iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 10 Issue: XII Month of publication: December 2022

DOI: https://doi.org/10.22214/ijraset.2022.48379

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue XII Dec 2022- Available at www.ijraset.com

Solar Panel Automated Cleaning Using Water Re-Capture and Re-Circulation System

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Abstract: Sun photovoltaic (SPV) module energy output is closely correlated with solar accessible irradiance, spectral content, and other factors including environmental and climatic factors. It is normal for dust from the outside environment to collect on solar photovoltaic (PV) system panels. Physical factors like rain, dirt, dust, snow, etc. can lower a solar panel's overall efficiency. So maintaining a clean solar panel is crucial. The performance of solar panels can be negatively impacted by collected dust, according to research, however, the results were not measured. This study's goal was to investigate how dust build-up affects the efficiency of solar PV panels. To test the electrical output and efficiency of solar panels, experiments were carried out utilizing dust particles on solar panels with a constant-power light source. The efficiency and resultant electrical power generated revealed it. According to the study, the effectiveness of a photovoltaic solar panel might be reduced by up to 30% by dust build-up on its surface. Therefore, it is crucial to clean the solar panel of any dust. We may clean the solar panels and improve their effectiveness by using the wiper on the water pump's base.

I. INTRODUCTION

When non-renewable energy sources are running out, solar energy is seen as the primary answer to the world's energy needs [1]. Solar-based energy systems are practical since they are simple to install, and maintain, and have a longer lifespan. In contrast to fossil fuels, the sun has more than enough energy to supply the entire world's energy demands, and it won't run out anytime soon. The sole constraint on solar energy as a renewable resource is our capacity to efficiently and economically convert it to electricity. Solar energy may be utilized in a variety of ways to power your house or place of business and is undoubtedly the cleanest and most dependable renewable energy source currently available. Solar photovoltaic (PV) panels work by harnessing photons from the sun to excite electrons in silicon cells, which in turn creates energy.

Your house or place of business may then be supplied with green energy using this electricity. When you generate power with solar panels, no greenhouse gas emissions are put into the environment. Solar energy is a key energy source in the transition to the creation of clean energy since the sun produces more energy than humans could ever require. Solar cells are arranged in a matrix-like arrangement and combined to form solar panels. After solar panels are deployed, maintenance expenses are quite minimal when compared to those associated with conventional power-producing methods. Solar energy doesn't require fuel; therefore, it can generate vast amounts of electricity without the risk and price of ensuring a fuel supply.

Coal, gas, and oil are no longer viable options for energy production due to the cost of inequity, depletion, and the natural impacts of climate change and carbon offset fossil fuels. Solar energy has also been rising internationally due to its advantages in both technical and economic aspects as a substitute for sustainable, renewable, and simple-to-use energy sources given the increasing need for energy on Earth. Additionally, it saves the economies of the nations that rely on power the most. Solar photovoltaic systems, which use solar light directly, and heat-supporting systems are the two main methods by that solar energy may be converted back into solar energy. Photovoltaic panels, however, are often used to produce solar energy [2]. One of the most crucial elements in obtaining the available energy from the sun is solar panel efficiency, which depends on the temperature and radiation of the sun.

With over 390 GWp currently built globally, the utilization of solar photovoltaic (PV) systems for energy production is growing. Solar-heavy nations including those in Northern Africa, the Middle East, Australia, China, India, the United States of America, and Latin America, are rapidly expanding PV technology [3]. Grid parity has been reached in many nations with abundant solar resources as a result of the widespread availability of solar resources and improvements in conversion technology [3,4]. Through several advancements in system balance, cell efficiency, and general control and administration, the overall system efficiency of solar photovoltaics (PV) has grown [5]. The impact of external circumstances, such as the deposition of foreign particles on module surfaces of a solar PV array, is one of the problems that fall outside the purview of such improvements, albeit [6].

