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Effect of Dust Accumulation on Solar Panels and Mechanism for Alleviation: Design for Street Lighting Purpose

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Abstract
As the conventional energy sources dry up, future of world lies with renewable energy sources. Solar energy is known as cleanest sustainable energy source and solar photovoltaics is the most sought after renewable source of energy these days. The output power of the solar PV panels depend on various factors such as solar cell build up, solar panel tilt, solar insolation, cell temperature, sun exposure hours and other meteorological factors. The aim of this research is to deal with the decrease in the power output due to the particle deposition in solar panels and provide detailed design of the modular cleaning device. After a number of design modifications, alterations and testing, a modular cleaning device for the street solar panels is proposed which is energy efficient, effective in cleaning and inexpensive. The cleaning module consists of rollers, sliders, pulley, brushes and a DC motor. Main focus of the design is to make it light-weight so the existing panels can easily hold device's weight. This research is based on the specifications of solar panels installed for street lighting purpose in Kathmandu by Nepal Electricity Authority. Cost-effectiveness is another advantage of this device as the device costs under 10% of the total cost of street solar panel system. The power output decrement due to dust deposition was found to be 3.16% in one day and reaching 10.41% in ten days and 15.74% in a month.

Keywords
Renewable energy sources – solar pv – solar insolation – meterological factors

Introduction

With growth in every field of development, modernization and industrialization, the energy demand is continuously rising and Nepal can't remain apathetic to this scenario. Nepal has seen steady rise in energy demands but being unable to meet that demand, is facing the problem of energy crisis for considerable years and looking at this, it's difficult to formulate future energy plans without addressing present power shortage problems. Absence of fossil ores of any kind compels Nepal to fulfill all of the energy requirements from either importing conventional sources or extensive use of renewable sources. Relatively huge availability of hydropower resources in Nepal are unexploited and being poor economy, spending large amount on importing fossil fuels doesn't help it's cause. So, it should opt for cheaper and sustainable alternative like promoting use of renewable energy resources. Solar energy is a kind of renewable energy technology where freely available energy from sun is converted into various forms of energy. Being geooghraphically feasible and abundent availability of solar insolation make harnessing of solar energy good option for Nepal. Solar photovoltaic is the technology which converts energy contained in Sun rays into electrical energy. The inherent commercial efficiency of the photovoltaic system is within 15-20%, with the appropriate installation design (orientation, exposure, sun-tracers) to maximize the solar insolation. These are vulnerable to on-site omnipresent practicalities such as dust and bird-droppings which can significantly deteriorate the efficiency, but these are often overlooked. Losses in efficiency due to these factors have been reported at many parts of the world. The degree of loss depends upon the tilt angle, time of exposure to the dust, windspeed and other meteorological factors. This sedimentation saturates the charging rate of the solar panel to a very low value thereby decreasing the solar panel's output power. In Kuwait, the reduction of efficiency of PV modules (glass) was found to be as high as 17% in 6 days [1]. Nepal is blessed with solar

resource as it lies at 30 degree northern latitude and over 300 days of annual sunshine which is ideal for solar PV installations. Further the annual average solar insolation is almost 4.7kWh/m2 per day. These conditions are perfect for harnessing solar energy for various conversion technologies. Kathmandu City has solar panel powered street lamps installed during 18th SAARC Summit 2014, around 1100 in number, by the aid of Asian Development Bank in co-operation with Nepal Electricity Authority. Various research works have primarily peeked into solar system characteristics such as tilt angle, wind (speed and direction), environment, pollution level, emission and glazing on the impact of dust accumulation. The properties of natural dust needs to be characterized which is a complex task. In this research, data loggers are used to investigate the voltage and current characteristics from which the degree of loss are calculated and along with it, various design parameters are also formulated. Additionally, the general criteria for solar panel cleaning is also generated. Based on these criterion and parameters, a competent mechanical design is proposed, fabricated and tested. Extensive iterations on tuning the design is done to check the working of the product on real time environment. Cost analysis is another aspect considered in this research as cost effectiveness of the proposed mechanism is of primary importance.

