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Performance of a directly-coupled PV water pumping system

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ABSTRACT

This paper describes the experimental study carried out to investigate the performance of a simple, directly coupled dc photovoltaic (PV) powered water pumping system. The system comprises of a 1.5 kWp PV array, dc motor and a centrifugal pump. The experiment was conducted over a period of 4 months and the system performance was monitored under different climatic conditions and varying solar irradiance with two static head configurations. Although the motor–pump efficiency did not exceed 30%, which is typical for directly-coupled photovoltaic pumping systems, such a system is clearly suitable for low head irrigation in the remote areas, not connected to the national grid and where access to water comes as first priority issue than access to technology. The system operates without battery and complex electronic control, therefore not only the initial cost is low but also maintenance, repairing and replacement cost can be saved. The study showed that directly coupled system attains steady state soon after any abrupt change.

1. Introduction

Long history of water pumping led to the development of many methods for pumping water with minimum efforts and energy. The techniques range from a simple hand pump to high efficiency electric pumps. In remote rural areas where access to electric supply is not practical, the use of diesel pumps is very common. However, the system suffers with number of problems, such as fuel supply, technical know how and of course the operating cost. Photovoltaic (PV) operated water pumping system provides an alternate. Various systems have been developed and tested around the world [1–4]. Their performance has been assessed under varying climatic conditions and isolation. These systems are operated with ac or dc, directly coupled or battery operated, using various pumps, running under different climatic conditions. The PV systems are becoming increasingly popular, especially in remote areas where power from a grid is not available or is too costly to be installed. Also the progress made in the world market of photovoltaics emphasizes the maturity of investments realized, guarantees the reliability of the technology utilized and makes it competitive for a variety of applications to meet the energy demands [5]. It is estimated that a single PV station of area 250 × 250 km^2 or 12 decentralized stations each 72 × 72 km^2 would be enough to meet the year 2020 world electricity requirement [6]. The water pumping systems are frequently used for irrigation, livestock watering and in households' water supplies and in many cases are cost effective. A study carried in Namibia shows that a PV powered system can operate at about half the life cycle cost to that of a diesel pumping [7]. However, two major issues – high initial investment and low efficiency, limit the wide spread use of PV system. The achievable efficiency in the conversion of solar radiation to electricity by solar cells is still low, 9–12% under real conditions [8,9]. The initial cost of a PV system is about three times more than that of a diesel pumps with the same performance [10].

Most African, South Asian and Latin American countries are exposed to sun almost through out the year, where the solar intensity is quite high [11]. Among these countries Algeria is the one blessed with a geographical location that holds one of the highest reservoirs where topography and local climate favours its use. The insolation time over the quasi-totality of the national territory exceeds 2000 h annually and may reach 3900 h (high plains and Sahara). The daily irradiation on a horizontal surface is 5 kW h/m^2 over the major part of the territory (1700 kW h/m^2/year in the north and 2263 kW h/m^2/year in the south of the country), as shown in Table 1, [12]. The interest towards the development of renewable energy in Algeria was perceived as early 1962 with the establishment of "Solar Energy Institute". Algeria intends to produce 7% of its power from renewable energy including solar and wind as main sources, by the year 2010 that represents at least 450 MW [13]. To

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Table 1
Solar energy potentials in Algeria.

Areas	Coastal area	High plateaus	Sahara
Surface (%)	4	10	86
Average sunshine (H/year)	2650	3000	3500
Average energy received (kW h/m^2/year)	1700	1900	2650

achieve the target a number of initiatives have been taken that include a comprehensive solar rural electrification programme of 20 villages and 150 MW hybrid solar-gas project at Hassi R'mel [12]. Since commissioning, over 1000 households have been electrified through this programme.

The performance of PV pumping systems is influenced by local weather conditions. It varies with variation in cloud covers, temperature, wind speed etc. Potential sites for solar application are however, mainly characterised by stable insolation. Fortunately these sites coincide with those parts of the earth where the need for water pumping is the greatest [14] and the same applies to Algeria. PV water pumping systems have been introduced in Algeria quite some time ago. The use of PV pumping at small-scale irrigation in isolated regions of Algeria is quite high. Thus the technical know-how is available locally. They also have the experience of using diesel pumps. They tend to deal with such systems in the same way as they use to do with a diesel unit i.e. being able to intervene when ever necessary to repair a pump, without seeking external technical assistance. This slightly compensates to relatively high initial investment. The system under study was restricted to the basic PV pumping system configuration, which is, a PV panel directly connected to a dc motor–pump and a piping system. The developed system does not need battery for intermediate energy storage and also no electronic control systems is added that would lead to high initial cost and maintenance complexity [10,15]. The paper describes the performance of this simple PV operated water pumping system.

