Design and Development of a Photovoltaic Water Pumping

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ABSTRACT

The aim of the paper is to present the influence of the solar radiation variation on the performances of a stand-alone photovoltaic pumping system which consists of a photovoltaic generator, dc–ac inverter, an immersed group motor-pump and a control box. The system was installed at the faculty of Engineering and Technology, University of Gezira. The incorporation of photovoltaic systems in water pumping applications is thought to be one of the most popular and ideal methods of solar energy exploitation, especially under the common allegation of coincidence between solar insulation and water demand. From the obtained results, it could be seen that the decrease of the solar radiation intensity degrades performance (solar generator voltage, inverter voltage and the flow rate) of the photovoltaic pumping system. The total performance of the pump is also dependent on the specification of the equipment used.
Key words: solar radiation, photovoltaic pump, photovoltaic generator, solar insulation, dc-ac inverter.

BACKGROUND

One of the renewable energy is solar energy, which can be the main source or alternative energy source in the power generator. Excellence of using the renewable energy is that it is clean energy and friendly to the environment. Beneficially solar radiation is equally distributed in any place on the earth, its density isn’t large, irradiation fluctuate sharply with the fickle weather, and the solar energy cannot be stored. In fine details, the irradiance intensity is influenced by the factors: geographic (longitude, latitude) of the location. The location around the equator has good irradiation throughout the year, but the location around the pole particularly in winter season has little irradiation (Harsono, 2003). Because of this, the equipment of solar energy in the tropic area is more effective than in other places (subtropics and poles). The survey, the observation and measurement must be made to ensure the irradiance intensity at the location. Although in the tropic area, the topography of the location and the weather also affect the irradiation. For example, the locations at the mountains are often rainy or cloudy. As a result, the total irradiation in one day is low. Based on the converting energy, the solar energy is classified into: direct (thermic) (Toshie, et al., 2001) and indirect (photonic) (Koenig and Ebest, 2001). In the thermic system, the solar energy is used directly to heat the object. For example: solar drying, thermal pumping and desalination, etc. In the photonic system, the solar energy works as the photonic energy.

Photovoltaic Water Pumping (PVP)

A solar photovoltaic (PV) water pumping system consists of a PV array, with support structure, wiring and electrical controls; the electric motor; the pump; and the delivery system, including pipe work and storage. These components have to be designed to operate together to maximize the overall efficiency of the system (or, rather, to optimize the cost effectiveness of the system). An electrical controller is sometime incorporated to improve the electrical performance of the system .Energy storage in the form of batteries is rarely used, since storing energy by storing water to cover periods of low solar input or high demand is cheaper and needs a simple design. The main advantage of the photovoltaic water pumping system is that the unit is suitable in the pumping system for its low maintenance, non-polluting, needing no fuel, reliable and long life. The main disadvantage on the other hand, is that the unit suffers from some noticeable setbacks such as high initial cost and low output (Mubarak, 2008).

Types of photovoltaic pumps

The photovoltaic pump system may be a centrifugal pump which is utilized for both surface and submerged water. Floating pumps which are utilized for surface water only like rivers and minors or submersible pumps which are suitable for long head (deep water). There are several types of these like the submersible pump and external motor, submersible cylinder pump and submersible motor and pump. The more frequently used type is the submersible pump because it is very easy to operate and more efficient than the other types (McNelis et al., 1992)

Operating Principles of Photovoltaic Water pumping

The operating principle of the photovoltaic pumping system is quite simple. A solar generator provides electricity for driving a submersible motor pump, which in turn pumps water into an elevated water tank that bridges night-time periods and cloudy days. 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.

On a clear, sunny day, a medium-size PVP system with an installed power of 2 kWp will pump approximately 35 m^3 of water per day to a head of 30 meters. That amount of water is sufficient for communities with populations up to 1400 (Hahn, 2000). Today‘s generation of PVP systems is highly reliable (Hahn, 1993). For the most costly part, the PV generator, the manufactures give a 20 year guarantee on the power output. A crucial prerequisite for the reliability and economic efficiency is that the system be sized appropriately to the local situation.

