Design and Analysis of an On-Grid Solar System Using PVsyst Software for Commercial Application

Kazi Abdul Kader, Florina Rahman, Nahidul Islam Nahid, Zahid Abedin, Dr. Mohammad Abdul Mannan
Faculty of Engineering
American International University Bangladesh (AIUB)

Abstract— Because of Bangladesh's geographical location, solar energy is one of the probable sources. Because Bangladesh is mostly an agricultural country, procuring land for huge solar power projects is quite challenging. Rooftop solar is the best alternative for Bangladesh in meeting its goals and alleviating its current energy problem. The PVsyst software was used to build and simulate a solar PV grid-connected energy generation system in this work. It also depicts the solar photovoltaic system's technical, economic, and annual performance. This planned solar PV plant generates a total of 209 KWp of power. This generated electricity could lower electricity rates by exporting excess electricity to the national grid, where industrial owners are normally paid a feed-in-tariff. Furthermore, the solar power plant saves oil and has a low environmental impact. This project can also be used as a model for other institutions solar systems.

Keywords— Solar Energy, Solar PV Plant, PVsyst Software, SketchUp Software, Skelion Software, Grid Connected PV, Sun Path, Array Loss Diagram, Performance Ratio, Normalized Production.

1 INTRODUCTION

WITH the rapid growth of Bangladesh's economy, the country's energy demand is increasing by the day, posing a serious threat to the country's energy security. Recently, the majority of energy has been generated by burning finite fossil fuels, whose supply will be depleted very soon. It is past time to find a viable substitute source for sustainable energy generation in order to overcome the current energy crisis. Because of its geographical location, solar energy is one of the viable sources in this regard. Bangladesh's government has already embarked on a number of initiatives to harness this solar energy potential and generate the required amount of electricity. However, there are a lot of misconceptions about solar energy potential in the country. One of the most pressing issues is obtaining appropriate land for the solar park. Because Bangladesh is mostly an agricultural country, obtaining land for major solar power facilities is quite challenging. Residential, industrial, commercial, and government buildings, on the other hand, can all provide ample rooftop area for solar power generation. As a result, rooftop solar is the best alternative approach for Bangladesh to meet its goals and alleviate the current energy crisis. The design and simulation of a solar PV grid-connected energy generation system using the rooftop of a selected commercial industry in Chandra, Gazipur, Bangladesh are presented in this paper. It also depicts the solar photovoltaic system's technical, economic, and annual performance [1]. PVsyst software is used to test and simulate the project, determining the best size, on-grid solar PV system parameters, and electrical power generation. A solar PV system may generate up to 209 KWp of power. This amount of electricity could be used to reduce the commercial industry's load shading and lower the industry's annual electricity cost. The project provides a brief financial analysis of the solar PV plant, as well as the expenses of operation and maintenance. Module orientation, near shading, and inter-row spacing are all essential design elements that are assessed. The performance ratio is derived after considering several types of losses such as losses due to temperature, losses owing to an internal network, shadings, and mismatch loss. The 209 KWp ground-mounted solar PV plant simulation results reveal a system production of 248.9 MWh/year and a performance ratio of 61.21%. The findings of this experiment should encourage business owners, particularly garment factory owners, to consider installing an on-grid solar PV system on their rooftop to reduce load shedding and lower the cost of supplying electricity to their facilities. Furthermore, the solar power plant saves oil and has a low environmental impact. This project can also be used as a model for future solar systems in other institutions [2].

- *Kazi Abdul Kader, Faculty of Engineering, American International University-Bangladesh(AIUB), Bangladesh, PH- +8801406568495, E-mail: abdulkader.aiub@gmail.com*
- *Dr. Mohammad Abdul Mannan, Faculty of Engineering, American International University-Bangladesh(AIUB), Bangladesh, PH- +8801799277730, E-mail: mdmannan@aiub.edu*
- *Florina Rahman, Faculty of Engineering, American International University-Bangladesh(AIUB), Bangladesh, PH- +8801955909248, E-mail: florina.aiub173@gmail.com*
- *Nahidul Islam Nahid, Faculty of Engineering, American International University-Bangladesh(AIUB), Bangladesh, PH- +8801740280027, E-mail: nahid1480@gmail.com*
- *Zahid Abedin, Faculty of Engineering, American International University-Bangladesh(AIUB), Bangladesh, PH- +8801765819331, E-mail: zahidabedin0@gmail.com*

