Zagazig J. Agric. Res., Vol. 46 No. (1) 2019

65-80

PERFORMANCE EVALUATION OF A SMALL AC/DC SOLAR WATER PUMPING SYSTEM FOR ROOF CULTIVATION

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ABSTRACT: Solar water pumping for irrigation and drinking purposes is considered one of the most recently power system needed. The most important usage of solar pumping systems is to irrigate the agricultural lands to help farmers instead of using electrical or fuel system that take a lot of time, high cost, effort and much losses. In this research, the performance evaluation of a mini water pump (5 Watt) powered by small solar photovoltaic (PV) panel (10 Watt) was investigated to supply the needed water for irrigating roof cultivation units. The experiments were carried out at Faculty of Agriculture, Zagazig University, Sharkia Governorate, Egypt (Latitude 30.5^o – Longitude 31.5^o) in winter and summer seasons of 2018. Two solar pumping systems were evaluated; DC solar pumping system (DSPS) and AC solar pumping system (ASPS) under different operating parameters of PV panel tilt angles (15°, 30°, 45°, 60° and 75°), solar radiation hours during daylight (9:00 to 15:00) and pumping heads (0 ,0.5, 1 and 1.5 m). All parameters were evaluated by determinations of pumping discharge, hydraulic energy, pump efficiency and cost. The obtained results revealed that, the best PV panel tilt angle for Zagazig region was 45° and 30° in winter and summer, respectively. Discharges and pumping efficiencies of ASPS were higher than DSPS. The optimum pumping conditions were 0.25 and 1 m of pumping heads with 220 l/hr., and (83 l/hr., for winter, 88 l/hr., for summer) of pumping discharge for ASPS and DSPS, respectively. Pumping costs of one cubic meter of water by DSPS at pumping heads of 0, 0.5, 1 and 1.5 m were (0.16, 0.17, 0.19 and 0.21 LE) and (0.15, 0.17, 0.19 and 0.21 LE), during winter and summer seasons, respectively. While pumping costs of one cubic meter of water using ASPS were about 0.22, 0.45, 1.23 and 7.11 LE/m^3 at the same heads, respectively. So, a small size of solar PV power system can be efficiently supply irrigation water for roof cultivation units.

Key words: PV, DC solar pumping system (DSPS), AC solar pumping water (ASPS), tilt angle, discharge, hydraulic energy, pump efficiency, cost.

INTRODUCTION

In Egypt, although the exerted huge efforts of government to face the challenges of lack access to grid electricity due to the inability of current producing to catch up with the rapidly increase in population **(Khattab *et al.,* 2011)**, therefore, depending on electric power source in remote and developing rural areas suffers many problems. So, it became necessary to utilize the renewable energy (RE) sources to produce the needed requirements of energy for developing those communities. Whereas, the cost of producing electricity from RE sources is lower than conventional electricity because of savings in the construction of infrastructure and cables extends. Also, high and continuous rapid in diesel prices and transporting costs in addition to its environmental problems make that non-reliable source of energy. Therefore solar PV is considered one of fastest growing RE technologies in the world. This is due to its simplicity installation, flexibility size, low operation and maintenance cost, environmentally friendly because there is no harmful greenhouse gas emission from it **(Said *et al.,* 2017)**. Additionally, solar PV panels are easy to install on rooftops, producing no noise, having no

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moving parts and depending on solar energy which freely supplied by nature and available anywhere there are sunlight. Egypt is one of the largest potentials of solar energy applications in the world. It locates in the World Sunbelt area and enjoys 9-11 hr., of daily sunshine with annual normal direct solar energy of 2000-3200 kWh/m^2. Egypt's present energy strategy encouraged and intended to increase the share of RE to 20% of Egypt's energy balanced mix by 2022 **(NREA, 2011)**. So, and according to the present national plan of solar power is to install 3500 MW by the year 2027; including 700 MW of PV **(NREA, 2013)**.

In this context, supplying energy for agricultural applications particularly, water pumping for irrigation or drinking purposes requires alternative, clean, reliable and available low-cost systems instead of using diesel generators or electric motors. One of the most advantages of the solar PV water pumping system was the most less cost system over the years in comparison to diesel, gasoline even electricity pumps. Additionally, operating cost is very low because it doesn't require fuel. It has a very low maintenance cost if the system has well set up, only it requires a simple periodic maintenance for cleaning of panels. The lower cost of solar pumping system will be selected by all farmers in the future because not only, the cost of PV panel decreased by over 80% in the last 10 years but also, the cost of diesel or gasoline increased by over 250% **(Foster and Cota, 2014)**, Hence there was a comparison between two systems the first was PV water pumping system while the second was diesel water pumping system by the life cycle cost (LCC) analysis resulted that the first system was the more economical choice **(Narale *et al.,* 2013)**. On other hand the PV water pumping system was obtainable as the commercial product, had proved efficiency, require few expert manpower once when operated, and maintenance cost was much low and cheap **(Yingdong *et al.,* 2011)**. Moreover, solar PV is characterized as a renewable resource doesn't produce any harmful contaminants to the surrounding environment *vice versa* in the case of fossil fuels which produce harmful gases **(Guiqiang *et al.,* 2017)**. Actually, it is found that, one of the main functions of PV water pumping systems is to decrease ecological effects as a result of the extravagant use of fuels, especially in irrigation **(Gopal *et al.,* 2013)**.

Noting that, the water pumping using solar PV was one of the best systems for irrigation **(Shinde and Wandre, 2015)**.

Singh and Mishra (2015) designed a mini unit that consisted of water tank with size of (400×400 × 300) mm, pump shaft coupling, DC motor voltage of 24 V, current of 14 A and power of 250 W, PV 8 A/21.6 V/150 W **(Gad, 2009)** investigated a DC water pump working by PV in Egypt. The pumping discharges were 24.06, 21.47 and 12.12 l/day in summer, equinoxes, and winter, respectively, and the PV efficiencies were 13.86 and 13.91% in winter and summer, respectively. The dynamic head of the pump impacts the performance of this system. In hours of the early morning or near to hours of evening time, the solar radiation was lower so the efficiency of the system was high when used a small of the head. Reciprocally in the hours at noon, the radiation was highest, and then the system using a big head was the highest efficiency. The max electricity efficiency from the PV panel is influenced by the tilt angle **(Benghanem *et al.,* 2014)**. **Hamidat and Benyoucef (2008)** designed a DC pumping water system and AC pumping water system. The two systems of PV pumping were first consisting of centrifugal pump and AC engine and second system consist of positive displacement pump and DC engine which have been tested with result the DC system was the best performance comparatively. Also, **(Chandel *et al.,* 2015)** reported that, the DC pump solar system without storage power in the battery was still low cost, easy and reliable to used small irrigation system with the sprinkler or drinking water supplies.

In this context, solar water pumping has been focused whereas; it can be directly converted solar energy into electricity for water pumping using PV solar panels. Whereas, it can produce electricity for either storing in batteries or using directly in DC motors or converting into AC by using inverter and then connecting water pumps. So, as a contribution for sharing and using PV systems in small applications to participate in achieving the national plan of solar power in Egypt, this paper aims to study and evaluate the performance of small PV water pumping system (5 Watt of pump, 10 Watt of PV) in summer and winter seasons to supply the needed irrigation water for roof cultivation units.

MATERIALS AND METHODS

The investigation was carried out during winter and summer seasons of 2018 at Faculty of Agriculture, Zagazig University, Zagazig, Sharkia Governorate, Egypt to evaluate technically and economically a small installation of solar PV water pumping system suit to roof cultivation units under solar Egyptian radiation conditions in Sharkia Governorate, Zagazig District.

Materials

Solar PV water pumping system

A solar PV water pumping system was installed as shown in Fig. 1. It consists of:

Solar PV panel

A 10 Watt solar PV panel (model of STPV-36CELLS A Grade), is a packaged type of polycrystalline connected assembly of crystalline silicon photovoltaic cells, was used as a DC output power source for operating of water pump. It has 0.56 A_{mp}/17.9 V_{mp} and 0.62 A_{sc} /21.5 V_{oc} with dimensions of 310 x 217 x 17mm. Solar PV panels use light energy of the sun to generate electricity through the photovoltaic effect.

