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Performance characteristics of solar pump in the Bhubaneswar region of Odisha

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Abstract

Irrigation is a major key for sustainable agriculture. In era of improved agriculture, irrigation through pumps are practiced everywhere. Despite of diesel and electric operated pumps, solar pumps gathered a huge popularity for its low installing and maintenance cost. The location where electricity is not available solar photo voltaic pump is the best substitute. Solar PV pumps are designed to operate on DC power produced by solar panels. The current experiment was conducted for studying discharge characteristics of selected solar pump at different levels of solar radiation along with the rate of energy consumption at Bomikhal, Bhubaneswar, Odisha. Different systems such as SPV water pumping system, SPV array, PV generator, D.C motor pump, A.C induction motor pump with suitable inverter were utilized for study purpose. The potential discharge of solar pump was found to be 2075.4 lph at an average temperature of 38 °C and voltage of 81.6 V.

Keywords: Solar pumps, solar PV pumps, SPV array, discharge, D.C motor

Introduction

There are about 21 million irrigation pumps in India among them 43% are diesel engine-operated and 57% are electric operated. Solar pump is considered as an alternative in small-scale irrigation for efficient crop production in the off-grid areas of India. Solar pump is a pollution free and eco-friendly water pumping system in agriculture. Being a tropical country, India is endowed with abundant supply of solar energy. For Bhubaneswar city (20° 16'N 85° 50' E), Odisha, the ranges of solar radiation are between 3.72 and 6.15 kWh/m²/day and bright sunshine hours varies from 6 to 9 h/day. In India about 19.47% land is covered under irrigation. Most of the areas in this location are not grid connected. Solar PV pump can also be used for irrigating the land to increase crop production and also to increase cropping intensity. The location where electricity is unavailable, photovoltaic pumping system is considered to be a better option for irrigating the crops and supply of drinking water. PV water pumping system in the recent past have shown significant advancements during the last decade. The first-generation PV pumping systems mostly used centrifugal pumps which are driven by DC motors and the variable frequency alternating current (AC) motors, with their long-term reliability and their hydraulic efficiency varying from 25% to 35%. The second-generation PV pumping systems uses positive displacement pumps, diaphragm pumps or progressing cavity pumps, generally characterized by their low PV input power requirements, high hydraulic efficiencies of even 70% and low capital cost. The present solar pumping technology uses the electronic systems which have further enhanced the output power, overall efficiency of the system and performance of the system. The controller provides inputs for monitoring storage tank levels, controlling the pump speed and uses maximum power point tracking technology to optimize the water. Advancement has taken place in the tracking mechanism of PV arrays from manual tracking to dual axis automatic tracking systems by microcontroller programming. Tracking the sun reduces the physical size of PV panel area required for a given output, improves power yield, overall efficiency of the system and return on investment. Tracking of a solar pumping system extends the time for peak water yield.

The solar pumps available in the market can lift water from 5 m to more than 200 m with outputs up to 250 m³/day. Advantages of PV pumping systems include low operating cost, unattended operation, low maintenance, easy installation, and long life.

These are all important in remote locations where electricity is unavailable. While viewing beyond original purchase price, the solar pumping systems cost from 22–56% of the diesel pumps' cost and can achieve a payback of over diesel engine-operated pump as small as 2 years period. It has also been reported that their maintenance and high fuel costs have been very long-standing problems with diesel engine. The systems were often present in remote locations, and the challenges of purchasing the imported spare parts and fuel have somehow made them unreliable. In the regions with high insolation levels, photovoltaic pumping systems were technically good, beneficial for the environment and were able to yield cost benefit over the diesel engine driven pumps. However, high initial investment costs were still the main hurdle for acceptance of solar pump. He added that the fuel and lubricants for diesel pumps often pollute wells, groundwater and soil. By contrast, photovoltaic pumps are mostly an environmentally sound and resource conserving technology. Unlike conventional diesel or electrical pumps, solar photovoltaic (PV) pumps are powered by an array of solar panels. Solar PV pumps are designed to operate on DC power produced by solar panels. These pumps are being used all over the world, especially in areas where the electricity is either unavailable or unreliable.

