PERFORMANCE EVALUATION OF WATER PUMPING SYSTEM POWERED BY SOLAR ENERGY

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ABSTRACT

There are many factors affect the performance and efficiency of photovoltaic system that need to study to avoid or reduce its negative impact when designing the photovoltaic system. The main objective of this study is to evaluate the performance of photovoltaic water pumping system under actual operating conditions by study the effect of intensity of solar radiation, dust accumulation on Pv panels, panels temperature, system components efficiencies, and the life cost comparison for Pv, and diesel water pumping systems. Experiments were carried out on photovoltaic water pumping station located in Bani Salamah- Al-Qanater-Giza Governorate-Egypt, which located at latitude 30.325364^o N, longitude 30.805797^{o}E, and 19 m above the sea level, from September 2016 to June 2017. The measurements were taken daily from sunrise to sunset every 15 minutes. The measurements include: solar radiation (tilted, direct, horizontal), panel`s temperature, solar generator output (DC current, DC voltage,), inverter output (AC current, AC voltage, frequency Hz), pump discharge, dynamic pressure. The study showed that; the pump flow rate was strongly affected by the intensity of solar radiation. where the hourly-average flow rate in December, March, and June was 18.2, 22.2, and 22.8 m3/h respectively. The degradation in panels efficiency, which decreased from 13.2% at dust density of 0 g / m^2 to 0.8% at dust density 375 g / m². When the temperature increases by 1 c^o in summer and winter the efficiency decreases with 0.48% and 0.42% respectively. The total cost in the Pv, and diesel-powered systems was 9.22, and 37.2 LE/h, and the cost of producing 1 kilowatt of energy reaches 1.23, and 4.96 LE/kW.h respectively.

Keywords: *photovoltaic, Pv water pumping, solar energy, dust accumulation, solar radiation, Pv panels.*

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INTRODUCTION

Egypt is located in the high radiation belt area, due to its proximity to the equator, also has a high number of sunshine hours up to an average of 10 hours. The risk of desertification and water scarcity for drinking and irrigation, lack of energy supply, especially in distant and desert areas are the recent crisis. Therefore, the importance of solar energy systems arises as a cheap and clean alternative for systems that depend on traditional energies such as diesel generators, which need periodic maintenance besides high fuel costs and their negative impact on the environment. Also, the importance of water pumping systems is arising as a suitable solution for water scarcity, particularly in remote and desert areas. **(Sontake and Kalamkar, 2016).**

Solar energy can be exploitation either thermally using solar thermal collectors for heating and drying purposes **(Kalogirou, 2004)** or using the photovoltaic effect by converting the sunlight into electricity using solar cells that are made from semiconductor materials like silicon. Solar cells are assembled in series to form solar panels, that also called photovoltaic panels, **(Ogbomo et al., 2017)**. any water pumping system can be operated using solar panels, it can be called photovoltaic water pumping systems.

Photovoltaic water pumping systems can be classified into two types; the direct current pumps where the Dc pump`s motor is directly coupled to solar panels, and the alternative current pumps where the Ac pump`s motor is connected to the solar panels by the inverter that converts the Dc current into Ac current. The Pv water pumping system consists of four main parts; PV panels, inverter, electric motor, and submersible pump **(Eker, 2005)**.

Abdeen et al., (2017) stated that the output power of a photovoltaic system depends on many factors such as PV surface temperature, tilt angle and dust accumulation. Many factors should be considered in the design of PV system such as and not limited to tilt angle, irradiation and dust accumulation. These factors have a significant effect on the PV output power.

Dousoky et al., (2011) mentioned that Egypt has high solar irradiance, Annual global solar radiation of over 2,000 kWh/m^2.

Kaldellis and Kapsali (2011) mentioned that the dust pollution effect strongly depends on the local area where the PV system is mounted, so it's difficult to apply a general model in all cases.

Park, et al., (2010) stated that as solar cell temperature increases by 1^{o} C, the output power is reduced by 0.48% under standard test conditions and by 0.52% under outdoor conditions at 500 W/m^2 irradiations.

Shouman, (2017) stated that renewable energy is the actual solution to face the future challenges in the Egyptian energy demands, especially the solar energy from an economical point of view using PV systems in feeding rural zones is very important, especially when their life cycle costs are competitive with the other types of conventional energy sources like diesel, as the result shows the cost of 1 kWh from the PV system is less than diesel system for rural residential electricity are 0.22$/kWh and 0.5$/kWh respectively.

The objectives of this study were as Performance evaluation of photovoltaic water pumping system under actual operating conditions. Via; Study the effect of intensity of solar radiation, dust accumulation on Pv panels, panels temperature, system components efficiencies, and the life cost comparison for Pv, power grid, and diesel water pumping systems.

MATERIAL AND METHODS

The photovoltaic system is consisting of three components; Pv generator, inverter and other electrical components (such as; wiring and control panel). A photovoltaic (PV) system is able to supply electric energy to a given load by directly converting solar radiation into electricity.

Pv panels:

PV panels are the main building blocks; these can be arranged into arrays to increase electric energy production (Fig. 1). The arrays are installed on a metal structure whose angle of inclination can be changed manually. Two sets of arrays were used to generate power to operate the pumping system. each array consists of 18 panels, that are connected in series. The two sets of arrays are connected in parallel in order to give a current 17 A and 549 v to inverter. The type of modules used in these experiments is Renesola (JC260M-24/Bb) 260 watt.

Fig. 1: The two sets of arrays and metal installation structure.

Inverter:

Inverter (Fig. 2) transforms the DC power produced by the PV modules to AC power used to drive the pump motor, also inverter adjusts the output frequency in real time according to the prevailing irradiation levels, furthermore inverter works with MPPT (Maximum Power Point Tracking) technology to maximize power output at all irradiation levels (Table 1). The other electrical components such as, DC wires (4 mm^2, and 10 m length), and safety switches (20 amp. circuit breaker) are very important in controlling and prevention system damage.

Fig. 2: The inverter.

