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Design and economic analysis of a solar PV water pumping system for irrigation of banana

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ABSTRACT : This paper presents design and economic analysis of efficient solar PV water pumping system for irrigation of banana. The system was designed and installed in solar farm of Jain Irrigation System Limited (JISL), at Jalgaon (Maharashtra). The study area falls at 21^0 05' N – latitude, 75^0 40'E–longitude and at an altitude of 209 m above mean sea level. The PV system sizing was made in such a way that it was capable of irrigating 0.41 acre of banana plot with a daily water requirement of 9.72m^3/day and total head of 26m. Also, the life cycle cost (LCC) analysis was conducted to assess the economic viability of the system. The results of the study encouraged the use of the PV systems for water pumping application to irrigate orchards.

KEY WORDS : Latitude, Life cycle cost, PV, Water pumping

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Recently the water demand has been increased due to the increase in the population and the availability of water has become more crucial than ever before. A source of energy to pump water is also a big problem in developing countries like India. Developing a grid system is often too expensive because rural villages are frequently located too far away from existing grid lines. Even if fuel is available within the country, transporting that fuel to remote, rural villages can be difficult. There are no roads or supporting infrastructure in many remote villages. The use of renewable energy is attractive for water pumping applications in remote areas of many developing countries. Transportation of renewable energy systems, such as photovoltaic (PV) pumps, is much easier than the other types because they can be transported in pieces and reassembled on site (Khatib, 2010). Photovoltaic (PV) energy production is recognized as an important part of the future energy generation. Because it is non-polluting, free in its availability, and is of high reliability. Therefore, these facts make the PV energy resource attractive for many applications, especially in rural and remote areas of most of the developing countries like India. Solar photovoltaic (PV) water pumping has been recognized as suitable for grid-isolated rural locations in poor countries where there are high levels of solar radiation. Solar photovoltaic water pumping systems can provide water for irrigation without the need for any kind of fuel or the extensive maintenance required by diesel pumps. They are easy to install and operate, highly reliable, durable and modular, which enables future expansion. They can be installed at the site of use, rendering long pipelines unnecessary (Andrada and Castro, 2008). Therefore, an attempt has been made to design and develop efficient solar water pumping system for irrigating banana at Jain irrigation system limited (JISL), Jalgaon (Maharashtra).

METHODOLOGY

Design of solar PV system for water pumping (Fig. A-C) :

Water requirement of the plant :

The water requirement of plants varies with time and depends on the season and growth of plants. It is essential to irrigate optimally during the stage of flowering to fruit maturity. The type of soil and the climatic parameters are other factors that need to be considered. However, in the present study the peak water requirement of the plant was evaluated to design the system and for that the following equation was used :

$$W_r = \frac{\text{Crop area} \times PE \times P_c \times K_c \times W_a}{E_u} \qquad \text{...... (1)}$$

where,

W_r = peak water requirement, (lit /day/plant)
Crop area= row to row spacing (m) × plant to plant spacing

Fig A: Side view of installed solar PV system

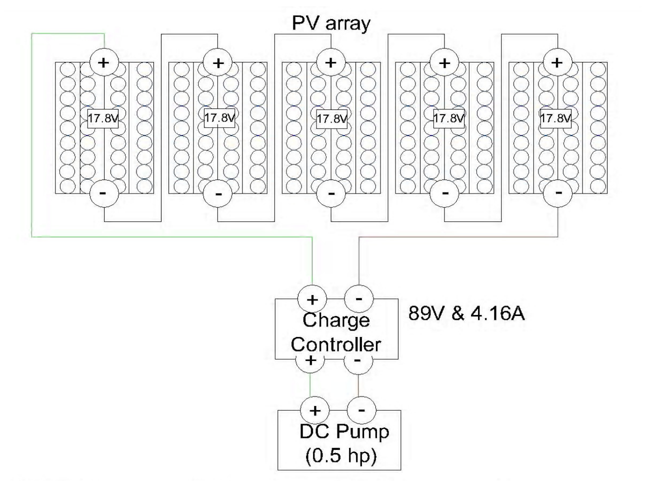

Fig C : Solar PV system with five modules each of 17.8V connected in series

Fig B: Designed solar PV system installed at site

of the crop (m)

