An Automated Retrofittable Street Light Solar Panel Cleaner

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Abstract. Solar energy is the most abundant and constant source available, across the surface of the Earth. A Solar panel or PV module is an essential component that is being used for the conversion of sunlight directly into direct current (DC) electricity. A major drawback of solar panel system is its extremely low efficiency of conversion of light energy to electrical energy and its further drop when there is laxity of care and maintenance of the panels. This project is focused on designing and developing a sensor-based street light solar panel cleaning mechanism which can be added as a retrofit and requires minimal human interference to operate. The water-based system with a pair of wiper blades is mounted on a pair of lead screws which are rotated by a pair of servo motors which are powered by current drawn directly from the panel. The water is supplied by a tank fixed on the underside of the panel and a catchment dugout at the bottom end of the panel allows the run-off water to get collected after the cleaning operation. The system operates based on the information collected from a timer, voltage sensor, current sensor, and humidity sensor. The operational frequency of the system is based on the information provided by the sensor and varies based on the accumulation rate of particulate matter on the panel and the reduction in transmittance because of the same.

KEYWORDS: Solar Panel Cleaner, Retrofit, Minimal human interference, Sensor-Based, Water-based.

1. Introduction
In the 21st century, with depletion of conventional fuels and increasing concern for global warming, turning towards renewable energy is the only way to a long-term solution. Amongst the various
renewable sources available, solar energy is the most abundant and constant source available, with a uniform and strong intensity of solar radiation incident on the surface of the Earth. To make effective use of this resource and to replace conventional fuels, the solar panels are implemented to convert the heat and light energy to electrical energy. A significant drawback of this system is the extremely low efficiency of existing solar panels, which is around 15-21%. Adding to the low conversion rates is the lack of care and maintenance of the panels exposed to the brunt of the atmospheric conditions, which over time results in a further drop in the output produced. The lack of maintenance is widespread and existing solutions require human interference which is not feasible periodically. This issue of human interference is further aggravated in the case of streetlight mounted solar panels, since these are generally installed by the municipality and are located at the top of streetlights, which makes accessibility difficult. Thus, these solar panels, not maintained and over time, become quite redundant, not completely serving their primary purpose of powering the streetlights.

During the period of the lack of maintenance, various pollutants get accumulated on the panel. In accordance with the research conducted by [1], most of the deposition appears to be dominated by dust and pollution that occurs over several days to roughly one week. The Particulate Matter (PM) mass contains dust (92%), organic carbon (4%), ions (4%) and elemental carbon (0.04%). This research shows the effect of Particulate Matter on power generation of solar panels. The data indicated that for solar panel surface cleanings that occur every 20−30 days, power generation increases by on average ∼50% after each cleaning.

Another study which occurred over 141 days of the dry season tested a Stand-alone Solar streetlight (SASSL) as shown in [2]. In the setup, one panel was cleaned daily while the other one was left uncleaned for the duration of the research. The following research outputs were observed: One of the observations made was that the battery attached to the uncleaned module recorded a more significant percentage of weight loss. This suggests that it recorded more substantial degradation within the same time, as compared to the cleaned panel. The other observation was that an uncleaned panel recorded an average of 23% reduction in operational hours for the SASSL at the end of the test period. Furthermore, in regions of Riyadh, KSA (Kingdom of Saudi Arabia), as per the research conducted in [3] which occurred over a year shows a single dust storm reduces the power output by 20% and in the sand storm over 60% power capacity is lost. Apart from these drastic effects, there was still a decrease up to 0.8% reduction in power daily, and more than 50% decrease in power output occurred if the system is not cleaned for a period greater than six months. In the nivous landscape, the snow coverage in the PV module leads to a reduction in electric generation. The research shown in [4] shows that even if the snow coverage area is one-sixth or less of the total solar cell array area, the influence of snow coverage decreases the electric power generation below a half. These observations consequently resulted that the soiling of the panel should be prevented from reducing the electric generation and erratic charging of the battery.

