Design and Analysis of Solar PV Rooftop in Motihari

Aditya Kumar1, Marya Andleeb2, Farhad Ilahi Bakhsh3

1Department of Electronics and Communication Engineering, National Institute of Technology Srinagar, Hazratbal-190006, Srinagar (J&K), India
2, 3Department of Electrical Engineering, National Institute of Technology Srinagar, Hazratbal-190006, Srinagar (J&K), India

E-mail: aditya_87btech18@nitsri.net

Abstract. Electricity in the modern world holds the backbone of humanity and its demand is increasing every day. Due to multiple factors, in developing countries like India, the continuous supply of electricity seems to be far-fetched due to the constant shutting down of grids (because of severe climatic conditions). The well-known sources for the production of electricity are conventional energy sources, but their supply is limited and more importantly they cause pollution. These factors raise the need to utilize renewable energy sources to the fullest. Among the available renewable energy sources, solar photovoltaic (SPV) is mostly used. In the paper, a 4 kWp SPV plant has been proposed for a residential building in Motihari, Bihar, India. The SPV plant is designed in such a way that it would ensure continuous supply of electricity. The selected location gets an average of 1156.39 W/sq.m of solar irradiation, which produces a 4.6 kWh amount of electricity using a solar rooftop plant having a capacity of 1 kWp considering 5.5 sunshine hours. The designed 4 kWp SPV plant is analyzed using PVsyst V6.8.1 software. The analysis shows that the designed SPV plant saves around 113 tonnes of carbon dioxide emissions, which is equivalent to planting 181 trees over a lifetime.

Keywords. Analysis, Solar photovoltaic (SPV), Motihari, PVsyst, and solar rooftop.

1. Introduction

Fossil fuels such as coal, oil, petroleum products, hydro, and nuclear energy constitute a significant proportion in the production of electricity all around the world. A safe assessment is that there is enough oil from traditional sources to cover the present demands for at least 30 years. Apart from problems generated by conventional fuels, there is also a significant concern about energy security [1]. India uses coal as its primary energy-supplying commodity to generate electricity. The energy conversion efficiency of coal is low, and it emits carbon dioxide, which imparts adverse effects on the environment. As coal is not available in abundant quantity, there will be acute shortages of conventional energy sources [2]. Hence, considering the above factors and issues, people must look forward to sustainable sources of energy. The SPV is among the best modes of producing clean energy. SPVs are a simple and effective mode of producing dc electricity in one juncture without requiring any additional components [3-17].

Ghenai et al. [3] have suggested a solution that implemented an off-grid hybrid solar PV/Fuel Cell system in a remote location to ensure the supply of electricity. Different conditions at a particular location like temperature and dust play an essential role in the SPV system’s performance. The PV system devised by the author offers an excellent penetration of renewable energy. Sharma et al. [4] have used PVsyst software to layout an efficient solar PV system for an academic institution. The authors claim that the
performance ratio (PR) increases as the load demand decreases. The system planned by the authors produced energy equivalent to that of the load. They also inferred that zero azimuthal angles gave the SPV system with an excellent performance and increased its efficiency. By using PVsyst, Rout et al. [5] have designed and simulated a 2 kW solar plant in Odisha. They calculated various parameters, such as solar irradiance and daily usage data. Information collected during inspection helps in laying out design of SPV system that fulfilled the energy requirements of the building. They found that a performance ratio of 0.7 was satisfactory in the city of Bhubaneswar in Odisha. Sharma et al. [6] have utilized the maximum power point tracking techniques (MPPT) to improve use of SPV systems. They demonstrated how MPPT increases the efficiency of the solar array and achieves maximum power output. Winston et al. [7] have described a method to improve output power at partial shading conditions by introducing novel PV array structures. They have used a 4x4, 4 kW SPV array consisting of 16 panels to construct their system. The method has been analyzed by studying different SPV array topologies under partial shading condition. Their work helped in the identification of an array configuration suitable for an SPV system. Islam et al. [8] have proposed a PWM inverter drivable by a solar cell. Different operating variables such as solar radiation and operating temperature of the photovoltaic cell have been considered and their impact on its performance has been analyzed. The proposed solar cell based inverter has various advantages, such as its load current containing lower harmonic contents with a sinusoidal output voltage. Bahaidarah et al. [9] performed the analysis of grid-connected PV system. They used two primary research methodologies, namely experimental investigation methods and numerical simulation for performance analysis. The numerical simulation method has various advantages, such as being low cost, quick and convenient. Aziz et al. [10] analyzed the performance of PV system around the year under different climatic conditions. They developed the PV system model using the HOMER software. The simulation results shows an optimal performance of PV system using different control strategies.