P_c = pan co-efficient, approximately taken as 0.7 to 0.8

K_c = crop co-efficient (Given in Table A)

PE = pan evaporation rate, (mm/day) (Given in Table B)

W_a = wetted area, (%) (Assumed 60 % for banana)

E_u = emission uniformity of drip system, (approx taken as 0.90).

Daily insolation levels :

The power output from the PV array depends upon the insolation and availability of sun per day *i.e.* sunshine hours available on a particular location per day. The insolation varies from one location to another, month to month because of seasonal and climatic changes. If water requirement is in the same range of the whole year then solar design calculations is based on the month with the lowest insolation of the year. If water consumption varies round the year then the system design is based on the ratio of water required to the insolation

Table A : Crop co-efficient constants (K_c) for computing crop water requirement

Growth stages	Crop co-efficient constant for banana
Initial	0.4-0.5
Development	0.7-0.85
Middle	1-1.1
Late	0.9-1
Harvest	0.7-0.8

(Source- Crop evaporation for computing crop water requirement, FAO, Irrigation and Drainage Paper, No-56, 1998.)

Table B: Monthly average pan evaporation rate (mm/day) of Jalgaon from 2006 to2010

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PE(mm/day)	4.09	5.015	6.22	9.95	13.01	8.78	3996	3.57	4.37	5.59	4.32	4.045

available. The month in which this ratio is largest can determine the optimum PV array size in W/m^2.

Orientation and direction of the PV array :

Orientation of the PV array is one of the most important aspects of the site assessment. The PV array is positioned in such a way that the sunlight is utilized to its maximum that is true south direction. The ideal orientation for panels is south as they will be exposed to the Sun for the maximum length of time during daylight hours, although other orientations still produce considerable amounts of power and attract significant tariff income. The local declination which depends on the location and changes with the times should, however, be taken into account.

Determination of tilt angle

The tilt angle was selected in accordance with the latitude of the location. Latitude of Jalgaon is 21° 05' N, therefore solar PV array was tilted at this angle with the help of clinometer.

Sizing and selection of PV module :

The size of a PV array was calculated by using following equation,

$$E=\frac{\rho gHV}{3.6\times10^{6}} \qquad \text{......(2)}$$

where,

E = hydraulic energy required (kWh/day)

ñ = density of water (1000 kg/m^3)

g = gravitational acceleration (9.81 m/sec^2)

H = total hydraulic head (m)

V = volume of water required (m^3/day)

By putting above all values, equation reduces as shown below;

$$E = 0.002725HV\ (\text{kWh/day}) \qquad \text{......(3)}$$

Life cycle cost analysis of system (LCCA) :

This is a method for assessing the total cost of facility ownership. It takes into account all costs of acquiring, owning, and disposing of a system. In this research, implementing LCCA for the current system (diesel driven pump) and for the alternative that considered to replace it (PV pump system) gives the total cost of both - including all expenses incurred over the life period of the both systems. There are two main reasons to implement life cycle cost analysis.

–To compare different power options and to determine the most cost-effective system designs.

The life-cycle cost of both alternatives listed in this project can be calculated using the formula:

$$LCC = CC + MC + EC + RC - SC \qquad \text{......(4)}$$

where,

CC= Capital cost

MC= Maintenance cost

EC= Energy cost

RC=Replacement cost

SC=Salvage value.

The capital cost (CC) of a project includes the initial capital expense for equipment, the system design, engineering, and installation. The energy cost (EC) of a system is the sum of the yearly fuel cost. Replacement cost (RC) is the sum of all repair and equipment replacement cost anticipated over the life of the system. The salvage value (SC) of a system is its net worth in the final year of the life-cycle period.

