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Effect of Dust on the Efficiency of Solar PV Panel in Khartoum

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Abstract - This paper presents an experimental study of deposited dust particles effect on the electrical performance of solar photovoltaic (PV) panels. Due to limited conventional resources (fossil fuels) renewable energy turns to be the best alternative as a source of clean energy. Enhancing the efficiency of PV panels has been presenting a significant part of the clean energy technology developments. Accumulation of dust on solar PV panels is a natural process. External resistance caused by light obstruction material, due to dust, reduces solar photovoltaic performance. Studies show that accumulated dust can reduce solar panel systems efficiency, however, the percentages depend totally on the environment conditions of the system site. Therefore, outdoor experiments were conducted, using two silicon mono-crystalline panels (washed before each measurement and unwashed panel) exposed to natural sun light for three months at the national energy research center (NERC), Soba, Khartoum state, Sudan. The results show that dust deposition reduces the efficiency of the solar PV panels in a range from 4.3% to 16.8%.

***Keywords*:** Dust, PV panels, Solar PV efficiency, Weather

1. Introduction

Renewable energy is defined as energy that comes from resources which are naturally replenished on a human time scale, such as sunlight, wind, and rain. The environmental impact related to the pollutants' emission and the consumption of conventional resources (fossil fuels) instigate the utilization of renewable energy. Thus, renewable energy turns to be the best alternative as a source of clean energy. Renewable hydroelectric energy provides 16.6% of the world's electricity [1]. Other renewables such as wind, geothermal, solar, biomass and waste, together they make the "renewables" total growth rate equal to 17.0% worldwide as of 2017 [2]. So recently there is an increasing worldwide interest in sustainable energy production and energy savings. For instance, the European Union targets by 2020 a share of 20% of the total energy consumption by the implementation of renewable energy technologies [3]. Furthermore, International Energy Agency (IEA) shows that in 2050, solar array installations will supply around 45% of energy demand in the world Mekhilef et al. [4].

Solar energy potential in Sudan is remarkable. It is one among six countries having the highest radiation intensity in the worldwide and has an average daily global horizontal irradiation up to 7.5 kWh/m2/day Osman [5]. Radiant light and heat from the sun, is harnessed using a range of ever-evolving technologies such as solar heating, photovoltaics, concentrated solar power, solar architecture and artificial photosynthesis. Photovoltaic systems can be considered one of the most popular solutions with significant margins of improvement while ensuring the generation of energy with low environmental impact. The technological growth as well as policy support Kaldellis et al. [6], economies of scale, improved manufacturing processes and rapid PV market growth Kaldellis et al. [7] and Cuchiella et al. [8] have led to significant reduction of manufacturing costs. Gu et al. [9] illustrated a well-documented downward trend in module prices over the years resulting in a price reduction from about $60/Wp to about $2.2/Wp from 1970s to 2010.

Despite this remarkable growth in PV production and cost reduction; various researches and development should not be neglected to enhance economic and effective way to capture, store, and convert solar energy into useful energy, [10]. Some important factors responsible for the performance and efficiency of a solar PV panel such as characteristic resistance, parasitic resistances, temperature, light intensity, and dust should not be ignored, Zaihidee et al. [11].

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2. Literature Review

A solar cell, or photovoltaic cell, is an electrical device that converts the energy of light directly into electricity Bisquert et al. [12] by the photovoltaic effect, which is a physical and a chemical phenomenon. It is a form of photoelectric cell, defined as a device whose electrical characteristics, such as current, voltage, or resistance, vary when exposed to light. Solar cells are the building blocks of photovoltaic modules, [13].

