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Annual Performance Evaluation of a Mobile Solar Water Pumping System

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A R T I C L E I N F O

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A B S T R A C T

The daily water produced from the solar water pumping system (SWPS) is dependent on several parameters like daily solar radiation falling on the photovoltaic (PV) module and its associated area. The SWPS is considered cost saving on a long-term basis if it is compared to conventional water irrigation systems. The water productivity of the SWPS is affected by the PV module's slope and its orientated direction. It was found that the optimal performance of the PV modules is obtained when facing south with tilt angles from 20^o to 30^o, respectively. The values of solar radiation and daily water produced from the four seasons were measured. The current experimental study includes the study of different tilt angles of 0,30,50,70 and 90; respectively at different azimuth angles equal to 90 , 60 and 30 , 0, -30 , -60 and -90; respectively. The maximum solar radiation and the daily water demand were recorded at the studied slopes and directions all over the seasons of the year. A comparative study between this proposed system and similar systems in terms of cost energy. It showed remarkable agreement and significantly acceptable relative to the cost comparison.

1. Introduction

In most agricultural areas where the national grid electricity is not available, the water irrigation system is mainly dependent on electricity generated by diesel engines. There are several disadvantages of using diesel-based water pumping systems such as the safe availability of fuel in desert areas, maintenance, expensive fuels, creating noise and air pollution. On the other hand, the water pumping using solar energy reduced the diesel fuel consumption and considered as environmentally friendly and has low operating cost (Foster R. et al. 2009). SWPS considered one of the most important applications of solar energy. The main difference compared to the traditional water pumping system is the power source produced by solar energy. The daily water produced of is affected by the incident solar radiation and PV areas. The SWPS is considered cost savings on a long-term basis if it is compared to conventional water irrigation systems.

Water can be stored in water pumping system instead of electricity storage in batteries for night irrigation. To develop safe operation, the water storage tank volume is designed to be three times the daily water pumped quantity (Rohit et al. 2013).

It was found that the integrated solar power system for green-houses irrigation using treated surface mixed water, Delta, Egypt was representing an ideal scenario to improve quality and maximize the yield products in farm irrigation (Okasha et al 2020). SWPS consists of a PV module, inverter controller, metallic frame, surface mounted/submersible pump set. The PV modules can be installed on fixed or tracked mechanism. The produced water can be used directly in the irrigation network or stored in an elevated water storage tank to be used at night or in cloudy and rainy periods. It was recommended to store water instead of storing electricity due to the high cost of battery storage system (Chandel, S. S. 2015). The PV modules were connected to inverter to convert the DC electrical energy output from the PV modules to AC electrical energy suitable to pump type either single or three phases. The productivity of the SWPS is depending on the water pressure, flow, and pump power (Pietro Elia Campana 2015). Several researches were published to study the performance of the SWPS for irrigation and recommended the utilization of solar energy for the water pumping system as cost effective and saving the environment. Kelley L.C. et al, 2010 presented a techno-economic feasibility study of SWPS for irrigation purposes, and recommended the utilization of the SWPS with no restrictions. Moreover, the integrated solar green house (ISGH) system used solar water desalination principle and works causing freshwater

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condensation. ISGH indicated that it could be used successfully to provide a low-cost solution in arid areas (El Awady et al, 2014).

High cost of the SWPS is considered one of the main barriers to spread it on the commercial level. Cuadros et al. 2004 performed a comprehensive design of the drip irrigation SWPS for of olive trees orchard in Spain and produced the proper size of the irrigation water network. Hamidat et al., 2003 studied the performance evaluation of the SWPS for irrigation in regions of the Sahara and found that the SWPS was suitable for crop irrigation in small-scale applications. Glasnovic and Margeta, 2007 presented an optimization model of the SWPS for irrigation to minimize its size. There are several studies for comparing SWPS for irrigation versus Diesel Water Pumping (DWP) and Wind Water Pumping (WPWP) systems. It is found that the SWPS has several advantages compared to traditional water pumping systems for irrigation in rural areas. As the operation of SWPS is independent from fossil fuels and so overcomes all the fuel related disadvantages (Meier T., 2011).

In addition, the SWPS contributed several advantages like high reliability and flexibility; low maintenance and operational cost, nondetectable noise during operation (Odeh I. 2006). Like SWPS, the wind power water pumping WPWP can be used either directly connected to the pumping system or indirectly connected through a power inverter (Meier T., 2011). Especially for livestock watering and crop irrigation, Bouzidi B. 2011 presented a techno-economic visibility study to compare the SWPS and WPWP systems for providing drinking water purposes in Adrar, Algeria.

Dıaz-Mendez et al. (2014) presented another techno-economic visibility study between SWPS and WPWP systems for irrigation of greenhouses and studied the effect of the location of the electric grid, need for a water storage tank, and water affordability. Recent researches on SWPS had been focused on the effective parameters that enhance the system performance improving, inverters, controllers and potential of CO_2 emissions mitigation (Mahjoubi A. 2014, Mozaffari N. 2011, Fernandez-Ramos J. 2010, Kordzadeh A. 2010, El-Ghetany H . et al 2022 and Ould-Amrouche S. 2010).

2. Mathematical Modeling

2.1 Effect of PV slope and direction

The theoretical analysis of the photovoltaic modules and its affecting parameters like maximum output power, instantaneous efficiency, short circuit current and open circuit voltage are described in details in the previously Author published work (Hussein H.M.S. et al., 2004). Two important findings from the Author ‘s previous work was the effect of the solar energy falling on the PV surfaces that facing south with different slopes and the annual maximum electric energy output as a percentage of its value at the optimal slope and direction. It was concluded that the slope of the PV modules has high significant effect on the monthly average solar energy in summer season and has low effect in winter season., It was found that when the PV slope equal zero (horizontal position), the monthly average incident solar energy was 7.8 kWh/m^2 day in summer season, 3.2 kWh/m^2 in winter season, and 5.5 kWh/m^2 day in spring and autumn seasons respectively.

On the other hand, it was found that when the PV slope equal 90 (vertical position), the monthly average incident solar energy was 2 kWh/m^2 day in summer season and 4.4 kWh/m^2 in winter season respectively. It was concluded also that the maximum yearly incident solar energy is recorded when the PV module is oriented to south direction and sloped by an angle equal to the local latitude (30^o). It was found that the value of solar radiation for the optimal slope, the yearly incident solar energy decreases with the increase of the shift of the south direction. The main concluded remarks of the author’s previous work (Hussein H.M.S. et al., 2004) for studying the performance of the PV modules, mounted in Cairo (Egypt) at any tilt angle and orientation under a typical year of the meteorological conditions of Cairo (Egypt) indicated that the PV slope and direction are the most significant effect on the PV system performance. Finally, it is reported that with PV slope =0 (horizontal position) can provide about 95% from the optimal electric energy output, while with PV slope =90 (vertical position) and facing east can provide about 41% from the optimal electric energy output as shown in Fig. 1 and Fig. 2 as per the author’s previously published work (Hussein H.M.S. et al., 2004).

