EVALUATION OF PHOTOVOLTAIC SOLAR-POWERED WATER PUMPING IRRIGATION SYSTEM DURING WINTER SEASON

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ABSTRACT

The experimental work was carried out at a private farm in Nubariah, Al Buhayrah Governorate, Egypt, which located at latitude and longitude angle of 30.07°N and 30.33°E, respectively, during winter season (2016).The experiments were evaluated the performance of solar powered pump on a drip irrigation system. The photovoltaic water pumping system performance (sun tracking orientated facing south direction and tilt angle, horizontal and 30˚, head pump, solar radiation) on the study indicator (electric power output of panel W, panel efficiency %, discharge of pump m³/h, hydraulic power W,. The results showed that, the discharge of water pump increased from (33, 35, 36.5, 38.5 and 39.5 m³/h) with solar radiation increased from (622, 711, 740, 752 and 812 W/m²) at constant of operating water head 30m and tilt angle (30˚), the discharge of water pump increased from (32, 34, 36, 37.5 and 38 m³/h) with solar radiation increased from (243, 266, 307, 312 and 527 W/m²) at constant of operating water head 30m and horizontal plane in 17 January, 2016. When the operating water head change from (30, 35, 40, 45 to 50 m) the discharge of water pump decreased from (33, 31.5, 29, 26 to 24.5 m³/h) in 17 January, 2016. PV efficiency decreased from (18.7, 16.8, 16.2, 15.9 and 16.5%) with the temperature increased from (19, 20, 21, 23 and 25°c) with in 17 January, 2016. The hydraulic power increased from 2698 to 3229 W with the discharge increased from 33 to 39 m³/h in 17 January, 2016. This study recommended using pump powered by solar energy in drip irrigation system at the large area under the experimental conditions.

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INTRODUCTION

The photovoltaic water pumping systems (PVWPS) is considered as one of the most promising areas in photovoltaic applications. Solar powered irrigation system can be a suitable alternative for farmers in the present state of energy crisis. **Leung and Yang (2012)** considered that, solar photovoltaic (PV) is one of the fastest growing renewable energy technology worldwide because of the rapid depletion and adverse environmental impact of fossil fuels. **Svantesson and Linder (2012)** defined, pv cells are solid state devices with no moving parts; therefore, nearly no maintenance is required for their simple and robust design. **Khalil and Shaffe (2013)** presented a comparative study of direct, diffuse and total solar radiation by using different models on horizontal and inclined surfaces in Cairo, Egypt. They found that three models provided a good estimation of the total solar radiation in the selected location. **Foster and Cota (2014)** showed that, photovoltaic water pumping (PVWP) has several beneficial characteristics including simplicity, reliability and cost effectiveness. The match between seasonal water needs and seasonal solar resource is a good one. “A typical system configuration includes a PV array, pump, controller, inverter for AC, and over current protection. **Foster and Majid (2014)** told that, the performance of PV water pump mainly depends on the water flow rate which is influenced by weather conditions at the location, especially solar irradiance and air temperature variations.The performance of solar pump depends on the water requirement, size of water storage tank, head (m) by which water has to be lifted, water to be pumped (m^3), PV array virtual energy (kWh), Energy at pump (kWh), unused PV energy (kWh), pump efficiency(%), and system efficiency (%) and diurnal variation in pump pressure due to change in irradiance and pressure compensation. **Chris (2016)** defined, solar cell is a device which can catch the sun light and transform it to electrical energy directly. The size of a solar cell is about a size of a palm of an adult. The shape is an octagon, and the color is blue-black. Solar cells are built with the solar batteries together very often. The large units are solar modules. The case of many solar cells are built together which are called a solar panel. **Narain and Winter (2016)** found that, drip irrigation can reduce water consumption by 70% and fertilization consumption 40%, whilst increasing crop yield by 50% when compared to flood irrigation, it has only been widely adopted in development countries. **Paudyal and Shakya (2016)** investigated the effects of dust on the efficiency of PV panels and presented a review of the degradation of a PV panel performance due to dust-induced physical damages, such as attenuation of the incident solar radiation and increases in the temperature of the PV module. **Tiwari and Kalamkar (2016)** have carried out the comparative performance analysis of four different PVWPS configurations under sunny day outdoor conditions at Nagpur, India and determined the best optimum configuration for the location and concluded that PV array optimization is one of the important factors to increase the overall efficiency and reduction in the cost of PVWP system. **Rahman et al., (2017)** investigated the effect of PV module temperature on the system energy efficiency. The researchers tested a photovoltaic (PV) system under Malaysian climatic conditions. It was shown that the electrical efficiency decreases by approximately 0.22% as the temperature of the PV module increases by 1 °C. The researchers have also reported that solar cell temperature, solar irradiation intensity, mass flow rate of cooling fluids, humidity, and dust significantly affect the performance of PV modules. The objectives of theses study are to:

