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The Effect of Soiling and Periodic Cleaning on the Performance of Solar Power Plants in Ma'an, Jordan

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Abstract
Environmental variables such as soiling in the outdoor environment can affect the overall efficiency of solar plants in arid regions with scarce rain negatively. The reduction in power is caused by reducing the amount of solar energy absorbed by the solar panel itself. The cleaning process of the photovoltaic can contribute to a significant cost of the plant operation cost. The objective of this work is to study the effect of soiling and the periodic cleaning process of solar cells in Ma'an district, Jordan. Yearly degradation and performance were studied in outdoor exposure between January and November of 2017. The study found that based on a one cleaning process per month, the worst scenario will cause a power degradation of 2.99% with an average of 2.22% for the whole period of the study.
Keywords: Solar energy in Jordan, Soiling and Cleaning, Performance ratio, Degradation, Photovoltaic solar panels

1. Introduction

The solar photovoltaic system in the studied power plant is composed of solar panels, tracking system, inverters, SCADA system and dedicated computers and software for storing, analyzing data and monitoring purpose.

The solar plant cost with respect to its lifespan can be considered high, since the solar cell's life is usually around 25 years, and it will take up to six years of operation to generate energy that is equivalent to the amount of energy used in its fabrication process (Kannan, 2006). Therefore, a drop in the efficiency of the solar plant can reduce the cost efficiency with respect to its lifespan. Many factors can affect the efficiency of the solar plant. Accumulated dust is one of these factors that depend on the forecast and geographical location.

The solar plant operation and maintenance can cost up to 11% of the Levelized Cost of Electricity (LCOE) according to (Kutscher, 2010), which contributes to the bill price, hence, reducing the cost of the operation and maintenance can lead to lower tariffs in general. One of the costliest processes of the maintenance is the cleaning process, especially in desert areas where water is scarce and soiling is prevailing due to the nature of the environment of arid regions. Therefore, reducing the frequency of cleaning process can lead to a lower electric bill in general.

In order to study the effect of soiling accumulation on the efficiency of the photovoltaic system, several studies were performed in the outdoor and indoor environment to quantify the effect of each parameter on the overall efficiency (Garg, 1974, Goossens, 1999, Syed, 2010, Mekhilef, 2012). Two trends were followed in general, the first one is to quantify the accumulated dust versus time, while the second one is to study dust accumulation versus time and therefore its effect on efficiency (García, 2011, Sulaiman, 2014).

Quantifying the accumulated dust versus time was studied by Boyle in Colorado, USA. Boyle found a dust deposition rate of 1 to 50 mg/m^2 per day. Boyle also found that one g/m2 of dust will cause 4.1% of light reduction (Boyle, 2015). In another work in Egypt by Hegazy, the accumulation rate reported was 150 to 300 mg/m^2 per day (Hegazy, 2001). The clear difference between the two results is due to the difference in the environment variables between the two-studied geographical locations.

The effect of dust accumulation versus time and its effect on the efficiency of the photovoltaic system was studied by several works, including some work in the surrounding region and worldwide. El-Shobokshy in Saudi Arabia quantified the losses in a controlled environment, where particles of cement, limestone and carbons were used under a tungsten halogen light to resemble the source of energy. The study found a reduction of 88% in power performance by adding 253 g/m^2 of dust. Remarkably, the author found the smaller the size of the particle of the same deposition density, the greater the power degradation would be (El-Shobokshy, 1993).

A study by Salim in Riyadh in Saudi Arabia shows a degradation of 32% in the solar system efficiency after eight months of dust accumulation (Salim, 1988). An older study by Nimmo in Saudi Arabia found that the reduction in efficiency can reach up to 40% in six months period (Nimmo, 1979). A study by Adinoyi in Saudi Arabia found that tracking system can help in reducing the accumulated dust by 50%, and un-cleaning the panels for a period of six months can lead to a power loss of 50%. In addition to that, a single sandstorm can drop the efficiency by 20% (Adinoyi, 2013). Mani found that the dust caused a reduction of 32% in eight months period in Saudi Arabia as well (Mani, 2010). A study in Kuwait by Sayigh, it was concluded that a reduction in efficiency between 17%-64% depending on the tilt angle after 38 days of exposure to surrounding environment variable (Sayigh, 1985). In another study by Hassan in Egypt, a degradation in performance of 33.5% and 65.8% were found in the duration of one and six months respectively (Hassan, 2005). Another study in Tehran, Iran by

Gholami found that a 70 days period without rain in the outdoor environment led to the accumulation of 6.0986 g/m2 of dust that caused 21.49% degradation in output power (Gholami, 2018).

