# SOLAR POWERED IRRIGATION SYSTEM FOR TURF AREA

**[9]**

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## ABSTRACT

Solar water pumping system may be a competitive application for remote and luxurious areas where power costs a lot. One may argue that solar photovoltaic water pumping systems not only comprises an environmentally friendly solution, but also contributes substantially to the satisfaction of remote communities' water consumption needs. Therefore, the study aimed to manage pump for sprinkler irrigation system operated by solar power in small area of turf. The required hydraulic experiment and measurements were conducted using Direct-coupled photovoltaic pumping system to operating sprinkler irrigation network at the experimental farm of soil and water Research Department, Nuclear Research Center, located at Inshas, Sharkia Governorate, Atomic Energy Authority, Egypt.

The essential idea to operate the sprinkler irrigation system and fulfill the water needs of turf area was to use a locally assembled pump-set to match the photovoltaic generator unsteady output.

Results indicated that, solar radiation increased during summer (April and July), so the electric power, pump discharge, pressure head, Hydraulic horsepower (hp) and Photovoltaic conversion efficiency are affected as solar radiation changed.

Four mathematical equations has been derived to illustrate the relationship between solar radiation and electric power, pump discharge pressure head , water hp and Photovoltaic conversion efficiency (PVCE) during the day hours.

**Keywords:** Solar, irrigation system, Photovoltaic cell, water pumping, turf, landscape

## INTRODUCTION

Solar Power is used extensively in Egyptian new Reclaimed lands due to its high environmental friendly. During recent years, numerous photovoltaic (PV) cells varying characteristics have become available in the Egyptian market. It could be directly connected to the motor, if the application needs a direct current  (DC) motor then the motor and pump are built in together, while  if the application needs an Alternative current (AC) motor, an inverter (usually called controller) needs to be placed in between the PV array and the motor.

PV can be implemented at any scale and size where the overall efficiency of systems available on the market varies between 6% and 18%, depending on the type of cell technology and application. Meanwhile, the expected life span of PV systems is between 25 and 30 years **(Meah et al 2008).**

Matched PV system components with a DC motor obtained from local markets to meet PV generator performance. Performance curves of both PV generator and DC motor was plotted. (**Hegazi, 2010).**

Solar pumps were operated by variable speed DC motors.it can be operated only during day light time when solar radiation is available. Due to motor variable speed, the pump can be operated even at cloudy day with lower discharge. But it cannot be operated at the solar radiation less than 350 W/m$^2$. Discharge varied in different times of a day due to variation of solar radiation. Solar radiation is instantaneous and it varies every moment **(Hossain et al 2014)**

The sun is a powerful energy source that provide earth each day with energy that can satisfy

the whole world energy demand for 27 years. In addition, solar power generates 250 gegawatts of energy per square kilometer each year which is considered very high compared to all other renewable energy source that generate a maximum of 30 GWs/km$^2$ /year. For these reasons, solar energy in specific can play a great role in providing the world with some of its energy needs including electricity, heating and cooling **(Balat, 2006; NREL.2009; Gladen, 2009).**

Egypt has a great potential in utilizing solar energy to generate energy products and electricity. That because it is being a country on the Sunbelt, especially the upper region **(Balat, 2006; EIA, 2007. Ghoneim, (2006**) mention that on a clear day, the solar radiation incident on the earth's surface can reach 1000 W/m$^2$. Photovoltaic (PV) is a technology in which the radiant energy from the sun is converted to direct current. The photovoltaic process produces power silently and is completely self-contained, as there are no moving parts. (**Ghoneim, (2006).**

Thousands of PV systems operating at pumping heads in the range from 0 to 120 m have been successfully realized over the last 20 years. Particularly in areas of average daily solar radiation intensity exceeding 5 kW.h/ m$^2$ /day. PV systems had proven reliability and economic feasibility in comparison with diesel powered pumping systems .In addition, these systems need very limited maintenance, since they operate without storage batteries and they do not pollute the environment. **(Abdel-Karim and  Marwan 2005).**

The objectives of this study were to manage the irrigation system in order to achieve optimum utilization of solar energy as a pumping system and Harmonize between available solar radiation insolation and scheduling irrigation system.

