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A case study on grid integrated solar roof-top PV system

Yash Ajgaonkar
yashaj2014@yahoo.co.in
Fr. Conceicao Rodrigues Institute of Technology, Mumbai, Maharashtra

Mayuri Bhirud
mayuri17b@gmail.com
Fr. Conceicao Rodrigues Institute of Technology, Mumbai, Maharashtra

Poornima Rao
punnag@yahoo.co.in
Fr. Conceicao Rodrigues Institute of Technology, Mumbai, Maharashtra

Vinit Surve
vinitsurve97@gmail.com
Fr. Conceicao Rodrigues Institute of Technology, Mumbai, Maharashtra

Sreehari S.
sreeharidav@gmail.com
Fr. Conceicao Rodrigues Institute of Technology, Mumbai, Maharashtra

ABSTRACT

With advances in technology and industrial development, there is an increase in the consumption of electrical energy. However, the rapid exhaustion of conventional fossil fuels to produce electrical energy has provoked the engineers to find sustainable means of electrical energy generation from renewable resources. Amongst all renewable resources, solar energy produces promising results. There has been a lot of research and development in the field of Solar PV systems. Hence with recent advancements in solar technologies, the PV systems have become more efficient and cost-effective. There are little awareness and knowledge about the implementation of Solar PV system amongst common people. The other main issue is the space required for installing solar panels for power generation. In this paper, efforts are made to create awareness and encourage people to adopt and implement solar roof-top PV system for sustainability and a better environment. This paper involves a case study on installation of roof-top solar PV system at RRR Laboratories Pvt. Ltd. Turbhe, Navi Mumbai. The paper provides a feasibility analysis in terms of both economics and design complexities using a Top-Down approach. The analysis suggests that grid integrated roof-top system is a more viable solution for city areas where available open space for the solar panels is the main constraint. If grid integrated PV systems are implemented on open rooftops in cities, it would become versatile utilization of roof-tops which otherwise would have been left unutilized. So, the study concludes that a simple grid-tied solar PV system is feasible to be implemented on any roof-top area in cities at the individual level with affordable expenses. Thus, popularizing the implementation of grid-integrated solar roof-top PV system makes productive utilization of roof-tops as well as contributes substantially towards sustainability and environment.

Keywords— *Grid-connected system, Top-down and bottom-up approach, MPPT and Inverter, Payback period*

1. INTRODUCTION

Electrical energy has become the most vital resource for mankind in many ways. However; the rapid exhaustion of fossil fuels cannot suffice the increasing demand for energy. Another growing concern is the relativity of energy consumption to environmental degradation. In the past few decades' considerable research has been conducted in the field of electricity generation from renewable resources. Energy generation from Solar PV systems has shown promising results and proves to be a viable option in most sun-belt rich countries like India. India being located within 20.593^0N [1] receives ample sunlight throughout the year thus proves an ideal location for energy generation from solar PV. The solar PV systems have different system methodologies that are grid integrated (with and without battery backup) and off-grid system which can be implemented according to the necessity and constraints. The solar PV panels have greatly improved in terms of its efficiency and manufacturing cost. In this paper, we have considered the most common simple and popular of all methodologies. There are three sections in the paper. Section 'A' is on the technical analysis and involves analysis on system components of solar rooftop PV systems. Section 'B' is on the Case study of the implementation of the Grid-tied system. Section 'C' is on the economic analysis of the proposed system design.

2. TECHNICAL ANALYSIS

2.1 PV Systems

The two main methodologies involved in implementing Solar PV systems are Grid-Integrated system and standalone system. Grid-Integrated Systems are further classified into two categories: 1. without battery backup 2. with battery backup. In Grid integrated systems without battery backup, the energy is being fed directly to system grid without using the battery storage. The feature of this type of the system is its simplicity in designing and cost-effectiveness. The disadvantage of the Grid-Integrated system is that it has to be islanded (an anti-islanding feature of the inverter) for the purpose of safety and to prevent the flow of reverse power during failure. The grid integrated systems with battery backup is a type of Hybrid systems which can supply energy to the grid as well charge the battery which in turn can be used to supply power to selected specific loads during the night or during grid failure. However, the design involved in this system is complex and require sophisticated control systems. Therefore, implementing the cost of this system is high. Off-grid systems are adopted in conditions where grid connection is either not possible or it is very costly. The feature of this system is that it is entirely self-sustaining without any grid supply.

