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Comparison of dust and high-temperature effects on mono and poly photovoltaic panels

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Comparison of dust and high-temperature effects on mono and poly photovoltaic panels

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Abstract. Solar Photovoltaic Panels are considered as one of the most powerful alternative renewable and sustainable energy sources. However, a major challenge is the effect of dust accumulation on the photovoltaic panels in natural outdoor environment as it reduces the transmissivity of the light on the surface of the solar panels. For many small communities, the decision of implementing mono or polycrystalline PVs should consider economic aspects. This study is a case study that is held at The British University in Egypt at El Sherouk city to study the effect of different parameters such as dust accumulation, water cooling and coating on the performance of both mono- and poly-crystalline panels at El-Sherouk City. The effects of high temperature and dust accumulation on different solar panels placed in natural outdoor conditions at El- Sherouk City are studied and the electrical performance of the solar panels is represented by measuring several characteristic parameters of dusty and cooled PV panels compared to cleaned and non-cooled panels. The effect of the tilt angle on the accumulation of dust on the surface of the solar panels is, also, studied. The mono-crystalline solar panels are installed at tilt angles 0°, 15°, 30°, 45°, and 60° for one month without cleaning, by any method. The results shows that the power reduction percentage is 17%,20%,25%,27% and 30% for tilt angles 60°,45°,30°,15° and 0°; respectively. Tilt angles 15° and 30° show to be optimal for the installation of the PV solar system, as they produce the highest amount of output power. It is found from the study that the accumulation of dust on the surface of different types of solar panels can reduce the efficiency by 30%. While the high temperature can reduce the efficiency by up to 10 %.

1. Introduction

Integrating renewable energy has become a key role in the growth and development of societies. Advanced and emerging societies are working towards increasing the renewable energy input from different sources such as solar energy, wind, hydro, etc.. as the movement towards renewable energies as an alternative to fossil fuels has become an important energy sustainability requirement. Considering the vast potential of renewable energy resources in the Mediterranean region, the development of efficient technologies for using renewable energy represents a key issue for sustainable growth in the region. In line with its 2030 development vision, the Government of Egypt has encouraged small investors and local communities to integrate solar energy in their residential facilities, as well as large investors to contribute in building power stations [1-4].

Figures 1 and 2 show the great development in solar PV capacity during the period from 2010 to 2019. Where, Figure 1 shows the world's capacity from solar Photovoltaics while, Figure 2 shows the recent massive development in Egypt's Solar PV capacity especially during the recent 5 years to achieve Egypt's vision 2030 which aims to achieve a diversified, competitive, and balanced economy within the framework of sustainable development as detailed in the Integrated Sustainable Energy Strategy in 2035, released by the Ministry of Electricity and Renewable Energy in 2015 [5].

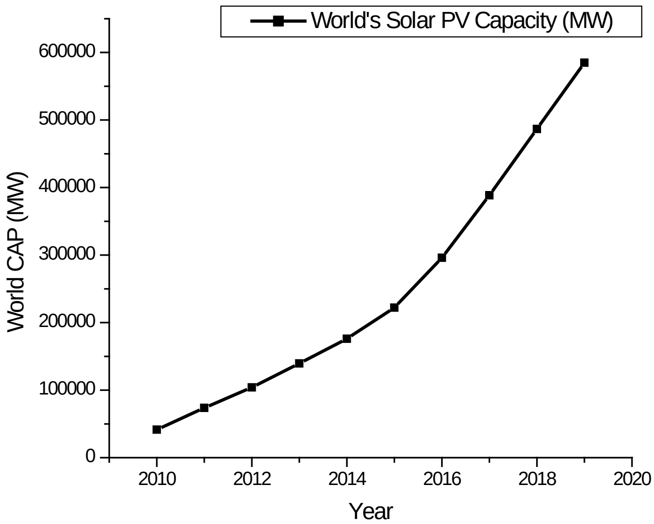

Figure 1: The World's Solar PV Capacity [5]

