A Project Report

On

Grid Connected Rooftop PV Plant Economic Analysis Using Present Time Frame Methodology

in partial fulfillment for the award of the degree

of

BACHELOR OF TECHNOLOGY (B. TECH)
IN
ELECTRICAL ENGINEERING

Submitted by:
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(*A Govt. Aided UGC Autonomous & NAAC Accredited Institute, Affiliated to RGPV Bhopal*)

MAY 2023

CANDIDATE'S DECLARATION

I hereby declare that the project titled **"Grid Connected Rooftop PV Plant Economic Analysis Using Present Time Frame Methodology"** submitted for the award of **Bachelor of Technology** degree in **Electrical Engineering** is my original work and the project has not been submitted elsewhere for the award of any other degree, diploma, fellowship, or any other similar titles.

Abhishek Singh (0901EE191005)

Place: Gwalior
Date: 26/05/23

This is to certify that the above statement made by the candidate is correct to my knowledge and belief.

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ABSTRACT

The rooftop PV installation is one of the most significant solutions for producing electrical energy without creating any pollution. PV plants need a significant initial investment, and they also provide energy assistance to grid and users. There is an urgent need to create a straightforward and error-free economic analysis methodology to attract consumers from commercial buildings (such as institutional buildings). The presented study covers a time-value of money based economic analysis for a 100 kWp PV plant at a composite climate in Gwalior, India. The study is performed through real-time data collection and analysis. The results show that there is 127020 kWh electricity generation in the first year, which declined to 104828.3358 kWh in the last year (of PV plant life) due to the degradation of the PV array. By considering the uniform cash flow and discount rate of 8.6%, the average annual benefit is Rs. 904374.88. The simple and discounted paybacks of the case study are 7 and 12 years, respectively, whereas the net present value and benefit-to-cost ratio of the plant are Rs. 4679070.0 and 2.04, respectively.

Index Terms- Grid connected PV plant, Economic analysis, Payback time, discount rate, Net present value.

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1. CHAPTER I: INTRODUCTION

The power system is undergoing a profound change as a result of today's high demand for electricity and the need to reduce carbon footprint. This change is paving the way for renewable electricity generation in the traditional grid, making the traditional network smarter [1]. Due to dwindling fuel resources and global fuel price fluctuations, the global energy systems are undergoing significant transformation; decentralized, renewable-based sources are now replacing conventional, bulky fossil-based sources in the energy ecosystem [2], [3]. The world is adopting alternative energy development Plans to install renewable energy such as photovoltaic (PV) systems or wind energy. A Thailand based case study was conducted to demonstrate the levels of PV penetration in various locations that were influencing the voltage quality of low-voltage distribution systems [4]. In such low-voltage systems, if the PV generation exceeds the downstream load, the power flow may be reversed towards the substation. As a technical result of the reverse power flow, a voltage rise along the distribution system feeder is expected [5], while on the part of economic results, a reduction in electricity charges is expected [6]. The variation of heating and cooling loads (AC systems, lighting systems, electrical power systems etc.) also affect the electricity consumption units [7]. Techno-economic studies for integrated rural energy system have been conducted, taking into account cost-optimal component sizing and evaluating economic performance in terms of Levelized Cost of Energy (LCOE), Net Present Cost (NPC), and Capital Recovery Factor (CRF). A 100% decarbonized society can be transformed into a smart decarbonized community by combining demand response-based systems. Both AC and DC loads considered in the study can be extended with consumer-driven participation in demand response programs [8]. In a study to determine the impact of energy savings in the Indian textile sector, several factors, including power factor, rooftop PV, power quality analysis, bill analysis, etc., were included. When looking for the impact of PV installation on electricity bills, it was discovered that possible savings could have been made in a pollution-free environment [9]. When case studies were conducted at various institutes, it was discovered that the electricity consumption was extremely high, resulting in exorbitant electricity costs. The consumption rises in direct proportion to the number of new laboratories or buildings built. The institute's analysis of power quality on the parameter of average current unbalance on MDP AC met the standards of Permen ESDM No.4 of 2009, which is a maximum of 20% [10]. The seasonal variations of solar PV generation, the grid supply used, and a detailed analysis of monthly electricity bills were studied to analyze the estimated consumption of energy, as well as the savings made by using renewable energy systems in the form of PV systems. It was discovered that time of use (ToU) and Night-time energy usage have a significant impact on the overall monthly electricity bill [11]. A five-year study conducted at a US university found that when solar panels were installed on the Durango building, it helped to reduce load during the day, which is also the peak consumption period. It was due to the weather conditions at the time. The campus's energy utilization intensity (EUI) data revealed that, despite the university's success in lowering EUI since 2010, it remained higher than ASHRAE standard requirements [12]. In-depth analysis of a solar PV plant for a library building in an academic setting using the Modified Greedy Search Algorithm. It investigates the financial viability of the solar PV module using real-time market prices [13]. The levelized cost of energy (LOCE) for a solar PV-DG battery is 23.08 INR, while the LOCE for a DG battery is 43.38 INR [14]. The findings indicate that PV systems can significantly reduce CO2. A 200 kWp PV plant can save 421.1 tCO2e, and a 90 kWp PV plant can save 2199.6 tCO2e [15]. Kumar N.M. et al. found that when environmental economics, such as CO2 mitigation, are combined with other economic factors, the payback time decreases from 15.5 to 10.7 years [16], [17]. In order to deploy ethical means in solar PV, new technologies necessitate policies based on research and development projects. As a result, the current scenario offers a diverse set of applications and energy enhancements for solar PV arrays through the use of a variety of tools and models. The goal is to maximize energy utilization while minimizing the economic burden and losses of the system. In this regard, the followings are the presented case-study's objectives: 1) To facilitate simple, step-by-step and accurate methodology for the economic analysis of Rooftop GCPV plants. 2) To present an economic case study under composite climate of Gwalior (India) and variable loading scenario of institutional building. 3) To consider the time value of money in terms of discount rate (d) and comparing the pay-back results obtained with & without d value. 4) To understand the concept of net present value (NPV) and benefit to cost ratio (BCR) for an economical GCPV plant.

