



A PV pumping station for drinking water in a remote residential complex

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Abstract

A photovoltaic application project was designed to pump drinking water from an appropriate well to a residential complex located in a remote area near the Iraqi-Syrian boarder. The system comprises, solar modules array, voltage controller, inverter and a submersible. A ground storage tank of 130 m³ is also used to store the pumped water that distributed to the complex. The work includes an evolution performance of one year operation of the whole system.

1. Introduction

The availability of sweet water wells in most Iraqi north villages, leads to think for providing such villages with drinking water from these wells, for its better cost effectiveness compared to high cost of transporting the water from far areas by tankers or pipes.

For the above purpose the Environmental and Energy Research Center in Baghdad design and implement a pilot PV system to pump

drinking water from such a sweet well existed in one of the villages in this area.

The system was installed in a remote residential complex belong to an irrigation company located 100 km north of Mousel city, 36° 14' N Latitude, 42° 14' E Longitude.

An existed well in the site was chosen to test the operation of the PV system, the well has the following specifications:

- Total depth 230 m
- Static water level 16 m
- Dynamic water level 38 m
- Inner diameter 5.6 in
- Water production 13.5 l/s

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Table 1
Monthly daily average of the complex consumption of drinking water

Mon	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
V	45.0	45.0	50.0	55.0	65.0	65.0	65.0	65.0	65.0	65.0	55.0	45.0

2. Project requirements

The complex site has a 30 residential houses, a workshop and a reception office. The monthly daily average water demand (V), of the complex was estimated in m^3 as in Table 1 according to the previous years levels of water consumption in the complex.

The station has a storage system consists of a ground storage tank of $130 m^3$ capacity to substitute any deficit in water demand during the days of low insolation levels. For this reason there is no need for batteries consideration in the PV system design.

The absence of storage batteries means the ability to pump water only during the day hours, bearing in mind that the station stops pumping in periods of low insolation levels especially in the early morning periods where the insolation is insufficient to provide the high starting current required of the water pump motor.

According to the requirements stated above an estimated periods of water pump operation (H), in hours are placed as indicated in Table 2 with the correspondent values of water flow rate (Q), that are determined in l/s as:

$$Q = V \times \frac{1000}{H} \times 3600 \quad (1)$$

Referring to Table 2 the maximum value of water flow rate (Q), which is considered in designing the appropriate water pump is (2.08) l/s. Then the new daily periods of water pump operation (H_n), that correspond to such flow are determined for each month by applying Eq. (1), the results are as shown in Table 2.

Also it is found experimentally, that the optimum depth of submersible pump is 22.0 m plus 3.0 m the height of the ground storage tank, yield a total head of 25.0 m.

3. PV pumping station design

The main goal of this research is to reach an optimum design of a pumping station used to pump drinking water from a well and store it in a ground storage tank to provide the complex with the needed water. Fig. 1 shows the layout of the operation principle of the project.

An appropriate water pump is designed according to the maximum demand of water

Table 2
The estimated and calculated monthly daily periods of water pump operation with the correspondent flow rate levels of water

Mon	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
H	6.00	6.00	7.00	8.00	10.00	10.00	10.00	10.00	10.00	9.00	8.00	6.00
Q	2.08	2.08	1.98	1.90	1.80	1.80	1.80	1.80	1.80	2.00	1.90	2.08
H_n	6.00	6.00	6.67	7.34	8.68	8.68	8.68	8.68	8.68	8.68	7.34	6.00

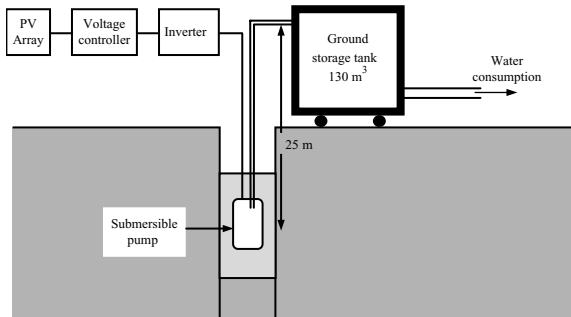


Fig. 1. The operation principle of the PV pumping station.

flow rate which is (2.08) l/s. The demanded hydrologic power of the pump (Ph), is determined in watts depending on [1], as:

$$Ph = \rho \times g \times Q \times h \tag{2}$$

where ρ , water density = 1000 kg/m³; g , gravity acceleration = 9.81 m/sec²; Q , water flow rate, in m³/sec; h , water pumping head, in m.

To find the demanded hydrologic power of the pump, Eq. (2) is applied with $h = 25$ m and $Q = 0.00208$ m³/sec, which gives Ph = 510W. Assuming the overall efficiency of the pump and electric motor is 40% which yields a demanded input electric power (Pe) of 1275W.

