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Cleaning frequency of the solar PV power plant for maximum energy harvesting and financial profit

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ABSTRACT

Cleaning frequency of the solar PV power system plays a major role in energy harvesting. This paper proposed an optimized cleaning frequency for the PV power plants. The objective is to maximize energy harvesting and increase financial profit. The proposed technique is tested in roof top grid connected 20 kW PV power plant in Cairo, Egypt. Experimental results are collected for one year throw the period from January 2021 to December 2021 based on real time monitoring under the regular cleaning of the PV plant every fifteen days. The collected data and results are used for deriving a formula to find the optimal frequency for cleaning the PV cells. This formula can be used for any PV power plant under different operating conditions. Therefore, the formula can detect the financial losses due to the dust accumulated on the surfaces of PV panels. The model proposed in this research is verified by the comparison between the generated power from the photovoltaic power plant and the cost of cleaning (water and cleaning workers) in case of manual cleaning, taking into consideration the various operating conditions though whole the period of the study.

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1. INTRODUCTION

The accumulation of dust on the surfaces of PV panels significantly degrades the access of solar radiation to them, and to prevent the loss of energy resulting from the dust accumulated on the surfaces of modules requires frequent cleaning of PV systems, its availability depends on the geographical location of solar plants [1]. There is a range of existing water pumping systems in Sharjah that rely on traditional and renewable energy sources like solar photovoltaic panels, mechanical types of windmills, diesel generators and wind turbines. that are influenced by environmental factors [2]. According to the international energy agency (IEA), Solar energy is on track to become the largest electricity supplier by 2050 [3]. The rate of maximum dust deposition has indicated for the 150 µm dust particles and tilt angle of 155°, the rate of dust deposition is 9.78%. In the same direction [4]. Photovoltaic (PV) systems are a source of renewable energy because they are friendly for the environment and affected by weather conditions [5].

The cooling of the solar power plant has an important topic of study, particularly, the dryer cooling system used in hot and humid areas. The dry cooling resulted in a 9.5% improvement in the output solar energy [6]. There are many types of painted paintings on the market that prevent dust from sticking to the surface of PV modules, the results showed that the electrical efficiency rate of PV panels for painting, mechanical vibrator reduced by 12.94% within (6) weeks of commissioning [7]. The reliability and efficiency of the PV systems were shown to be dependent on the factors of the surrounding environment [8]. Automated cleaners that are mainly found in large arrays are used to clean PV modules generally in dusty environments such as in tropical countries like India [9]. There has been a reduction in energy of more than 50% for solar modules if the modules are left unclean for six months [10]. Partial shading conditions are a factor that has an important impact on photovoltaics (PV) generation as they significantly reduce power generation [11], [12]. Applying different methods of cleaning solar PV modules can significantly increase efficiency of the generated electricity and solar panels durability [13]. The daily average of energy losses over one year due to the accumulation of dust on the surfaces of the photovoltaics is nearly 4.40%. The study indicates that PV losses due to dust accumulation are an unabandon able problem and may be a problem for achieving renewable energy targets in Nigeria [14]. The efficiency of PV modules decreases because of dust and temperature in addition to wind speed on the power conversion process in the unit by 2.1% [15]. To demonstrate the effect of dust in coastal areas on the performance of the grid-connected PV, a set of experiments were carried out on dirty and clean PV modules under normal conditions in order to find the electrical properties [16].

It contains a hybrid power system for pumping water. On two main renewable energy types: wind turbines and solar photovoltaic arrays where the system is affected in environmental conditions like wind speed, humidity and solar radiation [17], [18]. The impact of weather factors on the efficiency of PV systems was investigated, the results presented a big decrease in efficiency of the photovoltaic cells due to the environmental factors by 2.2 kilowatts per day [19]. Some countries contributed at reducing the emissions of the greenhouse gases. Moreover, they have improved access to generate the most electricity due to their various environmental conditions [20]. It was studied also the influence of the measurement period on the production of photovoltaic stations in the region of Tampere in Finland. It was shown that even shorter periods can reduce the profits of the PV systems [21]. An empirical study was conducted to evaluate and analyze the energy efficiency of the mounted PV plant, and the performance of a dusty photovoltaic array was compared with another one clean array of the same photovoltaic system. The clean solar PV array is equipped with an automatic spray cleaning system which is powered by the photovoltaic power system [22]. Finding dust is considering a significant problem that cannot be ignored regarding energy losses, as the effect of temperature, dust, and wind speed, the results showed that the efficiency was decreased by about 2.1%, experimental study of MPPT for solar PV plant at different weather factors [23], [24]. Making use of green energy types is necessary to reduce environmental degradation. Harvesting of energy is a replacement for achieving bigger scale in hybrid vehicles [25].