2. CHAPTER II: SYSTEM DESCRIPTION

A. Geographical Location The study is performed for the location of Gwalior, M.P., India. The geographic coordinates of the location are 26.23° N (latitude) and 78.18° E (longitude), with 5.63 kWh/m2/day of solar radiation (on average). The PV array's tilt angle is considered equal to the latitude angle, in a south direction. This is required to receive the most solar radiation. [18].

B. System The economic analysis is performed for a 100 kWp grid connected PV (GCPV) plant. The GCPV plant is planned to support the engineering institute's electrical load (as shown in Fig. 1). The two power sources for the system are the rooftop GCPV system and the Grid supply. The rooftop area required for the PV modules installation is 1000 m^2. As the rooftop PV array produce DC supply, the PV array is connected to an PV inverter. The inverter converts DC energy into AC energy, allowing the energy produced to be used by the institute's electrical load and lab's machinery. The PV inverter is connected to the point of common coupling (PCC), which also has a grid supply from Madhya Pradesh Madhya Kshetra Vidyut Vitran Co. Ltd. (MPMKVVCL). This is an alternate power source that provides energy to the campus. The contracted demand from this grid supply is currently 405 KVA and distribution transformer is connected with the grid supply.

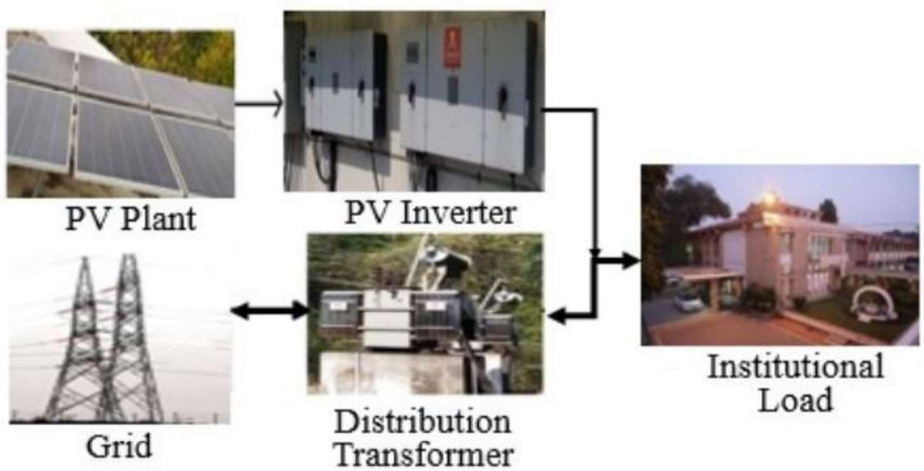

Fig. 1: Grid connected PV plant for institutional load

C. System working in the summer months (April - August), when the solar intensity is high in the composite region of Gwalior (India), the solar irradiance causes the higher production of electrical energy through GCPV system. During this season, the excess energy will be supplied to the grid system and will support the higher economic benefits. It also aids in obtaining better government incentives. When enough energy is not available through GCPV system during the winter months, the supply will be taken from the grid and savings in electricity bills will be achieved through Net-Metering concept.