1. Dust Effect on Solar Panels

The study of output power and the efficiency of solar collector is a complex matter as it is highly influenced by the various factors like solar flux, tilt angle, humidity, wind speed and dust deposition on the collector. Wind plays an important role on natural degradation of collectors as high winds help dust accumulation on solar cells causing decline in the performance of cell but contrary to the performance, transmittance is higher during higher wind speed. Dust deposition on PV surface can be studied by dust properties (composition, size of particles) and surrounding environmental conditions. Generally low wind is known to be a cause of dust accumulation on panels whereas high wind is known for cleaning action. Various impacts and reasons of dust accumulation on PV modules are explained [2]. Air borne dust is known to have major effect the performance of PV cells [3]. In arid and areas experiencing low rain, reduction in transmittance is fundamentally dependent on the dust deposited on the surface, also dust accumulation is related to tilt angle as lower tilt angles observe higher dust deposition density [4]. Presence of moisture content in the air accounts to radiation to be refracted, reflected and diffracted [5]. These effects drop the reception level of the direct solar radiation. Non-linear effect of humidity is evident on solar irradiance whereas solar cell being a current source, the irradiance causes small non-linear variations in Voc and large linear variations in Isc [6]. PV cells experience the degradation in performance for being exposed to humidity for long term. It has been observed that the high content of water vapor in the air causes encapsulate delamination [7]. The performance degradation is a result of passivized PV cells surface leading to Isc degradation, while having no considerable effect on Voc [8].

2. Dust Cleaning Module: Phases of Developmental Process

The idea to develop solar cleaning module cleaning device came with an idea to improve power output. The main aim of dust cleaning module is to clean off the accumulated dust from surface of solar panels. In addition, the durability, compactness and marketing ability of the product must also be considered.

2.1 Different Stages Prior to Cleaning Device Development

Solar Specification

i) Solar Panels used in street lighting purpose by NEA produces 130 W of electrical energy.

ii) The LED lamp used is rated 60 W, Battery type: 150 Ah, 12V,Tubular Plate GEL Type Battery.[9]

Site Selection

Based on the Accessibility of daily cleaning, high frequency of vehicular movement and no major constructions being done around, site was selected to be Pulchowk Campus guard house, lying attached to the road.

Pollution and major losses

The TSP observed at different sample sites in the valley

were found to be higher than the WHO guideline values (TSP-120 mg/m3 and PM 10 – 70 mg/m3 for eight hours) at all sample sites except residential and control sites. The TSP in the ambient air varied by month, highest level observed during April/May and lowest in July.[10]

Experimental Setup and Data Collection

After extensive literature review, an intuitive picture of worldwide scenario of dust accumaltion was framed. But specifically, considering Kathmandu's solar PV installations, familiarization of effect of dust prevalent here was certain to be helpful in many aspects like level of sedimentation of dust on PV, parameters for machine design, frequency of cleaning and other small details.

Figure 1: Set up for data collection

For this, comparative study of two solar panels of same specifications, one wiped once daily and the other left dusty, was done for a month of study period. The technical data (Voltage,Current and Cell Temperature) from this was obtained by coupling data loggers to both the panels; the data loggers were supposed to account power output of solar panels. Solar Irradiance data was recorded by the data logger installed at Pulchowk Campus. For the measurement of dust deposition, general microscopic slides of dimension(75.2mm*25.4mm*1.2mm) were istalled in array beside the solar panels. One slide per day was taken to measure the dust deposition density. This data represents the effect of dust on panel i.e, power output degradation and the need of cleaning device as such. This research focuses on the solar street lamps installed by NEA. The details of Solar PV modules ordered by NEA via contracting were known for design of data logger. Data loggers were fabricated in the Robotics Club, Pulchowk campus.