Currently, for cleaning of solar systems, few techniques are utilised. The study, as shown in [5], describes a comparison between the different modes of cleaning, in which manual cleaning is one of the operations where the human operator cleans manually with the help of mop or any wipers with suitable support structures. For the manual system, the cleaning process is found to be a very arduous task. The time required for the cleaning and the safety of the panel is said to be in threat. Another unique system for cleaning is the electrostatic precipitator system [5], which works with a non-contact mechanism. This filtration device removes the dust from the surface of the panel using the force from the induced electrostatic charges. Despite the uniqueness of the system, the cleaning capabilities of this system is inadequate since the system can only remove fine dust particles efficiently.

The sector of automation also contributes effectively to such cause, and one of the solutions includes the product as shown in [6]. The system uses a 525-gallon poly tank which distributes water along with a powerful 250mph cleaning fan. It virtually shears off dirt & debris that has accumulated...
onto the Solar Panels. The angle and direction of cleaning are fully adjustable to clean even panels. Nevertheless, one of the major disadvantages of the product is its usage of excess quantity of water, consequently making it not suitable for desert regions. Another novel system, Ecoppia E4, as mentioned in [7] uses a dry-cleaning robotic system for the removal of dust from the PV module. The system uses powerful microfiber elements and controlled airflow to remove the dust downward and off the panel. With the use of onboard solar panels and eco hybrid technology, the system remains self-sufficient, and the fully charged battery can sustain its energy for three full cleaning cycles. Even with such advantages, the use of special microfiber cloths makes the maintenance of the system strenuous and the initial cost of the system not suitable for a single street light solar panel. Also, this system does not take into account the concerns due to the bird droppings. For street light solar panel systems, one recent solution for cleaning is as shown in [8]. The system claims to be an autonomous simple and water-free light panel cleaning system that can clean efficiently for scenarios such as the bird dropping, dust, snow, and sandstorms. With high tech integrated solar streetlights, each solar system can exchange information and communicate with the control systems. Despite such unique features, the product provides a customised solution. It does not provide a viable solution for the existing solar panels, hence making it not cost-efficient and resource efficient.

There has not been a complete solution that can be fit on the existing street light solar panels without the use of sophisticated tools. The previous works done also do not consider the excessive power used by the cleaning system when used on a regular basis. The power consumed by the system often exceeds the power that it intends to save, when used on a daily/weekly basis due to the high-power requirements to run the cleaning system. Thus, it reduces the amount of energy stored in the battery and makes the light to operate for lesser hours per day. So we present a solution that can be mounted on any street light solar panel with ease and also cleans on a need to basis, such that the power savings is maximum, thus providing full operational time per day for the solar street lights. The work is organised as follows: Section 2 presents the design and functional requirements that the cleaning system should fulfil, Section 3 and 4 have the mechanical setup and the algorithm used respectively, explaining the unique mounting design and logic that enables the system to clean only when required; Section 5 presents the energy calculations done to set the threshold values, followed by the construction, prototyping done in Section 6 and the results of experiments in Section 7; Section 8 presents the discussions and conclusions arrived.

2. Design and Functional Requirements
Considering the previous works and evaluating their shortcomings, this solution takes into consideration the following design and functional requirements:

- Should clean the solar panel on a need to basis rather than a regular basis
- Can be retrofitted to existing streetlight solar panels
- The system should consume considerably lesser energy than what it saves
- Should be durable - should withstand the forces of nature
- Should increase the life of the battery by decreasing erratic charging
- Should not require human interference for each cleaning cycle
- Should be lightweight

3. Mechanical Setup
The solar panel is cleaned using a pair of rubber wipers. The rubber wipers are held against the surface of the panel by four compression springs and move along the length of the panel. A lock nut attached to lead screws on either side of the wipers causes the wipers to move over the panel, covering almost the
entire panel area. A solenoid valve is present near the control unit of the system, at the top end, which releases 20ml of water in between the two wipers through a plastic pipe. The wiper cleans the panel and reaches the other end where a small collection chamber is present. The water that has been used for cleaning gets collected in this removable chamber through a slit on the top surface. The water in the chamber usually evaporates during the summer and can hold the water during the monsoon seasons, thereby making it maintenance free. The chamber can be removed and cleaned when linemen check for repairs in the streetlights. The whole setup can be attached or removed from the solar panel at any point of time without the need for sophisticated tools.