A comparative study of various solar panel cleaning methods is conducted in this article where the innovative idea of dust separation from PV modules is focused on by means of an electrostatic precipitator (ESP) [26]. The results of this study provide optimal performance of the adopted models when comparing real power output with R2 & root main square error ranging from 0.93 to 1.56 MWh for both substations [27]. The effect of dust accumulation has been analyzed which mainly depends on the slope, direction, surface roughness, type of coating, other external factors such as wind speed, humidity, temperature, and regional characteristics like traffic and air pollution which play a very important role in deposition of dust [28]. There are several techniques that can be used for cooling of the cells of the photovoltaic [29]. Cleaning technology for Solar PV can greatly enhance the efficiency of the generated electricity and solar panels durability [30]. The impact of deterioration and escalation in prices of electricity, inflation on cleaning revenues and costs is studied and a methodology is proposed to increase the pollution mitigation profits of any power plant [31]. Factors affecting the performance and usability of PV arrays are discussed in decision-making models for intervention of cleaning. With some highlights on the core of cleaning to mitigate pollution problems in PV plants [32]. The presence of a group of environmental factors like dust which causes loss in energy production of 0.4-0.7% [33].

The temperature affects directly on the performance and efficiency of the photovoltaic cell [34]. The different climatic conditions like, temperature, solar radiation, humidity, and accumulation of dust on PV system performance in addition to develop an empirical formula that used for detecting the energy loss due to these conditions [35]. This paper aims to investigate the cleaning frequency of solar PV power plant for maximum energy harvesting derivation of the financial losses and represent the relation between o/p power and cleaning cost in a mathematical model.

2. METHODOLOGY AND MATERIALS

These experiments that assess the performance of the photovoltaic energy system under normal environmental conditions were conducted on a solar power plant located on the upper surface of one building that is based in Cairo, the capital of Egypt. The system used for this work consists of a group of photovoltaic panels connected to each other so that they can provide 20 kilowatts. The station is located in the city center of Cairo (latitude: 30.1 north, longitude: 31.3 east) where the current measurements were made. Data are collected over a period of one year, from January 2021 to the end of December 2021.

Figure 1 shows the PV modules installation at ASRT as governmental building, during two cases cleaning and dirty, in addition to central Inverter. The PV system was established using a 20 kW_p in STC (1000 W/m^2, 25 °C), covering an area of 200 m^2 tilted 26° from horizontal plane. The arrays are connected in a centralized mode inverter and composed of 4 parallel strings where each of them contains 20 modules connected in series in order to obtain a voltage terminal that can be appropriate for grid connection purposes, Figure 2 show a diagram of the complete PV power plant installation as a proposed system, Table 1 shows the system technical specifications carried out at the real irradiation R = 1000 W/m^2 and T = 25 °C.

Table 1. Solar PV specifications

ASRT solar panel specifications		
W_p	PV module capacity	250 (Wp)/Poly
V_{mp}	at P_{max}	32.20 (V)
I_{mp}	at P_{max}	7.77 (A)
V_{op}	Open-circuit voltage	39.75 (V)
I_{sc}	Short circuit current	8.28 (A)
η (%)	Efficiency	16.43 (%)