3. CHAPTER III: METHODOLOGY

A. Economic analysis considering 'present time frame' By using the benefit-cost analysis, the CGPV system's economic analysis is conducted. The reductions in electricity costs and government subsidies are considered the GCPV system's benefits (B), while the system's costs include the initial investment (C0) and annual maintenance (C) [19], [20]. The cash flow for benefit-cost analysis is shown in Fig. 2. All the benefits (B) of the systems are represented in positive vertical axis and all the costs (C) are represented in negative vertical axis. As shown in figure, the B and C are considered on annual basis, for which

1) B1, B2, B3 and BT are the annual benefits after completion of first, second, third and T^{th} year respectively.

2) C1, C2, C3 and CT are the annual costs after completion of first, second, third and T^{th} year respectively.

3) C0 is the initial invest cost of GCPV plant.

The net annual benefit (A) of GCPV plant is calculated by subtracting annual cost from benefit i.e. (B-C). So, the net benefit after first year (A1), second year (A2), third year (A3) and T^{th} year (AT) will be (B1 - C1), (B2 - C2), (B3 - C3) and (BT - CT) respectively. As given in equation (1), now by considering the uniform cash flow (i.e. A1= A2= A3..... = AT = A) and the discount rate 'd', the benefit-value (P) of GCPV plant at present time (t= 0) frame is given by [19], [20]-

$$P = A\left[\frac{(1+d)^T-1}{d(1+d)^T}\right] \qquad (1)$$

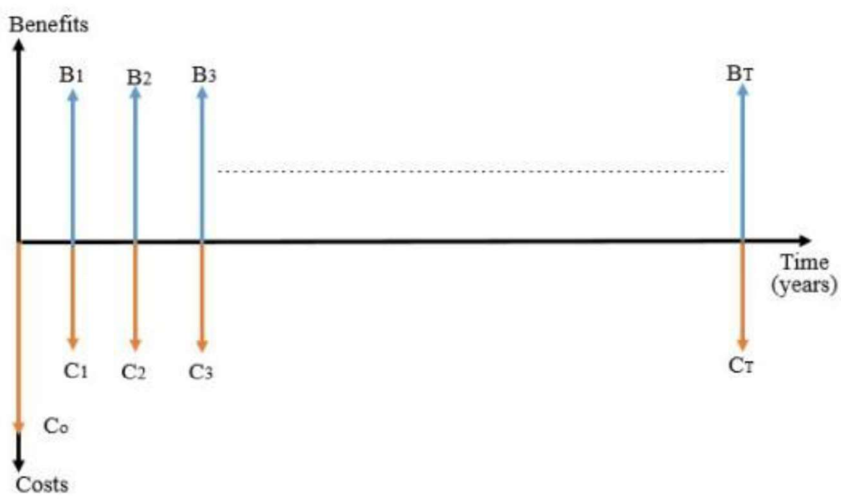

Fig. 2: Cash flow for benefit-cost analysis

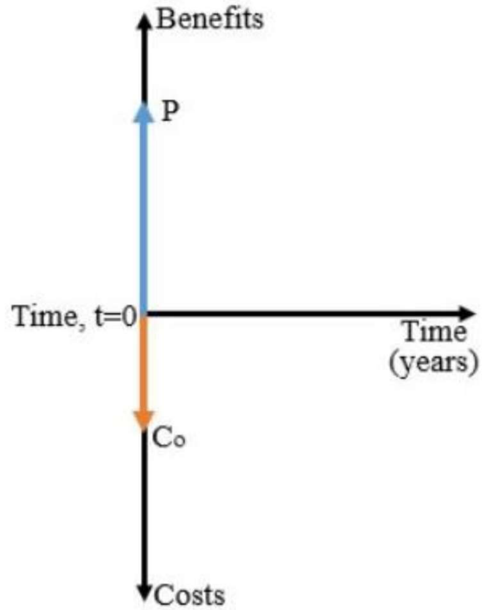

Fig. 3: Cash flow for benefit-cost analysis at present time frame, t= 0

Where, 'T' is the life of GCPV plant (in years). Fig. 3 shows the cash flow for benefit-cost analysis at present time frame (t= 0). This time frame considers the discount rate (d), which basically covers the time value of money and provides the more accurate results of economic analysis. Now, the net-present-value (NPV) of the GCPV plant at present time frame (t= 0) can be calculated by using equation 2 [21], [22].

$$NPV = P - C_0 \qquad (2)$$

The benefit-to-cost ratio (BCR) of the GCPV plant at present time frame (t= 0) can be calculated by using equation 3 [23].

$$BCR = PC_0 \qquad (3)$$

The discounted-pay-back time (T_{dP}) of the GCPV plant at present time frame (t= 0) can be calculated by using equation 4 [24], [25].

$$T_{dP} = C_0/P(per\ annum) \qquad (4)$$

The simple-pay-back time (T_{SP}) of the GCPV plant can be calculated by using equation 5 [24], [25].

$$T_{SP} = C_0/A_1 \qquad (5)$$

B. Annual energy production by CGPV plant

The calculation of GCPV produced electrical energy (kWh/ year) can be done by the coefficient of utilization factor (CUF), for which the formula is given in equation 6 [26].

$$CUF = \text{Energy produced (kW h/year)/ CGPV plant capacity} * 365 * 24 \qquad (6)$$

For the calculation of annual energy production, the equation 6 can be rewritten as given in equation 7.

$$\text{Energy produced (kW h/year)} = \text{CGP V plant capacity} * \text{CUF} * 365 * 24 \qquad (7)$$

Now the annual benefits from the GCPV plant can be calculated by multiplying the kWh energy produced (equation Fig. 3: Cash flow for benefit-cost analysis at present time frame, t= 0 7) with unit price of electricity of location (Rs/ kWh). The formula for calculating annual benefit is given in equation 8.

$$\text{Annual benefits (B)} = \text{Energy produced (kW h/year)} * \text{Electricity unit price (Rs/ kW h)} \quad (8)$$

With the help of these 'GCPV energy production based annual benefit values (B)', the economic analysis is performed by using the methodology given section III A.

4. CHAPTER IV: RESULT AND DISCUSSION

The data acquisition has been done for a period of 25 years (life of GCPV plant) considering the present time frame as zero. The value of the future costs has also been calculated in the present-day value. The various observations are represented in the graphical form here. As shown in Fig. 4, the trend observed in the kWh generation over the time period of 25 years is declining in nature. It is because- with time, the efficiency of the system tends to reduce as the damage caused by the high temperature causes the electron holes pairs in the PV modules to combine and hence reduce the final generation. The buildup of debris such as leaves, branches, shading effect, bird droppings and dirt might cause the solar panels to underperform. The rate at which such degradation in generation occurs is called degradation factor. Now, the Rooftop GCPV produced annual electrical energy is calculated by using equation 7, for which the required data is taken from followings-

1) Degradation factor of PV array is 3% for the first year and 0.7% for the consecutive years [2].
2) CUF = 14.5% (average for 24 hours a day and 365 days per year) [2]. As shown in Fig. 4, there is 127020 kWh generation in the first year, which is declined to 104828.3358 kWh in the 25th year.

