Site Selection of Solar PV Power Plant at Bathinda

Parag Nijhawan, Manish Kumar Singla, Jyoti Gupta

***Abstract:** In this paper, the technical and economical feasibility study of the photovoltaic (PV) power plant at Bathinda city in the Punjab state of INDIA has been carried out. For this, solar irradiance of this location has been used to assess the annual solar energy potential of the selected site PV plant. The complete work has been carried out using PVsyst simulation software. This study has been carried out to feed the electrical energy generation deficit and the increasing future electrical energy demand of Punjab State. At present, Punjab State Power Corporation Limited (PSPCL) is paying ₹ 9.04 per kWh to the private players and the other states to procure electrical energy to meet the consumer load demand. In this work, it has been found that the actual cost to the company generating electrical power using PV is around ₹ 3 per kWh after including the capital cost, loan interests, depreciation, running charges and maintenance costs. So, the proposed PV generation setup definitely will prove to be beneficial for profit-making proposition for the company supplying electrical energy to PSPCL. Besides, reduction in carbon and GHG emissions with this proposed generation has also been evaluated, which will save the environment from global warming. This is due to the fact that most of the electrical power generation in the Punjab state of India is through thermal power.*

***Keyword** - PVsyst; SPV design; Detailed Losses; Energy yield; Economics; Tariff; Carbon Emissions.*

I. INTRODUCTION

For developing countries like India, solar energy can empower it to attain ecologically sustainable growth, meet its challenge to meet its energy security, and reduce its carbon emissions. India is a tropical country with ample sunlit days throughout the year. India has the potential to harness 748.98 GWp (Marion et al. 2005) of solar power. The work presented by (Besarati et al. 2013) has an installed solar power capacity of 3883.507 MW at the proposed site. It has been reported in literature that Punjab has a solar potential of 2.81GWp (Marion et al. 2005), of which only 195.27MW (MNRE GOV.) till May 2015 is being tapped. India's solar program, Jawaharlal Nehru National Solar Mission (JNNSM), aims at encouraging public/private entities to capture solar energy potential. Several state nodal agencies like Punjab Energy Development Agency (PEDA) have been entrusted with the duty to promote and develop renewable energy projects. The solar maps proposed in paper (Khelif et al. 2012) give inputs into the levels of solar radiation, which acts as a database for future investments in Iran for solar energy.

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The feasibility of the plant study should consider several issues like investment cost, the total amount of annual cost of the project.

In the case of the AFRA power plant (Arjun et al. 2013), the project profitability is very sensible to fossil fuel cost, with a PV generator of 35 kWp and a battery capacity of 1100 Ah. The project feasibility of 10 MW PV-grid connected power plant using RETScreen version 4.0 software at 29 sites in Egypt to analyze the energy production, financial viability and greenhouse gas (GHG) emissions with maximum capacity factor of 33.7% at Waahat Kharga and minimum capacity factor of 27.6% at Safga is discussed in (Subrahmanyam et al. 2012).

The author of (Sawle et al. 2016) has been conducted on three software packages PVGIS, PV Watts, and RETScreen to compare their primary differences in the usage and results and finds them to be user-friendly even for untrained users. PV Watts is confined to calculations of PV systems within the US borders only. PVGIS is validated for Europe and Africa, and it seems to estimate produced energy with more accuracy than PV Watts and RETScreen. PVGIS utilizes more accurate databases for any specified location. Due to NASA's meteorological stations in each country, RETScreen has a more substantial location database. The various loss parameters in the PV system and other factors for solar PV performance like performance ratio (PR), cumulative utilization factor (CUF), and their optimization is discussed in (Khisa et al. 2017) and it discusses also various loss factors like irradiance, soiling, mismatch effects, Maximum Power Point Tracking (MPPT) losses, etc. and gives recommendations for optimizing the plant performance. This paper aims at studying the feasibility of 98.7 KWp PV power plant, which is proximity of the grid. An analysis of the design, economics, and emission reduction has been carried out using PVsyst software.

II. SOLAR PV POWER PLANT SETUP

Grid-connected solar PV power plant primarily consists of solar panels/modules, inverter unit, step-up transformer, and power evacuating line for grid connectivity. Electricity generated by solar modules at any plant is highly dependent on climatic conditions of the location of the plant.

Site Selection and Meteorological Data

The location of the proposed site is a few meters away from a 66kV substation of PSPCL for power evacuation. The site receives yearly average global Irradiance of 1.361 kWh/m^2 day, which is quite useful for PV power plants.