The incident radiation, which varies with location, climate, and installation, affects how much electricity solar panels produce. Despite the high radiation levels in equatorial locations, particularly in desert regions, they may have considerable energy losses from dust and other causes. It has been determined how dust is distributed around the planet North Africa and the Middle East show strong evidence of dust collection [7]. The Middle East is a good location for solar energy collection, but there is a lot of sand and dust there [8]. The consequences of dust build-up have been well researched, and [9] discusses the cleaning cycle and ways for removing dust based on the PM10 world map.

Turkey's position results in a lot of dust, which has an impact on how well solar power plants produce electricity. Such issues were seen in research conducted in Iraq [10], where the efficacy of solar panels in solar power plants (SPP) was dramatically decreased by dust buildup on their surface. Since it is advised to wipe the panel surfaces with an automated cleaning system once a month [9], Turkey frequently uses the European aqueous panel cleaning system. Due to environmental and climatic conditions, the width and shape of dust particles in the Middle East vary from place to region [11]; some locations have dry dust, while others have tiny, sticky particles that reduce power [12].

Cleaning solar panels after they have been installed on the roof of a home, business, or store is highly challenging because dust particles prevent solar energy from entering the panel effectively, reducing the panel's conversion efficiency and lengthening the time it takes for batteries to charge. Due to the aforementioned impact, solar panels must be properly maintained and cleaned to continue functioning effectively. Due to the usual installation and mechanisms, washing solar panels with traditional techniques like vacuuming or hand wiping/cleaning is difficult and, in some situations, impractical. Even when the panel is sufficiently exposed to the sun, the layer of collected dust prevents solar energy from entering the PV panel receiver correctly, leading to an ineffective conversion. In this case, dust particles can be removed using an electrostatic precipitator (ESP) made of fixed electrodes.

The PV panel is fitted with a weight sensor, and the ESP is installed on its sides. This sensor continuously detects dust thickness in terms of changes in the panel's weight. The microcontroller will notify the ESP to start separating the dust and gather it at a positively charged electrode for ultimate disposal if the weight of the dust exceeds the specified value. In the ESP, the second electrode is charged to a high positive voltage to repel the negatively charged dust particles while the first electrode is charged to a very high negative voltage to attract the negatively charged dust particles as they migrate to the area.

With the need for energy rising and the use of fossil fuels contributing to climate change, interest in renewable energy sources is rising [13]. One such source is the direct utilization of solar radiation using photovoltaic cells or solar panels. However, factors like location, climate, and weather conditions might cause them to lose some of their effectiveness. Other factors include the build-up of dust on panels, shadowing from nearby structures like trees and buildings, seasonal variations, the effects of weather such as snow, rain, and clouds, and animal migration patterns close to the production site [14,15].

These elements contaminate panels, which in turn impacts the output voltage of the panel and, consequently, the generation of energy [16]. At the project design stage, the effects of a number of these variables, including panel deterioration, location, and yearly average sunshine, may be evaluated. Solar power plants (SPP) nonetheless require data monitoring [17]. This is especially crucial in regions (such as North Africa and the Middle East) where there are heavy dust accumulations since they will result in a considerable waste of energy [18,19]. For instance, a 4 g/m2 dust deposition might cause a 40% reduction in electricity production [20]. Research has focused on the impact of dust and methods to lessen dirt and grime on solar panels during the past ten years. One research [21] with an update for 2012 concentrated on the years 2013 to 2015. The study was modified and expanded to include the years 2016 to 2017 [22].

II. LITERATURE REVIEW

Due to the accumulation of dust, sand, and things that resemble algae on solar panels, it has been shown that their output can drop by up to 85% [23]. As a result, it is necessary to regularly clean them to maintain production levels. Investigations have been done on how various forms of surface dirt affect the outcome [15]. There are two types of contamination-related masking: soft shading from air pollution and harsh shading from other causes [24]. The type of dust and its physical characteristics, such as particle size, affect light transmittance, which alters how well a photovoltaic (PV) panel performs [25]. Particles of all types and sizes make up dust [26]. Due to ionic charges, some dust particles can alter adherence to solid surfaces and create particle clustering in the dust layer. As a result, it may take much more time and energy to clean surfaces of dust particles [27]. Solar energy utilization and conversion is a challenging photochemical process that calls for the optimization of several variables to achieve an acceptable degree of efficiency. Surface properties and cleanliness directly affect how well the process works. Cleaning and dust avoidance for solar photovoltaic (SPV) systems are two key maintenance elements needed for increased and longer production.

