Optimal Sizing of Photovoltaic Irrigation Water Pumping System in Samara

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ABSTRACT

Water pumping from wells and rivers for irrigation is a well established procedure on many farms in Iraq and is practical on various levels around the world. Typical irrigation systems consume a great amount of conventional energy through the use of electric motors and generators powered by fuel.

The overall objective of this research was to determine the feasibility of using photovoltaic (PV) modules to power a water pump for a small-scale irrigation system in the North-West of Iraq (Samara). The study involved field observations, simulations of global solar radiation and PV electrical output.

Field observations involved an installation of 24-monocrystaline silicon PV modules as shown in figure (1). This system was installed to give maximum power equal to (1960 watt) with maximum open circuit voltage (V_{oc} = 175 volts) and maximum short circuit (I_{sc}= 14 Amp). This module was connected to the pump via a charge controller and AC inverter. The parameters monitored were voltage, current, back-of-panel temperature, pressure, and flow. These observed parameters were used to determine PV electrical output and volume of water pumped. Site latitude, elevation, and panel tilt were applied to the solar radiation and PV electrical output models. PV electrical output and volume of water pumped were monitored between January 2000 and December 2000. As expected, an increase in power causes an increase in the volume of water pumped.

Keyword: Solar Energy, Solar Water Pumping System, Design of Water Pumping System .

الحجم المثالي لمنظومة ري تعمل بالطاقة شمسية في سامراء

الخلاصة

ان ضـخ المـاء مـن الابـار او الانهر لغرض الزراعـة هـو إجراء معتمـد للعديد مـن المـزار ع فـي
العراق ويمارس على مختلف المستويات في جميع أنحاء العالم. نظم الري التقليدية تستهلك قدرا كبيرا
من الطاقة التقليدية من خلال استخدام المحركات الكهربائيه والمولدات التي تعمل بالوقود.

ان الهدف الرئيسي من هذا البحث هو لتحديد جدوى استخدام منظومـات الطاقه الشمسيه (PV)
لضخ المياه في منظومة الري في مدينـة سـامراء. وشـملت الدراسـة محاكـاة حاسـوبية للإشـعاع الشمسـي
PV والطاقة الكهربائية المتولدة.

تتكون المنظومة من تركيب ٢٤ وحدات monocrystalin PV. هذا النظام مثبت لإعطاء الطاقـة
القصوى تساوي (١٩٦٠ واط) مع أقصى جهد في الدائرة المفتوحه = ١٧٥ فولـت و اقصـى تيـار (I$_{SC}$
= ١٤ أمبير). هذه المنظومة تربط مع المضخة عبر مسيطر شحن وجهاز عاكس.

المعطيات التي تم رصدها هي الفولتيـة، التيـار، الضـغط و الحـرارة والجريـان والتـي سـاعدتنا فـي
تحديد الطاقه الكهربائيه المتولدة وحجم الماء المتدفق وارتفاع الماء وزاويه تثبيت الالواح الشمسية.
ان الطاقة الكهربائية المتولدة وكمية الماء الذي تم ضخه تمت حساباته ومراقبته للفترة من كـانون الثـاني
٢٠٠٠ ولغاية كانون الاول ٢٠٠٠ وقد لوحظ انه كلما زادت الطاقة الكهربائية المتولدة كلما زادت كمية
الماء المتدفقة كما كان متوقعا.

INTRODUCTION

In many developing countries, the inadequate supply of drinking and irrigation water is a severe problem. In rural areas with no access to grid power, national water authorities and private farmers have to rely on hand pumps and diesel-driven pumps, many of which are out of service due to technical defects or a lack of fuel.

As a rule, hand-operated pumps are the least-cost option for low consumption rates and low pumping heads. If hand pumps cannot satisfy the demand, diesel driven pumps are commonly used for drinking and irrigation water supply. These pumps stand in competition with photovoltaic water pumps (PVP), which present themselves as a reliable and environmentally- sound alternative means of water delivery.