Sizing A PVP System

The PVP system is 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 thwarted by a lack of time and money. Many systems are based on the known data of 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:

- water quality
- demand for water in the supply area
- pumping head with allowance for friction losses and well dynamics
- 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. Women in particular must be intensively involved in the planning, because they are the ones who are usually responsible for maintaining hygiene and fetching 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 quality. The most commonly employed approaches are outlined below.

Estimation of PV Generator Output

To arrive at a first estimate of how much the planned PVP system will cost for a just-selected site, it is a good idea to first estimate the required 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 mathematical formula allowing for the individual system component efficiencies can be used to calculate the required solar generating power P_{SG}. The equation reads:

$$P_{SG} = 11.6 * \frac{H * V_d}{G_d} \qquad (1)$$

According to this equation, it takes a 3.5-kWp PV generator to deliver water at the rate of 30 m^3/d at a head of 50 m for a daily total global irradiation of 5 kWh/(m^2*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 (Hahn, 2000).

Graphic Sizing / Nomograms

Several suppliers developed product specific system design diagrams that simplify the planning task by enabling quick and easy sizing of the equipment (Fig. 1).

Such diagrams cannot, of course, help arrive at a site-appropriate design, because they make no allowance for diurnal variation in terms of pumping heads, temperatures, wind velocities and irradiation rates. The design of systems with the aid of GRUNDFOS plots produced standard deviations in the order of 27 % (Vaaßen and Bewertung, 1996). Systems designed with the site-specific time-of-day dynamics in mind are therefore better.

PVP System Components used in the design

For the realizing of the PVP system with single pump, some supplements of the equipment are necessary, this includes Solar Generator, Control box, Inverter and Switch, the Motor, the Pump, the Well, and The cable (Fig. 2).

Solar Generator

The solar-generator consists of 28 photovoltaic modules, the modules are connected so that 7 modules are in series and 4 groups of it are connected in parallel. To optimize the power output of the solar generator in one year, the modules are put on the rig with an angle of 25^o. The direction of the rig is south, because the Wad-Medani location is at the north of the equator. The specifications of the photovoltaic module are as follows

Nominal power (P_n) : 51 Wp

Nominal voltage (V_n)	: 17.5 V
Nominal current (I_n)	: 2.5 A
Module efficiency	: 10%
Cell efficiency	: 11.5%
Number of cell	: 36
Material	: poly-crystal