Maximum output power	15	(KW)
Output voltage	380	(V)
Maximum output current	30	(A)
Maximum input power	21	(KW)
Maximum input voltage	800	(V_{DC})
MPPT voltage	500-600	(V_{DC})
Frequency	0-60	(Hz)

Table 1: Inverter datasheet.

Pumping unit:

The pumping unit is consisting of main three components,3 phase Ac motor, multi stages submersible pump, and deep well (water source).

Ac motor:

VSM 6/10 Submersible 3phase electric motor with technical data illustrated in (Table 2)

Submersible pump

Vsp ss 06030/08 submersible centrifugal Pump with 8 stages, and 30 m^3/h flow rate.

Water source

The water source is a deep well (Fig. 3) with 8-inch diameter, 90 meters depth, and the static water level is about 50 meters. the pump at 70 meters depth.

Fig. 3: water source (deep well).

Type	VSM 6/10
Power- kW	7.5
Volt- v	380
Current- A	17
Frequency-Hz	50
Efficiency	78 %
Dimensions-mm	Φ=142
	L =748
Power factor (Cos φ)	0.8
Revolution- rpm	2750

Table 2: Ac motor data sheet.

Measurement tools

1-Pyranometer, was used to measure intensity of solar radiation, it generates 10 μV (microvolts) per W/m^2, with sensitivity ($12.11*10^{-6}$) V/Wm^{-2}. **2- Digital solar radiation meter**, was used to measure intensity of direct solar radiation with W/m^2 ($1W/m^2$ accuracy). **3-Flow meter,** (Iso 4064 class B, 4-inch,10 bar) used to measure continuously, memorize, and display the volume of water passing through the measurement transducer, (0.01 m^3 accuracy). **4-Manometer,** was used to measure and display pressure (0.1 bar accuracy). **5-Digital Multimeter,** (UNI-T UT39C) used for measuring various electrical characteristics (V, amp., Ω). **6-Thermocouple Thermometer,** produces a temperature-dependent voltage as a result of the thermoelectric effect, and this voltage can be interpreted to measure temperatur (0.4 % accuracy), **7-Infrared thermometer,** (DT8011T) is a gauge, which infers temperature from a portion of the thermal radiation emitted by the object being measured, (±2% or 2°C accuracy). **8-Clamp**

meter, (DT 266) used to measure the current in a conductor without need to make physical contact with it, or to disconnect it for insertion through the probe (1mA, 1mV accuracy).

Methodology

Experiments were conducted during the period from September 2016 to June 2017, on photovoltaic water pumping station located in Bani Salamah-Al-Qanater-Giza Governorate-Egypt, which located at latitude 30.325364^o N, longitude 30.805797^{o}E, and 19 m above the sea level. The measurements were taken during the day from sunrise to sunset every 15 minutes. The measurements include: solar radiation (tilted, direct, horizontal), panels temperature, solar generator output (DC current, DC voltage,), inverter output (AC current, AC voltage, frequency Hz), pump discharge, dynamic pressure.

- The intensity of solar radiation was calculated in W/m^2 using the (Eq. 1)

$$I_R = \frac{(\mu V)}{(12.11 * 10^{-6}) V/Wm^{-2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where: I_R = intensity of solar radiation, μV = pyranometer output, and the pyranometer sensitivity = (12.11*10-6) V/Wm^{-2}

- Efficiency of the solar panels (η_{panels}) was calculated as a ratio of electric power output and solar power input using the Eq. 2 (Hegazi, 2010).

$$\eta_{panels} = \frac{V * I}{A * I_R} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where A=surface area of the solar array m^2; I_R=solar radiation w/m^2, I= current, amperage; V= voltage, volt.

- The electrical output power from inverter is calculated using the Eq. 3 (Nilsson, 2010).

$$P_{AC} = \sqrt{3} * V * I * cos\theta \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where: P_{Ac}= inverter output electric power(watt); V=line voltage(volt); I= phase current(amp.); cos θ= power factor.

- Friction losses were calculated using Hazen William equation (Eq. 4) of (**Kumar Tyagi, 2018**). then the hydraulic power delivered by the pump can be calculated with (Eq. 5).

$$h_f = \mathbf{k} * \mathbf{L} * \left(\frac{\mathbf{Q}}{\mathbf{C}}\right)^{1.85} \mathbf{d}^{-4.87} \quad \text{.................. (4)}$$

Where: h_f= friction losses, m; K Constant coefficient = 1.22*10[10];
L=Length of pumping pipes, m; Q=discharge, lit./s; d=Internal diameter of pumping pipes, mm.

$$H_p = \frac{\mathbf{Q} * \mathbf{h} * \boldsymbol{\rho} * \mathbf{g}}{\mathbf{3600}} \quad \text{........................... (5)}$$

Where: HP=hydraulic power, watt; Q=discharge m^3/h; ρ =water density kg/m^3; g=acceleration of gravity m/s^2; h= total dynamic head, m.

- Overall Efficiency(η_{all}) was calculated as a ratio of hydraulic power and solar power using the (Eq. 6).

$$\eta_{all} = \frac{H.p}{A * I_R} \quad \text{................................. (6)}$$

Where: HP=hydraulic power, watt; A=surface area of the solar array, m^2; I_R=solar radiation, w/m^2.

- The total cost LE /h can be calculated using the Eq. 7, (El Awady, 2015), and (Table 3).

$$C = \frac{P}{h}\left(\frac{1}{e} + \frac{i}{2} + t + r\right) + W + \frac{m}{270} \quad \text{...... (7)}$$

Table 3: Cost analysis equation terms for Pv, and diesel systems.

Term	Pv system	Diesel system
Price of system (P) LE	110240	110000
Yearly working hours (h)	3240	3240
Life expectancy (e), Year	25	10
Interest rate (I) %	0.14	0.14
Taxes (t) %	0.10	0.20
maintenance (r)	0.05	0.20
fuel cost (w) LE/h	0	16.91
monthly wages (m) LE/month	100	250
monthly average working hours	270	270

RESULTS AND DISCUSSION

Investigations were conducted to evaluate the performance of the photovoltaic water pumping system, components efficiencies (η_{panels}, $\eta_{inv.}$, η_{pump}, η_{all}), the effect of the intensity of solar radiation, the effect of panels temperature, and cost analysis. the effect of dust accumulation was investigated, the effect of dust accumulation and different dust densities (from 0 g/m^2 to 375 g/m^2) on panels output and efficiency.

