Detailed Economic Analysis of Solar Rooftop Photovoltaic System: Case Study of Institutional Building

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Abstract Energy conservation has become an important part of a country's economic growth. Our country, India, is committed to generating electricity through unconventional methods. The most extensively used renewable energy source is solar PV. A lot of money is invested in solar photovoltaic systems. Thus, rooftop photovoltaic systems require economic analysis. An economic analysis of a 100 kWp grid-connected solar rooftop PV system is presented in this research. Cost–benefit analysis, calculation of payback period, and analysis of electricity bills are covered in the study. After the cost–benefit analysis, the payback period is 5.5 years. After analysis of the electricity bills, it was seen that the maximum demand, running charges, and power factor decreases after the installation of the system. The average power factor before installation of the system was 0.963 and after the installation is 0.9143.

Keywords Photovoltaic (PV) · Economic analysis · Cost–benefit · Payback period · Power factor

1 Introduction

Non-conventional energy sources produce clean energy. Solar energy is widely used and has a good potential of producing electricity [1]. Solar PV has the largest share among all the renewable energy resources in most parts of the world, including India [2]. In India, solar capacity has risen from 2.6 GW to over 36 GW in recent years. [3]. Since solar PV technology has increased immensely, economic analysis becomes important. Various studies have been carried out in different parts of the world including India on the same. Economics of a 120 kW photovoltaic system showed that the system was highly efficient with payback period 5.24 years and internal rate of return 31.88%. It was observed that the system degradation factor has an important role in economic analysis. It was finally concluded that the Middle Eastern part of the world had great potential for installing solar photovoltaic system

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[4]. In the last few years, Europe has grown rapidly in the PV market. A study has been done to evaluate the economic parameters in seven European countries with different schemes and different types of solar PV systems. It was observed that the size of the system had a significant effect on profitability. It was also seen that Germany, Italy, Spain, and Greece were the countries that had good potential to install PV systems due to favorable conditions. But overall, in most cases, the systems came out to be not profitable [5]. A PV system in Jeddah, Saudi Arabia was studied. The size of the system was estimated to be 12.25 kW. It was seen that performance ratio of the system was low because of the high solar cell temperature at that place which further affects the efficiency of solar cell. Performance ratio was 78%. Capacity factor was found out to be 22%. Economic analysis was done and it was estimated that the net present value was $4378 and payback period was 14.6 years [6]. A 2.1 kW system at Norwegian University was analyzed. The levelized cost of energy was calculated and it came out to be US $0.246/kWh which was much higher than the tariff in Norway. But feed-in-tariff and some financial support can increase the development of PV systems. Less sunlight and other climate factors may reduce the system's economic utility [7]. Systems were evaluated economically and environmentally in several Italian locations. Less CO_2 emissions were measured by reducing net present value and internal rate of return. The annual average insolation value and the design philosophy applied influenced the outcomes. The design principle also affects the performance of the PV plants. The results obtained by using both the design principles, i.e., the principle of first year and principle of economic maximization were almost similar [8]. A study for the University of Jordan has been done. Different types of solar PV systems like fixed axis, single axis, and double axis was studied. Two different engineering models, BOT and EPC, were taken into account while doing the study. The fixed axis system utilizing the EPC model was shown to be more advantageous with a 3-year payback period and an IRR of 32%. In the BOT model, the single axis system had the best payback period of 8.5 years [9]. Three different types of buildings in two different states with different price plans were studied. Some economic indicators were used to evaluate the economic benefits of using the PV system in these buildings. It was concluded that building 2 had better results in state A and building 3 had better results in state B. Investment was not profitable in both the states as payback period was more than 20 years [10]. The performance of a 27 kW grid-connected system was observed in Suriname. The PR and CF were found to be 74.5 and 15%, respectively. The NPV of the project was estimated as $−110,527. The results showed that since the payback period is much more than the lifetime of the system, the system under study was not economically feasible. Moreover, the levelized cost of energy of the system was found out to be 3.5 times more than the current price of energy in that place [11]. A 1 MWp PV system in Adam, Oman was analyzed. The yearly yield factor of the system is 1875.1 kWh/kWp. The PV system's capacity factor was 21.7%. The energy cost was found to be roughly 0.2258 USD/kWh, with a 10-year payback period [12]. Along the southern coast of Iran, different cities were selected, and it was seen whether these places were suitable for developing PV plants or not. The results showed that the selected cities were good sites for installing PV plants and single axis system

