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Improvement and validation of PV motor-pump model for PV pumping system performance analysis

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ABSTRACT

To allow social and economic development of arid and isolated areas of Algeria, which represent 87% of the total area, one must provide energy and water. The photovoltaic (PV) pumping systems are expected to offer the appropriate solution for water supply in order to meet drinking and irrigation needs in these remote and scattered regions. In this study, we propose the improvement and validation of two mathematical motor-pump models for PV applications. These mathematical models describe the behavior of the motor pump's sub-system, using the characteristics parameters, current, voltage and pumping rate simulated for different pumping heads in the real conditions of operations. Because the motor pump manufacturer cannot provide the user or the farmer all the data for any application, the difficulties and the generation of failures will be on the field. The built pumping test facility of the Centre for the Development of Renewable Energies (CDER, Algiers, Algeria) avoids all these difficulties, by characterizing the various sub systems motor pumps for the area selected. The models were based principally, on the analysis of the experimentation results for two centrifugal pumps and two positive displacement pumps, coupled to DC motors. The current, the voltage, the flow rate and the head were the monitored dates. Current-voltage and flow-voltage were the modelled characteristics of the modelled motor-pumps. The improved models yielded satisfactory results'.

1. Introduction

Algeria is located in the northwest of Africa bordering the Mediterranean. It has an area of almost 2.4 million km^2, making it the largest country in the continent. The Sahara covers more than 2 million km^2, representing 87% of the total land area (L'irrigation en Afrique, 2005), with an annual average of daily solar irradiation which ranges from 5 to 7 $kW\,h/m^2$/day on tilted surfaces at optimum angles (Maafi, 2000). The 40 million hectares (ha) of arable land, cropland only 8.27 million ha, are mainly concentrated in the northern region. Nearly 0.5 million ha of land in the steppe zone are in the process of total desertification and more than 7 million hectares are threatened (L'irrigation en Afrique, 2005).

The substantial solar potential exists in the most rural and remote Algerian areas, more than 3000 h of sunshine per year with a high level of radiation (Maafi, 2000), where access to the grid supply is a very expensive operation, because of the scattered small villages in a very large area, and where the power demand is relatively small. For this type of applications, PV systems are often the most economical and the more reliable option (Ghoneim, 2006; Posovski, 1996).

Moreover, since these areas suffer from the unavailability of water, the PV pumping systems (PVPS) are an attractive alternative for this shortage of water supply, to meet drinking, livestock and irrigation needs. The Algerian High Commission for the Development of Steppe (HCDS) plans to put in each area of 1500 ha a point of water to release the producer of his drudgery. Currently there is one water point for an area of about 20,000 ha (Au Cœur des zones steppiques, 2014).

Solar powered water pumps present several advantages over their fuel and petrol. The life cycle costs are significantly lower, and the system duration is longer. There are also significant environment advantages. Solar pumps are silent and not polluting (Jafar, 2000; Al-Smairan, 2012).

The widespread use of (PV) pumping application is prevented by the lack of information, experience and initial installation costs (Gül Bayrakcı and Koçar, 2012). Among all the water-pumping options, an important distinctive feature of the photovoltaic pumping system (PVPS), is the possibility of system modularity, that closely match the hydraulic energy demand, this is not usually possible with other options (Purohit, 2007). The Algerian

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Nomenclature

I_{ph}	photocurrent of the PV array (A)
I_s	saturation current of PV array (A)
R_s	series resistance of PV array (Ω)
m	diode quality factor
R_{sh}	shunt resistance of PV array (Ω)
k	Boltzmann's constant ($J\,K^{-1}$)
T	temperature of the solar cell (K)
e	charge of the electron
I_m	current at Maximum power point of a PV array (A)
I_{sc}	short circuit current of the PV array (A)
V_m	voltage at maximum power point of a PV array (V)
h	pumping head
Pm	maximum power(W)
H_E	static level (m)
H_D	dynamic level (m)
Q_P	flow rate test (m^3/h)
Q_A	apparent flow rate (m^3/h)
f	friction coefficient of the walls of the piping
L	pipe length (m)
v	fluid velocity average (m/s)
hs	static head
hd	dynamic head
a_i, b_i, c_i, d_i and e_i	coefficients
V_{oc}	open circuit voltage of PV array (V)
R_{s0}	reciprocal of slope at open circuit point of PV array (Ω)
R_{sh0}	reciprocal of slope at short circuit point
m^2	square meter
D	piping diameter (m)
g	gravity acceleration (m/s^2)
K_{ac}	a coefficient depending of the type of accessory
R^2	correlation coefficients
RMSE	Root Mean Square
MAE	Mean Absolute Error