Solar PV pumps are a preferred choice in some remote locations in order to replace the hand-pumps, diesel pumps and grid-connected electrical pumps. In such places, solar PV pumps are economically viable in comparison to conventionally/traditionally run pumps. Ministry of New & Renewable Energy (MNRE) has been promoting the use of

Solar-Off Grid Programme since two decades. This programme size has enhanced many fold with the advent of Solar Mission, giving very much impetus to various components of the programme in which the solar pumping is one of the vital component. Solar Pumping Programme was first started by MNRE in the year 1992. From 1992 to 2014, 13964 no. of solar pumps have been installed in the country. This number is minuscule, if we compare with the pumps in agricultural sector. High costs of solar modules during these years resulted in low penetration of solar pumps. However, in recent times the module costs have started decreasing and are presently hovering.

The experiment was concluded with the following objectives

1. To study the discharge characteristics of the selected solar pump at different levels of solar radiation in a clear sunny day
2. To develop the relation between head and discharge.
3. To plot the performance characteristic curves.

Materials and methods

Study area

The present study area is situated at Tech Land Private Ltd., Bomikhal, Bhubaneswar. The area is located at longitude of 85°51'30.0492"E and latitude of 20°16'59.718"N. The altitude of this watershed ranges from 45 m above mean sea level. Location map of the study area is shown below.

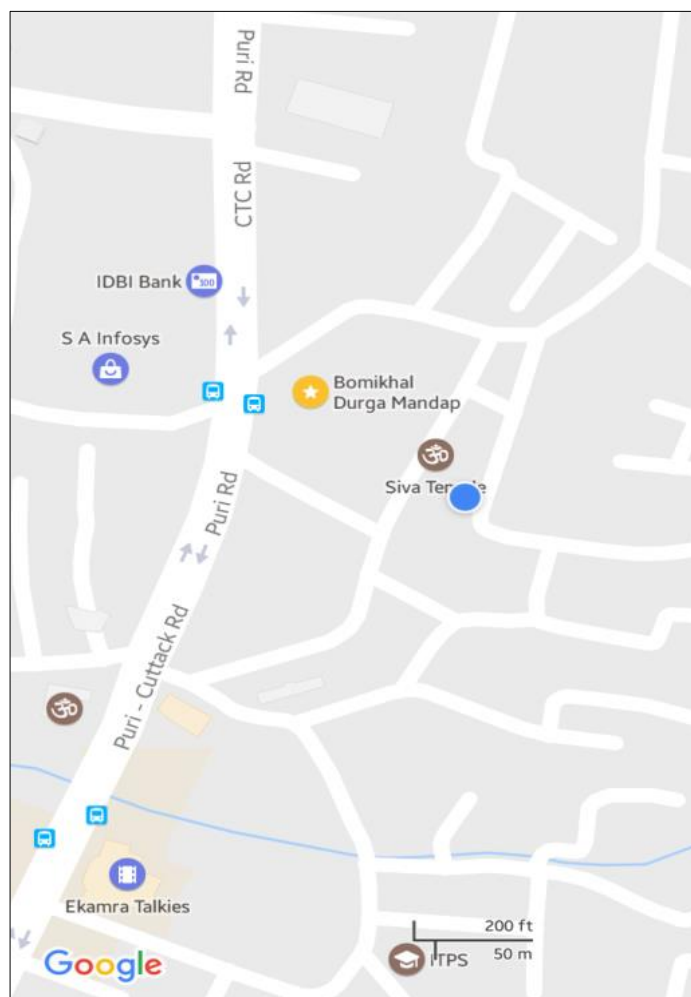


Fig 1: Location of study area indicating in the map



Fig 2: The mobile solar pump

Components of the system

1) SPV water pumping system

The major constraints of the study area are SPV panel and solar pump used in this project work. A SPV water pumping

system consists of a PV array, a DC 1hp submersible motor pump set, and electronics. The PV Array is mounted on a suitable structure with a provision