PVP systems offer numerous advantages over water supply systems utilizing conventional power:

(1) PVP systems may be the only practical water supply solution in many regions where the logistics make it too expensive or even impossible to supply diesel generators with the required fuel.

(2) PVP systems are ideal for meeting water requirements for villages between 500 and 2000 inhabitants and small-scale irrigation purposes (up to 3 hectares).

(3) PVP systems run automatically require little maintenance and few repairs.

(4) In areas where PVPs have entered into competition with diesel-driven pumps, their comparatively high initial cost is offset by the achieved savings on fuel and reduced maintenance expenditures.

(5) The use of solar energy eliminates emissions and fuel spills. Taken together, these reasons can persuade water authorities as well as private investors to decide in favor of a PVP system against conventional pumping techniques [1].

HOW A PVP SYSTEM WORKS

The operating principle behind any photovoltaic pumping system is a quite simple see Figure (2). A solar generator provides electricity for driving a submersible motor pump, which in turn pumps water into an elevated water tank that supplies water at night-time periods and cloudy days. The force of gravity causes the water to flow from the tank to public water taps and watering points for livestock or to the irrigation system. One major advantage of solar pumps is that they do not require

batteries, which are expensive and need a lot of maintenance. The maintenance of a PVP system is restricted to regular cleaning of the solar modules. Depending on the water quality, the only moving part of the system, the submersible motor pump, has to be checked every 3 to 5 years [2].

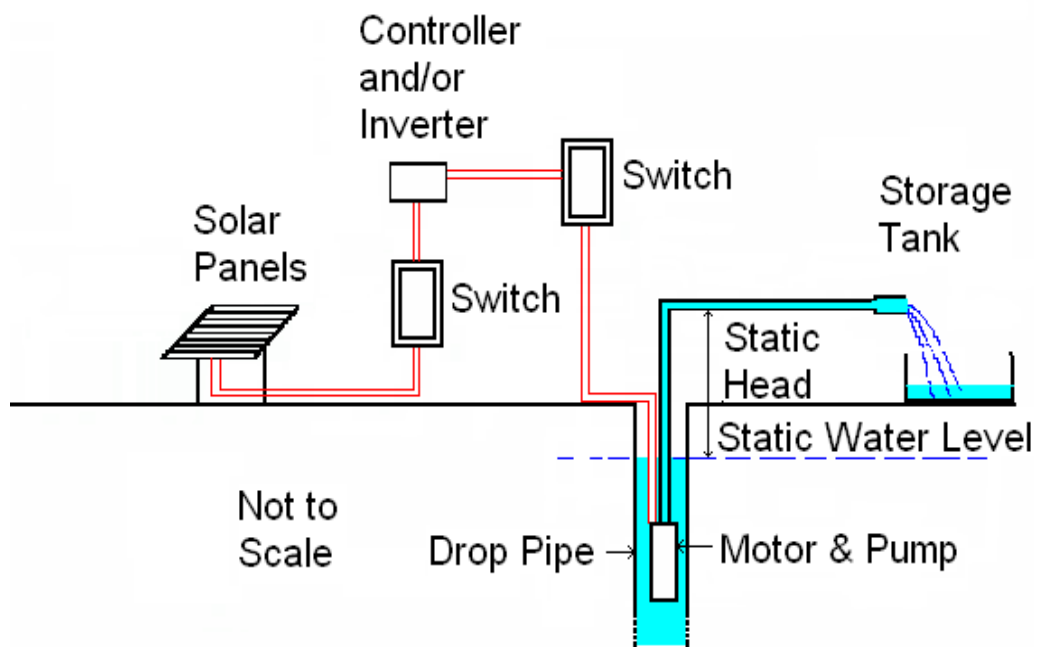**Figure (1) installation of 24-monocrystaline silicon PV modules**.