In PVsyst, the orientation panel shows the corresponding Transposition Factor (TF), which is known as the ratio of incident irradiation to the horizontal irradiation on the plane. At zero TF, the optimal angle is found. Figure 1 shows the graph of the TF as a function of the plane tilt and azimuth, and Table 1 represents the meteorological data of the site.

The generated curve helped in determining the maximum power point tracking of the projected PV system and is found to be equal to 98.7 kWp at STC, kWdc at 60°C, and 126 kWac.
Figure 2 and 3 shows the obtained MPP curve, and inverter output distribution for the selected site i.e., Bathinda and Figure 4 shows the azimuth angle of solar.

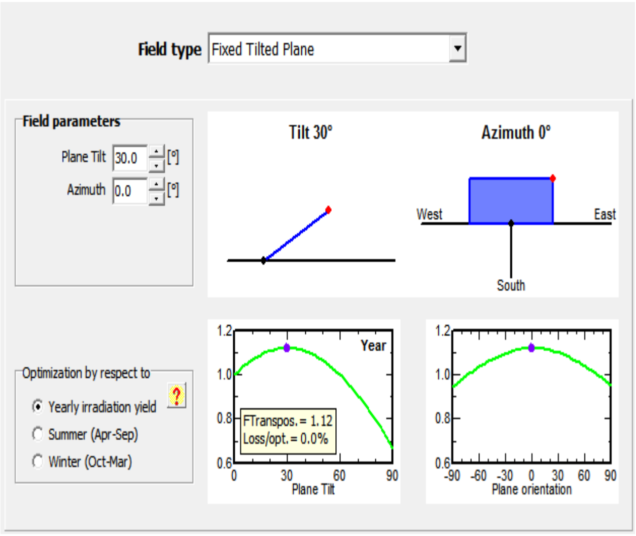

Figure 1 Graph of the TF as a function of the plane tilt and azimuth

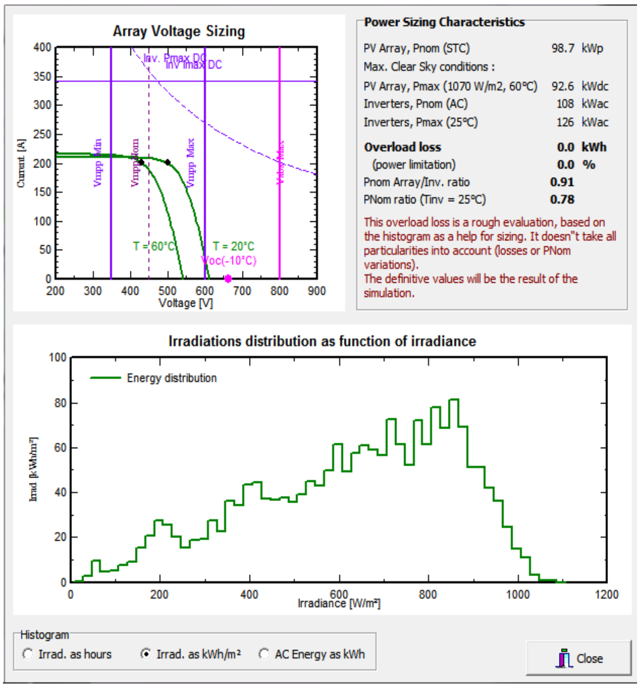

Figure 2 The obtained MPP curve and inverter output distribution for the selected site (Irrad. as kWh/m3)

The obtained results for the selected location throw light on the annual variation behavior of the total received energy, global incidence, ambient temperature, effective global incidence, energy generated, grid-transfer, PV array efficiency, and overall system efficiency. Table II below shows that annual global irradiance at Bathinda.