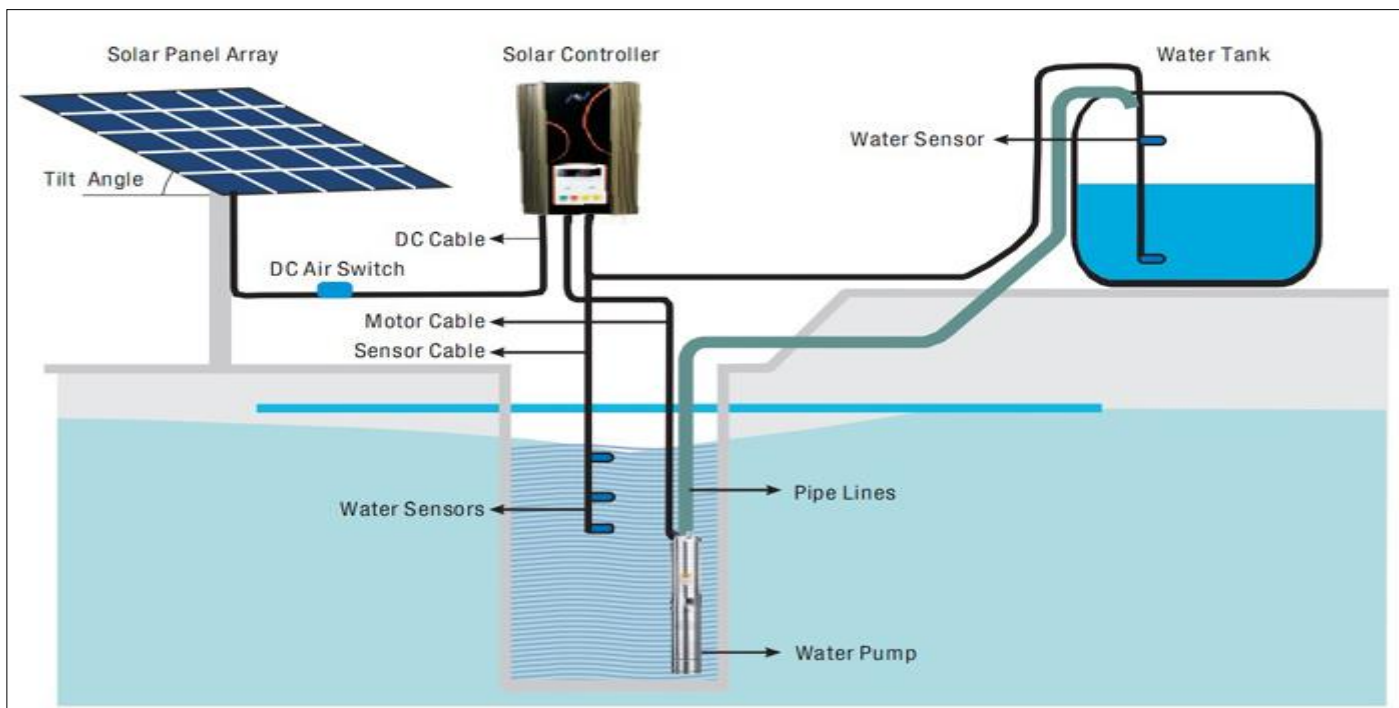


Fig 3: SPV water pumping system layout

of manual tracking. Water is pumped during day (6 Hr. working per day) and stored in tanks, for use during day time, night or under cloudy conditions. The water tank acts for storage and the generally battery is not being used for storage of PV electricity; however, for some specific reliable requirements it can be used. The components which are used in the PV water pumping system should conform to the national/international specifications, whichever is applicable in the country.

Solar water pumping is based upon the PV technology which converts sunlight to electricity to pump water. The PV panels are being connected to a motor (AC or DC) which converts the electrical energy supplied by the PV panel to mechanical energy which is converted to hydraulic energy by the pump.

The capacity of solar pumping system to pump water is a function of the three main variables: pressure, flow, and power to the pump. For design purpose the pressure can be regarded as work done by the pump to lift certain amount of water to the storage tank. The difference in elevation between the water source and the storage tank determines the work of the pump. The water pump draws a certain power of which a PV array needs to supply.

2) PV Array

The SPV water pumping system for irrigation and domestic drinking water is operated with a PV array of capacity in the range of 75 Watts peak to 5000 Watts peak which is measured under the Standard Test Conditions (STC). A sufficient

number of modules in series and parallel was used to obtain the required output of PV array power.

Indigenously produced PV module (s) which contain mono/multi crystalline silicon solar cells were used in the PV array for the SPV Water Pumping systems.

- Modules that were supplied with the SPV water pumping systems must have certificate as per IEC 61215 specifications or equivalent National or International Standards.
- Modules must qualify to IEC 61730 Part I and II for safety qualification testing.

- The efficiency of the PV modules must be minimum 14% and fill factor should be more than 70%.