2. Experimental rig

The experimental rig installed at Oran University of Science and Technology (latitude 35.69°, longitude −0.64°) is shown in Fig. 1. Three main design parameters that affect the performance of directly coupled PV systems at a given location (under particular climatic conditions) were taken into account during the early design of test rig. Based on these design parameters the installed directly coupled PV water pumping system comprises of:

- PV array – 30 PV modules, arranged in two parallel columns, each of 15 modules, connected in series,

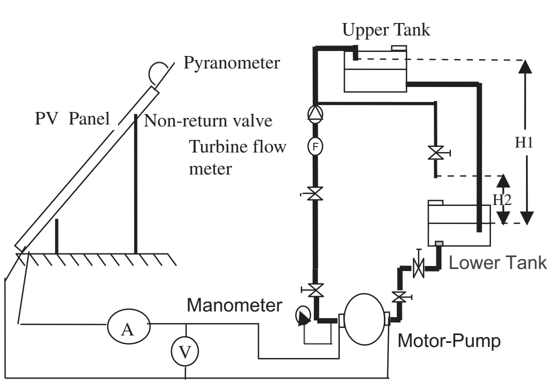

Fig. 1. Schematic diagram of PV water pumping system.

- Motor–pump assembly – a permanent magnet dc motor coupled with a single impeller centrifugal pump,
- Water Storage Tanks – two identical storage tanks and a set of piping.

Such a system serves similar purpose to that of battery storage and power point tracker systems. The later have improved efficiency, but are more expensive. A directly coupled system on the other hand is low cost most reliable PV system [16]. The performance of such a system can be optimized by varying the size of the PV array (a predominant factor), its orientation and pump–motor–hydraulic system characteristics [4].

With the exception of PV modules all system components are locally available. A locally manufactured motor–pump is experimentally studied and mathematically modelled. The model simulates the characteristic flow-power versus water pump for each total dynamic head [17]. Motor–pump parameters are obtained and by fixing pumping head the *I–V* and *Q–V* curves are acquired [18]. For optimum pumping head, regression analysis of measured data set for system head and flow rate is carried out [19].

PV modules were provided by JICA as a part of cooperation between the Algerian and Japanese government. The lower tank together with the motor–pump set and all measuring equipments were installed at the Power Electronics and Solar Energy Laboratory. The upper tank was installed on the roof of the double storey building, Department of Electronics. The experimental rig is a closed loop system, fitted with manual valves that enable to run the test with two static heads, 0.60 m and 11 m alternately. To assure the self-priming the pump was placed below the lower tank outlet level. The flow rate was measured with a plastic turbine flow meter installed in the delivery pipe line. Kipp & Zonen Pyranometer fixed at the top of the PV array frame at same tilt angle as that of array was used for measuring the solar irradiation incident on the PV array surface. The equipment used for measuring various parameters and their accuracy are listed Table 2. The data was recorded with EPROM data acquisition system (CIMEL). The system components are shown in Fig. 2.

2.1. The PV array characteristics

The PV array consists of 15 modules connected in series with 2 strings connected in parallel. Each module contains 36 cells all connected in series with a sensitive cells area of 0.37 m^2. According to the manufacturer's specifications, the characteristics of each of these, under standard conditions (i.e. $T = 25$ °C, $G = 1000$ W/m^2, AM = 1.5) are as given in Table 3.

The PV array was fitted with diodes for protection against reversed current flow. It was mounted in a fixed frame facing south with 35° inclination to the horizontal. The PV array is over 15 years old and has been exposed to dust accumulation on the surface, rain, pigeons and sea birds dejection. Special care was taken to avoid the effects of such outdoor elements, by thoroughly cleaning the array surface before any experiment. A small water storage tank was installed in the vicinity of the array for this purpose.

Table 2
Measuring instruments and their approximate accuracy.

Measured parameter	Instrument	Accuracy
Flow rate	Kobold DF sensor with frequency output	±2.5% of full scale
Pressure (head)	Siemens SISTRANS P series Z 7MF 1563 transmitter	±2.5%
Irradiance	Kipp & Zonen CM11 Pyranometer	±3%
Tension	Voltmeters	±0.5%
Current	Ammeters	±0.5%.