The construction of the system is such that it can be retrofitted to existing solar panels and can be scaled to any size. The frame consists of two parts: the mainframe and the water dispensing system. The mainframe is slid over the solar panel from one end as shown in figure 1.a and the water dispensing system is attached to the other end of the mainframe using knob bolts that can be tightened without any tools sandwiching the panel in between, constraining all possible degrees of freedom of the frame as shown in figure 1.b. The mainframe has an integrated case for the circuits, motors, sensors, and a water storage tank. The water storage tank is connected to the solenoid valve, which controls the flow of water to the wipers.

![Figure 1. Assembling procedure of the solar cleaning setup](image)

The lead screw mechanism is built upon the mainframe. The lead screw has two supports at its ends and allows free rotation through bearings, as shown in figure 2. The top-end of the lead screw is coupled to the servo motor. The bearing casings are bolted on to the mainframe. A cylindrical rod is also held by the casings to bear the load of the slider rather than the entire load acting upon the lead screw.
Figure 2. Slider assembly of the cleaning module

The slider is threaded to the lead screw. So, the slider is actuated when the lead screw rotates. The slider is also connected to a cylindrical rod through a roller, which allows only axial translation. The lead screw is used only to actuate, and the cylindrical rod is used to bear the loads.

Figure 3. Overall assembled design setup of the cleaning module

4. Algorithm/ Flowchart of process
The cleaning of the solar panel is initiated by a need to basis rather than the current practices that clean on a regular basis. For this, we use a unique algorithm as shown in figure 4.a, that monitors the voltage
and current output from the solar panel to the battery. The setup has a humidity sensor to monitor the humidity. When the power output from the solar panel goes below 10 percent of the rated value, the cleaning system should be initiated. But the humidity is simultaneously monitored and when the humidity is found to be greater than 70 percent, that is, signs of cloudiness/rain (due to which the power might have gone below 10 percent) are considered before deciding if the cleaning system should be actuated. Also, when there is a shower, the system need not clean since the solar panel is washed due to the rain itself. Once the rain stops and if still there are stains of dust and water causing turbid spots on the panel, then the system would be actuated based on the voltage and current values recorded. In other cases, during normal days, the system gets actuated when the power goes below 10 percent as specified above. This is calculated such that there is enough power for the full-time operation of the solar streetlight.

![Flow chart of the algorithm](image1)

![Circuit diagram](image2)

5. **Energy and performance calculation**

Power of solar panel used in streetlights is 120 Watts

In one cleaning cycle

The motors rotate for 1 minute. Specs 5 V, 150 mAmpps
Solenoid valve opens for 1 sec, 24 volt, 80mAmps
Arduino: 9 V, 50mAmps in idle situation. 300mAmp peak
Streetlight consumes 60 W, for 10 hours = 60x10x3600 J = 2160 kJ
Energy consumed by Arduino, sensors per day = 9x50x24x3600 mJ =38.8 kJ
Energy consumed by motor per clean = 2x5x150x60 mJ = 90 J
Energy consumed by solenoid valve per clean= 24x80x1 mJ = 1.92 J

Without the cleaning setup:

For a dust free solar panel - the charging time of 6 hours during the daylight
Energy input = 120x6x3600 J = 2592 kJ
Energy output required for 10 hours operation of the streetlight = 60x10x3600J = 2160 kJ

Energy required for the streetlight to operate for 10 hours + Energy required to run the system = 2198.8kJ

Energy stored in battery after a loss of 15%in efficiency = 120x0.85x6x3600 = 2203.2 kJ

When there is no cleaning setup, a drop of more than 15% of peak energy (the peak energy is calculated by finding the maximum energy produced during its initial five days of cleaning of the panel), makes the power insufficient to power the solar streetlight to the required operation time per day of 10 hours. Hence, we chose a threshold of 12% in peak energy keeping a safety factor which includes the power used by the system during the cleaning cycle. So, the system should initiate its cleaning process if it reaches this threshold. The above calculations are performed for a standard 120 W street light solar panel, but the system has been designed for a 20 W solar panel that was readily available in the institute.

