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A case study of Government College of Engineering Amravati for its design and assessment of solar PV plant and Carbon credit earned

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Abstract: As the country moves towards net-zero carbon emissions, we must switch to an alternative renewable source for power generation. The viable method to produce less CO_2 in the environment is to use renewable energy sources. These sources are solar, wind, bio, and hydroelectric power. Among these, the most acceptable method is abundant solar energy that can be used efficiently. Using solar energy sensibly and for sustainable development is the most critical challenge for the world. Solar energy is clean, inexhaustible, environmentally friendly, and a potential resource among the various renewable energy options. Development of green energy.

The proposed plan to use solar energy as an energy source will be implemented on a smaller scale at the Government College of Engineering Amravati campus, which has 105 acres of land. The campus consists of several departmental buildings, an administration building, a workshop, a central library, a gymkhana, and a canteen. The residential area includes four dormitories for boys and two for girls, the director's quarters, and four warders' quarters. The current institute electricity bill derived by Electricity Board is Rs. 5,38,400 per month and does there is a need of shifting to a green and renewable source of energy and does the carbon credit earned by the Government College of Engineering Amravati found to be 20574.07 tonnes of CO_2

IndexTerms **- carbon credits, Solar plant, financial assessment, Payback period.**

I. INTRODUCTION

In the current era, the use of renewable technology for energy generation is growing at a faster rate, as seen in the graph below, fig 1. Considering the low stock of conventional fuels and consistent price rise, the use of solar energy at places where solar radiations are available throughout the year must be utilized to its maximum. At the same time, as the efficiency of solar systems is low, a real-time financial analysis must be done to identify the conditions in which it will be most economical. The energy use for the renewable system's production and installation must be considered to calculate their energy payback time. This paper presents a complete analysis and assessment of a PV plant for the Government College of Engineering Amravati.

The idea of developing environmentally friendly PV plants was discussed. It suggests that with massive green energy sources generated from the sun, the PV industry will gain the best opportunity to grow up in government buildings and in every household where every house can contribute to environmental conservation. We should grasp the opportunity to build the most suitable environmentally friendly solar PV power plant. Considering this as an opportunity to propose a clean energy source for the college's total energy demand, a solar PV plant design, and its assessment has been carried out. The study for photovoltaic systems size optimization techniques suggests that the optimization of the PV system strongly depends on meteorological variables such as solar energy, ambient temperature, and wind speed (Khatib et al., 2013). Hence, it becomes essential to have a detailed analysis at various locations for accurate results. This paper will identify the design and assessment issues and allow the development of energy strategies for areas similar to the studies.

A case study on the Gambia (Sowe et al., 2014) evaluated the feasibility of crystalline Si (c-Si) and thin film (Cd–Te) modules based on NPV and IRR. Based on technical and economic assessments of the c-Si and Cd–Te PV power plants, the Cd–Te PV power plant presented reasonable technology for rural electrification in The Gambia. A similar case study (Messinaa et al., 2014) having two 2.4 kWp grid-connected PV systems installed at different locations, i.e., Tepic and Temixco-Morelos concluded that the Temixco-Morelos PV system supplied nearly 90% of the electrical energy need for the house and identified grid-connected PV in the urban and suburban areas or stand-alone PV systems for the remote agricultural communities in Mexico is both feasible and should form part of the sustainable national policies. In this paper, a 734.60 kWp on-site solar PV power plant was designed with the land required for it, and its economic analysis is proposed. This paper covers all the preferences (Soni and Gakkhar, 2014) in their paper, i.e., Costs, Payback period as an economic parameter, location, CUF as a technical parameter, and type of cell and performance ratio as PV parameters.

Sharma and Tiwari (2013) provide an inclusive comparative life cycle assessment of an on-field PV system dealing with an existing setup. Energy metrics (energy payback time, electricity production factor, and life cycle conversion efficiency) of hybrid photovoltaic (PV) modules have been analyzed and presented for the composite climate of New Delhi, India (Tiwari et al., 2009). A review has been done to estimate the environmental impacts of different solar PV-based electricity generation systems using the life cycle assessment technique (Sherwani et al., 2010).