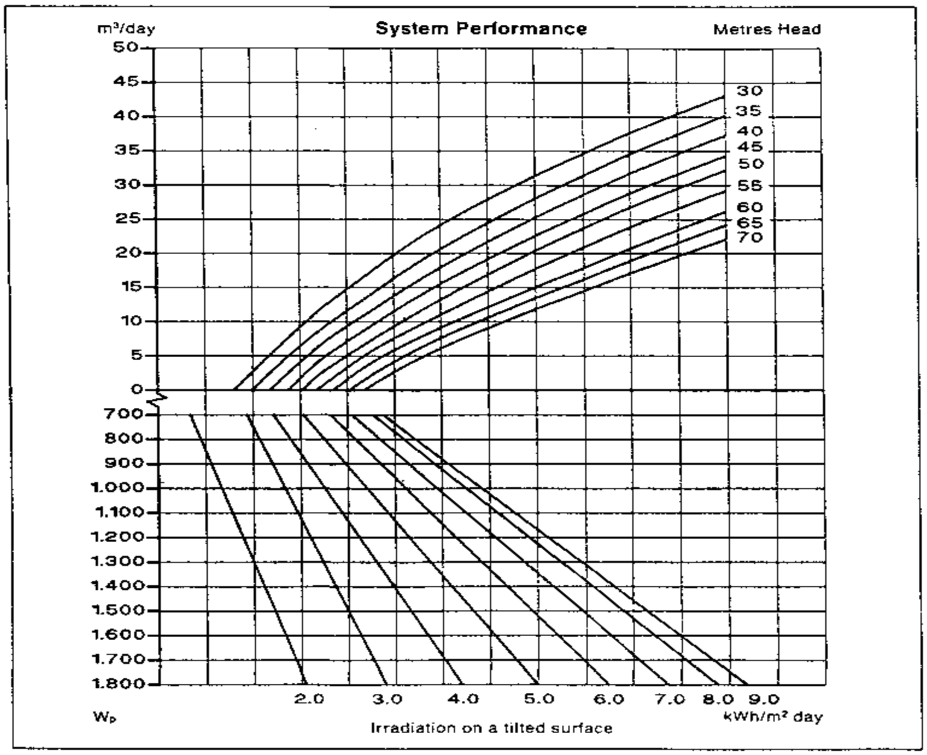

Fig. 1. System performance curves

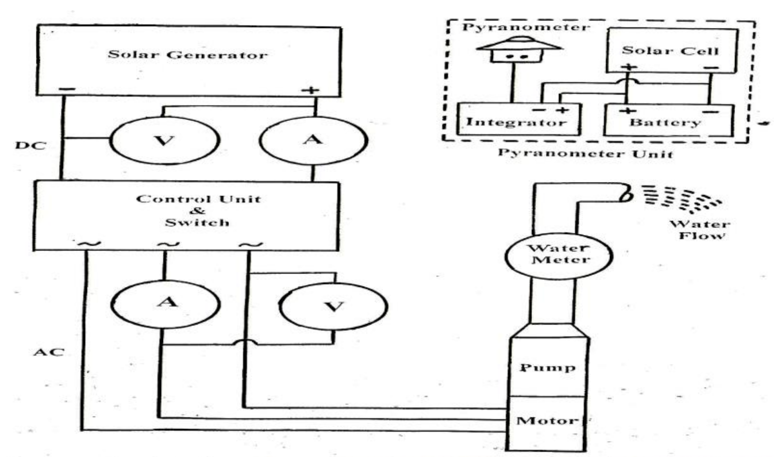

Fig. 2. PVP System Components

Control box

The cable which carries the electric energy from solar generator is connected to a control box so that all negative terminals as well as all positive terminals are connected. The control box is connected to the inverter or to the switch inverter.

Inverter and Switch

The electric energy from the solar generator is a direct current (dc). The load requires an alternating current (ac) power supply. To convert power from dc to the ac power, an inverter is utilized. The main component in the inverter unit is the switcher and the Pulse Width Modulation (PWM). Usually the switcher employs MOSFET or IGBT, which is driven and controlled by the PWM. The wave quality, frequency and voltage output of the inverter are influenced by the PWM.

The voltage output of the solar generator fluctuates and depends on the irradiation intensity. To get optimum power output of the solar generator, the frequency of the inverter must be controlled. According to the capacity power, the three-phase inverter are chosen and installed in the PVP system.

The specifications of the inverter are as follows

Product :Groundfos (Denemark)

Capacity	: 1500 VA, 3 phase
Voltage input (V_{in})	: 135 ~ 300 V dc
Output voltage (V_{out})	: 13 ~ 127 V ac
Maximum input current (I_{in})	: 16 A dc
Maximum output current (I_{out})	: 8.5 A ac
Frequency	: 5~50 Hz
Wave	: Sinusoidal

The Motor

In the submersible pump, the motor is coupled directly with the pump in one unit. To suit the phase of the inverter and the size of the motor, the 3-phase induction motor is chosen. Three-phase induction motor is installed together with the centrifugal pump. Because this PVP system is without the battery, the power output of the solar generator depends on the irradiant intensity. This causes the voltage and frequency output of the inverters to be unsteady, The maintenance of the induction motor is poor, because the rotor is squirrel cage type and without brush.

The specifications of the motor are as follows

Product	: Groundfos (Denemark)
The nominal data at 50 Hz	
voltage input	: 3 x 65V
Average power	: 1100 Watt
Current	: 8.5 Ampere
cos Ø□	: 0.84
rpm	: 2835
Weight	: 9 Kg

The Pump

The type of the pump utilized here is the centrifugal pump, which is connected with motor directly in one unit. The specifications of the pump are appropriate with the head of the location. The head is measured from the water source to the water outlet of the pump in the vertical direction. The specifications of the pump are as follows

Product	: Groundfos
Type	: SP 3A - 10
Head	: 53 meter
Maximum flow	: 2 liter/second (3 m^3/h)
Weight	: 5 kg

The Well

The dimension of well or specifications of the well are as follows

Head	: 37 m
Diameter	: 6 inch
Dynamic water level	: 18.6 m
Static water level	: 18 m
Pump depth	: 22.4 m

The cable

The specifications of the cable are

Type : 3 phase (resistant to water)
Diameter : 6 mm
Length : 39 m

RESULTS AND DISCUSSIONS

To evaluate and analyze the performance of the PVP system, some parameters of the system were measured. These include the sun irradiation in (W/m^2) measured using solar pyrometer, output voltage and current of the solar generator in (volt) and (ampere), measured using DC Voltmeter and Ammeter respectively, output of the inverter, measured using AC Voltmeter and Ammeter , flow rate measured using water flow meter in (m^3/h).

