Design, simulation and analysis of monofacial solar pv panel based energy system for university residence: a case study

Abdullah Al Mehadi, Misbahul Alam Chowdhury, Mirza Muntasir Nishat, Fahim Faisal and Md Minhajul Islam

Department of Electrical and Electronic Engineering (EEE), Islamic University of Technology, Dhaka, Bangladesh

{abdullahmehadi, misbahulalam, mirzamuntasir, faisaleee, minhajulislam40}@iut-dhaka.edu

Abstract. This paper proposes a design and software simulation of monofacial solar photovoltaic panel based energy harvesting system for university residence. As the site of the proposed system, the rooftop of North Hall of Residence of the Islamic University of Technology (IUT) is considered. The 3D model of the system is demonstrated by utilizing PVSOL software. The monthly energy production is obtained by performing the simulation in three software named PVSOL, PVsyst, and System Advisor Model (SAM). However, the monthly consumption of the residence is tabulated and graphical presentation is depicted. Hence, the energy flow diagram is illustrated showing that the proposed PV system can contribute 18.4% in the annual demand of the site. The performance of each of the software is evaluated and deviation analysis is performed so that more insight can be achieved in terms of harvesting solar energy. Hence, a cost-effective and self-reliant solar energy model for the rooftop of a university residence is proposed by utilizing monofacial solar PV panels.

Keywords. Monofacial PV panel, PVSOL, PVsyst, SAM, Solar Energy Model

1. Introduction

For the past few decades, most of the global energy consumption is heavily dependent on fossil fuels which causes severe carbon emission and leads to environmental pollution and ultimately global warming [1-5]. Considering all the negative aspects of fossil fuels and environmental concerns, renewable energy is a promising alternative, and it has a massive prospect in addressing real-world issues. The mainly used renewables are solar and wind energy, possessing the immense potential to be more reliable and efficient than coal-fired power plants in the context of a developing country like Bangladesh [6-8].

One of the most reliable forms of renewable energy around the world is solar energy which can be harnessed using Photovoltaic (PV) technology. Generally, two types of PV configurations are in use which are on-grid and off-grid systems [9]. On-grid PV system, being a grid-connected array is capable of converting DC energy to AC energy with the help of suitable power conditioning technology and synchronizing the AC energy to the grid [10]. By generating power during daytime when sunlight is abundant, this system also ensures that the average daily PV output matches the utility’s peak demand period [11]. Combining on-grid and off-grid capacity, the world saw a total production of 627 GW, which is substantially high in comparison to the production of the last ten years [12].
Hence, PV demand is increasing significantly in residential, commercial, and utility-scale applications. Rooftop based off-grid PV system is an effective method of utilizing solar energy. The installation of the solar panels is quite a challenge, especially in the crowded cities of Bangladesh. But open space, especially rooftops and highways, can be utilized for the purpose. Jamal et al. reported the potential rooftop distribution for solar installation using GIS mapping in the Dhanmondi area [13]. Mahmud et al. worked on a bifacial module based solar installation in some of the main highways of Bangladesh [14]. Shuvo et al. predicted the solar irradiation and evaluated the performance of an 80 kWp on-grid solar plant in Dhaka using fuzzy logic [15]. Kazem et al. conducted a case study on the techno-economic feasibility of a 1 MW on-grid connected photovoltaic system in Adam, Oman [16]. Dondariya et al. has reported a performance simulation for an on-grid solar panel system for small households in Ujjain, India, using several PV simulation tools [17]. Therefore, it is observed that the obstacles of available land area for PV installation can be mitigated by utilizing the open highways and the available rooftop areas in the urban areas.

In this paper, we present the Islamic University of Technology (IUT) as the site of our research, which is situated in the Board-Bazar of Gazipur district of Dhaka division. The area is still quite underdeveloped, and load shedding is a common problem. The University itself has a huge electricity demand. There are two residential halls, two academic buildings, and many laboratories and machine workshops, which require a continuous power supply for most of the time of the day. Our main objective is to design and develop an off-grid monofacial photovoltaic panel on the rooftop of one of the residential halls (North Hall) using three prominent PV simulation tools namely PVSOL, PVsyst, and SAM (System Advisor Model).

In Section 2, system design is illustrated where all the site details, meteorological data, load profile, solar components as well as system orientation are depicted. Afterward, in Section 3, the results of the software simulation of the system are shown and discussed. Lastly, the overall comparison and deviation analysis is presented. A rigorous software-based investigation and feasibility analysis are carried out.

2. Design of the System

2.1. Site Details

Islamic University of Technology (IUT), located in Board-Bazar, Gazipur, on the outskirts of Dhaka city, Bangladesh, is chosen as the site of our project. It is situated at a latitude of 23.9481° N and a longitude of 90.3793° E.