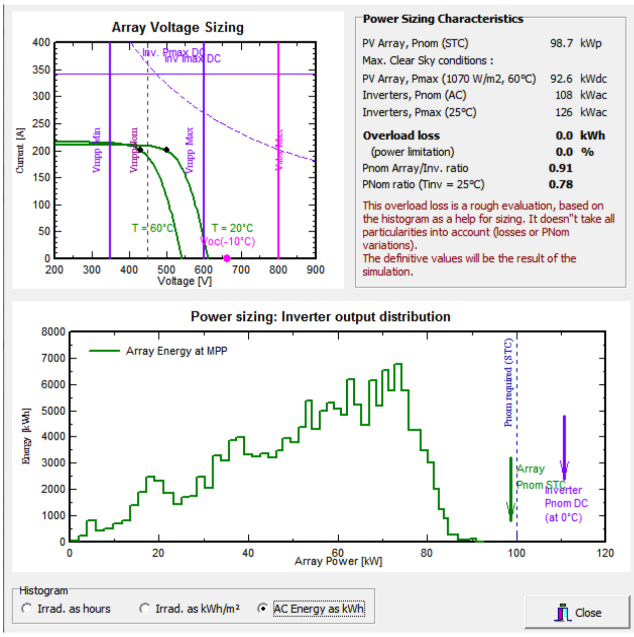

Figure 3. The obtained MPP curve and inverter output distribution for the selected site (AC Energy as kWh)

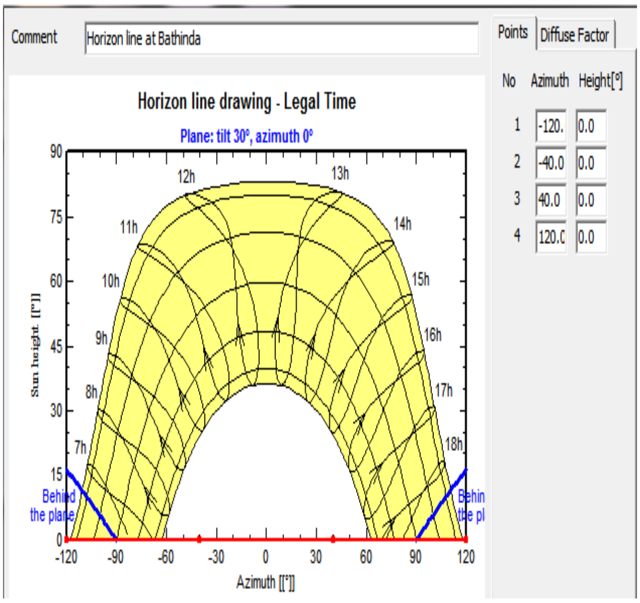

Figure 4. Solar azimuth angle

Selection of PV Modules

A PV module consists of interconnected solar cells, which, when exposed to sunlight, generate DC electric power. PV modules can be connected in series-parallel as per the requirement to derive DC electricity. For this system, solar modules manufactured by Mundhra Company have been proposed with the following characteristics, as shown in Figure 5.

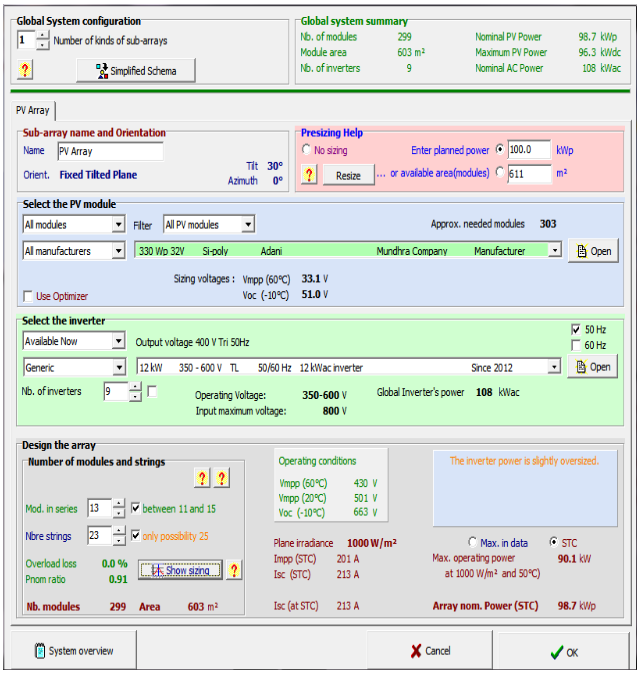

Figure 5 represents the global system summary

Table III shows the annual system losses, and in Table IV, inverter losses are given for the proposed system. The various incurred PV losses are (Singla et al. 2019):

1. Inverter loss
2. Module mismatch loss
3. Ohmic loss
4. Module quality loss

Results in Graphical Form

Figure 6 represents the Normalized production (per installed kwp) at the nominal power of 98.7 kwp, and Figure 7 shows the graph of Normalized production and Loss factor at the same nominal power. The Figure 8 shows the overall system performance ratio of the plant, and Figure 9 represents the detailed loss diagram of the plant. The graph between the global incidents in coll. Plane [w/m^2] and the global incidents in coll. Plane [kwhm^2/Bin] is shown in Figure 10, and in Figure 11, the graph between the power injected into the grid and energy injected into the grid is shown.

