Renewable and Sustainable Energy Reviews 87 (2018) 61–76

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

A review of solar-powered water pumping systems

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ARTICLE INFO

Keywords:
Solar-powered water pumping system
Photovoltaic water pumping system
Irrigation
Grassland degradation
Carbon capture and storage

ABSTRACT

Diesel-powered pumps are widely employed in farming and grassland irrigation. However, there can be problems of reliability and availability where fuel supply is erratic and expensive, high maintenance cost, and short life expectancy. These and recent concerns for the environment associated with the diesel engines call for a viable alternative source of power for irrigational water pumping. Renewable energy sources have gained a lot of attention as a replacement for fossil fuels or as a supplement in hybrid systems. Solar-powered (photovoltaic) systems are one of the viable alternatives that have attracted considerable attention in this regard. They have been deployed in many remote regions for various applications, ranging from rural electrification and community water supplies to irrigation and livestock water supplies. Although photovoltaic (PV) systems generally have a high investment cost, it has many features which make it attractive as an alternative source of power for water pumping. It is clean, as it produces no carbon emission, it generates no noise, and it has low operational and maintenance cost. This manuscript presents a detailed intensive review of solar-powered water pumping systems as reported in the literature to serve as a quick reference to researchers and engineers who are working or interested in the subject.

1. Introduction

Water is a necessity for surviving. It is needed for drinking and domestic uses, and it is required for large-scale irrigation, construction, and power production. Water plays a significant role in the development of any country. The quality of life in any country greatly depends upon the quantity and quality of available water resources in that country. It is estimated that an average of five liters of fresh water is required per person per day for daily survival [1]. Although a large amount of high-quality water is present in the world, often it is not available at locations where it can be readily used. This raises the need to pump high-quality water from its source to the locations where it is in demand. For this purpose, water pumps have been in use for decades.

The majority of the commercially available water pumps run on electricity or Diesel oil. Conventionally, electricity mostly generated by burning fossil fuels has been supplied from the national grids. This presented a problem for supplying water to remote areas which cannot be connected directly to a national grid station [2]. Also, with the realization of the negative impacts of burning fossil fuels on the environment, researchers became more focused on developing standalone water pumping systems that could be powered by renewable sources of energy.

Several renewable sources of energy can be used for water pumping. However, solar photovoltaic (PV) turned out to be the suitable one. While being clean and naturally available, solar energy has been proved to have a direct relationship between its availability and water demand [3]. The solar intensity is high in many locations where the electric grid does not reach and there is a high need for water.

Photovoltaic panels use solar energy to directly generate electricity which could be used to power the electricity-operated water pumps. For the past several years, researchers have been focusing on the development of efficient solar-powered water pumping systems [4]. These systems have been proven reliable even in severe weather conditions such as snowfall [2], and the recent search revealed that the largest PV system installed in the world is Tengger Desert Solar Park in China with 1500 MW installed capacity. Many aspects of solar-powered water pumping systems have been investigated, such as its overall efficiency, the efficiency of its

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https://doi.org/10.1016/j.rser.2018.02.010
Received 22 March 2017; Received in revised form 29 August 2017; Accepted 14 February 2018
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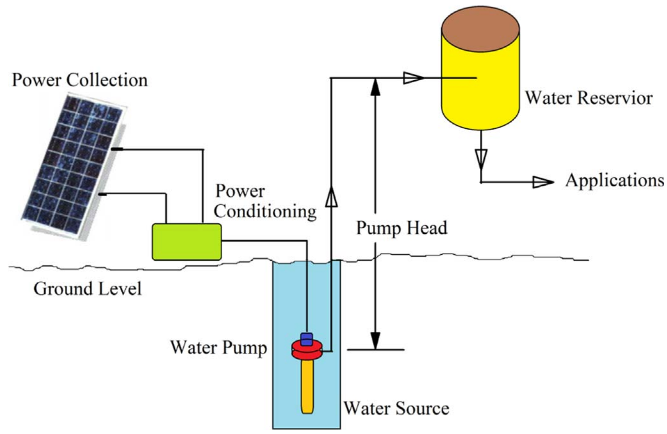

Fig. 1. Schematic diagram of a generalized solar powered water pumping system.

individual components, its economic viability, and its size optimization. In economic terms, the problem associated with the use of fossil fuel such as availability, transportation cost, price, and effect on the environment while the reduction in PV panel prices due to advancement in the PV technology; adds on increasing the feasibility of using solar-powered water pumping systems [5]. Control, maintenance, and data acquisition have yet been other aspects of research. Carbon sequestration in terms of decrease in the CO_2 emission, due to the use of such systems, have also been under investigation recently. Hence, this paper conducts a critical intensive review of the published research on the solar-powered water pumping systems.

