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The Performance of Photovoltaic Solar Pumping System Suitable for Remote Regions

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Abstract: The economy and reliability of solar electric power make it an excellent choice for remote water pumping. If water sources are spread over many km of rangeland where power lines are few and refueling and maintenance costs are substantial. If water source is 2 to 6 km or more from the power line, solar is a favorable economic choice. The main objective of this study is to evaluate the hydraulic performance of Photovoltaic Solar pumping system suitable for the remote regions and the new communities. Solar pumping system was tested during the summer of 2004 and 2005. The study included different factors affecting pump performance tilt angle of the photovoltaic panel; 15°, 30° and 45° with solar cells area of the photovoltaic panel; 30, 35 and 40 m^2. Cost analysis has been carried out to estimate the required water unites cost comparing with the values of diesel electrical pump. The highest values of pressure $13.0X10^4$ N/m^2, discharge 9.05 m^3/hr and efficiency 21.8 % were achieved at 30° of tilt angle and 40 m^2 of solar cells area. The cost of lifted water unit using solar surface pump was 0.56 L.E /m^3 compared with 0.19 LE./m^3 using the diesel electrical pumps respectively. Using of photovoltaic array for solar pump doesn't depend only upon the unit water cost but also to many other considerations. In case of non-availability of diesel or electrical power, the high cost of solar pumps must not be taken into account. It can be concluded that improving the solar pumping system must be focusing on minimizing the water unit cost in order to apply this technology on the large scale. The photovoltaic array takes the first place as the best cleaning energy.
Key words: Photovoltaic, solar, pump, energy, solar cells, cleaning energy.

INTRODUCTION and LITERATURE REVIEW

With the ambition of Egyptian government to develop the new and remote areas, construction of new communities such as Toshka, Halaib and Shalaten it must be thought about how to wrap the energy requirements of this new and remote areas to develop them. It could expected that the solar energy would be able to rival traditional types of energy in this areas where they are readily available, the solar energy contributed to improvement of economic productivity in that areas.

(Faber, 1973) summarized the using of solar energy and activities as the following: solar water heating, housing heating, solar baking, solar cooking, solar water pump, sewage treatment and solar distillation. (Ramakumar, 1977) discussed a step by step approach for the adoption of technologies to exploit renewable energy sources at the rural and remote areas in the developing world. Developing counties are will endow with the one or more of the renewable energy resources; they can be utilized with the intermediate technologies. The author also indicated that a realistic evolution of the technology proposed for remote level use in developing countries results in wind driven mechanical water pump, wind driven mechanical water pump with electric generator, solar water pumping and generator electricity using photovoltaic. (Abd El-Gawad, 1991) stated the source of air pollution and the quantities of pollutants of some fossil fuels on table (1)

(Braunschweig, 1993) reported that, in a project by the BMFT various solar pump system were tested at the federal agricultural research center .32 solar cells with an output of 1.5kW are required to irrigate a crop area of 1.5 hectares. 1kW system requires 10-20 m^2 area costs of around 7,500 to 11,000 US Dollar.

Table 1. The source of air pollution and the quantities of pollutants of some fossil fuels

Pollutant (g/kg)	Fuel type				
	Natural gas	kerosene	gasoline	diesel	coal
Hydrocarbon	variable	38.21	75.9	21.7	1.36
Nitrogen dioxide	2.585	22.94	16.4	25.5	9.12
Sulfur dioxide	**0.0088**	**3.22**	**1.3**	**4.6**	**17.24**

Table 2. Comparison of solar and other remote watering system

Pump Type	Advantages	Disadvantages
solar	• Low maintenance, Easy to install • No fuel costs or spills • Unattended operation	• Potentially height initial cost • Lower output in cloudy weather • Must have good sun exposure between 9AM and 3AM
Diesel	• Moderate capital costs , Can be portable • Extensive experience available • Easy to install	• Need maintenance and replacement • Maintenance often inadequate, reducing life • Fuel often expensive and supply intermittent