2.2 PV Panels

Basically, the most common types of panels used are monocrystalline and polycrystalline. The Monocrystalline Solar Panels uses high purity silicon and therefore considered to be highly efficient (reaching above 20%). Whereas a low-cost silicon is used to fabricate polycrystalline cells, their efficiency is typically in the range of 12%-14%. Monocrystalline solar panels last the longest they tend to be slightly less affected by high temperatures compared to polycrystalline panels 25-35 years. Monocrystalline panels have a high-power output, occupy less space, and last the longest. For the case study, Monocrystalline panels are considered.

2.3 Sizing of the panels and its specification

If small, shaded or unusually shaped roofs are available the solar panel sizing is of major considerations where we need to go for few panels but of higher efficiency. In case of large usable roof area, there can be a compromise made between efficiency and number of panels to achieve the targeted output. For the case study, we have selected the following data.

Terminology

1. STC- Standard Test Condition when 1000W/m2 irradiance, 25°C cell temperature.
2. Open Circuit Voltage (V_{oc}): Voltage measured across two terminals of a solar panel at no load.
3. Maximum Voltage (V_{mpp}): The V_{mpp} is the voltage when the power output is the maximum.
4. Maximum Current (I_{mpp}): The I_{mpp} is the current when the power output is the maximum.
5. Short Circuit Current (I_{sc}): Current flowing when both the terminals are shorted.

Table 1: Electrical and mechanical data

Electrical Data				Mechanical Data	
Specifications	STC				
1.Peak Power (W_p)	350	355	360	1. Dimensions (L X W X H)	1956 X 992 X 36 (mm)
2.Maximumvoltage (V_{mpp})	38.11	38.19	38.32	2. Weight Of each panel	22Kg
3. Maximum current (I_{mpp})	9.17	9.30	9.40	3. Bypass diodes	3
4. Open circuit voltage (V_{oc})	47.41	47.49	47.68	4. Number of Cells	72
5.Short circuit current (I_{sc})	9.71	9.82	9.96	5. Frame	Anodized aluminum frame
6. Efficiency (%)	18.03	18.31	18.82	6. Safety Class	Class II

2.4 String connections of PV Panels

Connecting solar panels together depends on overall system size, solar module output and system optimization between the solar modules and the inverter rating. Strings Connections can be done in two ways either in Parallel connections or in Series connections. If the inverter operates with the low input voltage, the modules can be connected in parallel to the inverter. The advantage is that the voltage on the DC side will be lower, safer installation, operation and system maintenance. In parallel, the shadow caused which covers the surface affects only that particular module. But the disadvantage of connecting solar panels in parallel is, low voltage implies large currents and therefore cables of larger diameter, higher cost, or greater electrical losses. In Series connection required cable size reduces, resulting in cost saving & improved efficiency due to lower inverter & cable loss. Therefore, a combination of series and parallel connection of PV panels are selected for optimum results.

2.5 Inverter

The inverter is an important component of the PV system. As the generated electrical power by PV panels is DC and hence they it is to be converted to AC. One of the most important features for the grid-tied feature is the Anti-Islanding. Islanding is defined as the situation in which the energy generation source remains energized while the grid to which its feeding remains isolated due to failure. This situation is dangerous as the energized source is connected to the other equipment connected to the grid which can pose threat not only to the equipment but also to the maintenance personnel working. Thus, in event of grid failure or isolation of a Solar PV system, the inverter should be capable of sensing that it is isolated from the grid and should immediately de-energize and stop feeding the grid. The anti-islanding can be done by passive and active methods; however, the reliability of passive methods is very poor and hence modern inverters are equipped with the active anti-islanding feature. The protection system in the inverter involves 1. Ground fault monitoring. 2. Surge arrester (DC). 3. DC side reverses polarity, Galvanic isolation, and AC short circuit current detection capability. 4. Overvoltage protection along with all pole sensitive residual current monitoring.