-Study the impact of the environmental conditions on solar powered pump discharge.

-Evaluated and tested the performance of solar powered pump on a drip irrigation system.

- Optimize the optimal parameter to maximize solar powered pump efficiency.

MATERIALS AND METHODS

The experimental work was carried out at a private farm in Nubariah, Al Buhayrah Governorate, Egypt, which located at latitude and longitude angle of 30.07°N and 30.33°E, respectively, during winter season 2016.

Solar modules

The system uses 40 modules (JKM250P-60). Each module measures length, 1650 mm, width, 992 mm, depth, 40 mm, Weight, 19 kg, and consists of 60 polycrystalline silicon cells connected in series and parallel.

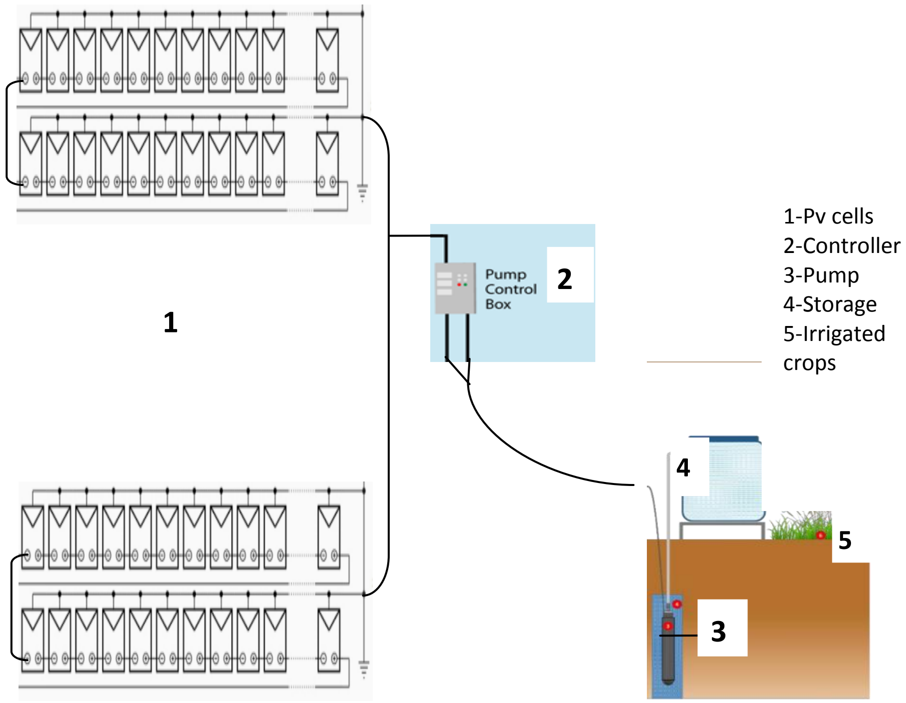

Fig.1: Solar pumping system

Controller

The system uses Controller PS9K2. Control input for dry running protection, remote control etc. Protected against overload and over temperature. Integrated MPPT (Maximum Power Point Tracking). The specification of controller PS9K2 is power, max. 10 Kw, input voltage, max.850 V, optimum Vmp, >575 V, motor current, max. 17 A, efficiency, max. 98%, enclosure class, IP54, weight, 17 Kg.

Pump Unit

The system uses pump unit PU C-SJ30-7. Borehole diameter, min. 6.0 in, water temperature, max. 30°C, weight, 70 kg.

Instruments

Solar Power Meter

TM-207 solar power meter measures solar radiation emitted from the sun in W/m^2 or BTU with a flexible sensor and is ideal for solar PV installations to set panels at optimal angles, for meteorological and agricultural applications.