Figure 2: Set up for dust weight measurement

3. Mechanical Design

The Cleaning system was designed based on the following design requirements.

- Total cleaning system needed to be modular and compact.
- It needed to be attached to the panel so that it could clean the panel automatically at a pre-defined frequency each day without any human control.
- The cleaning feature needed to clear all the dust sediment, bird droppings and not allow any chemical adhesion
- Total system needed to use locally available material as far as possible so as to reduce the cost.
- The material used needed to be light-weight as it had to be supported by the panel.
- As the power for the mechanism was to be extracted from the solar panel's battery, power required to actuate the mechanism needed to be as low as possible.

3.1 Fabrication and Assembly

The design proposed is fabricated in the least cost possible, without compromising on design parameter to a

noticeable level. The first hit has very less chances of working most efficiently, thus testing of the module at the lab facility and the real time environment rendered the scopes of improvement of the project. Finally, after a number of modifications, dust cleaning model was developed that works effectively and enhances the efficiency of the panels in the solar street panels of Kathmandu valley.

The assembly consisted of nylon wheels with flanges (similar in appearance to a pulley).The flanges on the wheel used in the configuration, will reduce the number of bearings, shafts and the wheels itself, as it would not require another set of wheels to restrain another degree of freedom.

Figure 3: Initial Concept for Module Design

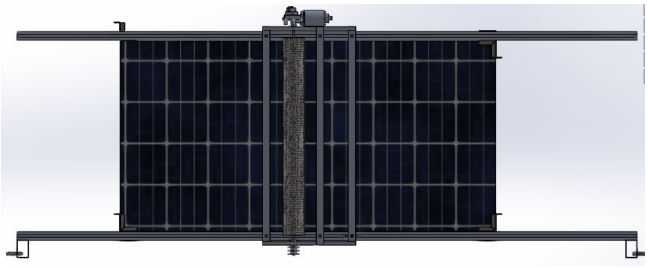

Figure 4: Top view of final Module Design

But after manufacturing one set of sliders, it was found that nylon pulley needed some clearance space between itself and the guide rails (20mm X 20mm X 2mm MS tube) as the tube available locally are not precisely squared at cross section. But, adding clearance to the wheel reduced the rigidity of whole assembly because it had space on which the wheels could run without sliding on the guide, thereby allowing the shaft and sections based above it to play. Thus, the design was discarded and an alternatives were searched.

After some research, a better slider, normally used in Aluminum Composite Panel (ACP) doors, was found. The finished part was cheaper and it exactly fulfilled the design requirements. These rollers have special aluminum guides to move along. The roller's wheels are made of hard plastic body and mounting accessories are made from stainless steel plate. The product is used to suspend aluminum and wood doors and will easily cope with the loading conditions of solar panel without failure. Each roller assembly has 4 bearings on each wheel. As slide rails have to carry the brush setup outside the solar panel to avoid any shadow of the brush-setup to fall on the panel, the slide rails must be extended outside the solar panel. At this extra length of slide rail, the brush setup will stay idle when not working.

3.2 Effectiveness of Cleaning Module Vs Efficiency Loss

Power consumption by solar cleaning module

The prototype developed for the solar panel cleaning consists of 12V single DC motor. The load consumption by the cleaning module is calculated on the basis of experiment rather than the theoretical calculation. The effectiveness of the solar cleaning module also depends on the power consumption by the module and average power loss due to the deposition of the dust on solar panel.

Maximum power consumed by the drive shaft motor
$= Vm \times Im$
$= 12 \times 2.47$
$= 29.64$W at 12V

Maximum time required to complete the cleaning operation, Tmax = 1.2 minutes

Total energy consumed in Wh,

$$E = \frac{29.64 \times 1.2}{60} = 0.59Wh \quad (1)$$

Total energy consumed in Ah,

$$E = \frac{29.64 \times 1.2}{60 \times 12} = 0.0098Ah$$

The required battery capacity is 150 Ah so, it is clear that the one cleaning device can be easily operated by the existing configuration of the street solar lighting system of the Kathmandu valley.

