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Experimental Study of Cleaning Techniques for improving Performance of PV Modules

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Abstract: **-** The present study concentrates effects of soiling on the performance of three monocrystalline Solar panels (a reference panel, a nano coated and a self-cleaned). The panels were installed at a tilt angle of 33° facing south on the roof of Mechanical Engineering Department, Mirpur University of Science and Technology Mirpur Azad Jammu and Kashmir (AJ&K), Pakistan for a period of five weeks. The performance parameters such as solar irradiance, dust density, power output and the cell temperature of the panels were measured on weekly basis. The outcomes of the investigation demonstrate that power output of the reference, nano-coated and self-cleaning solar panels was observed to be reduced to 12%, 10%, and 8% respectively. The rapid fluctuation in the direct normal irradiation (DNI) is noticed for the whole experimental duration. Moreover, the temperature of reference, nano-coated and self-cleaning solar panels are observed to be decreased 13%, 11% and 12% respectively. The dust density increases for the whole experimental period.

Keywords: Soiling, self-Cleaning, nano-coating, efficiency, dust accumulation, PV modules

1. Introduction

Renewable energy resources are the best alternatives to the conventional energy resources (fossil fuels) and amongst the renewables, solar energy is the cleanest and abundantly available energy resource [1]. Solar radiation falling on the earth can be used directly or indirectly for generation of electricity.

The process of converting solar irradiation into electricity can be accomplished by adopting various technologies i.e. concentrating solar power techniques (parabolic trough, parabolic dish, heliostat field, fresnal lens) or by photovoltaic process. The former processes utilize different additional components (heat exchangers, turbines) to convert solar radiation into power output (electricity), however, in photo voltaic system, solar energy is directly converted into electricity [2]. In the beginning era, the efficiency of PV panels was very low therefore, much research concentrated to understand the performance and factors affecting the performance of the PV modules. The dusting factor on the photo voltaic (PV) panel decreases the output power of Solar panels and many scientists and engineers contributed to the mitigation of this problem. Mani et al [3] provided the guideline to the researchers of 21st century by reviewing the work regarding the soiling of PV panel science 1940. Ghazi et al [4] also contributed to establishing the guideline for interested researchers by reviewing the work of different researches. Same effort was done by Mekhailf et a. in Kuala Lumpur Malaysia [5]. They covered the previous work of scientists and researchers to study the effects of dust, humidity and wind speed on the efficiency of PV panels. They summarized that due to the greater angle of tilt less dust was deposited on the panels which results in less transmittance losses.

Piliougine et al. [6] performed an experimental work for the reliability of anti-soiling coating for PV panels in Spain. Results were pretty encouraging as the transmittance losses for coated PV panels were 10% and for uncoated was 12%. Siddiqui et al [7] established an equation to describe the relationship of PV panel efficiency and the thickness of dust accumulated on the PV panel by using the data collected for all the season of Lucknow India. The final equation came out as;

$$\Delta\eta = 1.4128 + 3.45947t \qquad (1)$$

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Sulaiman et al. [8] found that the different types of dust have different effects on the efficiency of the PV panel. To quantify these results more clearly setup was set inside the room. Natural dust reduced the power output by 18%, while talcum powder and dry mud reduced efficiency by 6.1% and 3.6%, respectively. Appels et al. [9] found that the transmittance losses of PV panels in residential building in Belgium was 1.36% by using self-layer coating and it would reduce to 0.87% if the multilayer coating was used. Touati et al [10] found that the mono crystalline PV panels were more robust to the atmosphere of Qatar then the poly crystalline PV panels. Rao et al. [11] studied the effect of dust accumulation on the performance of PV panels using I-V curve for both indoor and outdoor conditions. They found that the dust accumulation raised the temperature of panel by 1-2% of the prevailing conditions. An anti-soiling coating increased the output of a 10 MW power plant by 3% annually, found by Klimm et al. [12] in the climate of Riyadh KSA using the glass slabs for three different scenarios including wet, dry and reference weather of that plant. Six different types of dust (limestone, ash, red soil, calcium carbonate silica and sand among the 17 types of pollutant dust) affected the performance of PV panel, was experimentally by Darwish et al. [13]. It has been observed that there is very little published literature available Solar panels to improve their efficiency using nano coating technology.