Pumps

Two pumps with the same power were evaluated: the first one was a DC pump (with specifications of: 5 Watt of power size, dimensions of 90 × 40 × 35 mm and 0.5-0.7A/12V); the second was an AC pump (with specifications of: 5 Watt of power size, operating voltage of 220-240 V and 50 Hz of frequency).

Voltage regulator

It was used to stabilize the outside voltage of the solar PV panel to 12 volt to operate pumps. This worked to protect pumps from any increased voltage difference that can cause damage of pumps. The maximum ampere was 5A.

Battery

A battery (model of UNKOR MxVolta) was used with specifications of 12V/7 Ahr., 20 hr., to store the produced electrical energy by the PV panel.

Charger controller

The charge controller was used in PV solar pumping water system if was used the battery so as to keep the battery from the overcharging. The model used was (ISO 9001) with rated voltage of 12/24V and the current of 20A.

Invertor

The inverter was used to convert direct current (DC) to alternating current (AC) by the capacity of 500 W and the input voltage was 12 V and the output voltage was 220 V. The model used was (HOPSON V500).

Roof cultivation units

Four basins of wood with dimensions of 150 × 100 cm were used on different heights of 0, 0.5, 1 and1.5 m from roof level to test pumping system on these heads, as shown in Fig. 2. The basins had been cultivated with Thyme (*Thymus Vulgaris*). It is a medicinal and aromatic plant. It was cultivated in two rows (50 cm in length and each row containing 5 plants for one basin). It has many uses like in cooking, medicine to treat gastrointestinal diseases and field of cosmetics. The medical part used by Thyme is the flowering branches and leaves. It was generally common in the countries of the Mediterranean basin, which is found in all types of land, preferably sandy and yellow.

Methods

Experiments were conducted to evaluate two installations (as shown in Fig. 3) of solar PV water pumping systems during winter and summer seasons of 2018 year; DC solar pumping system (DSPS) and AC solar pumping system (ASPS). Each treatment was for three consequently days for replicates. Two systems were 10 Watt of PV power and 5 Watt of pump power. They were evaluated by determinations of PV efficiency, pumping discharge, hydraulic energy, pump efficiency and cost under the following conditions:

Different PV tilt angles (15°, 30°, 45°, 60° and 75°)

Different daylight hours (from 9:00 to 15:00)

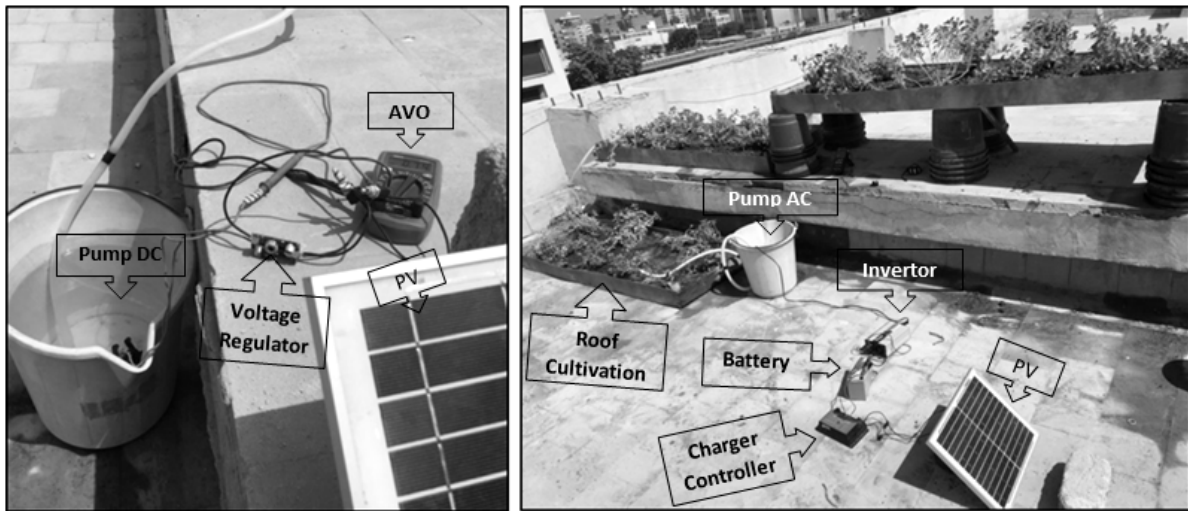Different pumping heads (0, 0.5, 1 and 1.5 m)
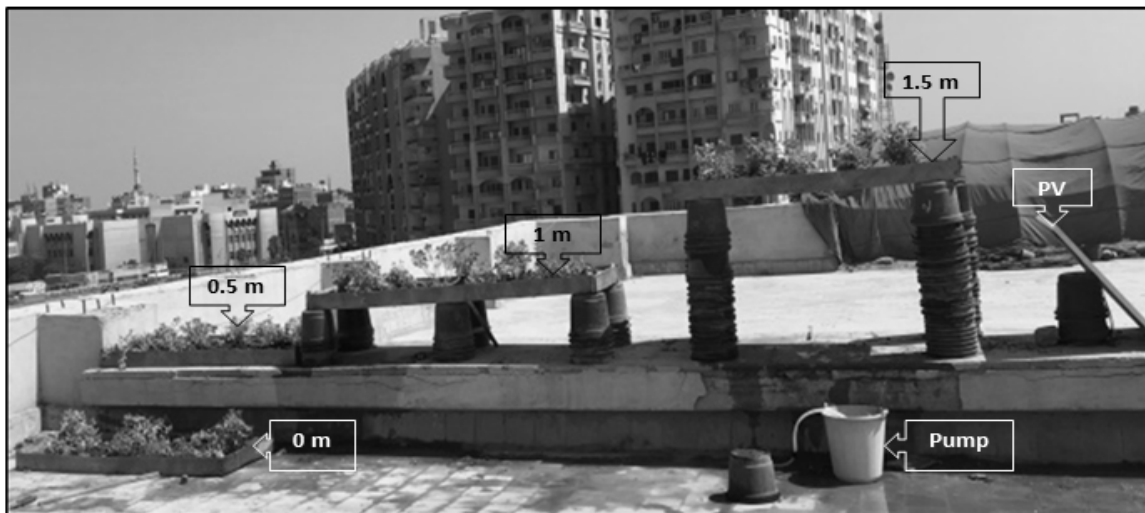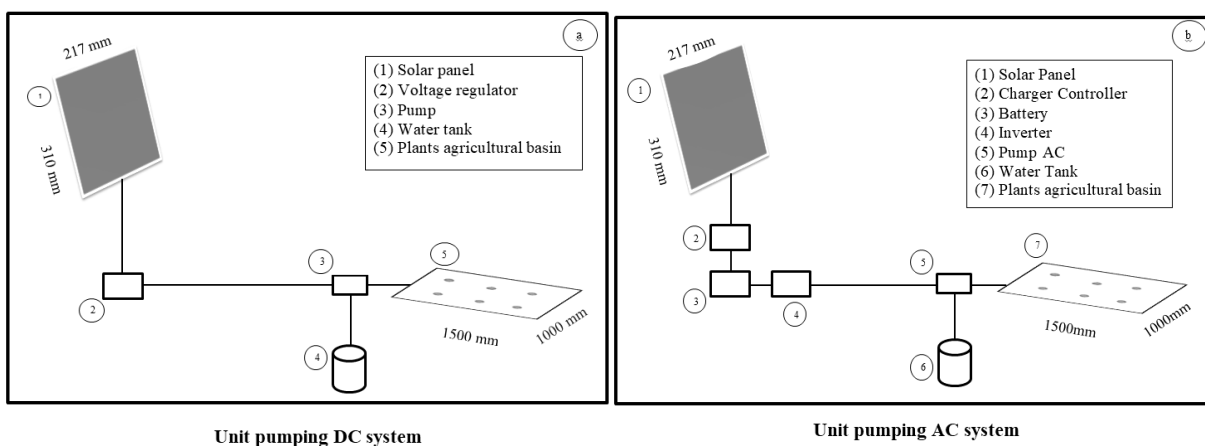
Fig. 1. The solar PV water pumping system

Fig. 2. A photo of roof cultivation units

Unit pumping DC system | Unit pumping AC system

(1) Solar panel
(2) Voltage regulator
(3) Pump
(4) Water tank
(5) Plants agricultural basin

(1) Solar Panel
(2) Charger Controller
(3) Battery
(4) Inverter
(5) Pump AC
(6) Water Tank
(7) Plants agricultural basin

Fig. 3. Installation of (a) DSPS, (b) ASPS

Orientation of PV panel

A 10 watt PV was oriented to face exactly the South direction (as shown in Fig. 4) with different tilt angle (α) to choose the best angle for winter and summer seasons to optimum the PV efficiency of collecting and converting solar radiation to electricity by indicated output ampere and voltage measurements.