The terminal box present on the module should have provision to open for replacing the cable, if required.

3) PV generator

PV generator of a solar pump consists of PV modules connected in series and parallel combination as per motor voltage requirement. A PV module consists of solar cells which convert solar radiation into direct electricity.



Fig 4: Display of folding type solar panel over a flatbed stand

A pump requires a certain power to produce a certain amount of pressure and flow. Therefore the PV array size was optimized for the required amount of power. A higher capacity PV generator allows the pump to start earlier and operate for longer period during the day under low insolation conditions. However, adding more PV panels than actually required will add to the cost. The large panel surface area acts as a linear current booster; and a separate linear current booster may not be required.

4) Mounting structures and tracking system

The PV modules were mounted on metallic structures of adequate strength and appropriate design, which can withstand load of modules and high wind velocities up to 150 km per hour. The support structure used in the pumping system was hot dip galvanized iron with minimum 80 micron thickness.

To increase the performance of SPV water pumping systems above 0.5 HP, manual or passive or auto tracking system should be used.

5) ON/OFF Switch

A good reliable switch suitable for AC /DC was provided with the motor pump set. Proper length of cable must be provided for the inter-connection between PV array and motor pump set.

For D.C. motor pump set with brushes or brushless D.C. (B.L.D.C.)

1. 100 litres of water per watt peak of PV array, from a Total Dynamic Head of 10 meter (Suction head, minimum of 7 meters) and with the shut off head being at least 12 meters.

2. 55 litres of water per watt peak of PV array, from a Total Dynamic Head of 20 meters (Suction head, if applicable, up to a maximum of 7 meters) and with the shut off head being at least 25 meters.
3. 35 litres of water per watt peak of PV array, from a Total Dynamic Head of 30 meters and the shut off head being at least 45 meters.
4. 21 litres of water per watt peak of PV array, from a Total Dynamic Head of 50 meters and the shut off head being at least 70 meters.
5. 14 litres of water per watt peak of PV array, from a Total Dynamic Head of 70 meters and the shut off head being at least 100 meters.

The real duration of pumping water on a particular day and quantity of water pumped might vary depending upon solar intensity, location, season, etc.

For A.C. Induction Motor Pump set with suitable Inverter

1. 90 litres of water per watt peak of PV array, from a Total Dynamic Head of 10 meters (Suction head, if applicable, minimum of 7 meters) and with the shut off head being at least 12 meters.
2. 50 litres of water per watt peak of PV array, from a Total Dynamic Head of 20 meters (Suction head, if applicable, up to a maximum of 7 meters) and with the shut off head being at least 25 meters.
3. 32 litres of water per watt peak of PV array, from a Total Dynamic Head of 30 meters and the shut off head being at least 45 meters.
4. 19 litres of water per watt peak of PV array, from a Total Dynamic Head of 50 meters and the shut off head being at least 70 meters.

5. 13 litres of water per watt peak of PV array, from a Total Dynamic Head of 70 meters and the shut off head being at least 100 meters.

Solar pumps



Fig 5: Submersible Solar pumps of different horsepower

Solar water pumps are being rated as per the voltage supplied and requires accessories like float valves, filters, switches, etc. to function optimally. Solar pumps are being constructed from very high quality, low lead marine grade bronze and stainless steel and are designed for corrosion-free and maintenance-free service even in harsh environment with long term performance and reliability.

Performance parameters of a solar pump

The performance of PV solar water pump mainly depends upon the water flow rate which is being influenced by the weather conditions in the location, especially the solar irradiance and air temperature variations. The performance of solar pump depends on the water requirement, size of water storage tank, head (m) by which water has to be lifted, water to be pumped (m^3), PV array virtual energy (kWh), Energy at pump (kWh), unused PV energy (kWh), pump efficiency (%), and system efficiency (%) and diurnal variation in pump pressure due to change in irradiance and pressure compensation. The efficiency of PV technology used in PV generator has also a great influence on the performance. Besides the degradation of PV panels is one of the important parameters which affect the performance of a solar pump.

The performance of solar water pumping system depends on

- Solar radiation availability at the location;
- Total Dynamic Head (TDH):

Discharge head (height from pump to storage inlet) was measured and frictional head losses were calculated and added together.