The aim of the present experimentation is to study the losses caused by dust accumulation on the surface of the Solar panels and to check the effectiveness of the self-cleaning mechanism and nano coating on PV modules, as few studies are available. There are three Solar panels one remains uncoated (reference), nano coatings are applied on the second one and the third one with self-cleaning mechanism. Loss in output power due to soiling and effectiveness of cleaning mechanism is studied.

2. Experimental setup and Methodology

This study concentrates on the experimental study of three Mono crystalline Solar panels having capacity 50 Watt each. One of the panel is used as a reference, the second panel equipped with mechanical cleaning mechanism and the third one coated with anti-soiling nano coating (the coating spray used is the product of Percenta). Six glass slabs are also used to measure dust accumulation. Experimental setup is installed on the roof of Mechanical Engineering Department at Mirpur University of Science and Technology Mirpur Azad Jammu and Kashmir (AJ&K), Pakistan. This building is selected as it is very close to a high traffic road, i.e. “Allama Iqbal Road” and is in the range of the airborne dust that results from heavy traffic. Mirpur city is situated at 33.14° North latitude and 73.77° East longitude. This site is blessed with high solar irradiance more than 800 W/m^2. The tilt angle of all panels was 33.3º. It could be seen in figure 1 that solar insolation at this site goes as high as 7kWh/m2/day during the summer months with an average value of 4.5-5kWh/m2/day. Solar irradiance is as high as 900W/m2 during the peak hours daily. The performance parameters of Solar panel is recorded by using Solar PV Analyzer 200A. The Performance of each cleaning mechanism is analyzed.

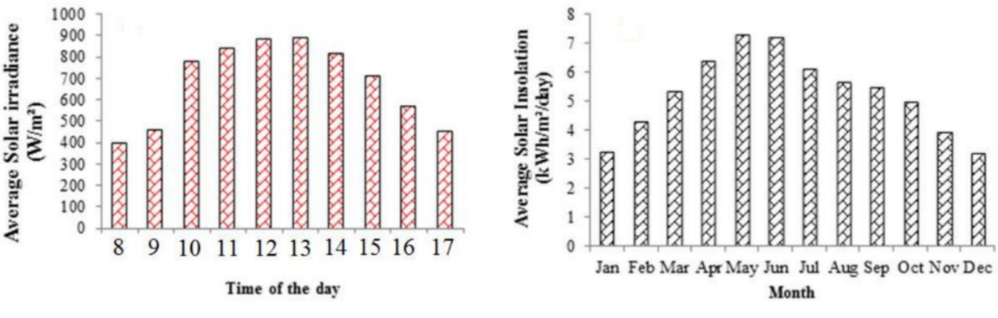


Figure 1. Average hourly solar irradiance (Left) and monthly solar insolation (Right) in Mirpur AJK [15]

Table 1 shows the technical aspects of the equipment detail used in the experimentation.

Table 1: Specification of the equipment

Equipment/Item	Technical Details
PV module	Mono-crystalline silicon, Rated Power =50 Watt each, No. of cells=12

	Cell area: 55x60mm; Short Circuit Current: 2.91A, Open Circuit Voltage: 22.6V, Panel dimensions: 760 × 540 × 40 mm, estimated life: 25 years
Solar PV Analyzer 200A	Max. solar panel power (P_{max}) search by auto-scan: 60V, 6A (180W) &I-V curve test for solar panel/module
Lead screw	Length=68.5 cm, Diameter=1.27 cm, Material=Iron
DC motor	Power=16.2 Watt, current= 1.35 A & Voltage=12 Volt
Pump	Power=12 Watt
Light sensor	Type=light dependent resistor made of cadmium sulphide (CdS)
Transistors	C945 NPN and A1015 PNP
Resistors	Types=10k, 47k, 1k & 390k
Digital temperature sensor	Temperature range:50 °C to +110 °C Usage temperature:5°C to 50 °C Humidity: 5% to 80% Accuracy: ±1℃
Battery	12V Li-Ion battery – estimated life: 5-6 years