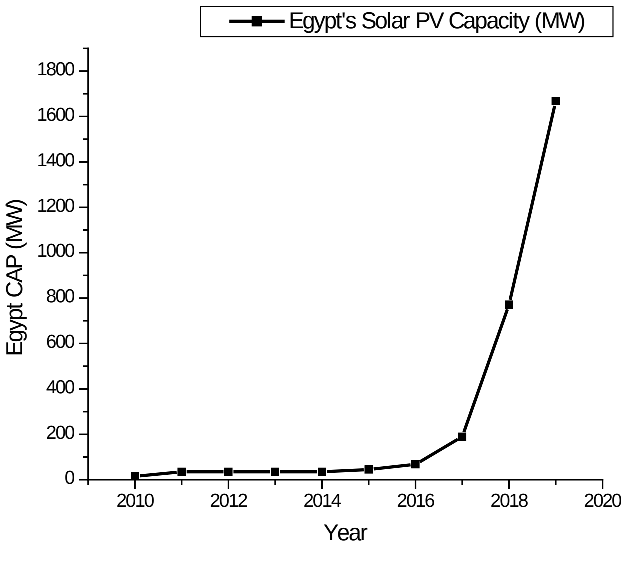

Figure 2: Egypt's Solar PV Capacity [5]

However, a major challenge associated with PV technologies in Egypt as well as other regional environments is its degraded performance with environmental conditions such as temperature, wind, dust, clouds, and shade, encouraging research on mitigation methods [6]. Examples include the concept of photovoltaic/thermal (PV/T) systems. The PV/T system can improve the cell's production, and electrical efficiency along with taking advantage of stored heat for other applications using air, water, nanomaterials, and phase-changing materials with nanofluids to cool the PV cell [7].

Among these weather condition factors that negatively affect the performance of PV cells is the accumulation of dust and pollutants on the cell surface, which reduces the transmissivity of the light on the surface of the solar panels and acts as a barrier between PV and solar irradiation. The impact of Dust on PV efficiency is one of the most important problems facing PV utilization in dusty countries. Additionally, the amount of dust suspended in the air, which reduces PV efficiency in desert areas causes efficiency degradation reaching 8.41% from the maximum power in dusty PV modules compared to cleaned ones [8].

The impact of dust accumulation on the PV panel surface has been studied with excessive concentration because of its great importance, particularly in the solar countries. Dust accumulation in desert countries can cause a cell electrical efficiency degradation up to 40% [9]. Studying the impact of dust accumulation on PV systems in Egypt has indicated up to 17.4%/month degradation in PV efficiency for the PV systems installed at 45° angle to the south. The effect of the PV tilt angle on accumulated dust was studied experimentally using 100 glass samples. The results revealed that dust deposition decreases with 70% for tilt angle 90° compared to tilt angle 0° for the same conditions [10]. On the other hand, the degradation in PV productivity due to dust accumulation was reported to reach 31–35% in Qatar, which is characterized by its high relative humidity and it's attached to the desert [11]. The intensity of the dust increases as the sun’s surface warms and wind speed increases. Dust follows the density of the type of land that passes through it, In addition to, humidity, wind deviation, and air altitudes. These factors are changeable with different locations consequently, dust accumulation effects can differ from one place to another [12].

Most of the photovoltaic installations in desert areas suffer from a loss in efficiency due to the accumulation of dust, airborne dirt, sand particles from sandstorms, and high temperature in the summer season. So, to sustain a steady performance of PV panels, regular cleaning is required. However, the traditional methods of manual cleaning are energy, labor, and time-consuming processes. Another disadvantage of manual cleaning is the introduction of cracks and scratches on the PV surface. Researchers and engineers around the globe have been developing new cleaning methods, namely electrostatic, mechanical, and coating methods. Cost-wise, the electrostatic and mechanical methods are more expensive than most coating methods. The development of low-cost coatings is, therefore, an attractive goal for many researchers. The adhesion of soiling on PV arrays results in a significant loss in their energy harvesting efficiency and can be drastically reduced by applying a hydrophobic or hydrophilic coating to the cover glass surface. Even if soiling occurs, the effort needed for cleaning is reduced, reducing costs significantly. However, the effect of sand erosion can cause the coating to deteriorate.

In this context, the British University in Egypt (BUE), which is located in a newly built area, works on solving the problems of its natural environment and community and has been working during the last year on evaluating and analyzing data showing the impact of dust and temperature rise on the performance of three different types of photovoltaic solar panels, mounted at BUE premises at El-Sherouk area. El Shorouk essentially has a hot desert climate, generally extremely dry all over the capital in addition to rarity of rain, extreme heat during summer months is also a general climate feature of El-Shorouk although daytime temperatures are more milder during autumn and winter.