2.6 MPPT (Maximum Power Point Tracking)

The inverter also incorporates a feature called MPPT (Maximum Power Point Tracking). It generally comprises Buck-Boost Converters that automatically adjusts itself to give maximum power condition in cases where there are changes in insolation level, temperature rises etc. MPPT control system has a basic principle of controlling the duty cycle D of the converter with changes in system parameters. With MPPT it is ensured that maximum power is extracted from the panels.

2.7 Protection system

With increasing plant capacity of solar PV system, the parameters like voltage, current and power increases. Thus there is a need for a sophisticated protection system to prevent damage to equipment as well as human life. The protection system in a Solar PV system involves protection against Overload, short circuit current, and Lightning Surges. DC fault current is associated with lower rate of rising of current under short circuit condition when compared to the same magnitude of AC short circuit current (Typically, the short circuit current for a 325 W solar panel ranges from 8.5 to 9.8 A). As the rate of rising of current is low the arcing time is high and fuse link melts slower than for similar AC fault currents. DC semiconductor fuses are a special type of fuses which act very fast within milliseconds and isolate the system to prevent further damage. Since the solar PV system is situated majorly on open building rooftops or open ground areas are highly vulnerable to lightning strokes which can enter the system. These high voltage transients can damage the equipment connected and may even put human life in danger. To protect the PV system from lightning surges Lightning arrestors and Lightning rods are used.

3. THE CASE STUDY ON SYSTEM IMPLEMENTATION AT RRR LABS

The proposed PV system is to be implemented on the RRR labs a Surface metal finishing company. The building is 2 storeyed and located in Turbhe, MIDC area, Navi Mumbai, India. The site latitude and longitude are 19.070710 N, 73.016210E [1]. The irradiance is defined as the ratio of average insolation to average daily sunshine hours. For the given site annual irradiance is 5.37 kWh/m^2/day [2]. For the northern hemisphere, the panels should be facing south and the tilt angle for the panel can be generally taken as the site latitude and for the given location tilt angle is 19.070. The average solar radiation incident is around 5.67 kWh/m^2 [1]. During summers i.e. in months of February to May the radiation is as high as 7.2 kWh/m^2 [1], whereas in monsoon the radiation drops to 4.5 kWh/m^2 [1]. In winter i.e. from October to January the radiation is around 5 kWh/m^2 [1]. Along with good solar radiation, the amount of active sunshine is also vital. More the sunshine more amount of time the system can generate. For year around the average number of active sunshine hours is greater than 190hours each month with the highest amount of 320 sunshine hours in summer months [1]. Thus, the above statistical data shows that the site location is suitable for effective solar PV generation.

For design implementation, the following approaches are followed:

A. Top-down approach: In a top-down approach, the solar system is implemented based on resource constraints. In this method, the number of panels required is calculated considering the available area in which the system can be implemented. Therefore, this method considers the practical viability of system implementation. After calculating the number of panels that can be fitted in the required area the annual system energy generation is calculated. Thus, the amount of savings is the difference between load energy consumption and energy generation by the PV system. The advantage of this system is that it can be easily implemented especially in cities.