In the paper, a 4 kWp SPV plant has been proposed for a residential building in Motihari, Bihar, India. Taking into account factors such as the solar radiation and ambient temperature of Motihari, a simulative study was carried out on the performance of SPV plant. The SPV plant is designed in such a way that it would ensure the continuous supply of electricity. The selected location gets an average of 1156.39 W/m² of solar irradiation, which produces a 4.6 kWh amount of electricity using a solar rooftop plant having a capacity of 1 kWp considering 5.5 sunshine hours. The designed 4 kWp SPV plant is analyzed using PVsyst V6.8.1 software.

This paper is segregated into five sections. Section 2 provides case study of Motihari district in India. Section 3 gives the information about the usage and design of SPV components. Section 4 presents the analysis of the developed SPV system and discusses obtained results. Finally, Section 5 concludes presented paper.

2. Case Study of Motihari

The district of Motihari is located at 26.67 (0N) latitude and 84.90 (0E) longitudes with a height of 62 m above the sea level. It is surrounded by hilly terrains of Nepal in the north. Every year, the district suffers from extreme floods and faces an abysmally discontinuous supply of electricity (from the grid) causing its shortage in the area. Thus, giving rise to the need of a standalone source of electricity, which can be fulfilled by use of SPV system. In Motihari SPV modules can be established on the roof of the house and can be utilized to obtain electrical energy directly from solar energy.

In the paper, the plant has been designed by analyzing the daily electricity usage of a residential building located in Motihari. To ensure continuous supply to the loads, data collection and load calculation is mandatory. The daily power demand can be calculated as under:

\[ P_T = n \times P_R \]  \hspace{1cm} (1)

\[ E_T = h \times P_T \]  \hspace{1cm} (2)

\[ P_D = \sum E_T \]  \hspace{1cm} (3)

\[ E_g = 1.2 \times P_D \]  \hspace{1cm} (3)
Where, $P_R, P_T, E_T, P_D, E_g, h$ and $n$ are rated power, total power, total energy, power demand, gross energy, no of hours, no of applications, respectively. The different appliances connected in residential building is given in Table 1 with their power ratings. Then the calculations are done for total power and total energy based on $h$ and $n$.

| S.no | Electrical Appliances | Rated Power $P_R (W)$ | Number of applications $n$ | Total power $P_T (W)$ | No of hours $n$ | Total Energy $E_T (\text{Wh/day})$ |
|------|---------------------|-------------------|-----------------|-----------------|----------------|-----------------|
| 1.   | Led Bulb            | 8                 | 10              | 80              | 06             | 480             |
| 2.   | Night Bulb          | 10                | 2               | 20              | 14             | 280             |
| 3.   | Electronic Charger  | 15                | 5               | 75              | 05             | 375             |
| 4.   | Fan                 | 75                | 5               | 375             | 10             | 3750            |
| 5.   | Television          | 110               | 2               | 220             | 05             | 1100            |
| 6.   | Refrigerator        | 130               | 1               | 130             | 24             | 3120            |
| 7.   | Grinder/Mixie       | 150               | 1               | 150             | 0.1            | 7.5             |
| 8.   | Computer            | 220               | 1               | 220             | 08             | 1760            |
| 9.   | Water Pump          | 400               | 1               | 400             | 03             | 1200            |
| 10.  | Washing Machine     | 900               | 1               | 900             | 01             | 900             |
|      | **Total**           | **29**            | **2570**        | **12972.5**     |                |                 |

The “fudge factor” of 1.2 must be multiplied to the calculated watt hour to get the desired amount of energy. From Table 1 for a residential building, total power demand has been computed as 12972.5 Wh/day = 12.97 kWh/day. Now the obtained energy is multiplied by 1.2 to find the gross energy required for the residential building whose value comes out to be 15.6 kWh/day.

