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Techno-economic feasibility of off-grid solar irrigation for a rice paddy in Guilan province in Iran: A case study

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ABSTRACT

In this study, a typical rice paddy in Guilan province of Iran is considered and the technical and economical feasibility of the solar powered pumping system is studied. The monthly mean daily solar irradiance has been studied for this area and the measured data is compared with European Photovoltaic Geographic Information System (EU PVGIS) model for Middle East, including Iran. The investigations imply that the average monthly mean daily solar irradiance in irrigation months are reported equal to 5.92 kW h/m^2/day by Guilan Meteorological Administration and 5.95 kW h/m^2/day by EU PVGIS. A mean monthly clearness index from 0.54 to 0.57, in irrigation period, gives Guilan province a good potential to employ photovoltaic (PV) pumping system. In this study, the appropriate size of the PV panels and the lifecycle cost estimation of PV pumping system in comparison with conventional systems are presented. Also, the area of the PV solar panel to supply required power of the pumping system for a rice paddy with specified area is calculated. Results show that though the initial outlay of the PV system is about 9 times of the conventional systems but the total lifecycle costs of the PV pumping system is just 65.6% costs of the conventional pumping system. Also in spite of high initial costs of the PV pumping system, it is found that after around 9 years, the total costs of both systems would be equal to conventional one i.e. gasoline pumping system and after this time, the costs of the conventional pumping system will exceed the PV solar panel system.

1. Introduction

The idea of using the sustainable solar energy by means of photovoltaic (PV) cells for irrigation and water pumping is a modern and well-accepted one. Many developing countries are using PV systems as a source of energy at least in remote areas (Zabihi et al., 1998; Al-Karaghouli and Al-Sabounchi, 2000; Diarra and Akuffo, 2002; Mahmoud and el Nather, 2003; Firatoglu and Yesilata, 2004; Ramos and Ramos, 2009; Bouzidi, 2011). The main problem of using PV in Iran and other developing countries is the initial cost of these systems. Because of both falling costs of the PV cells (Raugei and Frankl, 2009) and price fluctuations of the fossil fuels, the general tendency toward the employing solar energy systems is increased. It means that using PV as a source of green and sustainable energy can have economic reasons. Like other uses of PVs in industry, here, to irrigate a typical field, estimation of the required array area is an important part of design process. Hamidat et al. (2003) studied the Sahara regions; an area of high level of monthly average solar radiation. They considered several crops, say, wheat, potato, tomato and sunflower. It was found that the PV water pumping system could easily cover the daily water need rates for small-scale irrigation with an area smaller than two hectares. Cuadros et al. (2004) studied a procedure to estimate the required dimension of a PV installation designed to power a pumping system for the drip irrigation of an olive tree orchard in southwest Spain. They divided their work into three different parts: first, determination of the soil and climate characteristics of the considered land, second, a hydraulic analysis of the pumping system and finally calculating-measuring the peak photovoltaic power required for irrigation.

As it was remarked earlier, PV powered pumping is a tempting and modern way to use the available solar irradiance, so lots of countries are trying to examine the feasibility of the PV pumping system (PVPS) for irrigation or even for pumping clean water. Kelley et al. (2010) presented a comprehensive study on the feasibility of solar-powered irrigation. They showed that two main

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Nomenclature

A_{PV}	area of PV panels (m^2)	i	inflation rate
ACG	annual cost of gasoline pumping system ($)	K_c	crop coefficient
ACG_{net}	net annual cost of gasoline pumping system after n year ($)	NIWR	net irrigation water requirements (mm)
ACP	annual cost of PVPS ($)	NNSD	number of no sunny days
ACP_{net}	net annual cost of PVPS after n year ($)	n	number of year
A_0	price of equipments in present year ($)	P_P	pumping power (W)
CPWF	cumulative present worth factor	PW	present worth ($)
ECPWF	cumulative present worth factor at the end of year	PWF	present worth factor
EFR	effective rainfall (mm)	Q	pumping volumetric flow rate (m^3/s)
DP	deep percolation (mm)	R_{tot}	total rainfall (mm)
d	discount rate	SD	storage demand (W h)
ET_0	reference evapotranspiration (mm)	TDL	total daily load (W h)
ET_c	crop evapotranspiration (mm)	ρ	water density (kg/m^3)
g	gravitational constant (m/s^2)	η_A	array conversion efficiency
h	pumping head (m)	$\eta_{coulomb}$	Coulomb efficiency
I_p	peak solar radiation (W/m^2)	η_p	pumping efficiency