In the USA, Hottel and Woertz found a maximum degradation in performance of 4.7% with an average loss of 1% in the period of two months (Hottel, 1942). A study in northern Poland by Klugmann-Radziemska showed a maximum reduction in power of 3% per year, and of course, this is due to the nature of the climate in that region (Klugmann-Radziemska, 2015). The study also showed a reduction in efficiency of about 25.5% per µm of naturally accumulated dust. A study in Italy by Lay-Ekuakille found that leaving the solar panels without cleaning for six years can lead to losses in the performance that can reach up to 73.3% (Lay-Ekuakille, 2017)

(Syed, 2010) in Saudi Arabia made a review study that explored several cleaning processes. Those studies include the natural cleaning process of rain, mechanical and electromechanical dust removal method, electrostatic dust removal, dry hydrophobic surface that uses micro and nano-scale surface fabrication that prevents dust from sticking to the surface of the panels and finally the wet hydrophobic surface that serve the same purpose. The author concluded that there is no optimum cleaning process, and each method has its own strength and weakness, add to that, the author doesn't recommend any fixed frequency of cleaning process since it depends on the frequency of local sandstorms.

In this work, the natural accumulation of sand and dust on motorized solar panels, in a solar plant with a one cleaning process per month will be investigated to find the effect of the soiling and cleaning on the overall efficiency of the plant in Ma'an, Jordan.

2. The Cleaning Process of the Solar Panel's Experiment

The experiment itself simulates the real-life situation in power plant system. The main problem in cleaning the solar panels that it depends on the nature the photovoltaic panel (PV) terrain. In the station location, the panels are located over natural terrain, where the level of the ground is irregular; therefore, an automated cleaning process is not possible. Hence, the only way to clean the panels can be manual, which is a costly, tedious and lengthy work. Therefore, an estimation of the efficiency reduction overtime can help in reducing the expenses of the cleaning process by estimating the most proper period for cleaning.

Another problem with the cleaning process is that the cleaning water temperature should be less than 20 degrees warmer or colder than the panel's surface temperature (First Solar, 2017). Otherwise, exceeding the 20 degrees difference in temperature between the water and the surface of the panels will affect the panels and might cause some minor cracks and lead to an electrical shock to those performing the cleaning process. Therefore, if the water temperature is beyond the recommended value, heating or cooling the water will add an extra cost to the total bill of the electricity.

The experiment was performed outdoors in the same location of the solar plant. The measurements were conducted to quantify the effect of the natural soiling and cleaning process on the solar plant. During the period of the experiment, these cleaning processes were performed only according to the schedule; the cleaning process was performed with filtered deionized water only.

3. Experiment Apparatus and Setup

The data were obtained from a test sample that contains two separate photovoltaic panels of the same type mounted on the same beam, with a tracking system to increase the overall efficiency of the power plant. The first panel is cleaned every day, while the second panel is cleaned only when the scheduled cleaning is performed on the station. The interval of each cleaning is performed once a month. In some cases, an emergency cleaning may be performed after a sandstorm or when the difference in the efficiency between the test panels exceeds 2% as recommended by the manufacturer's manual.

Figure 1. Set-up of the daily and monthly-cleaned PV panels with the pyranometer

The solar irradiance was measured by the weather station in the location of the solar plant; however, the pyranometer was used on the same arm with the two cells for better accuracy. Figure 1 shows the two calibrated MET cells in addition to the pyranometer fastened on a motorized arm to track the sun for maximum efficiency. The dimensions of the panels were 266 mm by 266 mm by 35 mm. For the measurement of voltages and currents, a software was used to measure continuous readings for every minute during the period of the study.

4. Results and Discussions

The results contain two sections; the first is about the data obtained from the weather station in the power plant, while the second one contains the data obtained from the two PV panels.

4.1 Weather Station Results

The solar station is located in Ma'an district, Jordan. Based on recorded readings of one year of the weather station in the panels' area, the average daily value of the global horizontal irradiance (GHI) is 6.1 kWh/m^2. With a maximum value of 8.3 kWh/m^2 recorded in August and a minimum value of 1.2 kWh/m^2 recorded in January. The average daily value of the plan of array (POA) is 8.3kWh/m^2 with a maximum value of 12 kWh/m^2 recorded in June and a minimum value of 1.1 kWh/m^2 recorded in January. Knowing that, the shortest day in Jordan has 10 hours of the sun in January while the longest one has 14 hours in June ("Time and Date," 2018). Which gives it a huge potential for solar power generation.