1.1 System Design and Objectives

The purpose of this study is to design a PV system that meets the user's needs and to evaluate different PV system possibilities, such as:

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- Obtaining and evaluating meteorological data for the area in order to evaluate the solar resource and the surrounding environment.
- Examining the viability of building a photovoltaic system on existing rooftop ground surfaces.
- Designing and simulating a variety of PV systems while keeping constraints and limitations in mind.
- Considering the practicality of the PV systems that have been designed from a financial standpoint.

2 METHODOLOGY

2.1 Simulation Software SketchUp

It's a 3D modelling design software that may be used for a variety of drawing applications, including interior design, landscape architecture, civil, and mechanical engineering design. In the SketchUp software, there are certain unique features. The shadow analysis is the subject of this endeavour. To generate the most energy, solar power facilities must be located in an area where there are no shadows. As a result, when developing a solar power plant, we must consider the sun's position throughout the year as well as the azimuth of our site. For completing the shadow analysis, this type of solar system design typically used a sun path finder. Analysing the shadow in SketchUp software is simple and inexpensive. The model can be installed within "Google Earth" straight on the actual site using SketchUp. The geo-location is selected using a particular toolbar in the SketchUp software. We conducted shadow analysis for the selected area on December 21st and June 21st in order to make the site shade-free. Because these are the shortest and longest days of the year, the shadows will not spread throughout the year. We should have taken into account the height of the solar power system design and the project's azimuth while creating the 3D model [3].

2.2 Simulation Software Skelion

It's a SketchUp plugin that allows you to add solar photovoltaics and thermal components to any surface. The Skelion plugin allows SketchUp users to quickly put solar panels and research green solar energy. Other methods of inserting more precise solar components are possible with the software. It is feasible to place all of the solar panels in the primary area, compute each panel's shadow losses, and eliminate the panels with inefficient-shaded damage. The industry-recognized combination of SketchUp and Skelion helps you save time and money on solar design while also producing beautiful and professional presentations and proposals. Skelion for SketchUp allows us to add our own model or use the PV Modules data source [4].

2.3 Simulation Software PVsyst

PVsyst is a strong piece of software for PV systems. Swiss scientist Andre Mermoud and electrical engineer Michel Villoz created this software. PVsyst software is a program that allows users to precisely assess numerous configurations, evaluate the findings, and identify the best feasible solutions in order to develop PV technology in the best and most reliable way possible. Preliminary design, project design, database, and equipment are the four primary features of PVsyst. It is widely recognized as industry-standard software for PV system design and simulation. The most recent version of this software is V6, which comes with a 30-day demo mode and costs roughly $1,021 for the unlimited version. PVsyst is a software program for analysing, sizing, and analysing data from full PV systems. It works with grid-connected, stand-alone, pumping, and DC-grid PV systems, as well as standard solar power equipment, and has a full weather and database of PV system components. It takes inputs like plane orientation, system components, PV array (series and number of PV modules in series), inverter model, battery pack, and so on to run the simulation. Results can be obtained weekly, daily, or hourly after merging numerous simulation variables. A report can be printed for each simulation run, together with all of the simulation settings and the original findings. This software may also perform a full economic evaluation using real component pricing, any additional charges, and investment circumstances [4]. In PVsyst, Figure 1 depicts the numerous phases needed in developing and simulating a PV system.

Figure 1: Project designing and simulating steps in PVsyst software.

2.4 PV module and inverter

PV is the most significant component of a grid-connected PV system since it converts solar radiation energy into electrical energy. A solar array is created by connecting a number of PV modules to increase the output power. To supply the load throughout the year, the PV array must be carefully measured. The 400 Wp Generic, mono-crystalline 72 cells module was chosen for this project, and the parameters of the proposed module are listed in Table 1. To receive the most amount of solar radiation, the panel must be positioned at a specific fixed angle. For best solar radiation, the panel must be installed facing south. For maximum solar exposure, the panel must be positioned at an angle corresponding to the altitude of the site location. The panel is tilted at a 25-degree angle for this project. PV module specifications are shown in Table 1 [4].