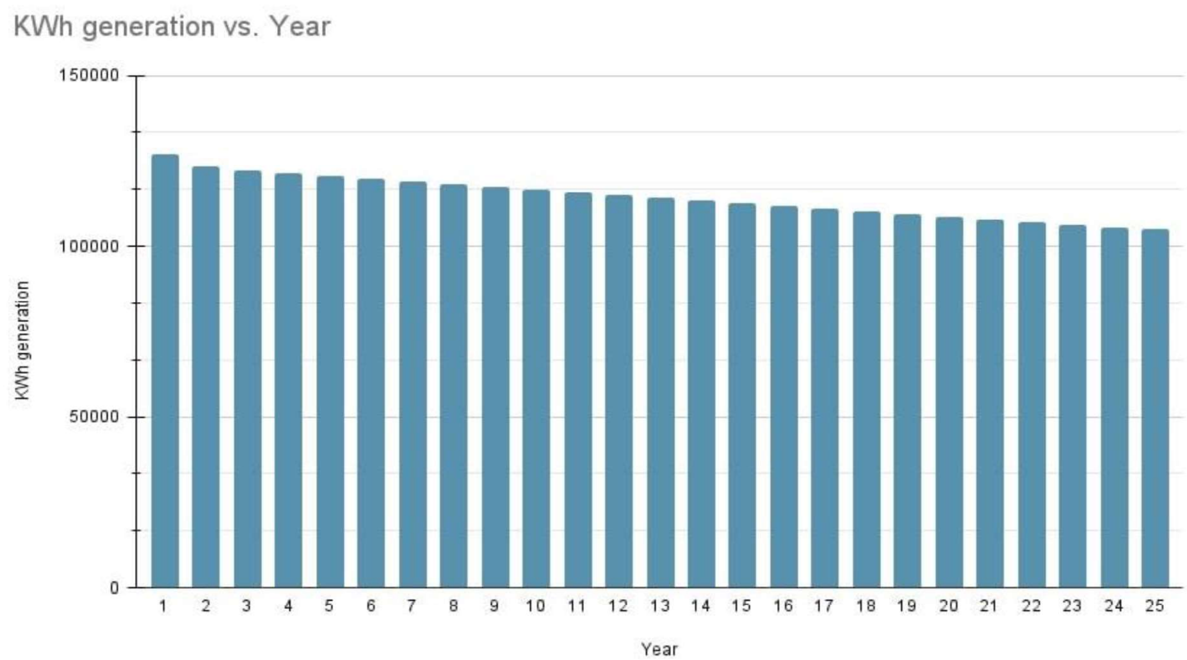

Fig. 4: kWh unit generation over the period of 25 years (life time)

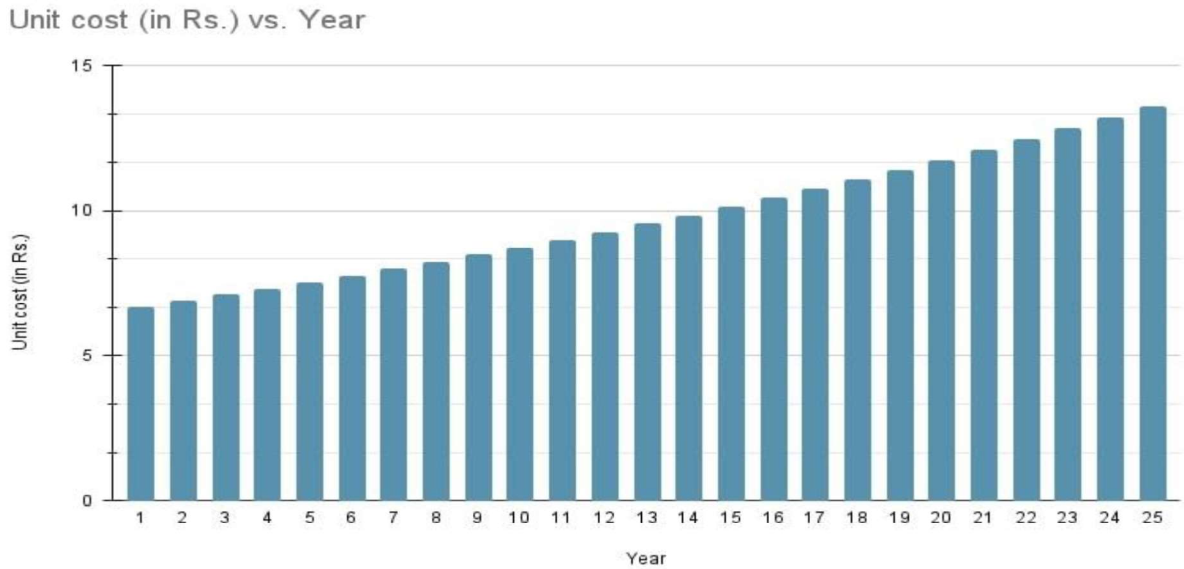

Fig. 5: Variation of unit cost of electricity over the period of 25 years (life time)

The annual monitory benefits from the GCPV plant are calculated by using equation 8. From the past 3 years data (from 2019 to 2022), it is observed that there is escalation in unit cost prices of electricity. The unit price saw a hike of 3% (average) over the entire period of rooftop GCPV system. The increase in price was based on the policies of the government. However, the average value taken for a period of three consecutive years showed that the price of per unit electricity will increase and hence it will impact the overall tangible benefits procured by installing the system. The main agenda behind the increase in cost is to discourage the users from using the electric supply at peak load. Using electricity at peak loads and over and above the contracted demand can cause faults and damage to the transmission lines which will impact the economy of the nation. The variation of unit cost of electricity over the period of 25 years (life time) is shown in Fig. 5. In the case of this hike in unit price of grid supplied electricity adds monitory benefits to the GCPV plants; because according to equation 8, the increase in electricity unit price will increase the annual benefit (B).

