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Performance-enhancing and improvement studies in a 210 kW Rooftop Solar photovoltaic Plant by Manual Cleaning

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Abstract

An installation of a solar power plant depends on many factors like geographical location, solar irradiation, latitude, longitude, orientation, tilt angle, etc. Further, dust is one of the important factors which affects electricity generation and profitability. Here, it was experimentally investigated that the dust effect on power generation and for which a 210-kW solar power plant was selected to perform the study. A 180-kW solar power plant was further selected for manual cleaning operation for easy movement and uniformity. The selected plant was divided into three sections of 60 kW, each connected with a 60kW inverter, where two sections were cleaned by water and wet cloth wrapped wiper respectively. A comparative study was made for obtained results and it was concluded that photovoltaic (PV) panel cleaned by water and wet cloth wrapped wiper generated 626.1 and 626.3 units respectively as compared to the PV panel which was not cleaned. Also, an economic analysis was performed to check the feasibility of a manual cleaning operation. It was observed that cleaned photovoltaic panels are highly cost economic.

Introduction:

Recently Government of India (GOI) has announced that country has achieved the milestone of 100 GW from renewable energy sources. Also, The Indian government wants to install 450 gigawatts of renewable energy capacity by 2030, with solar accounting for 280 GW (more than 60%). To ensure that the sun continues to shine over the country's sunrise industry for the next ten years, roughly 25 GW of solar energy capacity will need to be added each year (Sawhney, 2021). But a major problem with the solar power plant is the accumulation of dust and soiling on the surface of a photovoltaic panel. It reduces the efficiency of the photovoltaic panel. Generally, dust problem occurs in the desert area while soiling problem occurs in other locations. However, solar power plants performance also depends on the tilt angle, Surface material of photovoltaic panel, solar incidence angle, and weather patterns (humidity, rainfall, airborne particle concentration, wind, etc.). Accumulation of dust on the photovoltaic panel surface partially stops the transmission of solar radiation, which decreases photovoltaic panel conversion efficiency and the overall performance of the solar power plant (Guo *et al.*, 2015).

Dust effect on photovoltaic panel: Guo *et al.* (2015) conducted a study at Doha, Qatar, where photovoltaic panels power output per day lost was about 0.4-0.8%. This shows that there is about 12-24% photovoltaic panel power loss if the panel is not cleaned for a period of months. Lasfar *et al.* (2021) study show that the accumulation of dust reduces about 21.57% photovoltaic panel output power loss. They also concluded that proper cleaning and maintenance are required to avoid photovoltaic panel degradation by dust accumulation. Liu *et al.* (2021) experimentally analyzed the dust scaling characteristic, dust particle phase, appearance, and its formation and evolution. They also discussed the dust particles' phase composition on the photovoltaic panel which includes Fe_2O_3 , SiO_2 , Al_2O_3 , CaCO_3 , CaO . Al Shehri *et al.* (2017) estimated the efficiency of different cleaning brushes. The material of these brushes is silicon rubber foam, nylon, and cloth. They summarized that some brush materials had a markable impact on the solar panels but no significant impact was found on the photovoltaic panel surface which reduces panel efficiency. An allocation of the optimal brush is very desirable to clean the surface of the photovoltaic panel (Al Shehri *et al.*, 2017). Vaghani *et al.* (2019) developed an automated system for

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cleaning photovoltaic panels. They concluded that the cleaned photovoltaic panel gives more than 32% power output than an unclean photovoltaic panel. But this setup works for a single panel only. Deb & Brahmabhatt (2018) developed a brush-based mechanism for cleaning photovoltaic panels. This cleaning method is water-free. They have placed a mechanism on top of the panel surface and it moves parallel to the panel. The advantage of this mechanism is that they have used a frame for movement of mechanism in place of rails.

Syafiq *et al.* (2018) discussed several issues on self-cleaning devices for cleaning the surface of photovoltaic panels. The basic purpose of their discussion was to eliminate the external cleaning method. But the major problem with a self-cleaning technique is the implementation and cost of the system. They have compared the several recent publications on various self-cleaning techniques and then analyzed that there was a large number of research articles and approximately 9423 articles have already been published on robot cleaning mechanisms. Pickerel (2015) conducted a study on manual cleaning vs automatic cleaning and found that manual cleaning may be more precise with a higher level of quality while the automatic cleaning process is quickly processed and can be scheduled more frequently. Subsequently, there is very few research paper published on the Manual cleaning of photovoltaic panels. In this study, we are focussing on the manual cleaning process for the photovoltaic panel and comparing the results with the uncleaned panel.