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Table 1: PV module specification.

Specification	Parameters
Module name	Generic, Mono 400Wp 72 cells
Technology used	Mono-crystalline
Rated power	400Wp
Short circuit current	11.100A
Open circuit voltage	47V
Maximum voltage	38.40V
Maximum current	10.410A

The inverter is also a critical component of a grid-connected PV system. This component converts the DC power from the PV module into an AC power source. For the system to function effectively, it is critical that the inverter specifications match the PV specifications. The inverter, which is commonly used for research, has an MPPT innovation incorporated in, which will improve the system's efficiency. A 60KWac string inverter was chosen for this project. The inverter's specifications are listed in Table 2.

Table 2: Specification of the inverter.

Input side (DC PV field)	Parameters	Output side (AC grid)	Parameters
Model	Generic, 60KWac string inverter	Triphased	50/60 Hz
Minimum MPP voltage	500V	Grid voltage	800V
Maximum MPP voltage	1450V	Nominal AC power	60KVA
Absolute max. PV voltage	1500V	Maximum efficiency	98.50%

2.5 3D Shadow Analysis

For the purpose of finishing our project, we chose an industry in Chandra, Guipure, Bangladesh. We used the SketchUp software to construct the entire building in order to determine how much power may be generated on the rooftop of that industry. As we all know, the first step in designing any solar PV system is to do a year-long shadow study of the chosen location. To do this, a gadget known as a solar pathfinder is widely used. This device is mostly used for business purposes. However, we do not need that device in our project to complete the first phase, which is shadow analysis. We do, however, use the SketchUp program. We chose it because it allows us to perform shadow analysis for a variety of years and dates. There is a 3D store in the SketchUp software from which we may download several modules, but we are unable to do so. Because there is an issue if we do that, the software will not effectively perform shadow analysis and will run slowly. We don't have such advantage in SketchUp because we don't have the freedom to use any module we want. We use another piece of software called Skelion Software to fix this problem. Skelion is a piece of software that allows you to do just that. We have the option of selecting any module totally at our discretion, as well as importing any module into Skelion program by modifying the data base. Another advantage of using Skelion software is that we can use it to plug in specific features in Sketch Up. As a result, SketchUp and Skelion software are used to design the entire building and modules. We assemble the Apex holding limited industry's entire architected design. We chose that module from the default folder of the PVsyst program because we don't have a PAN file for it. We do the shadow analysis for the 21st of December and the 21st of June after we finish the entire design. For the shadow analysis, we chose the peak hours of 8 a.m. to 4 p.m. We determined the capacity that we can generate using our design and the number of modules we need to complete our project by completing the entire design section. Figure 2 depicts the creation of a 3D model with SketchUp and Skelion [5].

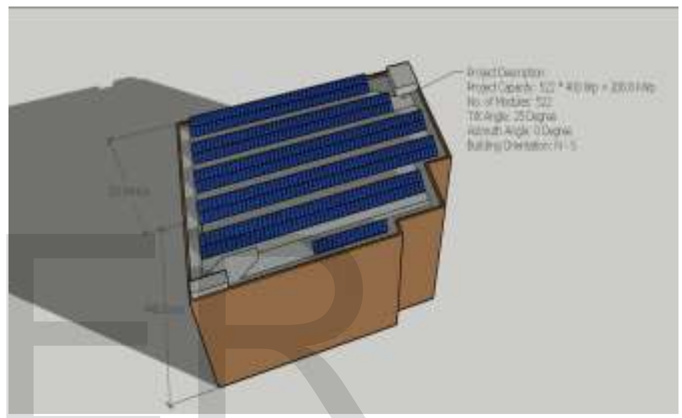

Figure 2: 3D model design using SketchUp and Skelion.