The photovoltaic water pump is efficient when pumping water from a barrel since the power required to pump water is less for the power of the motor of the water pump.

The use of the system for pumping water from a well 23 m depth by using a pipe of 2 inches diameters, as in this case, failed since the water flow rate depends mainly on the pipe diameter. By reducing the pipe diameter to 1.5 inch the system succeeded to operate efficiently. The water flow rate stated at 2.19 m^3/h at 8:00 AM and then increased to 4.92 m^3/h at noon time and then decreased with time. The measured data are summarized in table 1.

Table 1. Measured Data

Time (hour)	Solar Radiation (W/m^2)	Solar Generator (DC)		Inverter (AC)		Flow Rate (m^3/h)
		I (amp)	V(volt)	I (amp)	V(volt)	
6-------7	0	0	0	0	0	0
7-------8	150	0.8	56	0	0	0
8-------9	1570	4.5	102.1	6.80	59.20	2.191
9------10	2650	5.1	102.3	7.20	64.5	3.42
10----11	3615	5.7	103.6	7.33	69.20	4.12
11----12	4231	6.9	104	7.47	75.05	4.88
12 -----1	4485	6.9	105.2	7.55	79.00	4.92
1-------2	4134	6.8	105.0	7.52	78.2	4.75
2-------3	3585	5.9	104.0	7.51	68.70	4.12
3-------4	3135	5.2	103.8	7.44	65.80	3.87
4-------5	2454	4.8	103.2	7.32	61.30	3.23
5-------6	1491	4.2	102.4	6.61	58.60	1.82
6-------7	185	0.5	61	0	0	0

The measured data is displayed graphically, as shown in the figures below (from Fig. (3) To Fig. (8)). From Fig. (3) The pump started around 8:00 AM and solar radiation intensity around 150 W/m^2. The radiation intensity increased slowly as the time increases until it reaches its maximum value at 1:00 PM. Solar generator current and voltage increased with time as illustrated by Fig. (4) and Fig. (5) And reached its peak value of 6.9 A DC and 105.2 V DC respectively at noon time. This value of DC current and voltage were inverted to an AC equivalent current and voltage as given by Fig. (6) and Fig. (7) And the maximum output from the inverter is recorded as 7.55 A and 79 V for the AC current and voltage respectively and also this values happened at noon time.

The variation of water flow rate with time is shown in Fig. (8) And clearly it increases as the time increases and consequently as the solar radiation increases and reaches its maximum value of 4.92 (m^3/h) at noon time.

