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.

Key words - 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 3.883.507 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 (Khelifi et al. 2012) give inputs into the levels of solar radiation, which acts as a database for future investments in Iran for solar energy. 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 (Subrahmanyan 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/m² 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.

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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.
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/m²] and the global incidents in coll. Plane [kwh/m²/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.

Figure 5 represents the global system summary

Table 1 Meteorological data of the site

| Month   | GlobHor kWh/m² | DiffHor kWh/m² | T_Amb °C | GlobInc kWh/m² | DifSInc kWh/m² | Alb_Inc kWh/m² | 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/m²) | Global diffusion of irradiance (kWh/m²) | Ambient temperature (°C) | Global incident in collateral plane (kWh/m²) | Global energy efficiency (kWh/m²) | 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            |
### Table II. Annual system losses

| Month     | ModQual | MisLoss | OhmLoss | Array virtual energy at MPP | Global inverter loss |
|-----------|---------|---------|---------|----------------------------|----------------------|
| 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 III. 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                                            |

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| Month   | Value1 | Value2 | Value3 | Value4 | Value5 | Value6 | Value7 | Value8 |
|---------|--------|--------|--------|--------|--------|--------|--------|--------|
| April   | 13904  | 97.6   | 344.1  | 341.7  | 2.380  | 0.000  | 0.000  | 0.000  |
| May     | 14102  | 97.6   | 343.5  | 343.3  | 0.194  | 0.000  | 0.000  | 0.000  |
| June    | 12922  | 97.6   | 316.3  | 316.3  | 0.000  | 0.000  | 0.000  | 0.000  |
| July    | 12596  | 97.5   | 319.0  | 319.0  | 0.000  | 0.000  | 0.000  | 0.000  |
| August  | 13461  | 97.6   | 337.1  | 336.1  | 1.065  | 0.000  | 0.000  | 0.000  |
| September | 13924 | 97.6   | 338.0  | 332.4  | 5.646  | 0.000  | 0.000  | 0.000  |
| October | 13576  | 97.7   | 320.4  | 319.1  | 1.328  | 0.000  | 0.000  | 0.000  |
| November| 13008  | 97.7   | 301.2  | 301.2  | 0.000  | 0.000  | 0.000  | 0.000  |
| December| 11420  | 97.8   | 262.4  | 261.2  | 1.250  | 0.000  | 0.000  | 0.000  |
| Year    | 157365 | 97.6   | 3791.2 | 3774.5 | 16.700 | 0.000  | 0.000  | 0.000  |

**Figure 6 Normalized Productions**

**Figure 7 Normalized Productions and Loss Factor**

**Figure 8 Overall Performance Ratio of the System**

**Figure 9 Overall Losses in Plant**
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 m² |
| 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 %/°C |
| Temper. Coeff. of $V_{oc}$ | -0.31 %/°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 (CO₂) than their renewable, which leads to global warming. It would be wrong to say that solar energy does not lead to CO₂ 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 CO₂ 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 = $E_{Grid} \times$ system lifetime $\times$ LCE Grid – LCE System

Where LCE stands for Life Cycle Emissions

Produced emissions

Total = 2041.44 tCO₂
Replaced emissions
Total = 44887.94 t.CO₂
System production = 1918.29 MWh / year
Lifetime = 25 years
Grid lifecycle emissions = 936 g CO₂ / 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), INDA. 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.

REFERENCES

1. Marion, B., Adelstein, J., Boyle, K.E., Hayden, H., Hammond, B., Fletcher, T., Canada, B., Narang, D., Kimber, A., Mitchell, L. and Rich, G., (2005). “Performance parameters for grid-connected PV systems”. In Conference Record of the Thirty-first IEEE Photovoltaic Specialists Conference, pp. 1601-1606.
2. Besarati, S.M., Padilla, R.V., Goswami, D.Y. and Stefanakos, E., (2013). “The potential of harnessing solar radiation in Iran: Generating solar maps and viability study of PV power plants”. Renewable energy, 52, 193-199.
3. https://nre.gov.in/file-manager/UserFiles/Performance-analysis-of-Grid-Connected-Solar-Power-Projects-Commissioned-under-Phase%20%e2%80%93I.pdf
4. Khelif, A., Talha, A., Belhamel, M. and Arab, A.H., (2012). “Feasibility study of hybrid Diesel–PV power plants in the southern of Algeria: Case study on AFRA power plant”. International Journal of Electrical Power & Energy Systems, 43(1), 546-553.
5. Arjun, A.K., Athul, S., Ayub, M., Ramesh, N., & Krishnan, A. (2013). “Micro-Hybrid Power Systems- A Feasibility Study”, Journal of Clean Energy Technologies, 1(1), 27-32.
6. Subrahmanym, J.B.V., Sahoo, P.K., & Reddy, M. (2012). “Local PV- Wind Hybrid Systems Development for Supplying Electricity to Industry”, Acta Electrotechnica, 53(1), 10-15.
7. Sawle, Y., Gupta, S.C., Bohre, A.K., & Meng, W. (2016). “PV-Wind Hybrid System: A Review with Case Study”, Cogent Engineering, 3(1), DOI: 10.1080/23319196.2016.1189305.
8. Khisa, S., Ebihara, R., & Dei, T. (2017). “Dynamics of a Grid Connected Hybrid Wind-Solar and Battery System: Case Study in Naivasha-Kenya”, Energy Procedia, 138, 680-685.
9. Singla, M.K., Oberoi, A.S., & Nijhawan, P. (2019). “Solar-PV & Fuel

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Table VII System Lifecycle Emission Details

| Item           | Modules | Supports Etc. |
|----------------|---------|---------------|
| LCE (Kg CO₂ / kWp) | 17/13 | 6.24 Kg CO₂/Kg |
| Quantity (KwP) | 98.7 | 33450 Kg |
| Subtotal [ Kg CO₂ ] | 1832610 | 208832 |