3. Working principle

Solar panels are placed at angle of 33˚ for maximum irradiation. In self-cleaning mechanism (accompanied by battery, it gets charged only from self-cleaning panel) a Spring-loaded wiper is used to clean the panel as water sprayed on it through pump. The labeled diagram of the panel with self-cleaning mechanism is shown in Figure 2. Lead Screw mechanism is installed on panel which relates to motor and wiper with the help of bolt. Circuit board is used to control the motor (uses power stored in battery through solar panel) and movement of wiper. Circuit boards have resistance in series, which controls the speed (rpm) of motor. Light Dependent Resistor (LDR) in circuit board, when it turns ON, LDR experience variation in resistance consequently motor get started. At the same time pump will also start, which sprays the water on the solar panel. When motor starts moving anticlockwise, the wiper moves down with the help of the lead screw. This mechanism starts when light falls on LDR and returns to its position when there is no light, i.e., night. One limit switch is placed at bottom and the other at top of panel. Wiper moves downwards, when it touches the limit switch motor gets turned off and wiper stops at bottom too. When there is no light falling on LDR, the motor will start moving clockwise so the wiper moves upward until it touches the limit switch. The operational time of self-cleaning mechanism is 32s. Figure 3 represents the electrical circuit for self-cleaning mechanism. Reference panel is placed without any cleaning mechanism and coating.

Nano-coating is applied on the surface of the panel with the help of microfiber cloth. Nano coating improves the sunlight penetration and hence increases its efficiency. Nano coating for solar panel is a thick hydrophilic film. Because of hydrophilic properties, the water (rain, dew drops and externally provided if required) moves freely on the surface, not forming separate drops, thus self-cleaning the surface. Dust and dirt adherence is reduced by 95% due to the hydrophilic properties of the nano coating whereas during rain, the rainwater cleans the surface instead of polluting. For dust accumulation measurement, five identical glass slabs (14* 8.5 cm^2) are placed parallel to the setup. Figure 4 and 5 shows the experimental setup at start and end of study. At the end of every week, weight of one glass slab is measured using highly précised weigh balance in the chemistry lab of Mirpur University of Science and Technology (MUST), Mirpur AJ&K. The graphical representation of dust deposition is shown in Figure 6. Dust density can be measured by comparing the sample's weight before and after the exposure [11], by using weight difference of the mirrors placed parallel to panel's surface[16]. Dust Density on the surface of panel is 0.0016 mg/cm^2 and Area of Panel is 1460.75 cm^2.

3.1 Calculation of solar Panel performance

The maximum power P_{max} (2) and panel efficiency (3) can be found by the following relation.

$$P_{max} = V_{max} \times I_{max} \qquad (2)$$

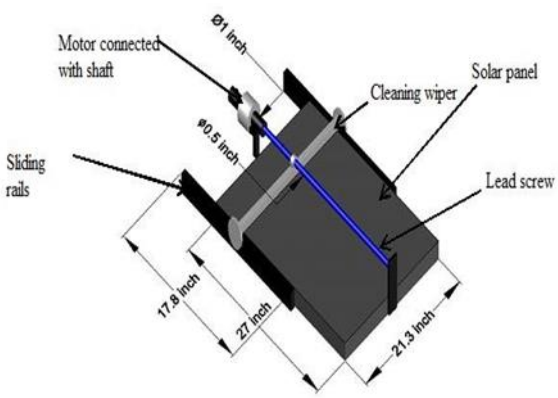
$$\eta_{module} = \left(\frac{P_{max}}{G \times A}\right) \times 100 \qquad (3)$$

G represents the solar beam intensity and A is the area of the module.

Fill factor of the PV cell is the ratio between Maximum power and theoretical power.

$$FF = \frac{V_{max} \times I_{max}}{V_{oc} \times I_{sc}} \qquad (4)$$

Where FF shows fill factor, V_{oc} is the open circuit voltage and I_{sc} is the short circuit current.