The global positioning systems (GPS)

The specification of GPS 72H is size, 3×6.9×15.75 cm, weight, 224 g, Gps accuracy, < 15 meters, RMS 95% typical. To measure latitude and longitude angle.

METHODS

The experiments were done during winter season, 2016. The photovoltaic water pumping system performance (sun tracking orientated facing south direction and tilt angle, horizontal and 30˚, head pump, solar radiation) on the study indicator (electric power output of panel W, panel efficiency %, discharge of pump m^3/h, hydraulic power W). The energy produced from solar cells powered the pump to provide the amount of water to the experimental area. The experimental area was (650 m × 220 m). Forty modules of PV (connected in series, parallel) were used to provide the system with required electricity, each one is (250 W, polycrystalline, 37.7 V and 8.85 A) with controller (17 A), pump unit is consist of (pump end, motor). In farm 5 crops are growed, distances agriculture (m) in Grapes (3×2m), Pomegranate (4×6m), Mandarin (4×4m), Oranges (4×6m), Lemon (4×6m), number of plantes in feddan for Grapes, Pomegranate, Mandarin, Oranges, Lemon (700, 175, 262, 175, 175 tree), Production / feddan for one plant of Grapes, Pomegrante, Mandarin, Oranges, Lemon (12, 8, 10, 10, 15 ton/feddan), Production / tree for one plant of Grapes, Pomegrante, Mandarin, Oranges, Lemon (20, 30,50, 120,150 kilo/season). Irrigation system was consisted of GR drip lines. Its made with flow-regulating cylindrical drippers that allow growers the ability to irrigate crops in a wide range of field conditions each one is diameter (16, 18, 20 and 32 mm), thickness: (0.7, 0.9, 1.0, 1.1, 1.2 mm), roll length:(400 m), drippers spacing: (20, 25, 30, 40, 50 and 100 cm). Flow rate: (2, 4, 6 and 8 l/h). Pipes (PE) with a diameter of 63 mm.

The experimental factors

1- Weather conditions

- Daily temperature in (winter)
- Daily solar radiation in (winter)

2- Panel performance

- Panel tilt angle (0^o and 30^o in winter)
- Panel orientation (east to west)

3- Pump performance

-Pump head (30, 35, 40, 45, 50 m)

Measurements and determinations

PV panel efficiency

PV panel efficiency is the measure of how efficient the PV panel is in converting sunlight to electricity:

$$\eta_{panel} = \left(\frac{V_{oc} \times I_{sc} \times FF}{I_{ns} \times a}\right) \times 100$$

Input and output power to the system

The insolation to the PV gives the input power (P_{in}) to the system (Hamza and Taha, 1995):

$$P_{in} = I_{ns} \text{ X } A \qquad , W$$

The direct current output power (P_{out}) from the PV is given by

$$P_{out} = V_{oc} \text{ X } I_{sc} \qquad , W$$

Where:

I_{ns} = Insolation, W/m² , A = Solar module area, m²

V_{oc} = Open circuit voltage, V , I_{sc} = Short circuit current, A

Hydraulic power

The hydraulic power output of the pump is the power required to lift a volume of water through a given water head:

$$P_h = \rho \times g \times Q \times H \qquad ,W$$

Where:

ρ= Water density, Kg/m³ , G= acceleration of gravity, m/s²

Q = Water discharge, m³/s , H= Total pumping water head, m

RESULTS AND DISCUSSION

The effect of solar radiation and ambient temperature on photovoltaic

Fig.2. shows the relationship between solar radiation and ambient temperature versus time at different tilt angles (0°, 30°) and fixed system in17 Jan, 2016. And from here also know the effect of tilt angle at fixed system (panel oriented to south along the day) in 17 Jan, 2016. The graph which is shown below the solar radiation on horizontal plane shows at any given time. the solar radiation on horizontal plane is approximately

243 W/m². The solar radiation on horizontal plane increases until it reaches the highest point of the path. The solar radiation on horizontal plane is approximately 527 W/m² at the highest point of the path. Then starts to decrease until it reaches the lowest point where is approximately 240 W/m². The solar radiation on tilted angle 30° in fixed system is approximately 622 W/m². The solar radiation on tilted angle 30° in fixed system increases until it reaches the highest point of the path. The solar radiation on tilted angle 30° in fixed system is approximately 812 W/m² at the highest point of the path. Then starts to decrease until it reaches the lowest point where is approximately 292 W/m². The ambient temperature from 8:00 am to 12:00 pm starts to increase until it reaches the highest degree (26˚c) then starts to decrease until it reaches the degree (21˚c) at 16:00 pm. It is evident that solar radiation increases along day time from sunrise and reaches its maximum value then it decreases with sunset in winter. And from here found incident radiation on the panel increases with changing tilt angle gradually from (0° to 30°).

