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Modeling and Performance Analysis of Automatic Solar Panel Cleaning System

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Abstract

Time dependent nature and due to an intermittent source, conserving maximum energy generated from solar panels has become difficult with an increasing trend of pollution level in urban areas, leading turned off operation of street lights, which indicated the average daily losses on solar conversion efficiency by 2.8% inside Kathmandu Valley. This paper aims to study the current scenario on the output trend of solar systems especially used for street light and traffic light purpose and generate a possible mechanical dry-cleaning method with the selection of the best mechanism depending on the performance. The two feasible concepts based on movement i.e. parallel and radial movement, wheel drive mechanism and crank rotor mechanism (wiper based) were designed on CAD systems and fabricated to evaluate the performance. The mechanisms were compared using the Pugh's decision matrix considering cleaning effectiveness, power required to drive and weight of the system as performance parameters and their importance were determined through the survey which resulted the cleaning effectiveness to be the most important parameter.From the experiment, the increment of solar conversion efficiency by 35.77% from wheel drive mechanism and 31.40% for crank rotor mechanism was obtained and was validated by analytical solution determining losses on panel after and before cleaning The matrix resulted with the selection of wheel drive mechanism as the best one to fit for the system according to performance. After the mechanism selection, financial analysis of the selected system shows to return its cost after 2.5 years with monthly energy saving of Rs.129 for 200-watt system.

Keywords

Automatic Solar panel cleaning, Effective cleaning time, mechanism, CAD, Decision Matrix, efficiency

1. Introduction

The dependency in the renewable energy for the generation of the energy, increasing demand of the energy is necessitating to conserve the maximum possible energy through an efficient operation. Despite the clean reliable and affordable source of energy, the solar energy is time dependent and intermittent source and the condition of PV modules used for the energy generation will also impact on the targeted energy conservation. On average, Nepal has 6.8 sunshine hours per day with a commercial potential of solar power for grid connection estimated to be 2,100 MW [1]. Constant dust accumulation, wind velocity, humidity and operating temperature reduces the efficiency of the modules by various means. Among them, dust accumulation creates a layer between the module encapsulant and outer environments which acts as a barrier to the solar radiation falling on the module surface. In the context of Nepal, the undergoing development works are increasing the level of air pollution on the urban areas mostly in Kathmandu, causing an energy loss by accumulating the dust on the panel surface. The dust accumulated on the solar surface also creates the partial shading on the solar panel cells which then reduces efficiency of solar panel. At Kathmandu, the daily power production was found to be reduced by 3.16% with the power loss by 40% within a month [2], for which proper cleaning technology is required to harvest maximum energy. Due to heavy dust accumulation on the solar surface used in the solar systems for the street lights in Nepal cause the system to operate only few days a week. Due to the lack of lights during the night, risk of having accidents on the street was found to be increased.

1.1 Automatic solar panel cleaning system

For the efficient generation of the solar energy, there mustn't be any disturbance on the incident light from the sun. The accumulation of dust on the surface of the solar panel must be removed on the periodic manner. Automatic solar panel cleaning system ensures removal of dust by a mechanized cleaning solution. The methods for the cleaning and removing the dust can be different depending on the nature of cleaning such as dry cleaning, wet cleaning, electrostatic cleaning etc. Besides that, the current systems have various difficulties such as heavy load on the panel surface, high cost of the system, complex design and design changes with the panel structure. The most of them also have slow operation and requires human attention and interference [3] which then leads to ineffectiveness of the automatic solar cleaning system in the current scenario of Nepal.