There are a few industrial-grade cleaning methods that might be applied in real-time by robots, but the effectiveness of these methods depends on the geographical topography, the application area, the cost of the equipment, its sophistication, and its performance. Other factors may cause sunlight to be scattered off the SPV surface, leading to limited absorption, such as temperature rise, overheating [28–30], and physical obstructions. Robotic methods have become a desirable alternative for cleaning the SPV surface in terms of price, the convenience of use, performance rate, water usage, etc.

The cleaning processes have several advantages and difficulties. By regulating electrostatic repulsion (ER), all strategies are primarily focused on minimizing the bond of adhesion between dust particles and the panel [32–33]. This tactic aims to incorporate products or system designs that employ continuous, non-contact cleaning methods that need little to no labor. Pollen, grit, filth, dirt, and even bird poop will eventually cover solar panels. When solar panels are filthy, their production typically drops by 10-15%. Solar energy has a far lower environmental effect than other forms of power generation since it is a renewable source of CO2-free energy.

The impact is mostly connected to the supply and manufacture of the unique metals and materials needed to make solar panels. Solar photovoltaic (SPV) technology can only provide electricity that is cost-effective if the PV modules can work consistently for 25 to 30 years in the field. The high initial investment cost and the comparably poor conversion efficiency of PV cells as a result of the heating of PV panels are the main issues preventing the broad adoption of PV applications. The temperature of the module is constantly greater than the surrounding air. The module's higher temperature is caused by the glass cover that covers it and traps infrared radiation.

The majority of solar panels have lifespan ratings of 30 years or beyond. Solar panels should be cleaned at least twice a year, preferably after the wet season has ended, even in arid areas. Several techniques can be employed to thoroughly clean severely polluted things (repaired car parts, watch mechanisms, clothing cleaning without a washer, etc.). A little amount of liquid that has been subjected to ultrasonic cavitations has a cleansing effect. It takes a fair amount of energy to produce cavitations. It's not always essential to produce volumetric cavitations. It is sufficient to produce cavitations in a small layer of liquid applied to the surface for flat surface cleaning. Numerous scientific studies [34, 35] discussed cavitations in liquid volume. Finding literature concerning the formation of cavitations in thin liquid layers is challenging. Authors have already discussed and conducted various studies in this area [36].

Modifying the dust layer to reduce surface adherence and aid in cleaning are examples of passive strategies used to clean solar panels [37]. Spraying compressed air on the panels will clear dust, although this method may cause particles to linger in the air and then settle again [9]. The amount of dust that accumulates is strongly influenced by the angle of inclination of the PV modules, and as this angle increases from horizontal (0 degrees) to vertical (90 degrees), the amount of dust that accumulates decreases [37]. Due to gravity, dust gathers more readily when positioned horizontally. The majority of the dust that gathers on a vertical surface will be made up of tiny particles [37]. The best output power is achieved from daily cleaning when a panel tilted at 30 degrees is cleaned daily, weekly, and monthly [38].

Additionally, altering the angle of panels in the early morning or late at night might lessen dust formation, although this operation is time-consuming [9]. The voltage produced by the panel is also impacted by the incidence angle. By protecting the surface from contamination and limiting the quantity of light reflected from the panel glass, dust impacts may be mitigated and solar panel efficiency can be improved. The deposition of dust on PV modules has been demonstrated to rise as wind speed increases, but when the height of the modules above the ground increases, the accumulation of dust at greater wind speeds are reduced [39]. The requirement for structural support, upkeep, and protection against strong winds restrict the height at which solar panels may be installed [16]. The amount of wind, gravity, rain, the time of day, and the angle of the solar panel are only a few of the variables that affect dust collection and clearance [19].