Figure (2) Schematic of Solar-PV Water Pumping System.

SIZING A PVP SYSTEM

The PVP system was sized on the basis of the findings from a local data survey. While an on-site survey of meteorological and climatic data would be worthwhile in any case, it is usually determined by a lack of time and money. Many systems are based on the known data on a nearby reference location for which relevant measured values are available. If it is possible to visit the intended location, the following field data should be gathered: (1) water quality (2) demand for water in the supply area (3) pumping head with allowance for friction losses and well dynamics (4) geographical peculiarities, e.g., Valley locus. It is also important to include sociological factors in the planning process. The future users should be involved in the data-gathering process at the intended PVP site in order to make early allowance for their customs and traditions in relation to water. Thus, the planning base for each different location should cover both technical and sociological aspects. The technical planner can choose from a number of design methods of various qualities. The most commonly employed approaches are outlined below [3].

ESTIMATION OF PV GENERATOR OUTPUT

To arrive at a first estimate of how much the planned PVP system will cost for a guest-selected site, it is a good idea to first estimate the requisite size of the PV generator. This, however, presumes knowledge of the essential sizing data, namely the daily water requirement within the area of supply (Vd), the pumping head to be overcome by the pump (H), and the mean daily total of global irradiation (Gd) for the design month. A simple arithmetic formula allowing for the individual system component efficiencies can be used to calculate the required solar generating power (PSG) [4].

$$PSG=11.6(H*Vd)/Gd \qquad \qquad ... (1)$$

Where:

PSG= Solar generating power
Vd= The daily water requirement within the area of supply.
Gd= The mean daily total of global irradiation.

According to this equation, it was taken a 3.5-kWp PV generator to deliver water at the rate of 30 m³/d at a head of 50 m for a daily total global irradiation of 5 kWh/(m²*d). This gives the planner an instrument for estimating the size of the PV generator and, hence, the cost of the planned system at the time of site selection During the day, the PV array supplies energy to the pump via the 3- phase inverter. The produced water was normally stored in a receiver tank and is then available when required; the possibility of storing the pumped water eliminates the need of batteries in the system. The required size of the PV array depends on the pumping head, required amount of water and the solar irradiation available at the site. The peak power P_{pv}, is calculated as:

$$P_{pv} = S_c A \eta_{pv} \qquad \qquad ... (2)$$

Where, Sc = Constant equals to 1000 W/m, η_{pv} = solar array PV efficiency

The average array efficiency was determined from the rated module characteristics for each specific solar panel technology. It was a function of the average module temperature, Tc (°C), as seen in Equation (3) given by Evans (1981) [5,6]:

$$\eta p = \eta R (1 - \beta p (Tc - Tr)) \qquad ....(3)$$

where
  Tr = reference temperature (°C)
  ηR = PV module efficiency at Tr (%)
  βp = temperature coefficient for module efficiency (%/ °C).
A is the total array panel area, which is determined as [7]:

$$A = \frac{1000 \times E \times SF}{T_f \times G \times \eta_R \times \eta_B \times \eta_{inv}} \qquad ... (4)$$

Where:
  E = Daily average demand of electric energy, in Wh.
  SF = Safety factor =1.25.
  G = Daily average insolation on a horizontal surface, in Wh/m2.
  ηB= Solar modules efficiency=0.7.
  ηR .= Regulator efficiency=0.95.
  ηinv = Inverter efficiency=0.9.
  Tf= Tilt factor

In referential condition (Standard Test Condition STC – intensity of solar irradiation 1000 W/m2, relative air mass AM1.5 and temperature of PV generator (25oC).

While the data for the isolating of Samara city are substituted for G, the solar radiation level was measured on the PV array panels.

