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Solar PV pumping system for irrigation purpose and its economic comparison with grid- connected electricity and diesel operated pumps

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Abstract

Objectives: Use of solar PV (SPV) pumping system for irrigation has recently been increased significantly specially under the national solar mission and these pumps may replace conventional electric or diesel pumps.
Methods/Statistical analysis: In this paper, economics of SPV pumping system has been evaluated through life cycle cost (LCC). In LCC analysis, capital cost, future maintenance cost and replacement cost are converted to present worth value considering inflation rate and discount rate during its total life cycle. Annualized life cycle cost (ALCC) of solar PV pumping system has been further compared with conventionally used grid connected electric pumps and diesel pumps.
Findings:The analysis revealed that the annualized life cycle cost (ALCC) of PV pumping system is lower than grid connected electric pumps and diesel pumps. For example, the ALCC for a 5 HP capacity SPV pumping system was found ₹ 56,620, whereas it were ₹ 60,475 and ₹ 1,19,664 for grid connected electricity operated pumps and diesel pumps, respectively. It has also been observed that the initial capital cost for solar PV pumping system is higher than grid connected electric pumps and diesel pumps. However, the maintenance cost and replacement cost are lower for PV pumping system.
Application/Improvements: Apart from economic advantage, PV pumps have additional benefits of using it for domestic and farm needs. Therefore PV pumping system may be considered as the first choice by farmers.

Keywords: Life cycle cost, Capital cost, Maintenance cost, Solar PV pumping system, Irrigation

1. Introduction

Water is the primary source of life for mankind and one of the most basic necessities for crop production. The demand for water to irrigate the crops is increasing. For sustainable production from agricultural farms, irrigating the crops at right stages is highly important. Even in rain fed situation, lifesaving irrigation during long dry spell has also been found beneficial for crop survival and to obtain the targeted yield. Considering the depletion of groundwater below the critical zone in most part of the country, energy intensive pumping for irrigation is not a viable option. Therefore utilization of available runoff water through surface storage systems followed by pumping may be a potential solution to achieve the set goal of 'crop per drop' mission. In this connection, micro-irrigation system including drippers and sprinklers is of great importance. However, ensured power supply is essential to operate the micro-irrigation system even in remote areas. Solar photovoltaic (PV) pumps are rapidly becoming more attractive than traditional electrified and diesel operated pumps. Powered by renewable energy sources, solar PV pupms are especially useful in remote locations where a steady fuel supply or electricity supply is problematic. About 16 million electric pumps and 7 million diesel pumps are in operations in the country for irrigation purpose; however they are highly energy intensive. Moreover, diesel operated and electrified pumps directly or indirectly emit large amount of CO_2 gas in atmosphere and hence are not environment friendly. To meet the energy demand for irrigation, solar photovoltaic (PV) pumps have been introduced under the off-grid power generation category of National Solar Mission (NSM) with a target of 1000 MW by the end of phase II (2013-2017) (Table 1).

Table 1. National solar mission targets

Sr. No.	Application segment	Target for Phase I (2010-13)	Target for Phase II (2013-17)	Target for Phase III (2017-22)
1.	Grid connected solar power generation	1,100 MW	4,000 MW	1,00,000 MW*
2.	Off-grid solar applications (includes solar PV pump)	200 MW	1,000 MW	2,000 MW
3.	Solar thermal collectors	7 million sq. m.	15 million sq. m.	20 million sq. m.
4.	Solar lighting systems	5 million	10 million	20 million

Source: Ministry of Renewable Energy Sources, Govt. of India
*The revised target (The target has been revised in 2015 to a total grid connected solar power generation of 1,00,000 MW comprising 40,000 MW roof top generation and 60,000 MW grid connected solar power plants (Resolution of MNRE, Govt of India, No. 30/80/2014-15/NSM dated 1st July 2015).

Rajasthan state has already been progressed along this mission targets through installation of nearly 6000 pumps by 2013 with each pump capacity of 2200 W_p or 3000 W_p[1]. It has been reported that Rajasthan state received the maximum share (79.36% of all India allocations) of renewable energy installations during the first phase of NSM [2]. However, long before this NSM targets, potential utility of solar PV pumps had been demonstrated through field experimentation on pomegranate orchard with drip network at ICAR-Central Arid Zone Research Institute, Jodhpur [3]. Since large portion of Rajasthan state are in critical stage of groundwater utilization, further extraction of it may not be a sustainable future irrespective of the use of solar PV pumps or diesel pumps/electrified pumps.