Acronyms

CDER	Centre for the Development of Renewable Energies HCDS High Commission for the Development of the Steppe
Ha	hectare
CP	centrifugal pump
DP	positive displacement pump
DC	direct current
PV	photovoltaic
PVPS	photovoltaic pumping system
I-V	current versus voltage
Q-V	flow rate versus voltage

experience is strengthened by entry into service of 200 pumps operating with solar photovoltaic cells for water drinking and irrigation. These pumps have been installed in the most remote areas of the country, with the assistance of the CDER (Près de 2000 Kits solaires, 2014 http://portail.cder.dz/spip.php? article4143).

One promising area of research and the most popular application of the PV array utilization is the power source for pumping water using DC motors as drive (Dunlop, 1988). Due to the sunshine duration in the Algerian remote areas, the use of PV in water pumping does not require any storage batteries, contrary to other applications of photovoltaic. This means important savings in terms of costs and efficiency since the system becomes more reliable and requires less maintenance (Dunlop, 1988; Labouret and Villoz, 2006; Silveira et al., 2004). Such system implies the use of an elevated tank for storage, which reduces the complexity of the system, and offers a hygienic solution for water provision to the rural population.

The performance of a PV water pumping system can be realistic only if we test the system at the installation site, where the real conditions of work are known and where the total head (static and dynamic) and the piping are taken into account. The present pumping test facility in the CDER avoids these difficulties (Hadj Arab et al., 2006). Several authors investigated the PV pumping system modelling, performance and analytical studies. They proposed different methods for designing and optimizing the PVPS to improve the system efficiency and reduce the investment using direct coupling of the system without batteries (Dunlop, 1988; Silveira, 2004; Jaehnig, 1998; Kou et al., 1998; Koner, 1995). Many studies have found that the performance of PV-powered motor pump was optimized when using a DC motor as drive (e.g., Ghoneim (2006), Akbaba et al. (1998) and Badescu (2003). For the rural applications, the economic studies discussed in Posovski (1996), Purohit (2007), Mahmoud and Nather (2003) and Meah et al. (2008) demonstrated that the PVPS is more reliable and less expensive than the conventional fuel driven pumps.

The sub system motor-pump represents the heart of all PVPS. Most of the available analysis methods and models are based on a specific pump and motor for a specific site that cannot be used in different locations. In the present work, the operational behavior of two mathematical motor-pump models for PVPS applications were investigated based on measured data of four different motor-pumps with DC motors.

2. Photovoltaic pumping system modelling

The system adopted in our study is a system that connects the PV array directly to the subsystem motor-pump without energy storage, i.e., without batteries. It consists of a PV array, a motor pump, a water well and a tank. The characteristics of the system are: the I-V characteristics for the PV array and DC motor, and the Q-V characteristics for the motor-pump. The PV water pumping system depends upon the capacity of the PV system, the average solar radiation availability, the total head and the piping. The existence of a nonlinear dependence on the radiation level makes the analysis of the PV pumping system and the prediction of its performance difficult.

2.1. Photovoltaic generator characteristics and model

The solar array consists of 30 modules A-75 (Fig. 1), with a total power of 2.4 KWp. That are composed of series parallel branches. Every module contains 36 cells of monocrystalline Silicon. The characteristics of the A-75 module are as follows:

The Short circuit current: Isc = 4,8A; the Open circuit voltage: Voc = 21V; the Current at the maximum power point: Im = 4,4A; the Voltage at the maximum power point: Vm = 17V; and the Maximum power: Pm = 75 W.

A mathematical model, can describe the performance of the solar array and predict how the solar module output, would vary with ambient temperature and radiation conditions. A PV module is a nonlinear power source. When the solar radiation and the ambient temperature change, the operating point of the PV module coupled to the motor-pump will also change. The equivalent circuit shown in Fig. 2 can represent the solar cell.