We are using a generic 400Wp mono 32v 72 cells module in Figure 2. We employ a 24mm gap between two modules and keep the same design throughout. The industry's height is 28194 mm and its breadth is 44836 mm. There are six rows of modules on the rooftop. Table 4 shows that each row has a certain number of modules. The rooftop has a total of 522 modules, each of which is 400 watts. So, based on theoretical calculations, the total power generated should be 208.8 KWp. The shadow analysis that we performed on the SketchUp software is also visible in this 3D image. The image also demonstrates that no shadows fall on the modules during peak hours, which is important for this design. The buildings in the industry are oriented north-south. We did two key things with SketchUp software: first, project capacity estimate, and second, a 3D visualization of the entire design. we perform a shadow analysis for the industry's specified peak period and generate a shadow report. Table 3 summarizes the project's essential details. The installed solar PV capacity is shown in Table 4 [5].

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Table 3: Necessary information about the project.

S.	Attributes	Details
1	Solar PV system description	209 KWp solar PV power plant
2	Location	Chandra, Shafipur, Kaliakoir, Gazipur.
3	Coordinates	24.04 degree North, 90.26 degree East.
4	Elevation from sea level in (ft.)	13.72 ft.
5	Irradiation on tilted plane (KWh/m2/day)	4.9
6	Site disposition	RCC roof

Table 4: Installed solar PV capacity.

All Building	No of Solar Modules	Module Wattage	Installed Solar PV Capacity (KWp)
Row - 1	90	400	36
Row - 2	98	400	39.2
Row - 3	110	400	44
Row - 4	110	400	44
Row - 5	98	400	39.2
Row - 6	16	400	6.4
Total Capacity	522		208.8

2.6 Sun path of the location

Figure 3 shows the sun path of the location.

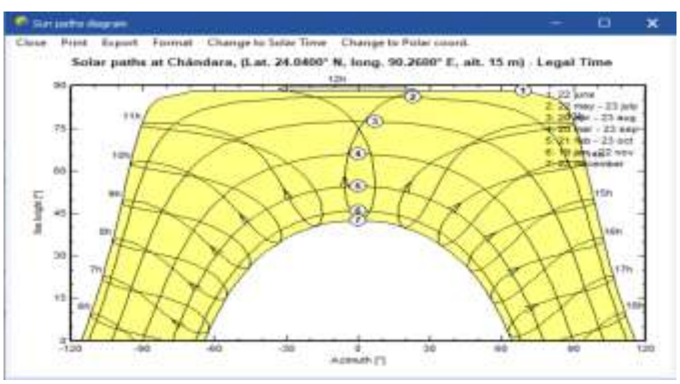
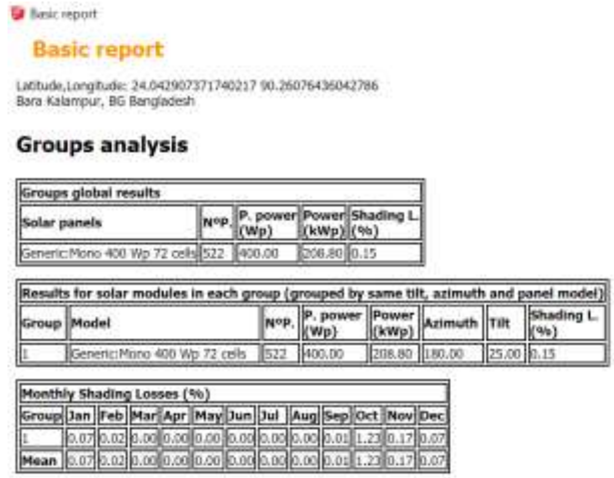


Figure 3: Sun path of the location.

2.7 Shadow report


Basic report

Latitude,Longitude: 24.042907371740217 90.26076436042786
Bara Kalampur, BG Bangladesh

Groups analysis

Groups global results				
Solar panels	N°P.	P. power (Wp)	Power (kWp)	Shading L. (%)
Generic:Mono 400 Wp 72 cells	522	400.00	208.80	0.15

Results for solar modules in each group (grouped by same tilt, azimuth and panel model)							
Group	Model	N°P.	P. power (Wp)	Power (kWp)	Azimuth	Tilt	Shading L. (%)
1	Generic:Mono 400 Wp 72 cells	522	400.00	208.80	180.00	25.00	0.15

Monthly Shading Losses (%)												
Group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.07	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.01	1.23	0.17	0.07
Mean	0.07	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.01	1.23	0.17	0.07

Figure 4: Shadow report of the 3D design.