Measurements and Determinations

Solar radiation

The solar radiation intensity during operating daylight hours (9:00 to 15:00) was measured using a solari-meter (Model of TES-132, TENMARS, Taiwan), with measuring range of 0-2000 W/m^2, resolution of 0.1 W/m^2 and accuracy of $\pm$ 10 W/m^2.

Volt and amber

Digital multimeter (Model of UT33C) was used to measure the output current and voltage for PV and pump. All ranges could be selected by a single rotary switch which set both the function and the range value. The DC Voltage ranges are: 200mV, 2000mV, 20V, 200V and 500V. While the current measurement was 4 positions on the rotary switch: 20mA, 200mA, 2000 mA and 10A. And it was used of 20V and 10A to measurement volt and ampere. Fig. 5 showed the connecting methods for measuring operations in both DSPS and ASPS installations. Whereas, using the multimeter in AC circuit was with battery, inverter and AC pump, while at DC circuit was with PV panel, voltage regulator and DC pump.

Efficiency of PV panel

The efficiency of PV panel to calculate the gained energy from the incident solar energy for each tilt angle for winter and summer seasons was determined using the following equation:

$$\eta_{PV} = \frac{I_{PV} \times \tilde{V}_{PV}}{SR \times A_{PV}} \times 100 \quad \textbf{(Chandel et al., 2015)}$$

Where:

η_{PV} = PV efficiency (%)

I_{PV} = Output current of PV (Ampere)

$\tilde{V}_{PV}$ = Voltage output PV (Volt)

SR = Average solar radiation intensity (W/m^2)

A_{PV} = Surface area of PV panel (m^2)

Electrical energy

The required electrical energy for operating the pump was calculated as the following equation:

$$E_e = I. \, V. \, Cos\theta$$

Where:

E_e = Electrical energy of the pump (Wh)

I = Current intensity (Ampere)

V = Voltage (Volt)

$Cos\theta$ = power factor (0.7) **(Umran, 2015)**

Hydraulic energy

The output hydraulic energy of pump was calculated as the following equation:

$$E_h = \frac{\rho \times g \times Q \times t \times TDH}{3600} \quad \textbf{(Chandel et al., 2015)}$$

Where:

E_h = Hydraulic energy of pump (Wh)

ρ = The water density (1000 kg/m^3)

g = The gravity acceleration (9.81 m/s^2)

TDH = The total dynamic head of pump (m), it concludes the head of pump and the head required to overcome friction loss (h_f , as following the equation:

$$TDH = H + h_f$$

Where:

h_f = required head to overcome friction loss taken (20% of H).

Q = the discharge of pump (m^3/s), The pump discharge was measured using a stopwatch and a scale pail of 18 L of plastic and the volume of water out of the pump was calculated in 5 minutes for each replicate then calculated as following equation:

$$Q = \frac{V}{t}$$

Where:

Q = Discharge of pump (m^3/s)
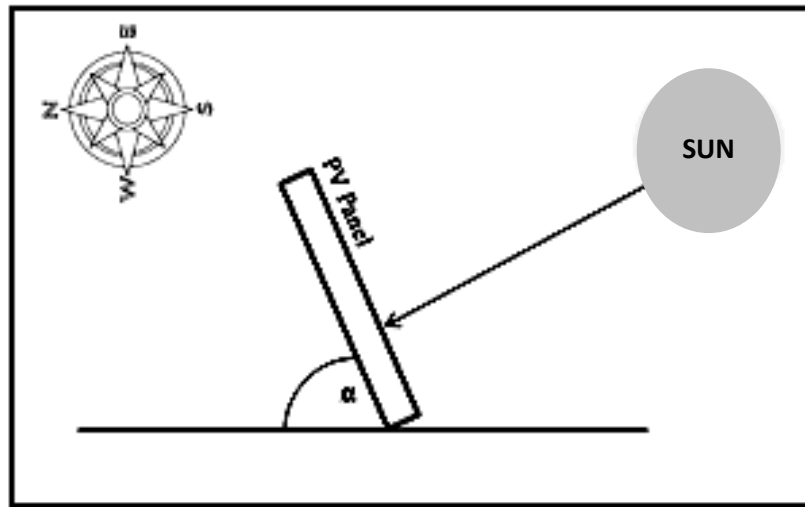
V = Volume of water (m^3)

t = Time (sec.)

Fig. 4. Tilt angle and the orientation of PV panel

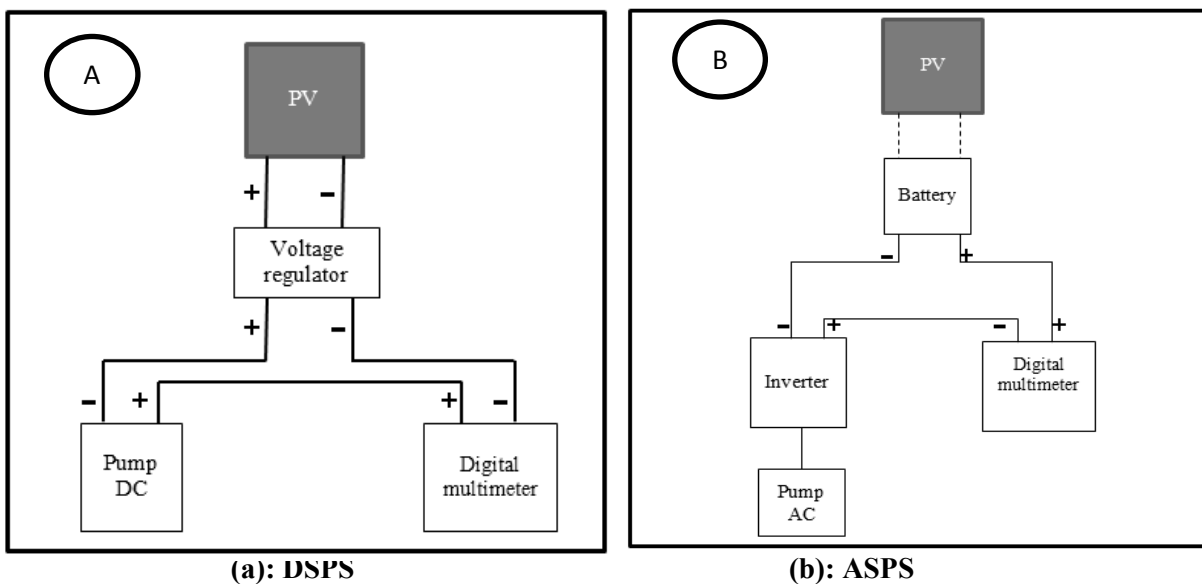**(a): DSPS**   **(b): ASPS**

Fig. 5: Measuring methods of voltage and ampere in DC and AC systems

Total efficiency of pump

The total efficiency of the pump was calculated as the following equation:

$$\eta_{tp} = \frac{\frac{Eh}{0.4}}{Ee} \times 100 \quad \textbf{(Benghanem \textit{et al.}, 2014)}$$

Where:

η_{tp} = Total efficiency of the pump (%)

0.4 = Factor of transmitted power for small pumps **(Frederick, 2010)**

Life cycle cost (LCC) analysis of DSPS and ASPS

The life cycle cost analysis was carried out for the DSPS and ASPS power systems assuming useful life of 20 years for PV panel system and ten years life for battery. The capital cost for two system is given in Table 1 (1$ = 17.8 EGP. This cost analysis was estimated in the following LCC analysis according to **(Chel et al., 2009)**.