Characteristic resistance, parasitic resistances, temperature, light intensity, and dust are some important parameters that influence the performance and efficiency of a solar PV panels. Dust, however, is the lesser acknowledged factor that significantly influences the performance of the PV installations. This may be because the dust natural accumulation is, not a global issue but, a site-dependence process. Few studies [11] and [14-24] investigated this effect and the consequent efficiency degradation. A village near Riyadh, KSA is using a solar PV system was considered as one of the excellent sites to study this phenomenon. Accordingly, Mani et al. [14] and Salim et al. [15] studied dust accumulation effect for eight months and indicated a 32% reduction in solar panels performance. Another site is in Kuwait City where Wakim [16] found a power reduction by 17% as a result of sand accumulation on panels after only six days. Also, for tilted glass plates with different tilt angles ranging from 0° to 60° the effect of dust accumulation was studied by Sayigh [17] and caused a reduction in plate-transmittance ranging from 17% to 64%, after 38 days of exposure. Also, an experiment conducted by Sayigh [17] was observed a reduction of 30% in useful energy gain by horizontal collector after three days of dust accumulation. The effect of dust on the performance of (Poly-crystalline) photovoltaic modules had been investigated in Oman desert climate by Kazem et al. [18]. Their work shows that a reduction in panels performance depend on the pollutant type and deposition level. The highest reduction in PV voltage was caused by ash pollutant with (25%).

In Bangladesh, Rahman et al. [19] found that in one-month photovoltaic solar panel system efficiency was reduced by up to 35% due to dust accumulation on the surface of photovoltaic solar panel. Moreover, in Roorkee, India after 10 days of exposure Shaharin et al. [20] reported that a reduction in glass plate [tilted at 45°] transmittance was 8% on average.

An experiment conducted by Ali et al. [21] in Taxila, Pakistan using two different types (monocrystalline silicon and polycrystalline silicon) of photovoltaic panels and two modules of each type, one module from each pair was left exposed to natural atmosphere for three months of winter to investigate the effect of dust deposited on the surface of photovoltaic modules. Systematic series of measurements were conducted [21] corresponding to the different dust densities. The difference between the output parameters of clean and dirty modules provided the information of percentage loss at different dust densities. At the end of three months the dust density deposited on the modules surface was 0.99 mg/cm2. The monocrystalline and polycrystalline modules showed about 20% and 16% decrease of average output power respectively compared to the clean modules of same type. Efficiency reduction of a monocrystalline and a polycrystalline module was 3.55% and 3.01%, respectively.

At the Renewable Energy Outdoor Testing Murdoch University, Perth, Australia an investigation conducted by Tanesab et al. [22] on photovoltaic modules have been operating for eighteen years without cleaning procedures as they measured the contribution of dust to the long-term performance degradation of various photovoltaic (PV) modules. The PV modules power output degradation was ranged from 19% to 33%. The degradation is mostly due to non-dust related factors account about 71-84%, however the contribution of dust is still significant at 16–29%.

Over a period of two month an experimental study was carried out (i.e. August-September 2009) in order to quantify the effect of urban air pollution on the energy performance of PV panels [23]. Kaldellis et al. [23] experiment was conducted in Athens, Greece. According to the results obtained, up to nearly 6.5% was a reduction of the PV-panels' energy production in comparison with a clean panel [22].

A reduction in a PV panel efficiency due to dust accumulation by 15–35% was recorded by Zaihidee et al. [11] as result of outdoor experiments were conducted to study the dust effect under natural operating conditions. Furthermore, the impact of TiO2 coating on glass surface (40nm and 60nm thick), which makes the surface hydrophobic, was tested [11]. The results show a transmittance reduction up to 0.9% was also recorded on glass samples with self-cleaning coatings, e.g. TiO_2, since rainfall washed dust off more effectively.

Hee et al. [24], at the department of electrical and computer engineering, Singapore, found that bare glass transmission was reduced despite the heavy rains in Singapore over several months. After 33 days, a reduction from 90.7% to 87.6% in plain glass slides transmission. The performance of TiO2 coating for solar panels with different thicknesses [60nm and 40nm] films was investigated [24]. Hydrolysis method was used to deposit TiO_2 films which is a low-cost and commercially

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viable process and was found that TiO_2 coatings do indeed help to reduce the effect of dust on transmission, with a thicker 60 nm coating being more effective than a 40 nm one.