2. Research advances in solar-powered water pumping systems

With increasing awareness about the emerging energy crisis in the world, solar-powered water pumping systems (SPWPS) have been a real focus of interest of researchers for decades. There are various possible designs for developing SPWPS. However, the most common is the one that involves PV panels [6]. Fig. 1 shows a schematic diagram of a generalized SPWPS. It is composed of a power collection system, power conditioning unit, water pump, and a water reservoir. The power collection system mostly involves the PV panels that collect solar energy and converts it to electrical energy. The generated electricity is normally DC while most of the water pumps available on the market require an AC electrical input. Therefore, there is a need to condition the generated power from the power collection system so that it can power up the water pump. A water pump is installed in the water source. It pumps the water from the source to a water reservoir located at a higher elevation from the ground level. The elevation difference from the water pump to the inlet of the water reservoir is known as the pump head. This pump head is an important parameter in designing the pumping system.

Recently a lot of research has been focused on increasing the overall efficiency of SPWPS. In this regard, all the basic components of SPWPS have been studied independently to develop a system with increased overall efficiency. The research advances, in this field, have been focused on solar collection system, water pump, pump head, control systems, and data acquisition system, and the maintenance of these components and systems.

2.1. Solar collection system

The solar collection system plays a vital role in the performance of the SPWPS [7]. Several aspects of solar collection system have been studied in the literature that has a direct effect on the overall efficiency of the SPWPS. These aspects involve the effect of PV configuration, use of tracking and concentrating collectors, and water spraying of the PV panels. Also, performance degradation due to shadows and prolonged usage of PV panels have been studied.

2.1.1. Effect of photovoltaic configuration

The performance of solar PV powered water pumping systems strongly depends upon the configuration of PV array. Photovoltaic configuration refers to the series-parallel arrangement of PV modules in the collector array. Several PV modules can be connected in series whereas several series modules can be connected in parallel to achieve the desired current and voltage from the array. In this regard, Boutelhig et al. [8] used outdoor measured data to analyze the performance of solar photovoltaic water pumping systems at Ghardaia, Algeria, for varying PV panel configurations. They reported an optimum PV panel configuration of 2 × 2 modules for a 300-W water pump and 2 × 1 modules for a 130-W water pump with an efficiency of 12.5% and 12%, respectively. Benghanem et al. [9] studied various PV configurations to optimize the performance of solar-powered helical pump that delivered 22 m^3 of water per day. Their experimental results indicated an optimum configuration of 8 × 3 modules and 6 × 4 modules. Hamidat et al. [10] developed a computer algorithm to evaluate the performance of solar PV pumping system for varying PV configurations. The results of their analysis indicated the best-suited configurations of 7 × 3 modules and 7 × 4 modules for operating a 750-W water pump installed in Algeria with an efficiency of PV system ranging from 30 − 35%.

2.1.2. Effect of tracking and concentrating collectors

Tracking and concentrating collector systems can enhance the energy efficiency of the PV panels. Caton [11] studied various cases of single-axis and double-axis tracking while comparing them with fixed collectors. The authors reported that vertical axis tracking resulted in the best performance among various single axis tracking. They also reported a 17.6% increase in solar collection due to double axis tracking on an hourly basis. It was also reported that there is an insignificant improvement in the performance between seasonal and monthly tracking systems. While the tracking systems increase the solar collection and thus the efficiency of the system, they also increase the cost due to the addition of a complex tracking system. Thus, it is imperative to justify the increase in performance against the cost of adding a tracking system. Campana et al. [12] studied the economic aspect of introducing a dual-axis tracking system for solar-powered water pumping system. The authors reported that, although the tracking system could increase the performance, yet the fixed collector system still proves to be more cost-effective. On the contrary, Bione et al. [13] reported that solar tracking systems are more cost effective with a cost reduction of 19% when compared to fixed collector system. However, they also reported that the most cost effective method is the utilization of V-trough concentrators that could reduce the cost by 48%. A similar result was also reported for the use of optical concentrators which reported a cost reduction of more than 50% when compared to fixed collectors [14].

2.1.3. Effect of water spray

It is known that the cell temperature significantly affects the

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