Table 1 Meteorological data of the site

Month	GlobHor kWh/m^2	DiffHor kWh/m^2	T_Amb ^{o}C	GlobInc kWh/m^2	DifSInc kWh/m^2	Alb_Inc kWh/m^2	DifS_GI
January	94.2	44.0	12.08	131.6	50.80	1.260	0.000
February	115.8	47.7	15.86	150.0	54.71	1.550	0.000
March	155.6	65.6	21.54	178.4	70.75	2.083	0.000
April	170.9	80.9	27.55	175.2	81.20	2.289	0.000
May	191.3	98.7	32.14	179.5	93.94	2.554	0.000
June	179.2	106.0	31.65	162.7	97.85	2.393	0.000
July	171.6	98.3	31.03	158.0	91.68	2.292	0.000
August	170.4	96.3	30.01	168.5	93.66	2.282	0.000
September	158.1	66.9	28.01	174.7	70.02	2.116	0.000
October	136.1	63.9	24.85	167.3	71.14	1.823	0.000
November	110.1	40.8	18.52	156.4	49.68	1.473	0.000
December	91.4	41.8	14.04	133.5	50.40	1.221	0.000
Year	1744.7	850.9	23.98	1935.8	875.83	23.336	0.000

Table II. Annual meteorological and incident data

Month	Global diffusion in a horizontal direction (kWh/m^2)	Global diffusion of irradiance (kWh/m^2)	Ambient temperature (^{o}C)	Global incident in collateral plane (kWh/m^2)	Global energy efficiency (kWh/m^2)	Effective energy at the output of the array (kWh)	Energy injected into the grid (kWh)	Performance Ratio
January	94.2	44.0	12.08	131.6	128.2	11602	11332	0.873

February	115.8	47.7	15.86	150.0	146.4	12885	12590	0.851
March	155.6	65.6	21.54	178.4	173.6	14874	14530	0.826
April	170.9	80.9	27.55	175.2	170.2	14248	13904	0.804
May	191.3	98.7	32.14	179.5	173.9	14445	14102	0.796
June	179.2	106.0	31.65	162.7	157.3	13239	12922	0.805
July	171.6	98.3	31.03	158.0	152.8	12915	12596	0.808
August	170.4	96.3	30.01	168.5	163.4	13798	13461	0.810
September	158.1	66.9	28.01	174.7	170.1	14262	13924	0.808
October	136.1	63.9	24.85	167.3	163.0	13896	13576	0.822
November	110.1	40.8	18.52	156.4	152.8	13309	13008	0.843
December	91.4	41.8	14.04	133.5	130.1	11682	11420	0.867
Year	1744.7	850.9	23.98	1935.8	1881.9	161156	157365	0.824

Table III. Annual system losses

Month	ModQual (kWh)	MisLoss (kWh)	OhmLoss (kWh)	Array virtual energy at MPP (kWh)	Global inverter loss (kWh)
January	180.3	130.2	107.5	11602	269.9
February	200.5	144.9	139.1	12885	295.1
March	231.6	167.3	170.2	14874	344.1
April	221.9	160.3	161.7	14248	344.1
May	224.8	162.4	153.0	14445	343.5
June	205.8	148.6	126.3	13239	316.3
July	200.8	145.0	123.6	12915	319.0
August	214.6	155.0	140.3	13798	337.1
September	222.2	160.5	168.8	14262	338.0
October	216.3	156.2	151.5	13896	320.4
November	207.2	149.6	144.7	13309	301.2
December	181.5	131.1	107.8	11682	262.4
Year	2507.5	1811.3	1694.6	161156	3791.2

Table IV. Annual inverter losses

Month	Available energy at inverter output (kWh)	Inverter efficiency (%)	Inverter Loss (kWh)	Inverter loss during operation (kWh)	Inverter loss due to power threshold (kWh)	Inverter loss due to nominal inverter power (kWh)	Inverter loss due to voltage threshold (kWh)	Inverter loss due to nominal inverter voltage (kWh)	Inverter loss due to maximum input current (kWh)
January	11332	97.7	269.9	267.8	2.030	0.000	0.000	0.000	0.000
February	12590	97.7	295.1	293.9	1.239	0.000	0.000	0.000	0.000
March	14530	97.7	344.1	342.5	1.566	0.000	0.000	0.000	0.000

