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Techno economic assessment of solar photovoltaic water pumping system

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ABSTRACT : This paper presents technical and economic analysis of solar photovoltaic 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 cost of solar photovoltaic water pumping systems was analyzed, solar technologies were compared economically with conventional diesel engine water pumping system considering present socio-economic environment to emphasize the need to supplement with and eventually replace existing water pumping systems in the remote areas of rural India with available, abundant and inexhaustible solar energy system. Life cycle cost (LCC) analysis was conducted to assess the economic viability of the system. Life cycle cost (LCC) of PV system was found to be ' 35,117.47/- while that of diesel engine was ' 8, 64,669.00/-. The results of the study encouraged the use of the PV systems for water pumping application to irrigate orchards in rural areas of India.

KEY WORDS : Life cycle cost, Photovoltaic/PV, Water pumping

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The most basic need of all the people in the world is energy and it is needed more than ever. The energy from burning coal, oil and gas called fossil fuels are widely used but these energy sources are deplectable, non renewable and harmful to the environment. It is environment harmful in utilization of conventional energy *i.e.* coal, natural gases and other conventional energy sources, as it spoils the surrounding atmosphere by releasing poisonous green house gases like CO_2, CO, S, NO_x etc. These gases are not only harmful to human being as it creates heart problems and skin diseases but also increases global warming by emission of carbon compounds in the atmosphere. India's conventional energy production is quite uncertain as compared to present requirement; therefore it is essential to harness renewable energy sources such as solar thermal, photovoltaic, wind and biomass for energy production. Among these photovoltaic is quite effective in rural areas as it produces direct current from sun radiations. There is enormous potential for off-grid photovoltaic deployment in India, based on real needs and benefits in the areas of rural lighting and electrification, for powering irrigation pump sets, captive power generation, urban applications and highway lighting etc.

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.

For the success and commercialization of any new technology, it is essential to know whether the technology is economically viable or not. Therefore, an attempt has been made to evaluate techno economics of the designed solar water pumping system.

Many researchers have studied a comparative economic analysis of water pumping by different methods. Oparaku (2003) evaluated cost comparison of the photovoltaic, diesel/ gasoline generator and grid utility options to supply power in rural areas of Nigeria. Offiong (2004) assessed the economic and environmental prospects of stand-by solar powered systems in Nigeria. Schmid and Hoffmann (2004) studied economic feasibility of PV-diesel hybrid systems in Amazon for replacing diesel irrigation pumps by PV systems. In Ireland a comparison of the economic viability of photovoltaic and diesel water pumping systems is presented by Odeh *et al.*

(2005) for system sizes in the range 2.8 kWp to 15 kWp. Purohit and Purohit (2007) studied technoeconomic evaluation of renewable energy systems for water pumping in India. Curtis (2010) studied the economic feasibility of solar photovoltaic irrigation system in great Basin for forage production. Mahjoubi *et al.* (2010) evaluated economic viability of photovoltaic water pumping systems in the desert of Tunisia. Sako *et al.* (2011) studied comparative economic analysis of photovoltaic, diesel generator and grid extension in cote d'ivoire.

The aim of this work is to compare the costs of pumping the water by these different methods by using the method of the life cycle cost (LCC). The question of whether the new system is more economical than diesel is the subject of this study. It is based on field results taking into account maintenance and operation costs, fuel costs, salvage costs, in addition to initial costs.

METHODOLOGY

The solar water pumping system coupled with drip irrigation was designed and installed at Jain Irrigation system Ltd., Jalgaon. The designed system was tested for its technical as well as economic feasibility for irrigating banana crop.

Economic analysis of the system carried out by employing following indicators

- Life cycle cost analysis (LCCA)
- Net present worth(NPW)
- Benefit-cost ratio(BCR)
- Internal rate of return(IRR)
- Payback period(PBP).

The capital cost, variable cost, fixed cost, total cost, revenue and net profit are the basic components for an economic analysis of any business. Different economic indicators were used in economic analysis.

Following assumptions were made to carried out the economic analysis of the system

– The operating life of the PV panels was assumed to be 20 years and life of diesel engine assumed to be as 10 years.

– The interest rate on capital was assumed to be 10 per cent and inflation rate assumed as 4% (Kolhe *et al.*, 2002).

– Maintenance cost of system assumed to be a 0.1 per cent of total capital cost.

– CO_2 emission per litre of diesel 2.7kg (Chaurey and Khandpal, 2009)

– Availability of sunshine hours considered to be a 300 days in a year.