III. METHODOLOGY

As briefly mentioned above, the systems created and put into place were intended to act as test beds where various cleaning techniques could be tried out, their effectiveness assessed, and their comparisons made. The latter is achieved by keeping an eye out for changes in the energy yield as outputs from the cleaned solar PV arrays, whether positive or negative. There are three main components integrated to facilitate cleaning and monitoring, in addition to the infrastructure (carport) on which the deployed pilot plant was built. Getting the essential information, such as the connections between the PV and the plant, the cost and current cleaning schedule (if any), the infrastructure diagrams for the PV plant, etc., is the first step.

The PV's performance is then evaluated to determine the effectiveness of the present cleaning method. The first step is evaluating the quality, method, speed, and cost-effectiveness of the present cleaning plan. This will act as a baseline for the study on cleaning technique selection. The second phase compares various PV cleaning techniques put forth by academics, scientists, and other businesses. To determine the best cleaning strategy, a comparison is done using assessment criteria. The proposed solution will next be compared to the other methods, which were covered in stage 2, after being economically assessed to meet the cleaning cost per PV cost criterion. A second performance review will be conducted once the suggested strategy has been used to gauge its quality.

A. *Physical Inspection*

Periodically check the solar panels for dirt and debris and make sure all connections are tight (frequency will depend on location or manufacturer's standards). In general, dusty locations need to be inspected more often.

B. *Use a Monitoring Service*

Utilizing monitoring devices and services is another approach to guarantee that your PV system is operating to its full solar potential. You may keep track of how your system is doing for a monthly subscription or a set upfront payment.

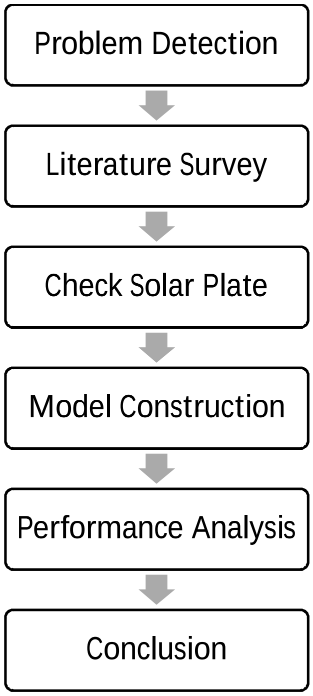

Figure 1 Process

Each month, the system is anticipated to produce a particular quantity of power. A solar monitoring system may conduct diagnostic algorithms and inform you if your system is offline or not functioning as it should. Solar monitoring systems may also serve as instructional tools by telling you how much electricity, CO_2, and money you've saved over time. You may be able to view your information from the web, a wall-mounted device, or even your phone or another mobile device, depending on the monitoring systems in place. Whether they are paid for upfront or every month, monitoring systems are often an added cost. Although not necessary, they do make system performance and problems simpler to notice.

C. *Method of Cleaning Solar Cell*

1) *Manual Cleaning:* Using a mop or other wipers with adequate support structures, as indicated in Figure 2, a human operator is required to clean manually. This method involves clearing PV of accumulated dust and debris using a method similar to washing building windows with soft-bristled brushes to prevent harming the clean surface, as seen in Figure 2. There is a chance that these brushes will receive a direct and ongoing supply of washing water. This is preferable to cleaning PV with compressed water or rainfall.

However, as the movement of the brushes and their pressure on the painting's surface cannot be guaranteed to be under equal pressure along the PV region, direct contact with the PV's surface might potentially result in slurry. Due to the need for expert personnel, this procedure is more expensive than the ones mentioned above. The operator evaluates the cleanliness of the surface using a visual technique until it is satisfactory or until all traces of dust have been eliminated. As seen in Fig. 2, this technique takes longer and requires more labor from the user. Using this technique, small solar plants may be cleaned. But with this kind of cleaning technique, there is more water waste. Additionally likely is solar panel damage.