3. **Components and Design**

The solar PV system incorporates various components in its design discussed in subsequent section. The performance of SPV system is dependent on various factors like solar irradiance, shading effects, rainfall patterns, and dust particles. Among all, solar irradiance is the most important factor upon which the SPV system depends. Depending upon the solar irradiance, the style of solar panels, their orientation, and inclination parameters are selected. The capacity of batteries and the quality of the inverter also varies with solar irradiation.

3.1 **System overview and components**

The various components used in the SPV system are solar PV panels, battery, inverter, charge controller, cables, utility grid, net metering, and loads as shown in Fig. 1. The dc power generated from PV modules is stored in battery through charge controller which manages the power input to battery bank from solar array. It ensures that the batteries are not overcharged during the day and power does not flow back from battery to solar panel. A battery bank is composed of multiple interconnected batteries that are wired to work as one large battery at a certain voltage and amp-hour capacity. Battery bank stores energy which is fed to the inverter. Conversion of dc voltages to ac voltages is carried out by the inverter. The ac supply is used for the operation of household devices. The output terminals of inverter is also connect to the grid with the support of utility meter and the fuse box. The excess ac produced by the inverter is provided to the grid with the support of a utility meter. To function appropriately, the phasing of the system with the grid is essential for grid-connected PV systems. The phasing is carried out by the inverter that operates in
phase with grid [11].

Figure 1. Layout of the SPV plant.

The SPV module has been selected based on the ease of availability and maintenance in Indian climatic conditions. The SPV system proposed contains 16 Si-poly PV modules, arranged in 2 strings of 8 modules each. Canadian Solar Inc module, CS6K-260P has been selected, with each module having a rating of 260 Wp. One solar inverter of the model, RPI H4A is used. With a rating of 4 kW, the inverter has an operating voltage between 100 V - 500 V.

The design of 4 kW rooftop grid-connected solar PV system for Motihari is done using PVsyst V6.8.1 software. The developed model has been used to run the simulation for the required SPV system.

4. Analysis and Results

The analysis of the developed SPV system is presented in section 4.1 and its results are shown in section 4.2.

4.1 Performance analysis

The grid-connected PV system can be examined by using parameters outlined by International energy agency (IEA) [12]. Some of the parameters required for analyzing the PV system are as follows:

4.1.1 Array Yield ($Y_a$):

$$Y_a = \frac{\text{DC Energy Generated}}{\text{Nominal Power}}$$

The dc energy generated is the amount of the energy produced by the SPV panel on a daily, monthly or yearly basis, and nominal power is the rated power of the SPV panel. The dc energy generated is given in units of kWh, and nominal power is given in units of kWp [13].

4.1.2 Reference Yield ($Y_r$):

$$Y_r = \frac{\text{Total Horizontal Irradiance}}{\text{Global Irradiance}}$$

At standard test conditions (STC), the ratio of the total horizontal solar irradiation to the global irradiance is known as reference yield. It shows an equivalent number of hours at the global irradiance or the total amount of solar radiation in-plain. Total horizontal irradiance is given in units of kWh/m², and global irradiance is given in units of kW/m² [13,14].

4.1.3 Final System Yield ($Y_f$):
\[ Y_f = \frac{\text{AC Energy Output}}{\text{Peak Power}} \]

It is the ratio of total ac energy output produced by the inverter to the rated SPV array power. The ac energy produced is given in units of kWh [13,14].