A study on the life cycle assessment of PV systems (Kannan et al., 2006) used EPBT as an indicator for primary energy use. Life cycle cost analyses are performed for a distributed 2.7 kWp grid-connected monocrystalline solar PV system operating in Singapore and concluded that GHG emission from electricity generation from the solar PV system is less than one-fourth that from an oil-fired steam turbine plant and one-half that from a gas-fired combined cycle plant, it shows a significant impact on the environment. The methodology adopted was based on the literature survey, and the process flow of the paper is shown in Fig. 1. This paper provides the design and analysis of a 734.60 kWp SPV plant with different parameters associated with real-time market prices and future escalation of the prices. This paper analyzes a feasibility study for the plant near the site with its energy metrics, i.e., Energy Payback Time (EPBT), Life Cycle Conversion Efficiency (LCCE), etc. A satellite image of the hostel location with its subpath is shown in Figs. 3 and 4, showing the land's availability near the site.

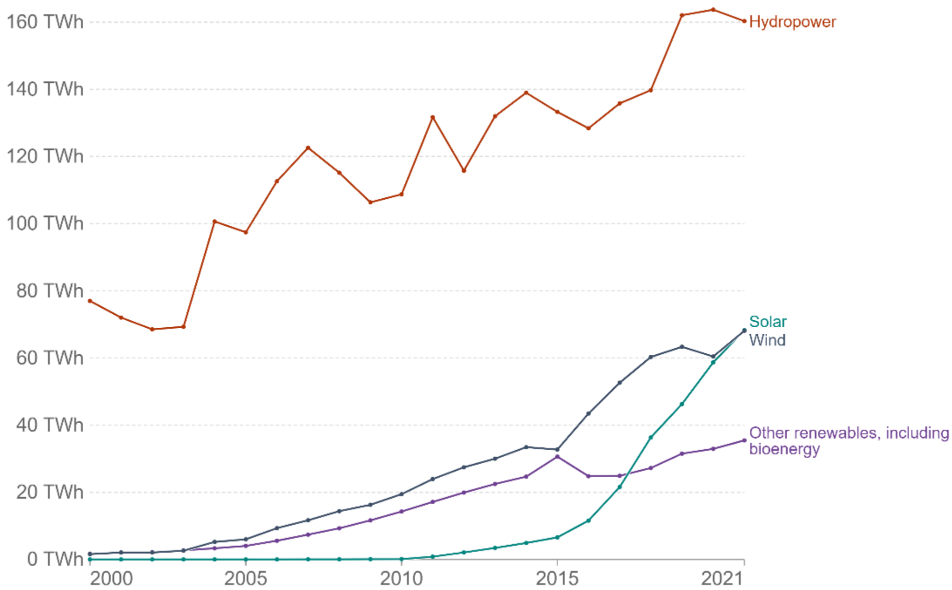

Fig 1 – renewable energy generation (by source World)

II. THE ENERGY DEMAND OF THE COLLEGE

A detailed survey of each college building was carried out to identify the amount of load connected. Tables 1 provide the complete details of the different building's power consumption (based on the survey) (How to Design Solar PV System). The total energy needed to be supplied by the solar PV system is estimated to be 2760.1 kWh/day

III. SOLAR PHOTOVOLTAIC POWER PLANT DESIGNING

The design of a solar photovoltaic power plant consists of PV module sizing, inverter sizing, battery sizing, and module circuit design. For designing a solar PV plant, geographical details and weather data of the site are required. Table 2 and Fig.4 provide monthly average radiation data for Amravati city, located at 20°57'25.2"N 77°45'26.9"E in Maharashtra state of India (Synergy Enviro Engineers).

3.1 Panel generation factor (How to Design Solar PV System)

Panel Generation Factor is a critical element in designing a solar PV plant which; gives for every Wp capacity in the panel, we can expect to get an average of Wh/day, and it is different in each site location, for Amravati city considering 5.52 kWh/m^2;

Panel Generation Factor
= (Daily Solar Radiation)/ (Standard Test Conditions Irradiance for PV panels)
= (5.52 * 1000)/1000 = 5.52 .

3.2 The energy required from PV modules (How to Design Solar PV System)

The energy required from PV modules will be the daily energy demand of the hostel and compensation for the system losses, which is generally considered 30%. Therefore, the total energy required will be

Energy required
= (Energy Demand ∗ System Losses Compensation Factor)
= 2760.1 ∗ 1.3 = 3588.13 kWh/day.