Fig.3. it is evident that solar radiation increases from (711,740, 752, 812 W/m²). The output electric power has the same trend of solar radiation where increases from (285, 338, 412, 432 W). PV efficiency increases from (15.9, 16, 16.5, 17.9 %).The output electric power and pv efficiency increases with the increasing in solar radiation.

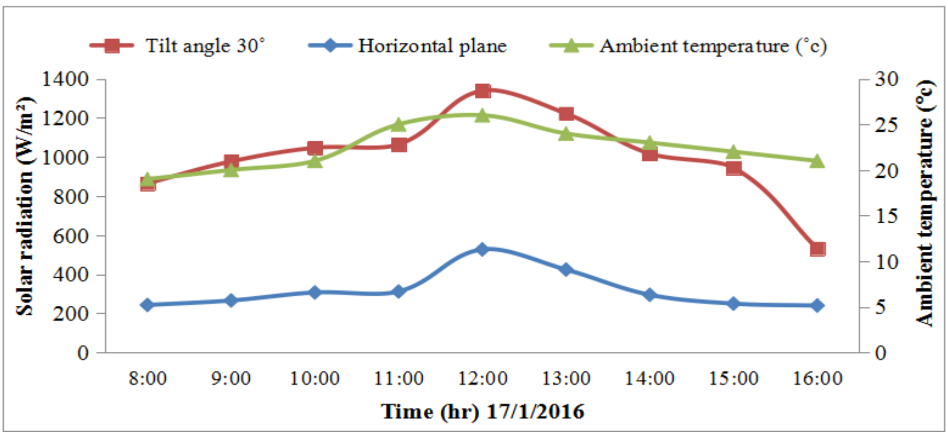

Fig. 2: Solar radiation and ambient temperature versus time at different tilt angles (0°, 30º) and fixed system in 17 January, 2016.

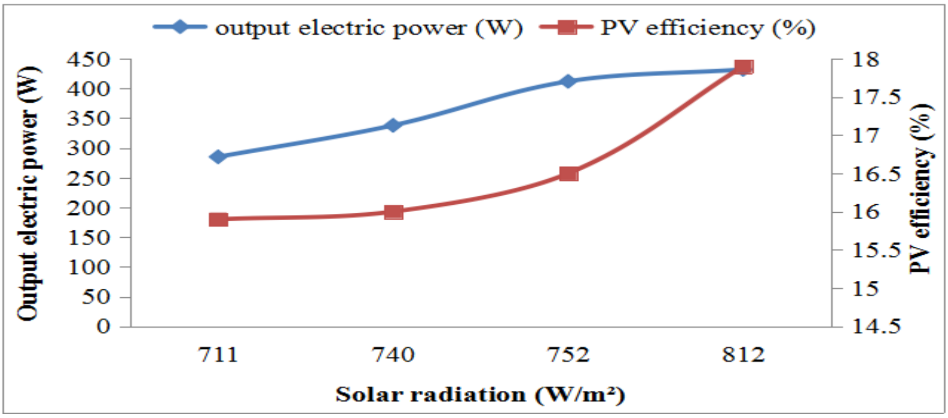

Fig. 3: Effect of different solar radiation on output electric power and pv efficiency in 17 January, 2016