4.1.4 System Losses (LS):

\[ LS = \text{Array Yield} - \text{Final Output Yield} \]

It is caused due to the inefficiencies of the inverter of the SPV system [13].

4.1.5 Array Capture Losses (LC):

\[ LC = \text{Reference Yield} - \text{Array Yield} \]

It occurs due to the losses occurring in the SPV array [13].

4.1.6 Performance Ratio (PR):

\[ PR = \frac{\text{Final System Yield}}{\text{Reference Yield}} \]

The ratio of the final system yield of PV system to the reference yield is known as performance ratio. The overall losses that occur during the conversion of dc to ac power are given by \( PR \). So, it acts as an indicator of the energy available after removing the amount of energy lost in the SPV system [15-17].

4.2 Simulation Results

Different parameters associated with the solar PV system have been portrayed in figure 2. The graph has been plotted between global incident (kWh/m².day) versus available solar energy (kWh/day). The straight line in the figure demonstrates the yield of the graph, which tends to saturate with higher irradiation values. The slight ebb demonstrates the impact of the temperature. Here in the outline of the graph, a few points have strayed at high irradiiances, which demonstrates the condition of overload.
Figure 3. I-V Characteristic of SPV system at different solar irradiance.

Figure 3 shows the I–V characteristics of designed SPV system. Here, the cell temperature is kept at 45°C. Here, power varies with incident irradiation. From the graph, it is clear that as the solar irradiation decreases the magnitude of SPV current and SPV voltage reduces and vice versa. Thus, increase in solar irradiance increases the output power of SVP system.

Figure 4. P-V Characteristic of SPV system at different solar irradiance.
Figure 4 illustrates the P–V characteristic of designed SPV system. Here, again the cell temperature is kept constant at 45°C. From the figure, it is evident that the maximum output power (238.9 W) of SPV system is achieved at solar irradiation of 1000 W/m². Further as the solar irradiation decreases, the value of maximum power also reduces accordingly. At lower values of solar irradiation such as 400 W/m² and 200W/m², the maximum power obtained are 94.7 W and 46.0 W, respectively.

![Figure 4. P–V characteristic of designed SPV system.](image)

**Figure 5.** I-V Characteristic of SPV system at different temperature.

Figure 5 illustrates the I-V characteristic of designed SPV system at varying operating temperature. The graph indicates that at higher temperatures, the maximum power decreases. The maximum power point (Pmpp) at cell temperatures of 25°C, 40°C and 70°C is 260.2 W, 244.3 W and 211.6 W, respectively.

![Figure 5. I-V Characteristic of SPV system at different temperature.](image)

**Figure 6.** P–V Characteristic of SPV system at different temperature.

Figure 6 presents the P-V characteristic of designed SPV system at varying operating temperature. The graph here indicates that with the increase in temperature, the maximum power output of SPV
system decreases. For cell temperatures at 25°C, 40°C and 55°C the maximum power ($P_{mpp}$) are 260.2 W, 244.3 W and 228.0 W, respectively.

Figure 7. $P_{max}$-Incident global Characteristic Curve

Figure 8. Efficiency at $P_{max}$ vs. cells temp Curve

Figure 7 illustrates the plot of $P_{max}$ vs. incident global. 15.90 % is the relative efficiency obtained for 1000 W/m² (STC) and figure 8 illustrates the plot of $P_{max}$ vs. cells temp of Canadian solar Inc., CS6K-260P
Figure 9. $P_{\text{max}}$-Incident global characteristic curve.

Figure 10. $P_{\text{max}}$-Incident global production curve.