Solar Radiation

(Fig. 4) illustrate that the direct radiation has the highest values all over day time, then the incident radiation on a tilted surface (tilt angle=30 ^{o}), while the incident radiation on horizontal surface has the lowest values all over day time.

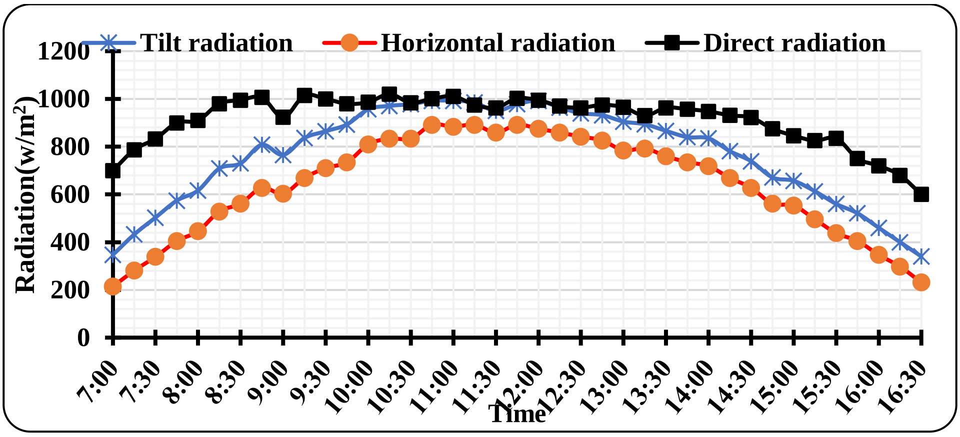

Fig. 4: Direct, tilted and horizontal solar radiation in June.

It is noticeable in the morning (before 10:00 a.m.) and after noon (after 2:00 p.m.) that there is a large difference between the value of direct solar radiation and incident solar radiation on horizontal surface, due to the small altitude angle and large azimuth angle of the sun, thus the South's facing solar panels receive a little solar radiation.

When solar radiation reaches a certain value of about 510 W / m^2, the solar panels begin to produce an electric current and the pump starts to work. it is also apparent that the voltage is not significantly affected by solar radiation, where the voltage tends to be stable from the beginning of Dc current production from panels until the end of current production, While the current produced by the panels is directly and uniformly affected by solar radiation. The relationship between solar radiation and the electrical power produced by the panels, which is a positive relationship that based on the positive relationship between radiation and electrical current (Fig. 5).

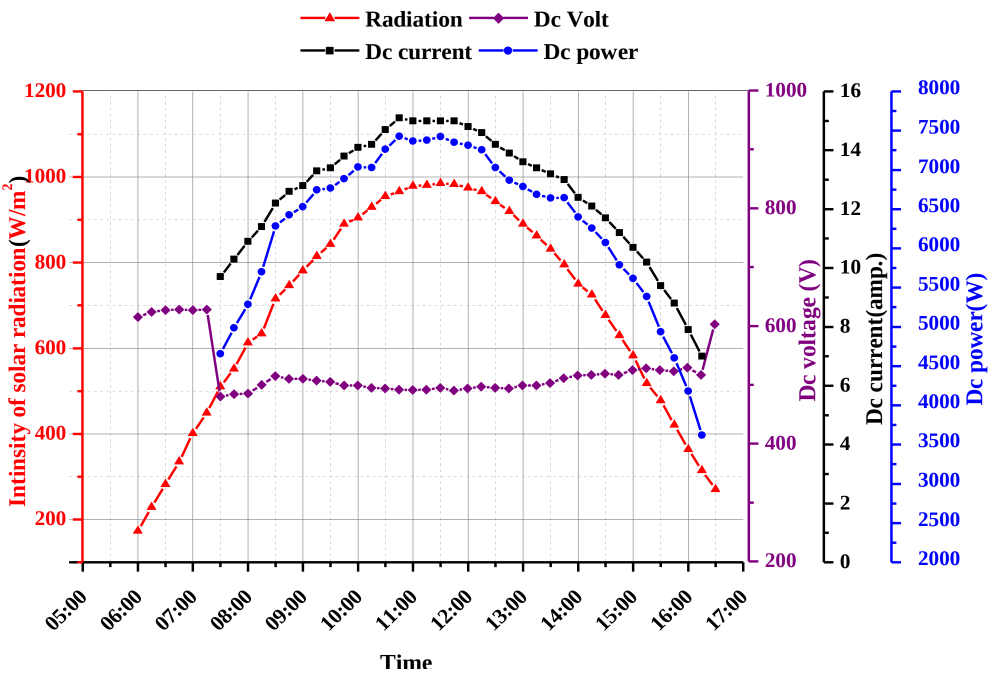

Fig. 5: Effect of solar radiation on voltage and Dc current in June.

The experiments show that the flow rate was strongly affected by the intensity of solar radiation, (Fig. 6) illustrates that the flow rate increase when the intensity of solar radiation increase.

The overall efficiency of Pvwps system is directly affected by solar radiation, but when solar radiation exceeds 900 W/m^2 at noon, this is accompanied by an increase in temperature, which negatively affects the efficiency of the solar panels and thus the overall system efficiency (Fig. 7).