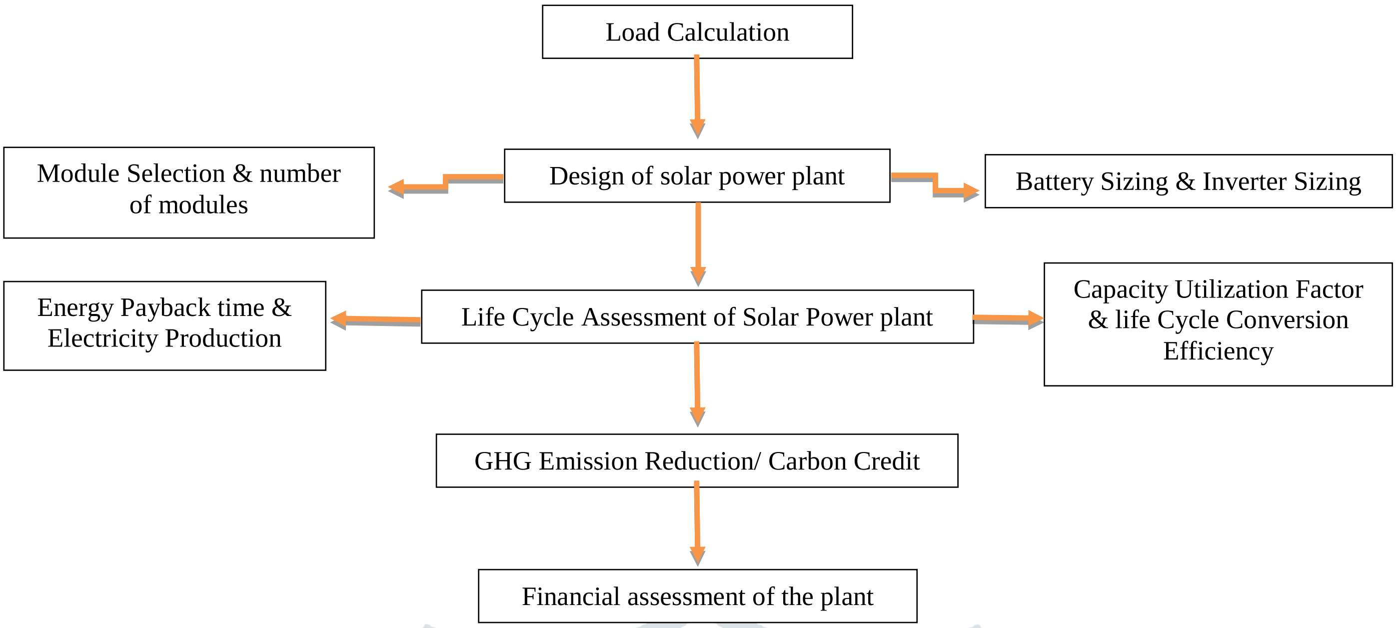

Fig 1. Process flow for design and assessment of the PV plant

3.3 Watt Peak rating for PV modules (How to Design Solar PV System)

The total Watt peak rating for PV modules is calculated to identify system sizing, which depends on the energy required from modules and the panel generation factor

Watt Peak rating for PV Modules
= (The energy required from PV modules)/(Panel Generation Factor)
= (3588.13)/5.52 = 650 kWp

3.4 PV modules (How to Design Solar PV System)

A nearby supplier of PV modules was identified for realistic analysis and availability of the modules, Bi-facial Solar module model of BI-SHARK 440 was considered in this analysis. This module was selected as the supplier is local. Table 3 gives the full specifications of the selected module. The total no of modules required for the proposed plant depends on the peak rating of the modules.

No. of modules required
= (Total Watt Peak Rating)/ (PV module Peak Rated Output)
= (650 * 1000)/440
= 1477 Modules.