Table 1. The capital cost of DSPS and ASPS

Components of system	Cost (LE)	
	DSPS	ASPS
PV	175	175
Cables	35	35
Voltage regulator	65	–
DC Pump	100	–
AC Pump	–	50
Battery	–	390
Inverter	–	300
Charge controller	–	400
Total	375	1350

Present maintenance cost

$$P_M = C_M \left[\frac{((1+i)^{20} - 1)}{(i \times (1+i)^{20})} \right]$$

Where:

P_M= Present maintenance cost (EGP).

C_M= Annual maintenance and repairs cost (taken 2% of capital cost).

i = Interest rate (taken 10%).

Net present cost

$$P_{Net} = P_i + P_M + \left[\frac{C_{B+P}}{(1+i)^{10}} \right] - \left[\frac{S}{(1+i)^{20}} \right]$$

Where:

P_{Net}= Net present cost for PV (EGP).

P_i= Capital cost (EGP).

C_{B+P}= Battery and pump cost (EGP).

S= Salvage value of system at the end 20 years (taken 15% of capital cost) (EGP).

Annualized cost

$$A_A - P_{Net} \left[\frac{(i \times (1+i)^{20})}{((1+i)^{20} - 1)} \right]$$

Where:

A_A=Annualized cost of system (EGP).

Cost per unit of electricity generated

$$C = \frac{A_A}{U}$$

Where:

C= Cost per unit of electricity generated by PV (EGP/kWh).

U= Total annual electrical energy used from PV (kWh/year).

Specific (Criterion) cost

Criterion cost of pumping one cubic meter of water by two systems (DSPS and ASPS) was calculated in (LE/m^3), as the following equation:

$$C_V = \frac{C}{V_E}$$

Where:

C_V = Criterion cost of pumping 1m^3 of water (LE/m^3).

V_E= Pump productivity (volume of pumping water per one kWh of electrical energy from PV) (m^3/kWhr.).

Pump productivity

$$V_E = \frac{Q}{Ep}$$

Where:

E_p= Required electrical energy for one hour of pumping (kWh/hr.)

Q= Discharge of pumping (m^3/hr.)

RESULTS AND DISCUSSION

Effect of Tilt Angle on PV Efficiency

The obtained results of PV efficiencies at different tilt angles during day light from 9:00 to 15:00 are shown in Fig. 6. The results showed that, in general, the output ampere values of the PV panel as well as the PV efficiencies are affected majority by the tilt angle and orientation of PV panel. This is due to the proportional relation of incident solar energy on PV panel and the output power (ampere and volt). Whereas tilt angle as a function of latitude is an important parameter affecting the orientation of incident and reflected solar radiation into/out of panel surface. Average solar radiation intensity increased gradually from 9:00 hour and reached to the peak at 11:00 to 13:00 hour then decreased to 15:00 hour.

In winter (28/1/2018), PV panel efficiencies increased from 15° until reached to the peak at 45° then decreased slightly until to 75° (in Egypt, latitude of 30.5° and longitude 31.5°). At average and maximum solar radiation intensity of 423, 525 W/m^2, respectively, the average daily PV efficiency was 28.4, 31.8, 36.9, 32.6 and 30.7 % for tilt angles of 15°, 30°, 45°, 60° and 75°, respectively. This because the incident sunbeam angle with the vertical plane is high, so increase of tilt angle led to increase the output power of PV panel as a function of gained solar energy till reach 45°. The 45° tilt angle of PV panel was the best angle. Higher or lower than angle of 45° led to reduce the normal solar radiation on the panel surface and increase the reflected solar radiation.

While in summer (29/7/2018), *vice versa* PV efficiencies increased by reducing the tilt angle because the lower incident angle of solar radiation and perpendicularity of sunlight during most daylight hours. The 30° tilt angle of PV panel was the best angle. Whereas, at average and maximum solar radiation intensity of 810, 891 W/m^2, respectively, the average daily PV efficiency was 18.1, 21.3, 17.5, 15.6 and 14.9 % for tilt angles of 15°, 30°, 45°, 60° and 75°, respectively.

Finally, it should be noticed that, values of PV efficiencies in summer compared to winter season was reduced. This is due to the great impacts of solar radiation changes and temperature levels on PV panel power output and its efficiency. Additionally, high temperature levels affect negatively the PV efficiency whereas there is an inverse proportion between temperature and panel power. Therefore, the PV panel power decreases when the ambient temperature increases. So, the PV panel was tilted with angle of 45° and 30° for winter and summer, respectively for all treatments of pumping evaluation.

Pumping Evaluation of DSPS

The results of pumping discharges at different heads and solar radiation variations during daylight from 9:00 to 15:00 for three days in winter and summer seasons were shown in Figs. 7 and 8, respectively. The obtained results showed that, in general, the discharge of pump in head 0 m is the highest one and by increasing the head until to 1.5 m, the discharge decreased. Where the discharge is inversely proportional to the head of pumping. Also, the results revealed that, the discharge as well as the solar radiation increased gradually from 9:00 hour and reached to the peak at 11:00 to 13:00 hour then decreased to 15:00 hour.

In winter, the average daily pumping discharges for three days were 100.8, 93.2, 83 and 77.5 l/hr., at average solar radiation intensity of 508.3 W/m^2 for head 0, 0.5, 1 and 1.5 m, respectively. While in summer, the average daily pumping discharges were 116.2, 101, 88.1 and 80.4 l/hr., at average solar radiation intensity of 782 W/m^2 for heads 0, 0.5, 1 and 1.5 m, respectively.

