Research article

Efficiency Evaluation of Solar Pumping System for Wadi Agriculture in Djibouti

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Received 11 Septem 2020 Accepted 30 November 2020 (*Corresponding Author)

Abstract Crop cultivation in Djibouti is mainly done by irrigation agriculture obtaining groundwater from wadi aquifer. The decreasing in the efficiency of solar power generation system due to panel-on-dust is reported to be the issue in terms of energy loss in pumping up water. In this paper, the effect of dust deposition for solar pumping system was evaluated at wadi agriculture farm in Dikhil, Djibouti. The amount of panel-on-dust was measured to be 1.88 and 2.1 g/m^2 in cooler season (dry deposition) and in hot season (wet deposition), respectively. Clearance of the panel-on-dust resulted a decline in the output power of photovoltaic panel due to the rise in panel surface temperature in January (cooler season), whilst the output power increased in September (hot season) when the panel surface temperature was relatively higher. The conversion efficiency of the photovoltaic power generation was calculated to be about 5 - 6% lower in September than in January. The whole conversion efficiency of solar pumping system was estimated to be about 2%. Since the ideal conversion efficiency was calculated as 6.76%, the gap from observed value of about 4.5% can be implied by suppressing water leakages from the system in pumping process.

Keywords Djibouti, panel-on-dust, photovoltaic panel, wadi agriculture

INTRODUCTION

The Republic of Djibouti, Northeastern Africa, locates under high temperature and low-rainfall climate environment. Most of the land surface is dominated by barren land (67-89%; Shimada et al., 2006) and the rainwater easily run off from the ground surface through wadi, ephemeral riverbed. Due to this harsh natural environment, agricultural activity is very difficult. In Djibouti, groundwater is pumped up to be used since enough amount of water cannot be collected from rainwater for agriculture. In the arid land under low-latitude regions such as Djibouti, abundant solar radiation is available, hence solar power generation has a potential for the pumping system. However, initial expense for installation of solar power system costs relatively higher than that of engine system. For this reason, engine systems are the most adopted cases for wadi agriculture, although the running cost exceeds in the long run for the engine pumps and causes pressure on management. The Government of Djibouti pronounces the use of renewable energy as a great important issue for the management of sustainable water resources to enhance the agricultural productivity. Therefore, it is important to establish an optimal method for operating solar power generation system in terms of cost and efficiency. Previous studies analyzed the cost of a pumping system using photovoltaic panel in wadi agricultural farm in Djibouti, a method for estimating an appropriate scale of pumping system (Tajima et al., 2012; 2014). However, in arid areas such as Djibouti, dust tends to accumulate on photovoltaic panels, and the dust accumulation normally reduces its output power (Sulaiman et al., 2011; Ghazi et al., 2014; Maghami et al., 2016; Daher et al., 2018). When introducing a PV system for agriculture, in arid environment like Djibouti, it is necessary to consider the effects of dust accumulation on photovoltaic panel. However, only a few studies analyzed on this effect and evaluated quantitively on photovoltaic pump in arid area like Djibouti (e.g., Tajima et al., 2012; 2014; Aden et al., 2009). In the current paper, we investigated one whole pumping system of wadi agricultural farm, where photovoltaic power generation is introduced as groundwater pumping system, in Dhikhil, Djibouti, in order to evaluate the efficiency of the system including the effect of dust deposition on photovoltaic panel.

METHODOLOGY

The target farmland located in Dikhil city (11.08863°N, 42.40089°E) (Fig. 2). The configuration of the solar pumping system used in the farm was as follows. LORENTZ: PS1800, SOLARWORLD: SW80 poly RNA: 80 W x 18 sheets. The solar array installation inclination angle was 11°, the azimuth angle was 130° (i.e., southeast), and the area of the array was about 12 m^2.