The photovoltaic panel cleaning method was observed by Jiang *et al.* (2018). They calculated the wind cleaning procedure of dust particles deposited on the solar panel surface using the particle suspension theory. Finally, they have concluded that removal of dust particles from the photovoltaic panel surface naturally is not feasible. It requires some external force for cleaning the dust from the panel surface.

Accumulation of dust is not only a problem for a photovoltaic panel but also reduces the efficiency of the solar collector. The influence of dust on the absorber plate absorptivity and emissivity was examined experimentally by Li *et al.* (2018). They have used the dusty heat transfer model for calculating the efficiency of the solar collector and compare the results with the clean one under the same operating conditions and the results show that there is a maximum 19.23% efficiency drop on the 110th day of dust exposure. Elminir *et al.* (2006) have used 100 glass samples on different tilt angles and azimuth angles for checking out the dust effect on the solar collector cover. They have experimented for seven months and then concluded that accumulation of dust density varies from 15.84 g/m² (when glass sample tilt angle is 0°) to 4.48 g/m² (when glass sample tilt angle 90° and oriented by 135° deviation from

the north) with the reduction of transmittance about 52.54-12.38% respectively. Xu *et al.* (2017) proposed a model for the optimum tilt angle so that rate of dust accumulation on the surface of the photovoltaic panel should be minimized. Further, they validated the model with the experimental result, and they found that when the accumulation of dust density is around 4.71 g/m² then there is about 60% output voltage dropped.

Cleaning solutions for Photovoltaic Panel: various cleaning methods, ranging from manual to automatic cleaning systems, are mentioned in the literature study. Mechanical cleaning is the most basic form of photovoltaic panel cleaning, and it includes all types of manual labour and cleaning robot. Usually, custom-made robots are used for cleaning large-scale solar power plants. It requires only a few operators and less time for photovoltaic panel cleaning (Kegeleers, 2015). Except this, there are also small robots, used for cleaning photovoltaic panels but they require a sufficient amount of water and labour to do the same and this installation cost is significantly high. Another type of cleaning process is the sprinkler. This cleaning is suitable for dry sandy areas. But the basic problem with this system is that it requires water in huge quantities (Sharma *et al.*, 2018). Sometimes dust and dirt particles like bird droppings are not removed by the sprinkler method. Also, the sprinkler method is not suitable where monkeys are available. For this, there is a requirement of some external force like robotic arm and manual cleaning because it but robotic arm cleaning cost is high so this task should be done by manual cleaning. Another way to prevent photovoltaic panels from dust is anti-coating material. In this method, a layer of anti-dust coating material is applied to the surface of photovoltaic panels. Super-hydrophobic and super hydrophilicity films are generally used self-cleaning films while TiO₂ is the most commonly used coating film (Isaifan *et al.*, 2017). Arabatzis *et al.* (2018) experimentally examined the effect of coating on a coated and uncoated photovoltaic panel for several months on different climatic seasons. They have used photocatalytic, self-cleaning and anti-reflective glass coatings. Finally, they concluded that the dust removal ability of coated surfaces gives better results than the uncoated surface. In 2013, Asahi Kasei Corporation company developed a self-cleaning coating for the surface of photovoltaic panel and then experimentally compared the result of coating and the non-coating surface of photovoltaic panel and then concluded that coated surface photovoltaic panel has 2.5% daily energy soiling losses while the uncoated photovoltaic panel has 3.3% soiling losses (Piliougine *et al.*, 2013). Luque *et al.* (2018) performed the soiling effect on the bifacial photovoltaic panel and compared the result with the monofacial photovoltaic panel. The result clearly shows that bifacial photovoltaic panels have a 0.236% soiling rate per day while monofacial photovoltaic panels have a 0.301% per day soiling rate. Also,

they have observed that about a .0394% soiling rate was obtained from the rear side of the bifacial photovoltaic panel which is about 8.8 times lesser than the front side of the bifacial module. Kimber *et al.* (2006) proposed a model for predicting soiling losses and also determined that 5 mm of rainfall is quite sufficient for naturally cleaning photovoltaic panels and to restore their original generation capacity. Except for the rainy season, rain is scarce in India. If we depend on the rain for cleaning the photovoltaic panel this means that the performance of photovoltaic panels deteriorates over time. To overcome this plant owner, need to interpret human interference for cleaning the photovoltaic panel. The dust effect on the photovoltaic panel surface was experimentally analyzed by Moharram *et al.* (2013). They have performed the cleaning by using water and surfactants and they proposed that a combination of surfactants minimizes the water amount needed for cleaning photovoltaic panels. Urrejola *et al.* (2016) proposed a critical cleaning period of 45 days which is independent of energy prices and cleaning cost. The mostly manual cleaning process uses soap and commercial cleaning detergent for cleaning photovoltaic panels. But continuously use of soap and detergents destroy the photovoltaic glass and its aluminium frame. Therefore always check the product thoroughly which is used for cleaning photovoltaic panels (www.solarpanelcleaningsystems.co/manual-solar-panel-cleaning.html).

