the wooden box and the variable speed fan. An opening on the box created for measurement of some environmental parameters, which can be open and close by sliding Perspex cover (850 x1300 x 4mm).

2.1.2 Mechanical vibrator and its mechanisms
This assembly comprises two parts, namely rotating parts and vibrating parts. The rotating parts in this experimental rig are impeller, shafts and gear assembly for a change of direction of rotation. Four (4) rotating impellers assembly was fixe to a steel frame with a total weight of 1646 g. The rotational movement of the impeller was transmuting with the aid of long shaft 1320 mm that shown in ‘figure 2’. An adjustable structure was also providing with four ball bearings to support the shaft. A bevel gear assembly, which was fabricating by using CNC machine, was also use to change the direction of shaft rotation and transmit the rotational movement down to the vibrating parts.

![Figure 1. Air ducting box](image_url)
Vibrating part of the rig contains a rotating shaft (stainless steel pipe SS304, 12, 0.7 mm for diameter & thickness respectively, and length of 1100 mm) used to transfer the rotational speed from rotating parts to vibrating parts. Rotating cams (initially, a steel type made using laser cutting machine from 2 mm plate with outer diameter of 300 mm, later, it was changed to plastic type which was improvised from plastic pulley, specifically to reduce noise, with 8 cams. It has an external diameter of 240 mm, Adjustment structure: The adjustment structure made from 2 mm thick steel plate. In all, three (3) plates used, one is having square cross-section with dimension of 400 × 400 mm and it is serving as base plate. Another two (2) H cross-section plate with dimension 400 × 100 mm placed on top of the former from both ends. This structure will serve as support for ball bearing to guide the rotating shaft. Lastly, another plate with dimension 400 × 200 mm serving as support for the moving parts assembly was at the top. All the plates arranged and joined together with aid of M10 stud, Moving parts consists of 310 mm long stainless steel pipe with 12 mm and 11.3 mm external and internal diameter respectively. This shaft welded to a 40 mm diameter circular disc with thickness of 2 mm. The disc side is encapsulated into a box and spring loaded to allow free return after it was being strike by the cam. The weight of whole assembly is 150 g and Nylon stinger (silicone type with diameter d = 12 mm) was used to translate the motion from moving parts to solar panel. This material used to minimize damage of the panel due to impact as shown in ‘figure 3’.

2.2 Solar Panel
Rectangular steel frame with dimensions of 690×1200 mm was fabricated using 25 mm square steel section to support the solar panel. The solar panel’s plain surface was representing by Perspex plate (1050×540×2 mm) which fixed to the aluminum frame (right angle section 25×25×1 mm) using adhesive. This arrangement was fixed to the rectangular frame with 6 supporting pads to prevent damage to the panel. The whole assembly has a total weight of 1500 grams.

3. Dust Removal Index (I)
Dust material, size and deposition density has a strong effect on loss of power output from PV system. Dust not only reduces the incoming radiation on the solar cell but also changes the dependence on the angle of incidence of such radiation. Dust removal index (I) which simply represents the ratio of the difference between the final index of dust after applying the effect of any parameter (I_f) and the index of dust before applying the effect of the same parameter (I_b) to the index of dust before applying the effect of the same parameter. The index of dust removal is just a number that represents the amount of dust removed from panel surface. So, the dust removal index can simply as follow:
The value of dust removal index is constrained to vary from zero to one. If the amount of dust removed increases, the value of dust removal index approaches to one.

4. Frequency of vibration and acceleration

Wind energy have the ability to rotate the mechanical vibrator, from the output rotating shaft with 8-rotating cams produced a reciprocating motion for the stinger that transfer the energy to panel surface. With the aid of tachometer, rotational velocity of output rotating shaft measured to calculate the frequency according to air speed. The measurement of the acceleration was done by with the aid of accelerometer (DeltaTron, type 4514-001, which fixed on the upper surface of the panel, with sensitivity 100.5), cDAQ-9171 and personal computer. With the aid of LabVIEW project build and DAQ assistance, acceleration data was acquired for a period of 10 sec. Maximum and minimum input range of 5 and -5 with 5 dB references. Then, the value of the acceleration can be obtained by 10 second continuous running for mechanical vibrator and choose the value of arithmetic mean as final value of acceleration. The surface vibration response is a characteristic, which is unique to each structure and depends on the structural properties. This vibration phenomenon can be modeled as a sinusoidal curve.

5. Testing the Mechanical Vibrator

After fabrication of the experimental rig, the MV tested by measuring the acceleration generated due to the vibration received by the solar panel, by fixing the accelerometer on the solar panel top surface. Data from all the measurements acquired with the project build in LabVIEW software 2013 as shown in ‘figure 4’. Various readings observed by varying the fan speed so that the air velocity inside the ducting will change. Indoor experimental conditions were noted which are; air velocity closed to zero, temperature equal to 22°C and relative humidity 50%.

6. Results and Discussion

Wind energy converted to mechanical energy, which intended to use for dust removal from the solar panel. This relationship is proportional to each other as depicted in Table 1. Furthermore, the ‘figure 5’ shows the linear relations between air velocities with frequency, acceleration. If the system assumed to have acted as a single degree-of-freedom system, the increase in the magnitude of acceleration will increase the vibration force subjected to the panel.

To test the effectiveness of utilizing acceleration on panel surface to remove dust, a 5 g of dust particles with a size of 75 ≤ Φ < 150 µm dusted on the solar panel surface. The solar panel was tilt to an angle of 15° and the experiment was run for ten seconds with the air velocity vary between 1 to 6 m/s as shown in table 1. The effect of air speed via MV has resulted changes in dust removal index. This relationship was depicted in ‘figure 6’, which shows that with the increase in air speed via mechanical vibrator, the dust removal index was increased. Additionally, the produced energy will cause dust particles to removed or change re-suspension position.
Figure 4. LabVIEW project for data acquisition.

The photographs of the solar panel before and after dust removal are shown in ‘figure 7’. From the photographs it means that the dust moves away from the region of high energy and migrates to region with low energy as also found in the work of [18].

Table 1. The performance Mechanical vibrator

| Run No. | Air Speed (m/sec) | Output Shaft RPM | Frequency (Hz) | Acceleration (m/s²) |
|---------|------------------|------------------|----------------|---------------------|
| 1       | 0.98             | 22               | 9.219          | 0.297               |
| 2       | 2.11             | 51               | 21.372         | 0.630               |
| 3       | 2.98             | 80               | 33.525         | 1.155               |
| 4       | 4.01             | 112              | 46.935         | 1.559               |
| 5       | 5.02             | 147              | 61.603         | 2.086               |
| 6       | 5.95             | 165              | 69.146         | 2.264               |
Figure 5. The performance of mechanical vibrator.

Figure 6. Effect of air speed on Dust Removal Index via mechanical vibrator.

Figure 7. Photography of dust removal from solar panel surface at 3.128 N; (A: cleaned surface, B: surface accumulated 5 grams of dust, C: dust remaining on the surface).
7. Conclusion
Wind energy have a significant effect on dust removal from solar panel surface that achieved by using via a mechanical vibrator without consuming any part of power produced also reducing manpower used for solar panels maintenance. Where wind is available on the solar panel site, this method produce a continuous operation of mechanical vibrator, where no chance for the dust to be accumulated hence reducing the operation cost. The dust removal index increased with increasing the excitation frequency at specific excitation amplitude. This increment is very logical because increasing the excitation force frequency leads to increasing the dynamic response at each point on the panel surface. The increasing of magnitude of vibration leads to the increase in the vibration inertial force, which was transform into kinetic energy for the dust particles and overcome the adhesion force.

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