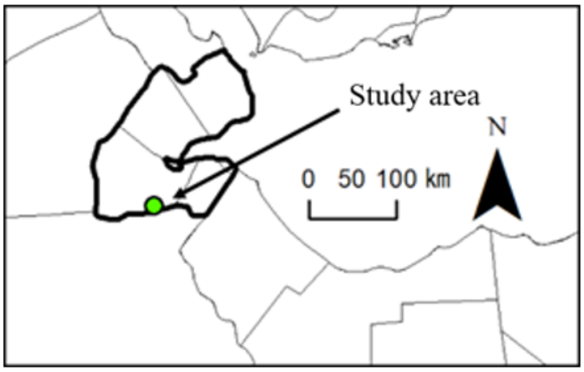


Fig. 1 Location of the study site in Djibouti

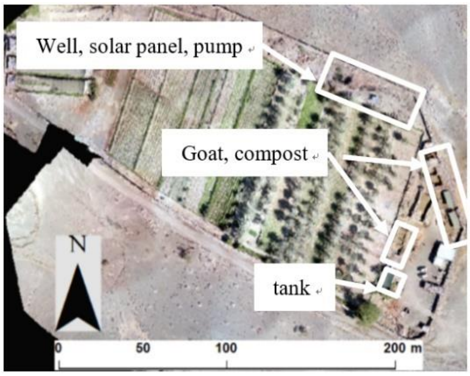


Fig. 2 Overview of the target farmland in Dikhil

Overview of solar pumping system is shown in Fig. 3, and agricultural system is shown in Fig. 4. During daytime, the farmers use solar pumping system to store groundwater into reservoir tank (about 100 m^3 storage). After around sunset, they switch to engine pumping system to pump up the groundwater from the well. The farmers use all the water needed for the farm management, such as irrigation, livestock, and others.

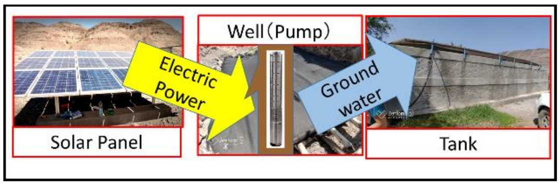


Fig. 3 Overview of solar pumping system in the target farmland

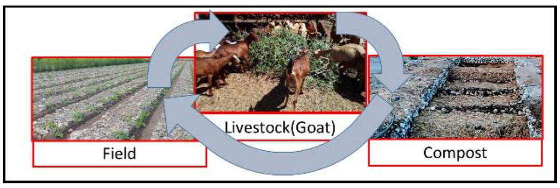


Fig. 4 Agriculture-livestock material cycling scheme in the target farmland

Survey was conducted in 2 seasons, i.e., cooler season (December 29, 2018 - January 14, 2019), and hot season (September 1, 2019 - September 30, 2019). Table 1 shows the items and periods of the data measurements, and Fig. 5 shows the overview of the measuring equipment in the farmland.

Solar pumping system consists of photovoltaic system and pump, which converts the electric power into the potential energy of water. However, the system has some loss of efficiency in the process of energy conversion (Fig. 6). The output electric power of the solar pumping system was measured by the multiplication of current and voltage. The values were compared before and after cleaning the panel-on-dust. The output efficiency was evaluated by comparing the changes in the output of the photovoltaic system with the output of the pumping system. The output efficiencies regarding panel-on-dust and panel surface temperature were also evaluated.

Table 1 Items and periods of data measurements

	Current ①	Voltage ②	Global solar irradiance ③	Panel surface Temperature ④	Temperature & Humidity ⑤	Wind Speed & Direction ⑥	Water level (Tank) ⑦	Water level (Well) ⑧	Flow rate ⑨
January	○	○	○	○	○	○	○	○	×
September	○	○	○	○	○	○	×	×	○

