Renewable and Sustainable Energy Reviews 81 (2018) 413–420

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Comparative assessment of the feasibility for solar irrigation pumps in Sudan

Babkir Ali

Donadeo Innovation Centre for Engineering, Department of Mechanical Engineering, University of Alberta, Edmonton, Alberta, Canada T6G 1H9

ARTICLE INFO

Keywords:
Solar energy
Irrigation
Water pumps
Sustainable energy
Sudan

ABSTRACT

Irrigation is one of the essential unit operations for agriculture and Sudan as an agricultural country with rich natural resources has an urgent need to optimize the utilization of energy, water, and land in a most sustainable way. The cost-effective irrigation pathway utilizing one of the clean energy technologies such as solar energy would contribute significantly to the sustainable development of agricultural sector in Sudan. This paper is intended to investigate the most cost-effective solar water pumping system for irrigation in Sudan. Three solar irrigation pumps were considered based on the collector configuration and type of energy conversion to include two thermal and one photovoltaic pump; parabolic trough pump (PTP), concentrating dish pump (CDP), and photovoltaic pump (PVP). Levelized energy cost (LEC) was used in this study as the economic indicator for the feasibility of solar water pumping systems. A comparative assessment model was developed based on weather conditions of Sudan and sensitivity analysis was conducted to study the effect of design parameters, weather conditions, and interest and inflation rates on the LEC of solar water pumping systems. The resulted LECs for PVP, CDP, and PTP in the base case were found to be 0.033 $/kWh, 0.062 $/kWh, and 0.075 $/kWh, respectively. PVP is the most feasible pathway among solar irrigation pumps in Sudan, and its initial cost per unit hydraulic power capacity is 1351 $/kW, compared to 4072 $/kW and 4884 $/kW for CDP and PTP, respectively.

1. Introduction

Sudan is an agricultural country with vast arable land and abundant water resources. Water is allocated to Sudan from the Nile the longest river in the world [1] at an annual rate 18.5 billion m^3, and the current actual water demand for the country was estimated at 87% of this total allocation [2]. In 2006, agriculture had contributed by 39% to the GDP, and more than 70% of the total population in Sudan depend mainly on this sector to generate their income [3,4]. Compared to the traditional and mechanized rain-fed, small irrigated farms in Sudan have contributed significantly to the GDP and used smaller land areas [5]. The Government of Sudan had shifted the focus of wheat growing from the northern part of the country to the big agricultural schemes to avoid the high cost of irrigation [6]. Irrigation is an essential unit operation in the agriculture life cycle [4,7] and needs to be optimized for more efficient performance and most cost-effective scenarios to make a breakthrough towards sustainable development.

Renewable energy in Sudan has a high potential due to the availability of solar, wind, hydro, and biomass resources [8–13]. This high potential would lead to more sustainable development after integration of Sudanese energy demand in the agricultural sector with the energy supply based on these clean technologies. Solar radiation intensity in Sudan is high and small scale thermal and photovoltaic applications were developed [14–16] with limited studies conducted on the feasibility of the systems. Most of the earlier studies related to the renewable energy in Sudan focused on the estimation of the resources [17–20] and comparative assessment research work for the most cost-effective pathways is scarce.

Solar water pumps as one of the renewable energy applications expected to have high initial cost [21] and obstacle by fluctuation in solar radiation. Irrigation pump is mostly operating during the daytime, and this can reduce the necessity of storage systems or use water storage tanks instead of other costly means [22]. Solar photovoltaic (PV) applications have the advantages of utilizing both direct and indirect solar radiation [23], and the technology is well established compared to the concentrating solar power (CSP) technologies. The global potential for CSP technologies is growing and expected to cover a range of 12–25% of the total electricity demand in the world by 2050 [24]. Penetration of solar pumps in Sudan faced a challenge of competing against the already operating conventional systems based on diesel and electric power. To evaluate this competition within the frame of sustainable development, it is essential to involve the

E-mail address: babkir@ualberta.ca.

http://dx.doi.org/10.1016/j.rser.2017.08.008
Received 12 May 2017; Received in revised form 25 June 2017; Accepted 2 August 2017
1364-0321/