(Daniel, 1994) indicated that, nonrenewable energy produce large amount of carbon monoxide and nitrogen dioxide and causes extraordinary environmental and economic damage worldwide even in the developing countries. (Ralph, 1996) and (Stokes et al.,1993) stated that, photovoltaic pumping systems in remote locations would often be cost effective compared to generators, even with 5 times the initial capital cost. Low end generators, which are initially inexpensive, require consistent maintenance and have a design life of approximately 15,00 hours. Small to medium sized solar pumping systems often initially cost less than a durable slow speed engine driven generator. Larger pump systems initially cost more than generator systems, but tend to be far more economical in the end. (Marsh, 2001) summarized the advantages and disadvantages of water pumping in remote application in table (2). (Ismail, 2002) reported, Egypt has a high potential for the production of solar energy, which can be considered, as a reliable energy source even during the winter season. The annual daily average of solar radiation on a horizontal plane in Egypt is 7.5 – 10.5 kWh/m^2.day, and the measured annual average of daily sunshine duration amounts to approximately 9-11 hours.

MATERIALS and METHODS

Experimental system

The experimental study has been conducted upon the photovoltaic pumping system and Diesel Electrical pumping systems located in Wadi Abo Saafa, Shalateen, Red sea governorate, development of Bedouin community project The solar pump system, consists of solar generator and a deep well turbine pump(grundfos) operated by D.C motor. The incident solar radiation on the photovoltaic panel (PV panel AEG-siemns)modelGP-50 its specification max power 50 Watt, short circuit current(I_{sc} 3.3Amp), open circuit voltage(V_{oc} 21.5 Volt) and Max system volt 600 volt is converted directly to electricity through the solar generator. The electric power is used to operate the motor, which directly connected to the solar pump. The system is fitted with a number of fittings to control the discharge and pressure of water flowing to the irrigation system. The D.C motor connected with a starter revolution, which contains a relay and two solar batteries charged by a small solar generator. The solar generator contains four modules with a peak power equal to400 watt. The solar generator consists mainly of a photovoltaic panel with an area of 40 m^2 and 90 solar modules. Each module contains 40 solar cells. The panel consists of two Modules connected in series. The generator contains 9 strings connected parallel to each other. The string consists of five panels, contain 10 module connected in series. The strings have been arranged in two arrays. Every array contains four strings. The Total number of modules in solar generator is 80 modules, with a total peak power about 3.072 kW peak. The modules are mounted and cabled on a support structure made of hot galvanized steel. The tilt angle can be adjusted from 15°, 30° to 45° according to the seasons and the radiation conditions. The D.C Motor used with the pump rotates at 2700 r.p.m and operates with 175 Voc at 16.9 Ampere with a maximum efficiency 95 %. The maximum discharge delivered with a 70 m maximum head with this type of turbine is 25 m^3/hr. The pump unit is installed vertically on a foundation in order to keep the position of the strainer above the ground level about 40 cm (at minimum).

Experimental Procedure

The study was carried out in order to investigate the following objectives:

1. The hydraulic performance of solar pump at different levels of tilt angles of the photovoltaic panel and solar cells area.
2. Estimating the required unit cost of water lifted by solar energy, and comparing it by the required for diesel electrical pumps.

The annual capital recovery cost in turn, using the equation given by (Riggs et al., 1996):

$$ACRC = C_o \left[\frac{d(1+d)^n}{(1+d)^n - 1} \right] \quad \text{.................(1)}$$

Where:

ACRC= Annual capital recovery cost

C_o= capital cost, LE (1 US Dollar = 5.5 LE)

d = discount rate, 12 %

n = expected useful life , (20 years for PV array and 10years for diesel electrical pumps

The study included different factors affecting pump performance likewise; tilt angle of the photovoltaic panel (15°, 30° and 45°), solar cells area of the photovoltaic panel (30, 35 and 40 m^2). According to these variations, the performance of the pump has been measured and analyzed. The performance includes hourly discharge, dynamic pressure, pump efficiency and electrical output power of solar generator. The climatic conditions are; solar radiation, wind speed, air temperature, clouds, and relative humidity. Measurements were carried out daily from 8 AM to 7 PM This test of study started at 15^{th} June and completed at 15^{th} September during years of 2004 and 2005. The measuring performance for each variable was averaged of each three successive days of this period. The hourly discharge was measured by a flow meter for a certain time, and the dynamic pressure was measured by a pressure gauge fixed in the delivery line of the pump. The hydraulic power was calculated using the equation given by (Fraenkel, 1986).

$$P_{hyd} = Q \times H / 367 \quad \text{............... (2)}$$

Where:

P_{hyd} = hydraulic power in (kW)

P =Total Dynamic head in (m)

Q = discharge m^3 per hour.