## MATERIALS AND METHODS

### Description of the photovoltaic system

Experiments were conducted in the experimental farm of Soil and Water Research Department, Nuclear Research Center, located at Inshas city, Sharkia Governorate, Atomic Energy Authority, Egypt. . During the period from January 2017 to November 2017, the Latitude and Longitude of the experiment site 30 º 24 N, 31 º 35 E, respectively. To manage Sprinkler irrigation system operated with quite simple photovoltaic system.

A photovoltaic array provides electricity for driving Centrifugal pump connected directly with DC motor, **Figure (1).**
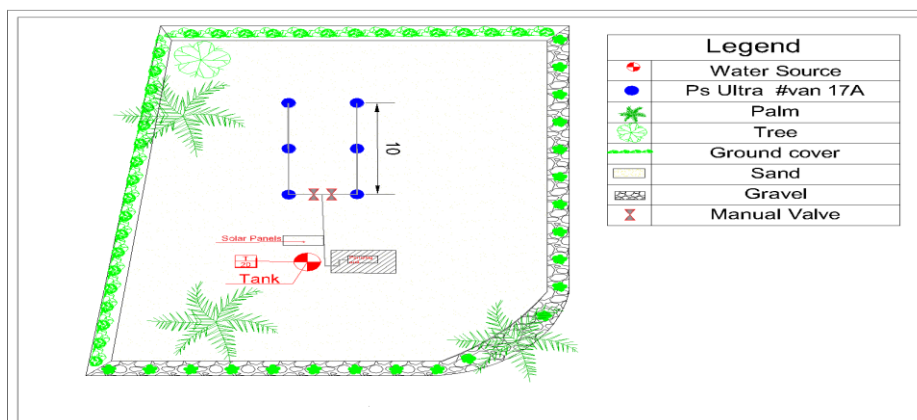


**Fig. 1.** Sprinkler irrigation System Layout

### 1- Photovoltaic  (PV) panels characteristic

Photovoltaic (PV) system was implemented consists of four panels with tilt angle as shown in **Figure (2)** 30º from the horizontal. Panels were connected in series to give 8 Ampere and 130 Volt at open circuit, (Voc).  The output of the PV generator, i.e. the generator current and voltage, was measured using a multi meter. The technical characteristics of the PV module are listed in **Table 1**

**Fig. 2.** Four panels with tilt angle.

**Table 1.** Specifications of the PV module.

| Model | DJ-240 PA |
|---|---|
| Peak Power | $P_{mp}$ 240 W |
| Rated voltage | $V_{mp}$ 29.7 V |
| Rated current | $I_{mp}$ 8.08 A |
| Open circuit voltage | $V_{oc}$ 36.2 V |
| Short circuit current | $I_{sc}$ 8.88 A |
| Cell material | Polycrystalline 240 W |
| Max series fuse rating | 15A |
| Module efficiency | 14.69 % STC * |
| Max. system voltage | 1000V , 600 V |
| Temperature Coefficient | NOCT (Normal Operating Cell Temperature) 48º c±2ºc |
| | $P_{max}$ − 0.45 % / K |
| | $V_{oc}$ -0.35 %/k |
| | $I_{sc}$ +0.05%/K |

*STC (standard test condition): irradiance 1000 W/m², module temperature 25º c, air mass= 1.5 G

Every (PV) array has its own (I–V) characteristics. The maximum power point (MPP) of the PV array depends on several factors including onsite solar radiation, temperature, the connected load, and if the load is directly connected. Solar cells are divided into three categories according to the type of crystal material used in fabrication: monocrystalline, polycrystalline and amorphous.

## 2- Solar radiation data

The average amount of solar radiation falling on a surface normal to the ray of the sun outside the atmosphere as measured by NASA is 1353 W/m². However, the amount of extraterrestrial depends on the change in the distance between the sun and the earth during the year. Because solar radiation measurements for most locations are not available. Most of the models use meteorological factors that are commonly reported by weather stations. **(Al-zoheiry 2006).** The monthly, daily average of solar irradiation are shown in Table 2.