Figure 2 Manual cleaning of Solar Panel

Solar power plants consist of several panels put at a height of 12 to 20 feet or more above the ground, making the operation exceedingly time-consuming and difficult. The needed amount of time and the panel's and person's safety are in jeopardy. Manually cleaning panels requires the use of fluids like cleansers or gels, which act on the panel and lessen the surface transparency if cleaning is not done correctly. The PV panels are highly susceptible to physical damage, which cannot be prevented.

Al Shehri et al. (2017) performed an empirical investigation to ascertain the most effective usage of silicone rubber foam brushes as well as nylon, fabric, and brushes made of cloth to increase PV efficiency. The study's findings demonstrated that some of the materials utilized had favorable effects on PV efficiency [45]. The scientists asserted that utilizing these materials had no obvious and long-lasting detrimental effects on PV efficiency. Another study from 2016 by Al Shehri et al. found that using a high-quality brush is essential for getting good cleaning results without harming the PV surface [44].

2) *Cleaning Robot:* They produce solar panel cleaning robots in the same way they produce robots for cleaning swimming pools. In addition to the usage of high-pressure water filters with a water storage tank, it is occasionally essential to run brushes or scanners using mechanical equipment like engines or robots [46]. According to Mani and Pillai (2010), periodic cleaning of the PV is needed once a week during dry days, and this cleaning is increased to one per day when significant rates of dust collection are present [47]. Figure 3 illustrates the application of automation in mechanical cleaning. The system is managed by a precise controller with the assistance of sensors.

Figure 3 Solar Panel Cleaning Robot

If water cleaning is not feasible, this procedure might be thought of as being quite helpful. Although water can be used, direct brush contact with the weight of the mechanical devices can cause the surfaces of the cleaned panels to be scraped. The mechanical components employed in this process require maintenance, and it uses more power than any of the other cleaning techniques previously discussed. For significant dust deposition, the complete efficiency of this approach has not yet been established. This technique is quite effective and can reduce the amount of time needed to clean solar panels. It can also do tasks depending on predetermined parameters and even future weather reports. Robots are more than capable of cleaning a sizable solar facility. This approach needs substantial initial investment and ongoing robot maintenance. Also needed to run such robots is specialized staff with the necessary expertise.

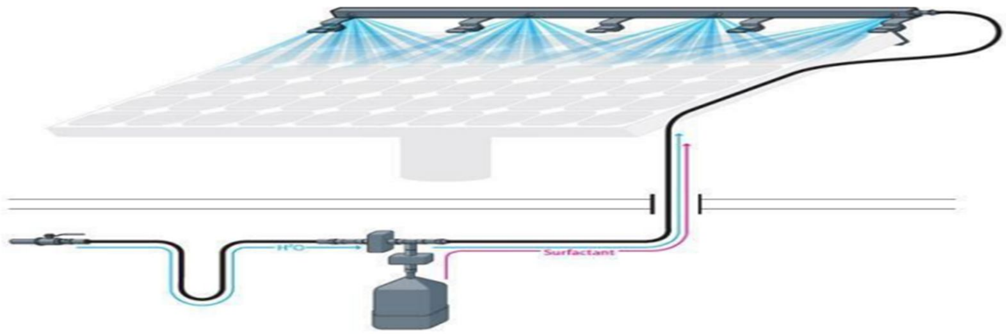

Figure 4 Automated Self-Cleaning System

You might wish to think about self-cleaning panels for big commercial or public utility installations, especially those in isolated and arid places. Compared to cleaning methods based on robots, this approach is less/not as versatile in terms of mobility. However, compared to robotic cleaning, this has a somewhat lower starting cost and less expensive upkeep as shown in Figure 4. At a significantly lower cost, this technique is quite effective at removing dust and other particles from the solar panel.