April	13904	97.6	344.1	341.7	2.380	0.000	0.000	0.000	0.000
May	14102	97.6	343.5	343.3	0.194	0.000	0.000	0.000	0.000
June	12922	97.6	316.3	316.3	0.000	0.000	0.000	0.000	0.000
July	12596	97.5	319.0	319.0	0.000	0.000	0.000	0.000	0.000
August	13461	97.6	337.1	336.1	1.065	0.000	0.000	0.000	0.000
September	13924	97.6	338.0	332.4	5.646	0.000	0.000	0.000	0.000
October	13576	97.7	320.4	319.1	1.328	0.000	0.000	0.000	0.000
November	13008	97.7	301.2	301.2	0.000	0.000	0.000	0.000	0.000
December	11420	97.8	262.4	261.2	1.250	0.000	0.000	0.000	0.000
Year	157365	97.6	3791.2	3774.5	16.700	0.000	0.000	0.000	0.000

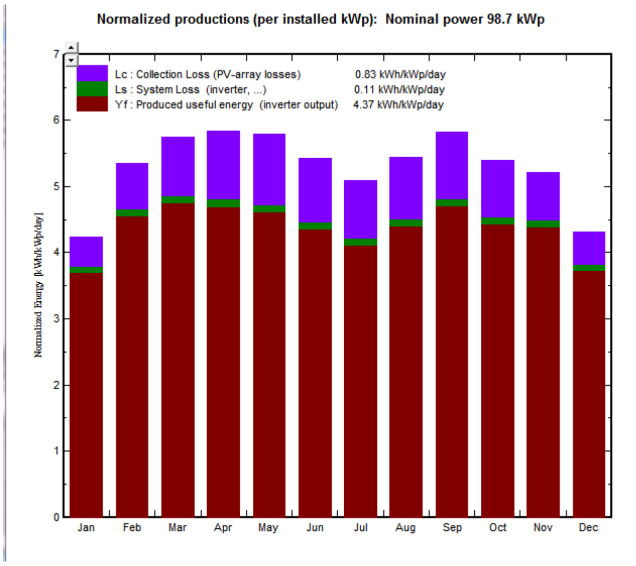