The SketchUp software is used to generate this shadow report. The report includes a shadow analysis during the prime hours of 8 a.m. to 4 p.m. The shadow loss is 0.15%, according to the shadow report. This report also includes certain required project design information that we created in SketchUp software, such as results for solar modules in each group (grouped by same tilt, azimuth, and panel model), and monthly shading loss (%). The shading loss calculation for the design is also visualized in this report. The shadow report is attached. The shadow report of the 3D design is shown in Figure 4 [6].

3 RESULT AND DISCUSSION

PVsyst software was used to simulate the design and analysis of an on-grid solar PV system in this research. The most satisfactory outcomes were found after numerous runs of the simulation followed by calibration, which were analyzed in the results analysis section. The following are the various results: daily input or output plots, representation of losses diagram, horizon line drawing plot of the chosen location, performance ratio data plot, daily energy output plot including incident variations, array power distribution plot, normalized productions including loss changes [7].

3.1 Balances and main results

Figure 5 shows the balance and main results.

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Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR ratio
January	125.7	52.7	17.09	165.5	155.7	24.66	21.55	0.624
February	137.1	56.3	20.66	166.2	156.9	24.13	22.14	0.638
March	173.3	79.2	25.29	190.1	178.7	26.92	24.56	0.618
April	178.9	98.6	27.37	179.2	167.4	25.14	22.85	0.611
May	180.5	106.4	28.06	169.3	157.3	23.80	21.38	0.685
June	145.1	98.0	27.71	133.0	122.5	18.77	16.41	0.591
July	148.8	89.1	28.18	136.5	126.0	19.17	16.29	0.571
August	144.4	92.2	28.41	136.5	128.0	19.51	16.54	0.572
September	143.5	79.7	27.63	149.2	138.9	21.07	18.86	0.685
October	142.8	66.8	26.76	164.5	154.4	23.40	21.23	0.618
November	139.8	42.5	22.81	183.1	173.0	26.48	23.62	0.618
December	126.4	47.0	18.91	172.2	162.1	25.45	23.42	0.652
Year	1785.7	900.5	24.92	1947.2	1820.8	278.50	248.86	0.612

Legends
GlobHor Global horizontal irradiation
DiffHor Horizontal diffuse irradiation
T_Amb Ambient Temperature
GlobInc Global incident in coll. plane
GlobEff Effective Global, corr. for IAM and shadings
EArray Effective energy at the output of the array
E_Grid Energy injected into grid
PR Performance Ratio

Figure 5: Balance and main results.

Figure 5 depicts the balances and key results, which include variables such as global irradiance on the horizontal plane, ambient average temperature, global incidence in collector plane, and effective global irradiance after soiling and shading losses. Aside from these factors, the DC energy generated by the mono-crystalline solar array, the energy injected into the grid after accounting for photovoltaic array losses, electrical components, and system efficiency were also simulated. Each of the variables specified in the balances was simulated, and the major findings were acquired monthly and yearly. As averages for temperature, efficiency, and summation for irradiance and energy, yearly values of the variables are possible. Annual worldwide irradiance on the horizontal plane for the research location is 1785.7 kWh/ Sq. m, while global incident in collector plane and effective global irradiance after optical losses are 1947.2 kWh/Sq. m and 1820.8 kWh/Sq. m, respectively. Annual DC energy produced from the PV array and annual AC energy injected into the grid are 278.50 MWh and 248.86 MWh, respectively, for this effective global irradiation value [7].

3.2 Normalized Productions

The normalized production of the PV power plant is depicted in Figure 6. It provides PV array collection losses, system losses, and important inverter output. It clearly displays monthly usable energy production and losses per kWh. The IEC norms establish these normalized products, which are standardized variables for evaluating PV system performance. 1.68 kWh/kWp/day Lc is the collection losses or PV array capture losses. The system loss is 0.39 kWh/kWp/day, and the solar energy produced is 3.27 kWh/kWp/day [8].