IV. WORKING APPROACH

This technique, as seen in Fig., involves channeling a hose from the stream of water to the PV surface to remove the collected dust particles. To attain the requisite high pressure, this approach needs a lot of water and the use of pumps. Modern techniques can combine pressurized water with a specific cleaning solution to help remove dust more efficiently. The use of water for PV cooling is similar to that used to clean the panels when it rains. The difficulty of utilizing water in locations with limited supplies is a drawback of this technology. Along with the potential for chemical build-up on the PV edges, it also results in significant water loss. In addition to the possibility of a thermal shock of hot PV when water falls, which will undoubtedly be cooler than the surface of the plate, using high-pressure water pumps means using some of the PV-generated power, which reduces efficiency. There is also the risk of water pipes becoming blocked or breaking. PV cleaning typically takes place at midday after dusk, and because the PV is left wet to dry, there is a chance that additional dust particles may stick to the surface, especially because the air stagnation and the main period of dust particle deposition start after nightfall. Heat shocks are often prevented by utilizing water that is heated by the sun to a temperature that is close to that of the PV. It was discovered that the best cleaning technique for PV is water [40]. When employed in places where there is a water shortage, this technology can be highly expensive in PV stations with large spaces.

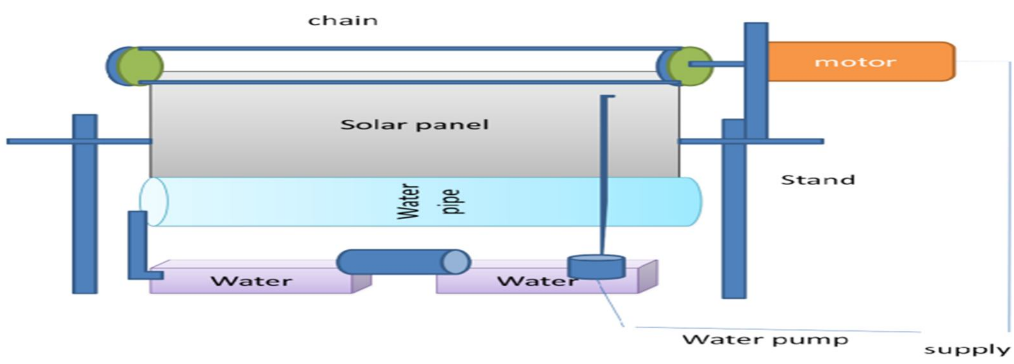

Figure 5 Water Capture System on Automated Self-Cleaning System

The total efficiency of this technology is greatly increased and water usage is decreased by adding a water recapture and filter system. In this experiment, the solar plate was cleaned automatically by a wiper. The sensors in this system begin to function when dust or other particles are deposited on the solar panel. When a sensor detects particles, it gives data to the wipers, who then begin to thoroughly clean the plate. We also manually operated this system. Here, water is poured on the panels by a water pump forcibly to clean them. Here, the sedimentation process cleans the water, which is subsequently used in another water tank. The block diagram shows how the components are organized. The pump and motor are supplied with power.

The transformer is used to scale down the primary voltage of a step-down transformer from 230 volts AC to 12 volts AC. After that, a rectifier circuit converts it to 12V DC for the DC motor. The solar panel's conduit has tiny holes from which water is dripping. Following this procedure, the wiper begins cleaning the solar cell. Water is gathered using an external hose that is fixed to the solar cell's end. The storage tank is connected to this pipe. In the exterior water tank, dusty water accumulated as shown in Figure 5. When the tank is filled with water, water is cleaned by the sedimentation process and when the valve is opened, the water is once more stored in the main tank. This tank is also linked to the main tank. This technique is always being developed. A drain valve is used to remove water from a storage tank when it starts to accumulate dust, and clean water is then added to the main tank.

A cleaning technique that requires less water and energy to clean PV was proposed, and an experimental comparison of the effects of using water alone vs water coupled with a surfactant was made. Uncompressed water is used in the system. According to the study's findings, using uncompressed water caused the PV efficiency to drop by 50% after 45 days. The efficiency remained unchanged for the same system, for the same period, and under the same weather circumstances in the second example (the usage of water combination with cationic and ionic surfactants in cleaning). The researchers concluded that the conditions in Egypt are adequate for using the suggested water system with a mix of surfactants. Elnozahy et al. (2015) conducted an empirical study on the usage of water for cleaning and cooling the PV in a hot, dry environment and compared the effectiveness of this unit to one that was not provided with either [41].