2.2 Sizing the water pump

The following parameters are considered to reach the complete design of the SWPS estimating the solar energy input, Total Dynamic Head (TDH), The water capacity, sizing the suitable water pump to cover the daily water demand at the desired pressure heads.

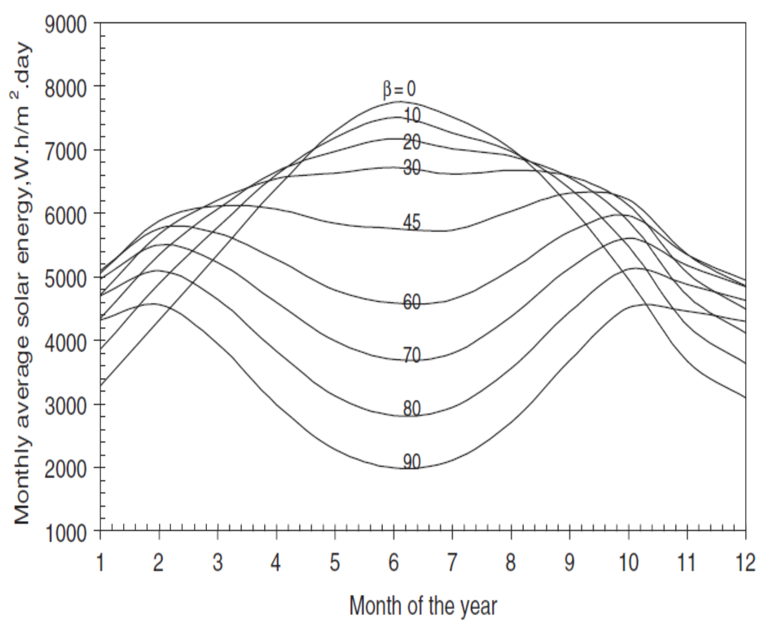

Fig. 1: Effect of tilt angle on monthly average incident solar energy (Hussein H.M.S. et al., 2004)

The pump hydraulic Power, P_h, can be estimated as a function of TDH and water demand as shown in equation (1).

$$P_h = Q\,\rho_w\,g\,TDH \quad (1)$$

Where

ρ_w = Water density (1000 kg/m^3),

g = Acceleration gravity (9.81 m/s^2), and

Q = Water volume flow rate in m^3/s.

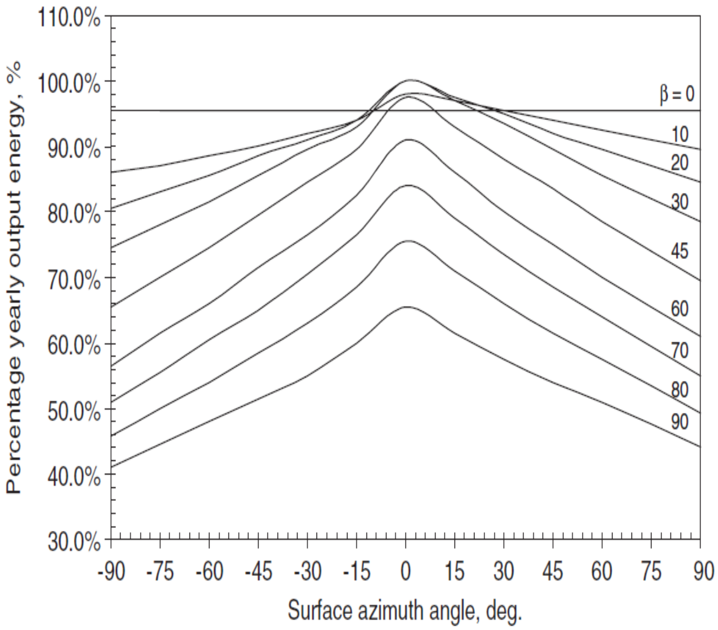

Fig. 2: Percentage of output energy of PV modules at different tilt angles and orientations (Hussein H.M.S. et al., 2004)

2.2 Sizing the solar system

The size of the PV system in Wp for the peak load can be defined as [Said M. A., 2018]

$$APV = \frac{EL}{H \times \eta_{pv} \times \eta_{inv} \times \eta_B \times \eta_{cc} \times T_c} \quad (2)$$

Where

A_{pv} = PV required area (m^2),

E_L = daily required electrical energy consumption (Wh/day)

H = daily solar energy falling on the PV modules (Wh/m^2/d),

η_{pv} , η_{inv} , η_B , η_{cc} = efficiencies for photovoltaic, inverter, battery, and charge controller, respectively

T_c = Temperature correction factor of the PV module.

The current system is designed to operate pump directly from the inverter without battery and charger, therefore, equation (2) can be rewritten as

$$APV = \frac{EL}{H \times \eta_{pv} \times \eta_{inv} \times T_c} \quad (3)$$

The required photovoltaic modules power P_{pv} (W), to meet the electric load demand can be estimated as follows

$$P_{pv} = A_{PV} \times Hsc \times \eta_{PV} \quad (4)$$

Where

H_{sc} = Standard solar irradiation, 1,000 W/m^2.

The number of modules defined as follows

$$N_m = \frac{P_{pv}}{P_m} \quad (5)$$

Where:

P_m is the power of the single module (W).

2.3 System Sizing Calculation

Hydraulic power = 1.5 hp = 1.5 x 735.5 = 1103.2 W

Daily electric energy consumed = 1103.2 W x 6 h = 6.62 kWh

$$APV = \frac{6.62}{6 \times 0.90 \times\ 0.90 \times\ 0.21} = 6.5\ m^2$$

P_{pv} = 6.5 × 1000 × 0.21 = 1.36 kW

The number of modules = 1360 W / 333 W ≈ 4 Modules

3. Experimental Work

The test rig of the experimental work has been installed at the National Research Centre, Dokki, Giza, Egypt. The PV system designed in such a way to investigate experimentally, the effect of PV slope and direction on the daily produced water in different seasons. The system is simply manufactured the metallic frame, PV system including PV modules, pumps, inverter, wiring system as shown in Fig. 3

Fig. 3: Photographic view of the studied PV system

4. Results and Discussion

Several experimental runs are made to present the effect of the PV slope and direction for the solar radiation falling on the PV panels, electric energy produced and amount of accumulated daily water pumped in the four seasons. The measured results are presented in the following sections.

