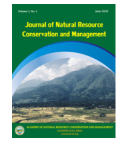
Journal of Natural Resource Conservation and Management
Vol. 4, No. 1, pp 50-54, 2023
doi: 10.51396/ANRCM.4.1.2023.50-54



Performance of solar irrigation pumps in the Eastern region of India

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Received : April 19, 2023
Revised : June 01, 2023
Accepted : June 02, 2023
Published : June 30, 2023

ABSTRACT

Groundwater abstraction to meet irrigation demand is becoming unaffordable to smallholders due to significant energy poverty at the farm level. Under this scenario, solar-powered irrigation pumps could be one of the most viable and sustainable options, given the solar energy potential of the Eastern region of India. However, as an evolving technology, its feasibility in groundwater abstraction should be assessed under the prevailing solar radiation intensity and groundwater depth regime. This study evaluated a 3.0 HP solar-powered groundwater pumping system installed at Patna (25.65° N) and energized by a 3.06 kW solar array for its groundwater abstraction capacity round the year. Studies showed that this solar system can abstract groundwater, ranging from 104 - 174 m^3 per day, depending upon the month on a bright sunshine day with 3-time manual sun tracking of the solar array. Further, the evaluation of the power output of operating solar array under the prevailing solar energy intensity ranging from 3.5-6.4 $kWh/m^2/day$ showed that under this size, array pumps operate at it rated power for 4-5 hours during high radiation months only.

Keywords: Solar irrigation pumps, solar irradiance, groundwater, diesel pump

INTRODUCTION

The major landscape area of India is distinguished for its fertility, excellent environment, and vast potential for groundwater reserve. However, the food production and productivity of the country are at risk of giving relatively low returns due to erratic rainfall and lack of assured irrigation facilities (Singh *et al.*, 2009; Lobell *et al.*, 2008; Held *et al.*, 2005). To save crops during long dry spells, farmers depend solely on groundwater for supplementary irrigation. The intensity of groundwater utilization is relatively high, as there are about 30 million groundwater abstraction structures in the country. Out of these, about 10 million pumps are diesel-operated, with an average annual duration of operation per pump of 462 hours (Shah, 2009). In general, 5 horsepower pumps are used, producing about 3.4 million tons of carbon (Nelson and Robertson, 2008). In the coming decades, the number of pumps and pumping hours will increase due to climate change and widened uncertainty in rainfall (Haris, *et al.*, 2013).

India is blessed with immense solar energy potential, with an average incident solar radiation of 3.5 – 7.0 kWh/m2/day and 250 -300 clear sunny days per year. This could be used as a year-round reliable source of energy in groundwater pumping (Sharma *et al.*, 2012; Ramachandra, 2011; Jaswal, 2009). Further, traditionally, farmers execute surface irrigation methods, leading to the overexploitation of groundwater. Therefore, pressurized irrigation technologies can be an additional water management strategy (Hillel, 1989; Keller *et al.*, 2001). The solar-powered groundwater pumping coupled with pressurized irrigation systems could be an appropriate alternative approach in minimizing diesel consumption, judicious exploitation of groundwater, and reducing carbon emission, as pressurized irrigation improves fertilizer-use efficiency and increases crop yield (Qureshi *et al.*, 2001; Sivanappan, 2002; Namara *et al.*, 2005,

Fig. 1. Solar-powered irrigation pump of the experimental site

Narayanamoorthy, 1997; Dhawan, 2000). Since crops differ in water requirements and fluctuate with crop growth, choice, succession, and combinations of crops have a decisive importance in the sizing of solar pumps. Crop rotation and cropping systems with high-value crops such as fruit, vegetables, and spices are to be grown to neutralize the capital cost of the solar water pumping system. For effective implementation of this technology, an appropriate groundwater pumping system is to be devised, developed, and tested, which could be referred to in further designing, installation, and optimization of solar-powered irrigation pumps, especially for small to medium land sizes given seasonal variation of incident solar radiation and groundwater level fluctuation. This paper presents performance evaluation of a solar irrigation pump tested in Bihar (25.65° N) to fulfil the above prepositions.

MATERIALS AND METHODS

In a solar photovoltaic water pumping system, solar photovoltaic electricity drives a surface or submersible pump to lift groundwater and inject it into the irrigation system. The pump may be an AC pump or a DC pump. In this study, an AC submersible pump was used, and the system is shown in Fig. 1. The attributes of solar arrays, pump, and accessories, are reported in Table 1.