came out to be the most economical. The cost of electricity was also determined for various types of tracking systems [13]. Another 5kWp grid-connected system was studied in Iran. Different parameters were determined. The LCOE of the system was very high. A new dynamic FIT strategy was given which was even suitable for other developing nations [14]. Analysis of off-grid PV for a typical household building (power consumtion-9.57 units/day) and typical hostel building (Total power consumed per day = 600 kWh) was done. Lifetime profit (in 25 years) and payback for household building was found to be Rs. 3 lakh and 10.5 years and for hostel building, it was Rs. 1.95 crores and 10 years [15]. A study has been done on 110 kWp system Bhopal, India. The main idea of this study was to design the system and evaluates the economics of the proposed system. Payback period and net present value were calculated. Payback was 8.2 years and NPV was 1.12 [16]. The cost of electricity (COE) and payback period of four different systems in Lucknow, India hve been analyzed. System 1 (5 kWp) had cost of electricity-5.44 INR/kWh (30 years lifespan 5% interest rate) and payback period-13.36 years. System 2 (198 kWp) had COE-2.94 INR/kWh and payback period-6.87 years. System 3 (75 kWp) and system 4 (50kWp) had COE and payback period 2.88 INR/kWh and 6.71 years and 3.23 INR/kWh and 7.12 years, respectively [17]. Economic examination of solar energy systems such as sun drying, solar heating, and solar distillation units are covered in [18].

The objectives of the paper are as follows:

1. To do energy analysis of a 100 kWp PV system taking into account the degradation of PV modules.
2. To perform cost–benefit analysis for 25 years.
3. To calculate the payback period of the system.
4. Electricity bill analysis, power quality analysis, and comparison of fixed and running charges before and after the installation of the PV system.

The following is a breakdown of the paper's structure:

Section 2 is system description.

Section 3 covers the methodology for economic analysis.

Section 4 of the paper is the result and discussion.

Section 5 of the paper is the conclusion.

2 System Description

The study system is 100 kWp PV at rooftop of institute building (26.23152 N, 78.20533 E). The location has extreme climatic conditions. Summer is very hot, humidity also increases, and winter is very cold. The PV system installed in the institution is divided into two parts. Each part is 50 kW with 154 panels and a 50 kW inverter. The effective area of each module is 1.955 × 0.982 m^2 and produces 320 W peak power. PV modules are made by connecting solar cells. It is made of semiconductor material. When sunlight strikes solar cells, the photovoltaic effect

Table 1 Rating of PV module

Peak power	320 Wp
Open circuit voltage	46.56 V
Rated voltage	37.85 V
Short circuit current	9.05 A
Rated current	8.46 A
Module efficiency	16.49%

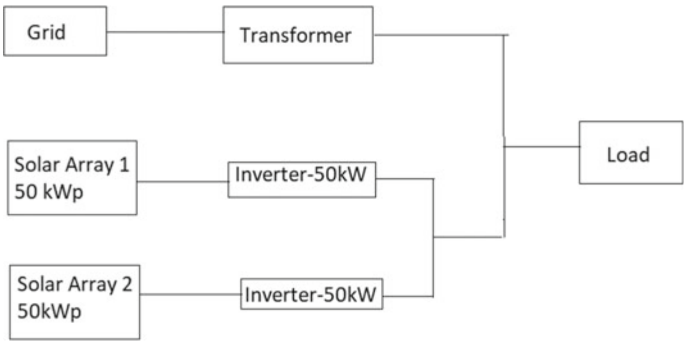

Fig. 1 Systematic diagram of grid-connected solar PV system

produces electricity. The power output is a direct current supply that is transformed to an alternating current supply by an inverter. Metering is accomplished by net metering. Net metering assumes that the power generated by the PV plant is utilized first by the linked load. When the electricity produced by the PV plant exceeds the linked load, the excess PV produced power is fed back into the grid. When the electricity produced by the PV plant is less than the linked load, the extra demand is met by grid supply.

The grid-connected solar PV rooftop system consists of 308 PV modules. The rating of each module is given in Table 1.