2. Experimental Setup

The experimental work includs three different phases. The first phase aims at studying the effect of dust and cooling. Figure 3 shows the Mono and poly-crystalline panels, where they are held on 30° tilted holders and directed to the South direction. The experiment is held on two different solar panels; monocrystalline with 280 Wp and polycrystalline with 270 Wp. The tested panels are of dimensions 1.6 m height * 1m width and total area 1.6 m^2. The system is installed in a natural outdoor area.

Figure 3: Tested solar panels held on 30° tilted holders facing South direction

A PV solar analyzer is used to measure solar radiation, the temperature of solar panels through wireless sensors, and develop the I-V characterization curve. The measured parameters are the short circuit current, the maximum current, the open voltage, the output power, and the weather parameters, solar radiation, and the panel's surface temperature. Table 1 shows the specifications for PROVA 1011 solar analyzer.

Table 1: PROVA 1011 Specifications

Dimension:	257(L) x 155(W) x 57(H) mm
Battery Type:	Rechargeable Lithium Battery (3400mAh)
Solar Detector	Remote Solar Detector
Temperature Sensor	Thermometer (connected wireless to the solar Analyzer)
Data Transfer	USB cable

The second phase included the study of the tilt anlgle effect in the range of 0° to 60° (by changing the facing angle by manual methods) on dust accumulation and the efficiency degradation for dusted panels. The measurements are taken for one month (May). While the third phase includs seven- days measurements of the same panels after applying a simple formula coating layer on the panels with average radiation of 950 W/m^2. The third part of experiments was performed to study the effect of accumulated dust and cooling effect on mono and poly crystalline solar panels where measurements were performed for three consecutive days in July, each with different conditions as shown in Table 2:

Table 2: Test conditions

Day (average Irr. = 950 W/m^2)	***Tested conditions***
Day 1	Panels with accumulated dust for one month
Day 2	Cleaned panels
Day 3	Cleaned and cooled panels

3. Results and Discussion

The radiation and temperature were measured for one year to calculate the average solar energy kWh/m^2/day over the months of the year in Egypt and is shown in Figure 4. The data were measured using the BUE weather station (WS-GP1) and data was logged at 5-minute intervals. The Figure shows the monthly incident solar radiation at a module inclination angle of 30° in the BUE location at Sherouk City Cairo, Egypt. Which is located at the northeast of Cairo and characterized by its desert hot climate with latitude 30.144212 and longitude 31.639718. The Figure shows high solar irradiance for the specified location, especially in the summer months. Also, the figure displays an example for a typical daily average solar radiation for this location for the month of March which ranges from 295 W/m^2 to 652 W/m^2.

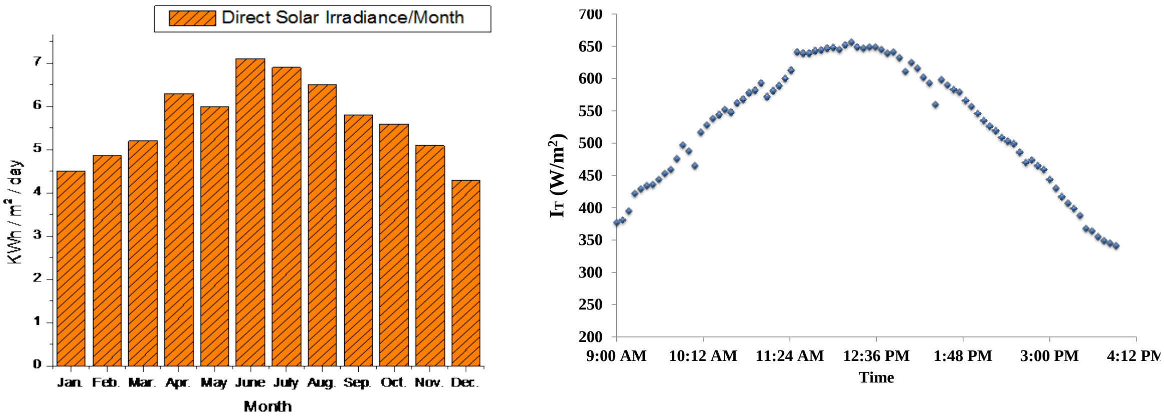

Figure 4. a) The average solar energy kWh/m^2/day over the months of the year in Egypt, b) Typical daily solar radiation measurement for El-Shorouk city, Egypt.

3.1 Effect of tilt angle on dust accumulation

A test was performed to figure out the optimal tilt angle of the PV modules to be installed in the specified location. Figure 5 shows that the efficiency of angles 15° and 30° are the highest compared to the output power of the other angles. Therefore, the optimal tilt angles to be used in the installation of the solar panels are preferred to be in the range of 15° to 30°, followed by angle 45°. The results of angle 0° are approximately near to the results of angle 45°. Therefore, it can be also used in specific conditions if there are no options in choosing the installation angle. Angel 60° has the lowest power output because of the high tilt angle and the lower radiation reaching the solar panel. Therefore, angle 60° is not preferred to be used.

The results presented in Figure 5 show that the panels with tilt angle 30° produce higher power than those with tilt angle 15°, at the start of the experiments, which indicates that the solar panels with a 30° tilt angle produce the highest power in clean conditions. Though the tilt angle of 30° remains the highest in power output, the difference between the inclination angles tends to decrease towards the end of the one-month experiment upon becoming dusty. The Figure shows that the difference between the output power values decreases till it reaches a minimal after 30 days with dust accumulation on the solar panels. The maximum value for difference occurs in the first week in favor of the clean panels. It can be concluded from the curve that the output power is highly influenced by the tilt angle for the clean panels, while the effect of the tilt angle tends to decrease for the dusted conditions for both inclination angles of 15° and 30°.

Figure 5.a PV panels at different tilt angles

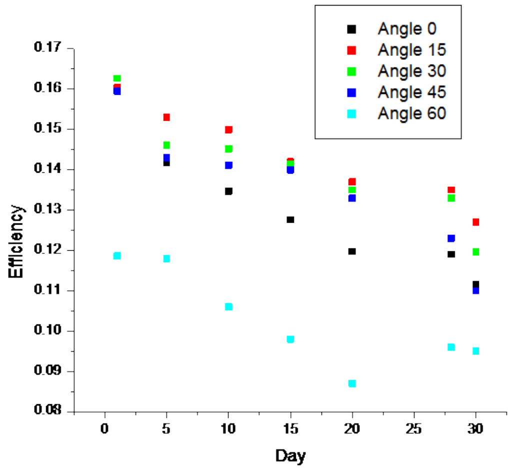

Figure 5.b The output power for different tilt angles for Mono/290 Wp

Figure 6 shows the average reduction in the PV out power over a month for the given tilt angles. The average reduction is about 14 % in the first two weeks for the tilt angle of 30°, which is reduced to about 8 % for the next two weeks of the month. However these values increaded for the lower tilt angles and reduced for the higher tilt angles. This implies that, the best cleaning period for the panels is two weeks of dust accumulation to avoid the effective reduction in the output power.

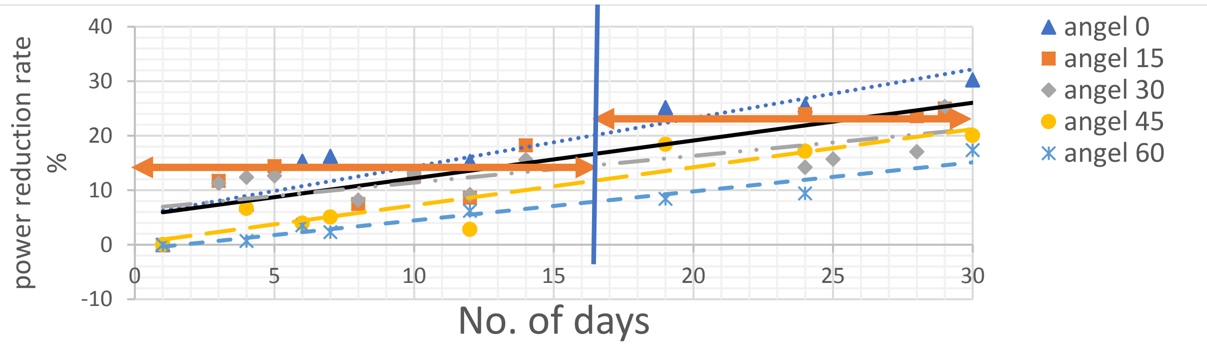

Figure 6. Power reduction rate for the Mono/290 Wp panel at different tilt angles

3.2 Combined effect of dust and temperature rise

Figures 7 and 8 show the performance of mono and poly-crystalline solar panels with the accumulation of dust and the cooling effect. First is the irradiance effect, which can be seen in the 2 graphs, as the efficiency of the panels increase from 09:00 Am reaching its maximum at 12:30 PM, which is approximately the time at which there is maximum irradiance. Efficiencies of the panels then start to decrease till the end of the testing interval as the irradiance also starts decreasing with time. Second, is the dust effect which is shown by the efficiency increase by 20 ~ 30% after it was cleaned on the second day of testing.

Third, is the effect of water cooling, where the panels were cooled every 2 hours. The curves for all types show higher efficiency by approximately7 % than the cleaned panels. The temperature of the panels at noon is usually around 58°C on a normal day without cooling compared to an average of 44°C obtained directly after cooling. The solar panels' efficiency was calculated by the following equation:

$$\eta = \frac{V_{OC} * I_{SC} * FF}{P_{in}} \quad (1)$$

Where V_{oc} is the open-circuit voltage; I_{sc} is the short-circuit current; FF is the fill factor and η is the efficiency.

As shown from Figures 7 & 8, the most important factor that affected the solar panels' performance was the dust accumulation on the surfaces. Thus, another test was performed to study the performance degradation due to dust accumulation by placing initially cleaned panels in the same place and keeping them without removing dust for four weeks.

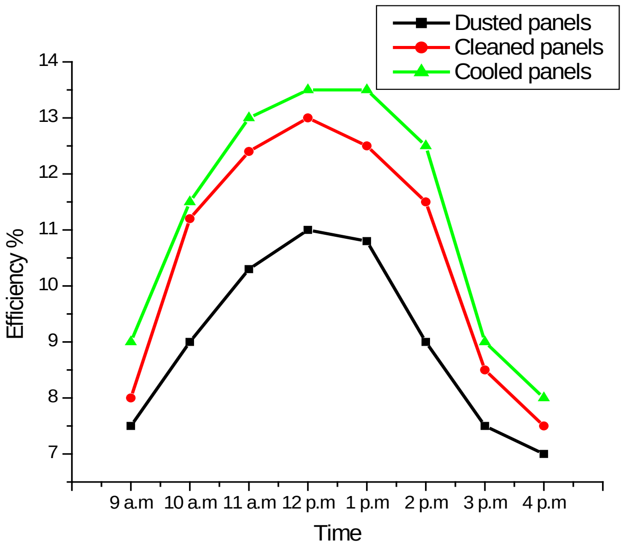

Figure 7: Monocrystalline-280Wp solar panel's efficiency measurements for three different conditions

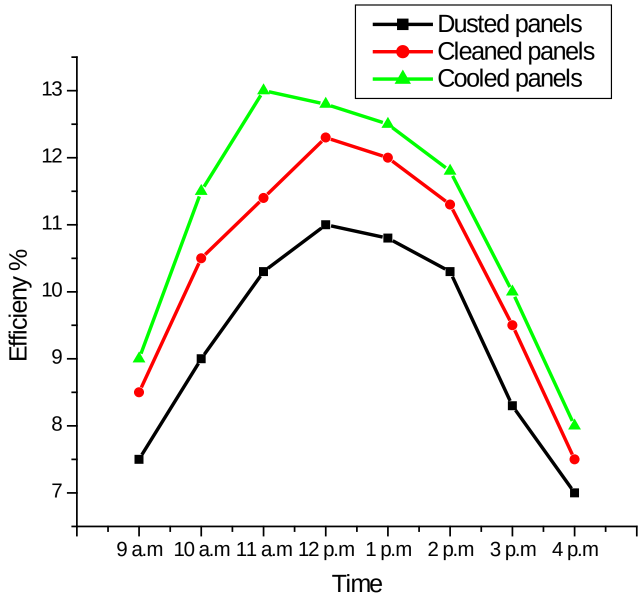

Figure 8: Polycrystalline-270 Wp solar panel's efficiency measurements for three different conditions

Figure 9 shows the electrical efficiency degradation during the examined period under approximately the same temperature and solar radiation conditions for the two different solar panels. The Figure shows that linear degradation starts at a maximum value of 10 % with clean conditions and the degradation keeps increasing up to the four testing weeks without cleaning, which reflects the big influence of dust accumulation on the solar panels.

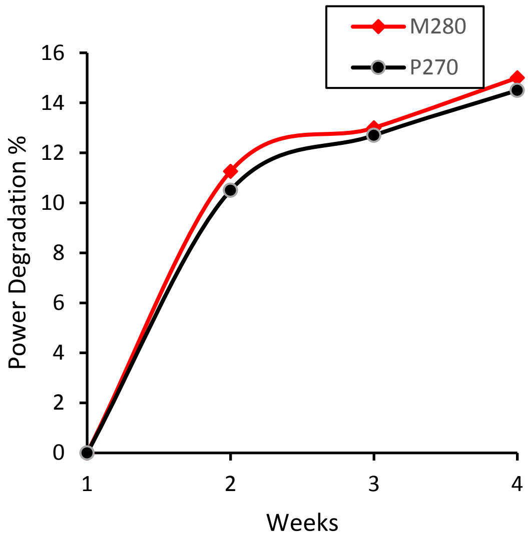

Figure 9: The electrical efficiency degradation during the examined period for poly- and monocrystalline Si modules

Finally, the effect of heat on solar PV efficiency is illustrated in Figure 10, where the temperature was measured for M/280 and P/270 solar panels at the same solar radiation (900 W/m^2) for different panels' temperatures. The curves show that the increase in temperature by 10^o results in a degradation of approximately 7 % in the panel's efficiency

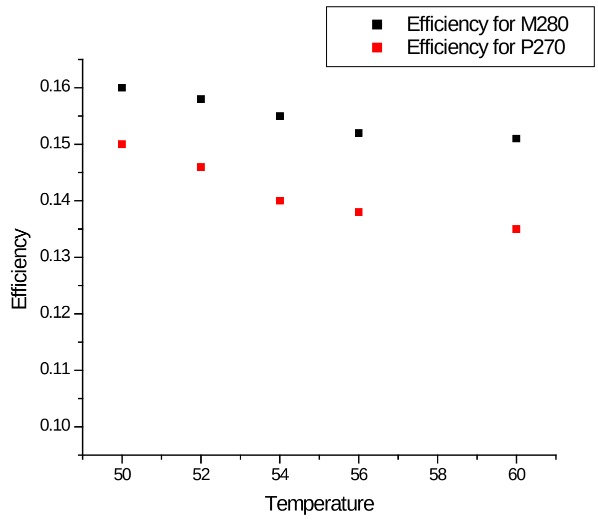

Figure 10: Effect of Temperature on PV efficiency

3.3 Effect of applying self- cleaning material

The previous results emphasize the significance of adopting self-cleaning technologies for PV systems installed in Egypt. Cleaning solar panels is one of the most important and economically urgent problems for the Mediterranean countries. Currently, most solar panel installations rely on one or a combination of these cleaning methods; natural methods (rain and wind), mechanical methods (manual cleaning, or scrubbing), and passive self-cleaning technologies. The cleaning method is summarized as natural means, mechanical means, self-cleaning nano-film, and electrostatic means [13]. However, there is an urgent need to develop a coating material that will mitigate PV cells' degradation in efficiency with soiling and increased temperature during service.

A simple formula for a self-cleaning coating was investigated at the Center of Renewable Energy Lab (CRE). The prepared material was made-up of Glycerin and Al_2O_3 nanoparticles. The nanoparticle concentration was 5wt% of the base carrier and was prepared by applying magnetic stirring for one hour. The design of the coating material was based on nano-materials properties that have been observed in other applications (e.g., enhanced absorbance of nanoparticles observed in selective solar applications, or good heat storage capacity observed in polymeric based materials used for phase change materials. Figure 11 shows the P/270 solar panels; one without coating and the other after applying the prepared nano-coating, to compare between measured efficiencies under the same weather conditions.

Figure 11: Solar Panel after applying the prepared Nano-coating

The results which were obtained after applying the prepared coating for one week and repeating the measurements at noon each day are shown in figures 12 and 13. The reported results show an improvement in the solar panel's obtained output power by about 1%. The results at the beginning of the experiments show a decrease in the panel's temperature of approximately 5°C and a 1 % increase in electrical efficiency. Figure 13 (showing the change in electrical efficiency through the seven testing days) confirms that the electrical efficiency of the coated panels increased during all the examined periods above the uncoated panels, even though the temperature records showed lower temperatures for the uncleaned conditions.