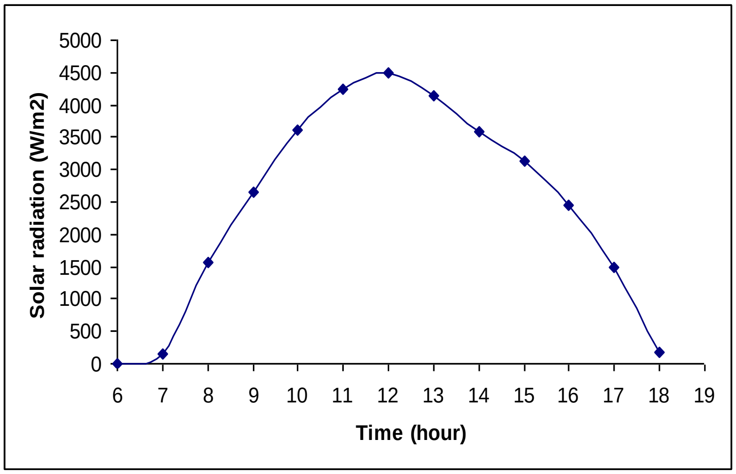

Fig. (3) Solar radiation versus Time

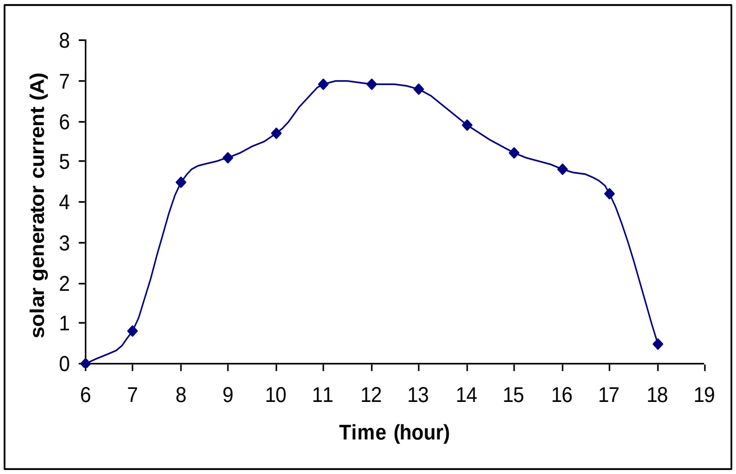

Fig. (4) Solar generator current versus Time

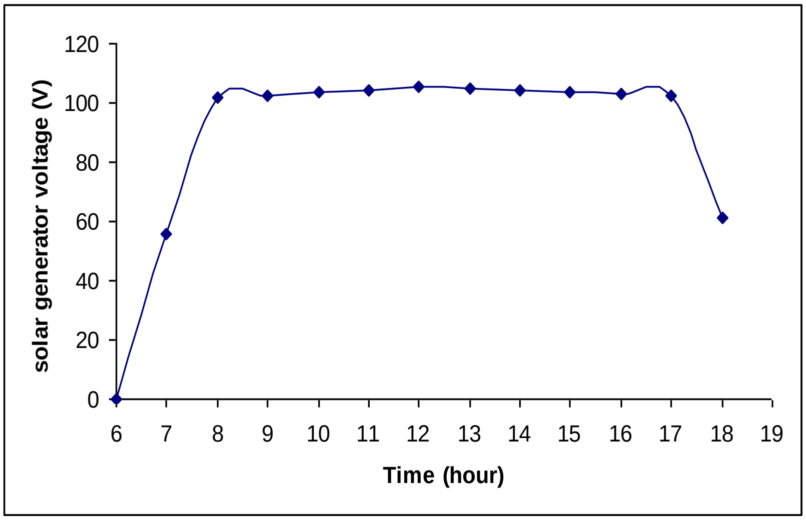

Fig. (5) Solar generator voltage versus Time

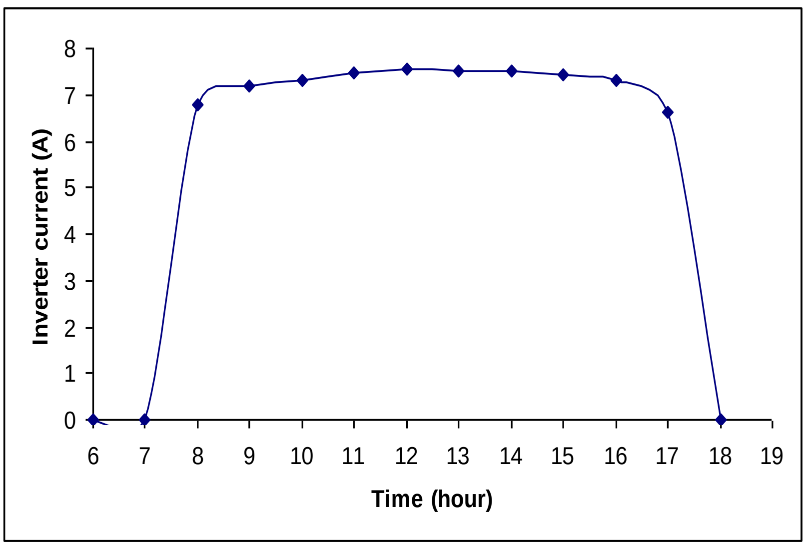

Fig. (6) Inverter current versus Time

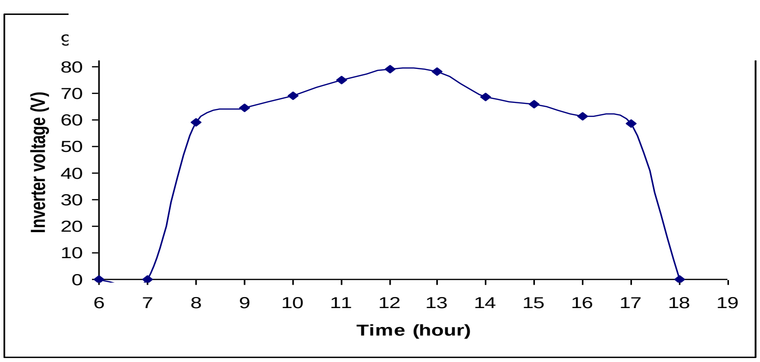

Fig. (7) Inverter voltage versus Time

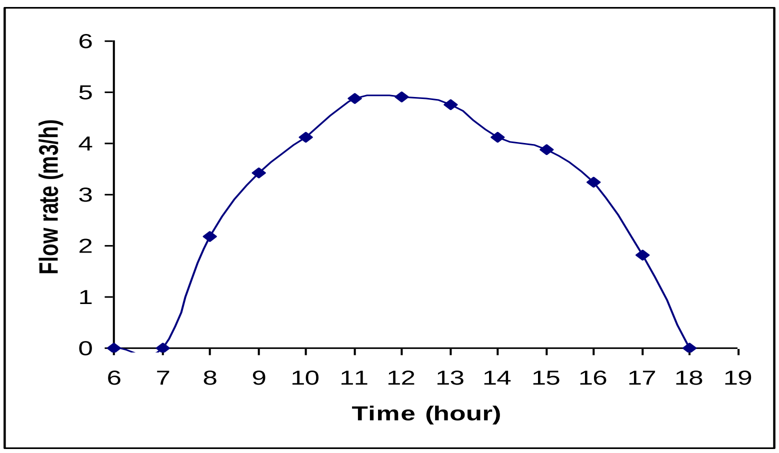

Fig. (8) Flow rate versus Time

CONCLUSIONS

Photovoltaic water pumping was installed at the Faculty of Engineering and Technology University of Gezira by using 28 solar modules connected in series and parallel combination in addition to the mentioned components. The Photovoltaic water pump can give sufficient energy to pump water directly from a river and it can be successfully used to replace the conventional energy in pumping drinking water from underground at different depths provided that the diameter of the water pipe is sufficiently small to make the pumped water power less than that of the pumping system. For 23 meter deep, as in this case, one needs 1.5 inch pipe diameter. The maximum solar radiation obtained is found to be 4485 W/m^2 and the equivalent water flow rate recorded is 4.92 (m^3/h).