The supply voltage from the grid to the college is 33 kV, and the contracted demand is 350 kVA. Institute load is connected to a 500 kVA transformer and hostel load is connected to a 315 kVA transformer (Fig. 1).

3 Economic Analysis of the System

Cost–benefit (CB) analysis

The economic analysis and calculation of the payback period of the system are done by cost–benefit (CB) analysis. In CB analysis, annual savings are calculated for the lifetime of the system (i.e., 25 years). Annual savings can be calculated by subtracting the annual cost from the annual benefits. The annual cost is the money that is spent on the system in a year (operation and maintenance cost). Annual benefit is the amount that is saved by generating electricity by a solar PV system. The amount of money saved is the amount it would have cost if the number of units generated by the PV system would have been taken from the grid supply. For calculating annual benefits, we need to find unit generation (kWh) of the system or how many units of electricity does the system generates in a year.

The following formula can be used for calculating the annual unit generation (kWh) of the solar PV system.

$$\text{Unit generation} = \text{system output} \times \text{capacity utilization factor} \times 24\ \text{hours} \times 365\ \text{days} \quad (1)$$

where capacity utilization factor is the ratio of actual output to the maximum possible output.

By knowing the unit generation of the system and unit price of electricity, we can find the annual benefits, i.e., savings in the electricity bills (Tables 2 and 3). For more accurate results, system degradation factor and escalation in the unit price of electricity are taken into account.

$$\text{Annual savings} = \text{Annual benefit} - \text{Annual cost} \quad (2)$$

Calculation of simple payback period

Payback period is the time (in years) required for the initial investment of the system to be recovered. In order to calculate and analyze the simple payback time of the 100 kWp grid-connected solar PV system, annual savings at the end of each year are

Table 2 Component wise cost of solar PV plant

SN	Component	Cost (Rs)
1	Solar panels	2,041,446
2	Solar inverter	343,500
3	Electrical items (DC/AC cables, earthing cable, earthing strip, earthing kit, ACDB junction box, MCCB box, MC 4 solar cable connector, lightning arrestor, etc.)	704,480
4	Civil and mechanical items (mounting structure, foundation, hardware, etc.)	687,904
5	Services (installation, commissioning, design, transport, freight, etc.)	165,760
	Total component cost	3,943,090
	GST on supply (5%)	197,154
	GST on service (18%)	709,756
	Net cost payable	4,850,000

Table 3 Energy analysis for 25 years

Year	Output (%)	Output (kW)	Unit (kWh) generation
2020	100.00	100.00	131,400
2021	98.00	98.00	128,772
2022	97.22	97.22	127,747.08
2023	96.44	96.44	126,722.16
2024	95.67	95.67	125,710.38
2025	94.90	94.90	124,698.6
2026	94.14	94.14	123,699.96
2027	93.39	93.39	122,714.46
2028	92.64	92.64	121,728.96
2029	91.90	91.90	120,756.6
2030	91.17	91.17	119,797.38
2031	90.44	90.44	118,838.16
2032	89.71	89.71	117,878.94
2033	89.00	89.00	116,946
2034	88.28	88.28	115,999.92
2035	87.58	87.58	115,080.12
2036	86.88	86.88	114,160.32
2037	86.18	86.18	113,240.52
2038	85.49	85.49	112,333.86
2039	84.81	84.81	111,440.34
2040	84.13	84.13	110,546.82
2041	83.46	83.46	109,666.44
2042	82.79	82.79	108,786.06
2043	82.13	82.13	107,918.82
2044	81.47	81.47	107,051.58

analyzed (Table 4). We need to find the time required to make the savings equal to the amount invested.

4 Result and Discussion

In our study, the initial investment of the entire system is Rs. 4,850,000, and operation and maintenance cost is taken as 2.5% of the initial cost. It is considered that the output of the system is reduced by 2% after the first year, and after the second year, it is reduced by 0.8% every year. Escalation in the unit price of electricity is taken as 3.84%. With the increasing scarcity of fossil fuels, the unit price of electricity