Figure 9 shows the plot showing the incident irradiation distribution of the SPV system drawn on a yearly basis and figure 10 shows the plot of the system output power distribution of the SPV system produced on a yearly basis.
Table 2. Balances and Main Results.a.

| Month   | GlobHor (kWh/m²) | DiffHor (kWh/m²) | T_Amb (°C) | GlobInc (kWh/m²) | GlobEff (kWh/m²) | EArray (kWh) | E_User (kWh) | E_Solar (kWh) | E_Grid (kWh) | EFrGrid (kWh) |
|---------|------------------|------------------|------------|------------------|------------------|-------------|-------------|---------------|-------------|--------------|
| January | 101.1            | 55.80            | 15.29      | 122.4            | 119.8            | 445.3       | 404.6       | 396.0         | 14.2         | 8.661        |
| February| 125.6            | 54.40            | 19.85      | 147.7            | 144.7            | 512.0       | 365.5       | 364.2         | 97.5         | 1.218        |
| March   | 165.8            | 73.60            | 25.45      | 180.1            | 176.6            | 599.0       | 404.6       | 404.6         | 151.5        | 0.000        |
| April   | 179.8            | 87.10            | 30.01      | 180.9            | 176.9            | 590.6       | 391.6       | 391.6         | 158.3        | 0.000        |
| May     | 190.9            | 93.50            | 31.45      | 182.0            | 177.7            | 593.6       | 404.6       | 404.6         | 145.9        | 0.000        |
| June    | 168.3            | 94.80            | 30.55      | 158.2            | 154.3            | 525.6       | 391.6       | 391.6         | 91.7         | 0.000        |
| July    | 150.2            | 97.50            | 29.71      | 142.6            | 138.8            | 484.1       | 404.6       | 404.6         | 45.2         | 9.546        |
| August  | 155.3            | 97.20            | 29.66      | 152.0            | 148.2            | 513.8       | 404.6       | 403.2         | 72.2         | 1.440        |
| September | 141.8          | 75.70            | 28.61      | 147.6            | 144.2            | 495.8       | 391.6       | 384.2         | 64.3         | 7.312        |
| October | 138.1            | 64.80            | 26.83      | 157.5            | 154.3            | 530.6       | 404.6       | 404.6         | 82.3         | 0.000        |
| November| 124.5            | 45.10            | 21.87      | 157.2            | 154.4            | 540.0       | 391.6       | 391.6         | 107.3        | 0.000        |
| December| 105.6            | 49.20            | 17.25      | 134.8            | 132.2            | 482.6       | 404.6       | 403.2         | 36.3         | 1.333        |

Total 1747.0 888.70 25.57 1862.9 1822.2 6313 4764.0 4734.5 1066.6 29.510

a Generated from PVsyst

Table 2. presents the balances and main results of the simulation. Various factors related to the SPV system including the most critical factors like ambient temperature, effective global irradiance and global irradiance are taken into account. The other factors are energy infused into the utility grid and dc energy delivered by the PV array. Each variable mentioned above has been calculated on a monthly and yearly basis. In the calculation of factors, losses occurring in various variables have been taken into consideration.

The results show that the annual global irradiance on the site location on a horizontal plane is 1747.0 kWh/sq. m. After optical losses, effective global irradiance is 1822.0 kWh/sq. m. Without correcting the losses occurring due to the optical losses, the global incident energy is 1862.9 kWh/sq.m. The amount of dc energy generated by the PV array in a year is 6313 kWh. The energy-infused to the grid in the form of ac is 1066.6 kWh.

The important Normalized production values are summarized in Table. 3

![Normalized productions](image-url)
Table 3. Normalized Production Values

| Normalized Production Values | Value (kWh/kWp/day) |
|-----------------------------|---------------------|
| Collection losses (LS)      | 0.95                |
| System Losses (LS)          | 0.34                |
| Produced useful energy (Yf) | 3.82                |

The yearly average performance ratio of SPV is around 74.9 %. Variations in PR are shown cross figure 12.