Figure 6 Normalized Productions

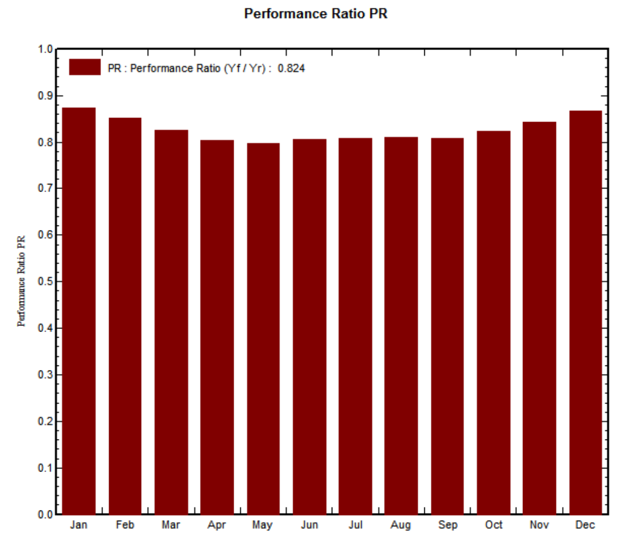

Figure 8 Overall Performance Ratio of the System

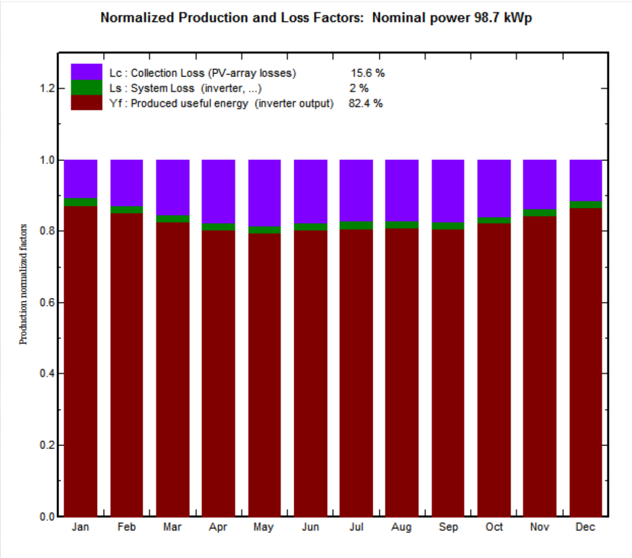

Figure 7 Normalized Productions and Loss Factor

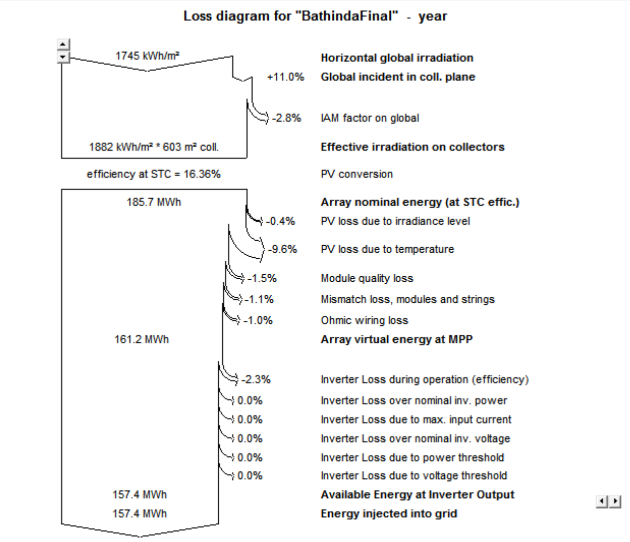

Figure 9 Overall Losses in Plant

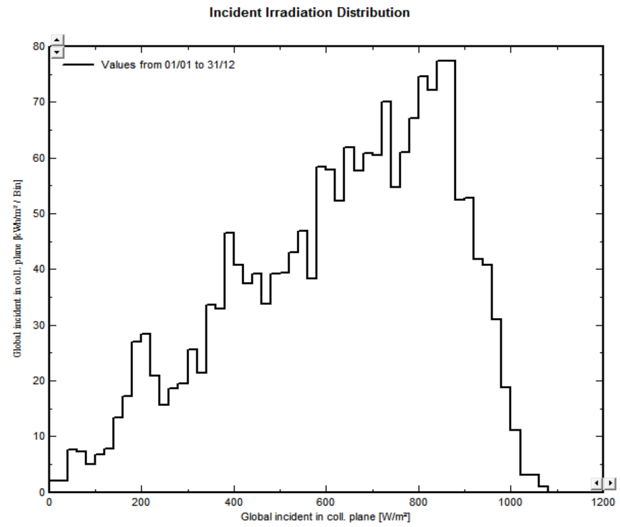

Figure 10 Incident Irradiation Distributions

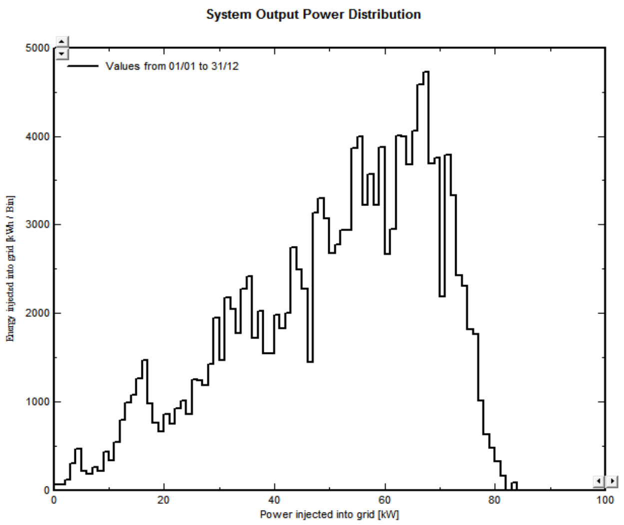

Figure 11 Overall System Output Power Distribution

III. ECONOMIC ANALYSIS

Table V represents the overall PV module specifications, and Table VI represents the detailed cost analysis of the overall plant.