A 3.06 kW solar array energized the 3HP AC submersible with a rated power value of 2.2 kW. The positioning depth of the pump was selected based on the groundwater depth scenario of the experimental site. The site's groundwater depth, m bgl, ranged from 5 - 10 m, as measured using a water depth meter. The site received global solar radiation ranging from 3.5-6.4 kWh/m^2/day, measured using a pyranometer, with a maximum in April (Fig. 2). As the solar array gives DC output; therefore, to operate the AC submersible pump, a variable frequency drive (VFD) along with maximum power point Tracker (MPPT) was used. The solar array was mounted on a dual-axis passive manual sun-tracking structure to get more energy.

RESULTS AND DISCUSSION

The solar radiation intensity varied with changes in the daytime, so the discharge of the solar irrigation pump also varied due to changes in input power. Therefore, instead of measuring instantaneous discharge, the measurement of the average discharge of the submersible pump was more relevant. As per the affinity law of capacity and pump speed, the discharge of the pump is proportional to the speed (rpm) of the pump (Jones, 2008). Therefore, the rate of discharge of the pump at any point of time was measured by using a relationship between the rate of discharge (d) and driving rpm (f) of the pump, recorded from VFD. The discharge vs. driving rpm relationship was plotted which showed a linear

Table 1. Characteristics of solar photovoltaic irrigation system

Attributes of solar modules and array		Attributes of pump	
Item	Description	Item	Description
Module size	170Wp±3%	Type	AC, Submersible
No. of modules	18	Capacity	3.0 HP
Material of cells	C-Si	Rating	2.2 kW
Efficiency	13.8%	Attributes of tracking structures	
Open circuit voltage (V_{oc})	43.66V	Item	Description
short circuit current (I_{sc})	5.21A	Mechanism	Passive manual
Voltage at maximum power (V_{mp})	36V	No. of mast	03
Current at maximum power(I_{mp})	4.82A	Rotation	Dual-axis
Temperature coefficient W/ ^{0}C	1.036W/^{0}C	No. of modules per mast	06
Array size	3.1kWp±3%		

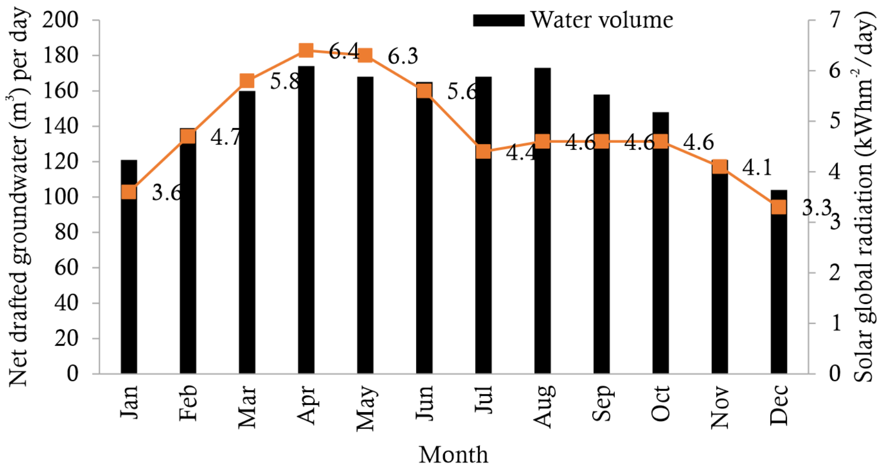

Fig. 2. Mean monthly daily water output along with global solar radiation of the site for different months on a bright day

relationship as $d = 0.2734f - 6.3496$ with $r^2 = 0.998$. To estimate the total volumetric discharge over a day the f values were recorded at every 15-minute interval over the whole day. Six solar modules were grouped and mounted on dual-axis passive rotational structures. All 18 modules were mounted on three different masts and rotation was performed 3 times. The solar modules were grouped into 6 and

The total volumetric discharge of the pump was calculated by using the mean value of f of two extremities of 15-minute interval discharges into the above linear relationship to work out the discharge and then multiplied by the period of 0.4 hr. The cumulative value of intervals over the whole day gave the total volumetric discharge per day (V)

$$V = \sum_{i=1}^{i=n} 0.4(0.2734 f_i - 6.3496)$$

Temporal variation in radiation was taken care of by VFD in terms of in rpm of the motor of the pump; however, the temporal change in groundwater depth regime was not factored in this equation. To address this, it was assumed that the groundwater depth regime remained unchanged over a fortnight and the equation was modified every fortnight to evaluate water yield per day for the next 15 days with due authentication of water yield by measuring the discharge and water volume in a tank at different intervals of 15 minutes. It was observed that there were about ±5% errors in estimated and measured values. In this way, the net drafted groundwater for bright sunshine days was estimated for different months. The mean monthly daily water output, along with global solar radiation of the site for different months on a bright day, and the depth of water below ground level are depicted in Fig. 3 and Fig. 4, respectively.