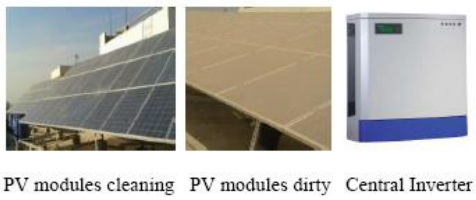

Figure 1. Installation of PV modules cleaning, dirty and central inverter

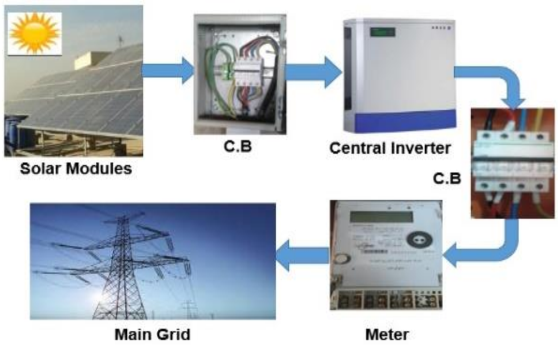

Figure 2. A diagram of PV power installation

3. TYPES OF CLEANING METHODS

There are different methods that used for cleaning PV Modules. Cleaning the PV modules is used for removing dust and other pollution the prevent the sun light to reach the PV module surface in 100%. The most common cleaning methods are manual cleaning, robotics and vacuum suction cleaning. The following subsections will introduce the process of performing each method.

3.1. Manual cleaning

Manual cleaning is one of the oldest methods of cleaning PV modules. This cleaning includes all washing methods, as cleaning is done by humans using special hand brushes, a grope of brushes is also directly connected to a water supply to do scrubbing and washing simultaneously. The main problem of this cleaning is labor costs, work safety, cleaning efficiency and productivity. Figure 3(a) shows the process of manual cleaning of PV array.

3.2. Robots cleaning

Machines are used to perform the task of automatic cleaning and storing water supplies. Mechanical cleaning damages glass surfaces while requiring huge amounts of water. However, robots are increasingly being used, especially in large solar projects. Mechanical cleaning, which involves robots, manpower and brushes, and usually requires a worker, is one of the most common types of cleaning for solar power plants. Figure 3(b) shows robot cleaning method.

3.3. Vacuum suction cleaning

Figure 3(c) shows a vacuum cleaner method. The vacuum cleaner is done using an air pump that creates a partial vacuum to absorb dust and dirt present on the surface of the PV units. The electrical current is supplied to the vacuum cleaner motor that creates the suction pressure [27].

(a) (b) (c)

Figure 3. Solar panel cleaning methods, (a) manual cleaning, (b) robot cleaning and (c) vacuum cleaning

4. RESULTS AND DISCUSSIONS

This section presented the analysis of PV system, such as production of energy, performance, and losses because of the influence of weather factors. It will allow us to verify system behavior and explain all results. Several results are recorded in all months of the year. All results are recorded and edited using Microsoft Excel and Matlab^{TM} software.

4.1. Energy production of grid connected PV plant

Figure 4 shows the monthly variation of energy production for grid-connected PV power plant that is proportional to the monthly global radiation and is sent to the internal network. The total energy supplied to the network during the year 2021 is 26,750 kWh. This energy ranges from 1,829.5 kWh in January to 1,826.8 kWh in December. The power generation expected in each hour was calculated using the (1) and (2).

$$P = I \times V \quad (1)$$

$$E = P \times t\,(Time) \quad (2)$$

The energy loss due to temperature was calculated from the actual efficiency of PV modules as a result of the fall of solar radiation compared to the ideal efficiency at 25°C. Figure 5 shows the mean minimum and maximum temperatures over the year in Cairo, (Cairo Governorate) in Celsius, Egypt.