![Figure 1. Imported 3-D model on PVSOL.](image)

The area selected for the installation of PV panels is the North Hall of Residence with a large space available on the rooftop, which can be effectively utilized for PV installation. The hall has approximately 503 square meters available mounting surface on it. The building is south facing and
there is no external shading on the rooftop by trees or any other obstacle [18]. The 3-D model of the entire building is shown in Figure 1.

2.2. Meteorological Data

After site selection, necessary meteorological data is collected from various online databases like Meteonorm, NASA, PVGIS, SOLARGIS, SOLCAST, NREL which will act as key factors in designing the system [19]. The required data is reported in Table 1, utilized for further design of the system in PVSOL, PVsyst, and SAM.

| Site Name                  | Islamic University of Technology Board-Bazar, Dhaka |
|----------------------------|------------------------------------------------------|
| Annual global irradiance   | 1793 kWh/m²                                          |
| Horizontal Diffuse Irradiance | 864 kWh/m²                                       |
| Average temperature        | 24.9 °C                                              |
| Wind Velocity              | 0.8 m/s                                              |
| Humidity                   | 81%                                                  |

2.3. Load Profile Analysis

An approximate monthly consumption for one hall (North Hall of residence) was collected from the engineering section of IUT, from which the estimated annual load was found to be 444733.5 kWh. The monthly load profile is tabulated in Table 2.

| Month      | Consumption (kWh) |
|------------|-------------------|
| January    | 24797.52          |
| February   | 30173.52          |
| March      | 47799.1           |
| April      | 47799.1           |
| May        | 23983.9           |
| June       | 47799.1           |
| July       | 47799.1           |
| August     | 23881.9           |
| September  | 47799.1           |
| October    | 48100.2           |
| November   | 30003.5           |
| December   | 24797.5           |
| Total      | 444733.5          |

As we can see from the load profile, the electricity consumption is naturally high in March, April, June, July, September, and October due to the summer and autumn seasons. The electrical demand is the lowest during the winter season in December and January. The electrical consumption is in the medium range in the early part of winter in November and towards the end of winter in January.
2.4. Solar Components

For any photovoltaic system, PV array is considered the heart of the system, which determines how much solar energy can be received from the sun [19]. LG modules have been chosen as they have relatively low degradation and longer life. For optimum operation, three inverter models from Huawei technologies have been selected. They are SUN2000L-3KTL, SUN2000L-4KTL, and SUN2000L-5KTL. The parameters of the PV system and their corresponding values are presented in Table 3.

| Parameters                      | Values                  |
|---------------------------------|-------------------------|
| PV Model                        | LG340N1K-v5             |
| Power                           | 340W                    |
| Module Type                     | Monofacial              |
| Nominal Efficiency              | 20.6                    |
| Maximum Power                   | 340.6 W                 |
| Maximum Power Voltage           | 34.9 V                  |
| Maximum Power Current           | 9.8 A                   |
| Open Circuit Voltage            | 41.2 V                  |
| Short Circuit Current           | 10.3 V                  |
| Nominal Module Operating Temperature | 42 ± 3 °C              |

2.5. System Operation

Monofacial modules were placed at an optimum tilt angle of 24° which is depicted in Figure 2 [20]. A total of 174 modules were utilized where all modules were set at 2 m height above the mounting [21]. A summary of the parameters necessary for our simulations and orientation is given in Table 4.
3. Software Simulation and Result Analysis

Three popular software namely PVSOL, PVsyst, and SAM are utilized for the simulation purpose. The parameters taken for simulation are tabulated in Table 4. By utilizing these parameters, rigorous simulation is carried out and a monthly profile is obtained from each of the software. However, each of the software showed quite a promising result in terms of energy production which is tabulated in Table 5 and the graphical representation is depicted in Figure 3. The annual yield was 82,076 kWh, 83,038 kWh, and 80,401 kWh in PVSOL, PVsyst, and SAM respectively. It is observed that maximum yield was obtained during March due to high global horizontal irradiation. However, the lowest yield was during June when the irradiation was low due to cloudy sky and rain.

| Parameters         | Values |
|--------------------|--------|
| Panel rating       | 340 W  |
| No. of Panels      | 174    |
| Total PV Generator | 59.16KW|
| Output             | 59.16KW|
| Tilt               | 24°    |
| Azimuth            | 180°   |
| Albedo             | 0.65   |
| Soiling loss       | 15%    |
| Mismatch Loss      | 2%     |
| Diode Loss         | 0.5%   |
| Module Gap         | 0.1 m  |
| Row Gap            | 3.5 m  |
| No. of Inverters   | 11     |
| Mounting Surface   | 2 m    |

Table 5. Monthly energy production in kWh.

| Month    | PVSOL | PVsyst | SAM  |
|----------|-------|--------|------|
| January  | 7369.4| 7481   | 6168.08|
| February | 6989.7| 7089   | 6690.24|
| March    | 7868.6| 7969   | 8139.5 |
| April    | 7404.6| 7458   | 7527.78|
| May      | 7036.5| 6978   | 7334.4 |
| June     | 5642.9| 5664   | 5728.9 |
| July     | 5923.9| 5867   | 6144.68|
| August   | 5884.5| 5969   | 6253.18|
| September| 6156.5| 6344   | 6172.1 |
| October  | 6751.6| 6702   | 7007.99|
| November | 7641.4| 7700   | 6822.54|
| December | 7406.6| 7817   | 6411.84|
| Total    | 82076.2| 83038 | 80401.23 |
Figure 3. Comparison of monthly energy profile among three software (PVSOL, PVsyst, and SAM)

For North Hall of residence of IUT, the annual energy demand was approximately 444,733.5 kWh. Considering the mean of three software, it can be presumed that the proposed PV system would be supplying 81,838.5 kWh (18.4 %), and the rest of the 362,895 kWh would be taken from the grid. The monthly energy consumption from the PV system and the grid are illustrated graphically in Figure 4 and tabulated in Table 6. Hence, the energy flow diagram is displayed in Figure 5.

Figure 4. Coverage of Consumption (kWh)
Table 6. Coverage of Consumption (kWh).

| Month   | Covered by PV | Covered by grid |
|---------|---------------|-----------------|
| January | 7218.7        | 18101.5         |
| February| 6989.7        | 20793.2         |
| March   | 7868.6        | 40887.7         |
| April   | 7404.6        | 39776.1         |
| May     | 6969.1        | 17485.3         |
| June    | 5642.9        | 41536.9         |
| July    | 5923.9        | 42828.5         |
| August  | 5774.7        | 18589.1         |
| September| 6156.5       | 41025.7         |
| October | 6751.6        | 42322.2         |
| November| 7641.4        | 21996.1         |
| December| 7296.6        | 18024.8         |

Figure 5. Energy Flow Diagram

Deviation analysis is performed among the obtained results of the software which will help to evaluate each software performance and aid in further estimation and planning for rooftop monofacial setup [22]. There is a difference in the system production between the three software. In the case of PVsyst vs. SAM and PVSOL vs. SAM, the monthly production difference is quite high, because SAM takes a few more loss parameters into account during the simulation. On the other hand, for the instance of PVSOL vs. PVsyst, there is a lesser deviation since they use pretty much the same parameters during the simulation process. Besides, there is a slight difference in the mathematical model used in each of the software and how irradiation value and yield are being calculated. Moreover, there is a dissimilarity in the weather profile used in each of the software which also affects annual yield or system production. The monthly deviation analysis among the three PV simulation software is tabulated in Table 7, Table 8, and Table 9. In Figure 6, the graphical representation is depicted.
Table 7. Deviation Analysis between PVSOL and PVsyst.

| Month   | Deviation |
|---------|-----------|
| January | -111.6    |
| February| -99.3     |
| March   | -100.4    |
| April   | -53.4     |
| May     | 58.5      |
| June    | -21.1     |
| July    | 56.9      |
| August  | -84.5     |
| September | -187.5 |
| October | 49.6      |
| November| -58.6     |
| December| -410.4    |

Table 8. Deviation Analysis between PVSOL and SAM.

| Month   | Deviation |
|---------|-----------|
| January | 1201.32   |
| February| 299.46    |
| March   | -270.9    |
| April   | -123.18   |
| May     | -297.9    |
| June    | -86       |
| July    | -220.78   |
| August  | -368.68   |
| September | -15.6  |
| October | -256.39   |
| November| 818.86    |
| December| 994.76    |

Table 9. Deviation Analysis between PVsyst and SAM.

| Month   | Deviation |
|---------|-----------|
| January | 1312.92   |
| February| 398.76    |
| March   | -170.5    |
| April   | -69.78    |
| May     | -356.4    |
| June    | -64.9     |
| July    | -277.68   |
| August  | -284.18   |
| September | 171.9  |
| October | -305.99   |
| November| 877.46    |
| December| 1405.16   |
Figure 6. Deviation Analysis between (a) PVSOL and PVsyst (b) PVSOL and SAM and (c) PVsyst and SAM
4. Conclusion

The design, simulation, and analysis of monofacial PV module on the roof of the North-hall of residence in IUT have been presented in this paper. A detailed 3D design was created and analysed using three different software. The 3D design of the rooftop simulation provided a promising yield and shading profile. To meet the annual energy demand of 444,733.5 kWh, a total of 174 modules rated 340W have been used to generate 81,838 kWh approximately in a year. Hence, 18.4% of energy demand is met using this PV setup which implicates that university can be self-reliant in energy consumption by adopting solar energy and installing it in different open areas and rooftops. As a result, huge load shedding during peak hours can be undertaken and the diverse international community and stakeholders of the university will be benefitted. On the other hand, this attempt of clean energy would be able to save up-to USD 5810.5$ annually considering the grid price to be 0.071 $/kWh. Therefore, a cost-effective and self-reliant energy system can be designed for such universities situated in load shedding prone industrial areas so that the academic and research activities can be carried out smoothly, without any interruption of power. In the future, there is scope to analyse the performance of the PV panels by utilizing various tilt angles and changing other parameters so that a more optimum energy production system can be designed and implemented in educational and healthcare institutions.