The performance of solar water pump also depends on

- Total quantity of water requirement; and Hydraulic energy: potential energy required in raising the water to discharge level.
- Stefan Boltzmann law states that

$$\text{i.e. Thermal radiation} = (P/A) = \sigma T^4$$

Where, Thermal radiation is expressed in J/m^2s

P/A is radiation per second per unit area
T is temperature in Kelvin.

$$\sigma = 5.6103 \times 10^{-8} \text{ watt}/m^2k^4$$

The above law indicates that thermal radiation is directly proportional to the power of temperature in Kelvin.

- Voltage generated by PV cell unit was measured by voltmeter.

Procedure for measurement of discharge of a solar pump

To study the Performance Characteristics of the Solar Pump required data's were taken. Total static head of 1hp DC solar pump, its discharge rate for 6hr working in a day, temperature, wind speed, PV cell volts for every half hour interval was noted.

The instruments used in this project are

- 1 hp DC solar pump (manufactured by Techland systems Pvt Ltd.)
- Foldable 3 PV module Type: Model TITAN M6-60 (class A, Safety class II)
- Delivery pipe of 10 cm diameter
- Steel tape
- Anemometer with temperature sensor

Static head of the submersible solar pump is 6.77m measured which is becomes 8.124m with addition of 20% friction losses.

$$\text{Total static head} = 6.77m + (6.77m \times 20\%) = 8.124m$$

For every half hour interval the discharge rate was measured. Wind speed in m/s and temperature in $^{\circ}C$ were recorded. Voltage of PV cell was also noted down for discharge measurement. The time taken to fill up the bucket was noted down. Then discharge was estimated. Finally, the average discharged was found out.

Results and discussion

This chapter deals with results obtained from the project work. Various performance characteristics were also plotted which are suitable for judging the performance of a 1hp SPV water pumping system.

Table 1: Observation of different parameters of 1 hp solar pv pump at different time scale in Bhubaneswar city.

Time (HH:mm)	Temperature (in $^{\circ}C$)	Wind Speed (m/s)	Voltage (volts)	Radiation (j/m^2s)	Discharge (L/hr)
10:30	33	1.364	79.3	497.154	1949.64
11:00	33	1.253	79.3	497.154	1949.04
11:30	34	1.345	81.6	503.685	1948.32
12:00	33	0.209	81.6	497.154	1980.17
12:30	38	0.509	81.6	530.453	2001.96
13:00	38	0.547	81.6	530.453	2075.4
13:30	35	0.88	81.7	510.28	1874.16
14:00	37	0.802	79.6	523.664	1811.19
14:30	34	0.993	79.7	503.685	1928.16
15:00	33	1.171	79.7	497.154	1837.44
15:30	34	0.835	79.7	503.685	1849.07
16:00	34	0.835	79.7	503.685	1877.3
Average=	34.66667	0.89525	80.425	508.1838	1923.488

*At an average temperature of $34.7^{\circ}C$, voltage of 80.42 V and radiation of $508.2 j/m^2s$. it was found that the average discharge was 1923.48 lph

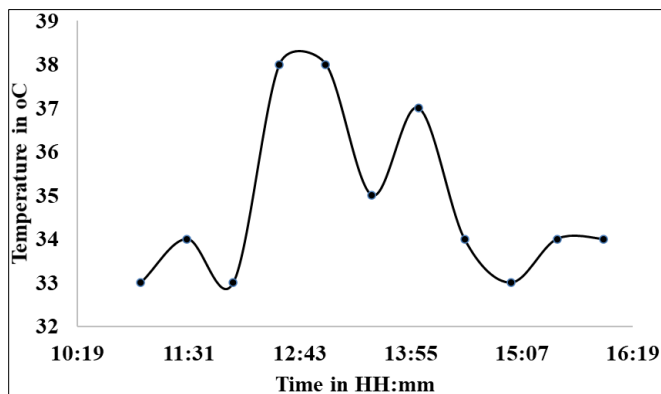


Fig 6: Temperature versus time

Temperature remains higher during 12 pm to 1 pm as shown in fig 6. This is the peak time to get higher discharge rate of solar pump.