**Table 2.** The monthly, daily average of solar irradiance:

| Month | Jan. | Apr. | Jul. | Oct. |
|---|---|---|---|---|
| **SOLAR IRRADIANCE W/M².Day** | 387 | 580 | 708 | 398 |

## 3- Pump unit

DC Electric motor shown in **Figure (3)** was coupled directly to a centrifugal pump as shown in **Figure (4).** The discharge rate of the pump unit was 7 m³/h at 18 m pressure head and 2143 rpm speed and about 16 % efficiency.

Motor responded softly to the unstable current PV generator supply during daytime through different months. The technical Specifications of DC motor which used in the studied project are shown in **Table 3 .**

**Fig. 3.** Dc Electric motor HN-1240B-6509T



**Fig. 4.** Connection between the centrifugal pump and the DC motor

**Table 3.** Technical specifications of the DC motor

| Voltage: | 140Volt (rated) |
|---|---|
| Max. Speed: | 2900RPM |
| Max. Power: | 1.5HP |

### 4- Irrigation system for small experimental turf area

Six adjustable orifice sprinklers were used in the experiments. The laterals were fixed at distance 5 m, and the spacing between the sprinklers along the lateral was 5 m. The sprinklers were arranged according to a Square layout (5 × 5). Full circle spray head sprinklers orifice on each corner were used to irrigate the Plot. The irrigation network were provided by pressure gauge (0-6 bar) and water meter The sprinkler unit includes a tubular body membrance with a rotatable cap mounted on one end there of that cooperates with peripheral edges of the tubular body member for defining an adjustable arc spray orifice for adjusting a spray pattern from an angle of from about 0º up to about 360º with the cap adjustable axially of the tubular body member for selectively adjusting the height of the orifice opening as shown in **Figure (5).**

The orifice size is selected to cover 5.2 m at 1.5 bar operating pressure; the flow rate is 0.93 m$^3$/h with precipitation rate 0.38 mm/h.

### 5. Methodology used in the determination of the power and efficiency of system

**Electric Power**

The hourly output Electric power of the PV generator at a solar radiation on tilted plane module (W/m$^2$), is given by

$$P = I*V ......................................................(1)$$

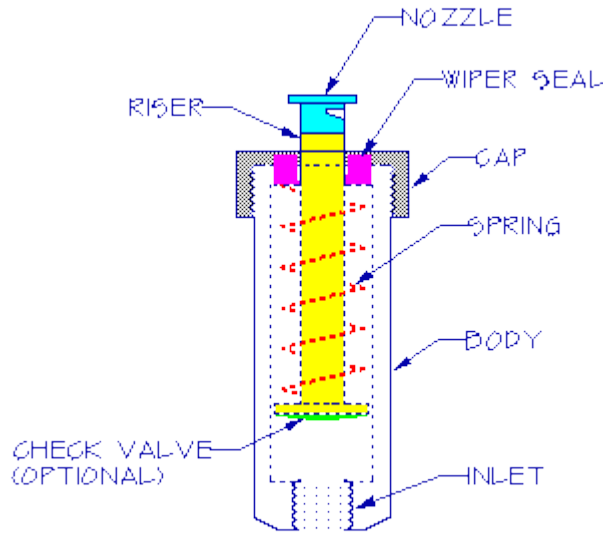Where P represent the Electric Power, I is the current and V is Voltage

**Fig. 5.** Internal structure of sprinkler irrigation

**Hydraulic horsepower**

The mechanical power of a Hydraulic flow is the product of the fluid flow rate, by the head at which it is transferred. The following formula was used to calculate

$$H_p = (QH/75) \times 0.746 ...................................(2)$$

Where
 $H_p$ : Hydraulic horsepower (kW)
 Q : Discharge (L/s)
 H : pressure head (m)

**Break Hp = hydraulic power / E ..................(3)**
Where
 E : the motor efficiency

**Efficiency of the solar generator (η) :**
 **η solar = (V.I) / (G.A) ………………………. (4)**
Where:
 I : current, amperage
 V : voltage, volt.
 A: surface area of the solar array, m2
 G: solar radiation, $W/m^2$

### RESULTS AND DISCUSSION

The performance of solar pump has been concerned and its characteristics was measured and analyzed, the performance chart for electric power, water HP power, discharge, pressure head and

efficiency of solar energy were studied at different levels of changing variables.

