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Design and Economic Analysis of a 74.1kW Grid connected Rooftop Solar PV Power system

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Abstract. The design and modeling of a commercial rooftop solar power system are essential for effective project planning and execution. Various factors must be carefully evaluated before implementation to ensure optimal performance and cost efficiency. This paper presents the design, modeling, and cost-benefit analysis of a 74.1 kW grid-connected rooftop solar power plant. It includes a detailed assessment of electricity generation and a two-year billing history, simulated using PVsyst software. The performance ratio (PR) of the photovoltaic (PV) system is analyzed, and validated results from the actual project execution are presented. Key aspects such as material costs, installation costs, energy output, and electricity savings are examined. This research serves as a valuable resource for designing and optimizing rooftop solar PV systems.

INTRODUCTION

Renewable energy sources are primarily harnessed to generate electrical energy, utilizing natural resources such as flowing water (rivers), solar radiation, wind, and tidal energy[1]. The global shift toward environmentally friendly and sustainable energy solutions has made renewable energy a critical focus. Among these sources, solar energy is one of the most abundant and accessible, particularly in India, where it has become a key contributor to the country's energy landscape. India receives an average solar radiation of approximately 4.6 kWh/m²/day in the northern regions and 5.6 kWh/m²/day in the southern regions[2]. Recognizing this immense potential, the Government of India has implemented a strategic plan to expand renewable energy by 2026, with a strong emphasis on rooftop solar power for both residential and commercial applications. The government actively promotes investment in rooftop solar projects, aiming to fulfill 40% of the nation's total power demand through rooftop solar installations and up to 80% of the contract demand for commercial users. To support this growth, many solar cell manufacturers and research institutions are developing advanced software for solar power system design and modeling. The adoption of simulation tools has become an essential trend in optimizing solar energy utilization[4]. Various software solutions, such as PVsyst, Sunny Design, SolarPro, and PV*SOL, have been developed for precise system analysis and performance evaluation. Despite the increasing global interest in rooftop solar power, it remains a relatively emerging field. The paper is about:

1. CO_2 emissions saved amount is calculated.
2. Selecting solar panels, inverters, and other equipment, designing and calculating accordingly.
3. Calculating economic indicators using MSExcel software based on simulated data.

ROOFTOP SOLAR POWER PLANT

Rooftop solar systems are installed on existing building roofs and are classified into three main types: off-grid, on-grid, and hybrid systems, each offering unique power generation and storage capabilities. Recently, rooftop-mounted tracking systems have been introduced to enhance solar energy capture. Unlike fixed-tilt systems, which remain stationary and provide stability with easy installation, tracking systems follow the sun's movement to maximize solar radiation absorption. There are two main types of tracking systems: single-axis and dual-axis trackers. Single-axis trackers move from east to west, while dual-axis trackers adjust in both horizontal and vertical directions, optimizing energy capture throughout the day. The use of tracking systems significantly improves the efficiency of solar power generation. In India, the pricing of solar power sold to state governments is typically determined through competitive bidding under schemes such as the Solar Energy Corporation of India (SECI) auctions or state-specific tenders. Solar electricity tariffs generally range from Rs. 2.00 to Rs. 3.00 per kilowatt-hour, with developers bidding to offer the lowest price. The design of a rooftop solar power system requires careful assessment of several factors, including load estimation, site evaluation, system sizing, component selection, inverter sizing, battery backup (if needed), electrical design, regulatory compliance, monitoring, maintenance, and safety considerations. The two primary PV panel technologies are crystalline and thin-film[5]. For this project, monocrystalline silicon panels were selected due to their superior efficiency.

Solar panels are connected to inverters, which play a crucial role in determining system performance and overall cost. Proper selection of inverters and solar modules is essential for ensuring long-term reliability and efficiency. The location photo, string connection, and side and front views of the 74.1 kW solar power plant are shown in Fig. 1.

FIGURE 1. Geographical site of solar power plant

SITE INFORMATION

The rooftop solar PV power system is located in Warangal, Telangana at a latitude and longitude of 17.97^0 N and 79.61^0E respectively(figure 2). The solar panels were installed using PVsyst software[3] on the site. A summary of the project and its system details are provided below.