4.1 Effect of PV slope and direction on Solar Radiation values in Spring Season

It is found that the solar radiation values (kWh/m^2/day) varied with the variation of tilt angle at fixed azimuth angle (south facing). In spring season, the average daily solar radiation values south facing were 5.61 kWh/m^2/day, 6.03 kWh/m^2/day , 5.73 kWh/m^2/day, 5.067 kWh/m^2/day and 3.98 kWh/m^2/day corresponding to tilt angles of 0,30, and 50 respectively. it is found that the max. solar radiation in spring season obtained with zero azimuth angles(facing south) and 30^o slope .The percentage of solar radiation values falling on the PV modules for variable slopes and fixed azimuth (South facing) angle in Spring season to the maximum value is shown in Fig. 4.

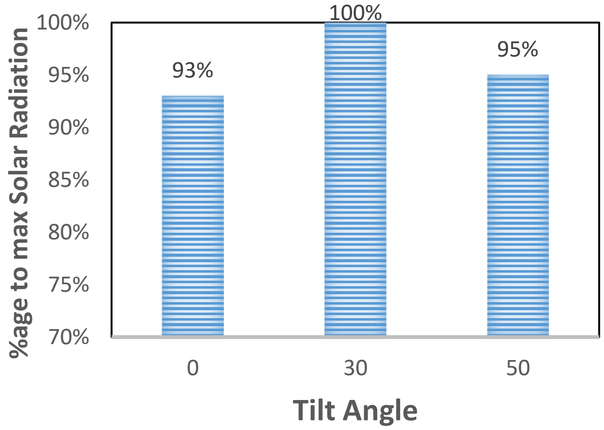

Fig. 4 Percentage of solar radiation values at different tilt angles and fixed azimuth (South facing) in Spring season

It is clear from Fig. 4 that the the percentage of the daily solar radiation values to the maximum values south facing were 93%, 100% , and 95% corresponding to tilt angles of 0,30, and 50 respectively. It is clear also that the maximum solar radiation obtained at tilt angle equal 30 and south direction (azimuth angle equal zero). The daily solar radiation values at slope equal 30 and different azimuth angles is measured. The percentage of solar radiation values falling on the PV modules for variable azimuth angles and fixed tilt angle (30) in Spring season to the maximum value is shown in Fig. 5.

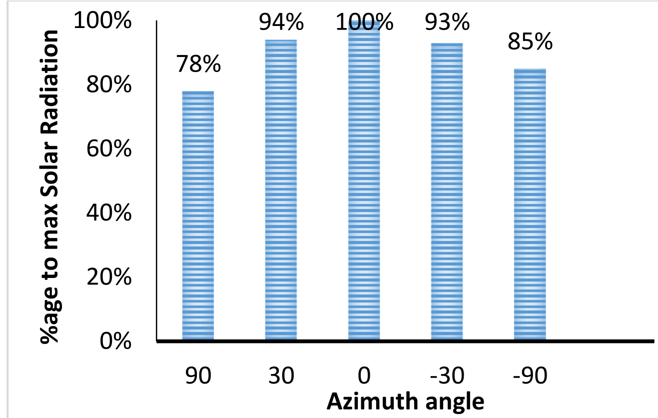

Fig. 5 Percentage of solar radiation values falling on the PV modules for variable azimuth angles and fixed tilt angle (30) in Spring season

It is found that the average daily solar radiation values at slope equal 30 were; (4.71, 5.67, 6.03, 5.61, and 4.85) kWh/m^2/day corresponding to azimuth angles of 90°, 30°, 0, and -30,-90; respectively. At fixed tilt angle (β=30°), the average to maximum solar radiation equals 78% and 94% at azimuth angle equals 90° and 30°, respectively. The average to maximum solar radiation reaches the maximum value 100% at azimuth angle equals zero. Then decreased to 93% and 85% at azimuth angle equals -30 and -90 respectively.

4.2 Effect of PV slope and direction on daily water produced value in Spring Season

It was found that the daily water produced values (m^3) varied with the variation of tilt angle at fixed azimuth angle (south facing). In spring, the daily water produced values south facing were 46.9 m^3, 50.5 m^3 and 47.9 m^3 corresponding to tilt angles of 0, 30 and 50 respectively. it is found that the max. daily water produced values in spring season obtained with zero azimuth angles(facing south) and 30 degree tilt angle.The percentage of daily water produced values for variable tilt angles and fixed azimuth (South facing) angle in Spring season to the maximum value is shown in Fig. 6.

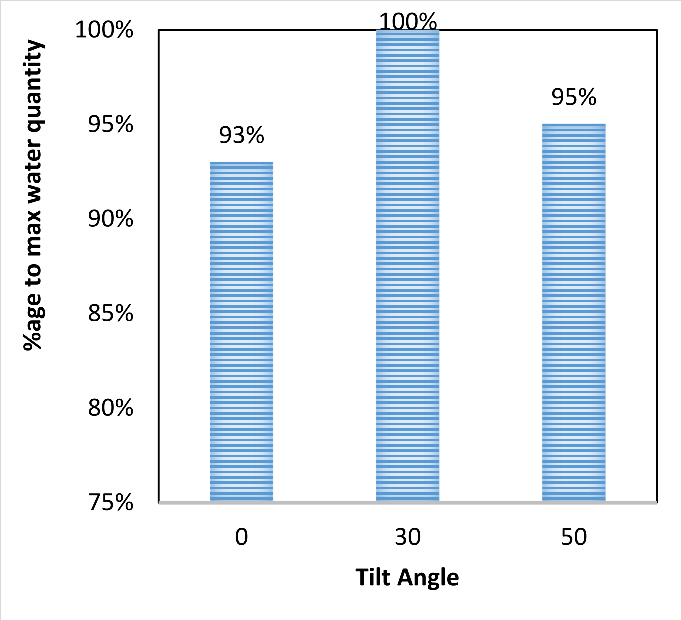

Fig. 6: Percentage of daily water produced to the max values at different tilt angles and fixed azimuth (South facing) in Spring season

For fixed azimuth angle (South facing), at tilt angle zero the average to maximum daily water produced is 93% , reached the maximum value 100% at tilt angle 30 , then decreased to 95% at tilt angles 50. The percentage of daily water produced values for fixed tilt angle (β=30) and variable azimuth angles to the maximum value in Spring season is shown in Fig. 7.