1- **The effect of solar radiation on electric power:**

Data in **Figure (6)** Show the average daily electric power through the selected months, the data indicated that the lower value found in January and October while it is increased in April and July.
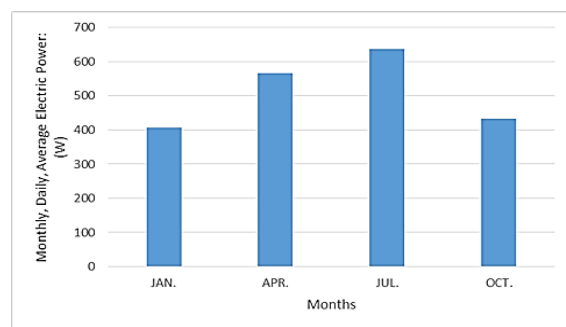


**Fig. 6.** Average daily electric power through the selected months at operating hours.

The results show that the maximum value of electric power reached 734 W from 10:00 to 13.30 am while the minimum value was 130W. At 17:00 pm. The solar radiation was at it's highest was from 10.00 to 12.30 and then clouds were shown

to reduce the solar radiation. the solar radiation was measured daily from 8:00 am to 19:00 pm through the operating time of the pump. The increase of daylights hours lead to increase the solar radiation as shown in **Figure (7).**

From the above results, a mathematical equation (5) has been derived to illustrate the relation ship between solar radiation and electric power Figure (8**)**

**P= -0.002S$^2$ + 3.62S - 864.88      ………………(5)**
Where
P is electric Power (W)
S is solar irradiance (W/m$^2$)
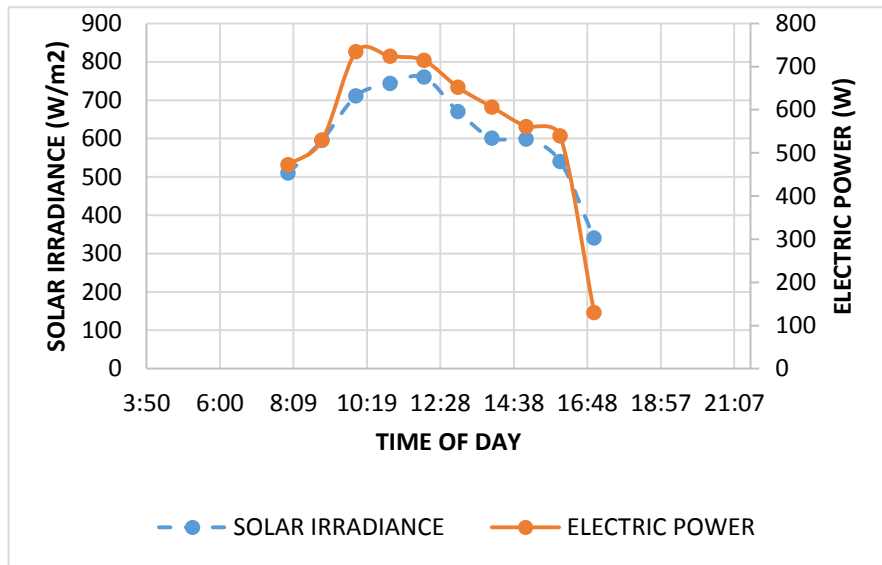