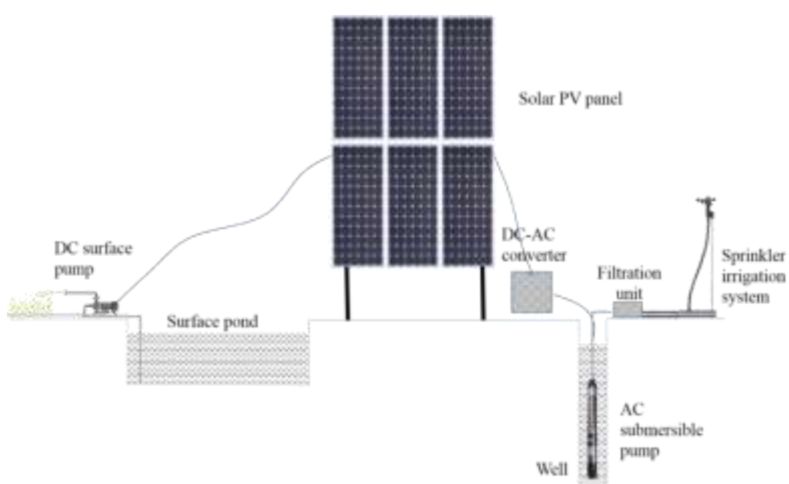
There exists substantial potential of using renewable sources of energy for irrigation water pumping in India [4,5,6]. Considering the plentiful availability of solar irradiation in India specifically in North-Western India with average irradiance of about 6 KWh m^{-2} day^{-1}[7], this energy may be utilized for operating the pump in agricultural farm for irrigation purpose. During last one decade, several studies were carried out on use of solar PV pump based irrigation systems and its different aspects [8-16]. Solar PV technology and its application in water pumping have also been reviewed by [17]. Financial aspect of water pumping system based on renewable energy was evaluated in detail by [18], [19]. In [14] discussed some policies to make solar photovoltaic water pumping system as the appropriate technology for several arid regions. Apart from solar PV pumping system, several research reports on economic evaluation of different systems e.g. processing mills, protected cultivation, lake conservation, labour employment scheme etc. are available in literature [20-23]. In this paper, we tried to analyze the economic feasibility of solar PV pumping system in India.

2. Materials and Methods

2.1. Components of solar PV pumping system

A solar PV system mainly comprises of i) PV panels (ii) mounting structure (iii) pump unit (AC/DC) and (iv) tracking system (Figure 1).

Figure 1. Schematic diagram of a solar PV pumping system



Sizing of PV panel depends on the capacity of pump to draw water. If the suction head is about 4-5 m, which is applicable in case of a surface water reservoir, 1 HP capacity pump is sufficient which requires about 900 W_p panel in case of DC pump and 1400 W_p panel in case of AC surface pump. If the solar PV pump is to be used for drawing more deep water from wells or tube wells, panel size will be higher accordingly. The mounting structure for erecting the panels with an angle from horizontal surface, which is generally equal to the latitude of any place needs to be strong enough to withstand the wind forces. The pumps to be used in a solar pumping system may be either DC or AC type and surface or submersible type as per situation. As the PV panels generate DC current, additional DC-AC inverter system is required for AC pumping system. To track the panel perpendicular to the sun, tracking system is required. Two types of tracking system are available i) one axis tracking which tracks the solar panel as per azimuthal rotation of sun from east to west, ii) in additional to azimuthal rotation PV panels can be tracked as per zenith angle of sun using a two axis tracking system. Both manual and auto tracking systems are available in the market. However, in case of auto tracking system there will be an additional cost of tracker.

2.2. Life cycle cost analysis

Economics of solar PV pumping system was calculated through life cycle cost (LCC) analysis. Total life cycle cost of a PV pumping system is comprised of capital cost, maintenance cost, replacement costs for damagaed components and operational cost. Before adding these above costs, all future costs (C) are converted to present worth considering the relative rate of inflation and discount rate.

$$\mathrm{PW} = \mathrm{C}\times\left[\frac{(1+i)}{(1+d)}\right]^{n} \qquad (1)$$

Where, PW is the present worth of any future cost, *i* is the relative rate of inflation and *d* is the discount rate per year and *n* is the time period in years. Relative rate of inflation accounts for the escalted increase or decrease in prices of a commodity in comparison to general inflation rate. For any commodity, if the price escalation is expected as per the genreal inflation rate then relative rate of inflation was considered zero. In this analysis, relative rate of inflation was considered zero. Discount rate accounts the real value of money in future and in most of the economies of the world it is about 8-12%, and therefore 10% was considered in this calculation. A discount rate of 10 % per year would mean that in real terms it makes no difference to a farmer whether he has ₹ 100 now or ₹ 110 in one year's time. Conversely, a cost of ₹ 110 one year from now has a present worth of ₹ 100. For a future single cost in n^{th} year, the present worth of that cost is calculated using Eq (1). However, for future multiple payments, costs are to be converted to present worth for each year and then needs to be cumulated.