Analysis and results of the influence of dust on the solar PV modules performance at the NERC, Soba, Khartoum state, Sudan, are presented in this paper. Based on all this information the effects of the dust on the PV panels electrical performances have been highlighted.

3. EXPERIMENTAL METHODOLOGY

Two solar PV panels were exposed to the sun. One of them is kept dusty and the other one is cleaned to measure the effect of dust on the PV panel performance as shown in figure 1. Owing to the sun-earth geometry and the location of Khartoum, Sudan, the solar panels were kept inclined at an angle of 15.5˚ due south with the horizontal. The length of each panel was aligned in the north-south direction. Each solar panel module is made up of silicon mono-crystal cells with electrical specifications as follows: [At STC (1000W/m^2, temperature 25°C) nominal values] peak power (P_{MP}) =43.62 W, voltage (V_{MP}) = 14.82 V, current (I_{MP}) = 2.943 A, open circuit voltage (V_{OC}) =19.24 V, short circuit current (I_{SC}) = 4.213A, and a surface area is 3600cm^2.

The system was installed and kept at the outdoor environment for three months to study the effect of the dust on the solar panels. Experiments were performed by taking the readings of different parameters. Solar radiation was measured using a Silicon Pyrometer SOZ-03 as shown in figure 2. Short circuit current, open circuit voltage, and ambient temperature were measured by a multi-meter with a thermocouple. The experiments commenced on the 18^{th} of April until the 10^{th} of July.

Readings were taken, half-hourly from 10:30 am to 2:00 pm, for only one day every week, to determine the efficiency of the solar panel.

From these measured parameters the efficiency of the solar PV panels was computed using the equation below:

$$\eta = (V_p * I_p)/(P_s * A) * 100\% \qquad ---------- .1$$

Where:

I_p is the electrical current produced by the solar PV panel (A).
V_p is the voltage of the produced electricity (V).
P_s is the power of the incident solar radiation (W/m²).
A is the exposed area of the solar panel (equal to 0.36 m^2).

Fig.1: The Exposed Two PV Panels

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Fig.2: Pyranometer SOZ-03 Inclined at an Angle of 15.5˚ Facing South.

4. Results and Discussion

The two exposed panels, are configured and assembled in the NERC, have the same specifications and surface area. However, the performance of these two panels is not identical though. They were initially washed and exposed to the same environmental conditions. When measurements were taken, the first day, it was found that the two panels did not produce equal output power, as shown in figure 3. Figure 3 depicts the output power (W) of the two panels. This difference was attributed to the fact that one of the panels (selected to be left unwashed) is recently manufactured compared to the other (was been washed every time before measurements).

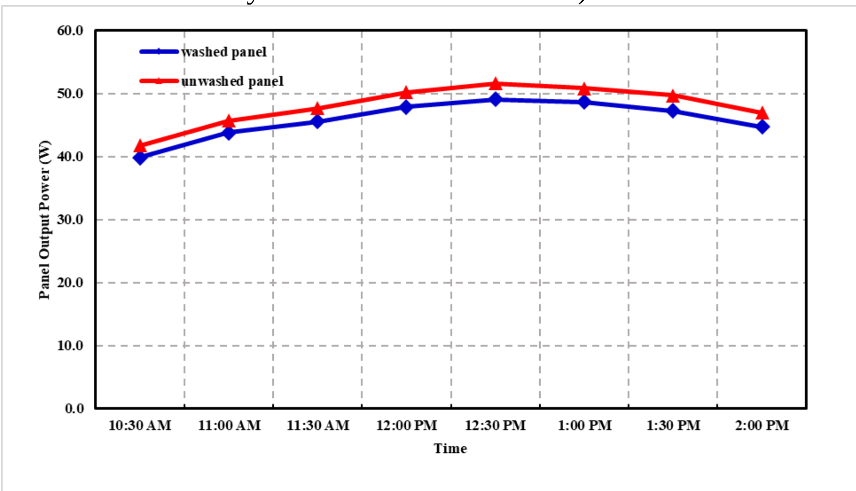

Fig.3: The Panels Output Power in the First Day

The difference in the measurements, of both the washed and unwashed panels, as shown in figure 3 was resolved, throughout this paper, by normalizing the results. As seen in figure 4 the power output of each panel is normalized by the maximum power produced on that first day. The results showed that the difference of the panels outputs was approximately averaged to 5%.