Sr. No.	**Name of the Department**	**Daily Energy Demand (kWh)**
1.	Administrative Building	314.230
2.	Department of Civil Engineering & Applied Mechanics	527.520
3.	Department of Mechanical Engineering Department of Electrical Engineering Department of Electronics & Tele-Communication Engineering	316.190
4.	Department of Computer Science & Engineering Department of Information Technology	681.310
5.	Workshop Building	99.680
6.	Central Library	126.980
7.	Residential Building (Boy's hostel, girl's hostel, Principal Residence, Warden & Rectors quarters)	675.784
8.	Other Building (Canteen & Gymkhana)	9.900
9.	Street and Garden lights	8.512
Total Daily Load		**2760.106 kWh = 2760106 Wh**

3.5 Inverter rating (How to Design Solar PV System)

The inverter size required for the plant depends upon the peak watts requirement. The peak requirement of the hostel is 650 kWp. The inverter must be large enough to handle the total amount of watts peak requirement. The inverter size should be 25%–30% bigger than the total watts requirement;

The inverter sizes

$= 650 * 1.3 = 845$ kW.

Cost-effective Solectria PVI, 82 kW Grid, Tied Inverter 480 VAC PVI-82 kW (Solectria) was selected for the system with 82 kW rated Power and max open circuit voltage of 600 VDC, integrated with PV Maximum Power Point Tracking (MPPT).

According to the rated power of the inverter, the no. of inverters required is:

No. of inverters = (Inverter Size Rated)/ (Power of an Inverter)

= 845/ (82) = 10

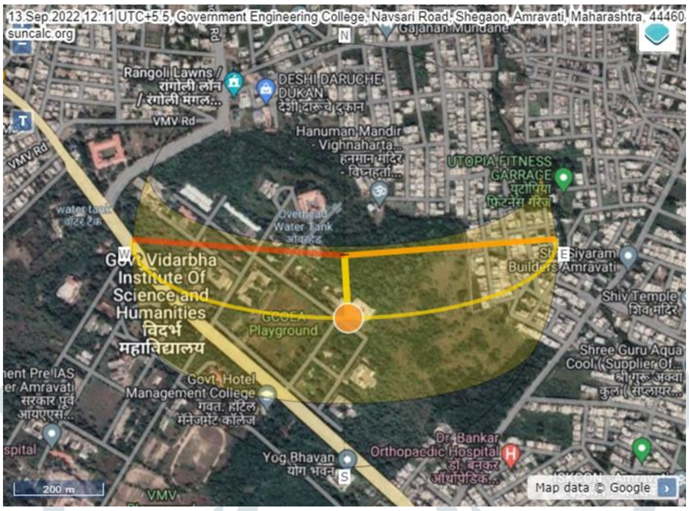

Fig. 2. Sun path on Sep-13 at GCoEA using SunCalc

3.6 Module circuit (How to Design Solar PV System)

The module circuit means the no. of modules to be connected in series, i.e., the size of an array and voltage input to the inverter and the total no. of arrays in the solar field. The size of an array depends on the inverter's maximum Voc and Voc of the module used.

Size of an array = (Maximum Open Circuit Voltage of Inverter)/ (Open Circuit Voltage of each PV Module) = 845/49.69 = 17 Modules.

The maximum voltage input to the inverter

(Maximum Voltage from a Module ∗ No. of Modules in Series) = (41.41∗ 17) = 703.97 V

The total No. Arrays in the solar field will be

= (No. of Modules)/ (No. of Modules in an Array) = 1447/17= 85 Arrays

Fig 3. Satellite view of GCoEA Amravati.

IV. Life cycle assessment of the solar plant

The assessment of any renewable system includes the amount of energy consumed by the system components for their materials, manufacturing transportation, i.e., embodied energy of the system, amount of energy generated by the plant, and its energy payback time (EPBT). Its life cycle conversion efficiency (LCCE) and capacity utilization factor (CUF). Table 4 provides the complete details of the life cycle assessment of the proposed plant

Table 2. Solar radiation data for Amravati (20°57'25.2"N 77°45'26.9"E)

Month	Average (kWh/m^2)
Jan	5.32
Feb	6.14
Mar	6.47
Apr	6.79
May	6.83
Jun	5.31
Jul	4.05
Aug	3.94
Sep	4.78
Oct	5.54
Nov	5.76
Dec	5.34
	Annual Average 5.52 (kWh/m2 /day)

4.1. Energy payback time of the plant

Energy payback time is defined as "How long does a PV system have to operate to recover the energy that went into making the system," and it is given by;

EPBT = $(E_m+E_{mf}+E_t+E_i+E_{mg})/E_g$

where;

E_m: Primary energy demand to produce materials comprising PV system.