Number of Cleaning Per Day

Maximum rated power of solar panel = 130W
Nominal solar hour for Nepal = 6 hrs
Total energy produced in Wh= 130 * 6 = 780 Wh
From the power loss curve, the maximum power loss in single day is 3.16%.
Power loss in one day = 3.16%

$$P = 30W \times 1.2min = 0.59Wh$$

For Solar Panel of rating 130 W, and 6hr of average peak sunshine
Loss of power due to dust for day 1,

$$= 0.0316 \times 130W \times 6 = 24.65Wh \quad (2)$$

So, even if the panel actuates 24.65 / 0.59 = 42 (approx) times a day, the loss of efficiency and the power consumption P would be equal, keeping the panel clean. This means the loss of 24.65Wh of energy will then be used to clean the solar panel.

Energy losses per day

$$= 130 \times 6 \times 0.0316 = 24.65Wh \quad (3)$$

Suppose, the cleaning mechanism is actuated 'x' times a day. Assuming, hourly loss of efficiency of solar panel increases linearly with time on day 1.
Percentage loss when panel is cleaned 'x' times a day = 3.16 / 60x
Corresponding energy losses

$$= \frac{3.16 \times 6 \times 130}{x} = \frac{24.65}{x} \quad (4)$$

Energy consumed by cleaning module per day Wh,

$$E = \frac{29.64 \times 1.2 \times x}{60} = 0.59 \times x \quad (5)$$

Then,

$$\frac{24.65}{x} + 0.59 \times x \quad (6)$$

is the total inevitable daily loss.

Finding the minima to equation(8) will give, x = 6.46

So the daily loss is,

$$\frac{24.65}{6.46} + 0.59 \times 6.46 = 7.6271Wh \quad (7)$$

Thus, actuating solar panel cleaning module 6 times a day produces best results.
Had the cleaning not been done the percentage loss in efficiency after few days would have been even larger. This loss is also prevented by daily cleaning.

And, Annual energy saving

$$= (24.65 - 7.6271) \times 365 = 6215Wh.$$

The cleaning process also insures that the loss does not increase daily, thereby stopping the possibility of continuously decreasing the efficiency of the panel.

4. Results

This study is carried out for the period of 30 days. Pyranometer was used to measure the solar irradiance and the figure5 shows the average daily solar irradiance over the study period. The solar flux density varies between $240W/m^2$ and $550W/m^2$

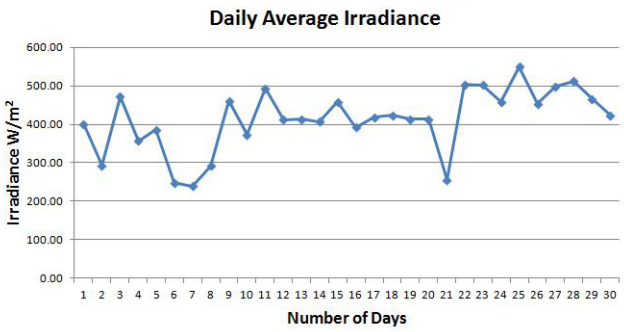

Figure 5: Average irradiance for study period

Similarly, the average daily cell temperature for the study period was also measured. Cell temperature is also a major factor that affects the Voltage of solar cell. The dust deposition density is another major variable in this research. The weight of dust deposited on the microscopic slides when divided by surface area of the slides gives dust deposition density.