Table 4 Cost–benefit analysis for 25 years

Year	Unit (kWh) generation	Unit cost with escalation	Benefit (Rs.)	O&M cost (Rs.)	Saving (Rs.)
2020	131,400	7.10	932,940	121,250	811,690
2021	128,772	7.37	949,389.60	121,250	828,139.60
2022	127,747.08	7.66	977,999.63	121,250	856,749.63
2023	126,722.16	7.95	1,007,406.98	121,250	886,156.98
2024	125,710.38	8.25	1,037,739.16	121,250	916,489.16
2025	124,698.6	8.57	1,068,915.37	121,250	947,665.37
2026	123,699.96	8.90	1,101,072.67	121,250	979,822.67
2027	122,714.46	9.24	1,134,244.93	121,250	1,012,994.93
2028	121,728.96	9.60	1,168,341.21	121,250	1,047,091.21
2029	120,756.6	9.97	1,203,943.30	121,250	1,082,693.30
2030	119,797.38	10.35	1,239,902.88	121,250	1,118,652.88
2031	118,838.16	10.75	1,277,510.22	121,250	1,156,260.22
2032	117,878.94	11.16	1,315,528.97	121,250	1,194,278.97
2033	116,946	11.59	1,355,404.14	121,250	1,234,154.14
2034	115,999.92	12.03	1,395,479.04	121,250	1,274,229.04
2035	115,080.12	12.49	1,437,350.70	121,250	1,316,100.70
2036	114,160.32	12.97	1,480,659.35	121,250	1,359,409.35
2037	113,240.52	13.47	1,525,349.80	121,250	1,404,099.80
2038	112,333.86	13.99	1,571,550.70	121,250	1,450,300.70
2039	111,440.34	14.53	1,619,228.14	121,250	1,497,978.14
2040	110,546.82	15.09	1,668,151.51	121,250	1,546,901.51
2041	109,666.44	15.66	1,717,376.45	121,250	1,596,126.45
2042	108,786.06	16.27	1,769,949.20	121,250	1,648,699.20
2043	107,918.82	16.89	1,822,748.87	121,250	1,701,498.87
2044	107,051.58	17.54	1,877,684.71	121,250	1,756,434.71

is increasing every year [19]. Considering the past 3 years' electricity bills, the escalation in electricity pricing is observed as 3.84%. The capacity utilization factor is taken as 15%. The cost–benefit analysis of the 100 kW grid-connected rooftop system for the next 25 years (the life of the system is considered as 25 years) is given in Table 4.

The cost for lightning protection and overvoltage protection installation has been considered in the total cost of the system. The cost of these components (Rs 704,480) is covered in electrical items, as mentioned in Table 2.

As per the calculation, the total savings at the end of the fifth year will be Rs. 4,299,225.37 and at the end of the sixth year will be Rs. 5,246,890.74. Since the initial investment is Rs. 4,850,000; therefore, the payback period will be approximately 5.5 years.

Table 5 Comparison of payback period with variation in unit cost of electricity

Variation in unit cost of electricity	Payback period
Unit cost with escalation 3.84%	5.5 years
Unit cost not increased	6.5 years
Unit cost increased for next 10 years and then kept constant	5.5 years

Savings after first year: Rs. 811,690.
Savings after second year: Rs. 811,690 + Rs. 828,139.60 = Rs. 1,639,829.60.
Savings after third year: Rs. 811,690 + Rs. 828,139.60 + Rs. 856,749.63 = Rs. 2,496,579.23.
Savings after fourth year: Rs. 811,690 + Rs. 828,139.60 + Rs. 856,749.63 + Rs. 886,156.98 = Rs. 3,382,736.21.
Savings after fifth year: Rs. 811,690 + Rs. 828,139.60 + Rs. 856,749.63 + Rs. 886,156.98 + Rs. 916,489.16 = Rs. 4,299,225.37.
Savings after sixth year: Rs. 811,690 + Rs. 828,139.60 + Rs. 856,749.63 + Rs. 886,156.98 + Rs. 916,489.16 + Rs. 947,665.37 = Rs. 5,246,890.74.

Payback period when escalation in the unit cost is considered is 5.5 years. If unit price is not increased, payback period comes out to be 6.5 years (Table 5).

Analysis of electricity bills

In our study, analysis of electricity bills is also done. The solar PV rooftop system was installed in November 2019. A summary of the electricity bills from February 2019 to March 2021 is given in Table 6.