Practically a motor and pump unit with power exceeds the theoretical value is used. This is to keep operation always under the rating, and also to face any probable decay in the volume of pumping water. To meet these requirements the calculated value of (Pe) is multiplied by a safety factor of 1.25, which gives a new value of (Pe) equal to 1594W.

A suitable grundfos submersible pump is used. It is a multistage centrifugal pump directly coupled to a 3 phase-380V submersible 2-pole asynchronous squirrel cage motor of 2 kW rating.

3.1. PV system design

According to the field requirements, the monthly daily demands of electric energy (E), that supply the water pump are determined by multiplying the demanded electric power by the correspondent periods of daily water pump operation (H_n). The results are as stated in Table 3.

To get an efficient design of PV system, the tilt factor consideration is taken into account, where the values of the tilt factors (Tf), is expressed according to Liu and Jordan formula [2], as

$$Tf = \frac{R_b H_{Tb}}{H_T} + \frac{(1 + \cos B)}{2} \cdot \frac{H_{Td}}{H_T} + \frac{\rho (1 + \cos B)}{2} \tag{3}$$

where R_b , direct beam elevation factor; H_{Tb} & H_{Td} , monthly daily average total horizontal beam and diffuse radiation; B , inclinations, in degrees; ρ , ground reflectivity.

Then, the necessary area of PV modules, (A), in m² is determined as:

$$A = \frac{E}{Tf \times G \times \eta_{PV} \times \eta_R \times \eta_{in}} \tag{4}$$

Table 3

The correspondent monthly daily demands of electric energy that needed to supply the water pump

Mon	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
E (w.h)	7650	7650	8504	9358	11067	11067	11067	11067	11067	11067	9358	7650

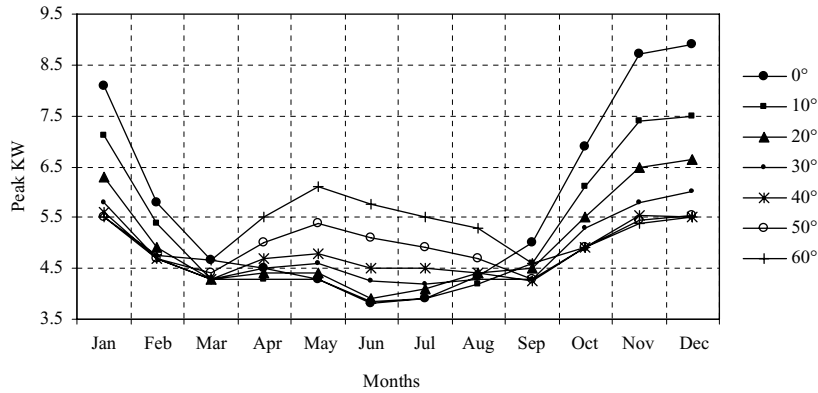


Fig. 2. PV peak power demands of the system for multi inclinations.

where E , monthly daily average demand of electric energy, in w.h.; G , monthly daily average isolation on a horizontal surface, in w.h/m²; η_{PV} , η_R and η_{in} , efficiencies of Solar modules, Regulator and Inverter.

To take the effect of temperature, dust, variation of solar radiation and resistive wiring losses on the output power produced by PV modules, it is necessary to multiply the calculated value of the PV peak power demand by a safety factor, varies between (1.25–1.40) [3].

Accordingly the correspondent PV peak power demand (P_{PV}), in watt is expressed as

$$P_{PV} = Sc \times A \times \eta_{PV} \times SF \tag{5}$$

where Sc , solar constant = 1000 W/m²; SF , safety factor assumed to be equal to 1.25.

Since there are no storage batteries, the water pump will stop pumping during periods of low isolation level especially at the early morning periods. This leads to correspondent losses in the received radiation energy. To compensate such losses the calculated value of P_{PV} in Eq. (5) is divided by a correspondent factor assumed to be 0.75, then from Eqs. (4) and (5) gets:

$$P_{PV} = \frac{Sc \times E \times SF}{Tf \times G \times \eta_R \times \eta_{in} \times 0.75} \tag{6}$$

where η_R , is taken = 0.90; η_{in} , is taken = 0.85; G , is the monthly daily average isolation on a horizontal surface in Mosul [4].

To get the optimum PV system design, various systems are designed at different inclinations from 0–60°. For each inclination the monthly values of tilt factors are calculated according to Eq. (3) using the related meteorological data of the area, then Eq. (6) is applied to calculate the PV peak power demands of electric energy (E) stated in Table 3. The results are shown in Fig. 2.