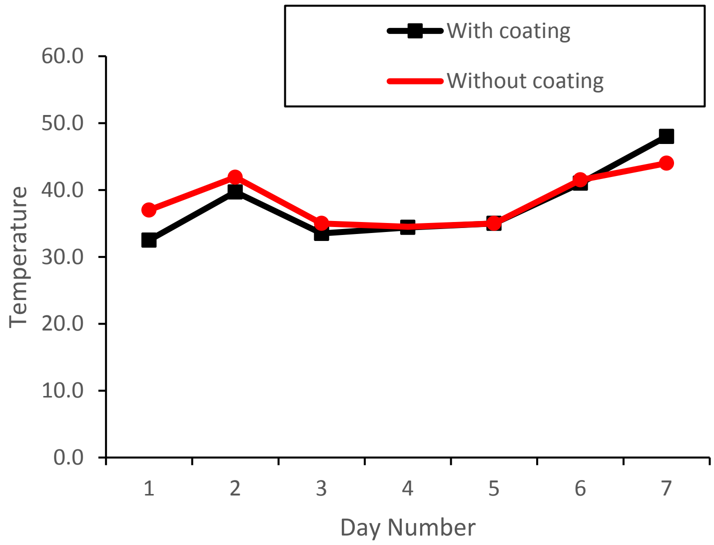

Figure 12: The temperature improvement for Mono/290 Wp

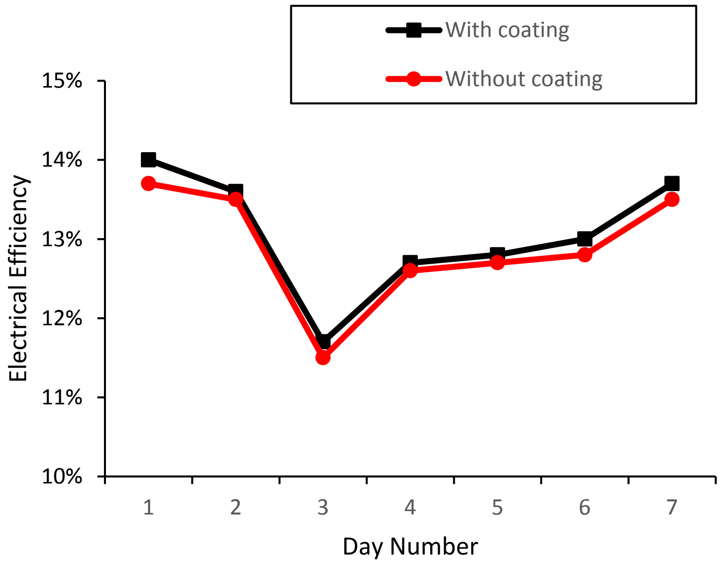

Figure 13: The output power improvement for Mono/290 Wp

The fact that all methods based on coatings have problems with environmental stability requires need for automatic sensing and cleaning of solar panels to keep them free of contamination all the time. This could be realized using technology, which would sense contamination and start cleaning immediately, without human intervention. The new emerging technologies that manage the transition of the ultrasonic cleaning process from a bath environment directly to the object being cleaned—solar panel—are poised to have great success in satisfying growing solar power generation market requirements [14]. The problems associated with manual cleaning result from mechanical impact like scratching by additional wiping, removal of stubborn deposits, the impact of hail, etc. And unfortunately, the better the self-cleaning performance (better super-hydrophobicity), the worse the environmental stability. Better hydrophobicity means a higher aspect ratio of nanostructures, which are more prone to damage by mechanical impact. Chemical resistance of hydrophobic coatings, especially in prolonged contact with water and acids in the rain is also problematic. Photocatalytic coatings contain nanoparticles, which could be released into the environment [14].

4. Conclusions

The effect of irradiance, high temperature, and dust accumulation has been studied on three different solar panels. The reduction in efficiency due to high temperature can be up to 5% while, it reaches 20% due to dust accumulation in all studied types. The degradation in electrical efficiency has been also studied and shows that solar panels may reach half their maximum values after only one month without cleaning in Egypt's weather conditions. The optimum tilt angle has been shown to be 30^{o} for Egypt's conditions. The effect of the tilt angle tends to decrease for the dusted conditions. The application of self-cleaning coating has increased the efficiency by about 1%.

Acknowledgment

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