For comparison purpose, annualized life cycle cost (ALCC) of solar PV pumping system was also calculated along with electrified pumping system and diesel operated pumping system. To calculate annuity of total cost, annuity factor (AF) was calculated for a period of life cycle of the pump as follows:

$$\mathrm{AF}=\frac{\frac{1+i}{1+d}-1}{\frac{1+i}{1+d}\left[\left(\frac{1+i}{1+d}\right)^{n}-1\right]} \qquad (2)$$

$$\mathrm{ALCC}=\mathrm{LCC}\times\mathrm{AF} \qquad (3)$$

Since the PV panel works for 25 years after its installment, the life cycle of solar PV pumping system was conidered 25 years. Since, the life of solar PV puming system is highest among three type of pumping systems considered here, LCC of electrified and diesel operated pumping systems were also calculated for 25 years.

3. Results and discussion

3.1. Solar PV pumping system

3.1.1 Capital cost of SPV pumping system

The capital cost of a solar PV pumping system is contributed by PV panel, AC pump, inverter, mounting structure, accessories/cables and miscellaneous cost including profits of the supplier. Life cycle costs for a 3 HP and 5 HP solar PV pumping systems have been presented here since these are commonly available in market and also are under the

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Govt. subsidy scheme. PV panels are the major contributor to capital cost of a solar PV pumping system and the size of it is governed by the pump capacity or wattage, inverter efficiency and available solar radiation for a location. Efficiency of commonly available inverter is about 85-95% and thus 0.9 is considered here. In order to run the solar PV pumping system throughout the year and for a minimum period of 6 hours a day from morning 10:00 am to afternoon 4:00 pm, the lowest amount of radiation available during this period in a year for a particular location plays the key role to determine the size of PV panel. Generally, a PV panel with a rated capacity of, for example, 100 W_p will generate 100 W power if available solar radiation is 1000 W m^{-2} and the ambient temperature is 25°C. Otherwise, we can say that the PV panel output is proportional to the available solar radiation, which means that if available solar radiation is 700 W m^{-2} during morning time, output from a 100 W_p capacity PV panel will be 70 W. From the available solar radiation data from Jodhpur, Rajasthan it has been observed that lowest amount of radiation available on a tilted surface during morning or afternoon time is 700 W m^{-2} in a year, a factor of 0.7 is therefore considered to determine the size of PV panel in a solar PV pumping system. Likewise, the PV panel size of a 3 HP and 5 HP solar PV pumping system was calculated by dividing the pump wattage by inverter efficiency factor of 0.9 and PV panel factor of 0.7, which were about 3500 W_p and 5900 W_p, respectively. Considering the present day PV panel price of about₹40/W_p, the cost for PV panels in 3 HP and 5 HP solar PV pumping system is about₹1,40,000 and₹2,36,000, respectively which leads to a total capital costs of₹2,92,250and ₹4,36,800after adding other capital costs.

3.1.2. Maintenance, replacement and operational cost of SPV pumping system

Maintenance cost for a solar PV pumping system is less as compared to others and is considered 1% of the capital cost per year. The maintenance cost is recurring in nature and need to be spent throughout the year and thus the cumulated discount factor for total life of 25 years was calculated, which is 9.08 corresponding to a discount rate of 10% and relative rate of inflation of zero. Thus, the maintenance cost of a 3 HP solar pumping system throughout its life was found ₹ 26,536 whereas for 5 HP system it was ₹ 39,661. It was considered that the AC pump of a solar PV pumping system needs to be replaced after 8 years of its operation and thus needs replacement for two times in its life cycle; one is at 8^{th} year and another is at 16^{th} year. Therefore, the discount factor for 8^{th} year and 16^{th} year were calculated using the Eq (1) and considering the discount rate of 10% and relative rate of inflation of zero, which were 0.47 and 0.22, respectively. The present worth of these two future replacements of AC pump was calculated for both 3 HP and 5 HP systems, which were about ₹ 21,700 and ₹ 24,150, respectively. Similarly, the replacement cost for inverter at 10^{th} and 12^{th} year of its life cycle was calculated for both the system, which were ₹ 10,800 and ₹ 13,500, respectively for 3 HP and 5 HP systems (Table 2).