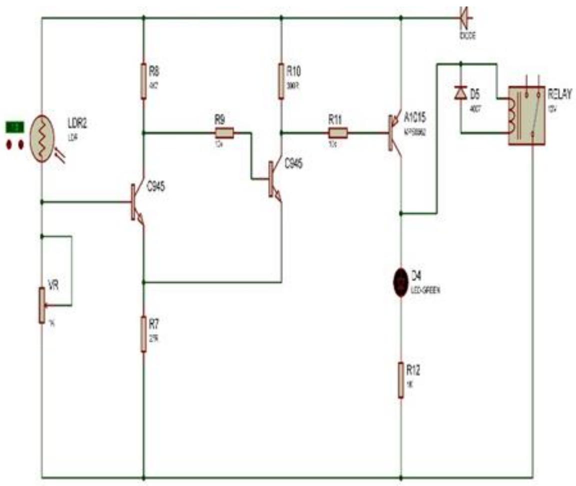


Figure 2 (left): Schematic of self-cleaning mechanism **Figure 3** (right): H-bridge circuit for the operation of cleaning mechanism.

Figure 4: (Left; Reference Panel: middle; Nano-coated Panel and Right; self-cleaning Panel on First week)

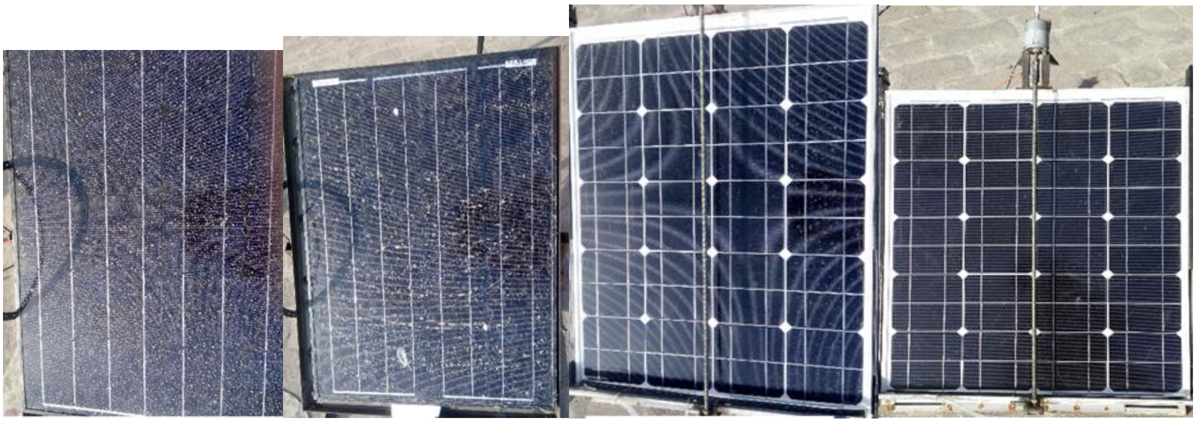
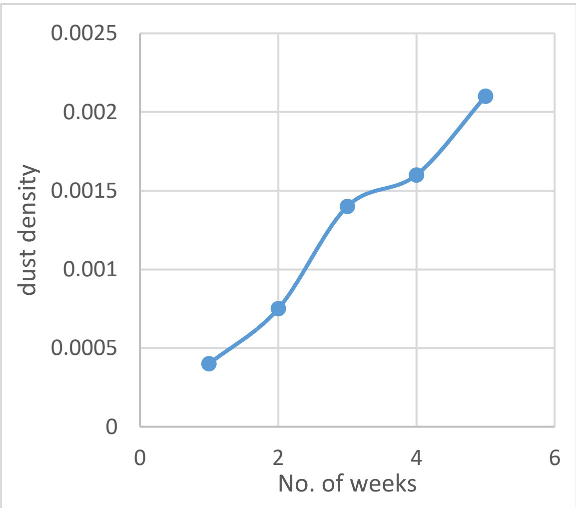