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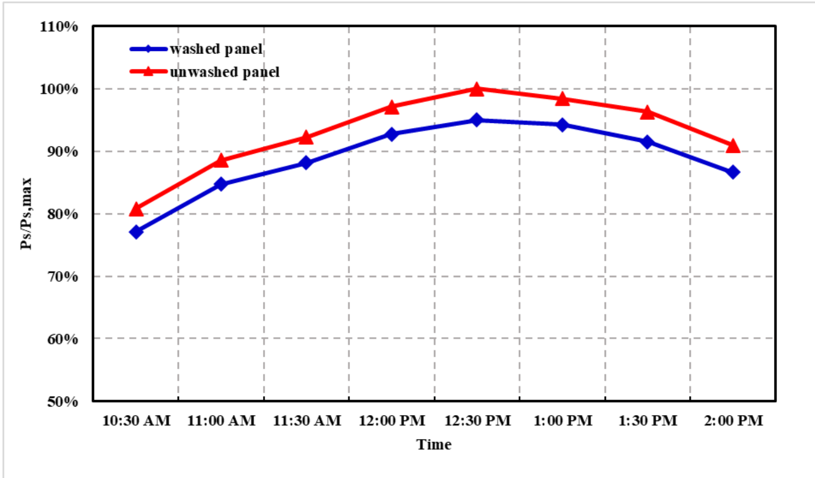

Fig.4: Panels Power Output Normalized by the Maximum Power Output

Some days abnormal readings were observed, especially from the unwashed panel, at certain solar time and irradiance values. This was a consequence of expected variations in the climatic conditions since the experiments had been conducted at the end of the summer and the beginning of the rainy season. This period is recognized to have different changes in the weather conditions. Instead of presenting daily performance, the results were grouped and presented according to fixed solar irradiance throughout the experiments period. Four values of irradiance were selected, namely, 750, 800, 850, and 900W/m^2. Figure 5 shows the normalized efficiency of the two panels exposed to solar irradiance of 750 W/m^2. The dust's effect was clearly observed by the reduction of the efficiency of the unwashed panel as compared to washed one. The drop in the unwashed performance in day 35 was attributed to the accumulation of the dust on that day. However, the rise afterwards shown in day 49 and 63 was due to windy weeks, [25], that washed out some of the dust and also led to a drop in the ambient temperature. The ambient temperature's effects were also observed in the performance of the washed panel as well, see figure 5. The broken lines connecting the data points were used to indicate that what would have occurred between those point don't lie on these lines. So, more experimental data points are necessary to illustrate what would exactly happen.