B. Bottom-up approach: In the bottom approach, the energy generation by the PV system should be equal or greater than load consumption. After considering the energy generation required, accordingly, the number of solar PV panels is calculated. The major disadvantage of this method is the requirement of adequate space to accommodate that many panels. Hence may not be viable with space and other constraints. For a present case study, the Top-down approach is adopted as the available area is limited. The Layout of the Rooftop area available for installing the PV panels is given below in Fig1. While measuring the rooftop, two important factors are to be considered: 1) Exclude the area where the shadow is present 2) Space around each panel for cleaning and maintenance. From the roof layout after excluding the shading areas the available rooftop areas are marked as rooftop 1 and rooftop 2 where the PV panels can be installed. Since the available area is very small we follow Top-down approach of implementation of a solar PV system in which we calculate the number of solar panels that can be fitted on rooftops 1 and 2. After considering the shadows and spacing between the panels to ensure maintenance and cleaning 10 solar PV panels can be implemented.

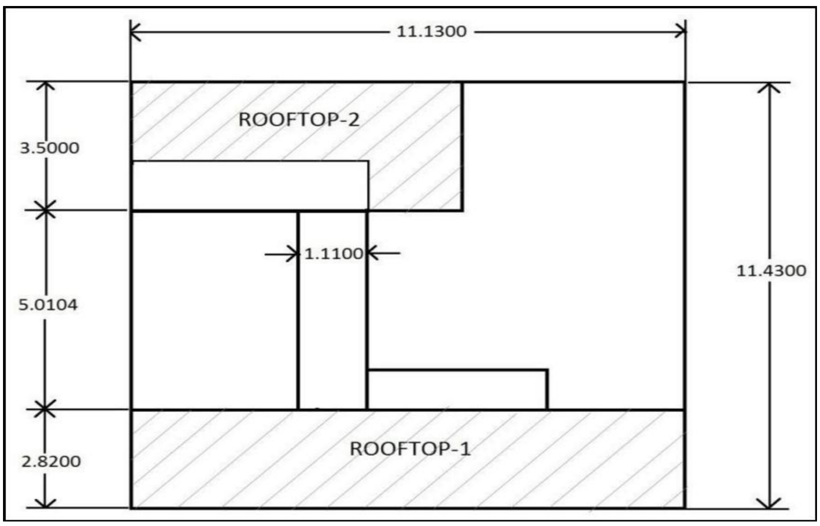

Fig. 1: Roof layout for the RRR labs

3.1 System components

3.1.1 Panel selection: As the available area for present location is limited the system should be able to generate maximum possible output. Thus, high efficiency 72 cells Monocrystalline solar panels are used even though they cost more than other solar panels. Based on the available roof area number of solar panels that can be installed are 10. If 10 panels of 72 cells monocrystalline panels each of 350 W each are used, then total plant capacity is 3.5 kW.