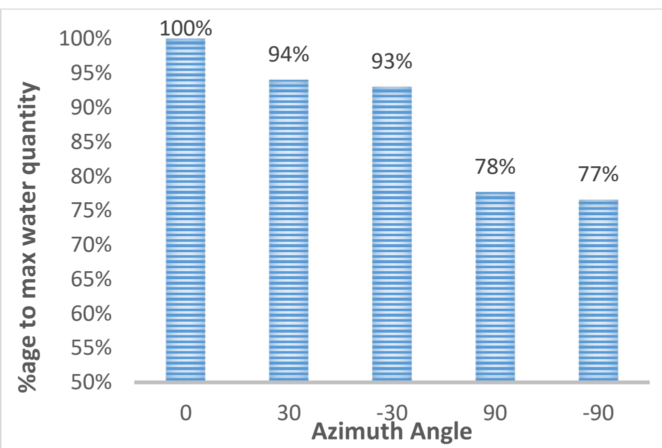

Fig. 7: percentage of daily water produced values for fixed tilt angle (β=30) and variable azimuth angles to the maximum value in Spring season

For fixed tilt angle (β=30), the daily water produced is 42.69 m^3 and 46.9 m^3 at azimuth angle equals -90 and -30 respectively. then reached the maximum value 50.5 m^3 at azimuth angle zero, and decreased to 47.5 m^3 and 39.5 m^3 at azimuth angle 30 and 90 respectively. For fixed tilt angle (β=30), at azimuth angle -90 and -30 the average to maximum daily water produced is 77% and 93% respectively. Then reached to the maximum value 100% at azimuth angle zero, then decreased to 94% and 78% at azimuth angle 30° and 90° respectively as shown in Fig. 7.

4.3 Effect of PV slope and direction on Solar Radiation values in Summer Season

It was found that the solar radiation values (kWh/m^2/day) varied with the variation of tilt angle at fixed azimuth angle (south facing). In summer season, the average daily solar radiation values south facing were 5.7 kWh/m^2/day, 5.8 kWh/m^2/day , 5.2 kWh/m^2/day, 4.6kWh/m^2/day and 3.7kWh/m^2/day corresponding to tilt angles of 0,30,50,70 and 90; respectively. it was found that the max. solar radiation in Summer season obtained with zero azimuth angle (facing south) and 30 degree tilt angle.The percentage of solar radiation values falling on the PV modules for variable tilt angles and fixed azimuth (South facing) angle in Summer season to the maximum value is shown in Fig. 8.

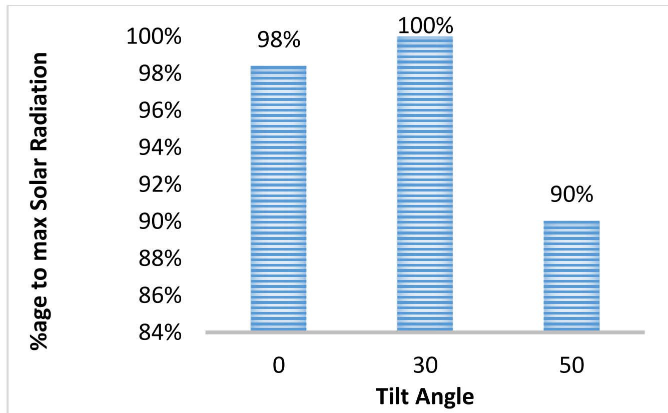

Fig. 8: Percentage of solar radiation values falling on the PV modules for variable tilt angles and fixed azimuth (South facing) angle in Summer season to the maximum value.

It is clear from Fig. 8 that the the percentage of the daily solar radiation values to the maximum values south facing were 98%, 100% and 90% corresponding to tilt angles of 0,30 and 50 respectively. It is clear also that the maximum solar radiation obtained at tilt angle =30° and south facing (azimuth angle = 0). The daily solar radiation values at tilt angle equal 30 and different azimuth angles is measured. It is found that the average daily solar radiation values at tilt angle equal 30 were 4.35 kWh/m^2/day, 5.25 kWh/m^2/day, 5.83 kWh/m^2/day and 5.19 kWh/m^2/day and 4.74 kWh/m^2/day corresponding to azimuth angles of 90, 30, 0 , -30, -90; respectively.

The percentage of solar radiation values falling on the PV modules for variable azimuth angles and fixed tilt angle (30°) in Summer season to the maximum value is shown in Fig. 9.

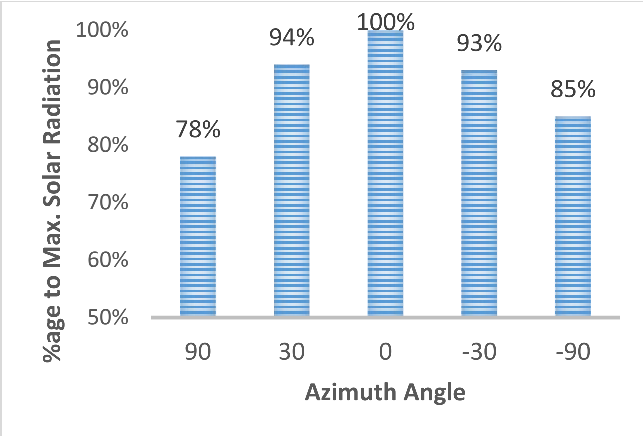

Fig. 9: Percentage of solar radiation values falling on the PV modules for variable azimuth angles and fixed tilt angle (30) to the maximum value in Summer season

At fixed tilt angle (β=30), the average to maximum solar radiation equals 78% , and 94% at azimuth angle equals 90 and 30 respectively. Then reached the maximum value 100% at azimuth angle equals zero. The average to maximum solar radiation decreased to 93%, and 85% at azimuth angle equals -30 and -90 respectively as shown in Fig. 9.

4.4 Effect of PV slope and direction on daily water produced value in Summer Season

It is found that the daily water produced values (m^3) were varied with the variation of tilt angle at fixed azimuth angle (south facing). In summer season, the daily water produced values south facing were 54.59 m^3, 56.32 m^3, and 53.20 m^3 corresponding to tilt angles of 0,30 and 50 respectively. It was found that the max. daily water produced values in summer season obtained with zero azimuth angles (facing south) and 30 degree tilt angle. The percentage of daily water produced values for variable tilt angles and fixed azimuth (South facing) angle in Summer season to the maximum value is shown in Fig. 10.