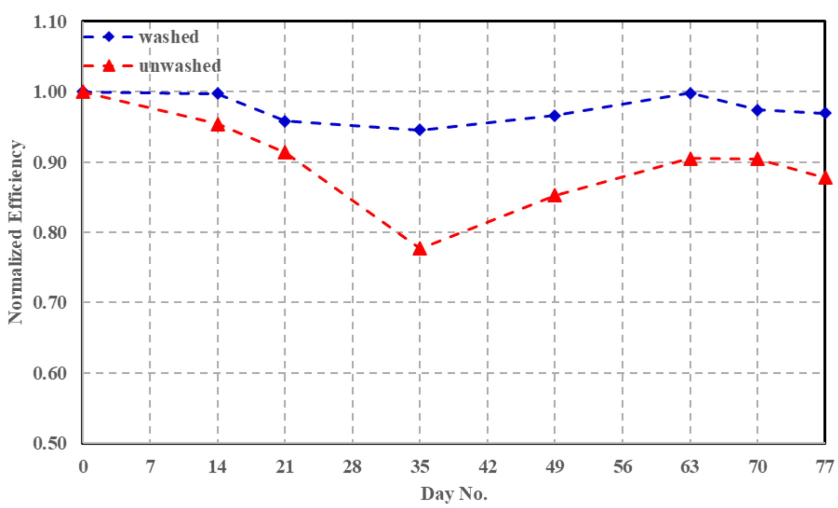

Fig.5: Normalized Efficiency Vs Time at Constant Irradiance of 750W/m^2

Figures 6-8 show the normalized efficiency during the whole period of the experiments. It is worth to mention that a missing point in a day simply means that there is no irradiance reading fall in the range of the figure. The range for each figure data set was established such that any reading within ±25 W/m^2 of the chart designated number was included. Here, again, a dip in the efficiency reappear in day 35 in figures 6 and 7, whereas in figure 8 all the recorded irradiances were out of the 900±25 W/m^2 range. As shown in figures 6 and 8, on day 42 which is May 29th, 2016, noticeable increases in the efficiencies were observed. This was due to windy days that cleared the dust accumulated on the surface of unwashed panel at that time. The wind accompanied by a reduction in ambient temperatures. The wind washed some of the dust and hence the amount of dust accumulated on the unwashed panel's surface was reduced and the low temperature increased the band gap of a semiconductor which led to higher efficiency [25].