The temperature of the PV rear side served as the basis for the researchers' automated water control system. The water spray reduced the PV's temperature to almost that of the surrounding air, and it also regulates how long it sprays to clean the PV surface. The surface temperature of the headboard and the back surface were both reduced by 45.5 and 39 percent, respectively, according to the experimental study's findings. During the research period, the cleaned and cooled panel's efficiency was 11.7 percent as opposed to the unclean and uncooled panel's efficiency of 9 percent. However, Chaichan et al. (2015) suggested treating the vehicle exhaust stack on PV with alcohol or a sodium-based surfactant. The researchers did not advise using non-ionized distilled water in these situations since it resulted in a 14 percent drop in PV-producing power for six consecutive weeks of exposure.

Jiang et al. (2016) created a model to predict the frequency of dust cleaning needed for PVs in arid environments. The speed of dust deposition and the correlation between the accumulation of dust density and the decline in PV performance served as the foundation for the researchers' model and actual measurement results. The research's findings indicated that when the amount of accumulated particles is around 100 mg/m3, and the power produced by the PV is degrading by about 5 percent, the PV of the study area has to be cleaned every 20 days [43].

V. CONCLUSION

The buildup of dust on the PV's surface has a significant impact on its electrical output. The geographical source of the accumulated dust determines the characteristics of the dust (type, size, shape, meteorology, etc.), which have the effect of not only reducing the amount of solar radiation that reaches the PV surface but also adhering to the surface, scratching it, causing corrosion, and shortening the life of the PV. By protecting the surface from contamination and limiting the quantity of light reflected from the panel glass, dust impacts may be mitigated and solar panel efficiency can be improved. According to the study, the effectiveness of a photovoltaic solar panel might be reduced by up to 30% by dust build-up on its surface. Therefore, it is crucial to clean the solar panel of any dust. We may clean the solar panels and improve their effectiveness by using the wiper on the water pump's base.

The deposition of dust on PV modules has been demonstrated to rise as wind speed increases, but when the height of the modules above the ground increases, the accumulation of dust at greater wind speeds is reduced Hence the significance of routinely cleansing these cells. Numerous researchers have looked at various cleaning and dust-mitigation strategies for PV. The issue of dust, its detrimental consequences, the state of cleaning techniques, difficulties, and expectations are all covered in the current article. The essay also offered researchers, engineers, and designers who were interested in this topic a thorough critical analysis of the dust problem and cleaning techniques.

The technical and financial merits of various cleaning techniques have been examined, debated, and contrasted. It has been discovered that the best cleaning techniques for each PV system rely on a variety of factors, including the system's size, design, location, access to water, and the types of dust it generates. Furthermore, some studies recommended a week between cleanings, while others recommended a month.

It has been discovered that there is no industry standard and that each situation depends on the PV system and local weather conditions. Numerous factors must be taken into consideration when choosing a cleaning technique, and the methodology currently in use has been shown in numerous tests to be ineffective. Based on cleaning frequency, cleaning strategy, and cost efficiency, a new cleaning approach was suggested. The new process will ensure that the best option is chosen in terms of technical and financial factors.

Heat shocks are often prevented by utilizing water that is heated by the sun to a temperature that is close to that of the PV. The following are the key results reached by this study project: The efficiency of solar panels might drop by 5 to 6 percent due to dust in just one week. There is a potential benefit of 150,000 NIS per year if panels are cleaned at least once per week. For more conclusive findings, additional study is required. The surface temperature of the headboard and the back surface were both reduced by 45.5 and 39 percent, respectively, according to the experimental study's findings. During the research period, the cleaned and cooled panel's efficiency was 11.7 percent as opposed to the unclean and uncooled panel's efficiency of 9 percent. The efficiency and resultant electrical power generated revealed it.

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