E_{mf}: Primary energy demand to manufacture PV system.

E_t: Primary energy demand to transport materials used during the life cycle.

E_i: Primary energy demand to install the system.

E_{mg}: Primary energy demand for end-of-life management.

E_g: Annual electricity generation in primary energy terms

Table 3. PV module specifications (Bifacial Solar BI-SHARK 440)

Module type	BI-SHARK 440
Peak power output watt (Wp)	440
Current at peak power output amp (Imax)	10.63
The voltage at peak power output volt (Vmax)	41.41
Short circuit current amp (Isc)	11.34
Open circuit voltage volt (Voc)	49.69
Dimensions (mm)	2131 *1047 * 35
Cell efficiency	20.2
Power Tolerance	±3%
The electrical specifications mentioned above are at standard test conditions of 1000 W/sq. m. AM 1.5 and at 25 °C cell temperature.	

The value for the total energy consumed in materials, manufacturing, transport, installation, and management for each m2 area of the module was proposed by Tiwari et al. (2009).

$(E_m+E_{mf}+E_t+E_i+E_{mg})$ = 1516.59 kWh/m^2 of the module,

therefore;

The total area of modules

= No. of Modules ∗ Length ∗ Width of Modules

= 1477 ∗ 2.131 ∗ 1.047 = 3295.42 m_2

Total Embodied Energy is = 3295.42 ∗ 1516.59 = 4997.801 MWh

Annual Electricity Generated (Eg) = 2760.1 ∗ (300) #

= 828.030 MWh/year.

No. of Clear Sunny days

Energy Payback Time (EPBT)

= (Total Embodied Energy of Modules)/ (Annual Electricity Generated from Plant)

= 4997.8/828.03 = 6.05 years.

4.2 Electricity production factor (EPF)

It is defined as the ratio of the annual energy output to the input energy, and it predicts the overall performance of the PV module. EPF is reciprocal of EPBT. Thus

EPF = $(E_g)/(E_m+E_{mf}+E_t+E_i+E_{mg})$

= (828.03)/ (4997.8)

= 0.16

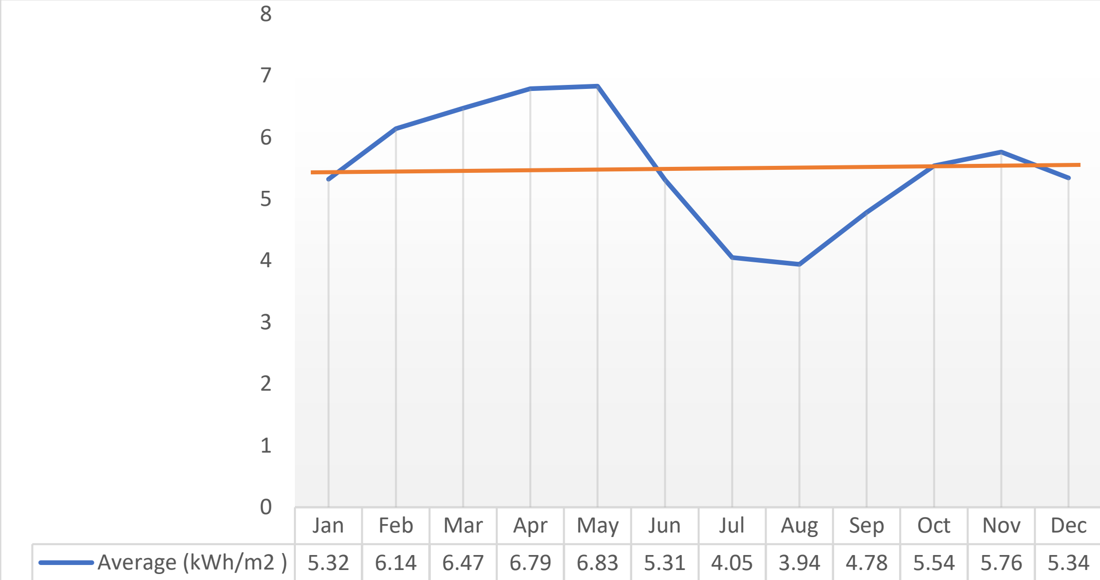

Fig 4. Monthly solar radiation variations in Amravati city.