RESULTS AND DISCUSSION

The experimental findings obtained from the present study have been discussed in following heads:

Water requirement of the plant :

Peak water requirement of the banana for Jalgaon was calculated as per the equation (1) and is tabulated in Table 1.

Table 1: Month wise calculated water requirement of banana

Month	Water requirement of the banana (litres per day) (for plantation in June month)
Jan	6.78
Feb	8.30
Mar	9.26
April	13.17
May	17.22
June	5.81
July	4.62
August	5.02
Sep	7.23
Oct	8.65
Nov	7.86
Dec	7.45

Daily insolation levels :

The monthly average daily global solar radiation was calculated using daily data of global solar radiation obtained by measurements by IMD in Jalgaon (Table 2). The solar radiation given was the global radiation received by a unit horizontal surface during a day, as recorded by the solar radiation meter.

Ratio of water requirement to solar radiation (W_r/S_r) :

From Table 3 it was clear that for a month of May the ratio of water requirement to solar radiations was largest, therefore, solar radiation of 680 W/m^2 and water requirement of 17.22 lpd per plant (nearly 18 lpd) were considered for optimum PV array sizing calculations.

Sizing and selection of PV module :

No of plants =540

Peak water requirement of plant =17.22˜18 lpd

Total head of the system =26 m

Volume of water required =18×540

=9720 litres

=9.720 m^3

Therefore, by using equation (3),

E=0.0002725×26×9.720

= 0.6886 kWh/day

= 688.66 Wh/day

Assuming, actual sunshine hours = 8 hrs in a day

Total wattage of PV panel =688.66/ 8

=86.08 W

Considering system losses,

$$\text{Total wattage of PV Panel} = \frac{\text{Wattage of panel}}{\text{System efficienc} \times \text{Mismatch factor}}$$

Table 2 : Month wise average solar radiation data (W/m^2) of 2011

Month	Average solar radiation (W/m^2)
Jan	633.18
Feb	473.24
Mar	722.307
Apr	751.37
May	680.00
Jun	579.39
Jul	417.39
Aug	436.44
Sep	554.08
Oct	606.43
Nov	488.068
Dec	482.64

Table 3 : Ratio of water requirement to solar radiations for banana plant

Sr.No.	Month	Water requirement (W_r) (lpd per plant)	Solar radiations available (S_r) (W/m^2)	Ratio of water requirement to solar radiations (W_r/S_r)
1.	Jan	6.78	633.18	0.01070
2.	Feb	8.30	473.24	0.0175
3.	Mar	9.26	722.307	0.01128
4.	Apr	13.175	751.37	0.0175
5.	May	17.22	680.00	0.0253
6.	Jun	5.814	579.39	0.0100
7.	Jul	4.62	417.39	0.01106
8.	Aug	5.02	436.44	0.01150
9.	Sep	7.234	554.08	0.01306
10.	Oct	8.651	606.43	0.01426
11.	Nov	7.867	488.068	0.0161
12.	Dec	7.451	482.64	0.0154

$$= \frac{86.08}{0.30 \times 0.85} = 337.56\ \mathrm{W}$$

Number of solar panels required
= 74 W panel each x panels = 370 W power

All these electrical measurements were carried out at standard test condition of 25°C cell temperature, 1.5AM (Air mass ratio) and 1000W/m^2 solar intensity.

Life cycle cost analysis of system (LCCA) :

To analyze the costs for the both systems, the following factors need to be considered for an optimum conclusion

- The operating life of the PV panels was assumed to be 20 years and life of diesel engine assumed to be as 10 years.
- Maintenance cost of PV system assumed to be a 0.1 per cent of total capital cost per year.
- Maintenance cost of diesel engine assumed to be a 10 per cent of total capital cost per year.
- Availability of sunshine hours considered to be a 300 days in a year.
- Cost of 0.5 hp diesel engine= ‘ 4800 and it consumes 0.5 litre of diesel/hr
- Operating hours= 6.02 hr/day
- The replacement value is evaluated to be once during the life analysis for diesel that covers the diesel engine as well as the pump.
- Net present worth in the final year of life cycle of PV system was ‘ 103840.7/-
- Salvage value of diesel engine was assumed to be a 20 per cent of capital cost of engine.