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 (Akinpelu and Eng, 2011). 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:

$$\mathbf{LCC = CC + MC + EC + RC - SC}$$

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. This cost is always considered as a single payment occurring in the initial year of the project, regardless of how the project is financed. The energy cost (EC) of a system is the sum of the yearly fuel cost. Energy cost is calculated separately from operation and maintenance costs, so that differential fuel inflation rates may be used. Replacement cost (RC) is the sum of all repair and equipment replacement cost anticipated over the life of the system. If the system required a battery, the replacement of a battery is a good example of such a cost that may occur once or twice during the life of a PV system. Normally, these costs occur in specific years and the entire cost is included in those years. The salvage value (SC) of a system is its net worth in the final year of the life-cycle period. It is common practice to assign a salvage value of 20 per cent of original cost for mechanical equipment that can be moved. This rate can be modified depending on other factors such as obsolescence and condition of equipment.

Net present worth:

The difference between the present value of all future returns and the present money required to make an investment is the net present worth or net present principals for the investment. The present value of the future returns can be calculated through the use of discounting. Discounting essentially a technique by which future benefits and cost streams can be converted to their present worth. The interest rate was assumed as the discount rate for discounting purpose.

The mathematical statement for net present worth can be written as

$$\mathbf{NPW} = \sum_{t=1}^{t=n} \frac{\mathbf{B^t - C^t}}{\mathbf{(1+i)^t}}$$

where, C_t = Cost in each year
B_t = Benefit in each year
t = 1, 2, 3................n
i = Discount rate.

Benefit cost ratio:

This is the ratio obtained when the present worth of the benefit stream is divided by the present worth of the cost stream. The formal selection criterion for the benefit cost ratio for measure of project worth is to accept projects for a benefit cost ratio of one or greater.

Benefit cost ratio is the present value of the benefits to the present value of the cost.

The mathematical benefit-cost ratio will be expressed as

$$\textbf{Benefit-cost ratio} = \frac{\sum_{t=1}^{t=n} B_t}{\sum_{t=1}^{t=n} C_t}$$

where,
C_t = Cost in each year
B_t = Benefit in each year
t = 1, 2, 3................n
i = Discount rate, %.

Internal rate of return:

The internal rate of return can be found out by systematic procedure of trial and error to find that discount rate which will make the net present worth of the incremental net benefit stream equal to zero.

Internal rate of return is the discount rate i such that

$$\sum_{t=1}^{t=n} \frac{B_t - C_t}{(1+i)^t} = 0$$

Payback period:

It measures the time required to recover investment costs. It will be estimated by adding net cash flow in the project until the cumulative net cash flow equal to initial investment.

RESULTS AND DISCUSSION

Techno economics were carried out on the basis of assumptions made in section 3.6. The detail costing is shown in Appendix. The system was compared with the conventional diesel operated system.

Life cycle cost analysis of system:

A comparison of the two water-pumping system, diesel and PV system in terms of life cycle cost analysis that shown in the Table 1.

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 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. 1 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 .

Table 1 : 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	846429
4.	Replacement cost (RC)	None	4800
	Total cost, `	138958.17	865629.00
5.	Salvage cost (SC)	6034.05	960
	Life cycle cost (LCC)	132924.12	864669.00

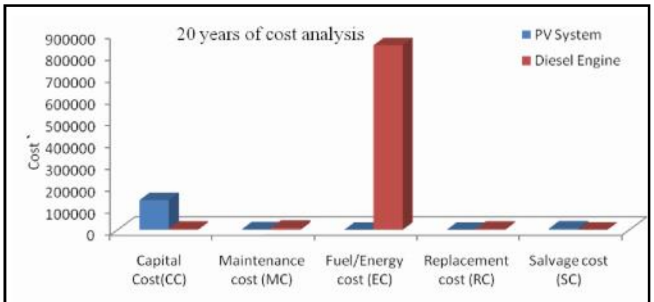

Fig. 1 : Cost comparison of PV system and diesel engine by life cycle cost analysis

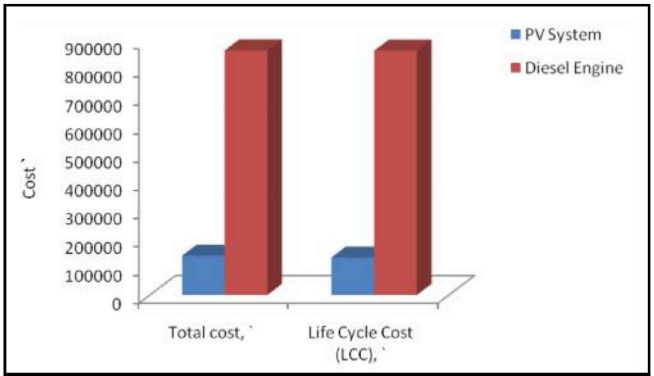

Fig. 2 : Total cost and life cycle cost in 20 years

Table 2 : Cash flow analysis for solar PV water pumping system

Maximum power from PV array	370	Watt
Operating days per year	300	Days
Operating hrs per day	6.023	Hrs/day
Operating hours per year	1806.9	Hrs/year
Area under irrigation	0.165	ha
Water requirement per day	9.72	m^3/day
Investments		
Installed cost of PV pumping system	136233.5	`
Total investments (A)	136233.5	`
Cost		
Power	Free of cost	-
Maintenance @ 0.1% of (A)	136.23	`/year
Land cost (Rs. 400/ month rent basis)	4800	`/year
Cost of electricity production (B)	4936.23	`/year
Profitability		
Cost of fuel(Diesel) saved per year@ ` 41 as on April 2012	42321.45	`/year
Environmental benefit –	3208.86	`/year
CO_2 emission = (0.5lit/hr×6.023 hr × 300 days/year × 2.7kg CO_2) = 2.43 tons/year		
Carbon tax benefit @ ` 50 per ton= 2.43×50 = `121.96		
Carbon trading rate (24.16 $ per tons) = 24.16× 52.58×2.43 = ` 3086.90		
(* 1 US $= ` 52.58 as on 27 April 2012)		
Total benefit from carbon = 121.96+ 3086.90=` 3208.86		
Total profit (C)	45530.31	`/year
Net annual saving (D)=C-B	40594.08	`/year
Net present worth (NPW)	209366.79	` for 20 years
Benefit cost ratio	2.17	
Payback period (A/D)	3.35	years

Table 3 : Cash outflow for solar PV water pumping system

Year	Cash out flow (`)	PW of cash outflow (`)	Cash inflow (`)	PW of cash inflow(`)	NPW (`)
0	136233.5	136233.5	0	0	-136233.5
1	4936.23	4487.48	45530.31	41391.19	36903.71
2	4936.23	4079.53	45530.31	37628.36	33548.83
3	4936.23	3708.66	45530.31	34207.60	30498.93
4	4936.23	3371.51	45530.31	31097.81	27726.30
5	4936.23	3065.01	45530.31	28270.74	25205.73
6	4936.23	2786.37	45530.31	25700.67	22914.30
7	4936.23	2533.07	45530.31	23364.25	20831.18
8	4936.23	2302.79	45530.31	21240.23	18937.44
9	4936.23	2093.44	45530.31	19309.30	17215.85
10	4936.23	1903.13	45530.31	17553.91	15650.78
11	4936.23	1730.12	45530.31	15958.10	14227.98
12	4936.23	1572.84	45530.31	14507.36	12934.52
13	4936.23	1429.85	45530.31	13188.51	11758.66
14	4936.23	1299.86	45530.31	11989.55	10689.69
15	4936.23	1181.69	45530.31	10899.59	9717.90
16	4936.23	1074.27	45530.31	9908.72	8834.45
17	4936.23	976.61	45530.31	9007.93	8031.32
18	4936.23	887.82	45530.31	8189.03	7301.20
19	4936.23	807.11	45530.31	7444.57	6637.46
20	4936.23	733.74	45530.31	6767.79	6034.05
Total	234958.1	178258.41	910606.2	387625.20	209366.79