As discussed in methodology (Fig. 2), the net annual benefits (A1, A2, A3 .... AT) are calculated by subtracting annual costs from the benefits. These benefits over the period of 25 years (life time) are shown in figure 6. The savings in the billing amount shows that the total cost of the system was retrieved back in about 6.75 years after the date of installation of the system (calculated by using equation no 5). Since the average life of the system is considered as 25 years, the simple payback period is quite small and hence highlights the fact that the system turns out to be highly economical in nature. The overall cost of the rooftop PV system is Rs. 45,00,000/- and total savings after 7 years is Rs. 4851746.25. It is desired that the payback time should be as least as possible so as to gain maximum savings. The cash flow diagram for benefit-cost at present time frame (t=

0) is now plotted and shown in Fig. 7. The calculation 'P' is done by using formula given in equation 1. Followings values are considered for calculating the 'P' value1) Average annual benefit, A = Rs. 904374.88 (considering uniform cash flow). 2) Present discount rate, d= 8.6% and life of GCPV plant, T= 25 years. The graph (shown in figure 7) suggests that the benefit of the system in discounted payback period is Rs. 91,79,070.16 while the system cost was just Rs. 45,00,000.00 The average of the net benefit was equal to Rs. 9,04,374.88.

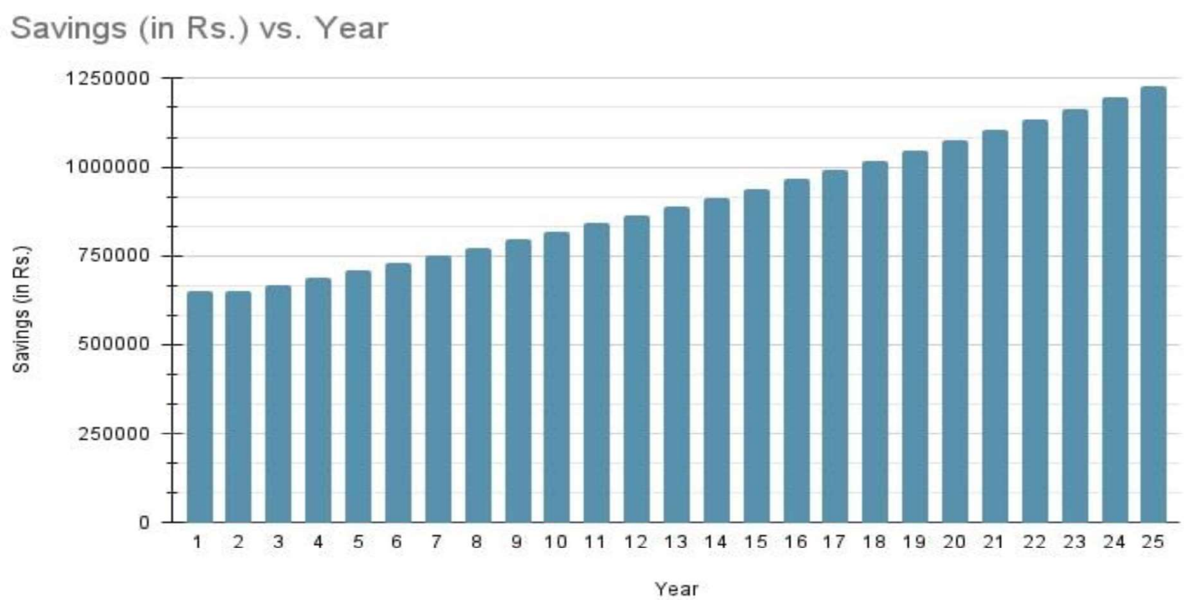

Fig. 6: Savings in electric bills over the period of 25 years (life time)

S.N.	Parameter	Calculated value	Remark
1.	NPV	Rs. 4679070.00	Economical
2.	BCR	2.04	Economical
3.	T_{dP}	12 years	Economical