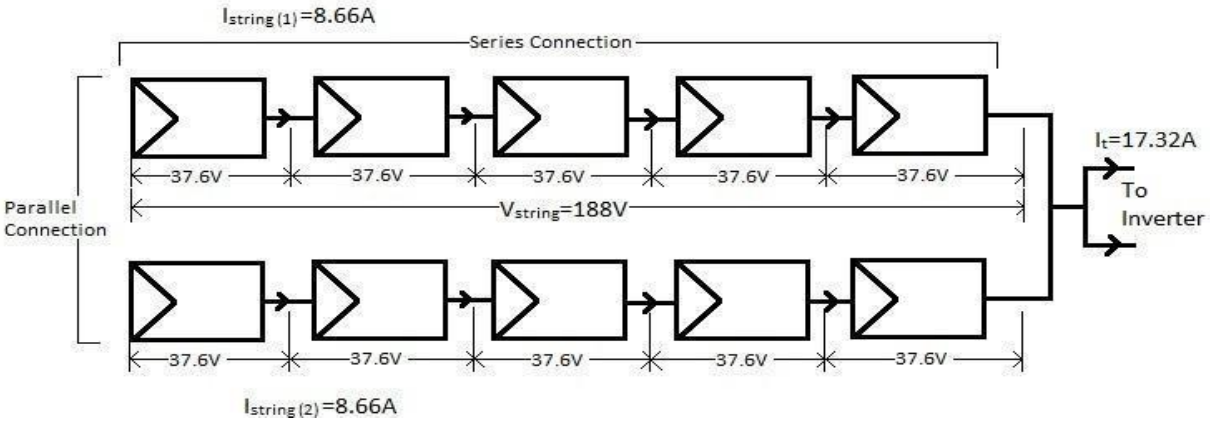

Fig. 2: The system configuration

3.1.2 Inverter and MPPT: After considering the panels, the next major component is the Inverter. A 4.6 kW dual MPPT inverter is used equipped with the anti-islanding feature. Generally, a single MPPT controller is enough, but with dual MPPT controller, the reliability of the system increases. The protection system can be categorized as DC side and AC side protection. At DC side high-speed DC Semiconductor fuses are used instead of HRC fuses. At AC side immediately after Inverter, a 4 pole MCB is used and at the substation, MCCB is used. The inverter has inbuilt overvoltage, ground fault detection circuit along with the anti-islanding feature. To prevent lightning surges each string will have 2 lightning arrestors on each side with effective grounding. In proposed design 10 panels are used of 350 W nominal power rating and 5 panels are connected in series and two such strings are connected in parallel. In series connection voltage across each panel gets added up and currently remains same whereas in parallel connection currents get added up and voltage remains same.

4. THE ECONOMIC ANALYSIS

The consumer always quantifies the product in terms of its cost and benefit in terms of profit and hence economics is governing factor. In earlier days the initial investment in solar PV system was very high and its returns were very low and hence at residential level consumers were reluctant to implement the solar PV system. With increasing technological advancements in Solar PV systems, the manufacturing cost has come down drastically and even on the residential level, it is now affordable. In Grid-Tied PV system due to the absence of batteries and other control systems, the initial investment is very less as compared to stand alone system and hence largely implemented at residential and small-scale commercial industries.

For a Grid-tied PV system following components are used

4.1 Solar PV Panel

The panel chosen has the following specification which can be referred from Table 1.

4.2 Irradiance calculations

To calculate irradiance levels, the sunlight is available for 9 hours is assumed.

4.2.1 During summer

Average irradiation is 6.75 kWh/m^2 [2]

$$\text{Irradiance} = \frac{6.75 \times 10^3}{9} = 750\ \text{W/m}^2$$

4.2.2 During Monsoon

Average Irradiation is 4.83 kWh/m^2 [2]

$$\text{Irradiance} = \frac{4.85 \times 10^3}{9} = 538\ \text{W/m}^2$$

4.2.3 During Winter

Average Irradiation is 5.31 kWh/m^2 [2]

$$\text{Irradiance} = \frac{5.31 \times 10^3}{9} = 590\ \text{W/m}^2$$

- Vmpp and Vocremains same for irradiance levels
- Voc = 47.4v
- Vmpp =38.2 V

4.2.4 During Summer (Feb– May)

Irradiance =750 W/m^{2}and Sunshine available for 8 hours

$$\text{Isc at } 750\ \text{W/m}^2 = \frac{750}{1000} \times \text{Isc at } 1000\ \text{W/m}^2 = \frac{750}{1000} \times 9.76 = 7.32\ \text{A}$$

$$\text{Impp at } 750 \frac{\text{W}}{\text{m}^2} = \frac{\text{Impp at } 1000\ \text{W/m2}}{\text{Isc at } 1000\ \text{W/m2}} \times \text{Isc at } 750\ \text{W/m}^2 = \frac{9.24}{9.76} \times 7.32 = 6.93\ \text{A}$$

$$\text{Pmp at } 750\ \text{W/m}^2 = \text{Impp at } 750\ \text{W/m}^2 \times \text{Vmpp at } 750\ \text{W/m}^2 = 264.72\ \text{W}$$

$$\text{Units generated during summer per panel} = \text{Power} \times \text{No. of hours for which sunshine is available} \times \text{No. of days}$$
$$= 264.72 \times 8 \times 120 = 254.18\ \text{units/panel}$$

$$\text{Total units Generated during Summer} = \text{units generated per panel} \times \text{No. of panels}$$
$$= 254.18 \times 10 = 2541.8\ \text{units}$$