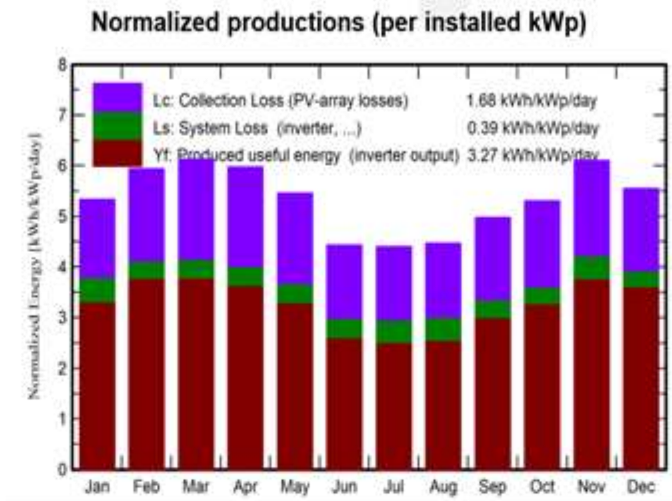

Figure 6: Normalized productions.

3.3 Array loss diagram

The array loss diagram is derived through simulated studies, which aid in the analysis of various losses that may occur during the installation of PV plants or constraints to be considered. Figure 7 shows the array loss diagram, which depicts the various losses in the system. On the horizontal plane, global irradiance is 1786 kWh/Sq. m. However, the collector's effective irradiance is 1821 kWh/Sq. m. As a result of the irradiance level, energy is lost by 0.46%. Electricity or electrical energy is produced when this simulated effective irradiance falls on the surface of a photovoltaic module or array. At standard testing conditions (STC), the array nominal energy after PV conversion is 379.9 MWh. At STC, the PV array has a 17.83% efficiency. MPP's annual virtual energy array is 278.5MWh. Temperature losses account for 9.67% of this stage's losses, while light-induced degradation accounts for 2%, module array mismatch accounts for 7.44%, and Ohmic writing losses account for 1.04%. Annually, the inverter output plant has 273.5 MWh of available energy, of which 248.9 MWh is injected into the grid. In this case, there were primarily two losses: 1.80% inverter loss during inverter operation and 0% inverter loss above nominal inverter power. The array loss diagram is shown in Figure 7.

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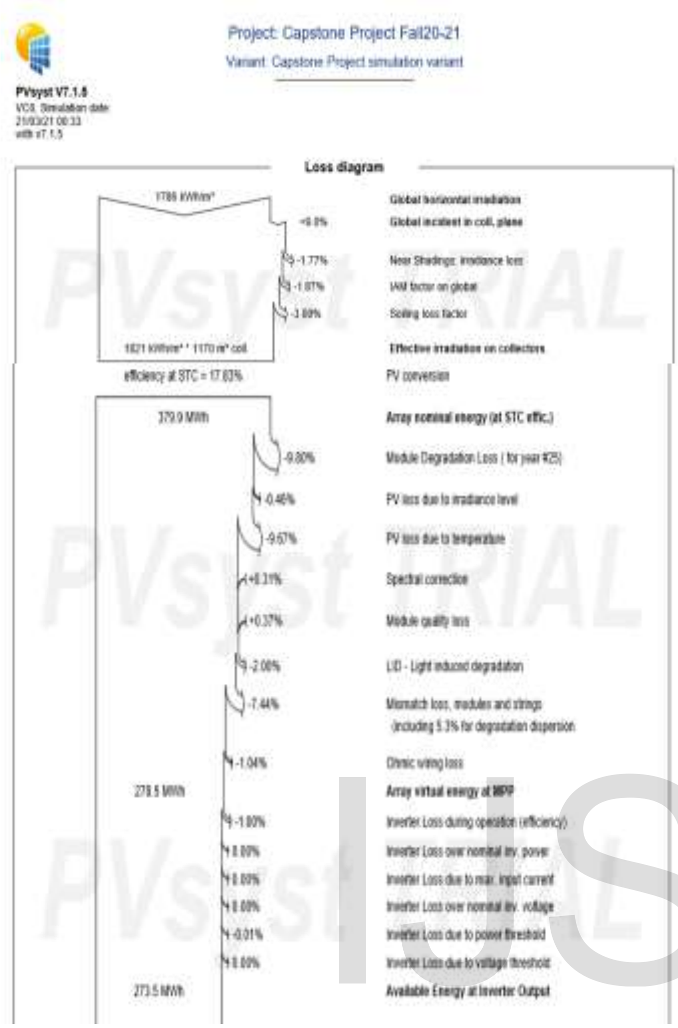