TABLE I: Economic analysis data at present time frame

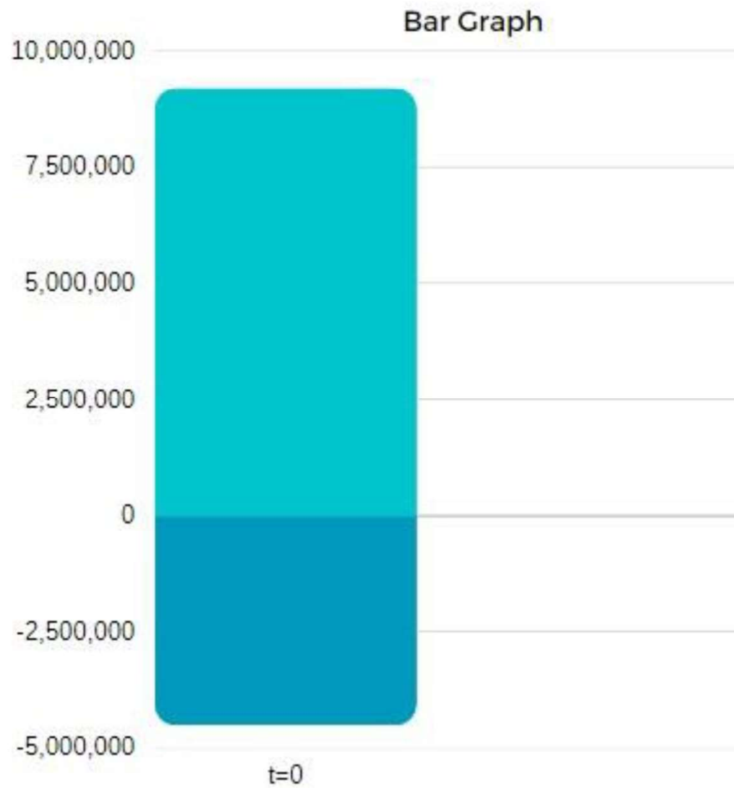

Fig. 7: Cash flow for benefit-cost analysis at present time frame, t = 0

The calculation of NPV, BCR and T_{dP} is now done by using equation (2), (3) and (4) respectively. The calculated values of these economic parameters are given in table 1. For an economical GCPV plant; the NPV should be positive, BCR should be greater than unity and the T_{dP} should be less than the life of system. As given in table 1, all the economic parameters are following the conditions of an economical GCPV system.

5. CHAPTER V: CONCLUSION

This study provides information on how to investigate the economic evaluation of a GCPV project using life-cycle analysis. The provided formulation and methodology will benefit independent power producers for future PV-based renewable energy projects. According to the study's presumptions, findings, and results, the proposed methodology is suitable for commercial operation. The key findings of the work are summed up in the following conclusions-

1) The degradation in PV array performance reduces the electrical energy output of the GCPV plant every year; whereas the escalation in grid supply electricity price affects the annual benefits of PV plant. These two factors should be considered for the accurate economic analysis of PV plants.

2) The consideration of 'time value of money' in terms of discount rate may increase the pay-back time. But the discounted payback is still less than the life of the GCPV plant, which comes under an economical PV system.

3) The NPV and BCR are also measures of economic performance. The positive NPV value and high BCR value (greater than unity) prove that GCPV plant is economical in operation. The presented study provides a step wise step and easy methodology for economic evaluation of any kind of GCPV plant. The estimation of economic parameters at early stages can also be done by provided methodology.

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APPENDIX A: SELF EVALUATION OF FORTNIGHTLY PROGRESS OF PROJECT

Table: Content of fortnightly progress of Project

Duration of Project Work	**Progress of Project**
01/01/23 - 15/01/23	Identification of title of project and objective of work
16/01/23 - 11/02/23	Searching the data related to the previous researches done in same field
13/02/23 - 25/02/23	Writing the Literature review
27/02/23 - 10/03/23	Collection of images and bills for electricity bill analysis (economic analysis)
11/03/23 - 17/03/23	Preparation of Methodological data
18/03/23 - 27/03/23	Writing of the paper in authentic format and worked to identify possible results
28/03/23 - 06/04/23	Searching for reputed conferences to submit the paper
09/04/2023	Submitted the draft paper in the APSIT conference

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