**Fig. 7.** The effect of solar radiation on the produced electric power on a selected day of October
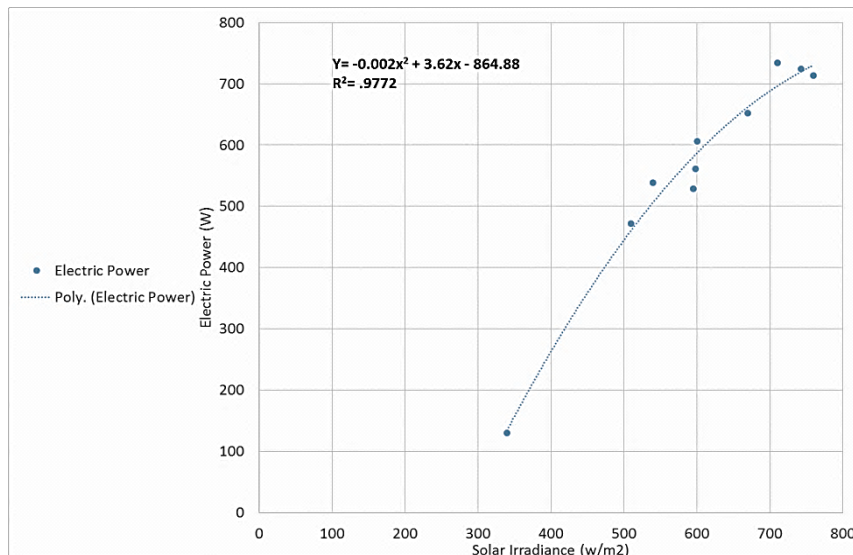


**Fig. 8.** The relationship of solar radiation and electric power

**2- The effect of solar radiation on pump discharge, Pressure head and Hydraulic power:**

**2.1. The effect of solar radiation on Discharge:**

Data in Figure (9) show the average daily pump discharge through the selected months , the data indicate that the lower value found in January and October while it is increased in April and July.
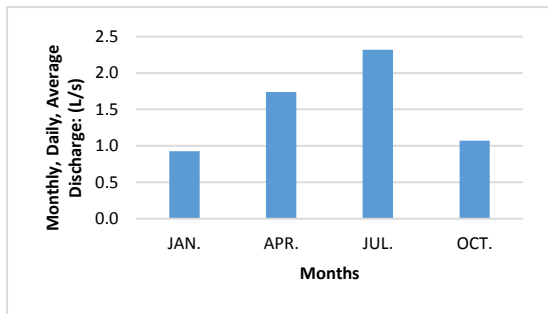


**Fig. (9):** Average daily pump discharge through the selected months.

The results show that the maximum value of pump discharge reached (1.86 L/s) at 11:00 am while the minimum value was (0.33 L/s) at 17:00 pm. Discharge increased with the increase of solar radiation and it reached   at the maximum solar radiation value at (11:00) and then decreased gradually as solar radiation decreased as  shown in **Figure (10).**
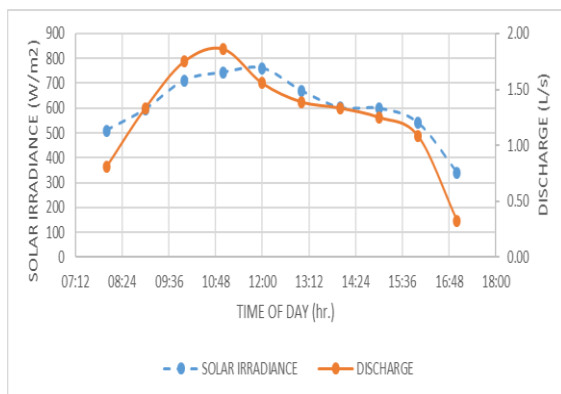


**Fig. 10.** Water pump discharge during the operating period

From the above results, a mathematical equation (6) has been derived to illustrate the relationship between solar radiation and pump discharge rate during **Figure (11).**

$$Q= 0.0034S + 0.8215 \quad ……………………(6)$$

Where
   Q is discharge (L/s)
   S is solar irradiance (W/m$^2$)
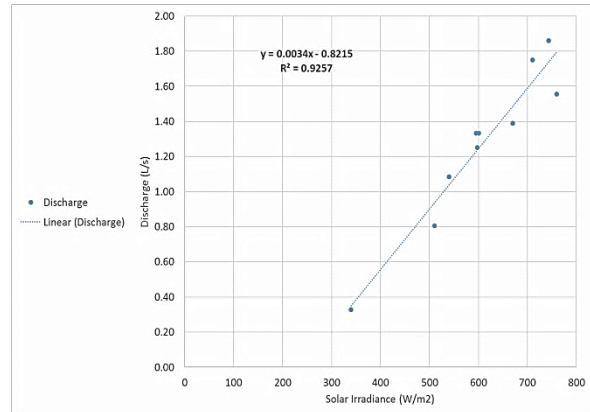