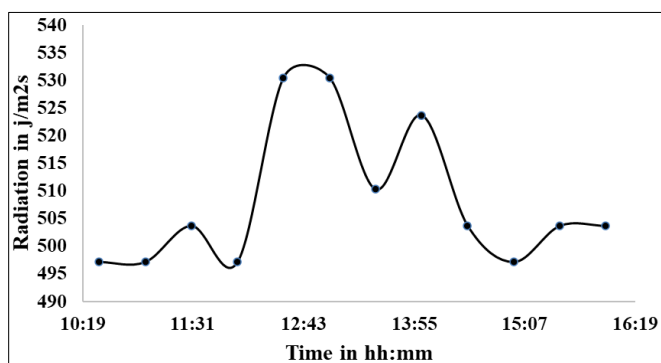


Fig 7: Radiation versus time

Radiation remains higher during 12 pm to 1 pm as shown in fig 7. This is the peak period for solar radiation. Cloud disturbance sometimes causes the decrease in radiation.

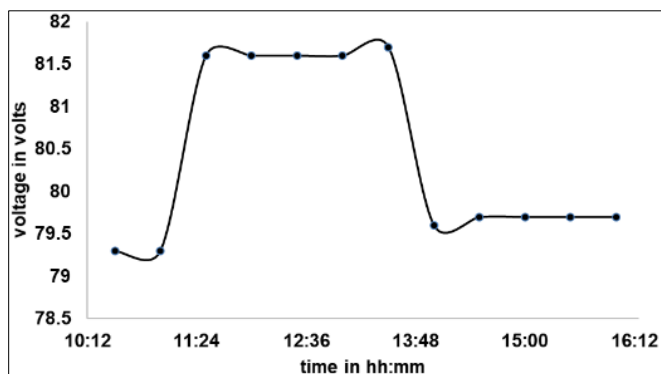


Fig 8: Voltage versus time.

During the period 12 pm to 2 pm the voltage remains higher as shown in fig 8, due to the perpendicular rays of sun falling on the PV cell.

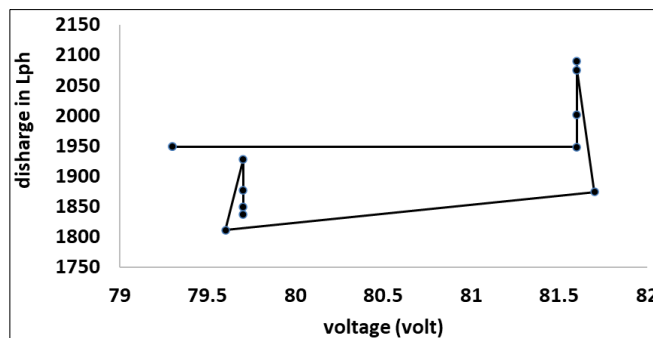


Fig 9: Variation of Discharge at different Voltage

Fig 9 shows that with increase in voltage, the discharge of water increases. Cloud disturbance sometimes causes the decrease in discharge.

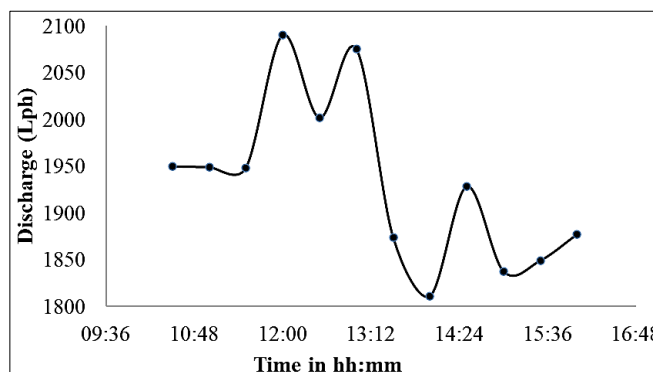


Fig 10: Variation of discharge at different times in a day

Fig 10 shows as the solar intensity increases with time, discharge rate increases. If discharge falls unusually, the factors like cloud weather, rain etc may be responsible.

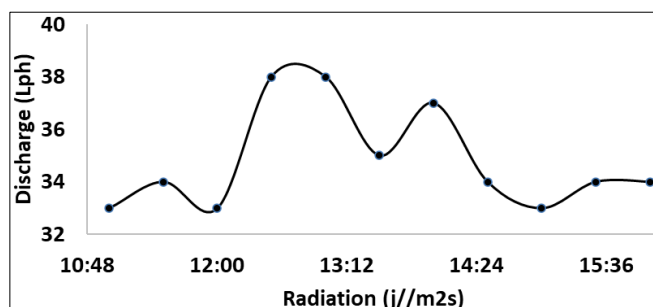


Fig 11: Variation of Discharge (Lph) at different Radiation (J/m²s)

Fig 11 shows that with increase of solar radiation, the volume of water pumping increases. But this may be affected with various factors at any time of a day.