Figure 7: Array loss diagram.

3.4 Performance Ratio

The performance ratio is primarily a quality factor that assesses a PV plant's quality. It describes the link between the PV plant's theoretical and real energy outputs. The PR depicts the energy after all energy consumption and losses have been removed. Due to unavoidable losses during operation, the Performance ratio is usually about 75%. The PV plant's performance ratio (PR) for the simulated 209 kWp mono-crystalline solar system is 61.21%, which is the annual average PR value, as shown in Figure 8. The PR value varies slightly on a monthly basis, as seen in Figure 8 [8].

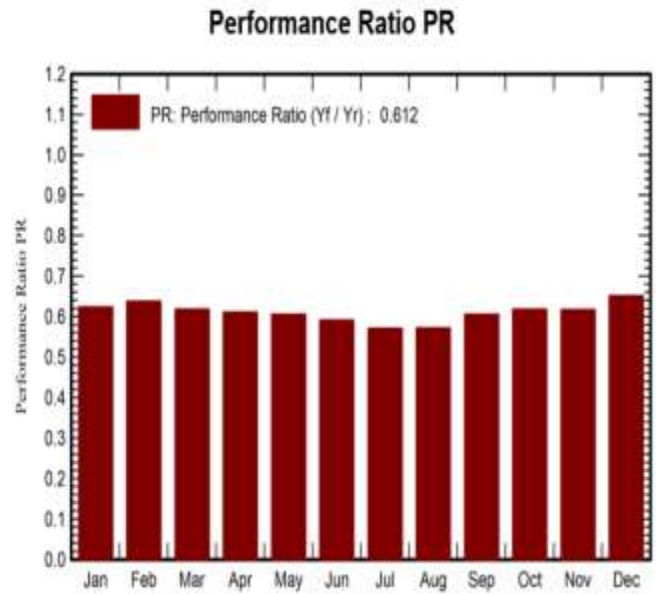

Figure 8: Performance ratio.

3.5 Yearly Net Profit

The following Figure 9 shows the values of net profit per year.

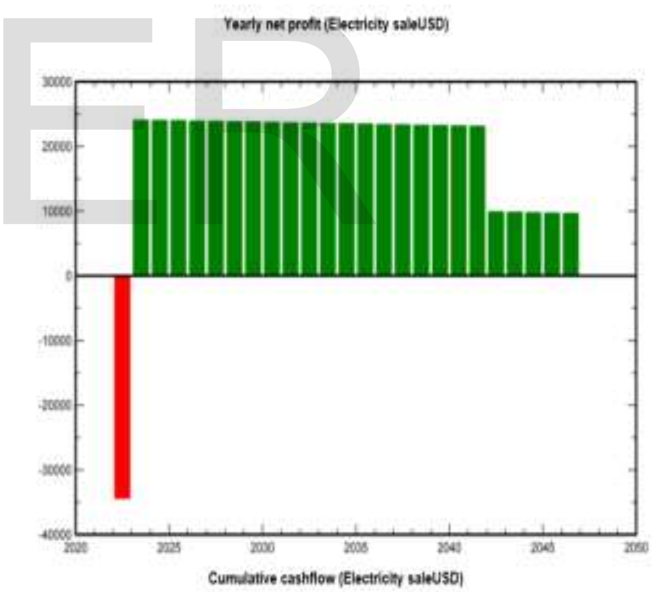

Figure 9: values of net profit per year.