**Fig. 11.** The relationship of solar radiation and pump discharge.

**2.2. The effect of solar radiation on pressure head**

Data in **Figure (12)** show the average daily pressure head through the selected months , the data indicate that the lower value found in January and October while it is increased in April and July.
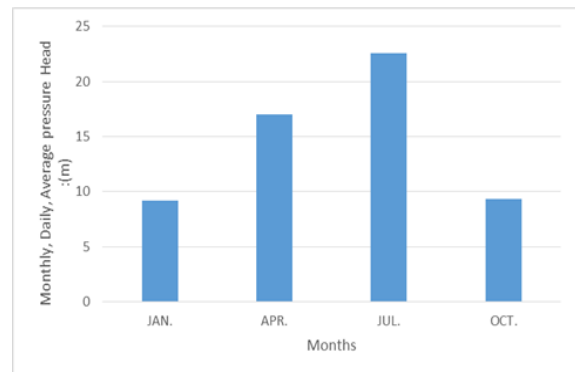


**Fig. 12.** Average daily pressure head  at operating hours through the selected months.

Average pressure head during three days in October are shown in **Figure (13).** The Results Show that the maximum value of pressure head is (18 m) at 11:00 am while the minimum value is (3 m) at 17:00 pm. While the minimum value this is mean that increasing of average daily pressure head as a result of increasing of solar radiation.
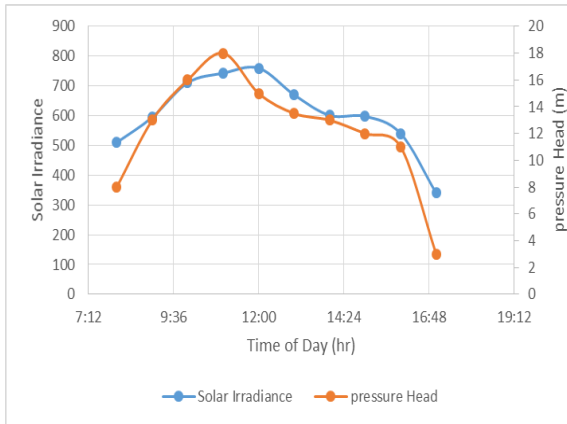
Fig. 13. The effect of solar radiation and pressure head during operating period.

From the above results, a mathematical equation (7) has been derived to illustrate the relationship between solar radiation and pressure head. **Figure (14).**

**h = 0.0325 S – 7.4989……….……………….(7)**
Where

h is the pressure head (m)
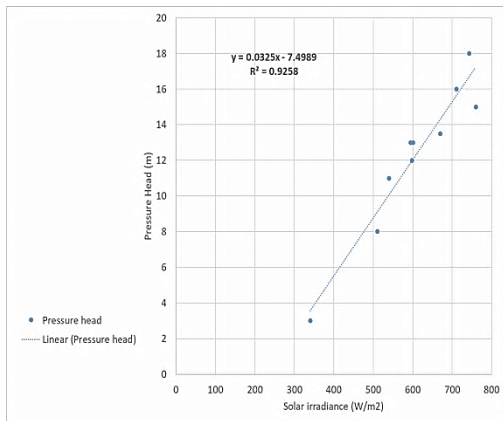S is solar irradiance (W/m$^2$)



Fig. 14. The relationship of solar radiation and pressure head

### 2.3. The effect of solar radiation on Hydraulic horsepower

Data in **Figure (15)** show the average daily water hp through the selected months, the data indicate that the lower value found in January and October while it is increased in April and July.
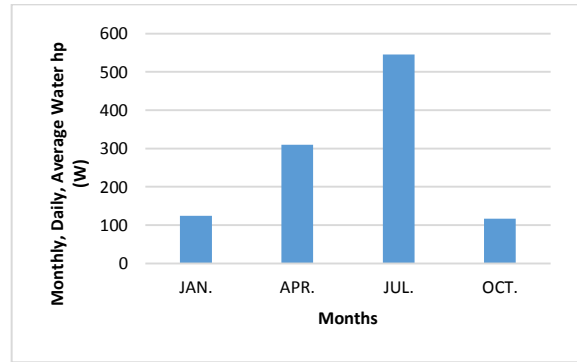


Fig. 15. Average daily hydraulic hp at operating hours through the selected months.