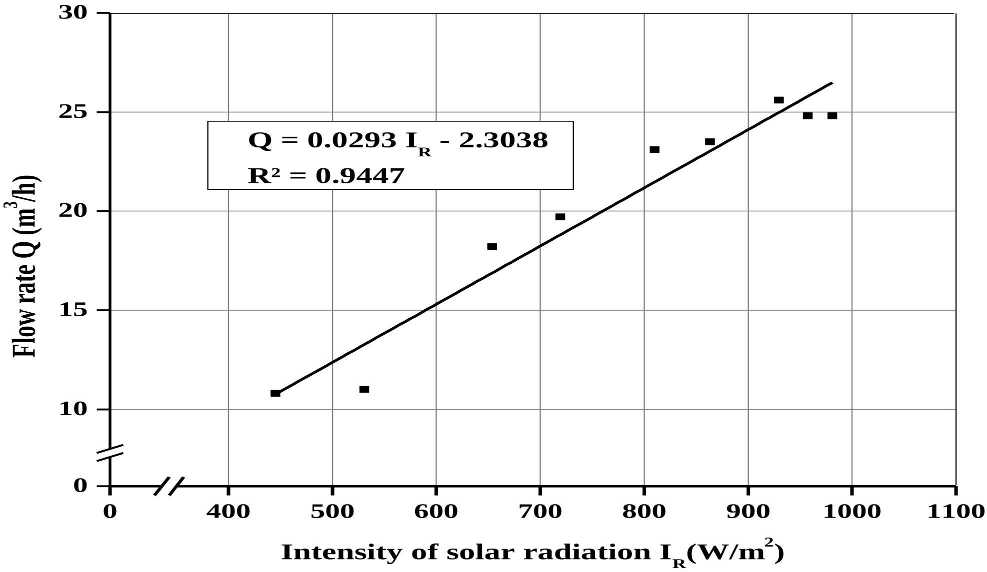

Fig. 6: Intensity of solar radiation and flow rate.

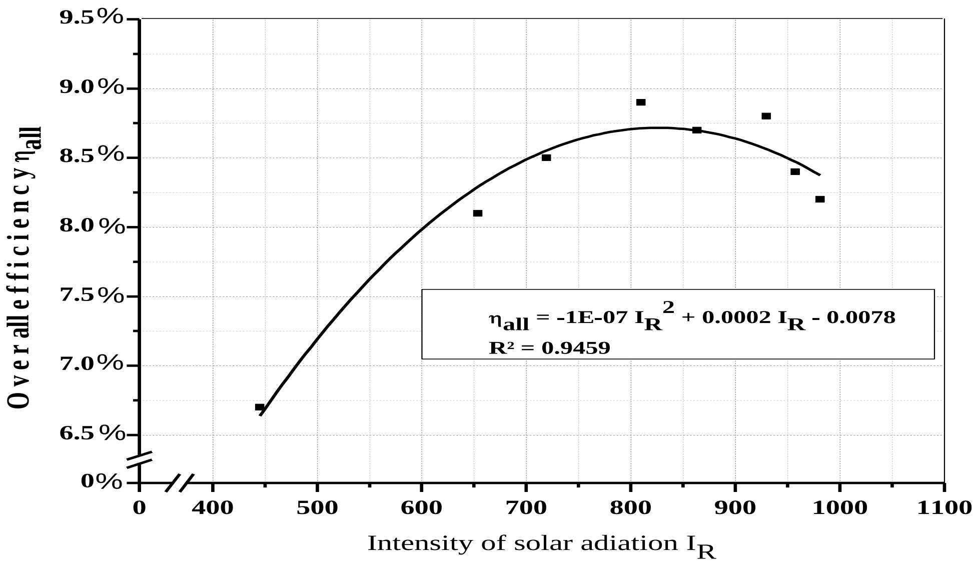

Fig. 7: Intensity of solar radiation and overall efficiency.

Effect of Dust accumulation

To study the effect of dust accumulation on the solar panels under the actual operating conditions, two experiments were conducted in two consecutive similar days in solar radiation and temperature, at the first day, the panels were unclean (the panels were left without cleaning for three months) and the accumulated dust density was 20.5 g/m^2, at next day, the solar panels were washed and cleaned, the system performance in these two days were compared.

The dust accumulation on solar panels has a negatively effect on the efficiencies (η_{panels}, $\eta_{inv.}$, η_{pump}, η_{all}) and, the output of all system components. The efficiency of clean and dusty solar panels is shown in (Fig. 8), it illustrates that the efficiency of clean panels is always higher than the efficiency of dusty panels. due to dust accumulation with density (20.5 g/m^2), the daily-averaged efficiency of solar panels decreased from 14.3 % for clean panels to 13.2 % for dusty panels.

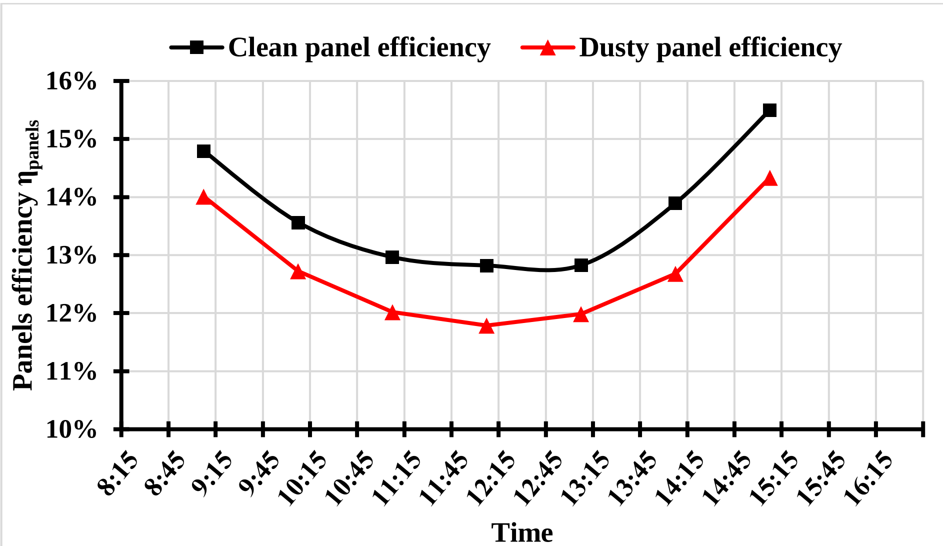

Fig. 8: The Efficiency(η_{panels}) of clean and dusty solar panels.