Hydraulic Energy and Pump Efficiency of DSPS

The variations of hydraulic energy and efficiency of pump for DSPS at different heads and sunlight hours during daylight from 9:00 to 15:00 for three days in winter and summer seasons were shown in Figs. 9 and 10, respectively. From the obtained results, it can be said that, the hydraulic energy and efficiency of pump in head 1.5 m is the highest one and by decreasing the head until to 0 m, they decreased. Where the hydraulic energy and efficiency is proportional to pumping head. Also, the results revealed that, the hydraulic energy and efficiency were related to a large extent to the solar radiation variations during daylight.
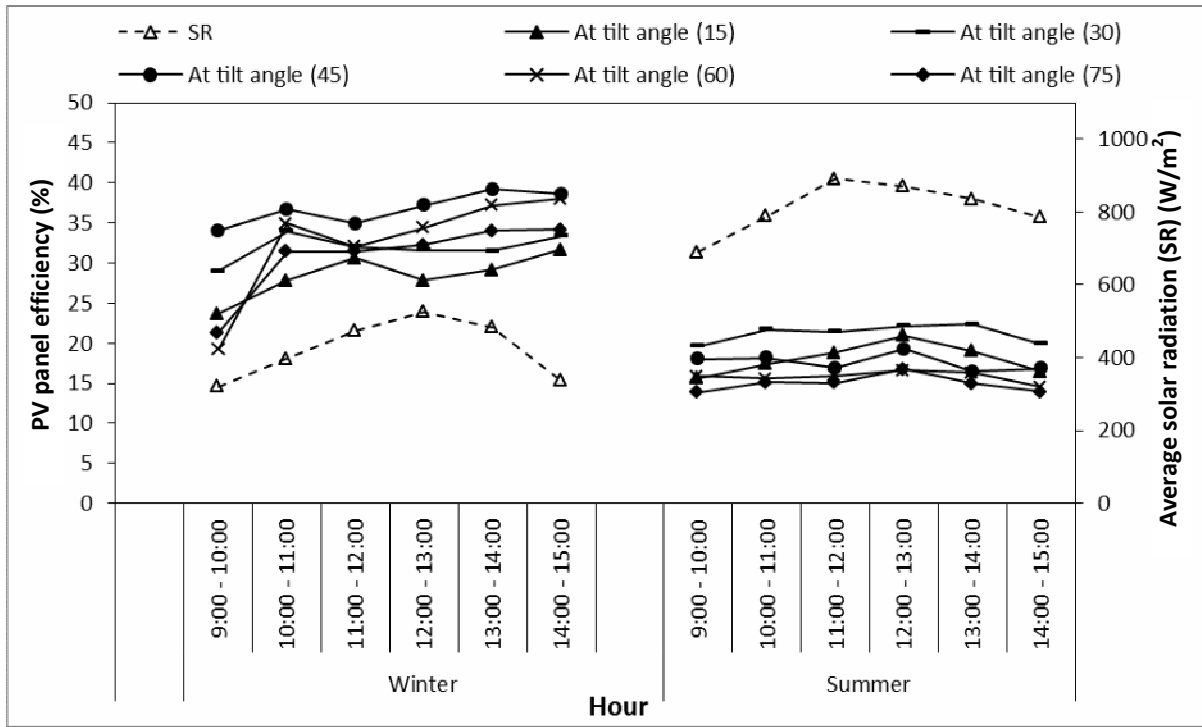
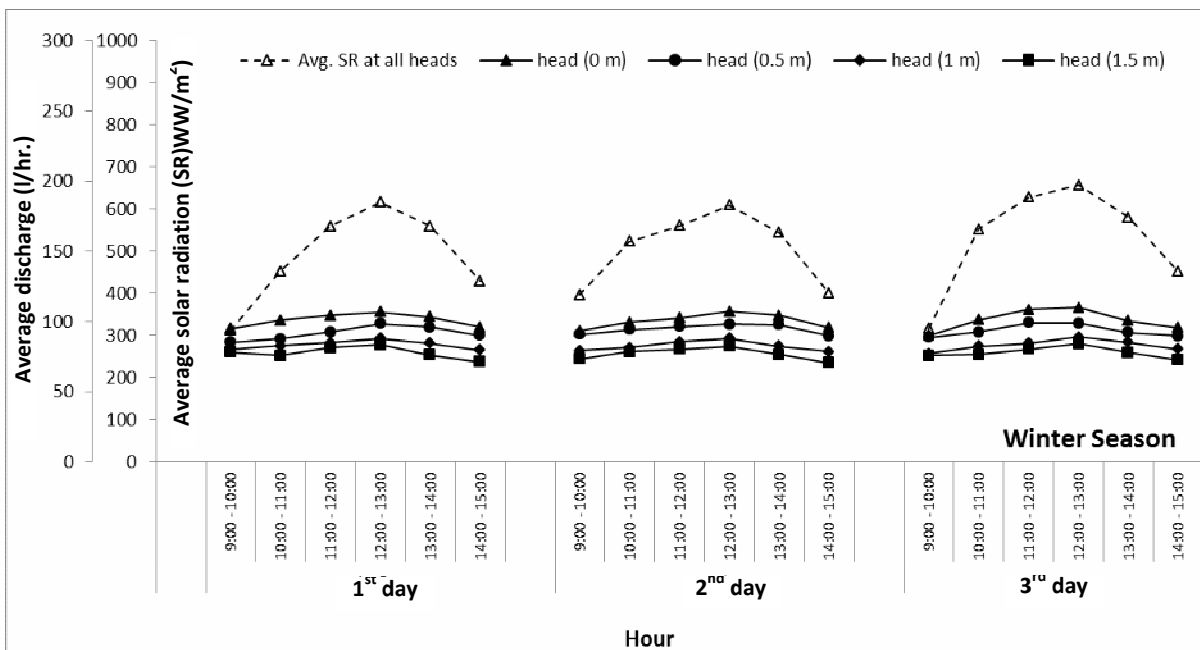**Fig. 6. Effect of tilt angle on PV panel efficiency**

Fig. 7. Effect of solar radiation on pumping of DSPS for different heads in winter
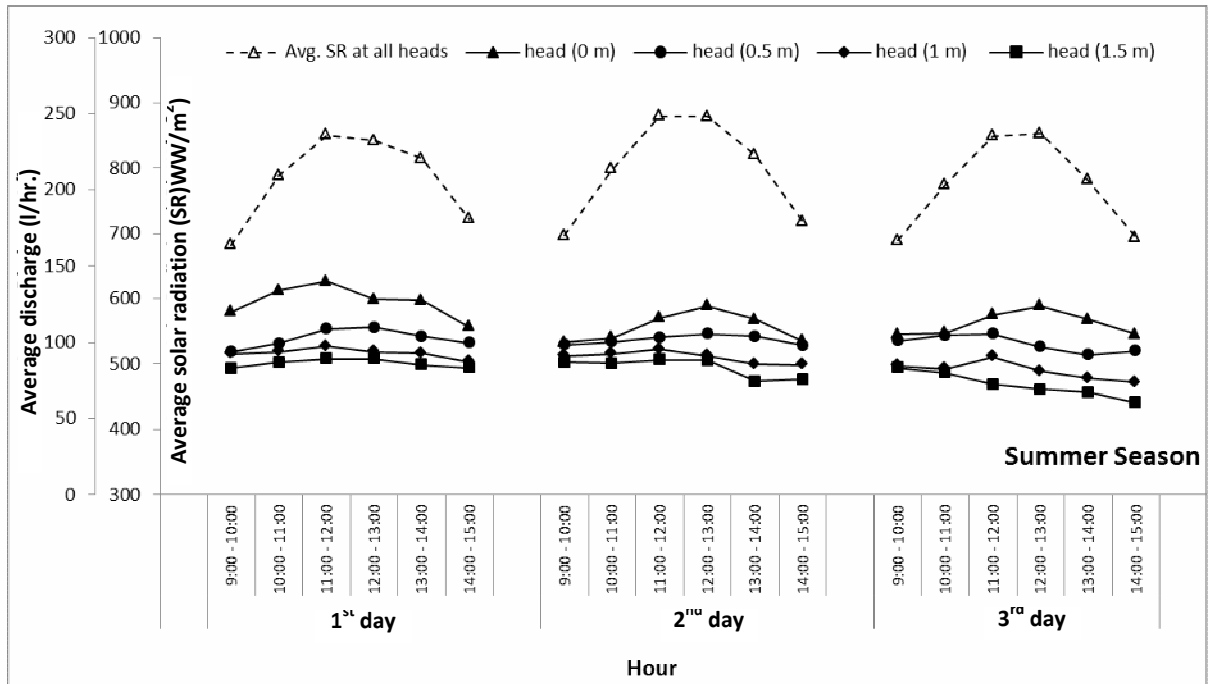
Fig. 8. Effect of solar radiation on pumping of DSPS for different heads in summer
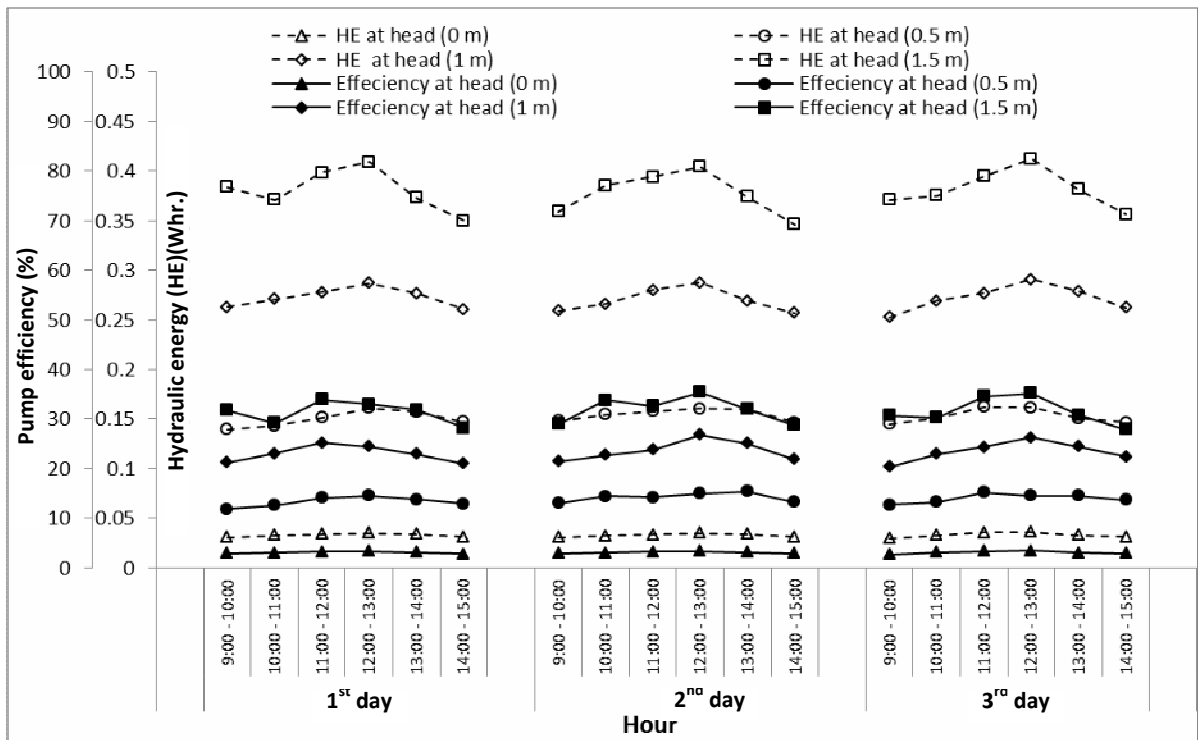