Average hydraulic horsepower during three days in October are shown in **Figure (16)**. The results shown that the maximum value of water hp is (333 W) at 11:00 am while the minimum value is (9.8W) at 17:00 pm. This is mean that increasing of hydraulic horsepower as a result of increasing the solar radiation
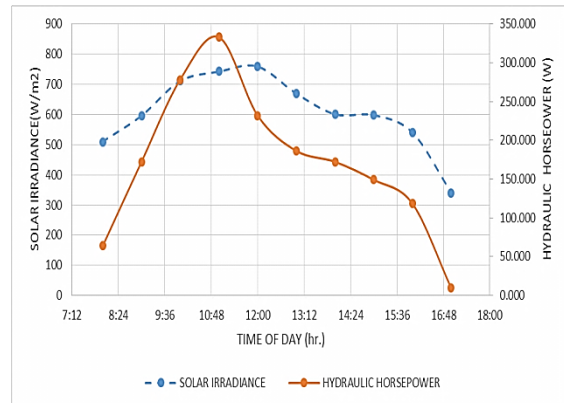


Fig. 16. The effect of solar radiation on hydraulic hp with during operating period.

From the above results, a mathematical equation (8) has been derived to illustrate the relationship between solar radiation and hydraulic hp. **Figure (17).**

**$H_{hp}$ = 0.0006S$^2$ + 0.0252S – 75.941……………. (8)**

**Where**
$H_{hp}$  is hydraulic horsepower
S     is solar irradiance (W/m$^2$)
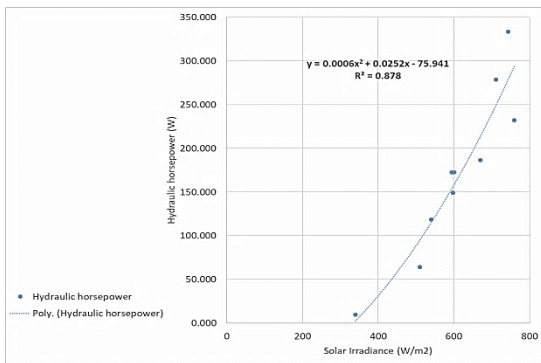
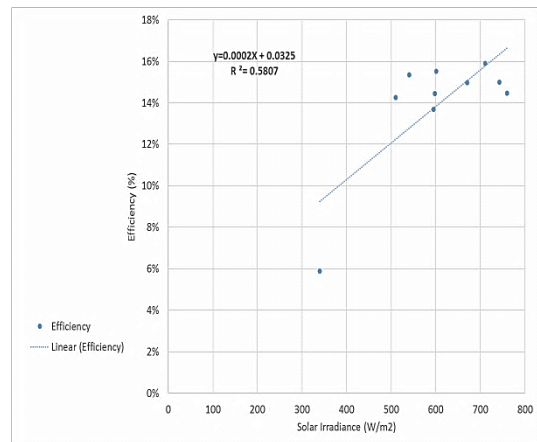**Fig. 17.** The relationship of solar radiation and hydraulic horsepower

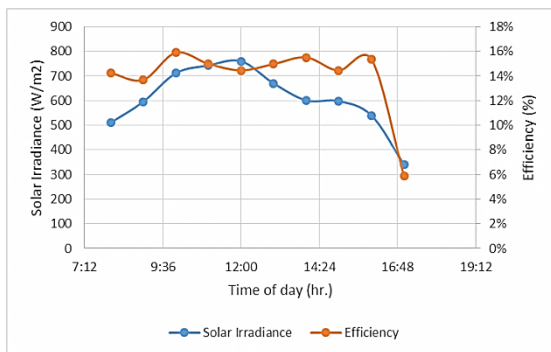### 3- Photovoltaic conversion efficiency (PVCE)