From the data shown in Fig. 2, one can deduced the worst months of each inclination that need maximum values of PV peak power demands in watts. These outcomes are indicated in Table 4.

It is clear from data in Table 4, that 50° is the optimum inclination where it has the worst month of the minimum peak power demand compared to other inclinations.

Table 4
PV peak power demands (watt) of the worst months at multi inclinations

B	0°	10°	20°	30°	40°	50°	60°
Month	Dec	Dec	Dec	Dec	Dec	Dec	May
P_{PV}	8896	7534	6656	6082	5721	5522	6018

4. PV system configuration

4.1. PV array

A PV array consists 512 a-Si solar modules 1ft × 3ft with specification 14.5 V, 759 mA and 11 W, are arranged to give an out put power of 5632 W at a voltage 464 V and about 12 A current.

The array includes 2 parallel sub arrays each consists of 16 series panels, where each panel contains 2 series 8 parallel models. Then each 4 panels are assembled on a single support unit as indicated in Fig. 3.

As a result the whole arrangement of the PV array consists of 8 units distributed in 2 rows, 4 units per row. Fig. 4 shows a simple circuit diagram of the whole PV array.

Since that the units are arranged into 2 rows, a reasonable distance of about 8 m between them is considered in fixing the supports to avoid shadowing effect between rows during winter days, and the height of support is about 4 m.

4.2. Voltage controller

The main function of the voltage controller is to provide a regulated voltage suitable to supply the inverter, to protect it against the over voltage conditions, and to isolate it during low voltage periods. The controller consists of the following units:

- (1) High voltage protection unit.
- (2) Voltage regulation voltage.
- (3) Over and under voltage control unit.
- (4) Electronic power supply unit.

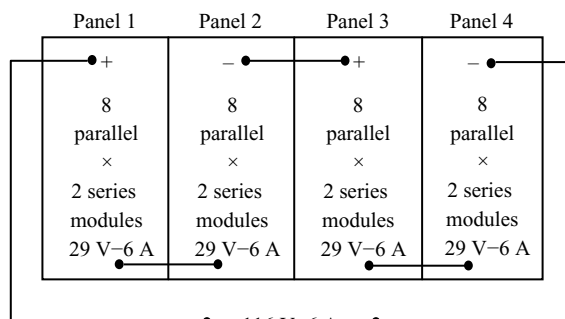


Fig. 3. Single unit circuit diagram.

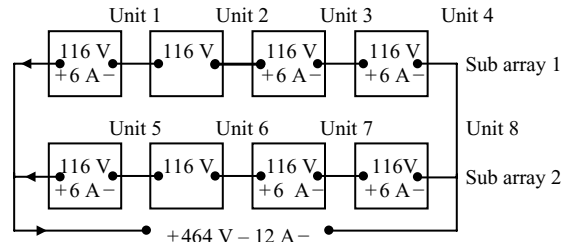


Fig. 4. Simple circuit diagram of the whole PV array.

4.3. Inverter

A modified inverter (danfoss type) 380.0/415.0 volt was chosen to provide 3 phase voltage, 50.0 Hz from 464.0 volt d.c regulated voltage.

The inverter has a voltage and frequency regulation of output voltage that supplies the water pump. If the insolation is intensified, the inverter will automatically increases the frequency and voltage to keep the system, as possible as it

Table 5
PV station evaluation

Month	Tf	G	EG	E	Va	Vs
January	1.46	2068	7918	7650	46	1
February	1.27	2839	8920	7650	52	7
March	1.04	3656	9853	8504	58	8
April	0.89	4518	10647	9358	62	7
May	0.79	5636	11396	11067	67	2
June	0.75	6300	11850	11067	69	4
July	0.79	6210	12050	11067	70	5
August	0.91	5601	12557	11067	73	8
September	1.14	4809	12940	11067	76	11
October	1.42	3485	11753	11067	69	4
November	1.6	2347	9777	9358	57	2
December	1.61	1877 ^a	7466	7650	44	-1

^aEG, monthly daily average of generated energy that supplies the water pump, in (W.h); Va, actual monthly daily average of the pumped drinking water volume, in m³; Vs, monthly daily average of surplus volume of the pumped drinking water, in m³.

could, continuing supplying water during periods of low insolation levels.

4.4. Storage system

The storage system consists of a ground storage tank of 130 m³ capacity sufficient to supply the complex by drinking water for two successive days during summer months and about three successive days during winter month.

5. PV pumping system evaluation

An evaluation of the PV pumping station operation was made for a period of one year, the data are as indicated in Table 5.

Table 5 shows that all months except December have a surplus amount of drinking water which proves the correctness of the design. Such surplus amounts can be used to face a certain future extensions in water consumption or to supply some other areas.

References

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