3.1.3. Life cycle cost of SPV pumping system

Component costs and total life cycle cost of 3 HP and 5 HP solar PV pumping systems are given in Table 2. Total life cycle cost for 3 HP solar PV pumping system was found ₹3,51,286 whereas it was ₹5,14,111 for 5 HP system. For comparison with other pumping systems, these life cycle costs were converted to annualized life cycle cost (ALCC), by dividing the LCC with cumulated discount factor for 25 years (9.08). The ALCC for 3 HP and 5 HP solar PV pumping systems were ₹38,688 per year and ₹56,620 per year, respectively.

3.2. Grid-connected electricity operated pumps

3.2.1. Capital cost of grid-connected electricity operated pumps

Capital cost of an electrified pumping system is mainly contributed by establishment of electric connection in the field site. Often it is observed that electric grid connections available in rural network are far away from the field site and thus needs extension of the existing connection to the required site which needs an initial investment. Apart from this, farmers have to bear the cost for a new electric connection and for purchasing an AC pumping system. Adding these costs, the capital cost for a 3 HP and 5 HP electrified pumping system was found ₹1,80,000 and `1,85,000, respectively.

3.2.2. Maintenance, replacement and operational cost of grid-connected electricity operated pumps

Maintenance cost for electrified pumping system was considered similar with the maintenance cost of PV operated pumps, which was 1% of the capital cost per year and it was found ₹16,344 and ₹16,798, respectively for 3

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HP and 5 HP pumping system. Replacement cost of AC pump was also considered similar with the cost for replacement of pumps in a solar PV pumping system. The operational cost of an electrified pumping system is the cost towards electric energy consumption from grid with an average tariff of ₹5.00/kWh. Since the conventional source of energy is becoming scarce, it is expected that the energy tariff will be increased at a faster rate than the general inflation rate. Relative rate of inflation for energy tariff was considered 5% while calculating the total operational cost in its life cycle. The discount rate was considered 10% as similar with other cases. Calculation as per above considerations led to an operational cost of ₹1,93,900 for 3 HP pumping system and ₹3,23,167 for 5 HP pumping system.

3.2.3. Life cycle cost of grid-connected electricity operated pumps

Component costs of electrified pumping system is presented in Table 3. Adding the capital cost, maintenance cost, replacement cost and operational cost resulted in to an annualized life cycle cost of ₹45,368 per year for 3 HP electrified pumping system, which is higher by ₹ 6,680 per year than the ALCC for 3 HP solar PV pumping system. When the 5 HP systems were compared, ALCC was found slightly higher for electrified pumping system (₹60,475/year) and solar PV pumping system (₹56,620/year).

Table 2. Life cycle cost of solar PV pumping system for irrigation

Sr. No.	Parameters	Solar PV pumping system	
		3 HP system	5 HP system
1.	Life cycle	25 years	25 years
2.	PV panel cost (₹40/W_p)	₹1,40,000	₹2,36,000
	AC pump cost	₹30,000	₹35,000
	Inverter cost	₹20,000	₹25,000
	Mounting structure	₹25,000	₹30,000
	Cables and accessories	₹10,000	₹10,000
	Miscellaneous cost (30% of total cost)	₹67,500	₹1,00,800
	Total capital cost	₹2,92,250	₹4,36,800
3.	Lifetime maintenance cost (1% of the capital cost)	₹26,536	₹39,661
4.	Replacement cost of AC pump (at 8th year and 16th year)	₹ 21,700	₹24,150
5.	Replacement cost of inverter (at 10th year and 20th year)	₹10,800	₹13,500
6.	Total life cycle cost	₹3,51,286	₹5,14,111
7.	Annualized life cycle cost	₹38,688/year	₹56,620/year

Table 3. Life cycle cost of electrified pumps for irrigation

Sr. No.	Parameters	Electrified pumps	
		3 HP system	5 HP system
1.	Life cycle	25 years	25 years
2.	AC submersible pump	₹30,000	₹35,000
	Electric connection cost at field	₹1,50,000	₹1,50,000
	Total Capital cost	₹1,80,000	₹1,85,000
3.	Lifetime maintenance cost (1% of the capital cost)	₹16,344	₹16,798
4.	Replacement cost of AC pump (at 8th year and 16th year)	₹21,700	₹24,150
5.	Operational cost (Average energy charge @ ` 5.00/kWh with escalated price of 5% and average hours of operation in a year is 6 hours per day for 200 days)	₹1,93,900	₹3,23,167
6.	Total life cycle cost	₹4,11,944	₹5,49,115
7.	Annualized life cycle cost	₹45,368/year	₹60,475/year