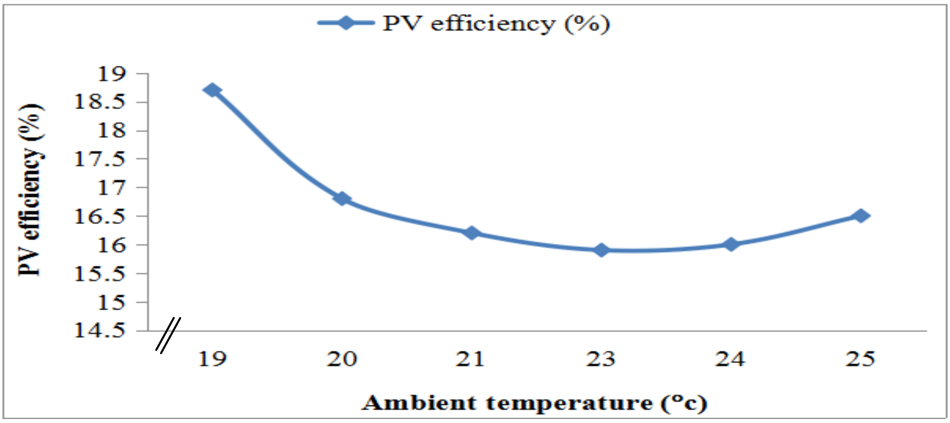

Fig. 4: Effect of different ambient temperature on pv efficiency in 17 January, 2016

Fig.4. shows that the relationship PV efficiency versus the ambient temperature in 17 January, 2016. at ambient temperature (19, 20, 21, 23 and 25°c), PV efficiency was as follow (18.7, 16.8, 16.2, 15.9 and 16.5%). It is evident that PV efficiency decreases with increasing temperature, fundamentally owing to increased internal carrier recombination rates, caused by increased carrier concentrations.

Pump of discharge

Fig.5. shows the relationship between pump discharge versus time in 17 January, 2016. The graph which is shown below. Pump discharge shows at any given time. Pump discharge increases until the mass reaches the

highest point. Pump discharge is approximately 26 m^3/h at the highest point. Then starts to decrease until it reaches the point where is approximately 20 m^3/h. It is evident that the discharge increases along day time from sunrise when it reaches its maximum value then it decreases with sunset.

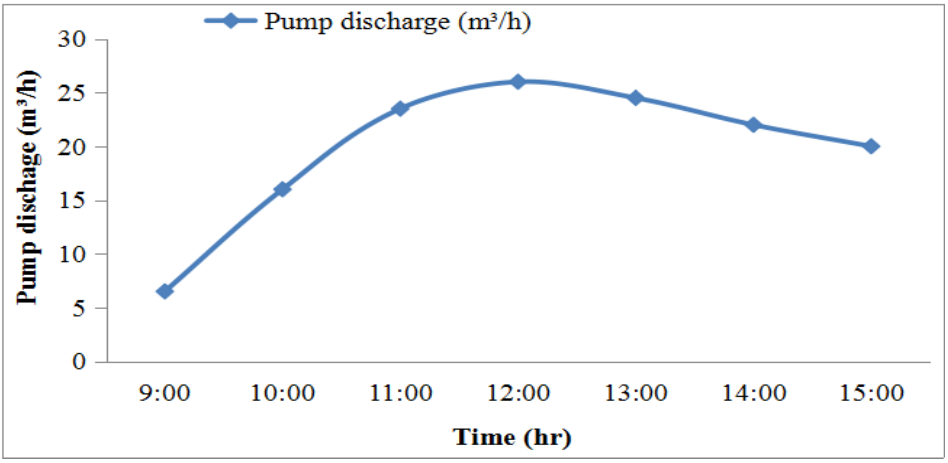

Fig. 5: The relationship between pump discharge versus time in 17 January, 2016

Fig.6. shows discharge versus solar radiation on tilted angle 30° in fixed system and power at constant water head of 30 m in 17 January, 2016. Solar radiation increases from (711,740, 752, 812 W/m^2) pump discharge increases from (35, 36.5, 38.5, 39.5 m^3/h), power increases from (285, 338, 412, 432 W). It is evident that pump discharge and power increases with the increasing in solar radiation.

Fig.7. shows that the relationship pump discharge versus head in 17 January, 2016. Pump discharge decreases from (33, 31.5, 29, 26, 24.5 m^3/h) with the increase in water head from (30, 35, 40, 45, 50 m). It is evident that the discharge decreases with the increasing in water head.