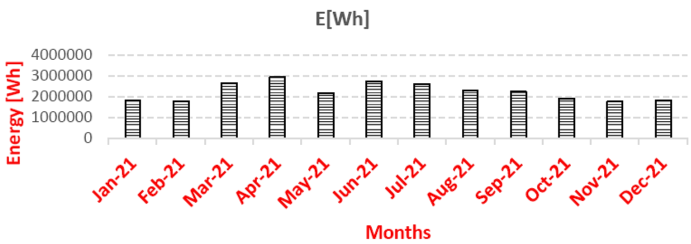

Figure 4. Monthly variation of grid connected PV energy production

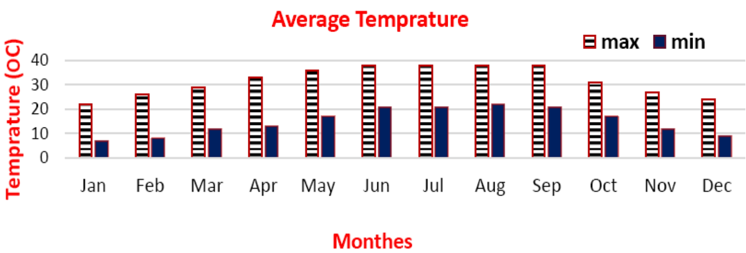

Figure 5. Monthly variation of average min and max temperatures in Cairo, Egypt

Figure 6 shows the relation between the average power and time in addition to average temperature at the same time during two days in January. The temperature increases with time advanced and reaches its peak degree and then it starts to reduce after 12 PM as the solar radiation reduces after this time. Also, April, July and November as showed in Figures 7 to 9.