5. References

[1] Dey, Diptiman, and Bidyadhar Subudhi "Design, simulation and economic evaluation of 90 kW grid connected Photovoltaic system." Energy Reports 6 (2020): 1778-1787

[2] Arent, Douglas J., Alison Wise, and Rachel Gelman. "The status and prospects of renewable energy for combating global warming." Energy Economics 33.4 (2011): 584-593.

[3] Bilgen, Selçuk, et al. "Global warming and renewable energy sources for sustainable development: a case study in Turkey." Renewable and sustainable energy reviews 12.2 (2008): 372-396.

[4] Lau, Lee Chung, Keat Teong Lee, and Abdul Rahman Mohamed. "Global warming mitigation and renewable energy policy development from the Kyoto Protocol to the Copenhagen Accord—A comment." Renewable and Sustainable Energy Reviews 16.7 (2012): 5280-5284.

[5] Yüksel, Ibrahim. "Global warming and renewable energy sources for sustainable development in Turkey." Renewable energy 33.4 (2008): 802-812.

[6] Khan, M. J., M. T. Iqbal, and S. Mahboob. "A wind map of Bangladesh." Renewable energy 29.5 (2004): 643-660.

[7] Nandi, Sanjoy Kumar, and Himangshu Ranjan Ghosh. "A wind–PV-battery hybrid power system at Sitakunda in Bangladesh." Energy Policy 37.9 (2009): 3659-3664.

[8] Islam, AKM Sadrul, Mazharul Islam, and Tazmirul Rahman. "Effective renewable energy activities in Bangladesh." Renewable energy 31.5 (2006): 677-688.

[9] Menconi, Maria Elena, et al. "Energy sovereignty in Italian inner areas: Off-grid renewable solutions for isolated systems and rural buildings." Renewable energy 93 (2016): 14-26.

[10] Mukherjee, D., and S. Chakrabarti. Fundamentals of renewable energy systems. New Age International, 2004

[11] Natural Resources Canada. "Clean energy project analysis: RET Screen Engineering & Cases textbook." (2005).

[12] “Renewables 2020 Global Status Report” https://www.ren21.net/wp-content/uploads/2019/05/gsr_2020_full_report_en.pdf

[13] Jamal, Taskin, et al. "Potential rooftop distribution mapping using Geographic Information Systems (GIS) for Solar PV Installation: A case study for Dhaka, Bangladesh." 2014 3rd international conference on the developments in renewable energy technology (ICDRET). IEEE, 2014.
[14] Mahmud, Md Sultan, et al. "Solar Highway in Bangladesh Using Bifacial PV." 2018 IEEE International Conference on System, Computation, Automation and Networking (ICSCA). IEEE, 2018.

[15] Shuvho, Md Bengir Ahmed, et al. "Prediction of solar irradiation and performance evaluation of grid connected solar 80KWp PV plant in Bangladesh." Energy Reports 5 (2019): 714-722.

[16] Kazem, Hussein A., et al. "Techno-economic feasibility analysis of 1 MW photovoltaic grid connected system in Oman." Case Studies in Thermal Engineering 10 (2017): 131-141

[17] Dondariya, Chandrakant, et al. "Performance simulation of grid-connected rooftop solar PV system for small households: A case study of Ujjain, India." Energy Reports 4 (2018): 546-553.

[18] Lodhi, Ehtisham, et al. "Application of particle swarm optimization for extracting global maximum power point in PV system under partial shadow conditions." Int J Electron Electr Eng 5.3 (2017): 223-229.

[19] Şenol, M., et al. "A guide in installing large-scale PV power plant for self consumption mechanism." Solar Energy 132 (2016): 518-537.

[20] Kalogirou, S. A. "Solar Energy Engineering: Processes and Systems, Else-vier." (2009).

[21] Yusufoglu, Ufuk Alper, et al. "Simulation of energy production by bifacial modules with revision of ground reflection." Energy Procedia 55 (2014): 389-395.

[22] Axopoulos, Petros J., Emmanouil D. Fylladitakis, and Konstantinos Gkarakis. "Accuracy analysis of software for the estimation and planning of photovoltaic installations." International Journal of Energy and Environmental Engineering 5.1 (2014): 1.