Figure 12. Performance ratio
Figure 13 shows the Arrow loss diagram that focuses on various existential problems and losses that take place at different stages of operation in the SPV system. Details of arrow diagram parameters are given in Table 4.

| Arrow Diagram Parameters | Values          |
|--------------------------|----------------|
| Global Irradiance        | 1747 kWh/sq.m  |
| Effective irradiance     | 1822 kWh/sq. m |
| Nominal array energy     | 7587 kWh       |
| The efficiency of the PV array | 14.90%       |
| Array virtual energy at MPP | 6313 kWh    |
| Losses due to temperature | 15.9%         |
| Mismatch loss, modules, and strings | 1.1%      |
| Ohmic wiring losses      | 1.1%           |
| Accessible energy        | 6131 kWh       |

### 4.3 Economic Analysis

The following data has been formulated from the official website of the Ministry of New and Renewable Energy [18, 19].

1. **Size of Power Plant [18]:**
   - Feasible Plant size as per Capacity: 4 kW

2. **Cost of the Plant [18]:**
   - MNRE current Benchmark Cost: Rs. 41000 Rs./kW
   - Without subsidy (Based on current MNRE benchmark): Rs. 164000
   - With subsidy 40% up to 3kW & 20% above 3kW up to 10kW (Based on current MNRE benchmark): Rs. 106600

3. **Total Electricity Generation from Solar Plant [18]:**
   - Annual: 5520kWh
   - Life-Time (25 years): 138000kWh

4. **Financial Savings [18]:**
   - Tariff @ Rs.7.15/ kWh (for top slab of traffic) -
     - No increase assumed over 25 years:
       - Monthly: Rs. 3289
       - Annually: Rs. 39468
       - Life-Time (25 years): Rs. 986700

5. **EMI Calculation [18]:**
   - Cost of the solar plant: Rs. 164000
   - Subsidy: 40%
   - Debt-Equity Ratio: 60: 40
   - Down-payment: Rs. 65600/kWh
   - Loan amount: Rs. 98400/kWh
   - Loan Interest Rate: 8.45%
   - Loan Period: 10 Years

**Remarks [18]:**
- EMI for Loan amount of Rs. 98400 for loan period of 10 years @ 8.45 % is Rs.1217 / month
The energy payback period for the solar PV System is calculated by multiplying the amount of generated electricity by the cost of the unit (in kWh). The cost of 1 kWh in Bihar for rural areas is fixed at Rs. 7.15 per kWh [19]. So, the amount earned per year is \( 6313 \times (7.15) = Rs. 45,137.9 \). To recover the cost of the plant solely by only selling the unused energy will take 44 months.

5. Conclusion
In the paper, the plan to execute a 4 kW grid-connected Si-poly photovoltaic system at Motihari, Bihar, has been proposed. The data of the SPV system has been gathered using the PVsyst simulation tool. The simulation could be extended to a residential complex comprising of 10 houses, each having their SPV system. In this designed, the energy is efficiently utilized and the unused energy is fed back to the grid, thus reducing the wastage of energy. Also, the continuity of supply is ensured even at the times of severe climatic conditions. From the investigation, the following details were extracted:

- On a yearly basis, 6313 kWh/year is the amount of energy available to the user and the amount of energy infused into the grid is 1066.6 kWh/year.
- March has the highest energy accessible to the customer, i.e., 599.0 kWh, and January has the lowest energy accessible, i.e., 445 kWh.
- The Average performance ratio (PR) in the simulated study for the planned location of the Si-poly PV system stands at 74.90%.
- Shading factor can be included in the PV system to analyze more accurate results.