issues must be considered for having a feasible PVPS. They urged that a feasible PVPS must be both technically and economically viable. Having available land to put the PV panel is the crucial point in the technical issue. On the other hand, the PVPS is considered economically feasible if its lifetime cost is the lowest among all alternatives available in the farm. Belgacem (2012) investigated solar water pumping in Tunisia. According to his studies, PVPS is one of the most economical ways to irrigation in remote areas especially in developing countries. He illustrated performance test of the water pumping system under the local climate condition and showed that at the constant head pumping, the maximum overall efficiency of the system is 3.7% and the mean efficiency in this period is 2.5%. Cloutier and Rowley (2011) investigated the feasibility of the renewable energy sources such as solar energy and wind energy for drinking water and other domestic or agricultural uses. They reported that the mean daily global solar radiation of 4.39 kW h/m^2 in some cities of Nigeria as a vital requirement value for having a feasible solar pumping system.

The technical and economic feasibility of the PV water-pumping in Turkey, a neighbor of Iran, is what Senol (2012) has studied. He proposed a mobile PV power station to derive a pump to store water in a tank for irrigation use. The ability of the power station movement allows using this system from one farm to another. In addition, protection of this system against the act of vandalism is easier than the fixed one. The economic analysis proves that the PV powered pump was preferable in the long run it Turkey.

Locating in the sun belt of the world, the application of PV systems has started since 1982 in Iran (Zabihi et al., 1998). The PV systems have been installed in all over the country, except the north and west bands. The reason is in the high price of PV systems and the few numbers of sunny days per year. Zabihi et al. (1998) reported some examples of PV power plant in the range of 5–10 kW for several purpose of use such as lighting of a village, building electrification, supply a telecommunication site, supply of VHF link and water pumping in the different cities of Iran. They stated that in 1993 CE a production line for fabrication of multi-crystalline silicon solar cells and modules was installed with the nominal capacity of 1 MW per year in one shift of operation. The efficiency of cells was between 12.5% and 14%. Nowadays there are several industrial corporations in Iran, which are working on fabrication, production and manufacturing solar panels.

Guilan province, the Southwest coast of the Caspian Sea, has a different climate in comparison with the other hot and dry parts of Iran. This region has a temperate and humid climate with average annual precipitation around 1850 mm (Guilan Meteorological Administration, 2012). It should be noted that the average annual precipitation in Iran is around 236 mm (Guilan Meteorological Administration, 2012). Having enough water, fertile lands and rather high relative humidity make Guilan province one of the main sources of producing rice in the country. More than 205,000 ha (0.5 million acres) of this province, which is 35.81% of the total paddy fields of Iran, has been cultivated with rice. In this region, the usual irrigation method is flood irrigation which continues from the beginning to the end of the growing season and the conventional method of cultivation is wet tillage with manual transplanting (Mostafazadeh-Fard et al., 2010). These flooded rice fields have different sizes about 200 m^2 up to several hectares. Fossil fuel price fluctuations and cutting and gradually elimination of subsidies by the government have urged the farmers to use the other sustainable types of energy to power the farm pumping system. Moreover, because of limitation in water source, using of water saving irrigation systems rather than conventional system is an inevitable plan in the near future. Solar energy by using stand-alone PV panels is superseding the conventional pumping system.

As stated before, this area has the lower sunny days than the other parts of the country so in this paper, the PV system is designed just for use in the sunny months when the energy usage for irrigation fields increases.

In the following sections, some climatologically aspects of the Guilan province, paddy fields description, water requirement and the conventional pumping system are presented. The measured global solar irradiance is studied and compared with EU PVGIS data. In addition the daily average clearness index is computed. The lifecycle costs method is used to compare the conventional and PV pumping system economically.

2. Field and pumping description

2.1. Field and climatologically characteristics

Fig. 1 illustrates Caspian Sea, Guilan province and its location in Iran. The Alborz Mountain range separates the Iranian plateau from the Caspian Sea and the Safidrud river crosses through the mountains and flat plain and enters into the Caspian Sea near the city of Rasht, the capital of Guilan province. Guilan has several synoptic meteorological stations. One of them is located at Rasht with lati-