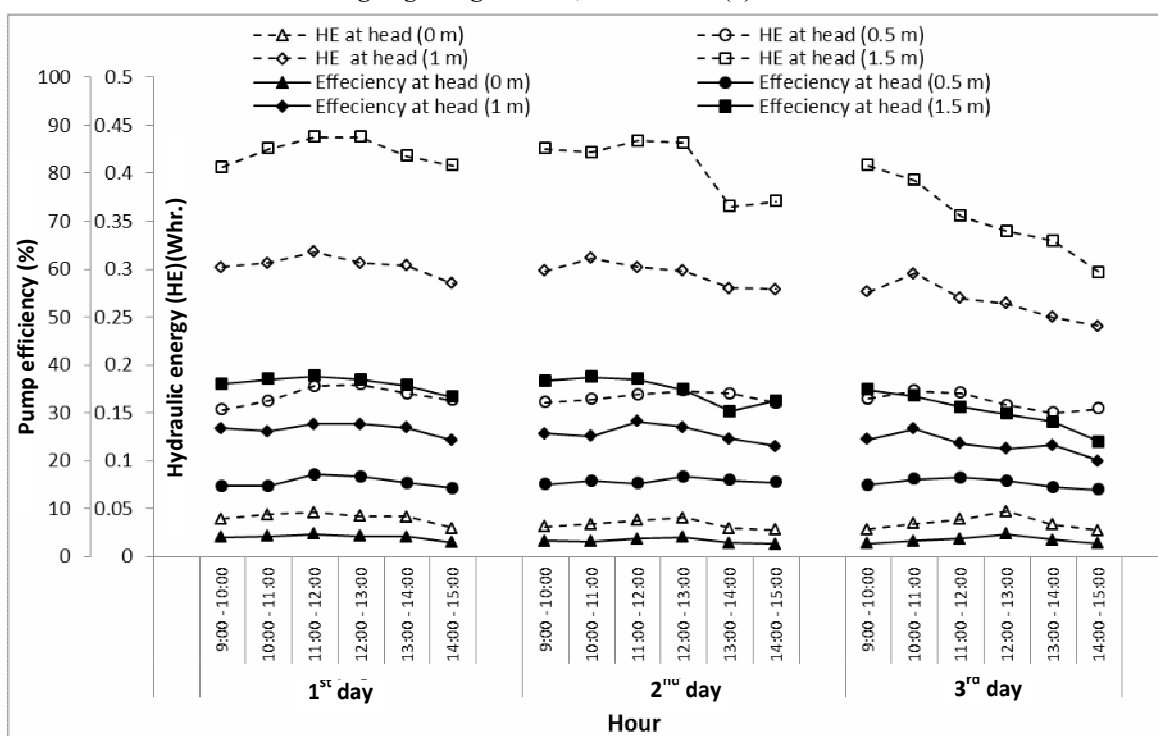**Fig. 9. Variations of hydraulic energy and pump efficiency of DSPS in winter**

Fig. 10. Variations of hydraulic energy and pump efficiency of DSPS in summer

In winter, the average values of hydraulic energy (for the three days) were 0.03, 0.15, 0.27 and 0.38 Wh with pumping efficiency of 3.1, 13.8, 23.4 and 31.6% for head of 0, 0.5, 1 and 1.5 m, respectively. While in summer, the average values of hydraulic energy were 0.04, 0.17, 0.29 and 0.4 Wh with pumping efficiency of 3.6, 15.5, 25.2 and 33.7 % for head of 0, 0.5, 1 and 1.5 m, respectively.

Pumping Evaluation of ASPS

In fact, performance pumping of ASPS haven't influenced by the season. This is due to its dependability on battery as a power source for operating of the AC pump. But the charging of battery affected by the solar radiation intensity during winter and summer seasons. So, battery completely charging time was estimated; 180 and 160 minutes at average solar radiation of 536 and 826 W/m^2 for winter and summer season, respectively.

Fig. 11 shows results of the average discharge and hydraulic energy value of AC pump for different pumping heads. These results revealed that, by increasing the pumping head, the discharge decreased but the hydraulic energy increased to reach the peak at 0.5 m of pumping

head then they together decreased after that. At heads of 0, 0.5, 1 and 1.5 m, the pumping discharges were 281, 140, 61 and 18 l/hr., respectively, while the hydraulic energies were 0.092, 0.229, 0.2 and 0.09 Wh, respectively. The optimum head can be concluded approximately at 0.25 m of head from the figure.