Hydraulic power

Fig.8. shows the relationship solar radiation on tilted angle 30° in fixed system versus hydraulic power in 17 January, 2016. Solar radiation increases from (622, 711,740, 752, 812 W/m^2) hydraulic power increases from (2698, 2861.3, 2984, 3147.4, 3229 W). It is evident that hydraulic power increases with the increasing in solar radiation.

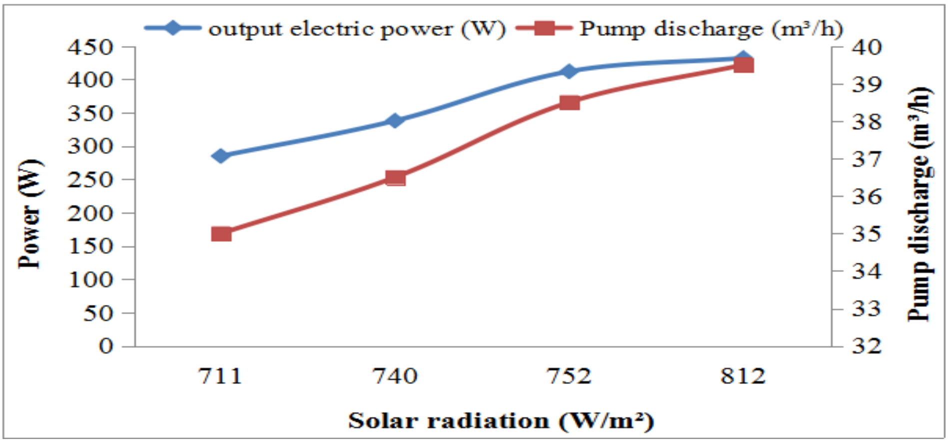

Fig.6: discharge versus solar radiation on tilted angle 30° in fixed system and power at constant water head of 30 m in 17 January, 2016

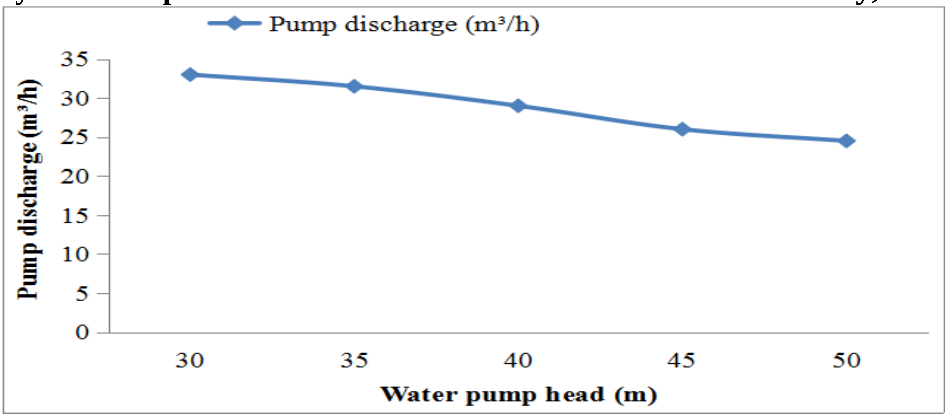

Fig.7: pump discharge versus head at different heads in 17 January, 2016

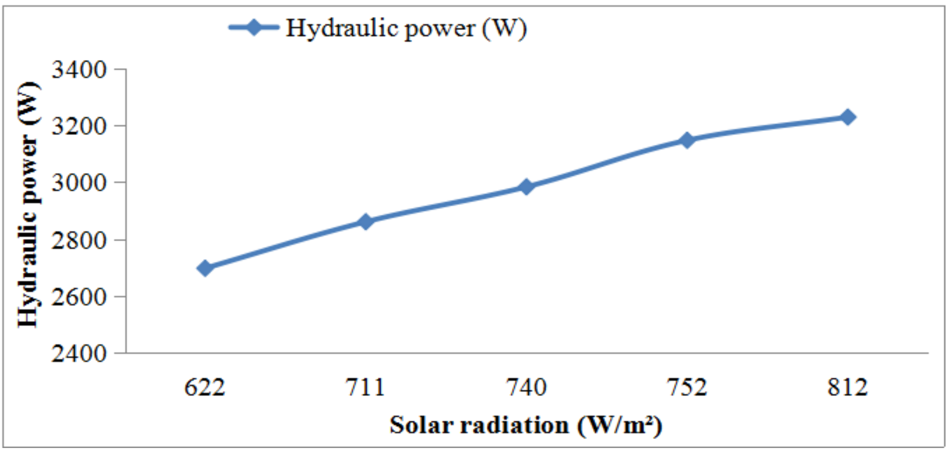

Fig. 8: The relationship solar radiation on tilted angle 30° in fixed system versus hydraulic power in 17 January, 2016

