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Performances' investigation of different photovoltaic water pumping system configurations for proper matching the optimal location, in desert area

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ABSTRACT

The standard sizing methodology of photovoltaic water pumping system is limited only on how to determine at least the number and type of solar panels required for capturing the needed solar energy, by considering the daily water flow and the total dynamic head. However, the feedbacks following different on-site operating tests proved that the lack of information on the geospatial of the area led to unexpected dysfunctions and failure in the system optimality. Accordingly, any deficiency in the comprehensive feasibility study, regarding the specifics of the soil, the climate, groundwater behavior, water demand/supply balance, technique of irrigation and kind of activity, can be the main hindrance to obtain a reliable system. Through this attempt, the field performance suitability of four different photovoltaic water pumping system configurations, namely; (DC/PVPS1), (DC/PVPS2), (DC/PVPS3) and (DC/PVPS4) have been investigated and discussed, according to the Ghardaia land specifics. Based on the characterization data, obtained following the test carried out on the mentioned configurations, at our PV water pumping test facility, the system performances have been assessed, at different pumping head levels ranging from 10 m until 30 m. In the meanwhile, the hydraulic characteristics have been calculated and the corresponding required peak powers have been estimated, for different dust and thermal losses. Thus, upon the geospatial characteristic distribution of the Ghardaia territory, each system configuration has been optimally matched to the suitable location. The adopted methodology can be an efficient tool to select technically and economically the appropriate system to the suitable area.

1. Introduction

Despite the abundance of huge groundwater sources available at low depths in the Algerian desert areas, a source of energy to pump water is also a big problem. Since, the most of these regions are located far from grid lines; the diesel water pumps are frequently the only tool to supply water. Nevertheless, the citizens still suffer from the high cost to import fuel, due the absence of the paved roads and the far of the fuel supply stations. Additionally, these pumps need frequent maintenance and they make air pollution. These constraints cause the instability of citizens and the rural depopulation phenomena, resulting degradation of agricultural areas and livestock reduction. As consequence, other challenges can be appeared, such as overpopulated cities, unemployment and housing crisis. Recently, crucial efforts have been made by the Algerian government to establish the renewable energy, whereas the agriculture sector is particularly encouraged to be focused on PV-powered Water Pumping System (PVWPS) [1]. Indeed, the country has significant solar potential source, with yearly average of about 1700 kWh/m^2/year, in the northern part and about 2263 kWh/m^2/year, in the southern part (Sahara) [2,3]. In other hand, more than 95% of Algeria's shale lies in the desert, featuring extremely low water surface depths [4]. This aquifer presents the main water reservoir which is estimated at about 12000 MCM/year (Million Cubic Meter per year), whereas, only 1900 MCM/year is currently exploited [5]. Accordingly, the PVWPS seems to be the appropriate solution to provide water for irrigation, livestock watering and to preserve the pastoral lands. Nevertheless, the PVWPSs have to be accurately designed and optimally erected. The dimensioning studies of the PVWPS were firstly focused on how to get an optimal design, upon sizing and experimental data of the system performances, whereas many reports have been carried out [6–10]. In fact, directly-coupled PVWPS was investigated optimally through different proper models and approaches, but the specific characteristics of the area were ignored. Accordingly, Z. Abidin Firatoglu et al. [11] used a multi-step optimization procedure to improve the performances of directly-coupled PVWPS by including only long-term meteorological data of Sanliurfa, Turkey. They found that the

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Nomenclature

I_n	nominal current of the PV Array(A)
V_n	nominal voltage of the PV Array (V)
P_n	nominal power of the PV Array (W)
FF	fill Factor (%)
E_m	estimated rating daily insolation (W/m^2)
E_i	hourly incident solar irradiation (W/m^2)
t_{sr}	sunrise time
t_{ss}	sunset time
n	number of the day through the year
L	latitude of the site
β	tilt angle of the PV surface
δ	solar declination angle
H_{SRC}	sunrise hour angle when the sun first strikes the PV surface at $\theta = 90°$
H_{SR}	is the sunrise hour-angle (in radian)
R	ratio of the monthly daily average beam radiation on the tilted surface to that on a horizontal surface.
E_i	incident Solar intensity (W/m^2)
E	daily solar radiation (Wh/m^2/day)
A_{pv}	total PV Array Area (m^2)
P_{pv}	output power of PV array (W)
P_i	incident power received on PV array (W)
I_{pv}	max.Current provided by the PV array (A)
V_{pv}	max.Voltage provided by the PV array (V)
E_{pv}	PV array output energy (Wh)
P_h	hydro·power provided by the pump (W)
P_e	electrical power consumed by the pump (W)
H	total dynamic Head (m)
Q	flow rate of water (m^3/h)
V_d	daily cumulative water (m^3/day)
C_h	hydraulic constant = 2.725
E_h	hydro. energy provided by the pump (Wh)
E_p	electric energy consumed by the pump (Wh)
ξ_p	efficiency of the Pump (%)
ξ_{pv}	efficiency of the PV array (%)
ξ_{pvs}	overal PVWPS system efficiency (%)
Dh	daylight-hours (hour)
Losses	thermal and dust Losses (%)
K_h	coefficient
Peak	PV field peak power (W)