2. Case study of solar panels

Solar panel outputs of the two different locations had been collected for the reference to evaluate the effect of environmental parameters and changes on the output of the system. The data were collected from the system having two solar panels of 150 Wp rated power at Baneshwor and two panels of 100Wp at Kalanki and the nature of the power output showed that for the most of the days, maximum power output was recorded in between 12:00 PM to 2:00 PM. For the study on the reduction of power, the power output of two 100 Wp system during this time was taken into consideration and the nature is plotted as;

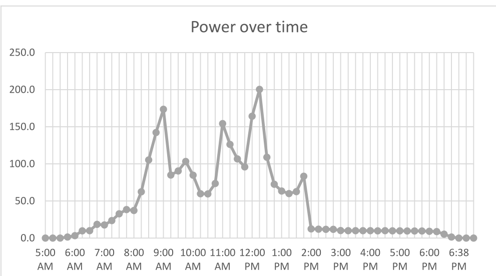

Figure 1: Nature of power generation throughout a day

It was observed that, an average daily loss in solar conversion efficiency was found to be 2.8% and the reduction in the solar panel efficiency was found to be 44.7% after 16 days with the reduction trend as shown in graph below;

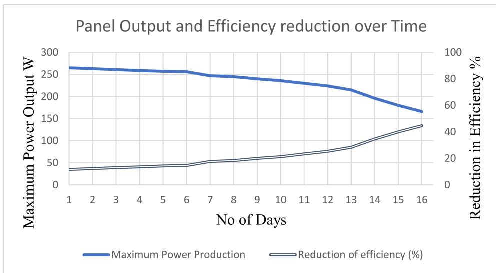

Figure 2: Trend of Power output

2.1 Effective Cleaning Time

The monetary losses arising due to the reduction in efficiency of solar panel after the accumulation of dust on its surface, must be analyzed properly with the cost of cleaning. The optimal number of days to clean the solar panel or the cycle time for solar panel cleaning can be obtained by minimizing the cost of cleaning the array and the reduced revenue from the dirty panels.

Average Daily loss in solar panel efficiency:

The concentration of dust particles in the atmosphere, wind speed and relative humidity will affect in the daily loss in the solar efficiency in the specified region. The efficiency of the solar panel was obtained from the case study each day and the reduction in the efficiency was determined by determing the difference on efficiency on two consecutive days. From the test conducted before, the average daily loss was found to be 2.8%.

Cost of Cleaning:

The cost of the cleaning includes the cost of materials used, cleaning process and power consumed. The cost of cleaning was found to be Rs. 10 considering the power consumed and multiplying it by the cost of energy provided by NEA. For the daily losses in the solar panel efficiency,

$$\alpha = \text{reduction in solar panel efficiency in day 2} - \text{reduction in solar panel efficiency in day 1} \quad (1)$$

The optimal Number of days between cleaning cycles can be obtained as

$$N = \sqrt{\frac{2P}{\alpha * si * \beta}}$$

[4] Where P is the cost of cleaning the solar panel in Rs, s is the average sun hours per day (6.8 hours in Nepal), i is the capacity of installed PV System in kW, α is average daily losses in solar panel efficiency due to dust, and β is the price of kWh in Rs/kWh (From

NEA, Rs. 10/kWh). Since, it depends on the system capacity, the optimal number of days of cleaning for different system capacity can be plotted as;

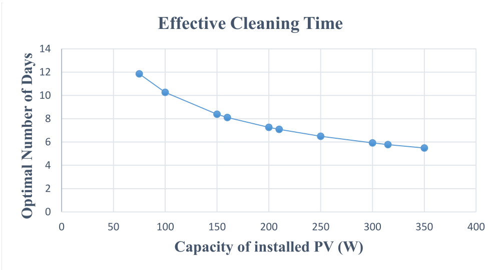

Figure 3: Effective cleaning time

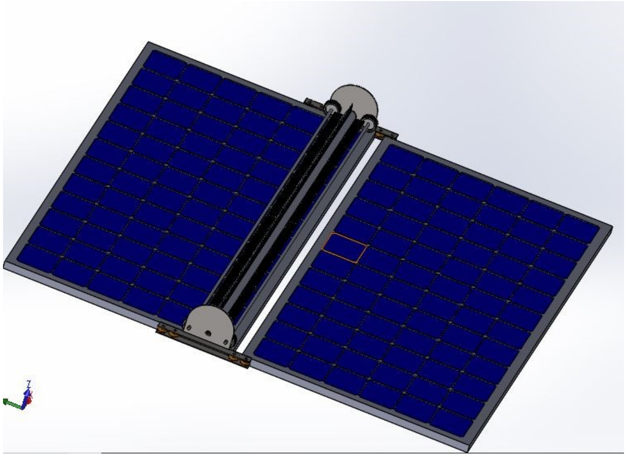

Figure 4: CAD drawing of mechanism1

3. Design and Fabrication

Design of the proposed solar panel cleaning device for the unipolar structures has been performed generating the basic concept regarding the movement of the system, i.e. parallel or radial movement and designed on CAD using Solidworks 2018 resulting in the below given practical designs and CAD models.

3.1 Motorized Wheel Drive

For the motorized drive mechanism, the concept of parallel movement through the rotation of the wheels on the surface of solar panel was considered. The drive concept was to couple the motor to the wheel for movement and the cleaning action to be performed by the rotation of the rotary cleaning brush. The brush and the wheel to be powered separately to balance the torque. The motorized wheel mechanism for solar panel cleaning system was fabricated with the purpose of its performance analysis in order to obtain the targeted solar panel efficiency with the effective cleaning approach. The system contains following components

- Rotary cleaning brush with 50 mm diameter of pipe
- Teflon bush
- Stainless steel shaft
- Bearing and Bearing mount
- DC motor
- Wheels

Figure 5: Fabricated mechanism 1

3.2 Crank rotor Mechanism

For the crank rotor drive mechanism, the crank rotates about its axis to carry the brush over the entire panel space and the rotor rotates the brush to accomplish the cleaning action. The components include

- Rectangular brush
- Rotating crank
- Motor mounting coupler
- connecting shaft
- DC motor

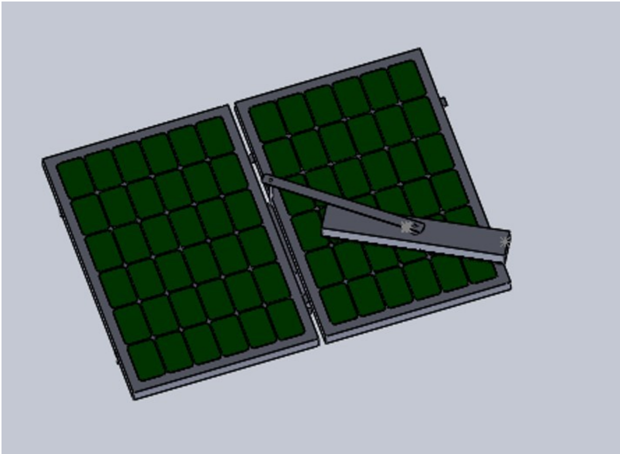

Figure 6: CAD drawing of mechanism2

4. Performance Analysis

Performance analysis of the system was conducted on the basis of performance parameters such as cleaning effectiveness, power consumed and weight of the system. The system was run manually without using any control kits and the result were obtained as for both mechanisms as;

4.1 Cleaning effectiveness

Cleaning effectiveness of the system was computed by obtaining the improvement in efficiency of the system after cleaning. The experimental setup for the evaluation consists of KL100W PV panel (100 Wp). The process was carried out by depositing the certain amount of dust on the panel surface manually and determining the power output. The improvement of efficiency of solar panel was found to be as per shown in graph below which indicated an average improvement in efficiency by 35.77%.