The hydraulic energy were calculated using the equation given by (Roy Barlow, 1993).

Hydraulic energy (kWh/day)= 0.002725 x volume (m^3/day) x head (m) .... (3)

The subsystem efficiency (η) is calculated according to the following equation:

$$\eta_s = (P_{hyd} / P\ output) \times 100, \quad \% \text{ ...(4)}$$

Where:

η_s = Subsystem efficiency in (%)

P_h = hydraulic power in (kW)

P output = Electrical output power of solar generator (kW).

Measuring instruments

The data for climatic conditions such as solar radiation, air temperature, wind speed, relative humidity, solar day length and clouds during the period of study was recorded hourly by the automatic meteorological station. The hydraulic pressure has been measured across the pressure gauge fitting on the piping system.

To measure the electrical output power of the solar generator, an avometer has been used to measure the voltage and the current. The electrical output power is calculated (Theraja, 1983) according to the following equations.

$$P_{output} = V_{oc} \times I_{sc}, \quad kW \text{ ......(5)}$$

Where,

P output = electrical output power for the solar generator in kW;

V_{oc} = potential difference in volt(open circuit voltage , V)

I_{sc} = current in ampere(short circuit current , A)

RESULTS AND DISCUSSION

Hydraulic Performance for solar pump

The performance of the solar pump was studied to determine the effect of the influenced factors of the system which are tilt angle and solar cells area of the solar generator, as well as the effect of the climatic parameters which are; solar radiation (R.S), air temperature (T), relative humidity (R.H), wind speed (W. S), solar day length (H) and the intensive of clouds. The recorded data show a slight difference between the values of the climatic parameters during the test. The measured solar radiation (R.S) in kW/m^2 affects directly on the solar power that converted D.C. by the solar generator to direct electrical current. The solar surface pump connected with an electric motor operated with direct current (D.C.).

Effect of tilt angle

The discharge of the solar pump increased with increasing the tilt angle except for the 45° tilt of angle. Increasing the tilt angle from 15° to 30° increased the discharge by 10.689%. Increasing solar cells area to 35 m^2 and 40 m^2 of the solar generator increased the discharge by16.66% and 24.8 % respectively. The hydraulic pressure increases by 5.77 and 8.33% at 35m^2 and 40m^2 solar cells area respectively. This means that increased the tilt angle increased discharge and pressure at the different levels of the solar cells area. The highest values of the measured pump pressure and discharge were 6.7 m^3/hr and 12 X 10^4 N/m^2 at 30° of tilt angle and 40 m^2 of solar cells area respectively. The lowest values were 2.7 m^3/hr and 9 X 10^4 N/m^2 obtained when the system operated at 45° tilt angle and 30 m^2 of solar cells area respectively. For the solar surface pump, the results found that the 30° of tilt angle with 40 m^2 solar cells area gave The highest values of the pump performance.

Effect of solar cells area

Increasing solar cells area increased discharge for the same valve of tilt angle. This is due to increasing the solar cells area increased the available solar power used which was strongly affect in increasing the input power for the pump. The highest value of the discharge (6.7and m^2 / hr) achieved at 40m^2 of the solar cells area and 30° of tilt angle shown in figures (3) while the lowest (3.7 m^2/ hr) was at 30 m^2 and 30° of tilt angle shown in figures (2). As for the effect of the solar cells area on the hydraulic pressure it wasn't significant difference between its value for the changed area it range from 5.7 to 8%. The value of the subsurface efficiency (η) tended to be due to both of hydraulic power and electric power. Its value depends strongly upon the value of the electric power. This value was almost the same for the changed values of the solar cells area at the same value of the tilt angle except for 30 m^2 of the solar cells area and 15° of the tilt angle shown in figures (1). The solar surface efficiency in this case was 28. 38%. This may be due to the lowest value of the measured electric power (1. 2 kW).

Solar pump performance characteristics

Performance of solar pump at different levels of tilt angles of the photovoltaic panel and solar cells area, shown in figures (1), (2) and (3). The figures show the maximum values of both discharge (Q_{max}), pressure (P_{max}) and efficiency (η_{max}) of solar pump.