To get the efficient PV system design, the tilt factor (Tf) must be taken into account. Tf was calculated from the relation [8]:

$$T_f = \frac{R_b H_{Tb}}{H_T} + \frac{(1 + \cos B)}{2} \frac{H_{Td}}{H_T} + \frac{\rho(1 + \cos B)}{2} \qquad …(5)$$

Where:
  Rb = direct beam elevation factor. HTb & HTd = monthly daily average total horizontal beam and diffuse radiations. HT = Total horizontal and diffuse beam radiation. B = inclination in degrees. ρ = ground reflectivity.

Selection of the type and power of the motor, the instantaneous water output m^3/h, and the water head (level of the water) must be known. Table (3) and Figure (2), [6] shows these values. The system performance was calculated by using the solar radiation and the required head in meter by using the relation in Figure (3)and connecting the point for the power output in watt for a given solar array with the irradiation value and the required head , the quantity of water in m^3 /day deliver by solar pumping system can be found from the curves. Connecting the points for the required quantity of water in m^3 /day with the required head and the irradiation value, the necessary power output in watt of the solar array can be found.

PRACTICAL SAMARA WORK

The solar array was positioned in such a way that the sunlight is utilized to its maximum. Taking the declination of (Samara) the solar array was fed toward the west of the north, and to attain the optimum DC output of the solar array, the array must have the correct tilt angle (α) in relation to the horizontal plane Figure (4a,b), the tilt angle (α) was selected in accordance with the latitude in which the solar pumping system had been installed.

Since Samara lies in (33) northern latitude, so the tilt angle (α) should be approximate (40°). Figure (7) Shows a principal schematic diagram for the 24-module system. Table (2), shows the evaluated data for the system operation for one year for Samara site..

This system installed to give maximum power equal to (1960 watt) with maximum open circuit voltage (Voc = 175 volts) and maximum short circuit (Isc= 14 Amp) .

The output module supply energy to the pump through 3-phase inverter was the "Grundfos solartronic" inverter as shown in Figure (6), type S.A 1500, 3-phase DC-AC inverter with a normal power of 1800 watts, Table (2) shows electrical data for the inverter.

The pump was a multistage centrifugal pump with the electrical data Voltage 3 x 65 v as shown in Figure (5), power 550 watt, current 8.8A, cos Φ = 0.87 and maximum Rating power = 1200 watt. The pump was supported by means of stainless steel straining wire. Figure (2) Shows the arrangement of the pump in the hole.

RESULTS AND CONCLUSIONS

For the practical results of the PV system, it was shown that the performance of the system station is designed to discharge water of a flow rate 1.3 m3/min for daily operation of 9 hours. This means   that a volume of drainage of about 702 m3 daily must be pumped. The evaluation of station operation was made for a period of 12-months. The experimental results show a good agreement with the expected performance of the station.

Table (1) Evaluated data for the systems operation during 1 –year (2000).

Month	T_f	G^a (1)	EG^b (2)	E
Jan.	1.57	4479	57068	49050
Feb.	1.38	5307	67618	49050
Mar.	1.1	5152	64768	49050
Apr.	0.9	4847	57969	49050
May.	0.8	4720	57318	49050
Jun.	0.71	4924	57719	49050
Jul.	0.73	5256	58932	49050
Aug.	0.85	5542	62890	49050
Sep.	1.04	5848	65569	49050
Oct.	1.34	5928	67272	49050
Nov.	1.54	4934	60351	49050
Dec.	1.69	4661	57803	49050

(1). G^a-monthly daily average insolation at 50° inclination, in Wh/m".
*(2). EG^b-monthly daily averages of generated energy that supply's the load Wh.*

Table (2) "Grundfos Solartronic" Inverter Electrical Data [9].

Input (DC)	Nominal	Maximum	Minimum
Load voltage	120V	140V	100V
No-load voltage	155V	175V	115V
Load current	12.5A	14.0A	-
Power	1500W	1860W	-
Battery operation	120V	140V	100V
Output (AC)	**Nominal**	**Maximum**	**Minimum**
Current	-	14.0A	-
Frequency	-	63Hz	7Hz
Efficiency	0.86	0.97	0.85
Battery operation	60Hz	-	-

Table (3) the relation between PV power, pumping head and daily water output.