Table V PV module specifications

Model	Adani
*STC Power	330 Wp
Technology	Multi-Crystalline
Module size	1976mm*992mm
No. of cells	1 x 72
Rough module area	2.0167 m^2
Sensitive area of cells	156.75*156.75mm
Open circuit voltage V_{oc}	45.87 V
Max. power point voltage	37.21 V
Max. power P_{max}	330.052 W
Short circuit current I_{sc}	9.42 A
Max. power point current	8.87 A
Efficiency/module area	16.84 %
Temper. Coeff. of P_{max}	-0.42 %/^{0}C
Temper. Coeff. of V_{oc}	-0.31 %/^{0}C
Temper. Coeff of I_{sc}	0.069 %/^{0}C

Table VI Detailed cost of power plant

Cost of module	Rs. 7590
Cost of installation of PV module	Rs. 1.8/watt
Cost of transportation	Rs. 15,000
Cost including project management and commissioning	2-4% of the total project cost
Mounting structure	7 tonn 86-91 Rs/kg
Average cost of remote control and monitoring system per year	Rs. 20,000
Energy monitoring system net meter and solar meter	Rs. 15,000
Cost of 1W solar plant	Rs. 68.35/watt
System cost	Rs. 68,35,000
Subsidy	Rs. 20,50,500
Net cost after subsidy (Capital Cost)	Rs. 48,32,500
Loan % of net cost after subsidy	40%
Loan	Rs. 19,33,000
Rate of interest	12%
Total interest per annum	Rs. 332795.16
Processing fees	2% of total cost
Loan period	10 years

Tariff: The PSERC (Punjab Electricity Regulatory Commission) has finalized the tariff for Solar Energy as ₹ 3 / kWh [11]. The PSPCL (Punjab State Electricity Power Corporation) has renewable energy purchase obligations put up by the PSERC.

Considering the fixed tariff of ₹ 3 / kWh over the lifespan (25 years) of modules & depreciation rate of 2.5% for one year and 0.68% for the remaining years. The total consumption per unit/ year is 1, 50,000 approximately. By calculating all the values, the break-even point comes around 4 years 8 months after this; we receive the actual profit from the solar power plant. After deducting the capital cost and the variable cost for the 20 years, we receive a profit of amount Rs. 25,48,424 approximately.

IV. CARBON BALANCE

Renewable energy sources help reducing carbon emissions. Conventional sources of energy release more carbon dioxide (CO_2) than their renewable, which leads to global warming. It would be wrong to say that solar energy does not lead to CO_2 emissions; instead, it does leave carbon footprints indirectly, which are in the form of manufacturing & transportation of the modules and other paraphernalia associated with the solar plant. Carbon balance accounts for the saved CO_2 emissions saved by the solar power plant over its life cycle of 25 years, as shown in Table VII. The single-player/inverter can also earn Renewable Energy Certificates (RECs) for the electricity generated by the SPV power plant, which can be traded/sold in the market to encash extra monetary benefits from it.

Carbon balance = E_Grid x system lifetime x LCE Grid – LCE System

Where LCE stands for Life Cycle Emissions

Produced emissions

Total = 2041.44 t.CO_2

Table VII System Lifecycle Emission Details

Item	Modules	Supports Etc.
LCE	1713 Kg CO2 / kWp	6.24 Kg CO2/Kg
Quantity	98.7 kWp	33450 Kg
Subtotal [Kg CO2]	1832610	208832

Replaced emissions
Total = 44887.94.t.CO_2
System production = 1918.29 MWh / year
Lifetime = 25 years
Grid lifecycle emissions = 936 g CO_2 / kWh
CO2 emission balance = 37851.1 t.CO2

V. CONCLUSIONS

The paper presents an extensive study of the feasibility of 98.7 kWp grid connected SPV at Bathinda (Punjab), INDIA. The study has been carried out using Mundhra Company modules due to their high efficiency. The project feasibility analysis has been carried out using the PVsyst software for calculating the electric energy production, economic, and greenhouse gas emission analysis. Considering the fixed tariff of ₹ 3 / kWh over the lifespan (25 years) of modules & depreciation rate of 2.5% for one year and 0.68% for the remaining years. The total consumption per unit/ year is 1, 50,000 approximately. By calculating all the values, the break-even point comes around 4 years 8 months after this; we receive the actual profit from the solar power plant. After deducting the capital cost and the variable cost for the 20 years, we receive a profit of amount Rs. 25,48,424 approximately. In addition to the economic viability, the project is evaluated for carbon emission analysis, which shows that the SPV power plant can reduce the CO2 emissions to the environment to the tune of 37851.1 tonnes over the entire life span of the project. Overall, the investigation confirms the SPV power plant feasibility at the proposed site.

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