Annual Fuel Cost = Specific fuel consumption× Fuel Rate× total no. of operating hours in a year
= 0.5 lit/hr × 6.023×300×41 ‘/lit
= ‘ 37041.45/-

Energy/ fuel cost of diesel engine for 20 years= 20×37041.45 = ‘ 740829/-

As shown in Fig. 1, the PV pumping system has higher initial cost than the diesel-powered pump but its recurrent cost proved declining over their current cost. However, in remote areas aspects such as lower operation and maintenance

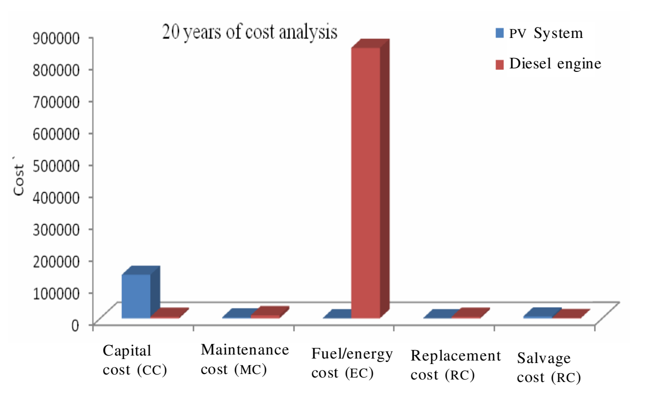

Fig 1 : Cost comparison of PV system and diesel engine by life cycle cost analysis

Table 4 : Technical specification of photovoltaic module

Module size (mm)	924×659×35
Module weight (kg)	7.5
Maximum peak power (W)	74
Open circuit voltage V_{oc} (V)	22.10
Short circuit current I_{sc} (A)	4.67
Voltage at maximum peak power V_{mpp} (V)	17.8
Current at maximum peak power I_{mpp} (A)	4.16
Maximum system voltage (V)	50

Table 5 : System cost comparison by life cycle cost analysis

Sr. No.	Costs (`)	PV system	Diesel engine
1.	Capital cost(CC)	136233.5	4800
2.	Maintenance cost (MC)	2724.67	9600
3.	Fuel/energy cost (EC)	None	740829
4.	Replacement cost (RC)	None	4800
	Total cost, `	138958.17	760029.0
5.	Salvage cost (SC)	6034.05	960
	Life cycle cost (LCC)	132924.12	759069.0

costs, the more reliability as well as the longer expected useful life of PV systems could economically justified the higher initial cost of PV systems. The comparison of the life cycle costs of the both systems also noted that the operation and maintenance cost and fuel cost are higher for the diesel system, and if it is considered that fuel prices are increasing, these numbers could keep going up. The bar chart in Fig. 2 shows that the fuel cost of the diesel system was really high compared with other costs within the system such as operation and maintenance cost, replacement as well as the capital cost. The total cost for the both system throughout the 20 years life cycle is shown in Fig. 2 .