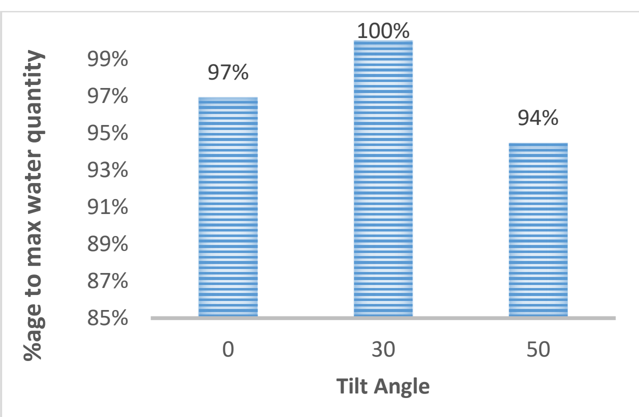

Fig. 10: Percentage of daily water produced values for variable tilt angles and fixed azimuth (South facing) angle to the maximum value in Summer season

For fixed azimuth angle (South facing), at tilt angle zero the average to maximum daily water produced is 97% , reached the maximum value 100% at tilt angle 30 , then decreased to 94% at tilt angles 50. Figure 11 represents percentage of the daily water produced to the max values for variable azimuth angles and fixed tilt angle (β=30) in Summer season.

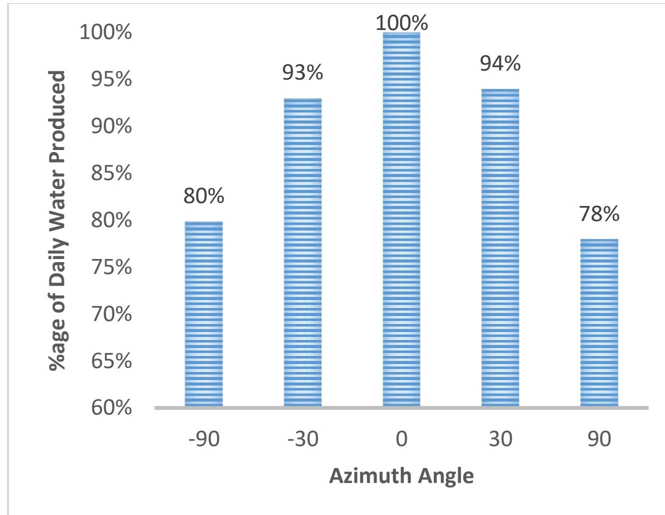

Fig. 11 Percentage of the daily water produced to the max values for variable azimuth angles and fixed tilt angle (β=30) in Summer season.

For fixed tilt angle (β=30), the daily water produced is 44.99 m^3, and 52.37 m^3 at azimuth angle equals -90 and -30 respectively. then reached the maximum value 56.32 m^3 at azimuth angle zero, and decreased to 52.93 m^3 and 43.9 m^3 at azimuth angle 30 and 90 respectively. For fixed tilt angle (β=30), at azimuth angle -90, and -30 the average to maximum daily water produced is 80% and 93% respectively. Then reached to the maximum value 100% at azimuth angle zero, then decreases to 94%, and 78% at azimuth angle 30 and 90 respectively as shown in Fig. 11.

4.5 Effect of PV slope and direction on Solar Radiation values in Winter Season

It is found that the solar radiation values ($kWh/m^2/day$) varied with the variation of tilt angle at fixed azimuth angle (south facing). In winter season, the average daily solar radiation values south facing were 3.55 $kWh/m^2/day$, 4.96 $kWh/m^2/day$ and 5.66 $kWh/m^2/day$ corresponding to tilt angles of 0,30 and 50 respectively. it is found that the max. solar radiation in Winter season obtained with zero azimuth angle (facing south) and 50 degree tilt angle. The percentage of solar radiation values falling on the PV modules for variable tilt angles and fixed azimuth (South facing) angle in Winter season to the maximum value is shown in Fig. 12.

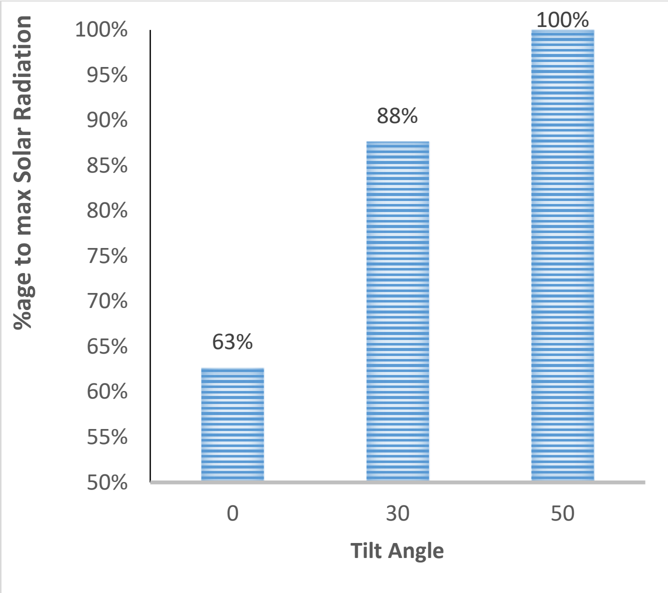

Fig. 12: Percentage of solar radiation values falling on the PV modules for variable tilt angles and fixed azimuth (South facing) angle to the maximum value in Winter season

It is clear from Fig. 12 that the the percentage of the daily solar radiation values to the maximum values south facing were 63%, 88% and 100% corresponding to tilt angles of 0, 30° and 50° respectively. It is clear also that the maximum solar radiation obtained at tilt angle equal 50 and south facing (azimuth angle equal zero) .

The daily solar radiation values at tilt angle equal 50 and different azimuth angles is measured. It is found that the average daily solar radiation values at tilt angle equal 50° were (4.25, 5.21, 5.66, 5.26, and 4.33) kWh/m^2/day corresponding to azimuth angles of 90°,30, 0, -30°, -90°; respectively.

The percentage of solar radiation values falling on the PV modules for variable azimuth angles and fixed tilt angle (50) to the maximum value in Winter season is shown in Fig. 13.

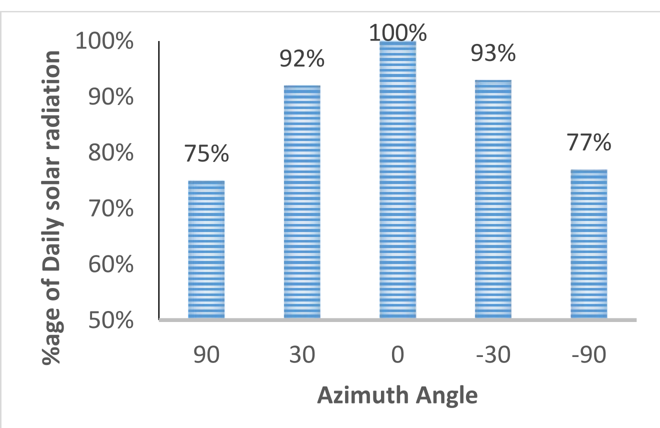

Fig. 13 Percentage of solar radiation values falling on the PV modules for variable azimuth angles and fixed tilt angle (50) to the maximum value in Winter season

At fixed tilt angle (β=50), the average to maximum solar radiation equals 75% and 92% at azimuth angle equals 90 and 30 respectively. The average to maximum solar radiation reached the maximum value 100% at azimuth angle equals zero. The average to maximum solar radiation decreased to 93%, and 77% at azimuth angle equals -30 and -90 respectively as shown in Fig. 13.