computation time for PV panel optimization has been reduced. Munzer S.Y. Ebaid et al. [12] developed a unified approach for designing a PVWPS station for water conveyance from Disi-Mudawara to Amman, Jordan with pumping average flow of about 100 million m3/year. The used data were the number and type of solar panels, number and capacity of batteries, inverter rating, cable dimensions, charge controller, and so on. However, the spatial characteristics of the desert were not included, except dust accumulation which was considered to be cleaned periodically. Meanwhile, Zvonimir G. et al. [13] developed an optimization model for sizing PVWPS for irrigation, by considering relevant spatial parameters as, local climate, type of boreholes, soil specifity, kind of crops and method of irrigation. It was reported that the obtimized PV array output power was relatively smaller than that of the usual sizing method. Accordingly, Rahul Rawat et al. [14] gathered a number of modeling equations and methodologies for designing PVWPS, based on techno-economic variables and environmental parameters. The geospatial factor was also ignored by many works discussing the Loss-of-Load probability of PVWPS as, Hadj Arab et al. [15], Hamidat et al. [16] and Bakelli et al. [17]. These methods being insufficiency due to unexpected circumstances. Hence, various attempts investigated the water demand/supply dynamic balance by taking special consideration to the water demand and to dynamic variation of groundwater table, respectively [18,19]. These methods were extended to the prediction of hourly flow rate and to maximizing the discharge of the daily water volume of a directly-coupled PVWPS [20,21]. A general classification including historical background and various efforts undertaken by researchers in PVWPS, during (1975–2014) has been discussed in a comprehensive review [22]. Due to the great influence of weather sudden change on the system dynamic, different real time control models have been integrated into PVWPS [23–25]. The PVWPS designing methods, control strategies and field performances have been gathered and discussed in special review [26]. Other works were only focused on the optimality of the PV panel conversion [27,28], whereas, the Artificial Intelligence algorithms provide the best method to overcome the complex problems, as partial shading and PV cell temperature effects [29,30]. In this view, various techniques have been concluded in different specialized literature reviews; in PV panel cooling [31], in PV power fluctuations [32] and in MPPT methods [33]. In fact, the spatial characteristic has been appeared in the techno-economic feasibility study to obtain an optimal PVWPS for irrigation of grassland and farmland conservation in China, adopted by P.E. Campana et al. [34,35]. In the meanwhile, He Xu et al. [36] investigated the feasibility analysis of solar irrigation system, in Mongolia. The techno-economic feasibility of the irrigation system has been developed for pumped storage and greenhouses [37,38]. This idea has been extended to multi-objective analytical models including reliability, Loss of load probability, life cycle cost, crop water requirements and optimal tilt angles [39,40]. Recently, P.E. Campana et al. [41] investigated the geospatial distribution of the suitable grassland locations for erecting PVWPS. Accordingly, two spatial explicit approaches were used: The spatial distribution of the available grasslands and the spatial distribution of PVWPS capacity. They concluded that the developed methodology can be applied in many regions in the world. In the meanwhile, the current work investigates the performances of four different PV water pumping system configurations, in the aim to erect the optimal system on the suitable well, through Ghardaia desert regions. Accordingly, for a best system dynamic adaptation and to avoid unexpected ambiguities and specific influences, the local geospatial characteristic distributions have been investigated and put into considerations. This methodology has been adopted, following the recurrent problems occurred, when alike systems are operated on real wells of the region. Therefore, it has been concluded that the acquired data of previous works on sizing and experimentation didn't provide enough information about the real characteristics of the candidate area of installation, since the tests were undertaken on simulated artificial well and without losses assumption. Hence, by combining the performance results, obtained following the characterization tests carried out on the four PVWPS configurations, at our PV water pumping test facility and the geospatial characteristic data of the local region, the suitable system can be selected accurately to be installed on the optimal area. The adopted methodology can be a predictive road map to choice the appropriate area for such PVWPS, therefore to prevent any dysfunctions, during the onsite operation.

2. Methodology

It is well-known that the characterization tests on such PVWPS are carried out on outdoor, at the PV water pumping laboratory, following the sizing study of the system. The purpose is to approve or disapprove the theoretical dimensioning and then to bring the suitable rectifications. The same system size in dimensions and technology type should confirm the recorded values, when it is operated on real well. However, various natural characteristics and specific parameters can prevent the system functioning at its optimal performances. Thus, the methodology adopted in this work is described as follows: