Economic Analysis of Floating Photovoltaic Plant in the Context of India

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1 Introduction

The solar photovoltaic power plant utilizes energy available from the Sun and provides a cleaner alternative to produce electricity. Widespread solar installations are the consequence of decrement in module prices and advancement in semiconductor technology. Solar photovoltaic (SPV) power plants are the solar installations on land, and solar rooftop photovoltaic (RTPV) plants are installed on the roof of the buildings. Many measures are taken, and schemes are continuously being implemented by the Indian government for encouraging the installation of solar photovoltaic power plants in India.

Solar photovoltaic modules when installed on water bodies offer numerous advantages and are called floating photovoltaic (FPV) power plants. FPV power plant as compared to SPV power plant does not require any landholdings, and therefore, the land is conserved. FPV plants have slightly greater energy generation than SPV due to the cooling effect of water. FPV plants conserve the water by preventing evaporation. FPV plant requires additional floating and support structure than SPV, thereby increasing the cost and complexity of installation. The Energy and Resources Institute (TERI) has predicted that India has the potential of installing 280 GW of FPV plants. By 2019, floating solar power plant capacity in India has already crossed 2.7 MW, and more than 1.7 GW was under development phase [1]. MNRE aims to install 10 GW of floating solar power plants by 2022 as a part of its 227 GW renewable energy target [2].

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Sanjeevikumar et al. (eds.), *Advances in Renewable Energy and Electric Vehicles*,
Lecture Notes in Electrical Engineering 767,
https://doi.org/10.1007/978-981-16-1642-6_13

In this paper, an economic analysis of installing 1 MW FPV power plant in Jaipur, Rajasthan, is done. Economic parameters for 1 MW SPV are calculated by considering different land costs. This paper illustrates the cost-effectiveness of the FPV plant in comparison with the SPV plant based on economic parameters. Economic analysis of 1 MW FPV plant is done for different values of cost–benefit of potable water, which is saved.

In this paper, Sect. 2 describes solar photovoltaic (SPV) power plants, Sect. 3 describes floating photovoltaic plants (FPV) power plants, and Sect. 4 presents a review on the installation cost of floating photovoltaic plants (FPV) power plants. Section 5 describes the economic parameters considered in the study. The methodology of the study is described in Sects. 6, and 7 presents the results from the study.

2 Solar Photovoltaic (SPV) Power Plant

Solar photovoltaic plants (SPV) convert solar energy to electricity using photovoltaic modules. Solar photovoltaic power plants can be installed on land and therefore require large landholdings. To encourage and facilitate SPV power plant installations, the Indian government is planning to create ten solar zones and 25 solar parks. The objective of solar zones and solar parks is to provide a collective land, transmission, and distribution infrastructure for minimizing the initial investment required in the SPV installations [3].

3 Floating Photovoltaic (FPV) Power Plant

Floating photovoltaic power plant (FPV) is installation of solar photovoltaic modules on the water body. Mittal et al. [4] reviewed the studies conducted on FPV system and also described the 10 kW FPV system installed in India at West Bengal, Kerala, and Chandigarh. Saving the valuable land, such installations can prevent water from getting evaporated by decreasing the exposed water surface to the Sun. Mittal et al. [5] showed the amount of water saved from being evaporated by FPV plants for different lakes of Rajasthan and concluded 64 million litres to 496 million litres water savings annually for lakes located at different places. Mittal et al. [6] estimated that the FPV plant has a 2.48% increase in annual energy generation and a 14.56% decrease in average module temperature.

These plants have an added advantage of increased energy production than SPV plants due to cooling of the back surface of PV modules by water. These plants when installed on a cooling pond of a conventional power plant could serve as an auxiliary power source, preventing evaporation of cooling water and also reducing carbon footprints of the plants. These plants when installed on a lake or pond could supply power to nearby localities with minimal transmission and distribution infrastructures.

These plants can maintain water quality by preventing algae growth. Despite numerous advantages offered by FPV power plants over SPV power plants, installations of FPV plants are globally less in number with a total capacity of 98 MW, and in India, it is a recent development with a small number of FPV plants having 10 kW rating. This is due to the enhanced capital cost of FPV plants, requiring floating structure, mooring system, and buoyancy anchors and also due to lack of knowledge on the breakeven analysis of FPV plants. This paper attempts to do an economic analysis of FPV plants.

4 Installation Cost of Floating Photovoltaic System

The floating photovoltaic system has a high installation cost. The total installation cost of FPV can be stated in two parts: the cost of installing a PV system and the cost of installing a floating system or structure. Table 1 shows the installation cost of FPV as stated by different researchers [7–12]. Sahu et al. [11] stated the FPV cost in the context of India. Therefore, the installation cost of 80 Rs/W is considered for calculating LCOE in this paper as per [11].

Table 1 Installation cost of FPV [7–12]

FPV	PV system cost (Rs/W)	Floating system cost (Rs/W)	Total installation cost (Rs/W)	References
FPV system with pontoon platform and monocrystalline PV modules	70.35	44.16	114.51	[7]
1 MW FPV system	NA	NA	175.76	[8]
Thin-film flexible floating PV array	NA	NA	733.932	[9]
100 kW FPV system with pontoon platform	148.6	52.04	200.64	[10]
1 MW FPV system	NA	NA	80	[11]
pontoon-based (poly-crystalline Si) FPV system	NA	NA	191.12	[12]
Flexible (amorphous Si) FPV system	NA	NA	132.48	[12]

NA; Not Available

5 Parameters Considered for Economic Feasibility and Financial Analysis in the Study

5.1 Levelized Cost of Electricity (LCOE)

LCOE is a parameter used for comparing the cost of energy production from different energy sources. LCOE takes into account the investment required and the revenue earned for the entire lifetime of the project as shown in (1). It indicates the price (Rs/kWh) at which the energy must be sold to completely recover the investment done for the entire life of the plant [13]. For solar projects, the high construction cost and low capacity factor produce higher LCOE [14]. Branker et al. [15] reviewed the general assumptions required for LCOE determination of solar PV projects.

Some of the shortcomings of LCOE are: (i) Financing method is generally considered the same for different technologies; (ii) The price in market is dynamic in nature, while LCOE gives a static price; (iii) LCOE is highly sensitive to the assumptions considered; and (iv) The lifetime and other parameter considered for LCOE determination mostly differ from actual value for the plant. Despite these shortcomings, LCOE provides a unique way to indicate the economic feasibility and cost-effectiveness of energy produced from different energy sources. Also, LCOE indicates the technical competitiveness of a power plant in comparison with other power plants.

$$\text{LCOE} = \frac{\text{Initial cost} + \sum_{n-1}^{N} \frac{(O\&M\ \text{Cost})+(\text{Insurance Cost})}{(1+r)^n}}{\sum_{n-1}^{N} \frac{E(1-d)^n}{(1+n)^n}} \tag{1}$$

where r is discount rate, d is degradation rate of photovoltaic modules, N is lifetime of the project, and E is the energy generation in kWh.

5.2 Net Present Value (NPV)

Net present value denotes the difference between present revenue and present investment of a project as shown in (2). Positive value of NPV indicates the net profit earned in the lifetime of the project, and therefore, the project will be economically feasible [16].

$$\text{NPN} = \sum_{n-1}^{N} \frac{(\text{Gross Revenue})}{(1+r)^n} - \sum_{n-1}^{N} \frac{(\text{Gross Cost})_n}{(1+r)^n} \tag{2}$$

where $(\text{Gross Revenue})_n = (\text{Net Revenue})_n - [t_n \times (\text{Total Investment})]$, and t_n is O & M cost as a percentage of total investment.

5.3 Internal Rate of Return (IRR)

Internal rate of return denotes the discount rate at which the NPV becomes zero as shown in (3). For the project to be economically feasible, the IRR should be greater than the discount rate [17].

$$\sum_{n-1}^{N} \frac{(\text{Gross Revenue})}{(1+IRR)^n} - \sum_{n-1}^{N} \frac{(\text{Investment Cost})_n}{(1+IRR)^n} = 0 \tag{3}$$

5.4 Profitability Index (PI)

The profitability index is the ratio of NPV to the initial cost as shown in (4). PI indicates the effectiveness of utilization of initial cost in the project [18].

$$\text{PI} = \frac{\text{NPV}}{\text{Initial Cost}} \tag{4}$$

5.5 Discounted Payback Period (DPP)

A discounted payback period is the period for which the NPV of the project becomes zero. If the DPP is less than the lifetime of the project, then the project is considered to be economically feasible [17].

6 Methodology

In this paper, an economic analysis of installing 1 MW floating photovoltaic plant in Jaipur is done and illustrates the cost-effectiveness of the FPV plant in comparison with the SPV plant. The PVWatts calculator is used to calculate the annual energy generation for 1 MW SPV plant in Jaipur. Firstly, the economic parameters of 1 MW SPV plant in Jaipur are calculated. The variation in economic parameters of SPV is studied by considering the following cases of A, B, C, D, E: (A) Zero land cost; (B) Land cost of Rs. 10.12 lakhs/acre [19]; (C) Land cost of Rs. 20.24 lakhs/acre; (D) Land cost of Rs. 30.36 lakhs/acre; and (E) Land cost of Rs. 40.49 lakhs/acre.

Secondly, the economic parameters of 1 MW FPV plant in Jaipur are calculated by considering a 3.6% increase in energy generation [20] due to the cooling effect of water in FPV systems. The economic parameters of FPV are studied by considering

Table 2 Assumptions considered for the Study [8, 11, 15, 19, 21]

Parameter	Value considered	References
Insurance cost	0.25% of initial cost	[21]
Lifetime	25 years	[21]
Degradation rate	1%	[15]
Discount rate	10%	[21]
Operation and maintenance cost for SPV	1% of initial cost for first year and 10% increment for each year	[21]
Operation and maintenance cost for FPV	0.69% of initial cost for first year and 10% increment for each year	[8, 21]
Initial cost of PV installations for 1 MW SPV plant	Rs. 476 lakhs	[19]
Initial cost for 1 MW FPV plant	Rs. 800 lakhs	[11]

the following cases of a, b, c, d, e, f: (a) Zero cost of water savings; (b) Rs. 0.10/l cost of water; (c) Rs. 0.20/l cost of water; (d) Rs. 0.30/l cost of water; (e) Rs. 0.40/l cost of water; and (f) Rs. 0.50/l cost of water. The LCOE, gross revenue, and NPV for FPV are calculated using (5), (6), and (2), while the IRR, PI, and DPP are calculated in the same way as calculated for SPV. The general assumptions considered for calculating economic parameters for the SPV and FPV plants are shown in Table 2 [8, 11, 15, 19, 21].

$$\text{LCOE} = \frac{\text{Initial cost} + \sum_{n-1}^{N} \frac{(O\&M\ \text{Cost})+(\text{Insurance Cost})-(\text{Cost water saved})}{(1+r)^n}}{\sum_{n-1}^{N} \frac{E(1-d)^n}{(1+r)^n}} \tag{5}$$

$$\text{Gross Revenue} = (\text{Net Revenue}) + (\text{Coast of water saved}) - [t_n \times (\text{Total Investment})] \tag{6}$$

7 Results and Discussion

7.1 Economic Analysis of 1 MW SPV Plant in Jaipur

The AC energy generation of 1 MW SPV plant in Jaipur is calculated by the PVWatts calculator as shown in Fig. 1. The annual energy production from 1 MW SPV plant will be 18, 37, 134 kWh. The cases considered for varying land costs are (A) Zero land cost; (B) Land cost of Rs. 10.12 lakhs/acre; (C) Land cost of Rs. 20.24 lakhs/acre; (D) Land cost of Rs. 30.36 lakhs/acre; and (E) Land cost of Rs. 40.49 lakhs/acre.

The variation in LCOE of SPV due to variation in land cost is shown in Fig. 2, and the variation in LCOE, NPV, IRR, PI, and DPP is shown in Table 3. It is observed

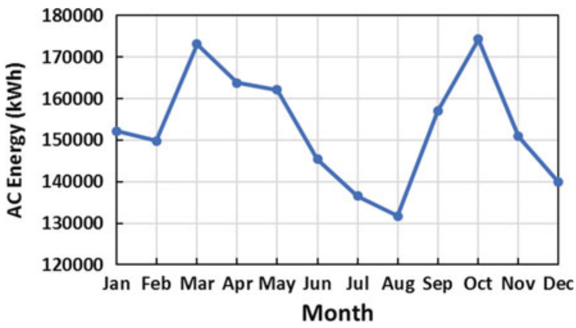

Fig. 1 AC energy generation of 1 MW SPV plant in Jaipur

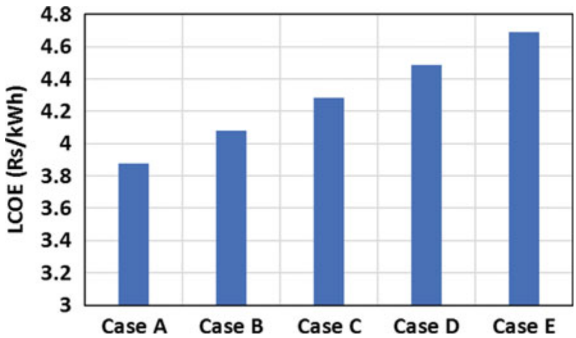

Fig. 2 Variation in LCOE of SPV due to variation in land cost

Table 3 Economic parameters of 1 MW SPV plant for different land costs

SPV land cost (Lakhs Rs. per acre)	LCOE (Rs/kWh)	NPV (Rs.)	IRR (%)	PI	DPP (Years)
0	3.88	5, 45, 23, 972	25.12	1.15	4
10.12	4.08	5, 13, 42, 241	20.83	1.02	5
20.24	4.28	4, 81, 60, 509	20.57	0.91	5
30.36	4.49	4, 49, 78, 778	20.31	0.82	6
40.49	4.69	4, 17, 97, 046	20.05	0.72	6

that LCOE and DPP increase while NPV, IRR, and PI decrease with increment in land cost for 1 MW SPV plant.

7.2 Economic Analysis of 1 MW FPV Plant in Jaipur

Considering a 3.6% increase in energy generation [17] due to the cooling effect of water in FPV, the annual energy generation is calculated. Economic parameters are estimated for 1 MW FPV plant by considering: (a) Zero cost of water savings; (b)

Rs. 0.10/l cost of water; (c) Rs. 0.20/l cost of water; (d) Rs. 0.30/l cost of water; (e) Rs. 40/l cost of water; and (f) Rs. 0.50/l cost of water. Figure 3 shows the cash flow and cumulative discounted cash flow over the lifetime for case a. The cumulative discounted cash flow is found to be negative till 9 years, while from the tenth year (i.e. after the discounted payback period), the value is found to be positive. Figure 4 shows the variation in LCOE with different values of cost–benefit of water, and Table 4 shows the economic parameters' values for the 1 MW FPV plant.

As the cost–benefit of water increases, it is found that LCOE for FPV decreases and becomes less than the LCOE value estimated for SPV although the initial cost of

Fig. 3 Cash flow and cumulative discounted cash flow over the lifetime of 1 MW FPV plant for case a

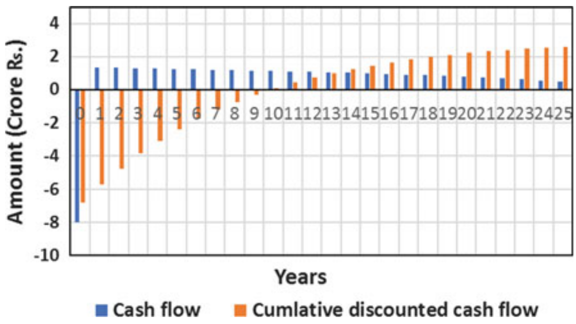

Fig. 4 Variation in LCOE of FPV due to different cost of water

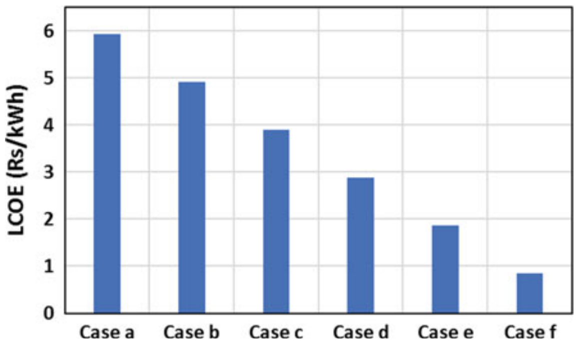

Table 4 Economic parameters of 1 MW FPV plant

Case	LCOE (Rs/kWh)	NPV (Rs.)	IRR (%)	PI	DPP (years)
a	5.93	2, 48, 87, 005	10.91	0.3	10
b	4.92	3, 98, 22, 703	15.43	0.5	8
c	3.90	5, 60, 12, 924	15.91	0.7	7
d	2.88	7, 22, 03, 146	20.43	0.9	6
e	1.86	8, 83, 93, 367	20.88	1.1	5
f	0.84	10, 50, 00, 000	25.37	1.3	4

FPV is higher than SPV. The amount of water saved from being evaporated by FPV represents a large profit even at lower rates of water tariff. Therefore, such a system can ensure economic energy generation along with substantial water conservation.

7.3 Comparison of Economic Parameters for 1 MW SPV and 1 MW FPV.

1 MW photovoltaic plants when installed on land and water have different working environments as well as different types of construction. While SPV plants require large landholdings, still they have comparatively easier installations and maintenance. The FPV plants require no land, but construction and mounting of the floating system on the water body require a skilled workforce. Figure 5 shows the comparison of the total investment required over the lifetime and net present value for SPV and FPV plants. Figure 6 shows LCOE, Table 5 shows cases considered, and Table 6 shows a comparison of parameters for 1 MW SPV and FPV power plant.

1 MW FPV, with zero and Rs. 0.10/l water tariff, is found to be less economical than 1 MW SPV (all cases). While, 1 MW FPV with Rs. 0.20/l and above, water tariff is found to be more economical than 1 MW SPV (all cases). The FPV plants may seem

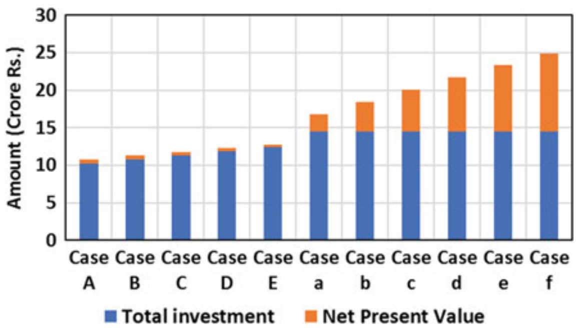

Fig. 5 Total investment required over the lifetime and net present value for 1 MW SPV and FPV plants

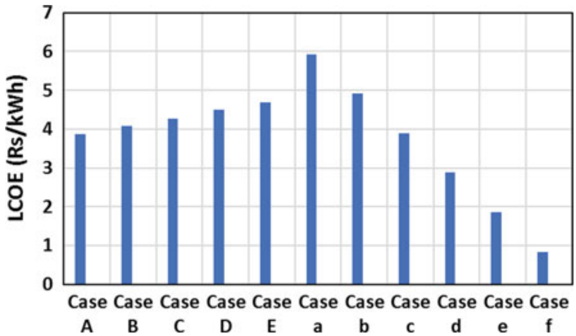

Fig. 6 LCOE for 1 MW SPV and FPV power plant

Table 5 Cases considered in the study

PV type	Case	Description
SPV	A	Zero land cost
	B	Land cost of Rs. 10.12 lakhs/acre
	C	Land cost of Rs. 20.24 lakhs/acre
	D	Land cost of Rs. 30.36 lakhs/acre
	E	Land cost of Rs. 40.49 lakhs/acre
FPV	a	Zero cost of water saving
	b	Rs. 0.10/l cost of water
	c	Rs. 0.20/l cost of water
	d	Rs. 0.30/l cost of water
	e	Rs. 0.40/l cost of water
	f	Rs. 0.50/l cost of water

Table 6 Comparison of parameters for 1 MW SPV and 1 MW FPV plant

		Annual energy generation (kWh)	Initial cost (crore Rs.)	Water saved from evaporation (l)	Annual cost of water saved (Lakh Rs.)	LCOE (Rs/kWh)	DPP (years)
SPV	*A*		4.8			3.9	4
	B	18, 37, 134	5	0	0	4.1	5
	C		5.3			4.3	5
	D		5.5			4.5	6
	E		5.8			4.7	6
FPV	*a*	19, 03, 270	8	1, 78, 36, 455	0	5.9	10
	b				18	4.9	8
	c				36	3.9	7
	d				54	2.9	6
	e				71	1.9	5
	f				89	0.8	4

to be costly in terms of initial investment; however, the long-term benefits of FPV in terms of higher energy generation and valuable water savings due to reduction of evaporation could represent FPV as a cost-effective technology in comparison with SPV.

8 Conclusions

In this paper, economic analysis of installing 1 MW FPV power plant in Jaipur is done. Economic parameters for 1 MW SPV are calculated by considering different land costs. Economic analysis of 1 MW FPV plant is done by considering different values of cost of potable water saved there by giving overall cost–benefit. Levelized cost of electricity and discounted payback period increase, while net present value, internal rate of return, and profitability index decrease with increment in land cost for 1 MW SPV plant. The LCOE value varies from 3.88 Rs/kWh (SPV with zero land cost) to 4.69 Rs/kWh (SPV with land cost of Rs. 40.49 lakhs/acre). The discounted payback period varies from 4 to 6 years.

The LCOE for 1 MW FPV plant is estimated to be 5.93 Rs/kWh for zero water tariff. However, LCOE decreased with increase in water tariff and even became close to 0.84 Rs/kWh (for Rs. 0.50/l water tariff). The discounted payback period varies from 10 to 4 years. The values of LCOE obtained indicate that even at lower tariff of electricity, the project can be economical.

FPV plants have higher initial cost than SPV plant and seem to be less economical, if water saving due to reduction in evaporation by FPV is not considered. If the water saving due to reduced evaporation by FPV is taken into account, then FPV could become meritorious and cost effective than SPV. More advancement and research on materials for floating structures can help reduce installation cost of FPV plants. The advantages offered by FPV plant over SPV plant can encourage adaption of the FPV technology.

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