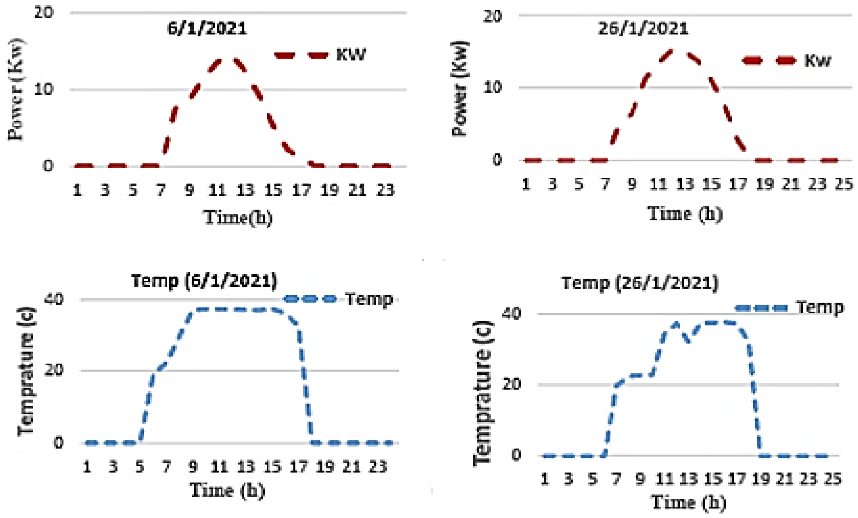

Figure 6. Temperature and power during two days in January 2021

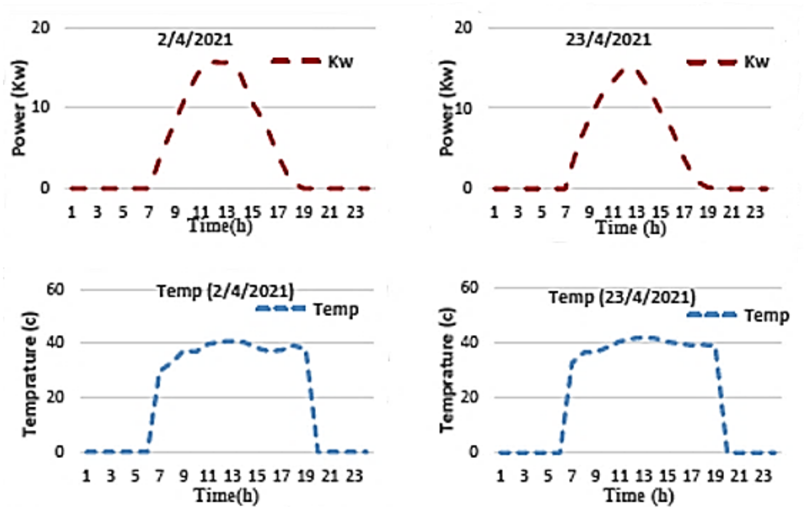

Figure 7. Power and temperature during two days in April 2021

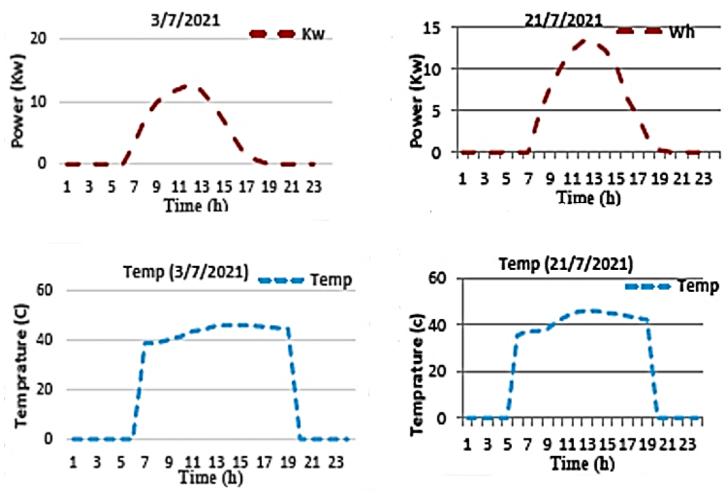

Figure 8. Power and temperature during two days in July 2021

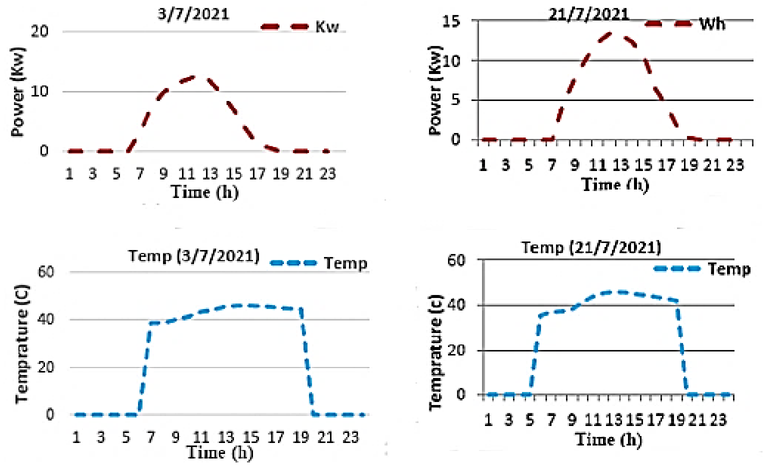

Figure 9. Power and temperature during two days in November 2021

4.2. Derivation of the cleaning cost and financial losses

Early in the morning or late at night are the best times to clean the solar panels during the spring and summer months when the panels are cool and before the heat of the midday sun. Cleaning hot panels leads to rapid evaporation of water, which means that they are more likely to leave smudges and may affect the glass on the surface of solar modules, which leads to its damage. Accumulation of dust on the PV surface modules will cause decreasing the efficiency of the PV modules to its nominal value. So,

$$\mu = (1 - \alpha N)\, \mu nominal \tag{3}$$

where: μ is the PV modules efficiency, α is the daily average losses in PV efficiency because of dust, N is days' number between cleaning times. So, the economic loss because of energy degradation of dust that accumulated on the surface of PV panels for consecutive N days is,

$$C1 = \frac{30}{2}\,(N+1)\,\alpha\, Sh\, Ci\, Pr \tag{4}$$

$$C2 = \frac{30}{2}\, CL \tag{5}$$

where: S_h is the sunshine average hours / day (11 h), Ci, the capacity of PV installed power plant (20 Kw), and, P_r is the kWh price (1.25 LE). So, the financial losing C1 as a result of energy degradation because of accumulation of dust per month, and if C_L is the cleaning cost for PV panel, then the cleaning cost for the panels is C2 each month.