Power of PV Generators	Pumping head	Daily water output*
	10 m	50 m^3
1 KWp	30 m	15 m^3
	50 m	10 m^3
	10 m	100 m^3
2 KWp	30 m	35 m^3
	50 m	20 m^3
	10 m	160 m^3
3 KWp	30 m	50 m^3
	50 m	30 m^3
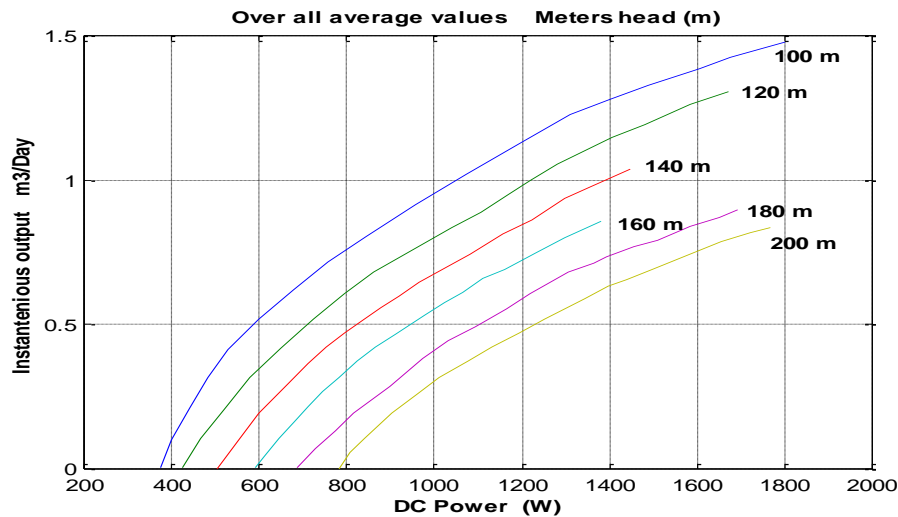
Figure (3) the power output in watt for a given solar array with the instantaneous output value and the required head.
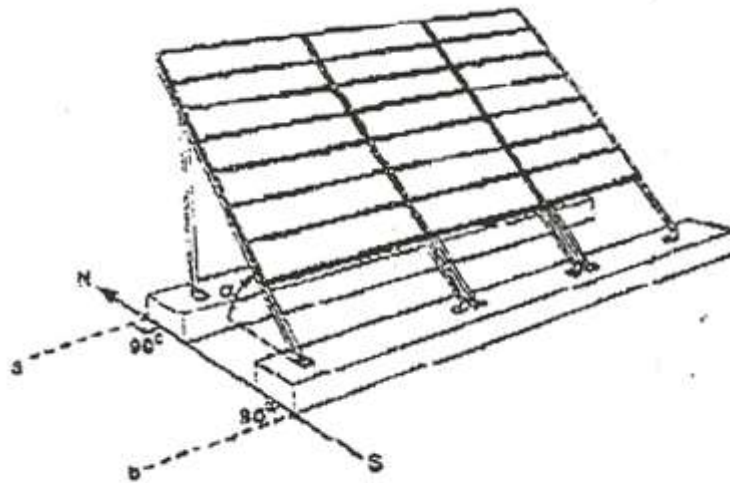
Figure (4a) Diagram shows the array tilt angle (α) in relation to the horizontal plane.