<u>Dust effect on overall efficiency and flow rate.</u>

The overall system efficiency (η_{all}) when using clean solar panels is always higher than it when using dusty panels (dust accumulation density was 20.5 g/m^2). the daily-averaged overall efficiency decreased from 8.3% when using clean panels to 7% when using dusty panels as shown in (Fig. 9).

Also, the pump flow rate decreased from 21.3 m^3/h when using clean solar panels to 17.7 m^3/h when using dusty solar panels (dust accumulation density 20.5 g/m^2). Thus, the amount of pumped water during the day decreased from 181.8 m^3/day when using clean solar panels to 145.5 m^3/day when using the dusty panels (dust density 20.5 g/m^2).

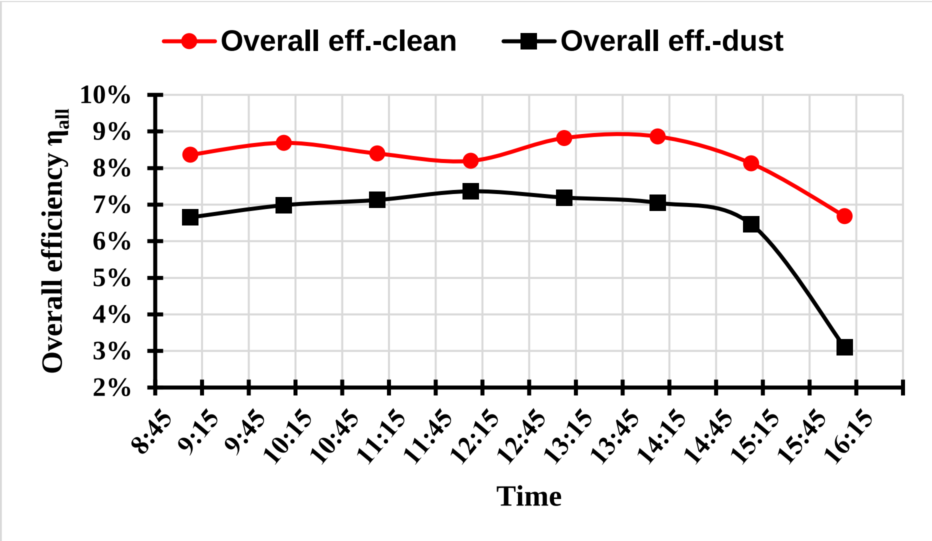

Fig. 9: The overall efficiency when using clean and dusty panels.

Effect of different dust densities on the panel`s efficiency.

Fig. 10 shows the deterioration in panels output Dc power, which decreased from 192 Watts at dust density of 0 g / m2 to 11.6 watts at dust density 375 g / m², the percent of power degradation reached to 93.9%. Fig. 13 shows the degradation in panels efficiency, which decreased from 13.2% at dust density 0 g / m2 to 0.8% at dust density 375 g / m².

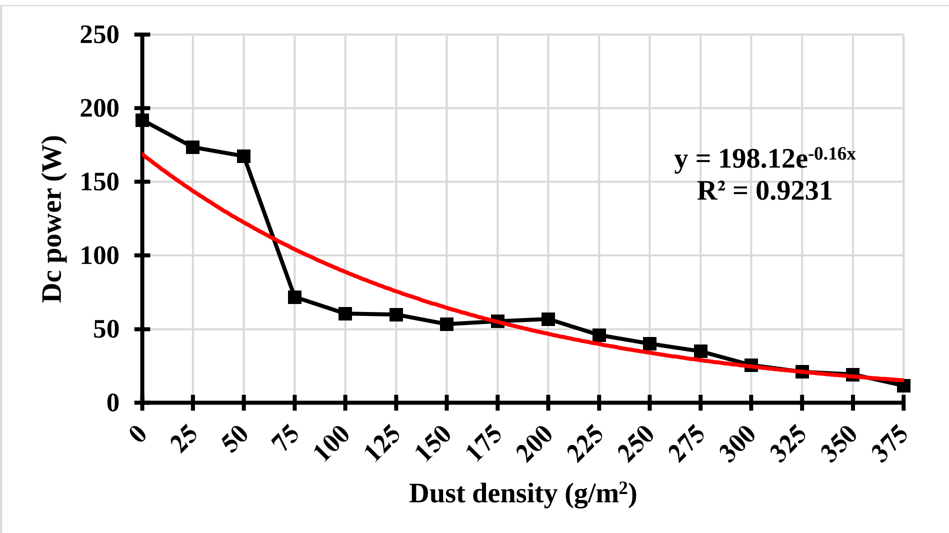

Fig. 10: The deterioration in panel`s output Dc power.

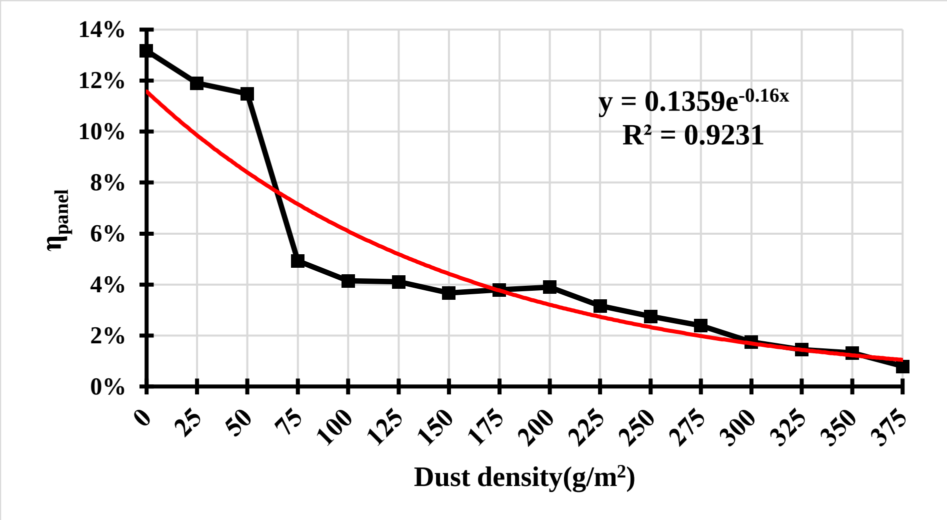

Fig. 11: The degradation in panels efficiency due to dust accumulation.