Table 2: Characteristics curves between total head and discharge capacity of different horse powered solar pump

Discharge rate (lpm)	Head in meters					
	0.5 Hp	0.75 Hp	1 Hp	1.5 Hp	2 Hp	2.5 Hp
0	15	17.5	19.5	21.5	24.5	30
38	14	17	19	21.1	24.1	28.7
76	13	16	18.5	21	23.9	27.2
114	12	15	17.5	20	23	26
151	10	13.5	16.5	19	22	25
189	7.5	11	15	18	21	24

227	4	8	13	16	19.5	22
265		5	10.5	14	18	21
303			7.5	12	16	19
341				9	14	16.5
379					12	13.5
416					9	

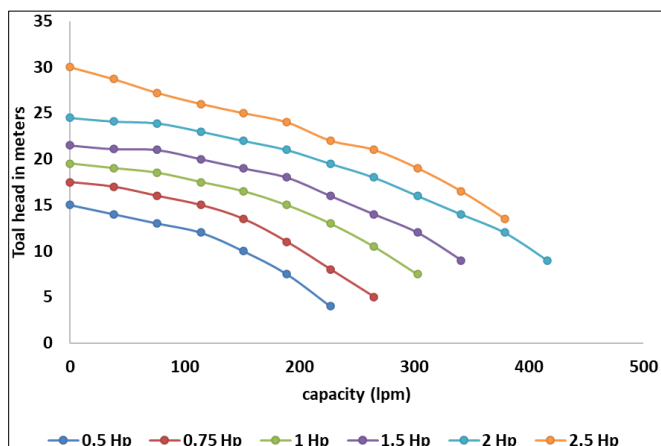
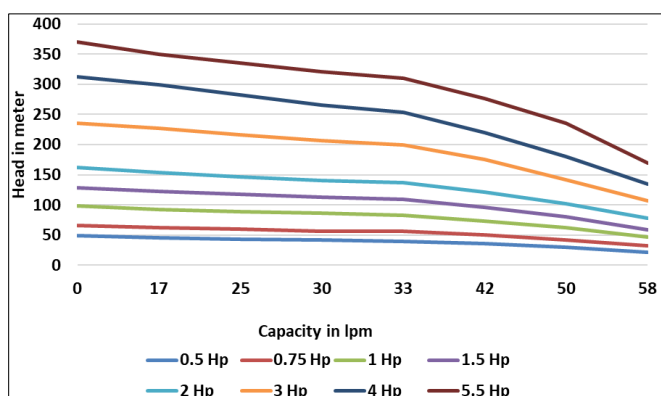


Table 3: Characteristics curves between total head and discharge capacity of different horse powered solar pump

Discharge rate in lpm	Total head in meters							
	0.5 Hp	0.75 Hp	1 Hp	1.5 Hp	2 Hp	3 Hp	4 Hp	5.5 Hp
0	49	66	98	129	162	236	313	370
17	46	63	93	123	154	227	299	350
25	43	60	89	118	147	216	282	335
30	42	57	86	113	141	207	266	321
33	40	56	83	109	137	200	254	310
42	36	50	73	96	121	175	220	276
50	30	42	62	81	102	142	180	235
58	22	32	47	59	78	107	135	170



Conclusions

The following conclusions were drawn from the study.

- The potential discharge of solar pump was found out to be 2075.4 lph at temperature of 38°C, voltage 81.6 V and radiation of 530.453 J/m²/s.
- From the study it was found that, the effective working hour of solar pump in the month of April is 5½ hrs.
- Wind speed has no interference on the discharge of solar pump.
- The average discharge at an average temperature of 34.7 °C, voltage of 80.425 V, and radiation of 508.1838 j/m²/s, was found to be 1923.48 lph.
- The other major aspects that influence the working of SPV water pumping system are

- Weather condition (i.e. cloudiness, raining, higher wind speed)
- Orientation of the solar panel towards sun.
- Total static head of the pump
- Diameter of the delivery pipe
- Quality and efficiency of solar panel.
- Material of the PV cell
- Area specific discharge rate
- Elevation of the area

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