FIGURE 2. Photo of the site taken by satellite

Geographical site- Sri Vani Industries, India

Situation- Latitude 17.96^0 N, Longitude 79.61^0 E, Altitude 261m, Time zone UTC+5.3

Project settings- Albedo 0.20

PV Field orientation- Fixed planes: 2 orientations

Tilts -10/90^0 ,10/-90^0

Near shadings- No shadings **User's**

need- Unlimited load(grid) **System**

information

PV Array- Number of modules: 136 units	Pnom total: 74.1 kWp
Inverter- Number of units: 1 unit	Pnom total: 70.0 kWac

Results Summary

Produced Energy	112097 kWh/year	Specific production	1530kWh/kWp/year
Performance ratio PR	84.50%		

System Summary

Total installation cost	3405738.00INR	Operating costs	00.00INR
Produced Energy	112MWh/year	Cost of produced energy(LCOE)	1.242INR/kwh

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Financial analysis:
Simulation period
Project lifetime 25 years Start year 2022
Financing
Subsidies 681163.80 INR
Loan- Redeemable with fixed annuity -5 years

2724641.20 INR

Interest rate:8.75% year
Electricity sale
Feed-in tariff 7.6400 INR/kWh Duration of tariff warranty 20 years

Feed-in tariff decreases after warranty 50.00%

Item	Quantity units	Cost INR	Total INR
PV Modules			
LX-545M/182-144+	136	17440.00	2371820.00
Supports for modules	136	1090.00	148220.00
Inverters			
MAX 70KTL3LV	1	185280.00	185280.00
Other components			
Wiring	1	111160.00	111160.00
Surge arrester Installation	1	74100.00	74110.00
Global installation cost per module	136	1090.00	148290.00
GST			366864.00
Total			3405738.00
Depreciable asset			2705360.00

Table 1. Installation cost

Item	Total INR year
Total(OPEX)	0.00

Table 2. Operating cost

SIMULATION

The PVsyst program is utilized for simulation purposes in this investigation[8]. The figures are exclusively created through the modeling procedure for the proposed site[9]. The PVsyst software is used. Simulation of input parameters such as weather conditions, building direction, solar radiation, tilt angle, and other aspects are taken into consideration[10]. As computer modeling has been conducted in this study, only the simulation findings are discussed. The simulation process using PVSYST software can be done by setting location, setting azimuth angle and tilt angle, and selecting inverter and solar modules[12]. Then running the simulation, the result is obtained.

1. PV ARRAY CHARACTERISTICS

PV Module

Manufacturer Luxor | Model LX-545M/182-144+

Unit Nom. power 545Wp | Number of PV modules 136 units

Unit Nominal (STC) 74.1kWp | Modules 8 strings x 17 in series

Inverter

Manufacturer Growatt New Energy Model MAX 70KTL3LV (Original PVsyst database)

Unit Nom. Power 70.0 kWac | Number of Inverters 1 Unit

Total power 70.0 kWac | Operating voltage 200-1000 V

Pnom ratio(DC:AC) 1.06

At operating cond.(50°c)

Pmpp 67.4kWp | U mpp 633 V | I mpp 107 A

Total PV power

Nominal (STC) 74kWp | Total 136 modules

Module area 351 m² | Cell area 323 m²

Total inverter power

Total power 70kwac | No. of inverters 1 unit

Pnom ratio 1.06

2. ARRAY LOSSES

Thermal loss factor

Uc (const) 20.0W/m^{2}K/m/s | Uv(wind) 0.0W/m^{2}K/m/s

DC wiring losses

Global array res. 98mΩ | Loss fraction 1.4% at STC

Module quality loss

Loss fraction 2.01% at MPP

Module mismatch losses

Loss fraction 0.11%

3. RESULTS OF SIMULATION AND DISCUSSION:

Investment global 3405738.00INR | Specific 45.5INR/Wp

Running cost 0.00INR/yr | Payback period 4.0 years

Energy cost 1.25INR/kwh

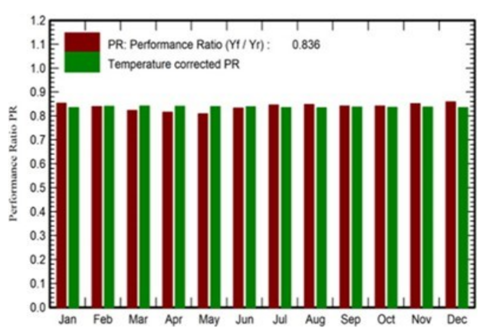

FIGURE 3. Performance ratio.