4.6 Effect of PV slope and direction on daily water produced value in Winter Season

It is found that the daily water produced values (m^3) varied with the variation of tilt angle at fixed azimuth angle (south facing). In Winter season, the daily water produced values south facing were 38.5m^3, 46.48 m^3 and 51.47 m^3 corresponding to tilt angles of 0,30° and 50° respectively. it is found that the maximum daily water produced values in Winter season obtained with zero azimuth angle (facing south) and 50 degree tilt angle. The percentage of daily water produced values for variable tilt angles and fixed azimuth (South facing) angle in Winter season to the maximum value is shown in Fig. 14.

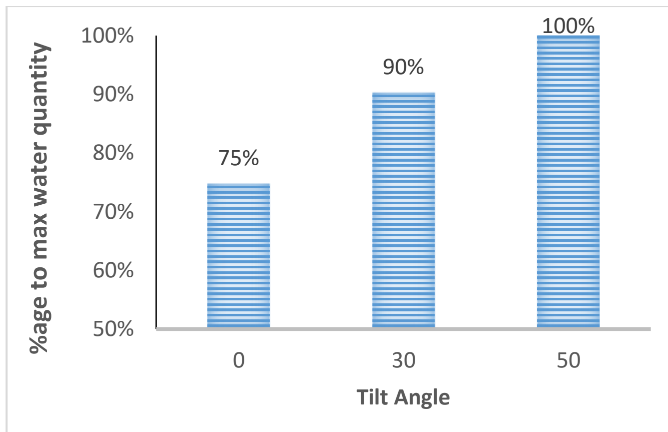

Fig. 14: Percentage of daily water produced values for variable tilt angles and fixed azimuth (South facing) angle to the maximum value in Winter season

For fixed azimuth angle (South facing), at tilt angle zero and 30, the average to maximum daily water produced is 75% , and 90% respectively and reached the maximum value 100% at tilt angle 50. For fixed tilt angle (β=50), the daily water produced is 42.9 m^3 and 47 m^3 at azimuth angle equals -90 and -30 respectively. then reached the maximum value 51.5 m^3 at azimuth angle zero, and decreased to 47.5 m^3 and 39.4 m^3 at azimuth angle 30 and 90 respectively.

The percentage of daily water produced values for variable azimuth angles and fixed tilt angle (50°) to the maximum value in Winter season is shown in Fig. 15.

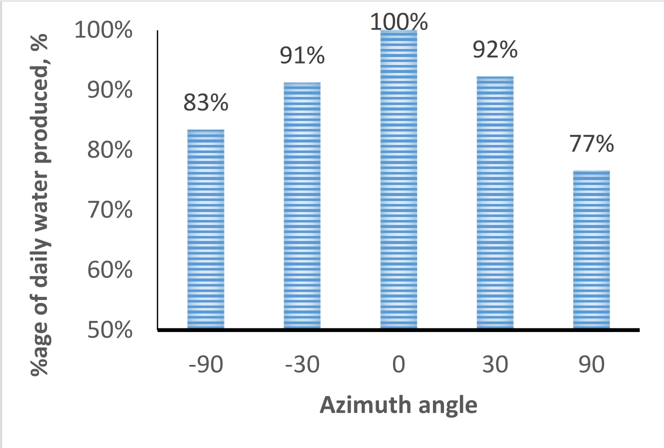

Fig. 15 Percentage of daily water produced values for variable azimuth angles and fixed tilt angle (50) to the maximum value in Winter season

For fixed tilt angle (β=50), at azimuth angle -90 and -30 the average to maximum daily water produced is 83% and 91% respectively. Then reached to the maximum value 100% at azimuth angle zero, and decreased to 92% and 77% at azimuth angle 30 and 90 respectively as shown in Fig. 15.

4.7 Economic Analysis

The experimental investigation stage, a commercial scale of mobile PV water pumping unit was designed, manufactured, and tested in National Research Centre, Dokki, Giza, Egypt as shown in Fig. 16. The costs of a standalone PV system include acquisition costs, operating costs, maintenance costs, and replacement costs. Although the initial cost of the system is high, maintenance and replacement costs are low and there is no fuel cost. The economic analysis of the PV water pumping system is based on calculating indicators like Life Cycle Cost (LCC) and Cost of Energy. The LCC method is the largely used worldwide to evaluate the economics of the PV system. LCC is applied based on the following assumptions; the lifetime of all the items is considered 20 years and the interest rate is about 10%. It can be defined as shown in equation (6)

$$LCC = C_{capital} + \sum_1^n C_{O\&M} + \sum_1^n C_{rep} - C_s \tag{6}$$

Where

$C_{capital}$: The capital cost of a project
$C_{O\&M}$: The yearly operation and maintenance costs
C_{rep} : The cost of all equipment replacement and repair
C_s : The net worth of the system at the final year of project lifetime

Fig. 16 Final View of the mobile solar water pumping system

The cost analysis of the solar water pumping system is shown in Table 1. Based on the experimental results, the following information is recorded.

The daily average electric power produced through the year	= 5 kW
The daily average electric energy produced through the year	= 30 kWh
The annual average electric energy produced through the year	= 10,950 kWh

The Cost of Energy (CoE) can be calculated as shown in equation (7).

$$CoE = \frac{LCC}{\sum_1^n EPV_{Annual}} \tag{7}$$

$$CoE = \frac{\$\,6920}{10{,}950 kWh} = 0.632 \quad \$/kWh$$

A comparison in terms of cost of energy between the systems proposed in this study and other systems in the literature is shown in Fig.17 (Al-Smairan M. 2012, Majid Alabdul Salam et al., 2013 and Nagwa M. Khattab et al. 2020). The cost of the proposed system seems to be acceptable, relative to the comparison.