4.2.5 Monsoon (June–September)

Irradiance =538 W/m^{2}and Sunshine available for 4 hours

$$\text{Isc at} \frac{538\text{W}}{\text{m}^2} = \frac{538}{1000} \times \text{Isc at } 1000 \frac{\text{W}}{\text{m}^2} = \frac{538}{1000} \times 9.76 = 5.25\text{A}$$

$$\text{Impp at } 538 \frac{\text{W}}{\text{m}^2} = \frac{\text{Impp at } 1000\ \text{W/m2}}{\text{Isc at } 1000\ \text{W/m2}} \times \text{Isc at } 538 \frac{\text{W}}{\text{m}^2} = \frac{9.24}{9.76} \times 5.25 = 4.97\text{A}$$

$$\text{Pmp at } 538\ \text{W/m}^2 = \text{Vmpp at } 538\text{W/m}^2 \times \text{Impp at } 538\text{W/m}^2 = 189.85\text{W}$$

$$\text{Units generated during monsoon per panel} = \text{Power} \times \text{No. of hours for which sunshine is available} \times \text{No. of days}$$
$$= 189.85 \times 4 \times 122 = 92.648\ \text{units/panel}$$

$$\text{Total units Generated during Monsoon} = \text{units generated per panel} \times \text{No. of panels} = 92.648 \times 10 = 926.48\ \text{units}$$

4.2.6 In Winter (October – Jan)

Irradiance =590 W/m^{2}and Sunshine available for 7 hours

$$\text{Isc at } 590 \frac{\text{W}}{\text{m}^2} = \frac{590}{1000} \times \text{Isc at } 1000 \frac{\text{W}}{\text{m}^2} = \frac{590}{1000} \times 9.76 = 5.75\ \text{A}$$

$$\text{Impp at } 590 \frac{\text{W}}{\text{m}^2} = \frac{\text{Impp at } 1000 \frac{\text{W}}{\text{m2}}}{\text{Isc at } 1000 \frac{\text{W}}{\text{m2}}} \times \text{Isc at } 590 \frac{\text{W}}{\text{m}^2} = \frac{9.24}{9.76} \times 5.75 = 5.44\ \text{A}$$

$$\text{Pmp at } 590\ \text{W/m}^2 = \text{Vmpp at } 590\ \text{W/m}^2 \times \text{Impp at } 590\ \text{W/m}^2 = 207.8\ \text{W}$$

$$\text{Units generated during winter per panel} = \text{Power} \times \text{No. of hours for which sunshine is available} \times \text{No. of days}$$
$$= 207.8 \times 7 \times 123 = 178.91\text{units/panel}$$

$$\text{Total units Generated during winter} = \text{units generated per panel} \times \text{No. of panels} = 178.19 \times 10 = 1781.9\ \text{units}$$

4.2.7 Annual unit generation by the System

$$\text{Total Units generated by the System in a year} = 2541.31 + 926.48 + 1781.9 = 5.249\text{Mwh/year}$$

$$\text{Total Load consumption} = 12.645\text{Mwh/year}$$

$$\mathbf{Savings\ in\ units = 5.249Mwh/year}$$

4.3 Load consumption and cost analysis

The RRR labs in Turbhe Navi Mumbai has a 3 phase connection from MSEB (Maharashtra state electricity board). The annual energy consumption by the RRR l labs is obtained from the Bill generated by the MSEB along with the billing amount. Following figures show annual energy consumption along with the amount.