Fig.9. shows that the relationship pump discharge versus hydraulic power in 17 January, 2016. Hydraulic power increases from (2698, 2861.3, 2984, 3147.4, 3229 W) pump discharge increases from (33, 35, 36.5, 38.5, 39.5 m^3/h). It is evident that hydraulic power increases with the increasing in pump discharge.

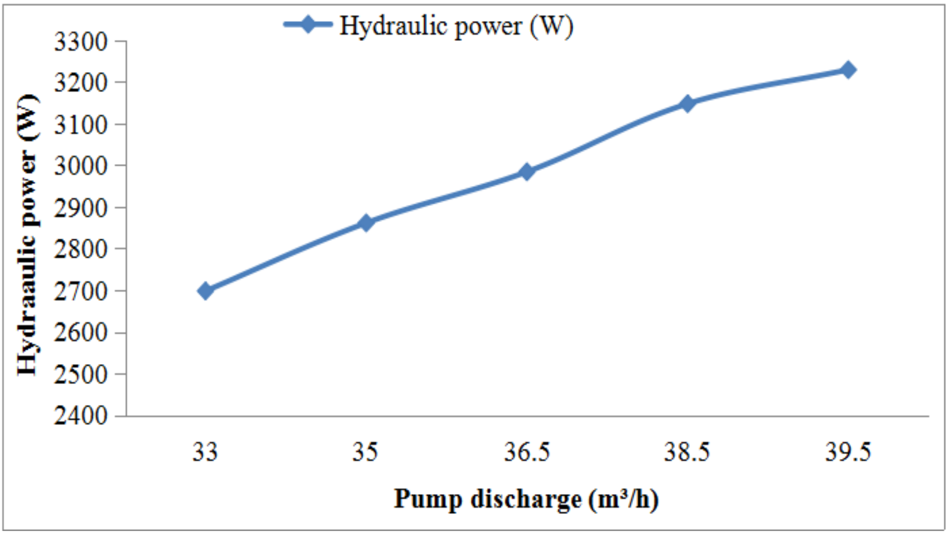

Fig. 9: The relationship pump discharge versus hydraulic power in 17 January, 2016

CONCLUSION

The photovoltaic water pumping systems is able to save the energy to remote locations where the electricity produced by the photovoltaic water pumping system better than the electricity produced by a diesel. When using the system found that output power from the system is (285, 338, 412, 432 W) and input power to the system is (955.3, 1339.4, 1485,1548.2, 1570 W) in 17 January, 2016.

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الملخص العربي

تقييم نظام ضخ مياه الرى بالخلايا الشمسية خلال موسم الشتاء

طارق فوده*، أسعد درباله *، عادل المتولى* و أسماء البلكيمى *

نظرا لزيادة تكاليف الكهرباء وعدم توفرها فى الاماكن البعيدة وكذلك صعوبة الحصول على المياه وخصوصا فى المناطق النائية تم الاتجاة الى استخدام نظام ضخ مياه الرى باستخدام الطاقة الشمسية لرى المحاصيل البستانية (العنب والرمان والبرتقال واليوسفى والليمون) باستخدام نظام الرى بالتنقيط اجريت الدراسة بمزرعة خاصة بالنوبارية - محافظة البحيرة (٣٠,٠٧ شمالا و ٣٣,٣٠شرقا خط عرض وخط طول) خلال موسم الشتاء ٢٠١٦.

وكانت أهداف الدراسة كما يلي:

١ - اختباروتقييم اداء مضخة تعمل بالطاقة الشمسية على اساس نظام الرى بالتنقيط.

٢ - دراسة تاثير الظروف البيئية على نظام ضخ مياه الرى بالطاقة الشمسية.

٣ - تحديد المعاملة الامثل لتحقيق اقصى قدر من الكفاءة فى نظام ضخ مياه الرى بالطاقة الشمسية.