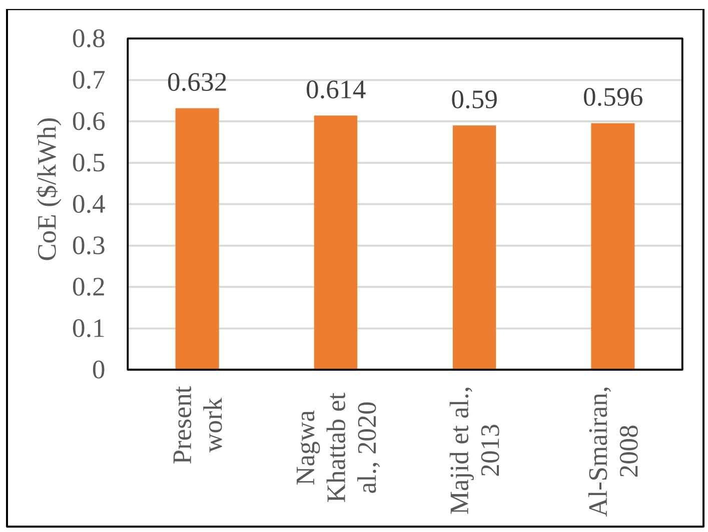

Fig. 17 Cost energy comparison of different systems

Table (1): Cost analysis for the solar water pumping system

Cost item		Components	N.	Unit price ($)	Total price ($)
$C_{capital}$	Capital Cost	PV module 333W	6	80	480
		Controller	1	40	40
		Inverter (2 kW)	1	150	150
		Installations	1	90	90
		Mobile Metallic frame	1	1200	1200
		Hydraulic system	1	400	400
		Water Pump (2 hp)	1	200	200
		Total			2560
		Inflation Rate			5%
		Capital Cost with inflation Rate			6792
$C_{O\&M}$	O&M Cost	operation and maintenance costs for 20 years	20	50	1000
C_{rep}	Replacement Cost	Replacement of pump and inverter	2	250	500
C_s	Salvage Value	Salvage Value = 20% from Capital Cost	1	1358	1358
LCC	Life Cycle Cost (LCC)	Life Cycle Cost (LCC)	1	2701.5115 75	6934

5. Conclusion

The PV system was designed in such a way to experimentally investigate the effect of tilt angle and orientation on the pumped water in different seasons. Some concluded remarks can be summarized as follows:

Spring Season

- It was found that the maximum solar radiation (kWh/m^2/day) obtained with zero azimuth angle (facing south) and 30 degree tilt angle. The daily solar radiation values to the maximum values south facing were 93%, 100% , 95%, 84% and 66% corresponding to tilt angles of 0,30,50,70 and 90 respectively. While the percentage of the daily solar radiation values to the maximum values at tilt angle 30° and different azimuth angles were 78% , 86%, 94%, 100%, 93%, 87% and 85% at azimuth angle equals 90 , 60 and 30 , 0, -30 , -60 and -90 respectively.
- It is found that the electric energy produced from the PV modules (kW) obtained with zero azimuth angle (facing south) and 30 degree tilt angle. The electric energy produced from the PV modules to the maximum values south facing were 86%, 100% , 90%, 71% and 44% corresponding to tilt angles of 0,30,50,70 and 90 respectively. While the percentage of the daily solar radiation values to the maximum values at tilt angle 30 and different azimuth angles were 72% , 76%, 86% , 100%, 88%,74% and 61% at azimuth angle equals 90 , 60 and 30 , 0, -30 , -60 and -90 respectively.
- It was found that daily water-produced values (m^3) obtained with zero azimuth angle (facing south) and 30 degree tilt angle. The daily water produced values to the maximum values south facing were 93%, 100% , 95%, 84% and 66% corresponding to tilt angles of 0,30,50,70 and 90 respectively. While the percentage of the daily water produced values to the maximum values at tilt angle 30 and different azimuth angles were 77% , 87%, 93% 100%, 94%, 86% and 78% at azimuth angle equals 90 , 60 and 30 , 0, -30 , -60 and -90 respectively.

Summer Season

- It was found that the maximum solar radiation (kWh/m^2/day) obtained with zero azimuth angle (facing south) and 30 degree tilt angle. The daily solar radiation values to the maximum values south facing were 98%, 100%, 90%, 78% and 64% corresponding to tilt angles of 0,30,50,70 and 90 respectively. While the percentage of the daily solar radiation values to the maximum values at tilt angle 30 and different azimuth angles were 78% , 86%, 94%, 100%, 93%, 86% and 85% at azimuth angle equals 90, 60 and 30 , 0, -30 , -60 and -90 respectively.
- It was found that the electric energy produced from the PV modules (kW) obtained with zero azimuth angle (facing south) and 30 degree tilt angle. The electric energy produced from the PV modules to the maximum values south facing were 90%, 100% , 88%, 66% and 44% corresponding to tilt angles of 0,30,50,70 and 90 respectively. While the percentage of the daily solar radiation values to the maximum values at tilt angle 30 and different azimuth angles were 72% , 74%, 86% , 100%, 88%,74% and 61% at azimuth angle equals 90 , 60 and 30 , 0, -30 , -60 and -90 respectively.
- It was found that daily water-produced values (m^3) obtained with zero azimuth angle (facing south) and 30 degree tilt angle. The daily water produced values to the maximum values south facing were 97%, 100% , 94%, 81% and 66% corresponding to tilt angles of 0,30,50,70 and 90 respectively. While the percentage of the daily water produced values to the maximum values at tilt angle 30 and different azimuth angles were 80% , 84%, 93%, 100%, 94%, 82% and 78% at azimuth angle equals 90 , 60 and 30 , 0, -30 , -60 and -90 respectively.

Winter Season

- It was found that the maximum solar radiation (kWh/m^2/day) obtained with zero azimuth angle (facing south) and 50 degree tilt angle. The daily solar radiation values to the maximum values south facing were 63%, 88% , 100%, 90% and 70% corresponding to tilt angles of 0,30,50,70 and 90 respectively. While the percentage of the daily solar radiation values to the maximum values at tilt angle 30 and different azimuth angles were 75% , 85%, 92% 100%, 93%, 84% and 77% at azimuth angle equals 90 , 60 and 30 , 0, -30 , -60 and -90 respectively.
- It was found that the electric energy produced from the PV modules (kW) obtained with zero azimuth angle (facing south) and 50 degree tilt angle. The electric energy produced from the PV modules to the maximum values south facing were 78%, 97%, 100% , 86%, and 64% corresponding to tilt angles of 0,30,50,70 and 90 respectively. While the percentage of the daily solar radiation values to the maximum values at tilt angle 50 and different azimuth angles were 72% , 78%, 89% , 100%, 91%,76% and 63% at azimuth angle equals 90 , 60 , 30 , 0, -30 , -60 and -90 respectively.
- It was found that daily water produced values (m^3) obtained with zero azimuth angle (facing south) and 30 degree tilt angle. The daily water produced values to the maximum values south facing were 75%, 90% , 100% , 82% , and 65% corresponding to tilt angles of 0,30,50,70 and 90 respectively. While the percentage of the daily water produced values to the maximum values at tilt angle 30 and different azimuth angles were 83% , 85%, 91% 100%, 92%, 84% and 77% at azimuth angle equals 90 , 60 and 30 , 0, -30 , -60 and -90 respectively.