Effect of Pumping Head on Both Discharge and Efficiency of the Pump

The results of the effect of pumping head on both discharge and efficiency of the pump are shown in Fig. 12. Generally, the average efficiencies of both DC (winter and summer) and AC pump increased gradually by increasing of the pumping head *vice versa* the pumping discharges decreased. For the AC pump, the average discharge values were 281, 140, 61 and 18 l/hr., and the average pump efficiencies were 60, 70.4, 74.8 and 79.2% for pumping heads of 0, 0.5, 1 and 1.5 m, respectively. While for DC pump, the average discharge values were 101, 93, 83 and 77 l/hr., with average pump efficiencies of 3.1, 13.8, 23.4 and 31.6% in winter (at average solar radiation of 508.3 W/m^2) for pumping heads of 0, 0.5, 1 and 1.5 m, respectively; and average discharge values were
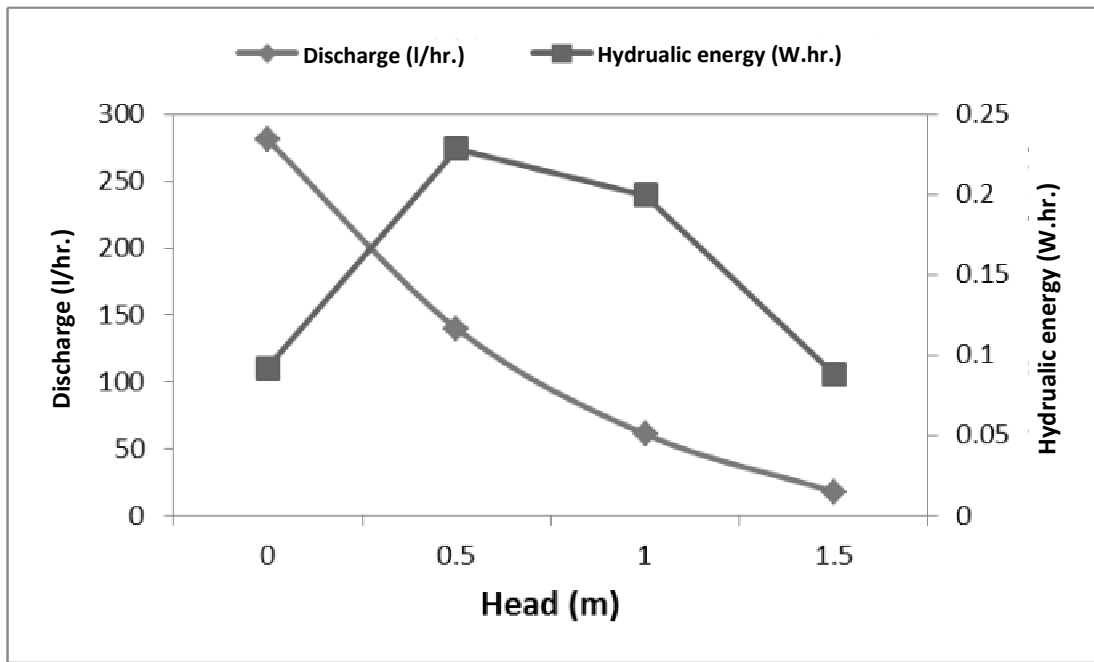
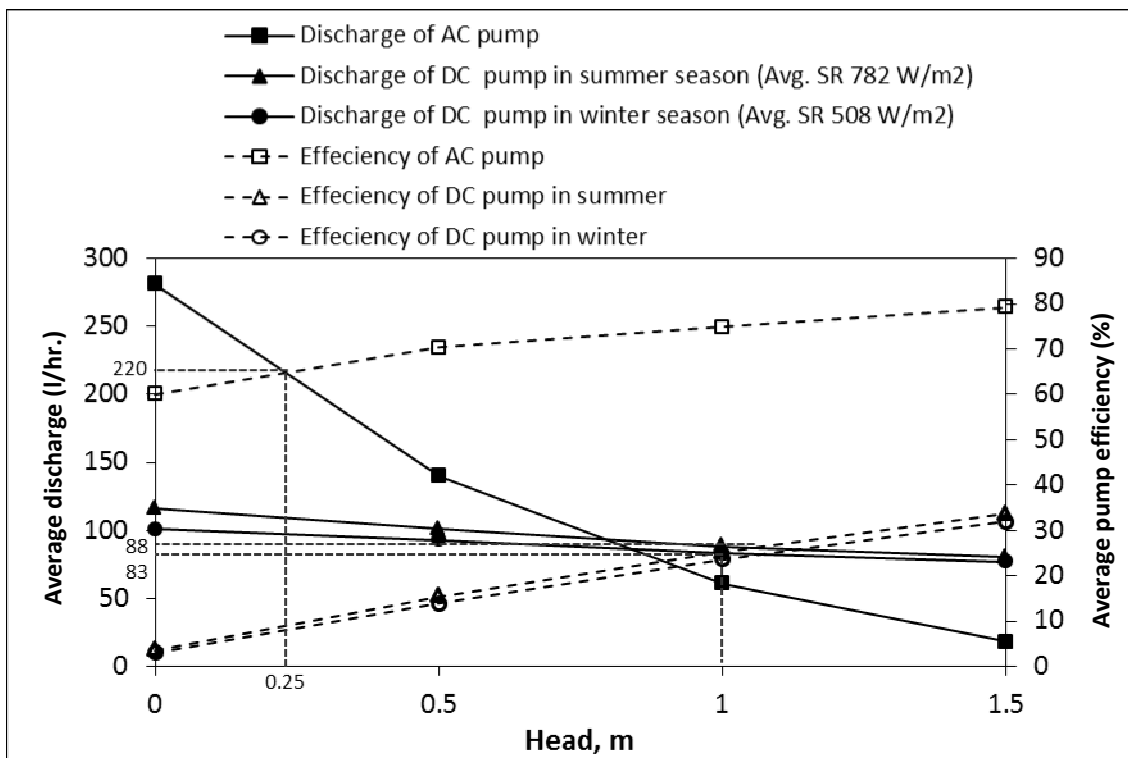**Fig. 11. Average discharge and hydraulic energy of AC pump**

Fig. 12. Effect of pumping head on both discharge and efficiency of the pump

116, 101, 88 and 80 l/hr., with average pump efficiencies of 3.6, 15.5, 25.2 and 33.7% in summer (at average solar radiation of 782 W/m^2) for pumping head of 0, 0.5, 1 and 1.5 m, respectively. From these results, it can be concluded that, the optimum pumping heads could be obtained by crossing the discharge and efficiency lines. So, for the used pump the optimum pumping head was 0.25 m in case of ASPS (with discharge of 217 l/hr.,) and 1 m in case of DSPS (with discharges of 83 and 88 l/hr., for winter and summer seasons, respectively).

Specific Pumping Productivity of Both DSPS and ASPS

Fig. 13 shows the results of specific pump productivity for both DSPS and ASPS. From the figure it can be concluded that, the pump productivity (function of discharges) was inversely proportional to the pumping head. Where, DSPS produced 9.31, 8.61, 7.66 and 7.15 m^3/kWh of water pumping during winter;

10.03, 8.72, 7.60 and 6.95 m^3/kWh during summer, at pumping heads of 0, 0.5, 1 and 1.5 m respectively. While the average pumping productivity of ASPS was about 24.27, 12.09, 4.49 and 0.77 m^3/kWh at the same heads, respectively.

Cost Estimation of Both DSPS and ASPS

Fig. 14 shows the results of criterion costs for both DSPS and ASPS. From the figure it can be concluded that, the criterion costs of DSPS was lower than in the ASPS, this is due to the additionally fixed costs of ASPS components included charger controller, battery and inverter. Pumping costs of one cubic meter of water by DSPS at pumping heads of 0, 0.5, 1 and 1.5 m, respectively were (0.16, 0.17, 0.19 and 0.21 EGP) and (0.15, 0.17, 0.19 and 0.21 EGP) during winter and summer seasons, respectively. While by ASPS were about 0.22, 0.45, 1.23 and 7.11 EGP/m^3 at the same heads, respectively.
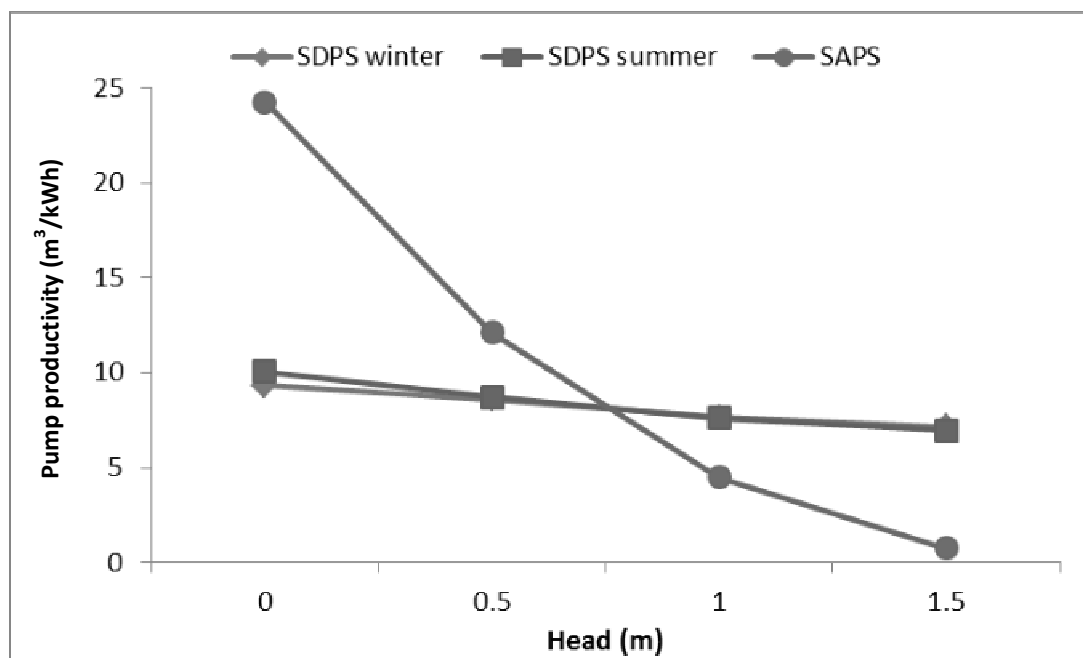