أخذت المؤشرات التاليه فى الاعتبار

الاشعاع الشمسى - زوايا الميل - درجة الحرارة المحيطة - كفاءة الخلية - تصرف المضخة - الضاغط - القدرة الهيدروليكية

قد تم التوصل الى النتائج التاليه من خلال التجارب الحقليه:

١ - الاشعاع الشمسى زاد مع شروق الشمس الى ان وصل الى اقصى قيمة له فى فترة الظهيرة ثم يقل مع غروب الشمس. حيث انه فى الوضع الافقى يبدا يزداد حتى يصل الى اعلى نقطة ٥٢٧ وات لكل متر مربع ثم بعد ذلك يقل مع غروب الشمس حتى يصل إلى ٢٤٠ وات لكل متر مربع . وفى الوضع المائل ٣٠ درجة يبدا يزداد حتى يصل الى اعلى نقطة ٨١٢ وات لكل متر مربع ثم بعد ذلك يقل مع غروب الشمس حتى يصل الى ٢٩٢وات لكل متر مربع.

٢ - تصرف المضخة يزداد بزيادة الاشعاع الشمسى فى ١٧ يناير ٢٠١٦حيث ان الاشعاع الشمسى عندما يزيد من (٧١١ ، ٧٤٠ ، ٧٥٢ و ٨١٢ وات لكل متر مربع) التصرف يزيد من (٣٥ ، ٣٦,٥ ، ٣٨,٥ و ٣٩,٥ متر مكعب لكل ساعة) والقدرة تزيد من (٢٨٥ ، ٣٣٨ ، ٤١٢ و ٤٣٢ وات).

٣ - كفاءة الخلية تقل بزيادة درجة الحرارة المحيطة فى ١٧ يناير ٢٠١٦ حيث ان عند درجة الحرارة (١٩ ، ٢٠ ، ٢١ ، ٢٣ و ٢٥ درجة سليزيوس) كانت كفاءة الخلايا كالتالى (١٨,٧ ، ١٦,٨ ، ١٥,٩ و ١٦,٥ %) الحرارة المحيطة بالخلايا تؤثر على الطاقة الكهربائية الناتجة من الخلايا وبالتالى اداء وكفاءة الخلايا تقل.

***قسم الهندسة الزراعية – كلية الزراعة – جامعة طنطا.**

٤- القدرة الهيدروليكية تزداد بزيادة الاشعاع الشمسى فى ١٧يناير ٢٠١٦ حيث ان الاشعاع الشمسى عندما يزيد من (٦٢٢ ، ٧١١ ، ٧٤٠ ، ٧٥٢ و ٨١٢ وات لكل متر مربع) القدرة الهيدروليكية تزيد من (٢٦٩٨ ، ٢٨٦١,٣ ، ٢٩٨٤ ، ٣١٤٧,٤ و ٣٢٢٩ وات).

٥ - القدرة الهيدروليكية تزداد بزيادة التصرف فى ١٧ يناير ٢٠١٦ حيث ان التصرف عندما يزيد من(٣٣ ، ٣٥ ، ٣٦,٥ ، ٣٨,٥ و ٣٩,٥ متر مكعب لكل ساعة) القدرة الهيدروليكية تزيد من (٢٦٩٨ ، ٢٨٦١,٣ ، ٢٩٨٤ ، ٣١٤٧,٤ و ٣٢٢٩ وات).

٦ - زاد تصرف المضخة مع شروق الشمس الى ان وصل الى اقصى قيمة له فى فترة الظهيرة ثم يقل مع غروب الشمس فى ١٧ يناير ٢٠١٦ حيث ان تصرف المضخة يبدا يزيد حتى يصل الى اعلى قيمة ٢٦ متر مكعب لكل ساعة ثم يقل مع غروب الشمس حتى يصل الى ٢٠متر مكعب لكل ساعة.

٧ - تصرف المضخة يقل بزيادة ضاغط التشغيل حيث ان ضاغط التشغيل عندما يزيد من (٣٠ ، ٣٥ ، ٤٠، ٤٥ و ٥٠ متر) التصرف يقل من (٣٣ ، ٣١,٥ ، ٢٩ ، ٢٦ ، ٢٤,٥ متر مكعب لكل ساعة).