6. Construction and prototyping
A standard 20 W solar panel is used as reference for the purpose of this work, and the dimensions are designed accordingly. It can be modified according to the panel of any size, including domestic and industrial applications. The frame and the collector box is made out of 1mm thick galvanized iron sheet metal. The sheet metal is bent to the required shape, and the edges are gas welded. The box that contains the electronic circuits are manufactured in the same way and gas welded to the frame. The bearing housing is made by machining mild steel. Holes are drilled in the housing and the frame to connect them. The bearings are tight fitted in the housing. Support rods are also tight fitted with the bearing housing. The lead screws are inserted into the bearings using an adaptor. Servos are attached to the lead screw using a coupler.

The wiper assembly is built upon a sheet metal frame where the wiper is attached through springs to provide a normal reaction. The ends of the wiper frame are connected to supporters, which slide upon the support rod and the lead screw. The supporter has a nut bolted to it to translate when the servos are actuated and a roller to transfer the load to the supporting rod with minimal friction. The tank is made from thin sheet metal by bending and sealing the edges. The tank is placed in front of the circuit housing in such a way that the valve opening is above the wiper assembly such that water is dropped precisely in between the wipers.

The sensors, circuit boards, and servo motors are placed within the housing which is integrated with the frame. The table 1 contains the price of the materials used; the cost value is represented in Indian currency: Indian rupee (sign: ₹; currency code: INR).
Table 1. Materials and Cost table for the prototype

| Sno | Material                          | Cost (in INR)    |
|-----|----------------------------------|-----------------|
| 1   | Frame (incl. Water Tank)         | 300             |
| 2   | Lead Screw                       | 250             |
| 3   | Wiper Blades                     | 240             |
| 4   | Bearing                          | 150 x 4         |
| 5   | Coupling                         | 50 x 2 (Shaft) + 25 x 2 (Bearing) |
| 6   | Support Rod                      | 50 x 2          |
| 7   | Humidity Sensor                  | 50              |
| 8   | Voltage Sensor                   | 50              |
| 9   | Current Sensor                   | 50              |
| 10  | IC Chip                          | 25              |
| 11  | Servo Motor                      | 500 x 2         |
| 12  | Wiring                           | 50              |
|     | Total                            | ₹2865           |

7. Experimental Setup
The polycrystalline panels, rated at 20 watts of peak output along with our cleaning module, were used for the experimentation. The solar panel was kept untouched for a few weeks exposed to the environment and exacerbated further by putting sawdust over the surface of the panel. As shown in figure 5 the cleaning action in the solar cleaning module was performed in wet mode, which consequently recovered the efficiency of the panel at the end of the cleaning process.
8. Conclusions and Discussion
The designed model proves to be an effective and cost-efficient alternative to the existing equipment available. This product is primarily aimed at helping the municipality increase the scope of installing solar street lights without having to bear large overheads, such as maintenance, while also effectively ensuring that the panels continue to effectively and efficiently serve their primary purpose over a prolonged period. This system’s adaptability allows for extensive use beyond just the niche market of solar streetlight, and it could be implemented in solar farms or residential installations too. Its simplistic design coupled with its effectiveness ensures that the user does not face a plethora of obstacles during operation. The limited number of parts and simplicity of all make error handling easy and cost-effective too. It’s operation without the requirement of human interference and minimalistic focus on maintenance cements it as a user-friendly, versatile and cost-efficient product.

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