Dust accumulation and panel`s cells temperatures (Detect hot spots)

The temperature`s difference between cells occur in series-connected PV cells. In most commercial PV panels, cells are arranged in series to reach high output voltages required for many PV applications. There are many factors that can lead to temperature`s difference from cell to another, and then to hotspots, such as manufacturing error tolerance, partial shading, dust accumulation, and degradation. to detect temperature`s difference (hot spots) a dusty panel was randomly selected from the solar array, the temperature of each cell in that module was measured three times a day at 10:00 am, 12:00 pm, and 2:00 pm. The ORIGIN program was used to create a contour map that represents the distribution of cells temperature on the module. Fig. 12 illustrate the colorful contour map that represents the distribution of the panel`s cells temperatures at 12:00 pm.

It is clear that there are differences between cells temperatures, Where the average difference between the lowest and the highest temperature reached 6.7 degrees, this difference in temperature from one cell to another is due to the dust accumulation on the surface of the solar panels, and the differences in the dust layer thickness from one cell to another. This leads to partial shading on cells, therefore the temperature varies from one cell to another. Increasing the amount of dust on the panels may lead to hot spots that negatively affect the performance of the panels.

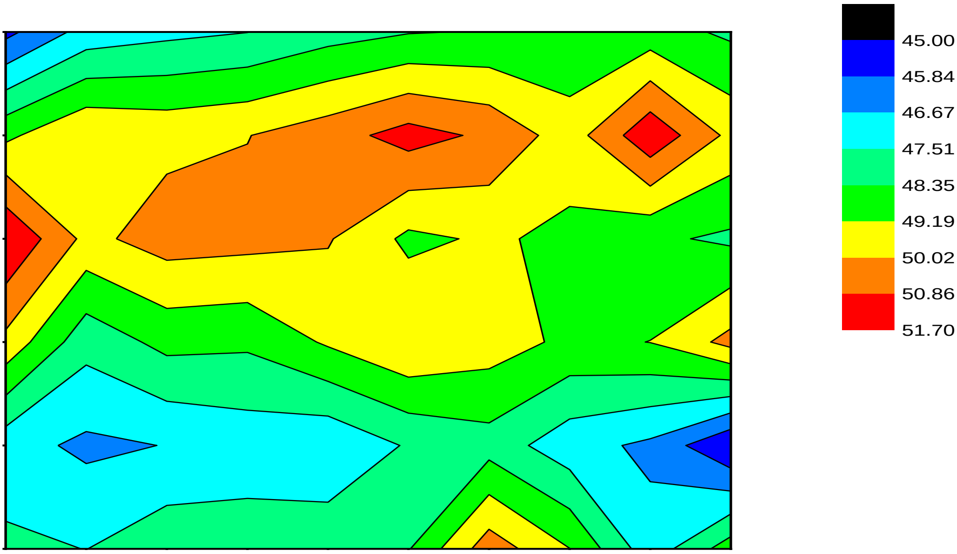

Fig. 12: Colorful contour map that represents the distribution of the panel`s cells temperatures at 12:00 pm.

Effect of temperature on Pv panels efficiency(η_{panels}).

The efficiency of solar panels is negatively affected by temperature increasing (Fig. 13). It's noticeable from (Fig. 14) that when temperature increases, the modules efficiency decreases, and when the temperature reaches to the highest values during the day 47.4 c° in summer and 41.8 c°

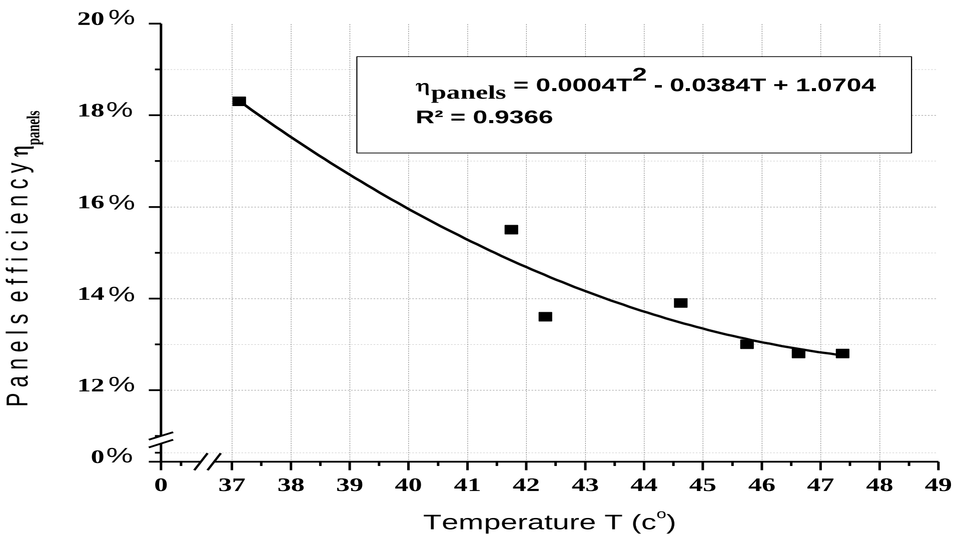

Fig. 13: Effect of panels temperature on its efficiency.