From the analysis, it can be seen that maximum demand has decreased after the installation of the solar PV system. The average maximum demand (kVA) before installation was 334.5 kVA and after the installation was 152.625 kVA. Also, it is evident that the power factor has decreased after the installation of the system. The average power factor before installation of the system was 0.963 and after the installation is 0.9143. It is a disadvantage that the power factor slightly decreases. The power factor of PV produced power majorly depends on inverter output power with respect to its rated power. During the morning and evening time, the PV generation is very low in comparison to the rated power of solar inverter [20, 21]. This reduces the average monthly power factor of the plant. It is clear from Table 6 that the fixed and running charges have also decreased after the installation of the solar PV system. Running charges has decreased from an average of Rs. 692,138.15 to an average of Rs. 293,981.875. Average electricity bill before the system was installed is Rs. 871,867 and the average electricity bill after the installation is Rs. 432,020.

Table 6 Summary of electricity bill

Month	Contracted demand (kVA)	Maximum demand (kVA)	Power factor	Running charges (Rs.)	Fixed charges (Rs.)	Total bill (Rs.)
Feb 2019	350	209	0.96	520,504.5	159,637.5	680,142
Mar 2019	350	168	0.96	409,553.5	159,637.5	569,191
April 2019	350	365	0.97	704,925.5	161,787.5	866,713
May 2019	350	405	0.96	918,260.5	181,137.5	1,099,398
June 2019	350	432	0.96	801,820.5	198,552.5	1,000,373
July 2019	350	435	0.95	675,898.5	200,487.5	876,386
Aug 2019	350	420	0.96	828,188.5	193,827.5	1,022,016
Sept 2019	350	415	0.97	922,832	200,675	1,123,507
Oct 2019	350	294	0.97	677,638	170,775	848,413
Nov 2019	350	202	0.97	461,760	170,775	632,535
Dec 2019	350	169	0.96	437,496	170,775	608,271
Jan 2020	350	219	0.98	503,892	144,900	648,792
Feb 2020	350	166	0.97	457,408	144,900	602,308
Mar 2020	350	163	0.93	304,115	144,900	449,015
April 2020	350	72	0.87	125,354	–	125,354
May 2020	350	81	0.85	132,436	289,800	422,236
June 2020	350	180	0.89	–	144,900	–
July 2020	350	195	0.93	264,372	144,900	409,272
Aug 2020	350	177	0.92	321,656	144,900	466,556
Sept 2020	350	159	0.94	326,106	144,900	471,006
Oct 2020	350	162	0.89	312,596	144,900	457,496
Nov 2020	350	106	0.86	262,061	144,900	406,961
Dec 2020	350	130	0.92	272,953	144,900	417,853
Jan 2021	350	172	0.95	381,330	147,850	529,180
Feb 2021	350	153	0.91	324,731	148,050	472,781
Mar 2021	350	138	0.86	277,188	148,050	425,238

*Fixed charges of April 2020 are considered in bill of May 2020

5 Conclusion

The installation cost of the grid-connected solar PV rooftop system is very high. Since we invest a lot of money in the system, it becomes important to carry out economic analysis. It becomes important to analyze the payback period and other economic benefits. If the system is able to recover the invested amount in less than the lifetime (25 years) of the system, the system is considered to be economically feasible and efficient. Lesser the payback back period, the more efficient the system is.

1. In our study, the solar PV rooftop system has capital investment of Rs. 4,850,000. Economic analysis of the system is done by energy analysis, cost–benefit analysis, analyzing electricity bills, and by calculating the simple payback period.
2. Payback calculation is done by considering capacity utilization factor (CUF) equal to 15%, escalation in the unit price of electricity is taken as 3.84%, and O&M cost is taken as 2.5% of the initial cost. Considering this, the simple payback time is 5.5 years.
3. After analyzing the electricity bills, it was seen that the maximum demand decreases after the installation of the system. The power factor slightly decreases which is a disadvantage. The average power factor before installation of the system was 0.963 and after the installation is 0.9143. Measures should be taken to improve the power factor.
4. Fixed and running charges also decreased after the installation of the solar PV system. Average electricity bill before the system was installed is Rs. 871,867, and the average electricity bill after the installation is Rs. 432,020.
5. Since the payback is 5.5 years which is very less than the lifetime of the system, the system installed is economically efficient. Although the system under the study is economically efficient, the efficiency of the PV system can be further improved by proper maintenance of the system.

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