Renewable and Sustainable Energy Reviews 81 (2018) 413–420

Nomenclature

AC	alternating current	LEC	levelized energy cost [\$/kWh]
A_C	collector aperture area [m^2]	MJ/m^2	megajoule per square metre
C_{AUX}	auxiliary cost [\$]	n	lifetime of the systems [year]
C_C	total collector cost [\$]	OM_C	operation and maintenance costs [\$/year]
C_{CIV}	civil work and connection costs [\$]	P_G	hydraulic power generated [kWh]
CDP	concentrating dish solar thermal pumping water system	PTP	parabolic trough solar thermal pumping water system
C_{IN}	total initial cost [\$]	PV	solar photovoltaic
CSP	concentrating solar power	PVP	solar photovoltaic pumping water system
C_{UR}	cost per unit collector area [\$/m^2]	P_W	pump hydraulic power [kW]
DC	direct current	Q	water flow rate from the pump [m^3/sec.]
f	inflation rate [%]	R_C	receiver cost [\$]
g	the gravitational acceleration [m^2/sec.]	R^2	fit degree of the regression line
GDP	the gross domestic product	S_{VAL}	scrap value [\$]
h	discharge head of the pump [m]	T_D	operation period [hour/day]
i	interest rate [%]	T_{PV}	net present value [\$]
I_D	direct solar radiation [W/m^2]	\$/kWh	U.S. dollar per kilowatt-hour
I_T	total solar radiation [W/m^2]	\$/kW	U.S. dollar per kilowatt
		ρ	water density [kg/m^3]
		η_T	overall conversion efficiency [%]

economic pillar for one of the most underdeveloped countries in the world [2].

The contribution of this paper is the assessment of solar irrigation pumps through an economic indicator based on the weather conditions of Sudan. Levelized energy cost (LEC) is the economic indicator used for the three types of solar pumps. This economic impact assessment would contribute to the science by filling the literature gap and ease integration with other sustainable development pillars of environmental and social impacts. The novelty of this study is the significant contribution to the knowledge through comprehensive feasibility assessment of three different types of solar water pumping systems, which is according to the knowledge of the author not conducted before simultaneously.

Levelized cost of electricity has been used as a well-established indicator in the literature [25–27] to conduct the comparative assessment of the feasibility for electricity generation pathways. A similar LEC indicator is used in the current study taking its advantage of correlating two different indicators covering the system costs and the output power.

2. Solar water pumping system

Three types of solar irrigation pumps were considered in this paper based on the solar collector configuration and energy conversion pathway. Solar water pumps were set in this study to include two types of thermal conversion pathway; parabolic trough pump (PTP) and concentrating dish pump (CDP) and one photovoltaic type (PVP). Irrigation pump can be used to deliver water from surface or underground source with different types such as centrifugal and positive displacement pumps. The hydraulic power (P_W) of a pump would govern the water flow rate (Q) and the discharge head (h) through a specific relationship [28,29]:

$$P_W = \rho * g * Q * h \tag{1}$$

where ρ is the water density and g is the gravitational acceleration.

2.1. Parabolic trough water pumping system

Fig. 1 shows the main components of solar thermal irrigation pump with parabolic trough collectors. The systems composed mainly of solar collectors in parabolic trough geometry with auxiliary components. The auxiliary components consist mainly of the heat exchanger, turbine with condenser, and water pump. The inside surface of the parabolic collector is covered with reflectors to concentrate the incoming direct solar radiation into the focal line. The receiver is stainless steel tube covered by transparent glass envelope located along the focal line and carrying the heat transfer fluid. Oil is usually used as the primary heat transfer fluid circulated in a closed loop between the collector and the heat exchanger. Water is circulated in a secondary loop as working fluid to extract heat from the heat exchanger. The pressurized heated working fluid is forcing the turbine to rotate while steam is converting its kinetic energy into mechanical energy [23]. The steam from the turbine would be condensed and returned to the heat exchanger to start a new cycle. The rotating shaft of the turbine is directly coupled to the pump to lift the water. The steam turbine engine could be used to generate power through electric generator and then running the water pump [30]. The tracking system is needed for the parabolic trough collector and affects significantly the performance of the system through improvement of the optical efficiency [31–33].

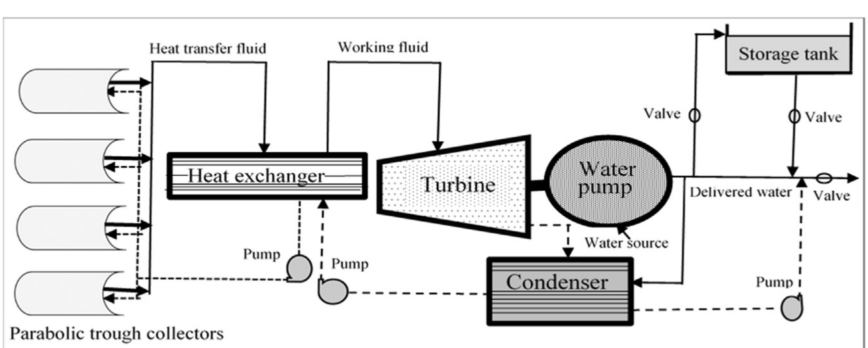

Fig. 1. Main components of the PTP system.