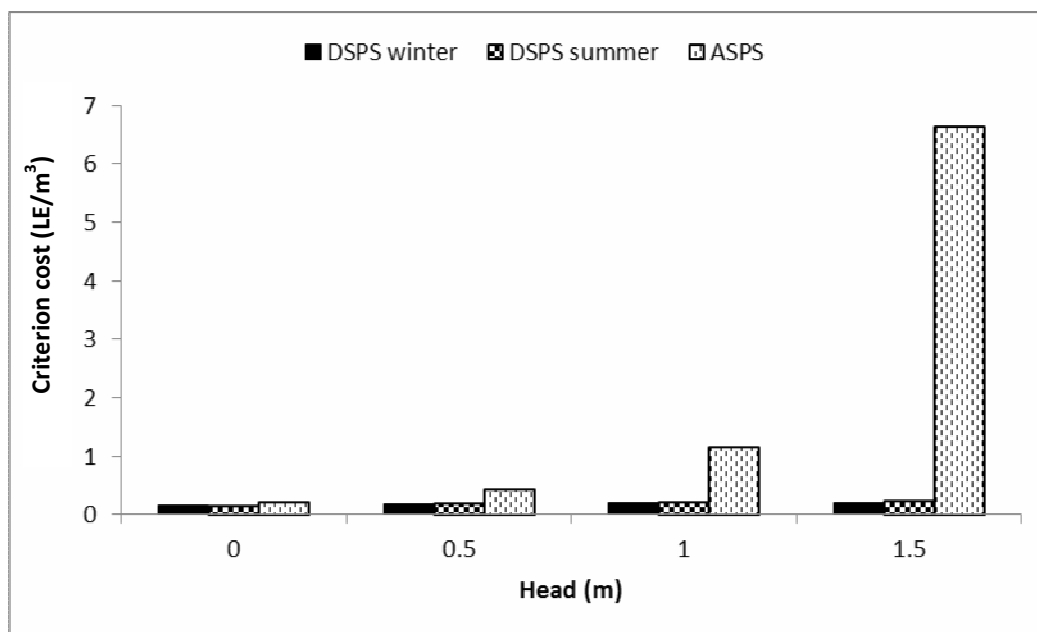**Fig. 13. Specific pump productivity of both DSPS and ASPS**

Fig. 14. Criterion cost of both DSPS and ASPS

Conclusion

From the obtained results, it can be concluded that:

- The small size of solar PV power system (10 Watt) is efficient to operate a small pump (with power of 5 Watt) under the solar radiation conditions of Zagazig District for supplying irrigation water for roof cultivation units.

- The best tilt angle of PV panel for Zagazig District was 45° and 30° in winter and summer, respectively.

- Pumping head affects the pumping performance to a large extent.

- Discharges and pumping efficiencies of AC pumps are higher than DC pumps with the same power.

- The optimum pumping conditions of the used pump (5 Watt) are 0.25 and 1 m of pumping heads with 220 l/hr., and (83 l/hr., for winter, 88 l/hr., for summer) of pumping discharge for AC and DC pumping systems, respectively.

- One kilowatt in hour by DSPS pumped 9.31, 8.61, 7.66 and 7.15 m^3 of water during winter; 10.03, 8.72, 7.60 and 6.95 m^3 during summer, at heads of 0, 0.5, 1 and 1.5 m respectively. While the average pumping productivity of

ASPS was about 24.27, 12.09, 4.49 and 0.77 m^3/kWh at the same heads, respectively.

- Pumping costs of one cubic meter of water by DSPS at pumping heads of 0, 0.5, 1 and 1.5 m, respectively were (0.16, 0.17, 0.19 and 0.21 EGP) and (0.15, 0.17, 0.19 and 0.21 EGP) during winter and during summer seasons, respectively. While by using ASPS the water pumping costs of 1m^3 were about 0.22, 0.45, 1.23 and 7.11 EGP/m^3 at the same heads, respectively.

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تقييم أداء نظام صغير يعمل بالتيار المتردد/ المستمر لضخ المياه بالطاقة الشمسية لزراعة الأسطح

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يعتبر استخدام الطاقة الشمسية في ضخ المياه من أكثر أنظمة الطاقة احتياجاً لما لها من استخدامات عديدة في عمليات استصلاح الأراضي والعمليات الزراعية مثل الري وإمداد المواشي بالمياه، وقد تستخدم أيضا في إمداد المياه اللازمة للإنسان في المنازل، والأكثر أهميه لها هي عملية ري الأراضي الزراعية لمساعدة الفلاح المصري لأنه مازال يستخدم الكهرباء أو الوقود حيث تستغرق تلك الطرق الكثير من الوقت والجهد والتكاليف حيث ينتج عنها فواقد كبيرة، لذا فقد تم تقييم نظام ضخ للمياه يعمل بالطاقة الشمسية باستخدام كلا من: مضخة مياه صغيرة (٥ وات) و لوحة شمسية صغيرة (١٠ وات) لتوفير المياه اللازمة لري وحدات زراعة الأسطح الصغيرة، وتمت التجارب في كلية الزراعة- جامعة الزقازيق - محافظة الشرقية - مصر (خط العرض ٣٠,٥°ــ خط الطول ٣١,٥°)، وذلك خلال موسمي الشتاء والصيف عام ٢٠١٨ وتم تقييم نظامين من أنظمة ضخ المياه بالطاقة الشمسية هما: نظام يعمل بمضخة ذات تيار مستمر وآخر يعمل بمضخة ذات تيار متردد وذلك تحت عدة متغيرات هي زاوية ميل الألواح الشمسية (١٥°،٣٠° ، ٤٥°،٦٠° و٧٥°)، وساعات الإشعاع اليومية (٩:٠٠ـ ١٥:٠٠)، ارتفاعات الضخ (٠ ، ٠,٥ ، ١ و١,٥)م، وتم تقييم جميع المعاملات من حيث: تصرف المضخة، الطاقة الهيدروليكية، الكفاءة، التكاليف، وقد أوضحت النتائج المتحصل عليها أن أفضل زاوية ميل للألواح لمركز الزقازيق ٤٥° و٣٠° في فصل الشتاء والصيف علي التوالي، وكان تصرف وكفاءة الضخ بالمضخة ذات التيار المتردد أعلى من المستمر وكانت ظروف الضخ المثلي بارتفاع ٠,٢٥ و١ متر وتصرف ٢٢٠ لتر/س و(٨٣ لتر/س للشتاء، ٨٨ لتر/س للصيف)، وذلك كله للنظام المتردد والمستمر علي التوالي. بينما كانت تكلفة ضخ المتر المكعب الواحد من الماء في نظام الضخ بالمضخة ذات التيار المستمر عند ارتفاعات ضخ (٠ ، ٠,٥ ، ١ ، ١,٥) م علي التوالي هي (٠,١٦ ، ٠,١٧ ، ٠,١٩ ، ٠,٢١ جنيهاً مصرياً) لفصل الشتاء وفي فصل الصيف كانت (٠,١٥ ، ٠,١٧ ، ٠,١٩ و٠,٢١ جنيهاً مصرياً)، بينما في نظام الضخ بالمضخة ذات التيار المتردد بلغت التكلفة (٠,٢٢ ، ٠,٤٥ ، ١,٢٣ و ٧,١١ جنيهاً مصرياً لكل متر مكعب) لنفس الإرتفاعات علي التوالي؛ وقد نجحت التجربة في إمداد مياه الري بنظام شمسي صغير القدرة لذلك يمكن استخدام وحدات الضخ الشمسي الصغيرة لضخ مياه الري لزراعة الأسطح بكفاءة.