Energy Conversion and Management 77 (2014) 334–339

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Effect of pumping head on solar water pumping system

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ARTICLE INFO

Article history:
Received 19 August 2013
Accepted 26 September 2013

Keywords:
Photovoltaic water pumping system
Pumping head
Deep well
Outdoor conditions

ABSTRACT

The photovoltaic water pumping systems (PVWPS) is considered as one of the most promising areas in photovoltaic applications. The aim of this work is to determine the effect of pumping head on PVWPS using the optimum PV array configuration, adequate to supply a DC Helical pump with an optimum energy amount, under the outdoor conditions of Madinah site. Four different pumping head have been tested (50 m, 60 m, 70 m and 80 m). The tests have been carried for a different heads, under sunny daylight hours, in a real well at a farm in Madinah site. The best system efficiency has been obtained for the head of 80 m which is recommended for SQF submersible pump for a deep head. Also, the flow rate Q depends basically on two factors: the pumping head H and the global solar irradiation Hg. The model developed should be able to predict the flow rate Q for any head chosen with a best accuracy.

1. Introduction

Photovoltaic (PV) water pumping system is one of the most important applications in PV systems. PV water pumping system was interested essentially either in water pump modeling and control [1,2]. The relation between flow rate and insolation was determined for a low head centrifugal pump [3]. The performance of PV water pumping systems (PVWPS) has been studied under varying climatic conditions using various pumps operating with AC or DC [4–6]. Solar pumps are particularity useful for intermediate applications like small villages and moderate agricultural needs [7–9]. There are several theoretical and experimental studies about PV water pumping systems, which are installed in remote regions to supply water for drinking and irrigation [10–13].

Over the last few years, many studies were focused on PVWPS sizing, based on the potential of solar energy and water demand [14,15]. However, many sizing studies neglect the importance of the PV array configuration which can provide a maximum rate of energy. Recently, a performance study of PV powered DC pump has been done on an artificial well [16]. The maximum simulated head was 35 m and the corresponding maximum daily average volume of water was 3 m^3.

Proper sizing of system components is important for maximum utilization of PVWPS [17]. An increase in total system efficiency will reduce the PV array size and thus the total system cost [18]. A simple model for modeling small-scale PV water pumping has been developed to predict the flow rate in Fiji [19]. A simulation model for AC PV water pumping systems has been developed and validated in Jordan [20]. It is also necessary to match the load characteristic with the PV array characteristic [21–23]. The performance of the directly coupled PV water pumping system has been monitored at different conditions of varying solar irradiance values and two static head hydraulic system configurations [24]. The impact of dust accumulation, humidity level and the air velocity was elaborated separately and finally the impact of each on the other was clarified [25]. Others research papers have been investigated to study the performance of PV systems affected by the ambient temperature [26]. It was reported that the total system efficiency was improved by 1.35% at a head of 16 m. Also, it was reported that the effectiveness of solar water pumping systems depends on the ability between the generated energy and the volume of water pumped. A Recent review of work on renewable energy source water pumping systems reported that many parameters such as solar radiation, ambient temperature and wind velocity affect the performance of solar water pumping systems [27]. Recently, an experimental PVWPS has been installed in Bahra valley (25 Km of Madinah city) characterized by a great potential of solar radiation, a hot ambient temperature, a very low relative humidity and wind velocity [28]. The best PV configuration has been obtained for a real deep well of 120 m using a helical pump SQF2.5-2 [29].

The aim of this present work is to determine the effect of pumping head on PVWPS using the optimum PV array configuration, adequate to supply a DC Helical pump with an optimum energy amount, under the outdoor conditions of Madinah site.

Four different pumping head have been tested (50 m, 60 m, 70 m and 80 m). The tests have been carried for the above heads, under sunny daylight hours. The best system efficiency has been obtained for the head of 80 m which is recommended for SQF submersible pump for a deep head.