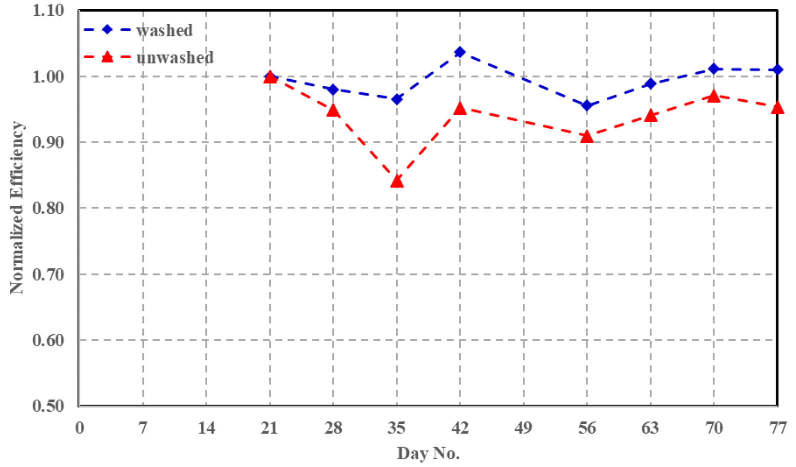

Fig.6: Normalized Efficiency Vs Time at Constant Irradiance of 800W/m^2

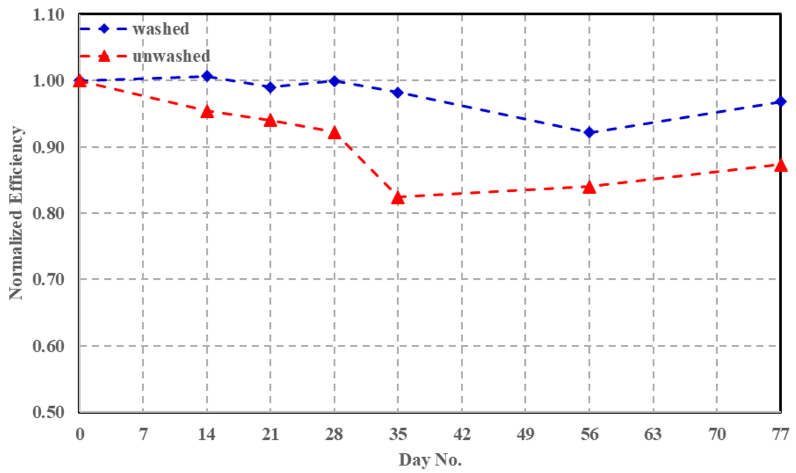

Fig.7: Normalized Efficiency Vs Time at Constant Irradiance of 850W/m^2

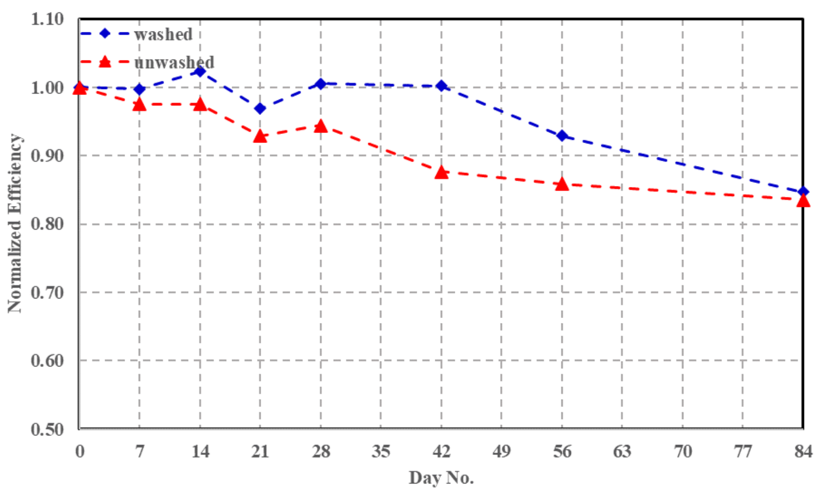

Fig.8: Normalized Efficiency Vs Time at Constant Irradiance of 900W/m^2

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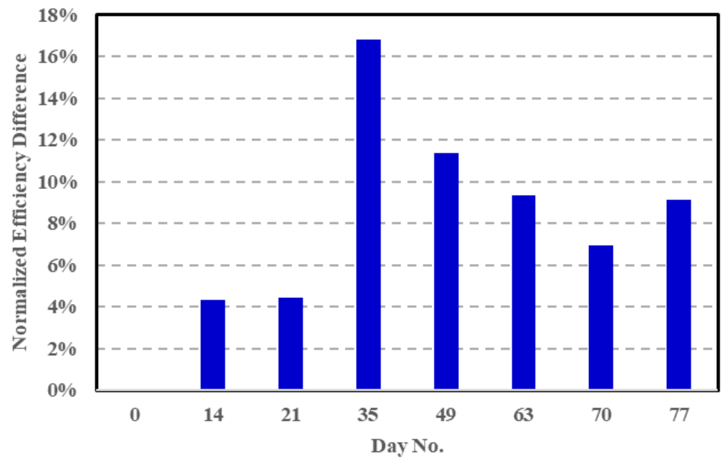

Fig.9: Normalized Efficiency Difference Vs Time at Constant Irradiance of 750W/m^2

For the three months, it was observed, as shown in figure 9 that the normalized efficiency between the two panels was reduced, due to dust deposition, with time in a range from 4.3% up to 16.8% when the irradiance (input) was held constant at 750W/m^2.

5. Conclusion and Recommendation

The effect of dust particles' presence was studied and the power and efficiency reduction of a solar PV module were quantified with outdoor complemented experiments at NERC at Soba, Khartoum, Sudan. The following points could be concluded:

- Reduction in efficiency peaked at 16.8% and bottomed to 4.3% for a irradiance of 750W/m^2 during three months.
- Wind and rain enhance the performance of the solar PV panels. Wind washed out the dust accumulated on the panel's surface whereas the rain cooled the panel by lowering the ambient temperature.

The following further researches and experiments are recommended to enhance the performance of solar PV panels:

- Study the effect of dust accumulation on the performance of the solar PV panels for a whole year
- Define site-based optimum cleaning intervals according to site conditions are recommended to. Also, it is recommended.

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