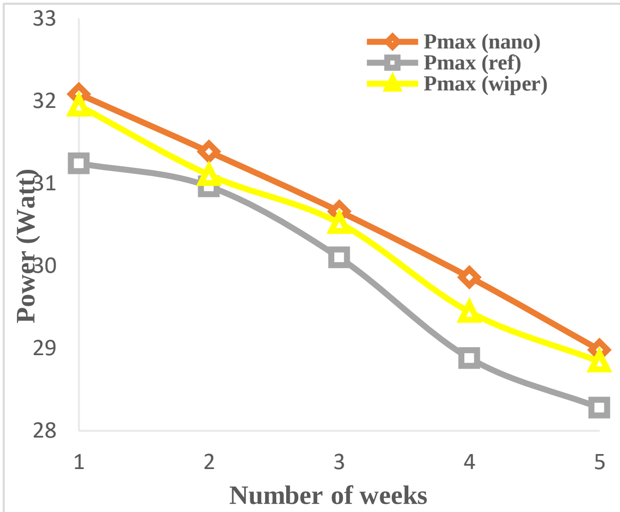
Figure 5: (Left; Reference Panel   Middle; Nano-coated Panel and Right; self-cleaning Panel on fifth week)

4. Result and Discussions:

The performance parameters are the power output, DNI, temperatures of the modules, I_{sc}, and the dust density are investigated. Initially, the readings of all the Solar panels are recorded with the help of PV analyzer and the output power of all solar modules is approximately same as there is no dust accumulation on the surfaces of the solar panels. Figure 7 is the graphical representation of the power output of the PV modules. The panel with nano coating has almost maximum power as compared to the other two panels. The output power of reference panel, nano coated and self-cleaning is reduced from 32.3 to 28.66W, 32.4 to 29.2 W and 31.21 to 28.8 W, respectively, during the study periods.

Figure 6: Dust density vs No. of weeks   **Figure 7**: variation in modules output power during the five weeks

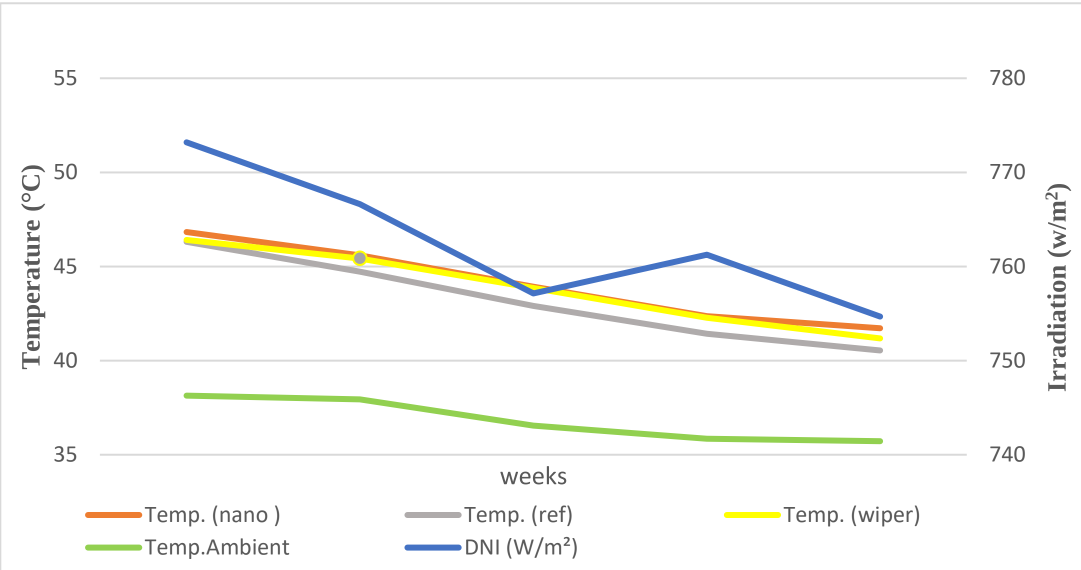




The variation of the modules temperature, ambient temperature, and direct normal irradiance (DNI) is plotted in Figure 8. The ambient temperature decreases almost steadily along the time, whereas solar radiation shows a dramatic behavior depending upon the weather conditions. The maximum DNI is achieved in the second and the fifth week. Dust deposition on the PV panel causes a rise in cell temperature. The surface temperature of the reference panel is the lowest during the whole period of study as compared to other panels. The increase in the nano coated panel temperature is due to the additional hygroscopic layer, whereas the surface temperature of the panel having wiper mechanism is the highest due to the additional heat caused by the friction produced by the cleaning action and the latent heat of the components. The drop in the surface temperature of the reference and the nano coated panel is due to the rain shower. The decrease in the temperature of the reference panel, nano coated, and self-cleaning Solar panels are observed to be 12%, 10.91% and 11.26%.