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0196-8904/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enconman.2013.09.043

Nomenclature

A, $B1$, and $B2$	regression coefficients of model 1	Im	maximum current of the pump (A)
A', $B'1$, and $B'2$	regression coefficients of model 2	Isc	short circuit current of the PV Array (A)
Apv	total PV array area (m^2)	MPPT	maximum power point tracking
Ch	hydraulic constant (Ch = 9800 Kg/(m^2 s^2))	P	power required by the Pump (W)
E	solar intensity (W/m^2)	Pm	max peak power of the PV Array (W)
E_i	incident energy on PV Array (kW h/day)	PVWPS	photovoltaic water pumping system
E_h	hydraulic energy of the pump (Wh/day)	Q	flow rate of water (m^3/h)
H	head (m)	R^2	correlation coefficient in Tables 1 and 2
Hg	global solar irradiation (Wh/m^2/day)	ξ_{sys}	total system efficiency (%)
I	PV current (A)		
V	PV voltage (V)		

2. System configuration and data collection

The Madinah site (Latitude = 24.46°N and Longitude = 39.62°E) is classified as semi-arid area and has a great potential of solar radiation [30], with a daily annual average yield ranges from 4.5 KWh/m^2/day until 8.5 KWh/m^2/day, received on tilt PV surface. We have setting up a PV water pumping system in a reel well of 120 m depth. We have tested four different heads (80 m, 70 m, 60 m and 50 m) in order to study the influence of pumping head on PVWPS performance. The PVWPS is composed by: photovoltaic generator of 1.8 KW, submersible helical pump of type SQF.5-2, flow meter of type Electromagnetic and Agilent data logger system connected to computer for data acquisition and treatment (Fig. 1). We have used a calibrated mono crystalline silicon solar cell to measure solar radiation. The measurement of PV current is realized by measuring the voltage across the shunt resistor. The acquisition of PV voltage is given by measuring the output voltage of PV generator as shown in the photograph of the experimental setup (Figs. 2a and 2b). The measure of the temperature is dedicated to a sensor based on a thermocouple of type K. All data of the instantaneous output pump power P (W), flow rate Q (m^3/h), PV current I (A), PV voltage (V) and global solar radiation intensity (W/m^2) were stored in data logger Agilent 34970A [29]. The obtained data have been treated to study the effect of pumping head on PV water pumping system performance.

2.1. Characteristics of the PV array configuration

The proposed PV array design consists of 24 solar panels, based on mono-crystalline silicon (75 W/20 V) PV modules, the tilt angle equal to the latitude of the site (24.46°) and facing to south direction [31]. The best PV array configuration chosen [29] is: (8S × 3P) which means 24 modules connected in three parallel rows with 8 serial modules in each. The characteristic curve of the PV array is given by Fig. 3.

3. Methodology

The study included different parameters affecting the pump performances as, the hydraulic energy provided by the pump

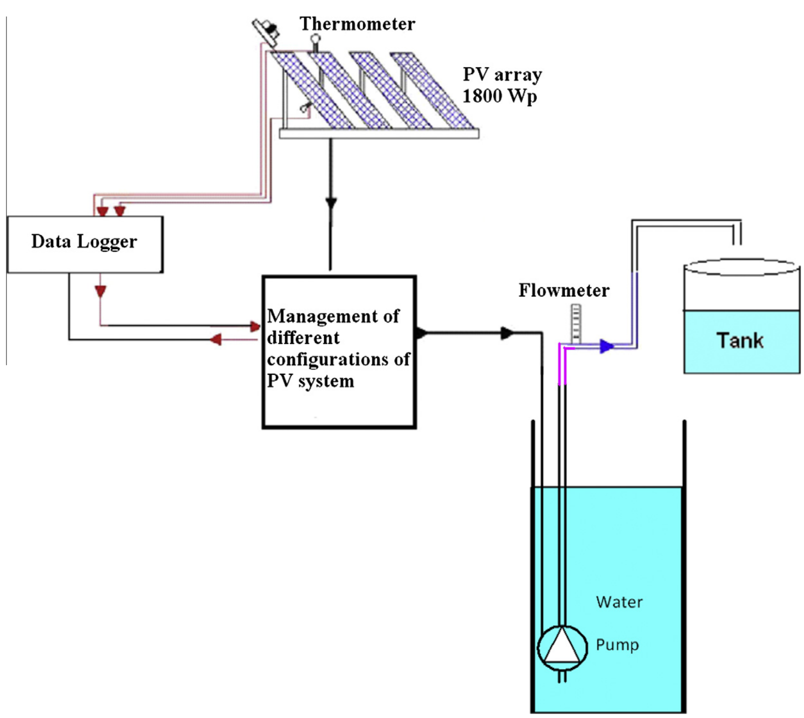

Fig. 1. Control and data acquisition for PV water pumping system [29].