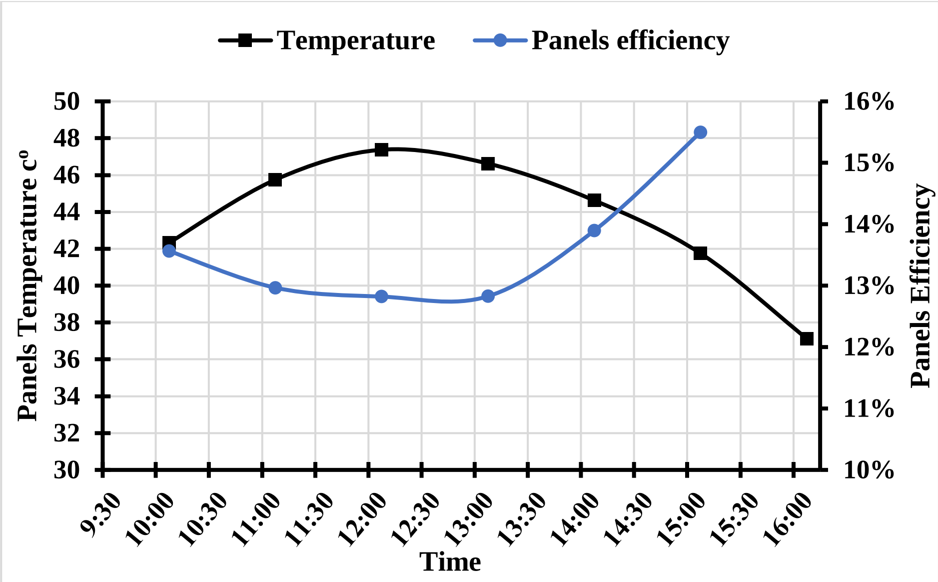

Fig. 14: Panels temperature and efficiency(η_{panels}) in June.

in winter; the efficiency decreased to the lowest values 12.8% and 12.3% respectively. also, when the temperature increases by 1 c° the efficiency decreases with 0.48%.

Pv cost

The life cycle costs of PV, and diesel-powered systems were compared. In each system, the cost of a kilowatt of energy was calculated, and this will tell us which system is economically viable. knowing that the current market prices in 2018 was used. The total cost in the Pv, and diesel-powered systems was 9.22, and 37.2 LE/h, and the cost of producing (1 KW.h) energy reaches 1.23, and 4.96 LE/kW. h, the operating cost (LE/m^3) reaches 0.43, and 1.75 LE/m^3 respectively.

CONCLUSION

This study was conducted to evaluate the performance of the photovoltaic water pumping system, components efficiencies, the effect of the intensity of solar radiation, panels temperature, dust accumulation and cost analysis. Based on the results of this study, the following conclusions were obtained:

- The direct radiation has the highest values all over daytime with daily-average 913 W/m^2, then the incident radiation on a tilted surface with daily average 764 W/m^2, while the incident radiation on a horizontal surface has the lowest values all over daytime with daily average 637 W/m^2.

- When the temperature increases by 1 c^o in summer and winter seasons, the efficiency decreases with 0.48% and 0.42% respectively.
- Pump flow rate was strongly affected by the intensity of solar radiation. where the hourly-average flow rate in December, March, and June was 18.2, 22.2, and 22.8 m^3/h respectively.
- The amount of water pumped during the day was significantly affected by the number of sunshine hours, Where the average number of sunshine hours in December, March, and June reach 7, 8 and 9 hours respectively, and the amount of water pumped during the day reached 129, 164.1, and 181.8 m^3/day, respectively.
- The deterioration in panels output Dc power, which decreased from 192 Watts at dust density of 0 g / m^2 to 11.6 watts at dust density 375 g / m^2, the percent of power degradation reached to 93.9%.
- The degradation in panels efficiency, which decreased from 13.2% at dust density of 0 g / m^2 to 0.8% at dust density 375 g / m^2.
- After three months without cleaning, the daily-average efficiency of solar panels decreased from 14.3 % for clean panels to 13.2 % for dusty panels.
- The flow rate decreased from 21.3 m3/h when using clean solar panels to 17.7 m3/h when using dusty solar panel.
- The total cost in the Pv, and diesel-powered systems was 9.22, and 37.2 LE/h, and the cost of producing 1 kilowatt of energy reaches 1.23, and 4.96 LE/kW. h, the operating cost (LE/m3) reaches 0.43, and 1.75 LE/m3 respectively.

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الملخص العربي

تقييم أداء نظام ضخ المياه بالطاقة الشمسية

سمير أحمد طايل(١)، أحمد ماهر الليثي(٢)، أحمد محمود حجازي(٣)، يوسف فايز السعداوي(٤)

هناك العديد من العوامل التي تؤثر على أداء الألواح الشمسية ومن ثم نظم ضخ المياه المعتمدة عليها. لذا يجب دراسة هذه العوامل لتجنب أو تقليل تأثيرها السلبي عند تصميم النظام الكهروضوئي. وبالتالي؛ كان الهدف الرئيسي من هذه الدراسة هو تقييم أداء نظام ضخ مياه بالطاقة الشمسية (الكهروضوئية) تحت ظروف التشغيل الفعلية من خلال دراسة تأثير شدة الإشعاع الشمسي، تراكم الغبار على الألواح الكهروضوئية، درجة حرارة الألواح، كفاءة مكونات النظام، ومقارنة تكلفة الإنشاء ودورة الحياة لكل من الأنظمة الكهروضوئية. والأنظمة التي تعمل بشبكة الطاقة (الكهرباء)، والأنظمة المعتمدة على مولدات الديزل.

أجريت التجارب في بني سلامة - القناطر - محافظة الجيزة - مصر، والتي تقع على خط العرض ٣٠,٣٢٥٣٦٤ درجة شمالا، وخط الطول ٣٠,٨٠٥٧٩٧ درجة شرقا، وترتفع ١٩ م فوق مستوى سطح البحر، خلال الفترة من سبتمبر ٢٠١٦ إلى يونيو ٢٠١٧، وكانت تؤخذ القياسات خلال النهار من شروق الشمس إلى غروب الشمس كل ١٥ دقيقة. تشمل القياسات: شدة الإشعاع الشمسي (المباشر، على سطح مائل، على سطح أفقي)، درجة حرارة الألواح، خرج المولد الشمسي-مصفوفة الألواح الشمسية- (التيار المستمر، فرق الجهد، القدرة)، خرج الانفرتر-العاكس- (التيار المتردد، جهد التيار المتردد، التردد HZ)، تصرف المضخة، الضغط الديناميكي.