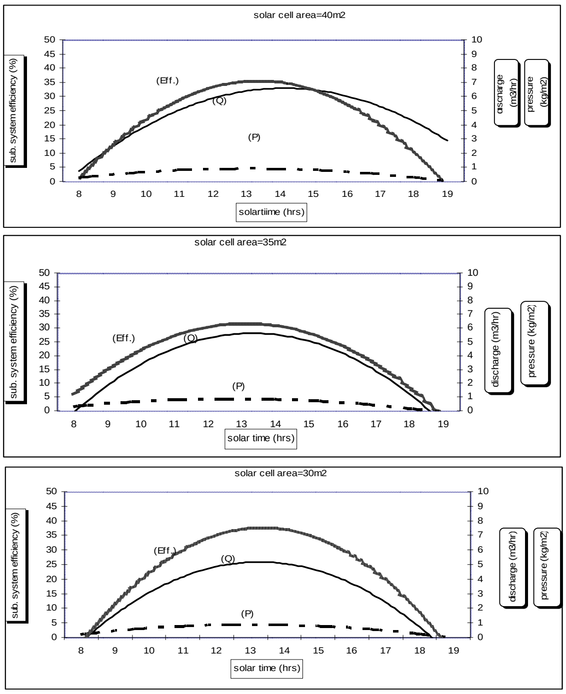

Fig .1. Performance parameters of the deep well pump at tilt angle equal to 15°of the solar cells generator at the different levels of the solar Cells area.

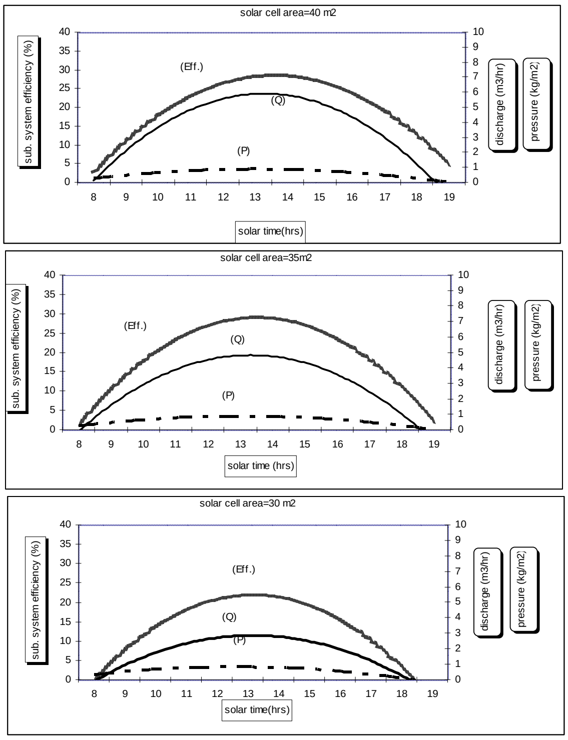

Fig 2. Performance parameters of the deep well pump at tilt angle equal to 30°of the solar cells generator at the different levels of the solar cells area.

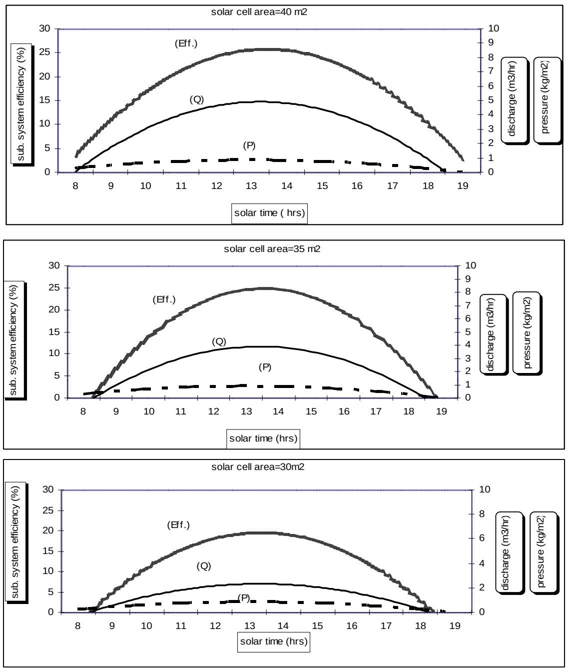

Fig .3. Performance parameters of the deep well pump at tilt angle equal to45° of the solar cells generator at the different levels of the solar cells area.