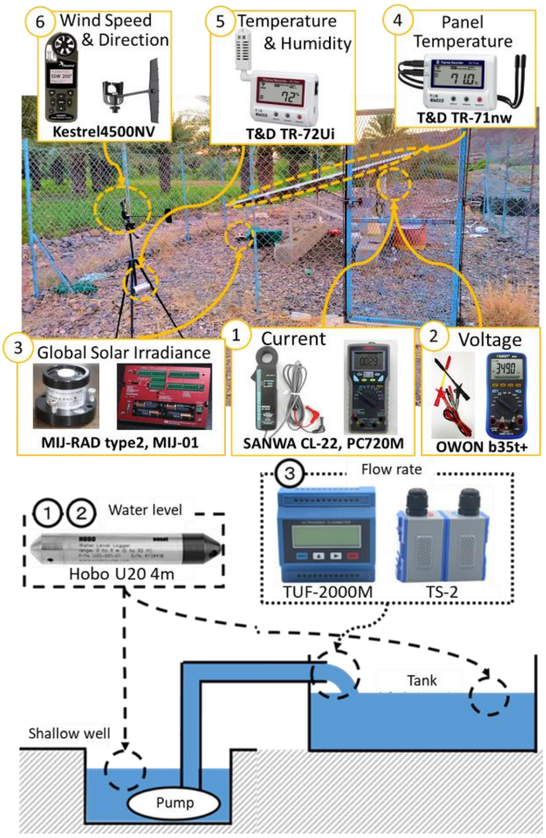


Fig. 5 Overview of the measuring equipment in the target farmland

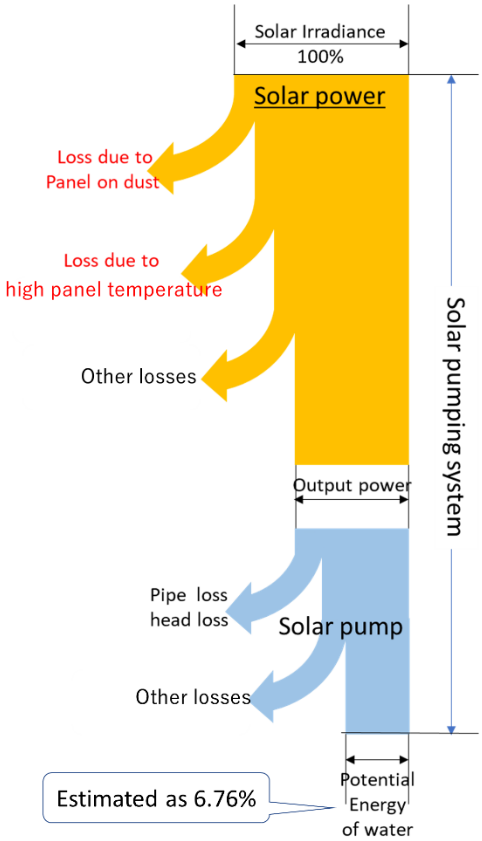


Fig. 6 The flow and loss of energy in the farm solar pumping system

RESULTS AND DISCUSSION

Cleaning of panel-on-dust was conducted on January 6, September 13 and 24, for the cooler and the hot season experiments, respectively. Fig. 7 shows the schedule and measured dry weights on cleaning of panel-on-dust. The panel-on-dust seems to occur more in September than in January. Dust accumulation for cooler season was observed to be dry deposition and weighed 1.88 g/m^2 in dry mass, while weighed more than 2.1 g/m^2 in dry mass and seemed as wet deposition due to rainfall events for hot season.

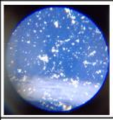
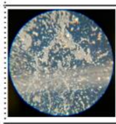
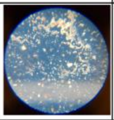
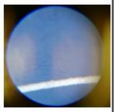
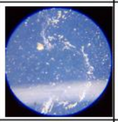
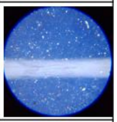
	1/6	1/7	~	9/12	9/13	9/14	9/15	9/24	9/25
Dust cleaning	○		~		○			○	
Dust weight	1.88g/m²	–	~	–	2.41g/m²	–		2.11g/m²	–
Panel surface image			~						
weather	Sunny	Sunny		Sunny 9/11 was rainy	Sunny	Sunny	Rainy	Sunny Sometimes cloudy	Sunny Sometimes cloudy

Fig. 7 Results of panel-on-dust measurement

Fig. 8 shows comparison of the output electric power of the photovoltaic system before and after clearance of panel-on-dust in January and September. As a result, the effectiveness of panel cleaning on output power was negative in January (75%), while positive in September (140%). This result indicates that clearing of the dust on the solar panel can cause decrement of photovoltaic efficiency in cooler season (January). This efficiency loss can be explained by the reason that effect of risen temperature of the photovoltaic panel surpassed the increase in input solar irradiance from the clearance of panel-on-dust.

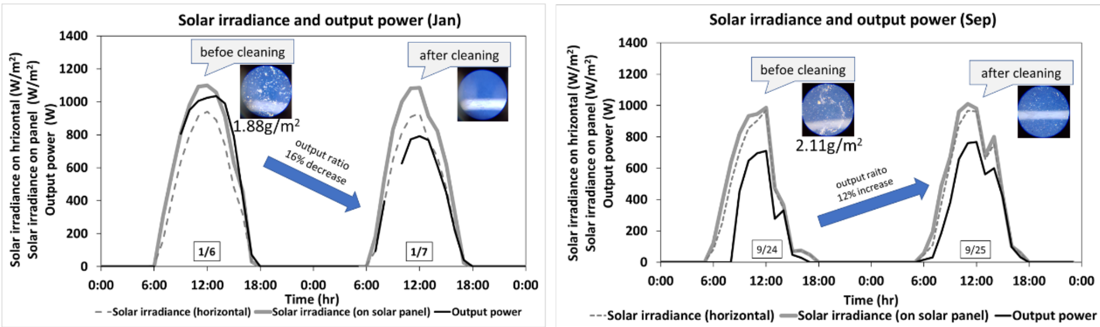


Fig. 8 Output power with solar irradiance (horizontal and on panel) before and after cleaning panel-on-dust (Left: cooler season, Right: hot season)