The objectives of this study are as follows:

- To check the dust effect on the energy generated by photovoltaic panels.
- To determine the most efficient method for photovoltaic panel cleaning.
- To check the feasibility of the Manual Cleaning method.

Methodology:

The 210-kW grid-connected rooftop solar power plant was selected for manual cleaning, which was located at the roof of Maharaja Agrasen Bhawan, Agra, India. A 210-kW solar plant was divided into four sections were 60 kW, 60 kW, 60 kW, 30 kW, and each section were further connected with a separate inverter. The cleaning operation was performed on 180 kW (60 kW + 60 kW + 60 kW) to maintain uniformity so that we can easily compare the results of cleaned panels and not cleaned panels. The experimental setup consisted of total 180+180+180= 540 photovoltaic panels manufactured by Vikram solar. Its model number and specification are listed in Table-1. The manual cleaning was performed for a month at the same time. The output of each 60-kW inverter was checked in terms of energy generation at the end of the day before and after the cleaning of photovoltaic panels. In this experiment, firstly, a set of 180 photovoltaic panels were cleaned by water jet which was connected to first 60 kW inverter then secondly, another set of 180 photovoltaic

panels were cleaned by combined wet cloth wrapped wiper which was connected to second 60 kW inverter and rest of 180 photovoltaic panels were not cleaned and connected to the third inverter as shown in Fig.-2. The cleaning system consisted of the following parts:

- 540 Photovoltaic panels were used in the study
- Water Tank
- Water pump of 1.0 HP and 1.5 HP.
- Discharge pipe for cleaning photovoltaic panel
- Cloth wrapped on the wiper.

In addition to this, manpower was also used for cleaning photovoltaic panels.

Figure-1: Solar Plant Capacity and its cleaning operation

Experimental protocol: the operation of cleaning i.e., cleaning by water and wet cloth wrapped wiper were carried out for 2.5 hours daily for 30 days. The water flow rate for cleaning a photovoltaic panel was 20 litre per minute. Water was sucked from the water tank with the help of a water pump then the spray of water through the discharge pipe was discharged on the surface of photovoltaic panels for cleaning them. First, the cleaning operation was performed by water then after completing water cleaning, the wet cloth wrapped wiper cleaning operation was started. This cycle was continued for the next 30 days to check the dust effect on the surface of photovoltaic panels. The manpower pressed a discharge pipe mouth by hand to make exit water more pressurized as shown in Fig.-2(a). Solar power plants are generally installed on the rooftop and monkeys always try to sit on the highest elevated rooftop and the selected site was the highest elevated rooftop in the nearby area. Therefore, the selected site had a lot of monkeys and sometimes they tried to break the photovoltaic panel. therefore, the sprinkler method was avoided for solar panel cleaning here and Maharaja Agrasen board members decided on manual cleaning for cleaning photovoltaic panels. A boy always held a stick for the safety of the monkey at the time of photovoltaic cleaning as shown in Fig.-2(a). The procedure of cleaning i.e., water cleaning and wet cloth wrapped wiper cleaning is shown in Fig.-2 (a) & (b) respectively.

Figure-2: Photovoltaic panel cleaning by (a) water and (b) Water and cloth wrapped wiper

Table-1: Specification of photovoltaic module used in our study

Name	Details
Model	ELDORA VSP.72.335.05
Rated Peak Power	335 W
Open circuit Voltage	46.5 V
Short Circuit Current	9.35 A
Rate Voltage	38.1 V
Rated Current	8.80 A
Fill Factor	77.12 %
Efficiency	17.26 %
Dimension	1956 x 992 x 36 mm
Measurement Uncertainty	±3 %

Result & Discussion

Cleaning impact on power output: the Cleaning operation was performed on a 180 kW solar power plant for 30 days continuously at the same time. On the first day of cleaning, power generated from water cleaned photovoltaic panels was 281.1 units which were higher than the not cleaned panel which generated 233.5 units while cleaning done by wet cloth wrapped wiper generated 271.3 units which were again higher than the not cleaned panel. The power generated by cleaned and not cleaned photovoltaic panels is shown in Fig.-3, showing cleaned panels generated more power compared to not cleaned panels.

Figure-3: Comparison of Power output generation by cleaned and not cleaned Photovoltaic panel during June & July month of year 2021

Figure-4: Energy generation by 180 kW cleaned and not cleaned Photovoltaic Panel

Figure-5: Average Cleaning data of different cleaning techniques.