An equation was derived for the ideal number of days between solar module cleaning times by reducing matrix cleaning cost and lost revenue from dirty panels. The formula assists in determining cleaning times depend on the weather conditions where the PV modules were installed, and the cost incurred in carrying out the process of washing.

$$CT = \frac{30}{2}\,(165.6(N+1)^2 - 5447.11(N+1) + 147943.3) Ls\, Sh\, Wp\, Ta\ + \frac{30}{(165.6N - 5447.11N + 147943.3)} Cc \tag{6}$$

Where: C_T, total cleaning cost, N, number of days between periods of cleaning, L_S, is the loss of pollution, S_h, is the average sunshine hours per month, W_p, maximum installed capacity, T_a, is energy tariff, and C_C, the cleaning cost including the water and labor cost.

In this study, the solar power plant is cleaned twice per month during the year. The cleaning cost (Cc) of PV modules is taken in an amount equivalent to 250. L.E. per month, if a contract is to be contracted with a specialist in cleaning solar modules, and the tariff of electricity (T) is taken as 76.6 piasters per Kw, 0.047 US dollars, which is a standard tariff for energy used in homes.

After obtaining the results from the PV power plant throughout the seasons of the year, each season separately, the best period for the maintenance of the solar station was determined after finding the curve fitting to draw the relationship between the time and energy produced from PV plant, then the financial loss equation was found throughout each season, and thus the financial loss was determined throughout The study indicated that there is a big difference between the current study and the comparative stud, taking into account that all the calculations are true without making any assumptions , where he assumed that the dust accumulation on the solar plant was linear, that is, increasingly, without taking into account Different environmental conditions throughout the day, month and year, as was done during this study.

The new developed of financial losses during seasons of the year after curve fitting between time and energy experimentally model is shown in (7) to (10).

$$C1 = \frac{30}{2}\ \alpha\ Sh\ Ci\ Pr\ (37.19N2 - 50.71.67N + 112846.37)\ at\ winter\ season \quad (7)$$

$$C2 = \frac{30}{2}\ \alpha\ Sh\ Ci\ Pr\ (173.6N2 - 2977.66N + 112670.63)\ at\ spring\ season \quad (8)$$

$$C3 = \frac{30}{2}\ \alpha\ Sh\ Ci\ Pr\ \ (109.12N2 - 1727.97N\ + 106235.24)\ \ at\ summer\ season \quad (9)$$

$$C4 = \frac{30}{2}\ \alpha\ Sh\ Ci\ Pr\ (\ (176.9N2 - 6564.03N + 112077.67)\ at\ Autumn\ seson \quad (10)$$

The energy daily loss because of dust is discussed by the term (Eei – Eai), the total cost including financial losses during year is indicated in (11),

$$CT = \frac{365}{N}\ Cc + 365T\ \sum_{i=1}^{n} \frac{1}{2}\ (\ 165.6N - 5447.11N + 147943.3)\ (Eei - Eai) \quad (11)$$

where: i = 1, 2, 3, ..., n is i^{th} day, Eei = estimated energy, Eai = actual energy, and N = number of cleaning days. The cleaning cost of solar panel depends on site, local labor costs, number of solar panels, number of floors you have in your building, and how accessible your panels are professional window cleaning companies may charge for the panels number.

5. CONCLUSION

This study was conducted to optimize the power production rate of PV power plant grid-connected and monitor the effect of environmental conditions and the characteristics of site on system performance, also, indicated the effect of pollution on the PV power plant performance by obtaining the highest rates of energy production under different environmental conditions over the course of a whole year. The performance curves for comparative analysis led to understanding the relationship between energy produced and accumulated dust on the surface of PV units. The relationship was found between the amount of energy produced and the cleaning cost of the solar modules. Therefore, this was done by making a periodic schedule to clean the solar cells due to the accumulation of dust on them. The study showed that pollution rates differ every day and every month, and therefore pollution cannot be considered fixed during the year. The results indicated that it is mandatory to clean once every fifteen days to reduce losses related to cleaning frequently as a result of water and labor consumption. In addition, the energy generated from the solar power plant and the efficiency are affected by different climatic factors that depend on the weather. These results may help us in developing suitable solutions to overcome these shortcomings. Also, in this paper equations are developed for the initial evaluation and comparison of the power drop of PV modules Because of the dirt. The use of these equations shows that dust accumulates on the units as these equations can be used to perform a reduction analysis of the PV module power output from accumulated dust.

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