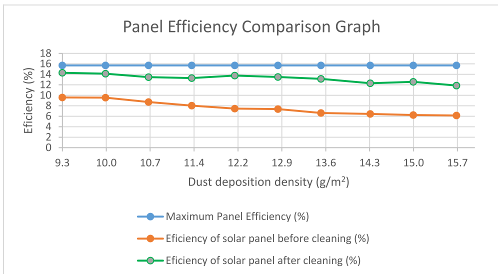

Figure 7: Panel efficiency before and after cleaning from mechanism 1

The result was compared with the analytical approach by determining the losses on the solar panel after and before cleaning the solar panel from the corresponding dust deposition density. The dust accumulation density on the solar panel surface can be obtained by

$$D = 0.47e^{\frac{L}{34.93}} - 0.37 \quad (2)$$

Where D is dust accumulation density in mg/cm2 and L is the power production loss of solar panel in % [5]

After rearranging above equation, we get,

$$L = 34.93ln\frac{D+0.37}{0.47} \quad (3)$$

The solar panel was subjected to the dust by screening it through a simple screening mesh and depositing dust of mass varying form 6.5 grams to 11 grams manually by increasing the amount of 0.5 grams of dust each step. Then, the dust deposition density was determined by deviding the amount of dust by the area of solar panel. And improvement in solar panel efficiency is obtained by the difference between the losses on solar panel before cleaning and after cleaning which was obtained from the corresponding dust deposition density. The result obtained from both approach for different dust deposition densities were plotted as shown in graphs below:

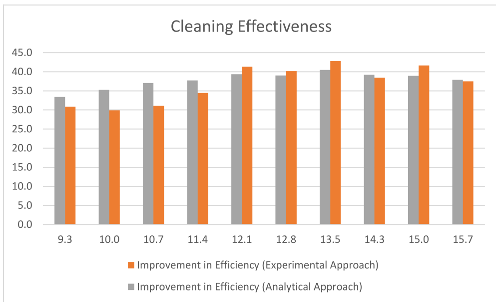

Figure 8: Improvement in efficiency from mechanism 1

Similarly, for mechanism 2 the result obtained from the experimental approach were as shown in figure below which has an improvement in efficiency at an average of 31.40%.

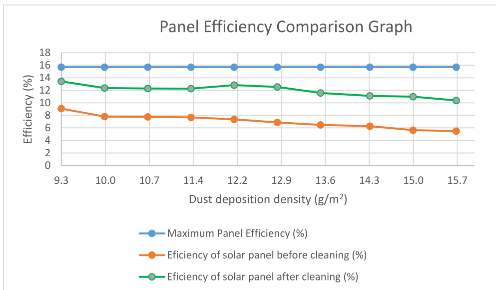

Figure 9: Panel efficiency before and after cleaning from mechanism 2

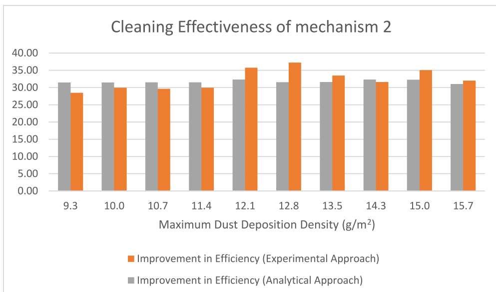

Figure 10: Improvement in efficiency from mechanism 2

This resulted an average efficiency increment by 35% for mechanism 1 which analytically was found to be and by 31% for mechanism 2.

4.2 Power Consumed and weight of the system

For one complete cleaning cycle of operation from experimental analysis, wheel drive mechanism was found to be consuming 0.566wh energy with 82 seconds cleaning time which has integral weight of 3.53 kgs and crank rotor mechanism consumed 0.42wh of energy with 70 seconds of cleaning time having weight of 3.3 kgs.