4.3 Capacity utilization factor (CUF)

Capacity Utilization Factor (CUF) is the ratio of actual energy generated by the SPV plant over the year to the equivalent energy output at its rated capacity over the yearly period. The energy generation for the SPV project depends on solar radiation & number of clear sunny days

CUF = (Annual energy Generated for each kW peak capacity)/ (8760 hours)

= (828030/650)/8760=0.145

4.4 Life cycle conversion efficiency (LCCE)

It is the net energy productivity of the PV system concerning the solar input (radiation) over the lifetime of the PV system,

LCCE = $(E_g*L_s-E_{em})/(E\_sol*L\_s)$

= ((828.03*1000*30)-3667*1000)/(4463.628*1000*30)

=0.158

V. Estimating Greenhouse Gas Emissions Reduction, Mitigation, and Carbon Credits

Photovoltaic is a clean source of energy requiring no fuel and no GHG emissions during its service periods. India is highly dependent on the coal based thermal power plants for electricity generation, and the average CO_2 emission is 0.98 kg of CO_2 per kWh

5.1. CO_2 emissions

CO_2 emission from the embodied energy of the PV plant includes the emissions in manufacturing, materials, etc. The average CO_2 emission for electricity generation and other embodied emissions from a coal-based thermal power plant is 0.98 kg of CO_2 per kWh (Sharma and Tiwari, 2013).

CO_2 Emissions = $(E_{em} * .95) = 3847 * 10^3 * 0.98 = 3770$ tonnes of CO_2.

5.2 CO_2 mitigation

CO_2 mitigation is the amount of CO_2 emission reduction by generating the energy from the PV plant that would otherwise release by the thermal power plant in the case of India.

Yearly CO_2 mitigation = $(Eg * .98)$

= $828.03 * .98$

=811.469 tonnes of CO_2.

5.3. Net CO_2 mitigation

Net CO_2 mitigation for the proposed PV power plant will be the difference between the CO_2 emission and CO_2 mitigation over its entire life, i.e., 30 yr.

Net CO_2 mitigation = (Yearly CO_2 Mitigation $*$ L**s**) − (CO_2 Emissions)

= (811.469 $*$ 30) − 3770

= 20574.07 tonnes of CO_2

5.4. Carbon credits

Carbon Credits are awarded against reduction in greenhouse gas emissions, CO_2, etc. Carbon credits can be traded in the international market at their current market price. One carbon credit is earned against a reduction in one tonne of CO_2 emissions (tCO_2e). In the present work, the net CO_2 mitigation is 35415 tCO_2e. The current market price of one carbon credit is \$0.67 / tCO_2e i.e., IRC 50. Rakhi Sharma et al. used \$31/tCO_2e, which is nearly 50 times more than the current exchange rate.

Carbon Credits (\$) = 20574.07 $*$ 50 = Rs 1028703

Yearly Earnings from carbon Credits: Rs 34290 or \$416.31

VI. Financial assessment of the plant

Renewable energy technologies have enjoyed a period of rapid growth in recent years. They will have to become price competitive to sustain their growth. For the financial assessment of the plant, the realistic values or the current market prices of the components associated with the project must be taken. Most of the studies for the financial assessment do not include the actual market prices which are highly unrealistic in the current market. This study uses the current market prices of the components for real-time financial analysis.

The project cost includes

i. Cost of Modules.

ii. Cost of Inverters.

iii. Miscellaneous

6.1. Cost of modules

The bifacial Solar BI-SHARK 440 module is considered in the plant's design. The global module cost is decreasing every day, and the market trends show that currently, it is around Rs 50 or \$0.6 per Wp in India (Global PV Module Pricing).

Total module cost = 650 $*$ 10^3 $*$ 50 = 3,25,00,000 or \$3,94,582

6.2. Cost of inverters

The inverter is an electronic device that can convert a DC potential normally derived from solar panels or batteries into a stepped-up AC potential which may be comparable to the voltage found in domestic AC outlets. Solectria PVI, 82 kW Grid, Tied Inverter 480 VAC PVI-82 kW (Solectria) was considered for this system.