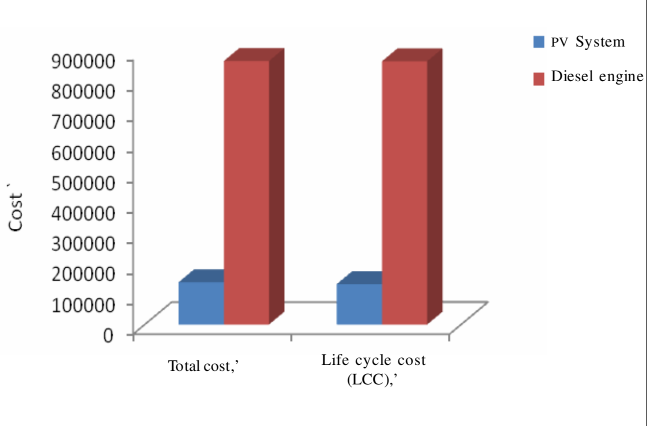

Fig 2 : Total cost and life cycle cost in 20 years

Conclusion :

Based on the results of the investigation, the following conclusions were drawn:

- The installed system of solar PV water pumping system was capable of irrigating 0.41 acre area of banana crop within 6.02 hrs with an daily water requirement of 9.72m^3/day.
- The results of the study indicate that irrigating orchards in the remotest areas using PV systems is beneficial and suitable for long-term investments as compared to diesel powered engines as total cost (TC) of PV system considering life span of 20 years was found to be ‘ 138958.17/- while total cost (TC) of diesel engine was ‘ 760029.0/-.
- Life cycle cost (LCC) of PV system was ‘ 132924.12 /- while that of diesel engine was found to be ‘ 759069.0/-. The life cycle cost analysis done that covered both systems proves that the PV water pumping system is the more economical choice over the diesel water pumping system.

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REFERENCES

Andrada, P. and Castro, J. (2008). Solar photovoltaic water pumping system using a new linear actuator. Grup d’Accionaments Electrics amb Commutació Electrònica (GAECE), ENGLAND.

Anonymous (1998). Crop evaporation for computing crop water requirement, FAO, Irrigation and Drainage Paper, No-56.

Cuadros, F., Fernando, L. and Marcos, A. (2004). A procedure to size solar-powered irrigation (photoirrigation) schemes. *Solar Energy,* **76**: 465–473.

Curtis, K.R. (2010). Economic feasibility of solar photovoltaic irrigation system use in great basin forage production. *Eco. Appl. Econ.*,2010-04p.

Khatib, T. (2010). Design of photovoltaic water pumping system at minimum cost for Palestine: a review. *J.Appl. Sci.,***10**(22):2773-2784.

Kolhe, M., Kolhe, S. and Joshi, J.C. (2002). Economic viability of stand-alone solar photovoltaic system in comparison with diesel-powered system for India. *Engy Eco.,* **24**:155-165.

Mahjoubi, A., Mechlouch, R.F. and Brahim, A.B. (2010). Economic viability of photovoltaic water pumping systems in the desert of Tunisia. *Internat. Renew. Engy Congress* ID84.

Nafeh, A.E. (2009). Design and economic analysis of a stand-alone PV system to electrify a remote area household in Egypt. *Open Renew.Engy J.,* **2**: 33-37.

Odeh, I,Yohanis,Y.G. and Norton,B.(2005). Economic viability of photovoltaic water pumping systems. *SolarEnergy,* **80:**850-860.

Pande, P.C., Sing, A.K., Ansari, S., Vyas,S.K. and Dave, B.K. (2003). Design development and testing of a solar PV pump based drip system for orchards. *Renew. Engy,* **28**:385–396.

Sako, K.M.,N‘guessan,Y.,Diango,A.K.andSangare,K.M. (2011). Comparative economic analysis of photovoltaic, diesel generator and grid extension in cote D’ivoire. *Asian J.Appl. Sci.,* **4**: 787-793.

Stoppato, A.(2008). Life cycle assessment of photovoltaic electricity generation. *Energy*, **33**(2):224–32.

Vick, B.D. and Clark, R.N. (2007). Comparison of solar powered water pumping systems which use diaphragm pumps. *ASES 2007, Sustainable Energy Puts America to Work,* **12**:6.

Yesilata, B. and Firatoglu, A.Z. (2008). Effect of solar radiation correlations on system sizing: PV pumping case. *Renew. Engy.,* **33**(1): 155-161.

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