Table 4 : Internal rate of return (IRR) for solar PV water pumping system

Year	Cash flow	29.63 % Discount factor		29.64 % Discount factor	
		Discount factor	Present value	Discount factor	Present value
0	-136233.5	1	-136233.5	1	-136233.5
1	40594.08	0.2963	31315.34	0.2964	31312.93
2	40594.08	0.2963	24157.48	0.2964	24153.76
3	40594.08	0.2963	18635.72	0.2964	18631.41
4	40594.08	0.2963	14376.08	0.2964	14371.65
5	40594.08	0.2963	11090.09	0.2964	11085.81
6	40594.08	0.2963	8555.18	0.2964	8551.23
7	40594.08	0.2963	6599.69	0.2964	6596.13
8	40594.08	0.2963	5091.18	0.2964	5088.04
9	40594.08	0.2963	3927.47	0.2964	3924.74
10	40594.08	0.2963	3029.75	0.2964	3027.41
11	40594.08	0.2963	2337.23	0.2964	2335.25
12	40594.08	0.2963	1803.0	0.2964	1801.33
13	40594.08	0.2963	1390.88	0.2964	1389.49
14	40594.08	0.2963	1072.96	0.2964	1071.80
15	40594.08	0.2963	827.71	0.2964	826.75
16	40594.08	0.2963	638.51	0.2964	637.73
17	40594.08	0.2963	492.57	0.2964	491.92
18	40594.08	0.2963	379.98	0.2964	379.45
19	40594.08	0.2963	293.12	0.2964	292.69
20	40594.08	0.2963	226.12	0.2964	225.77
		NPW	6.64	NPW	-38.2

Internal rate of return (IRR)= 29.64 per cent

Table 5 : Economic Indicators of the solar water pumping system

Sr. No.	Economic Indicators	Value
1.	Net present worth (NPW)	` 209366.79
2.	Benefit cost ratio (BC ratio)	2.17
3.	Pay-back period	3.35 years
4.	Internal rate of return (IRR)	29.64 per cent

Cost analysis:

The analysis was made by considering the present investment and the assumption as given in the section 2. The results obtained were enlisted in the table given below for economical analysis of the system. It was observed that the investment of the solar PV water pumping system was achieved in 3.35 years only which is viable and feasible as well. The total investment and possible achievable profit was given in the Table 2. The cost benefit ratio was found to be 2.17 with a payback period of 3.35 years. It can be inferred that the developed photovoltaic water pumping system was technically as well as economically feasible.

Net present worth (NPW):

The net present worth for the system was calculated on the basis of present investment and the interest rate considered for the system and the profit achieved in each year. The life of PV system was consider for 20 year thus the NPW for the water pumping system was '209366.79/- . The net present worth were calculated for next 20 years and presented in the Table 3.

Internal rate of return for solar PV water pumping system:

The internal rate of return for solar PV water pumping system was calculated and found to be 29.64 per cent for 20 years. The higher percentage of internal rate of returns indicated the good commercial return of the investment. Table 4 shows the calculations of IRR for solar PV water pumping system.

Conclusion:

The eloquent conclusions were drawn from the results of the study which are as follows :

– Total cost (TC) of PV system considering life span of 20 years was found to be ' 138958.17/- and total cost of diesel engine was ' 865629.00/-

– Life cycle cost (LCC) of PV system was ' 35117.47/-

Appendix 1 : Economics of solar PV water pumping system

Sr. No.	Material	Material description	Quantity	Rate, `	Total amount, `
1.	PV Panel	74 watt panel	5	6200	31000
2.	Panel mounting structure	Supporting structure assembly, actuator and tracking controller	1	48000	48000
3.	DC submersible pump with controller	Model Ps-600HR(Lorenz) 0.5hp DC pump	1	50300	50300
4.	Safety rope	ϕ10mm	30m	9.00	270.00
5.	Cable	4 square mm, 4 core wire	35m	85.21	2982.35
6.	HDPE pipe	ϕ 40mm	30m	48	1440
7.	Foundation cost	Includes material and labor cost for construction			1800
		Total Material Cost			1,35,792.3
8.	Installation charges				400
9.	Service tax	10.30%of installation charge			41.20
		Grand Total, `			1,36,233.5

while that of diesel engine was found to be ‘ 864669.00/-

– Net present worth (NPW) of the system after 20 years was found to be ‘209366.79/- and internal rate of return (IRR) was found as 29.64 per cent.

– The benefit cost ratio was found to be 2.17 with a payback period of 3.35 years.

Appendix :

Economics of solar PV water pumping system:

Determination of annualized cost of diesel engine:

The annual cost of 0.5hp engine running on diesel fuel includes engine cost, annual fuel cost and operation maintenance and repair cost.

– Engine cost= 4800 Rs

– Annual Fuel Cost= Specific fuel consumption× Fuel Rate× total no of operating hours in a year

= 0.5 lit/hr × 6.023×300×41Rs./lit

= ‘ 37041.45

– Annual operation, Maintenance and repairs cost =

= Depreciation Rate × Capital Investment

= 0.1 × 4800

= 480 Rs

Total annual cost = 4800+ 37041.45+ 480= ‘42321.45

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