The short circuit current I_{sc} is substantially influenced by the dust deposition. The short circuit current of the panel is reduced due to dust deposition that further causes the loss in the power output of PV modules. But the operating temperature elevation caused the large drop in open circuit voltage of the modules as it is proved by [14].

Figure 9 represents the relation between time period versus dust density and short circuit current of three panels. Dust deposition density is noticed to be increased as the period of exposition has increased. Natural cleaning actions of rainfall, wind speed and dew are evident, as these agents lowered the dust deposition density [17]. As it can be seen in Figure 9 that dust deposition density increases from 0.7 mg/cm^2 to 1.88 mg/cm^2 during the period. This effect can be accounted for some high values of deposition in March due to the bird dropping. Another factor is solar density. The short circuit current of the three panels has decreased due to the increase in dust deposition. The short circuit current for reference, nano and self-cleaning panel decreased from 2.23 to 2.02, 2.29 to 2.07 and 2.28 to 2.06 respectively. Efficiencies of the modules are presented in Figure 10. The percentage reduction in the efficiency of the reference panel during the five weeks is nearly 3.6%, whereas the efficiency of the nano-coated and self-cleaning panel decreased from 60.54% to 58.83% and 60.52% to 58.46% respectively. Power output of Solar panel is inversely proportional to dust density as shown in Figure 11. As the dust accumulation on the surface of Solar panels is increasing, the output power is decreasing. The effects of nano-coating and self-cleaning are obvious as the power drop is more in reference panel.



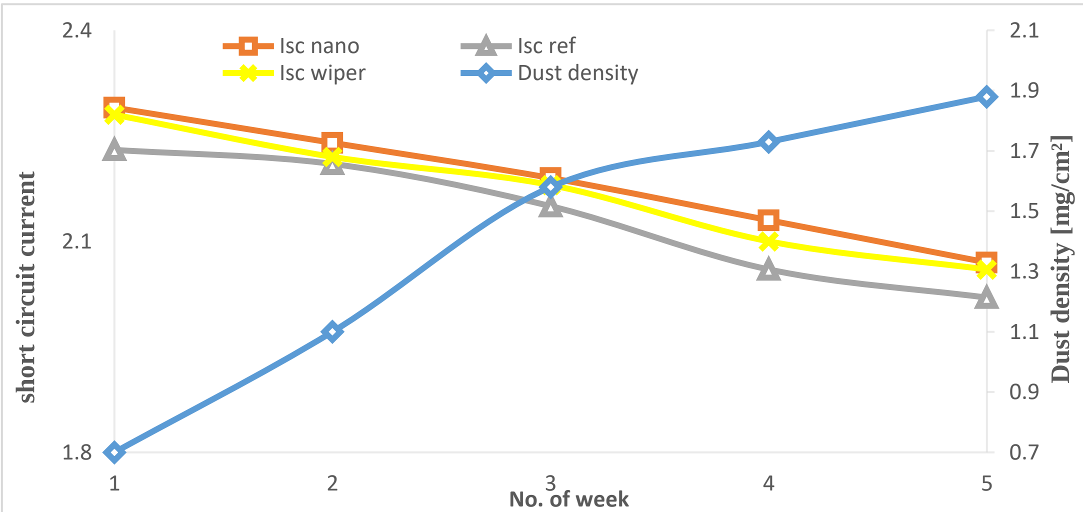


Figure 8 (Top): Variation in temperature and solar irradiation **Figure 9 (bottom)**: Effect of dust density on I_{SC}