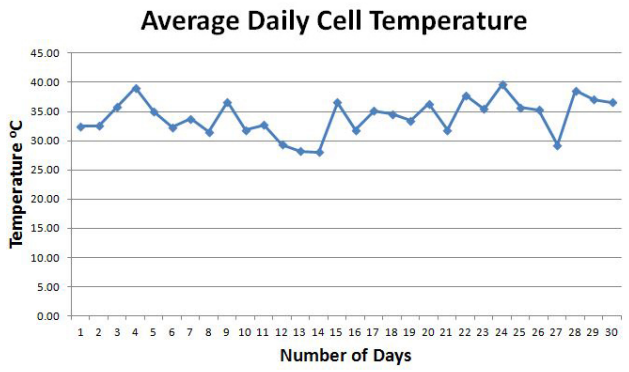

Figure 6: Average daily cell temperature

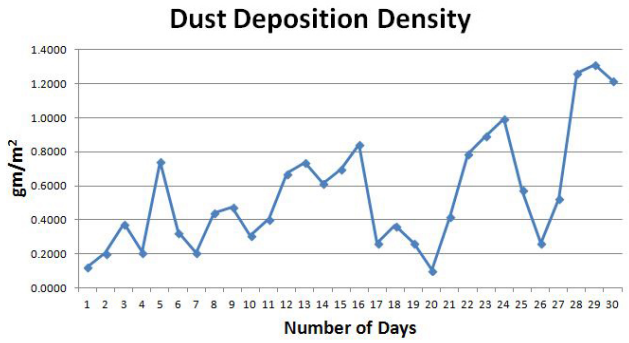

Figure 7: Dust deposition density

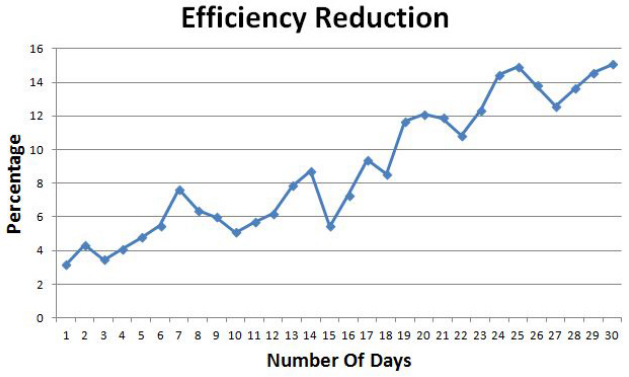

Figure 8: Efficiency Reduction due to dust

From Figure 6 we can clearly see that dust deposition density has a varying value. Rain and wind in specific case acting as a natural cleaning agent have the cleaning action on the panels. The decrease in deposition density can be related to the direct effect of rain. The efficiency of solar panel is seen to be varying in accordance with the fluctuating rate of dust deposition density. The study period coincided with the immediate post monsoon season in Kathmandu so, variables like solar irradiance and dust deposition density have considerably low values.

Dust deposition has the adverse effect on efficiency of solar panels. As the dust accumulation on panels increases, unless any cleaning effect applied to it, the power generation efficiency of solar panels start to decrease. Over the study period, the efficiency of solar panels decreased by 3.6% in first day and reached upto 15.74% in 30 days. Due to rainfall and wind speed acting as cleaning agent, the efficiency reductions is seen to improve on some days.

5. Conclusion

A modular cleaning device is designed for the solar street lights from the rigorous data analysis and is finally fabricated after number of design alterations and testing. Data analysis shows that the power loss is 3.16% in one day and reaches to 15.74% in 30 days. One sixth of power loss in one month is a huge drawback for the solar system which makes the cleaning device mandatory. The cleaning module designed here is energy efficient, economic and can effectively clean out the dust accumulated on the surface of the panels. It is also a light weight (4.14 kg) device which can actuate itself in pre-defined time and frequency to clean the panel.

It is found from experimentation that running this module 6-7 times a day, the energy loss in a day is optimized to 7.5Whr/day owing to the fact that power as high loss as 3.16% occurs each day. The module also is economical one, as the cost comes within 10% of the panel system that NEA has installed for street lighting purpose.

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