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The city is located in the southern part of India where the temperature is high when compared to standard conditions. So, the heat loss is high.

4. FINANCIAL ANALYSIS

Fig.4 gives the data of yearly net profit in INR and Fig.5 gives the idea of cumulative cash flow in kINR.

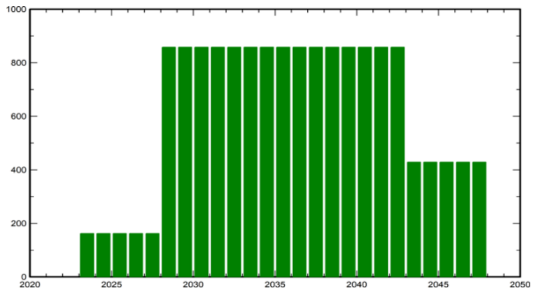

FIGURE 4. Yearly net profit(INR)

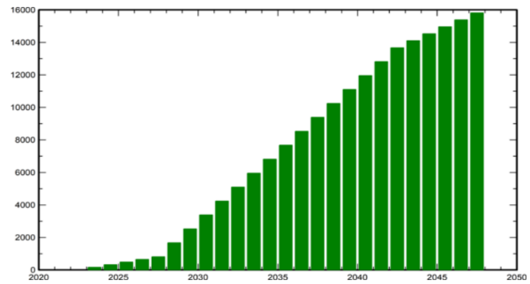

FIGURE 5. Cumulative cash flow(Kinr)

Fig.6 and Fig.7 give the systems output power distribution data.

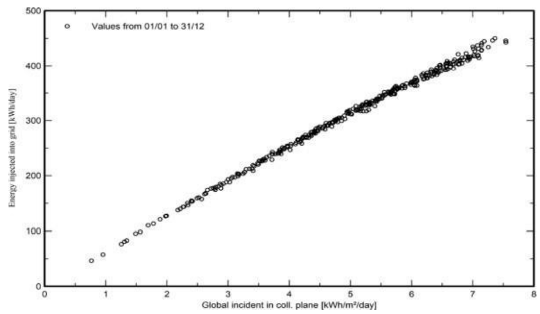

FIGURE 6. Daily inputs/outputs diagram

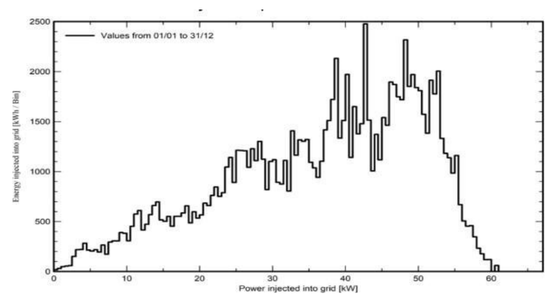

FIGURE 7. System output power distribution

ENVIRONMENTAL IMPACT ANALYSISAND ECONOMIC INDICATORS

1. ENVIRONMENTAL ANALYSIS

The projected lifespan of the photovoltaic system is approximately 25 years, with the inverter expected to last around 10 years. Key economic indicators, such as the benefit-cost ratio, net present value (NPV), cost of energy, payback period, and internal rate of return (IRR), are assessed based on simulation results and the total cost of installing the system[11].

Under a tiered electricity tariff, households that adopt a solar energy system are exempt from paying for electricity at the local cost. Assuming that daytime energy consumption equals nighttime consumption, Table 3 shows the calculated results for the economic indicators, using discount rates of 0%, 3%, and 11%, respectively[13]. The profit from the solar PV system is determined by the total electricity consumed and the total energy sold to the utility company.