**Fig. 18.** The effect of solar radiation on

**PVCE during operating period.**

From the above results, a mathematical equation (9) has been derived to illustrate the relationship between solar radiation and photovoltaic conversion efficiency (PVCE). **Figure (19).**

**E = 0.0002S + 0.0325 ……………………….. (9)**

**Where**
E is the photovoltaic conversion efficiency (PVCE).
S is solar irradiance (W/m$^2$)



**Fig. 19.** The relationship of solar radiation and PVCE

The correlation shows a very low value (R2= 0.5807), this is due to the interaction of other factors affecting the module efficiency such as air temperature, module temperature and mass.

### CONCLUSION

Experiments were conducted using direct-coupled photovoltaic pumping system. Deferent relations were carried out in order to manage irrigation system for fulfill the water needs of a certain area in the desert of Egypt. The idea was using local assembled pump-set to match the Photovoltaic generator unsteady output. The results showed high relation between pumping system delivery and Solar Radiation. This relation was utilized to predict the proper area to be irrigated without shortage in irrigation requirements.

Results indicated that, solar radiation increased during summer (April and July). Electric power, pump discharge, pressure head, hydraulic hp and Photovoltaic conversion efficiency (PVCE) are affected as solar radiation fluctuating values.

Four mathematical equations has been derived to illustrate the relationship between solar radiation and electric power, pump discharge pressure head, Hydraulic hp and Photovoltaic conversion efficiency (PVCE) during operating period

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# إدارة نظام ري يعمل بالطاقة الشمسية في المساحات الخضراء

# [9]

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## الموجـــــــز

يعتبــر   ضـخ الميـاه بالطاقـة الشمسـية تطبيقًـا تنافسـيا للمنـاطق النائيـة والمنـاطق الفـاخرة حيث تزداد تكلفة الطاقة التقليدية كثيرا. ليس فقط أنظمة ضـخ الميـاه بالطاقـة الشمسـية الكهروضـوئية حـل صـديق للبيئة، ولكنها تسـهم أيضا بشكل كبير في تلبيــة احتياجـات اسـتهلاك الميـاه في المجتمعـات النائية. ولذلك، هدفت الدراسة إلى إدارة نظام ري بالرش يعمل بالطاقة الشمسية في منطقة صغيرة مـن المسـطحات الخضـراء. وقـد أجريـت التجربـة والقياسـات الهيدروليكيـة المطلوبـة باسـتخدام نظـام ضـخ مكـون مـن مضـخة وموتـور (DC) موصـل مباشـرة بالخلايا الفوتو فولتيـة لتشـغيل شبكة الـري بـالرش فـي المزرعـة التجريبيـة لإدارة بحوث التربـة والميـاه، مركز البحوث النووية، هيئة الطاقة الذرية، الموجـود فـي مدينـة إنشـاص، محافظـة الشـرقية، مصر.

الفكـرة الأساسـية لتشـغيل نظـام الـري بـالرش وتلبيـة الاحتياجـات المائيـة لمنطقـة المسـطحات الخضراء هي استخدام نظام ضخ مجمع محليا تم توصيله مباشرة بخلايا فوتوفولتية.

أشارت النتائج إلى أن الإشعاع الشمسي قد زاد خلال الصيف (أبريل ويوليو)، وبالتالي فإن الطاقة الكهربائية، وتصرف المضخة، وضغط  التشغيل، والطاقـة الهيدروليكيــة، وكفـاءة تحويـل الطاقـة الضوئية قد تأثرت مع تغير الإشعاع الشمسي.

تـم استخدام أربـع معـادلات رياضية لتوضيح العلاقـة بين الإشعاع الشمسي والطاقة الكهربائيـة، ضـغط التشـغيل وتصـرف المضـخة، والطاقـة الهيدروليكيــة وكفـاءة تحويـل الطاقـة الضـوئية (PVCE) خلال ساعات النهار .

**الكلمـات الدالـة:** الطاقـة الشمسـية، نظـام الـري، الخلايـا الضـوئية، ضـخ الميـاه، المسـطحات الخضراء، المناظر الطبيعية