A performance comparison between the solar radiation values falling on the PV modules, electric energy output and daily water produced for all seasons at different tilt angles and orientation is showed that there is a significant effect on the performance with changing tilt angles and orientation. The study can be positively contributed in designing the PV water pumping system. Based on the comparison in terms of cost of energy between the proposed systems in the current study and other systems in the literature showed acceptable system cost analysis.

References

Al-Smairan M., Application of photovoltaic array for pumping water as an alternative to diesel engines in Jordan Badia, Tall Hassan Station: case study, Renew. Sustain. Energy Reviews 16, 4500–4507 (2012)

Bouzidi B., “Viability of solar or wind for water pumping systems in the Algerian Sahara regions, case study Adrar”, Renewable and Sustainable Energy, Reviews, vol. 15, p. 4436– 4442, 2011.

Chandel S. S., Nagaraju Naik M., and Rahul Chandel. "Review of solar photovoltaic water pumping system technology for irrigation and community drinking water supplies." Renewable and Sustainable Energy Reviews 49 (2015): 1084- 1099.

Cuadros F., López-Rodríguez F., Marcos A., Coello J., A procedure to size solar-powered irrigation (photo-irrigation) schemes, Solar Energy, Vol. 76, p. 465–473, 2004.

Diaz-Mendez R., Rasheed A., Peillon M., Perdigones A., Sanchez R., Tarquis A.M., Garcia-Fernandez J.L., “Wind pumps for irrigating greenhouse crops: Comparison in different socio-economical frameworks”, Bio-systems Engineering, vol. 128, P. 21–28, 2014.

El-Awady M.H., H.H. El-Ghetany, M.A. Latif. “Experimental Investigation of an Integrated Solar Green House for Water Desalination, Plantation and Wastewater Treatment in Remote Arid Egyptian Communities”, Energy Procedia doi: 10.1016/j.egypro.2014.06.063, 1876-6102 © 2014, 50 520 – 527, Elsevier Lt, 2014

El-Ghetany H., Halawa M., Mohammed M., Elmasry I., 'Experimental Investigation of A Mobile PV Water Pumping System', *Journal of Al-Azhar University Engineering Sector*, 17(65), pp. 1290-1314. doi: 10.21608/auej.2022.265717, (2022).

Fernandez-Ramos J., Narvarte-Fernandez L., Poza-Saura F., “Improvement of photovoltaic pumping systems based on standard frequency converters by means of programmable logic controllers”, Solar Energy, vol. 84, p. 101–109, 2010.

Foster R., Majid G., Cota A., Solar Energy. Renewable Energy and the Environment, ISBN 9781420075663, 1st Edition, Published August 19, 2009 by CRC Press, 380 Pages 186 B/WIllustrations, https://doi.org/10.1201/9781420075670

Glasnovic Z., Margeta J., “A model for optimal sizing of photovoltaic irrigation water pumping systems”, Solar Energy, Vol. 81, p. 904–916, 2007.

Hussein H.M.S., Ahmad G.E., and El-Ghetany H.H.; Performance Evaluation of Photovoltaic Modules at Different Tilt Angles and Orientations, Energy Conversion & Management, Vol.45, pp.2441-2452 (2004).

Hamidat A., Benyoucef B., Hartani T., 2003. "Small-scale irrigation with photovoltaic water pumping system in Sahara regions," Renewable Energy, Elsevier, vol. 28(7), pages 1081-1096.

Kelley L.C., Gilbertson E., Sheikh A., Eppinger S.D. and Dubowsky S., On the feasibility of solar-powered irrigation. Renewable and Sustainable Energy Reviews, Vol.14, pp. 2669-2682, 2010.

Kordzadeh A., “The effects of nominal power of array and system head on the operation of photovoltaic water pumping set with array surface covered by a film of water”, Renewable Energy, Vol. 35, p. 1098–1102, 2010.

Mahjoubi A., Mechlouch R.F., Mahdhaoui B., Brahim A.B., “Real-time analytical model for predicting the cell temperature modules”, Sustainable Energy Technologies and Assessments, vol. 6, p. 93–104, 2014.

Majid Alabdul Salam, Ahmed Aziz, Ali H A Alwaeli, Hussein A Kazem, Optimal sizing of photovoltaic systems using HOMER for Sohar, Oman, International Journal of Renewable Energy Research, Vol.3, No.2, 2013

Mathew S., “Wind Energy-Fundamentals, Resource Analysis and Economics”, Springer, 2006.

Meier T., “Policy Recommendations to Improve the Sustainability of Rural Water Supply Systems”, IEA, 2011.

Mozaffari N., Danyali S., Sharifian M.B.B., Feyzi M.R., “Brushless DC motor drives supplied by PV power system based on Z-source inverter and FL-IC MPPT controller”, Energy Conversion and Management, Vol. 52, p. 3043–3059, 2011.

Nagwa M. Khattab, Mervat A. Badr, Essam Tawfik El Shenawy, Hassan H. Sharawy and Marwa S. Shalaby, Economic Analysis of Stand-Alone Hybrid Wind/PV/Diesel Water Pumping System: A Case Study in Egypt, Intech Open, DOI: http://dx.doi.org/10.5772/intechopen.89161, 2020

Odeh I., Yohanis Y.G., Norton B., “Economic viability of photovoltaic water pumping systems”, Solar Energy, Vol. 80, p. 850–860, 2006.

Okasha E.M., M.H. El-Awady, H.H. El-Ghetany, “Integrated Solar Power System for Green-houses Irrigation Using Treated Surface Mixed Water, Delta, Egypt”, Egypt. J. Chem. Vol. 63, No. 10 pp. 4017 – 4027, 2020

Ould-Amrouche S., Rekioua D., Hamidat A., “Modelling photovoltaic water pumping systems and evaluation of their CO_2 emissions mitigation potential”, Applied Energy, Vol. 87, p. 3451–3459, 2010.

Pietro Elia Campana, PV Water Pumping Systems for Agricultural Applications, doctoral thesis, School of Business, Society and Engineering, Mälardalen University, Västerås, Sweden, ISBN 978-91-7485-189-2, 2015

Rohit K.B., Karve G., Khatri M. Solar water pumping system. International Journal of Emerging Technology Advanced Engineering; 3:225–59, (2013). 11 pages

Said M. A. Ibrahim, El-Ghetany H. H., Shabak A. G. M., Mathematical Modelling and Performance Evaluation for A Solar Water Pumping System in Egypt, Journal of Al Azhar University Engineering Sector, Vol. 13, No. 48, 2018.

Conflict of Interest

The authors declare no conflict of interest.