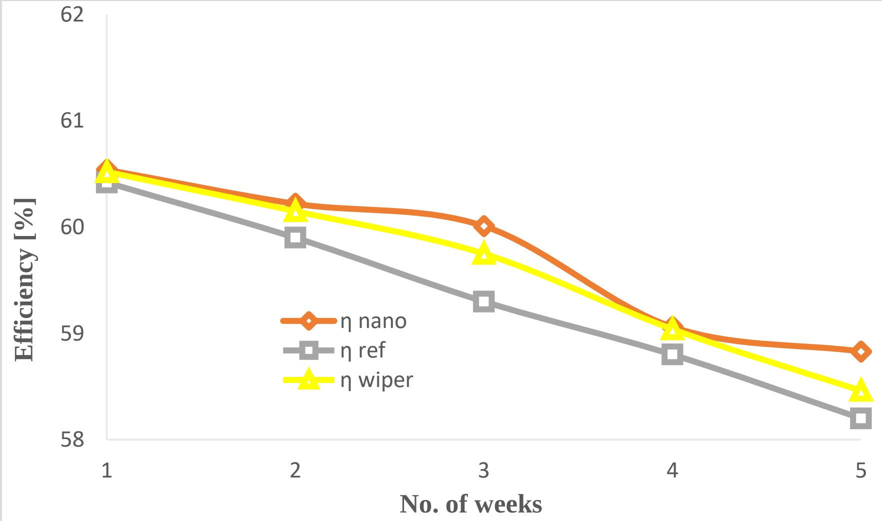


Figure 10: Efficiency Vs No. of weeks

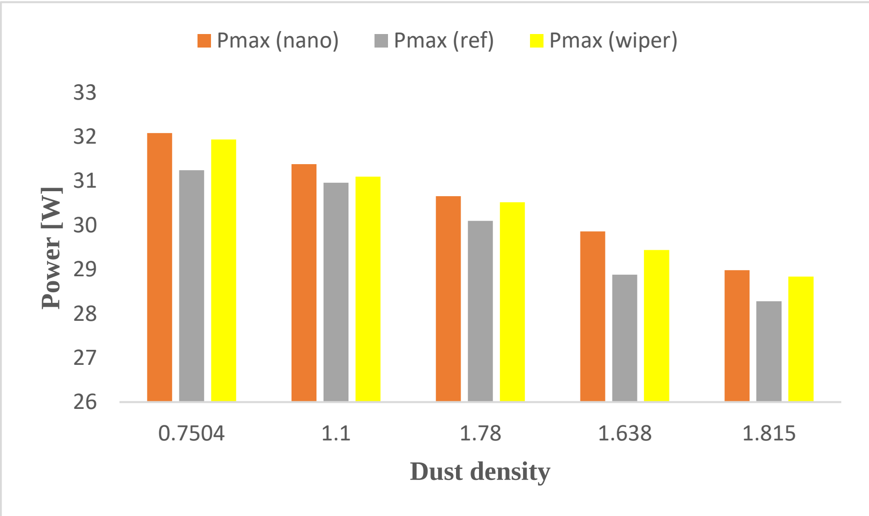


Figure 11: Influence of dust density on Solar panel output power

Conclusions

The nano-coated panel represented the power drop of 10% due to soiling, for reference panel it was almost 12% and for the self-cleaning, the power drop of 8% was observed. Solar intensity is noticed to be varied weekly due to the rain and mild weather conditions. The dust density increases from 0.7 mg/cm^2 to 1.88 mg/cm^2 as it affects the output power. Nano coating is better option specially in rainy areas for cleaning of PV modules, as it has no maintenance cost, cheap and no harmful effect for the surface of the solar panel. Mechanical cleaning mechanism make scratches on the surface of panel as a result surface temperature increase due to friction consequently power drops is observed.

Nomenclature

C	Capacitor
DC	Direct current (ampere)
DNI	Direct normal Irradiation (W/m^2)
E	East
I_{sc}	Short circuit current

LDR Light dependent resistor

N North

P_{max} Power maximum (Watt)

PV Photovoltaic

R Resistor

t Time (sec)

T Temperature (°C)

Ref Reference

V_{oc} Open circuit voltage (Volt)

η Efficiency

Rpm Revolution per minute

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