References
[1] D. Infield, L. Freris, *Renewable Energy in Power Systems*, 2nd Edition, John Wiley and Sons, Feb. 2020.
[2] F. I. Bakhsh, D. K. Khatod, "A new synchronous generator based wind energy conversion system feeding an isolated load through variable frequency transformer," *Renewable Energy*, vol. 86, pp. 106–116, Feb. 2016.
[3] C. Ghenai, T. Salameh, A. Merabet, "Technico-economic analysis of off grid solar PV/Fuel cell energy system for residential community in desert region," *International Journal of Hydrogen Energy*, vol. 45, no. 20, pp. 11460-470, April 2020.
[4] S. Sharma, C. P. Kurian and L. S. Paragond, "Solar PV System Design Using PVsyst: A Case Study of an Academic Institute," 2018 *International Conference on Control, Power, Communication and Computing Technologies (ICCPCCT)*, Kannur, pp. 123-128, 2018.
[5] K. C. Raut, P.S. Kulkarni "Design and Performance evaluation of Proposed 2 kW Solar PV Rooftop on Grid System in Odisha using PVsyst," 2020 *IEEE International Students' Conference on Electrical, Electronics and Computer Science (SCEECS)*, Bhopal, India, 22-23 February, 2020.
[6] N. Sharma, F. I. Bakhsh, S. Mehta, "Efficiency Enhancement of a Solar Power Plant Using Maximum Power Point Tracking Techniques," *IEEE International Conference on Computational and Characterization Techniques in Engineering & Sciences (CCTES-18)*, Integral University, Lucknow, India, 14-15 September 2018.
[7] P. Winston, D. Kumaravel, S. Kumar, B. Devakirubakaran "Performance improvement of solar PV array topologies during various partial shading conditions," *Solar Energy*, vol. 196, pp. 228-242, 2020.
[8] S. Islam, F. I. Bakhsh, Q. U. Islam, "Modeling and Analysis of the Photovoltaic Array Feeding a SPWM Inverter," *Advances in Intelligent Systems and Computing, Applications of Artificial Intelligence Techniques in Engineering*, vol. 698, Springer Book, Singapore, pp 449-457, 2019.
[9] H. M. Bahaidarah, B. Tanweer, P. Gandhidasan, N. Ibrahim, and S. Rehman, "Experimental and numerical study on non-concentrating and symmetric unglazed compound parabolic photovoltaic concentration systems," *Applied Energy*, vol. 136, pp. 527–536, 2014.
[10] A. S. Aziz, M. F. N. Tajuddin, M. R. Adzman, M. F. Mohammed, M.A.M Ramli "Feasibility analysis of grid-connected and islanded operation of a solar PV microgrid system: A case study of Iraq," Energy, vol. 191, no. 116591, 2020.

[11] M. A. Eltawil, Z. Zhao "Grid-connected photovoltaic power systems: technical and potential problems.a review," Renewable and Sustainable Energy Reviews, vol. 14, pp.112-129, 2010.

[12] IEC. "Photovoltaic System Performance Monitoring-Guidelines for Measurement Data Exchange and Analysis," IEC Standard, no. 61724, Geneva Switzerland, 1998.

[13] L. M. Ayompe, A. Duffy, S. J. McCormack, M. Conlon, "Measured performance of a 1.72 kW rooftop grid connected photovoltaic system in Ireland," Energy Conversion and Management, vol. 52, no. 2, pp. 816–825, 2011.

[14] C. E. B. E. Sidi, M. L. Ndiaye, M. E. Bah, A. Mbojdi, A. Ndiaye, and P. A. Ndiaye, "Performance analysis of the first large-scale (15 MWp) grid-connected photovoltaic plant in Mauritania," Energy Conversion and Management, vol. 119, no. 1, pp. 411–421, 2016.

[15] S. Wittkopf, S. Valliappan, L. Y. Liu, K. S. Ang, S. C. J. Cheng, "Analytical performance monitoring of a 142.5 kWp grid-connected rooftop BIPV system in Singapore," Renewable Energy, vol. 47, no. 6, pp. 9-20, 2012.

[16] R. Dabou, F. Bouchafaa, A. H. Arab et al., "Monitoring and performance analysis of grid connected photovoltaic under different climatic conditions in south Algeria," Energy Conversion and Management, vol. 130, pp. 200–206, 2016.

[17] A. Balaska, A. Tahri, F. Tahri, A. B. Stambouli, "Performance assessment of five different photovoltaic module technologies under outdoor conditions in Algeria," Renewable Energy, vol. 107, pp. 53–60, 2017.

[18] https://solarrooftop.gov.in/rooftop_calculator

[19] http://energy.bih.nic.in/docs/Tariff-Order-2019.pdf