Cost of One Inverter = \$36 300

Total Cost of Inverters = \$36 300 $*$ 10 = \$363,000 or Rs 2,98,99,221

6.3. Miscellaneous cost

Miscellaneous cost, including Operation and Maintenance costs, Installation Costs, Electrical Items (Cables, etc.), Packing, and Freight, comes out to be nearly \$0.13/Wp (Chandel et al., 2014). Thus, the total miscellaneous cost of the proposed plant will be

Miscellaneous cost = 0.13 $*$ 650 $*$ 10^3 = \$84500 or Rs 69,60,011.

6.4. Land required

Financial assessment includes the land cost of the site. Therefore, two cases were taken while the assessment, i.e., once land cost was considered and the land cost was not considered in the second case. If land cost is to be considered for the plant, the area required for the plant must be calculated. The area of the plant depends on the module's layout and arrangements.

The number of PV modules required is 1477; the arrays can be arranged as 10 arrays in a row and 12. So, the area required will be

Dimension of one PV module = 2.131 m *1.047 m

No of Modules connected in series = 17

Width of an array = 1.047 $*$ 17 = 18 m^2

Width of the solar field = No. of the array in row $*$ 18

= 10 $*$ 18 = 180 m

No. of rows in solar field = 12

Assuming the Ground Cover Ratio of the plant is 0.5, the pitch distance between consecutive arrays will be

= 2.131 $*$ 2 = 4.2 m

The total length of the solar field

= (4.2 $*$ 11) + 2.131 m (Either for first or last row) = 48 m

So total area required for the plant is = 180 ∗ 48 = 8640 m2

6.5. Cost of land

The current price of the land is $245/m^2 near the proposed site. The total investment required to acquire the land will be = 245 ∗ 8640 = $20,90,880 or Rs. 17,22,19,513

VII. Results

The analysis of a solar PV plant designed for the Government College of Engineering Amravati is carried out. PV technology is not used only to reduce fossil fuel consumption. However, it can be a continuous energy source for critical areas like institutes where uninterrupted supply is demanded, as this is a case study. In this paper, efforts have been made to identify the plant's requirements for a continuous supply of energy to the hostel. Its feasibility was identified with its environmental and financial assessment. This will be useful for energy planning and developing new strategies for PV implementation.

Reduction in CO_2 emissions from the energy generated with solar energy, which could be otherwise generated with highly polluting coal-based thermal power plants, was also analyzed. For a precise assessment, the embodied energy of the plant is also taken into account, which was used to analyze the energy payback time of the plant, i.e., 6.04 years with a capacity utilization factor of 0.145. The PV technology used can also earn carbon credits from a reduction in CO_2 emissions, and in the present case, the proposed plant can earn nearly 20574 Carbon credits worth $12489. However, the recent market prices are very low for the carbon credits still, an absolute value is used in this paper.

The peak capacity required for meeting the energy demand of the hostel is 650 kWp which requires an area of nearly 8640 m_2, as discussed, abundant land is available inside the institute campus. The land cost must not be a factor in its financial assessment, but this paper proposes an analysis of the location, not only of the site. Therefore, two cases with and without land cost are considered so that the effect of land cost on the project's financial viability can be identified.

This case study brings a complete analysis of a proposed PV plant for the Government College of Engineering Amravati. The possible future scope of this study will be the practical implementation which will help develop a sustainable environment and improve policies for the better use of solar energy.

VIII. Conclusion

This paper has attempted an assessment of a Solar PV plant for the Government College of Engineering Amravati. It examines its financial viability with parameters associated and real-time market prices. The findings of the presented study are concluded as follows

- The 650 kWp system designed for the hostel requires 1477 modules of 440 Wp with an array containing 17 modules each. The plant requires an area of 8640 m2. This can cost nearly the same as the capital cost of the plant.
- The EPBT of the plant comes out to be 8.24 years with a life cycle conversion efficiency of 0.148. The capacity utilization factor of the proposed plant is nearly 0.145.
- The carbon credits that can be earned from the plant resulted in 20574 tCO_2e, worth $12489 for $0.61/Credit

The result shows that even in areas where solar energy is abundantly available, real-time market prices could affect the financial viability of the project and its energy-saving potential. Therefore, it is necessary to analyze all the parameters carefully before installing a PV plant, especially in areas where land cost is a considerable parameter. This paper can be utilized to identify shortcomings in the energy policies and strategies for the countries or states trying to reduce their GHG emissions and make this technology more attractive and financially viable.

IX. Acknowledgment

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