3.6 Energy Injected to Grid

The PV array cannot produce the same amount of electricity as the energy fed into the grid. The PV array generates DC energy, which must be converted into AC energy before being fed into the grid. Some energy is wasted in the form of AC wire loss during the conversion of DC to AC energy. Every year, the proposed mono-crystalline solar plant of 209 kWp injects 248900 kWh of energy into the grid. The total amount of particular electricity injected into the grid on a monthly and daily basis is 1190.90 kWh/kWp and 3.27 kWh/kWp/day, respectively. In March, the PV facility generated and injected

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24560 kWh of energy into the grid. In the month of July, the lowest quantity of AC energy put into the system was 16290 kWh [8].

3.7 Cumulative cash Flow

The following Figure 10 shows the simulated values of Cumulative cash flow.

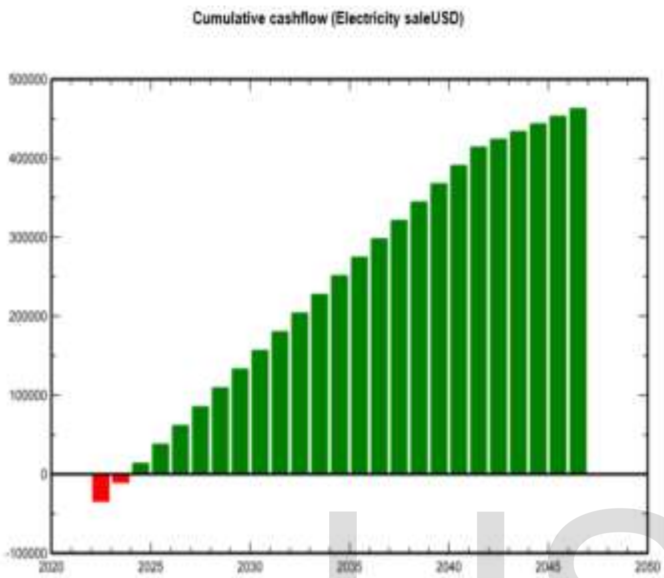

Figure 10: Simulated values of Cumulative cash flow.

3.8 CO_2 Emission Balance

The following Figure 11 shows the simulated values of CO_2 Emission Balance.

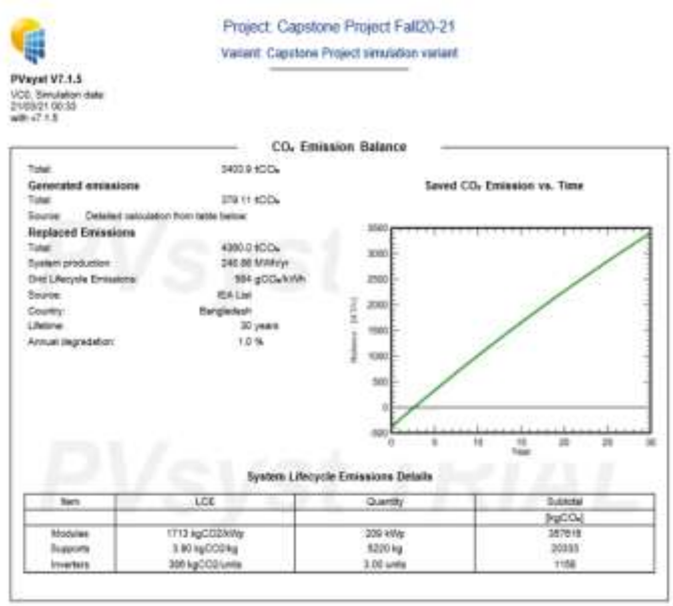

Figure 11: CO_2 Emission Balance.

4 FURTHER WORK

There is a need for more information on the electrical layout, potential mechanical loads, mounting structure and protective dimensioning, disconnection switches, and metering. It may also be necessary to investigate the sort of ground soiling. Furthermore, today's market offers a diverse selection of module and inverter technology options. Other systems might be examined and compared to see how well they operate and how much they cost. Gathering and comparing cost information from multiple PV system manufacturers should help to reduce the uncertainties in the economic evaluation [9].

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