كانت النتائج الرئيسية كالتالي:

• الإشعاعات المباشرة بلغت أعلى القيم طوال النهار بمتوسط يبلغ ٩١٣ واط / م ٢ ، يليه الإشعاع الحادث على سطح مائل بزاوية علي الأفقي بمتوسط ٧٦٤ واط / م ٢ ، في حين أن الإشعاع الحادث على سطح أفقي كان الأقل قيمة بمتوسط ٦٣٧ واط / م ٢.

• عندما تزداد درجة الحرارة بمقدار ١ درجة مئوية في الصيف والشتاء ، تنخفض كفاءة الألواح الشمسية بنسبة ٠,٤٨٪ و ٠,٤٢٪ على التوالي.

• تأثر معدل التدفق تأثرا مباشرا بشدة الاشعاع الشمسي، وبلغ متوسط معدل التدفق (تصرف المضخة) في ديسمبر ومارس ويونيو ١٨,٢ و ٢٢,٢ و ٢٢,٨ م ٣ / ساعة على التوالي.

١- **أستاذ الهندسة الزراعية المتفرغ، كلية الهندسة الزراعية-جامعة الأزهر بالقاهرة.**
٢- **أستاذ الهندسة الزراعية، كلية الهندسة الزراعية-جامعة الأزهر بأسيوط.**
٣- **مدرس، وحدة بحوث المياه والتربة، هيئة الطاقة الذرية.**
٤- **معيد بكلية الهندسة الزراعية - جامعة الأزهر بأسيوط.**

• بلغ متوسط عدد ساعات السطوع الشمسي (المؤثر) في شهر ديسمبر، مارس، ويونيو ٧، ٨ و٩ ساعات على التوالي، وبلغ متوسط كمية المياه التي تم ضخها خلال النهار ١٢٩ ،١٦٤,١ و١٨١,٨ م ٣ / يوميا على التوالي.

• تدهور أداء وخرج ألواح الطاقة الشمسية نتيجة لتراكم الأتربة، حيث انخفضت قيمة كل من فرق الجهد والتيار من ٣٢ فولت ،٦ أمبير عند كثافة ٠جرام/م٢ إلي ٥ فولت ، ٢,٣ أمبير عند كثافة أتربة ٣٧٥ جرام/م٢.

• تدهورت كفاءة ألواح الطاقة الشمسية نتيجة لتراكم الأتربة، حيث انخفضت قيمة الكفاءة من ١٣,٢% عند كثافة ٠جرام/م٢ إلي ٠,٨% عند كثافة أتربة ٣٧٥ جرام/م٢.

•بلغت كثافة الأتربة المتراكمة ٢٠,٥ جرام/م٢ وانخفضت كفاءة الألواح الشمسية من ١٤,٣٪ للألواح النظيفة إلى ١٣,٢٪ للألواح الغير نظيفة (نتيجة تراكم الأتربة لمدة ثلاثة أشهر بدون تنظيف).

• انخفض متوسط معدل التدفق (تصرف المضخة) من ٢١,٣ م ٣ / ساعة عند استخدام الألواح الشمسية النظيفة إلى ١٧,٧ م ٣ / ساعة عند استخدام الألواح الشمسية الغير نظيفة (كثافة الأتربة المتراكمة ٢٠,٥ جرام/م٢).

• بلغت تكلفة التشغيل في كل من نظام الطاقة الشمسية، ومولد الديزل ٩,٢٢، ٣٧,٢ جنيه/الساعة، وتكلفة إنتاج (الكيلوواط. ساعة) بلغت ١,٣٢ ، و٤,٩٦ جنيه / كيلوواط. ساعة على التوالي، وتكلفة ضخ المتر المكعب من المياه (جنيه / م ٣) ٠,٤٣، و١,٧٥ جنيه /م٣ على التوالي.جنيه /م ٣ على التوالي.

كلمات البحث: الطاقة الشمسية، الألواح الكهروضوئية، ضخ المياه بالطاقة الشمسية، تراكم الغبار، الإشعاع الشمسي، كفاءة الألواح الكهروضوئية، درجة حرارة الألواح الكهروضوئية، زاوية الميل.

التوصيات:

١- يجب دراسة شدة الإشعاع الشمسي وتصميم المنظومات الكهروضوئية بالاعتماد علي أقل قيمة للإشعاع حتى لا تتوقف المنظومة عن العمل في فصل الشتاء أو عند انخفاض شدة الإشعاع.

٢- يفضل تزويد الألواح الكهروضوئية بأنظمة تتبع للشمس، حتى تستقبل أكبر قدر ممكن من الإشعاع الشمسي وبالتالي ترتفع الطاقة المنتجة من نفس وحدة المساحة.

٣- لاستقبال أكبر قدر ممكن من الاشعاع الشمسي جب الاهتمام بزاوية ميل الألواح وتغييرها في كل فصل تبعا للعلاقة ($\beta = \varphi \pm 15$)، وزاوية السمت حيث في نصف الكرة الشمالي يتم توجيه الألواح في اتجاه الجنوب.

٤- مراعاة التنظيف الدوري (مرة في الشهر) للألواح من الأتربة المتراكمة، حيث تؤدي الي انخفاض الكفاءة وحدوث حروق بالخلايا (hot spots)وبالتالي فشل المنظومة كلها.

٥- يجب اختيار المضخة المناسبة عن طريق حساب التصرف المطلوب، والضاغط الكلي (TDH) الذي ستعمل عنده المضخة، ثم استخدام مخططات الكفاءة لاختيار المضخة المناسبة من منطقة الكفاءة المرتفعة.

٦- الإهتمام بوسائل الأمان والحماية مثل التأريض، وتركيب قواطع التيار بين الألواح والانفرتر، وبين الانفرتر ووحدة الضخ وذلك لحماية المنظومة من دوائر القصر والحرائق.

٧- دراسة طرق فعالة واقتصادية لتبريد الألواح لتجنب انخفاض الكفاءة.

٨- دراسة نظم التتبع الشمسي لزيادة المردود الاقتصادي والانتاجي للألواح الكهروضوئية.