3.3. Diesel operated pumping system

3.3.1. Capital cost of diesel operated pumps

Capital cost for establishing a diesel operated pumping systems involves the cost for diesel engine and for the arrangements to lift water from a well, which was estimated about ₹60,000 for 3 HP pumping system and ₹70,000 for 5 HP pumping system.

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3.3.2. Maintenance, replacement and operational cost of diesel operated pumps

Maintenance cost for diesel engine was approximated as flat rate of 5% of capital cost per year, which was found about ₹3,000-3,500 per year. Considering a discount rate of 10% and relative rate of inflation of zero, cumulative discount factor for 25 years was calculated as 9.08, which was multiplied with annual maintenance cost to obtain the lifetime maintenance cost of ₹27,240 for a 3 HP system and ₹31,780 for a 5 HP system. A diesel engine generally performs optimally for a period of about 6-7 years and therefore three replacements will be required in its life cycle of 25 years. Calculation of these future replacement costs at 6th, 12th and 18th year of its establishment to the present value resulted in total replacement cost of ₹63,600 and ₹74,200 for 3 HP and 5 HP systems, respectively. While calculating the operational cost of diesel pumping system, few assumptions were made. Considering the calorific value of diesel as 10.5 kWh per litre and diesel engine efficiency of 30-35%, the energy generation capacity by a diesel pump was calculated as 3.4 kWh per litre of diesel. Using this value, diesel consumption per year was calculated for an average operation of 6 hours per day and 200 days per year. Further, the relative rate of inflation for diesel was assumed as 5%, since this fossil fuel is becoming scarce and escalated price in future is expected. Discount rate was considered 10%. Thus, the total operational cost was found ₹5,46,337 for 3 HP diesel pumping system and ₹9,10,571 for 5 HP diesel pumping system in its life cycle of 25 years.

3.3.3. Life cycle cost of diesel operated pumps

Component costs of diesel operated pumping system are given in Table 4. The ALCC for 3 HP and 5 HP diesel operated pumping system were obtained as ₹76,782/year and ₹1,19,664/year, respectively. As compared to ALCC for solar PV pumping system and even to electrified pumping system, it is quite higher.

Table 4. Life cycle cost of diesel operated pump for irrigation

Sr. No.	Description	3 HP system	5 HP system
1.	Life cycle	25 years	25 years
2.	Capital cost	₹60,000	₹70,000
3.	Maintenance cost (5% of capital cost)	₹27,240	₹31,780
4.	Replacement cost of diesel (at 6th, 12th and 18th year)	₹63,600	₹74,200
5.	Operational cost*	₹5,46,337	₹9,10,571
6.	Life cycle cost (LCC)	₹6,97,177	₹10,86,551
7.	Annualized life cycle cost (ALCC)	₹76,782/year	₹1,19,664/year

*Average use of diesel pump in a year for irrigation = 200 days × 6 hrs per day; Diesel price at Jodhpur as on 15th August 2015 = ₹47.9 per litre; Energy value of diesel = 10.5 kWh per litre; Diesel pump efficiency = 30-35%; Energy generation by diesel pump = 3.4 kWh per litre.

4. Conclusion

Solar PV pumping systems has been viewed as one of the most viable options for future energy secured agriculture and a significant progress has been made in states like Rajasthan and Gujarat. Comparative analysis of solar PV pumps with diesel operated pumps and electrified pumps revealed that solar pumps will be highly beneficial to farmers. Apart from the lower life cycle cost, solar PV pumping system has additional advantages over other pumping systems: (i) PV panels of a solar pumping system reduce the CO_2 emission in atmosphere at a rate of about 1360 kg CO_2 m^{-2} panel area; (ii) Assured power supply in a solar PV pumping system enables the farmer to get an improvement in crop yield; (iii) During off time, when pump is not used for irrigation purpose, electricity generated by the solar PV pumping system may be used for domestic needs and for operating small farm machines; (iv) solar PV pumping system may be used in far remote locations, where electric grids are not available. Considering the low life cycle cost and above said benefits, solar PV pumping system will obviously be considered as the first choice by farmers to irrigate crops.

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