Figures- 4 & 5 revealed that there is no apparent difference between water cleaning and wet cloth wrapped wiper cleaning while it was also observed that cleaned panels generated more energy compared to not cleaned photovoltaic panels. From Fig.-5 it was clearly observed that there was an average difference of 20 units per day between cleaned and not cleaned panels. Water cleaned PV panel and combined wet cloth wrapped wiper cleaned PV panel generated an excess of 626.1 units and 626.3 units respectively. Total 1252.4 units generated by 120 kW cleaned photovoltaic panels.

Economic analysis: overall cost of cleaning plays an important role in determining the practicality of cleaning techniques. During the cleaning, every cost was considered which was associated with cleaning like labour cost, water cost, electricity cost and other costs. Every cost factor plays an important role in making any cleaning device effective. In this paper, all of the above cost factors were considered in order to compare energy generation. Some assumptions were made in this study which is as follows:

- Water pumps and water storage tanks used in this study were also used for other purposes therefore their purchasing cost was not included.
 - There was a submersible pump used for water. Therefore, the per litre water rate was not considered in the analysis
- Except for this cost, the remaining cost which was considered are as follows:

Labour cost: a man was hired for cleaning a photovoltaic panel. He took 2.5 hours to clean 36 photovoltaic panels and he was paid Rs 120 per day for this work. Therefore, Total labor cost = $120 \times 30 = \text{Rs } 3600$ per month.

Electricity cost: 1 HP for 2.5 hours = $746 \times 2.5 = 1865$ Watt-hour = 1.865 units and 1.5 HP for 2.5 hours = $746 \times 1.5 \times 2.5 = 2797.5$ Watt-hour = 2.7975 units

Total units consumed in a day = $1.865 + 2.7975 = 4.6625$ units. If per unit cost is Rs 7 then capital used for cleaning a photovoltaic panel in a month = $4.6625 \times 7 \times 30 = \text{Rs } 979.125$

Water cost: water discharge flow rate per minute is 20 liters. Total water required in a day = $20 \times 60 \times 2.5 = 3,000$ liters.

Other costs: equipment cost consisted of two water pumps, discharge pipe and cloth. In this method, 2 water pumps were used, one was used for storing water in a water storage tank which had a power rating of 1.5 HP and another one was used to convert water into pressurized form to remove dust particles from the panel in a better way and its power rating was 1.0 HP. The rate of discharge pipe was Rs. 5 per meter and we purchased a 50-meter-long pipe whose life can be considered about 6 months and the quantity of cotton cloth used for a month was 2 Kg costing Rs. 17 per Kg. Discharge pipe cost = $5 \times 50 = \text{Rs } 250$

Cost of cloth = $2 \times 17 = \text{Rs } 34$

Total cost associated in manual cleaning = Labor cost + Electricity cost + Other cost = $(3600) + (979.125) + (250 + 34) = \text{Rs } 4863.125$

➤ Water cleaned PV panel and wet cloth wrapped wiper cleaned PV panel generated 626.1 units and 626.3 units respectively.

Total units generated by cleaned panel = $626.1 + 626.3 = 1252.4$ units.

As we consider per unit cost is Rs 7 then, Total Revenue generated by cleaning = $1252.4 \times 7 = \text{Rs } 8766.8$

Total Savings per month = Total revenue generated by cleaning – cost associated in cleaning

= 8766.8 – 4863.125 = Rs 3903.675

Total Savings per month = Rs 3903.675

It is obvious from the economic analysis of manual cleaning on 180 kW solar plant that the total cost associated with manual cleaning was Rs 4863.125 and revenue generated by the cleaned panel was Rs 8766.8. Therefore, Rs 3904 was saved by cleaning photovoltaic panels.

Conclusively, the cleaning operation was performed on PV panels for checking the dust deposition effect on the performance of power output of photovoltaic panels. The experiment was conducted on a 180-kW solar plant by dividing it into three sections. Also, an economic analysis was performed to check the feasibility of manual cleaning. It was concluded that:

- Dust accumulation on the surface of photovoltaic panels increased gradually and Performance was reduced.
- Photovoltaic panels which were cleaned by water generated 626.1 more units as compared to the not cleaned photovoltaic panel.
- Photovoltaic panels which were cleaned by wet cloth wrapped wiper generated 626.3 more units as compared to the not cleaned photovoltaic panels.
- There was almost 20 units difference between cleaned and not cleaned panels.
- Total 1252.4 units generated by cleaned photovoltaic panels.
- There was no significant difference between water cleaning and wet cloth wrapped wiper cleaning.
- Manual cleaning was economically feasible and a total amount of Rs 3904 was saved at the end of the month.

Finally, a significant difference in the power output and economic feasibility of cleaned and not cleaned photovoltaic panels was observed.

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