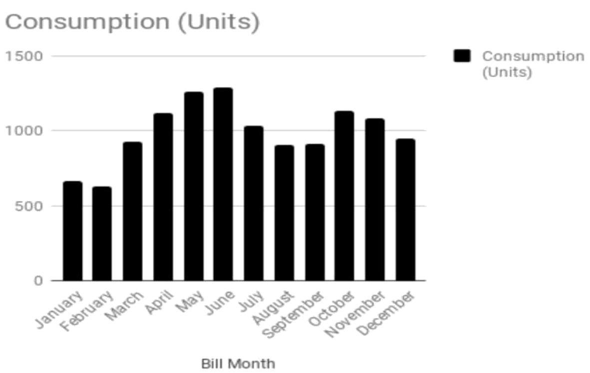

Fig. 3: Monthly Consumption

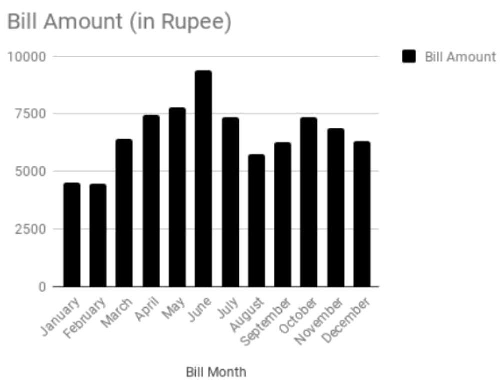

Fig. 4: Monthly Expenditure

Figure 3, depicts that mean consumption of energy is around 900 units with a peak consumption of 1300 units in summer months and lowest consumption of 600 units in winter.

From figure 4, the consumption rates are greater than Rs. 6000 with highest and lowest rates of Rs. 9000 and Rs.4000.

4.4 Cost calculations

Table 2: Cost calculations

S. no	Equipment	Quantity	Unit Cost	Cost
1.	Solar Panels	10	12,000	120,000
2.	Inverter (2MPPT)	1	56,000	56,000
3.	Cabling		Rs 2/watt for 3.5 kW plant	7000
4.	Protection			8000
4.	Structure		Rs 3.5/watt for 3.5 kW	12250
5.	Peripherals		Rs 4/watt for 3.5 kW	14000
6.	Design and Installation		Rs 5/watt for 3.5 kW	17500
Total Cost Including 5% GST				246488

4.5 Incentives and Government subsidies

Government Schemes for solar rooftop PV systems

1. Rajiv Gandhi Gramin Vidyut Karan Yojana (RGGVY)
2. Subsidy by MNRE on Total System Cost

$$\text{By 30\% Subsidy from MNRE} = \text{30\% of Total cost} = \text{Rs } 73946$$

Therefore,

$$\text{Initial Investment} = \text{Total Cost} - \text{Subsidy} = \text{Rs } 172542$$

$$\text{Cost per kilowatt} = \frac{172542}{3.5} = \text{Rs } 49297.7/\text{kilowatt}$$

$$\text{Pay Back Period} = \frac{\text{Initial Investment}}{\text{Electricity bill cost}} = \frac{172542}{57354} = 3.008 \text{ Years}$$

5. CONCLUSION

In this paper, a 3.5 KW grid-tied solar PV system is designed for RRR labs, Turbhe Navi Mumbai. The Top-down approach is adapted for carrying out the technical and economic analysis of the system. After considering the available area for installation, excluding the shading areas, the proposed system has a plant capacity of 3.5 KW. The annual system generation is calculated to be 5.249 MWh. The initial investment for the proposed system is projected to be Rs 246,488 which includes system components, installation, and other miscellaneous accessories and taxes. The system can acquire a 30% subsidy on total cost from MNRE (as per their current policy). After considering the subsidy, the total investment reduces down to Rs 172,542. The cost per kilowatt for the system is Rs 49,297. The payback period for the system is calculated to be 3.13 years without MNRE subsidy and 2.19 years considering 30% subsidy. In this work, emphasis is given on the need and importance for installing Grid-tied Solar Rooftop PV system in city areas. The paper strives to create awareness and promote the use of renewable resources especially solar PV system. With the implementation of the Solar Rooftop PV system, apart from financial benefits, the major payback in long run is the contribution towards sustainability and environment thereby promoting sustainable development.

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