When applying an 11% discount rate, both the anticipated interest rate and inflation rate are accounted for. At a 0% discount rate, neither interest rates nor inflation are considered[14]. When the discount rate is set at 3%, only the inflation factor is included, excluding the projected interest rate.

NPV refers to the net present value, and the formula for calculating NPV is:

CO_2 Emission Balance			
Total	2595.2 tCO_2		
Generated emissions			
Total	138.07 tCO_2		
Replaced Emissions			
Total	3148.9tCO_2	System production	114.11 MWh/yr
Grid Life cycle Emissions	936 gCO_2 /kWh	Source	IEA list
Country	India	Lifetime	30 years
Annual degradation	1.0%		

The energy from the sun can be harnessed to produce power without global warming, harmful pollution, or contributing to global warming.

2. ECONOMIC INDICATORS

The projected lifespan of the photovoltaic system is around 25 years, while the inverter is expected to last for about 10 years. The economic indicators such as benefit-cost ratio, net present value, cost of energy, payback period, and internal rate of return are examined based on the simulation results and the overall cost of installing the system.
Under the tiered electricity tariff, households that adopt a solar energy system are exempt from paying for electricity based on the local cost[9]. Assuming that the amount of energy consumed by households during the day is the same as the amount consumed at night. The below table 3. presents the computation results of economic indicators, where the discount rate is 0%, 3%, and 11% respectively. The profit made by the solar PV system is determined by the total electricity consumed and the total energy sold to the utility company. When considering a discount rate of 11%,both the anticipated interest rate and the inflation rate are included. When the discount rate is set at 0%, neither the predicted interest rate nor inflation is considered. When the discount rate is set at 3%, just the inflation coefficient is taken into account, while the projected interest rate is not factored in.
LCOE is the levelized cost of electricity. LCOE=life cycle cost/ lifetime energy production.
The table below shows the economic indicators for different scenarios:

Economic evaluation criteria	Discount rate at 0%	Discount rate at 3%	Discount rate at 11%
Payback period	6.0045	6.7409	12.07432
NPV(VND)	25611722	15942452	284718101
IRR(%)	14.51	14.31	14.302
BCR	2.11	1.721	1.052
LCOE	909.53	1124.061	1824.362
Project life	20 years		

TABLE3.Economic indicators for different scenarios.

NPV is the net present value. The formula for calculating NPV is:

$$NPV=\sum_{n=0}^{N}\frac{B_n}{(1+i)^n}-\sum_{n=0}^{N}\frac{Cn}{(1+i)^n};$$ where, B_n : expected benefit at the year end, C_n : expected cost at the year

IMPROVING PARAMETERS

Efficiency, reliability, and resilience can be enhanced by replacing outdated components and incorporating sensors and remote monitoring systems that detect and address potential issues before they cause outages. Energy storage systems, such as electricity accumulation batteries, can store excess energy for later use. Artificial intelligence can improve predictive systems, allowing for more accurate weather forecasts and energy consumption predictions. This approach helps utility companies better plan for their clients' electricity needs, while smart energy management solutions make green energy a reliable alternative to fossil fuels. Improving cost-benefit analysis can be achieved through initial cost optimization and the use of financial modeling tools. It's important to consider high-quality components with longer warranties and better long-term performance. Performance optimization can be further enhanced by ensuring optimal panel orientation and tilt, selecting high-efficiency solar panels, maximizing inverter efficiency, minimizing shading, and performing regular maintenance.

CONCLUSION

The information about design modeling and cost-benefit analysis is obtained. The solar power plants are economically feasible and profitable. Due to the rapidly growing global climate changes in India, it contributes to the implementation of green economy development. The solar PV system reduces environmental pollution. The solar power system requires an initial investment of 3405738.00 INR for a 74.1kw rooftop solar PV power system. The amount of produced energy is 112mwh/year and the cost of produced energy is 1.239INR/kWh. In conclusion, making rooftop solar power projects is more economical as the price of solar power panels and inverters is reducing.

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