RECOMMENDATIONS

- Promotion and adoption of solar energy technology due to availability of this energy.
- Introduction of solar energy equipment and devices and making them accessible.
- Provision of University of Gezira Solar Energy Station with necessary research facilities so as to be solar energy laboratory.
- Establishment of energy production from solar sources at the National Electricity Cooperation.

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تصميم و تطوير مضخة مياه شمسية

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الملخص

هدف الورقة أن تقدم تأثير اختلاف الإشعاع الشمسي علي أداء مضخة مياه شمسية تحتوي علي مولد فولتية ضوئية، محول تيار مباشر-متردد، مجموعة محرك و مضخة غاطسة، صندوق تحكم. النظام تم تركيبه بكلية الهندسة والتكنولوجيا بجامعة الجزيرة.
اندماج أنظمة الخلايا الضوئية في تطبيقات مضخات المياه يعتبر بأنه احدي الاستعمالات الأكثر شعبية و مثالية في استغلال الطاقة الشمسية خصوصا تحت الادعاء السائد بين مطلب الماء و التعرض للشمس. من النتائج المتحصل عليها سوف نستعرض بأن نقصان أشعة الشمس يخفض الأداء (مثل فولتية الخلايا الشمسية، فولتية المحول، و معدل تدفق المياه) لمضخة المياه الشمسية.
أن الأداء الكلي للمضخة يعتمد يشكل رئيسي علي مواصفات الأجهزة المستخدمة.