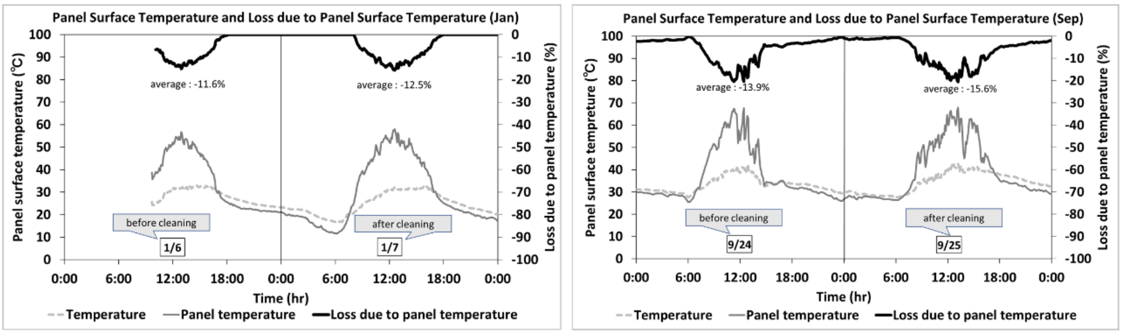


Fig. 9 Surface temperature of photovoltaic panel, air temperature and power loss before and after cleaning panel-on-dust (Left: cooler season, Right: hot season)

Fig. 9 shows panel surface temperature in January and September, and the output power loss due to the panel surface temperature. The maximum panel surface temperatures in January and September were 60.8℃ and 71.9℃, respectively. The theoretical daily power loss due to high panel temperature calculated from the photovoltaic panel specification (-0.48% $℃^{-1}$) was 11-13%, and 13-16%, in January and September, respectively. From the above results, the power loss from the high panel temperature is more remarkable in the hot season (September) than in cooler season (January). Clearance of panel-on-dust in the hot season can gain the efficiency of the output power, although theoretical energy loss from high panel temperature is relatively higher.

Table 2 shows calculated pumped water amount in January and September. Fig. 10 shows input and output energy of whole solar pumping system. Input energy is the solar radiation intensity received by the panel. The input energy was observed to be greater in January than in September. Ideal efficiency was estimated as 6.76% (Fig. 6), however, the efficiency of whole pumping system was calculated to be between 2.1 - 2.4% (Fig. 10). The reason for this gap in efficiency might cause mainly in the water loss, such as leakage from the water pipe.

Table 2 Output capacity of water pumping system before and after cleaning panel-on-dust

	1/6	1/7	9/24	9/25
Pumped water by solar	36.7 m^3	35.3 m^3	29.1 m^3	33.6 m^3
Pumped water by engine	36.0 m^3	43.3 m^3	38.0 m^3	36.1 m^3
Total pumped water	72.7 m^3	78.6 m^3	67.1 m^3	69.7 m^3

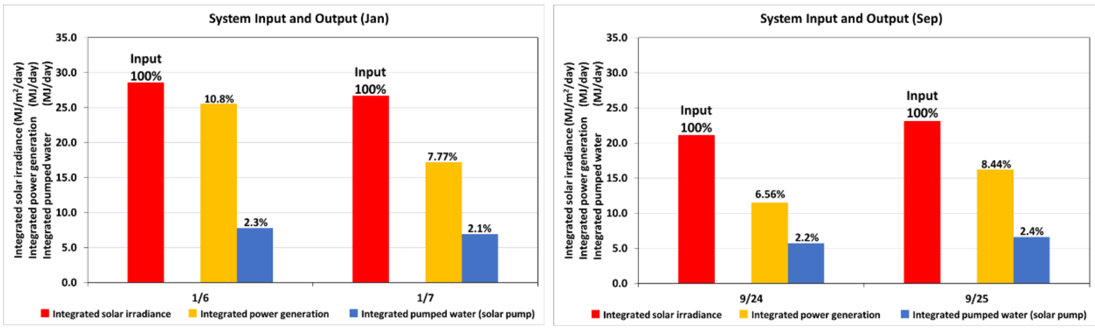


Fig.10 Input and Output energy of daily integrated energy before and after cleaning panel-on-dust (Left: cooler season, Right: hot season)

CONCLUSION

The panel-on-dust effects on photovoltaic efficiency for wadi agriculture solar pumping system in Djibouti was examined. The efficiency decline by the clearance of panel-on-dust in cooler season was discovered in this paper for the first time. This energy output loss was implied by the effect of risen temperature of the photovoltaic panel from the clearance of panel-on-dust. However, the clearance of panel-on-dust in the hot season can gain the efficiency of the output power.

The whole conversion efficiency of solar pumping system of wadi agriculture in Djibouti was also evaluated in this study. It was estimated to be slightly above 2%, although the ideal conversion efficiency was calculated as 6.76%, which gap can be caused by the water loss in the pumping process.

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