5. Selection of best mechanism

The selection of the best mechanism was performed by using Pugh's decision matrix which compares the alternatives according to the different parameters and their relative importance [6]. For the selection of the concepts, three basic performance parameters were considered for the evaluation as per listed above. The parameters were ranked based on their weightage and importance which was obtained through a survey by filling the google form by the participants. While taking the survey, different personals from the different field were participated to give their own requirement. The data showed the following statistics of the participants from the different sectors among 17 participants. The field of the participants were

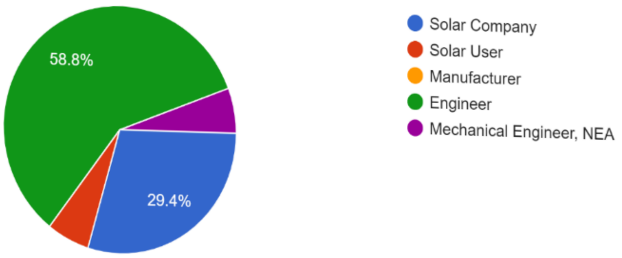

Figure 11: The field of participants

The survey conducted showed that the cleaning effectiveness to be considered the most important parameters followed by power consumption and being the weight of the product least important parameters among. For an effective comparison of the mechanisms on the performance, an ideal method for cleaning which has higher cleaning effectiveness was considered i.e. manual cleaning as a baseline for the comparison and matrix was formed as

From the decision matrix it has been found that the mechanism 1 has score of 216 which is greater score than of mechanism 2, which then leads to the selection of mechanism 1 for the cleaning of the solar panels.

Table 1: Decision matrix

The Issue: Selection of best mechanism for solar panel cleaning	Importance	Alternatives	
		Mechanism 1	Mechanism 2
Cleaning effectiveness	43	3	1
Weight	27	1	2
Power consumption	30	2	2
Total	100	216	157

6. Financial analysis

6.1 Total product cost

Total cost of the product has been determined by including the cost of electronics, installation, mounting and overheads leading total of Rs. 19850.

Table 2: Total Cost of product

SN	Particulars	amount
1	Manufacturing and material	12850
2	Electrical and electronics components	4000
3	Installation cost	1000
4	Cost of Mounting	1000
5	Overheads	1000
	Total	19850

6.2 Net present value analysis

For installing the system of automatic solar panel cleaning system, the initial investment, cost of cleaning, and maintenance cost are cash outflows while the cost saving over the manual cleaning and cost of energy saving are the cash inflows. The NPV analysis is performed by determining the net cash flow during a month and considering present value index factor with an annual interest rate of 20%. Now initial investment on the product = Rs. 19850

Cash Outflow

Cost of cleaning = Rs. 30 for a month (Source: NEA customer tariff).

Maintenance Cost = Rs. 103 (5% of product cost annually)

Thus, total cash outflow = Rs. 133

Cash Inflow

According to the stakeholders of solar systems used for street lights and traffic lights, the system need to be cleaned in every 15 days for the period of 7 months a year. Thus, taking an average cost for cleaning indicates cash inflow of Rs. 934 by reducing necessary monthly expenditure on cleaning the system.

Also, the cost of saved energy was determined by calculating the amount of energy generation being increased due to the cleaning action and using the cost of energy provided by Nepal Electricity Authority which leads to, The cost of saved energy = Rs. 129

Thus, total cash inflow after implementing the system = Rs. 1063

Thus, Net cash flow from the system = Cash inflow – Cash outflow = Rs. 927

After the NPV analysis. taking a yearly interest of 10% for Present value index factor lead to the return on initial investment after 27 months after which the net present value is positive.

7. Conclusion

The study envisaged and the research regarding the performance analysis of the automatic solar panel cleaning system with the following conclusions as;

- The output of the solar panel was found to be maximum at the time of 12:00 PM to 2:00 PM and the losses on the system was found to be nearly 45% after 16 days without cleaning at average daily losses of 2.8% on solar panel efficiency.
- From the survey conducted, cleaning effectiveness was the most important parameter to be considered while designing the system followed by power required to drive and then the weight of the system.
- Using the decision matrix approach, motorized wheel mechanism was selected as the best suitable mechanism for the cleaning of solar panels used on the street and traffic lights.
- The total cost of the product was found to be Rs. 19850 while product generating net cash flow of Rs. 927 which ensures the net present value of the product will be positive after 27 months.

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