4.2 Effect of Dust on the Overall System Performance.

The effect of dust and cleaning process on the panel is quantified by tabulating the average power of the daily cleaned and monthly-cleaned panels starting from first of January 2017 until October 31 of the same year. Table 1 shows the values of the GHI, POA, panel's monthly average power per month and the percentage difference between the average power of the two panels. The percentage difference in power was calculated according to Eq. (1).

$$\Delta P = \frac{P_C - P_{PC}}{P_C} \times 100\% \quad (1)$$

where P_C, represents the output power of the daily cleaned panel, P_{PC}, represent the output power of the monthly cleaned panel and ΔP, represent the percent difference between the power of the two panel. Both panels were subjected to the same weather variables during the experiment, the power was recorded per minute and summed up to give finally the monthly power. Then the monthly-cleaned panel was cleaned at the end of the month, and the data was collected for each month in the same manner.

It is shown from the results of Table (1) that the maximum percentage difference of power between the two panels occurs in January and August, where January tends to have a windy weather with very scarce rain, while August tends to have a windy and very dry weather. The difference in power for both months' show a reduction in power of 2.99% and 2.98%, which is above the recommended value by the manufacturer of 2%. Seven months out of the ten months surpasses the recommended value as shown in Figure 2; however, the extra loss in power in its worst form does not exceed 1% of a difference in the power. Therefore, a monthly cleaning process can be sufficient to maintain a healthy status of the system without wasting extra cost on the cleaning process.

Table 1. The GHI, POA, output power of the panels and the percentage difference of the power

Month	GHI kWh/m^2	POA kWh/m^2	Cleaned Panel Wh	Uncleaned Panel Wh	Percentage Difference of Power %
Jan	117.8	163.7	854370	828814	2.99
Feb	134.5	196.6	1048649	1029715	1.81
Mar	187.8	258.3	1407046	1371507	2.53
Apr	212.2	280.6	1537657	1504229	2.17
May	249.2	333.8	1873881	1848424	1.36
Jun	250.3	338.7	1914802	1886931	1.46
Jul	245.6	320.1	1767574	1724088	2.46
Aug	235.2	314.8	1741675	1689788	2.98
Sep	184.4	253.2	1548597	1516067	2.1
Oct	160.7	221.9	1292212	1263905	2.19

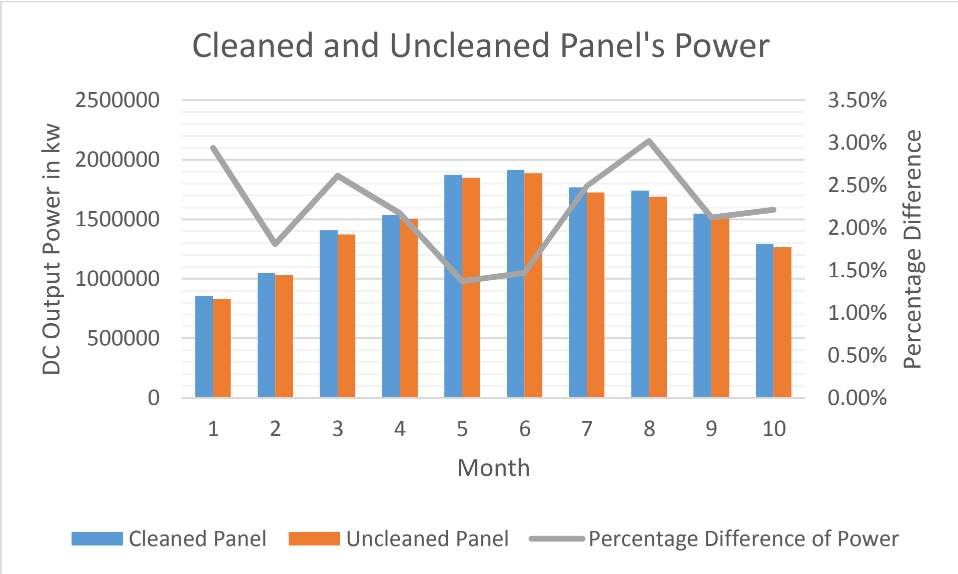

Figure 2. The DC output power difference between the daily and monthly-cleaned panels with percentage difference.

5. Conclusions

The effect of the dust of the outdoor environment on solar cells in Ma'an district was studied to conclude the optimum cleaning process schedule for a power plant located in the area. It was found that, due to the sunny nature of the area and lack of rain, that the dust has a minimal effect on the plant performance if the cleaning process was performed periodically on monthly basis. The experimental tests showed that the worst effect of dust could cause a loss of 2.99% of power per month. The wind and tracking system contribute naturally to the cleaning process; hence, an exaggerated cleaning process will become costly and tedious with respect to the gained efficiency in general. Based on the operation manual, a drop of 2% in power efficiency requires a cleaning operation for the whole plant. Based on the results, the average power degradation was 2.22% per month, which in turns means a monthly cleaning process can be sufficient to maintain a healthy power plant status.

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