Interpretation of Fig. 2 showed that on a bright sunshine day in April, the net drafted groundwater per day was 174 m^3, whereas in December, it was 104 m^3 per day. In other months, water output per day lies between these two values. Variations in daily water output in different months could be attributed to the change in day length, difference in global solar radiation, and water depth below ground level, m bgl.

The solar irradiance at the site ranged from 200-900 W/m^2 from March to October, and from November to January, it ranged from 200-650 W/m^2. Evaluation of the power rating of a solar array for a given solar irradiance in different months is important in sizing a solar array for a given capacity of solar AC pump. For this, the power rating of a solar array was measured by measuring voltage (V) and current (I) using a multi-meter at intervals of 15 minutes and its rating power using the equation P=VI, where V is the voltage output, and I is the load current of the array as done in other literature (Ajao *et al.*, 2013). The result is depicted in Fig. 3. Interpretation of the plot indicates that only in a few months, over a certain time band, pump runs for 4-5 hours only at its rated power value if the solar panel ratio concerning its operating pump capacity is 1HP:1.kWp.

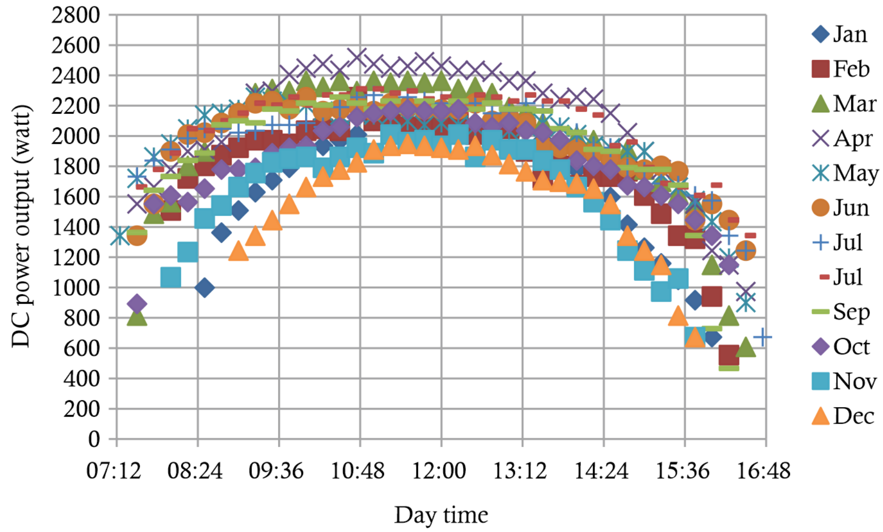

Fig. 3. Power output of 3.06 kW solar array in different months of the experimental site

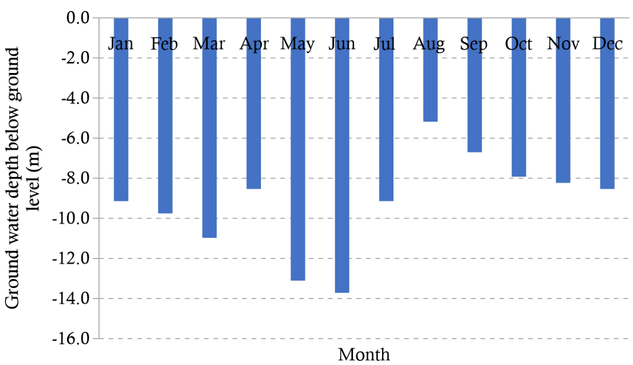

Fig. 4. Groundwater depth regime in different months of the experimental site

CONCLUSIONS

Based on water availability per day, rainfall, and the crop coefficient command area of the 3.0 Hp solar system comprising 3.0 Hp AC energized by a 3.0kWp solar array with tree times manual tracking, the irrigation of this system can be computed. Further, the optimization technique can be implemented to work out a combination of crops for better profitability for the farmers of this region. This system is good for small to medium farms. This study could help optimize the system according to the needs and requirements of farmers, as practical performance does not match factory performance.

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