The maximum value of the discharge (Q_{max}) 9.05 m^3/hr achieved at 30°of the solar panel tilt angle and 40 m^2 of the solar cells area. The maximum value of the operating pressure (P_{max}) 13 10^4 N/m^2 obtained at 30° of tilt angle and 40 m^2 of the solar cells area. The maximum efficiency (η_{max} %) 26.72% obtained at 30°of tilt angle of the solar panel and 30 m^2 of the solar cells area. From the above results it can be noted that, the maximum operation of the solar surface pump at the solar panel adjusted at 30°of tilt angle and 40 $m^2$of the solar cells area. These observations show that 30°of the tilt angle of the solar panel recommended angle to achieve the maximum discharge. Concluded that the combination of discharge, pressure and efficiency has been occurred at 30° of tilt angle 40 $m^2$of the solar cells area.

Cost analysis

The decision on whether to install a photovoltaic pumping system and Diesel Electrical pumping systems should include the cost analysis. Pumps, well and irrigation equipment are expensive. The returns from crop sales must be large enough to repay investment and operating costs. The cost of pumping includes both fixed and variables costs The decision on which pumping method to select should include a complete cost analysis of both fixed and operating costs. Some of the more expensive pumps may have significantly lower due to higher operating efficiencies. Power costs are a function of the individual rate structures; the amount of energy used, and demand charges.

Water unit Cost

The results of the cost analysis presented in table (3). The results shown that water unit cost for pump operated by photovoltaic array is 0.56 L.E/$m^3$and 0.19 L.E/m^3 for diesel electrical power pumps respectively.

Table 3. Unit Water Cost for a Small Scales P.V Pumping System Compared to Diesel Pumping systems operating costs

Items	Solar pump	Diesel pump
System parameters power source pump Distribution: Diameter Length Life cycle Annual water Discharge Area	 P.V Array 4.5 HP 100 mm pipe 50m 25 years 24000 m^3 3 hectares	 Diesel Engine 16 HP 100 mm pipe 50m 10 years 72000 m^3 3 hectares
Total Fixed Costs	6000 L.E	3400 L.E
Total Annual Variable Costs	6000 L.E	9000 L.E
Present worth for total costs at 12% discount rate	1440 L.E	1488 L.E
Unit Water Cost	0.56 L.E/m^3	0.19 L.E m^3

The highest achieved value of the unit water cost for solar surface pump is due to increasing the fixed cost. The increasing of the fixed cost for solar pumping system due to increase the power source cost in comparing with its values for both of diesel and electrical engine pumped system. The power sources cost for photovoltaic arrays system is 150000 and 34000 L.E of diesel engine electrical system respectively. The results show that diesel engine electrical pumped system has the lowest value for the unit water cost. Using of photovoltaic array for solar pump does not depend upon the unit water cost only, but depends on many other conditions. In case of non-availability of diesel or electric power the high cost of solar pumps must be considered. It can be concluded that improving the solar pumping system must be focused on minimizing the unit water cost in order to use it in a large scale From the point of view of pollution, the photovoltaic array takes the first place as the best cleaning energy. The photovoltaic panel has many advantages but the unique disadvantage is the highest value of the unit water cost.

CONCLUSION

The final results obtained concluded that :

1. The photovoltaic array system should have the ability of changing the tilt angle according to the climatic conditions throughout the year.
2. The average power output were 2.44, 1.98 and 1.52 Kw for 40 , 35 , 30 m^2 of the solar cells area 30° tilt angle respectively
3. The average pump efficiency (η max) were 26.7 ,17.86 and 14.28 % for 40 , 35 , 30 m^2 of the solar cells area and 30° tilt angle respectively
4. The average pressure were 12 , 9.8 and 9 10^4 N/m^2 for 40 , 35 , 30 m^2 of the solar cells area 30° tilt angle respectively
5. The average discharge M^3 /hr were 8.23, 7.41 and 6.77 M^3 /hr for 40 , 35 , 30 m^2 of the solar cells area 30° tilt angle respectively
6. Solar water pumps can provide simple and low labor watering options for farms that require water in remote areas.
7. The periodical maintenance of the system must be carried out carefully throughout the year.
8. Improving the efficiency of solar cells will lead to maximize the rate of transformation to electrical energy.

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