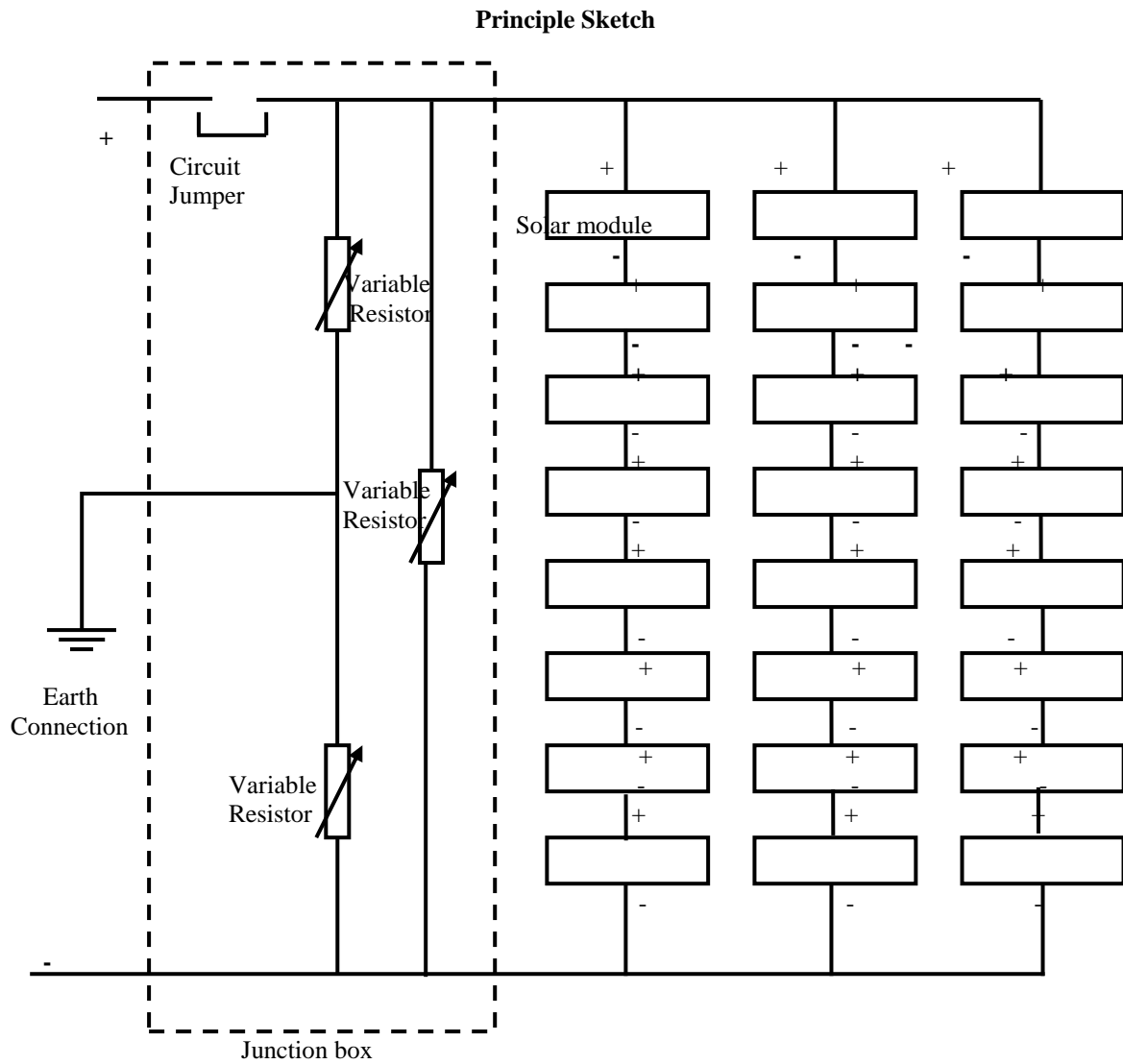**Figure (4b) positioning array tilt angle (α) in relation to the horizontal plane.**

Figure (5) solar water pump.

Figure (6) "Grundfos solartronic" inverter.

Principle Sketch

**Figure (7) shows the principal schematic diagram
For the 24-module system**.

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